COKE

A TREATISE ON THE

MANUFACTURE OF COKE AND OTHER PREPARED FUELS

AND THE

SAVING OF BY-PRODUCTS

WITH SPECIAL REFERENCES TO THE METHODS AND OVENS BEST ADAPTED
TO THE PRODUCTION OF GOOD COKE FROM THE
VARIOUS AMERICAN COALS

BY

JOHN FULTON, A. M., E. M.

Member of American Institute of Mining Engineers,
American Philosophical Society of
Philadelphia, Etc.

SCRANTON, PA.
INTERNATIONAL TEXTBOOK COMPANY
1906

Very truly,
Jno. Fulton

Copyright, 1895, by The Colliery Engineer Company
Copyright, 1905, by International Textbook Company
Entered at Stationers' Hall, London
All rights reserved
Printed in the United States

LOAN STACK

GIFT

B--17303

TP336
F.10,

PREFACE TO SECOND EDITION

The first edition of Coke was issued by The Colliery Engineer Company, of Scranton, Pennsylvania, in the year 1895 and was the first treatise on this growing and important industry published in the United States of North America. This edition was exhausted over one year ago.

In the great progress of industrial manufacturers so manifest in the United States, this interval of nine years since the appearance of the first edition has retired some of the former methods in the manufacture of coke, and introduced many new ones. This advance in the progress of the industry has been induced by the large increase in the demand for coke, arising from the expansion in the use of steel and iron in architectural construction, as well as in railroad supplies. In the manufacture of these materials, a pure quality of coke fuel is an imperative necessity, and with the consequent large demand on the best coking coal fields, it has become necessary to extend coking operations outside these fields to regions possessing coking coals of a lower grade, requiring, in most cases, cleansing from the two principal impurities, slate and sulphur, by the modern processes of crushing, classifying, and washing.

This necessary preparation or cleansing of coals for coking has been an inviting field for mechanical experts in which to devise machinery for this special purpose. It has also impressed the necessity for studying the several conditions in which these foreign matters are found in coals, so that proper machinery could be devised to meet the several conditions necessary for eliminating slate and sulphur.

This department of the coke industry has, during the past decade, made commendable progress, especially in the preparation of the coal for introduction into the washer, in disintegrating the lumps of coal to certain sizes, and in the classification of the crushed product as it is being conveyed into the washers. This important auxiliary in the manufacture of coke enables the lower qualities of coals to be utilized in the production of an acceptable metallurgical fuel.

In addition to this coal-cleansing auxiliary in the coke industry, an additional element has been introduced, meeting the conditions of some coals low in bituminous matter—dry coals—in a fairly satisfactory manner. These dry coals, low in fusing matter, could

857

not be made to produce the best possible product in the usual open beehive coke oven. To meet these exceptional conditions, the retort coke oven has been introduced; it is made in several types, but the different types have one element in common—the retort or closed-chamber principle, which affords a quick heat and permits the utilization of the small content of volatile matter in these dry coals.

The large cost of these retort coke ovens, with the additional expense of the apparatus for saving the by-products of tar and ammoniacal liquor, has prevented their general introduction. In addition to the large cost of installation, a retort-oven plant requires a supply of coal for a long period to cover the investment in the plant of ovens. Only certain localities can assure this supply of coal, and unless the conditions of the manufacture will bear the railroad freight charges necessary to continue the coal supply, when it has to be obtained outside the immediate limits of the coke plant, a retort-oven plant is impracticable. In situations where water transportation can be secured, with its moderate freight rates, the coal supply can usually be secured for long periods.

The use of the by-product tar in roofing and other applications, with its anticipated use as a bonding element in the manufacture of briquets, will enhance the value of this by-product.

In the first edition, the conditions were submitted that compelled the writer, in 1875, then General Mining Engineer of the Cambria Iron Company, to the study of the physical properties of blast-furnace coke. At that time the blast furnaces of this company were supplied mainly by coke made from native coals in Belgian ovens located at the works in Johnstown. This home-made coke failed when the expansion of the steel industry required the smelting of the Lake Superior iron ores in the production of Bessemer pig iron. The furnaces became hot above and cool below, and the general manager, the late Hon. Daniel J. Morrell, requested an investigation of the cause or causes of the inefficiency of this coke fuel in the blast-furnace work.

Chemical analyses failed to disclose the trouble, as the native coke was found to be much purer than the celebrated Connellsville. This result came as a disagreeable surprise, causing a general search of authorities on fuels for light on this matter, but without helpful results. After a careful examination and study of the principal blast-furnace fuels, anthracite coal, charcoal, Connellsville and Johnstown cokes, it became evident that as chemical investigation had failed to disclose the value of these fuels, it must be determined by physical research.

In this investigation it became evident that two principal requirements were demanded in blast-furnace fuel: hardness of body and fully developed cellular structure; the first property to resist the dissolution of the fuel, in its passage down the furnace, from the attack of hot carbonic-acid gas, and the second to assure its rapid combustion and calorific energy in the melting zone of the furnace.

The hardness of the body of the coke was determined in the usual way. The cellular space was determined by accurately cutting inch cubes, weighing them dry and in water, and equating conditions to determine the cell space in the body of the cokes. The home-made coke was condemned from its lack of hardness of body, while the Connellsville became the standard of blast-furnace fuels from its hardness of body and full cell development.

The author believes that he was the first to originate this course of investigation of blast-furnace fuels. Some criticism followed the early results of these investigations, but the fact of priority in it has not been questioned. During the meeting of the American Institute of Mining Engineers, at Roanoke, Virginia, in June, 1883, Mr. Fred G. Dewey, Washington, District of Columbia, a representative of the National Museum, in submitting a paper on the "Porosity and Specific Gravity of Coke," said: "So far as I am aware, the credit of the first systematic investigation of the physical properties of coke belongs to Mr. John Fulton, Mining Engineer of the Cambria Iron Company."

In a recent publication on the chemistry of coke, being the "Grundlagen Der Koks-chemie" by Herr Oscar Simmersback, translated and enlarged by W. Carrick Anderson, M. A., B. Sc., of Glasgow, Scotland, it is submitted in the introduction: "Upon the physical properties of coke, experiments were carried out first of all by Americans. In 1875, John Fulton, then manager* of the Cambria Iron Works Company, at Johnstown, Pennsylvania, discussed the variable action in the blast-furnace fuels containing the same quantity of carbon. This variability he ascribed to the difference in their physical condition, anthracite, coke, and wood charcoal being, as he showed, characteristically unlike in structure." (Iron, 1884, No. 602; Berg-and Hüttenmannische Zeitung, 1844, p. 526.)

The author appreciates that in this wide field of research there remains very much to be disclosed, but he trusts that this contribution may be helpful, especially in a practical way, to those interested or engaged in this large and expanding industry—the manufacture of coke.

In the preparation of this second edition, the author has necessarily drawn from various sources, and due acknowledgment of such help has been given in the text whenever it has been possible to do so. He is laid under many obligations to the several publications of the United States Geological Survey, especially in the valuable "Twenty-Second Annual Report, 1900–1901, Part 3, Coal, Oil, Cement;" and to the very comprehensive annual volume, "The Mineral Statistics of the United States." Correspondence and requests with this important department of the government have always received prompt, accurate, and courteous responses.

---

*At the time noted above by Mr. Anderson, Mr. Fulton was the General Mining Engineer of the Cambria Iron Company; subsequently he became General Manager.

To Mr. James M. Swank, General Manager of the American Iron and Steel Association at Philadelphia, he is indebted for valuable statistics and helpfulness in the chapter on Briqueting.

Mr. J. V. Schaefer, formerly engineer of the Link-Belt Machinery Company, of Chicago, but now of the firm of Roberts, Schaefer & Co., Engineers, Chicago, Illinois, has contributed largely to chapter III, on the preparation of coals for coking, especially on the treatment in the Lührig washer.

Messrs. Stein and Boericke, Metallurgical Engineers, Primos, Delaware County, Pennsylvania, have contributed much matter on the treatment of coals by crushing and washing, in preparation for coking.

The Semet-Solvay Company, of Syracuse, New York, has contributed drawings and statistics showing the size, product, and cost of the Semet-Solvay retort coke oven.

Dr. F. Schniewind, of New York, has furnished many drawings of the Otto-Hoffman and other retort coke ovens and statistics of its work.

Mines and Minerals, a monthly journal, published by the International Textbook Company, Scranton, Pennsylvania, has been largely drawn upon for matter that has been used in several chapters of this edition.

Extracts have also been made from several volumes of the transactions of the American Institute of Mining Engineers.

Valuable help has been cheerfully afforded by the several inventors of coke ovens, disintegrating machinery and washeries, as well as from managers of coking establishments.

In the full chapter on "Briqueting in Europe and America," the reports of the United States consular service have been largely utilized in presenting and illustrating this young industry.

Sincere thanks are returned to the many others who have so kindly contributed to the matter in the pages of this second edition.

JOHN FULTON.

Johnstown, Pennsylvania, January 1, 1905.

PREFACE TO FIRST EDITION

The manufacture of coke in the United States of North America began in a feeble way with four small establishments in the year 1850. During the 30 years following, the progress of the industry was rather slow, but from 1880 to 1892 it made rapid advances, showing in the latter year 261 establishments, using 42,002 coke ovens and producing 12,010,829 tons of coke, valued at $23,536,141 at the ovens.

In the year 1869, coke outranked charcoal for use in blast furnaces; and in 1875, it surpassed anthracite coal. Since the latter date, it may be said that we fully entered into the era of coke. It is also evident that this coke fuel is destined to retain this leading place of usefulness in metallurgical operations, and its increase is destined to accompany the expansion of the iron and steel industries.

In considering the present condition and future requirements of the coke-making industry, with its paramount value in the manufacture of iron and steel, it appeared that a volume embracing the principles and practice of the manufacture of coke would prove of permanent value to those engaged in these correlated industries. Its publication is regarded as the more needful at this time on account of the efforts being made to introduce the modern types of retort coke ovens, with their auxiliary apparatus for saving the chief by-products—tar and sulphate of ammonia—from the gases expelled in coking, and thus supplementing the profits in the coke industry.

In the United States, the manufacture of coke has hitherto been confined mainly to localities affording the best qualities of coking coals. It required little skill to make excellent coke from such good coals, but with the large expansion of the production of coke, and the gradual exhaustion of the areas of the prime coking coals, compelling the use of the secondary qualities of coking coals, a thorough study of the merits of the several kinds of coke ovens now being offered is regarded of the most important interest.

In this volume, the papers on the manufacture of coke that have been published in The Colliery Engineer and Metal Miner, have been recast and carefully revised. They give the several methods of coking, with the results obtained, for the consideration of those interested in this industry.

The author feels that very much remains to be learned in this department of industrial art, but trusts that this initial volume will suggest matter that will lead to an accelerated advance in useful knowledge along the several sections embraced in its pages.

The work has been undertaken with a feeling of the difficulty of doing it the justice its importance deserves. But, in this respect, the author trusts that some truth has been gleaned under the conditions of the old adage that "necessity is the parent of invention."

In the 20 years' experience of the author, in his official position of General Mining Engineer and General Manager of the Cambria Iron Company, he has been required to study the manufacture of coke in its elements of quality and cost. The extensive operations of this company in the different sections of the Appalachian coal region, by several methods of coking, afforded desirable opportunities for investigation and for the comparison of results.

In the year 1875, the coke made at the works at Johnstown, in Belgian coke ovens, failed to meet the furnace requirements. The management requested an investigation of the cause or causes of the inefficiency of this fuel in blast-furnace work. It appeared at first to be an easy task to ascertain the nature of the defect or defects in this coke. It was assumed that a chemical analysis would disclose the whole matter, but, contrary to expectation, it did not; it showed the coke to be very pure, with much less ash than the Connellsville coke, and with marked exemptness from other injurious elements. The result compelled an expansion of the method of investigation, as the chemical method alone would not reveal the cause.

A study to devise a method for the physical examination of the coke was then entered upon, which, after many trials, resulted in developing a plan that disclosed the main cause of the failure of this coke for blast-furnace use—its want of the principal requirement, hardness of body. From the softness of the body of this coke, much of it was wasted in the upper section of the blast furnace by dissolution in the bath of the ascending carbon-dioxide gas, thus lowering the temperature at the zone of fusion, and disarranging the regular operations of the workings of the furnace.

These early methods of testing the physical properties of coke were very crude and open to criticism, but the urgency of necessity, it is believed, has ultimately disclosed accurate methods of determining the true value of coke for metallurgical uses, the practical results in furnace work sustaining the reliability of these determinations.

It has become evident in the manufacture of coke from the secondary qualities of coking coals, that from the nature of the requirements of quick and high-oven heat to secure the hardest-bodied coke possible from such coal, the retort type of coke ovens will have to be used.

It is confidently hoped that the plans and statements of the actual work of these retort ovens, with and without apparatus for the saving of by-products, will prove helpful in enabling the coke manufacturer to make intelligent selection and application of the special type of oven best adapted to assure the best coke from the coal used in its manufacture.

Very much care has been given to the consideration of the best modern methods in the preparation of coals for coking, especially to the process of crushing and washing, for the elimination of slate and pyrites.

In the preparation of this work, the author has necessarily drawn from many sources, and due acknowledgment for such help will be given when possible to do so. He is laid under many obligations to Mr. Joseph D. Weeks, of Pittsburg, for extracts from his admirable reports for statistics of the manufacture of coke, and for the results of his recent visit to Europe. Mr. Walter M. Stein, metallurgist, Philadelphia, agent for the Siebel retort coke oven, has kindly contributed many papers on plans and work of coke ovens. Dr. F. Schniewind, of Cleveland, Ohio, agent of Dr. C. Otto & Co., has generously contributed very full information of the plan, cost, and work of the Otto-Hoffman oven. Mr. W. B. Cogswell, general manager of the Solvay Process Company, of Syracuse, New York, has kindly contributed plans and results of the working of the plant of Semet-Solvay coke ovens at his place.

The author is also placed under renewed obligations to Sir Isaac Lowthian Bell, of England, for plans of his Browney coke ovens, and for his admirable method of testing the resistance of coke to the action of carbon dioxide.

Mr. Henry Aitken, Falkirk, Scotland, has kindly contributed his plans and studies in his methods of saving by-products from beehive ovens.

The "Mineral Statistics of the United States," by Dr. David T. Day, of Washington, District of Columbia, has afforded much help in many ways; as have also the works of the Second Geological Survey of Pennsylvania, by Prof. J. P. Lesley, State Geologist, and his able assistants. Many valuable extracts have been made from the several volumes of the transactions of the American Institute of Mining Engineers.

Sincere thanks are returned to the many others who have so kindly contributed to the matter in the pages of this volume.

CONTENTS

Preface to Second Edition.
Preface to First Edition.

CHAPTER I

Page
The Coal Fields of North America.............................. 1
The Coal Periods.............................. 4
Coal Fields of the United States.............................. 5
The Anthracite Fields.............................. 5
Coal Fields of Canada.............................. 16
Mexican Coal Fields.............................. 17

CHAPTER II

The Formation and Chemical Properties of Coal................ 19
Composition of Coking Coals.............................. 24
Fusibility and Coking Properties.............................. 31
Impurities in Coal.............................. 38

CHAPTER III

Preparation of Coals for the Manufacture of Coke............. 43
Crushing Coal.............................. 46
Coal Washing.............................. 56
Trough Washers.............................. 57
Jigs.............................. 61
Brookwood, Ala., Washery.............................. 75
Coal-Washing Plant for Bituminous Coals at Coahuila, Mex....... 79
Improvement of Coal Effected by Washing.................... 97
Robinson Coal Washer Plant.............................. 99
The Lührig Washer, Dowlais, Wales.......................... 101
The Lührig Washer, Nelsonville, Ohio....................... 108
The Lührig Washery at Punxsutawney, Pa...................... 110
The Stewart Coal Washer.............................. 113
Stein & Boericke Washer.............................. 122
Baum Washer.............................. 123
A Baum Washing Plant at Gladbeck, Westphalia................ 128
Washer for Fine Coal.............................. 129

CHAPTER IV

Page
HISTORY AND DEVELOPMENT OF THE COKE INDUSTRY 131
Statistics Showing Development of Coke Industry 133
Coal Required to Produce 1 Ton of Coke 137

CHAPTER V

MANUFACTURE OF COKE 145
Methods of Coking Coal 145
Coking Coal in Heaps or Mounds 145
To Determine Loss of Carbon in Process of Coking 147
Beehive Coke Oven 148
The Coking Process 157
Old Welsh Oven 164
The Thomas Oven 164
Browney Coke Plant 167
Use of Waste Gases for Steaming at Pratt Mines, Ala 169
The Ramsay Patent Beehive Coke Oven 173
Daube's Economic Down-Draft Coke Oven 177
Improved Heminway Process 178
Newton-Chambers System 186
The Smith Coke Drawer 187
The Hebb Coke Drawer 188
Silica Brick 191
Coking Experiments and Results 192
Effects in Physical Properties of Coke Produced by Crushing the Coal 195

CHAPTER VI

RETORT AND BY-PRODUCT-SAVING COKE OVENS 200
Introduction 200
The Belgian Oven 206
The Coppée Coke Oven 208
The Appolt Coke Oven 212
Comparison of Oven Types 214
Modification of Appolt Coke Ovens at Blanzy 215
Simon-Carvés Ovens 219
G. Seibel's Retort Coke Oven 223
Manufacture of Sulphate of Ammonia 232
Otto-Hoffman Retort Coke Oven 235
Otto-Hoffman Ovens and By-Product Apparatus of the Pittsburg Gas and Coke Co 248
The Schniewind Oven 252
Utilization of the By-Products of the Coke Industry 256
Festner-Hoffman Coke Oven 260
Semet-Solvay Coke Oven 263
West Virginia Coals in Semet-Solvay Ovens 268

Page
Semet-Solvay Plant at Dunbar, Pa. 273
Connellsville Coke from Semet-Solvay Ovens 277
The Rothberg By-Product Coke Oven 290
The A. Hüssner Coke Oven 291
The Bernard Coke Oven 294
The Brunck Coke Oven 298
The Bauer By-Product Coke Oven 302
The Lowe Coke Oven 306
The New Lowe Coke Oven and Gas-Making System 306
Beehive By-Product Oven 311
The Manufacture of Coke From Compressed Fuel 312
Coke Pusher 318
Coal-Distillation Plant at the Matthias Stinnes Mines in Carnap, Germany 320

CHAPTER VII

PHYSICAL PROPERTIES OF CHARCOAL, ANTHRACITE, AND COKE, AND A COMPARISON OF BEEHIVE AND BY-PRODUCT COKE 326
Comparison of Beehive and By-Product Coking 335
Effects of the Several Types of Coke Ovens on the Physical Properties of Their Coke Products 348

CHAPTER VIII

THE LABORATORY METHODS OF DETERMINING THE RELATIVE CALORIFIC VALUES OF METALLURGICAL FUELS 353

CHAPTER IX

THE LOCATION OF PLANTS FOR THE MANUFACTURE OF COKE 361
The Morrell Plant 364
No. 3 Plant, H. C. Frick Coke Co. 365
Oliver Plant 366
Coke Making for Profit 369
American Coke Company's Plant 375
The Hostetter Connellsville Coke Company's Works 375
The Joseph Wharton Coke Plant 376
Retort Oven Plants 379
Production of Illuminating Gas From Coke Ovens 381
The Everett Coke Oven Gas Plant 384

CHAPTER X

GENERAL CONCLUSIONS ON THE WORK, COST, AND PRODUCTS OF THE SEVERAL TYPES OF COKE OVENS 392
Comparison of Different Types of Ovens 397
Advisability of Saving By-Products 401

CHAPTER XI

Page

THE FUEL BRIQUETING INDUSTRY........ 406
Composition of Briquets........ 409
Methods and Cost of Manufacturing Briquets........ 417
Briqueting in Austria-Hungary........ 417
Briqueting in Belgium........ 419
Briqueting in France........ 422
Briqueting in Germany........ 433
Peat Manufacture........ 439
Briqueting in Norway and Sweden........ 445
Briqueting in Great Britain........ 448
Briqueting in Canada........ 453
Briqueting in the United States........ 462

TREATISE ON COKE

CHAPTER I

THE COAL FIELDS OF NORTH AMERICA

Importance of Coal.—Geology, like history, has its special and important epochs. The coal-making periods are the most remarkable in the geology of our planet, for, during these periods, the great deposits of mineral fuel were stored up, anticipating and providing for the wants of the coming man, in the order of his comfort, civilization, and power.

Among all the valuable gifts the Creator has bestowed upon man, coal is the most essential to his well being and progress. It is true that man could exist, under the beneficence of the sun's warmth and the fuel from the vegetation of the field and forest; but it is clearly evident that to attain the best conditions of civilization and power, he must have the fuel supply, the stored up and crystallized sunlight, of the old-time coal-making periods.

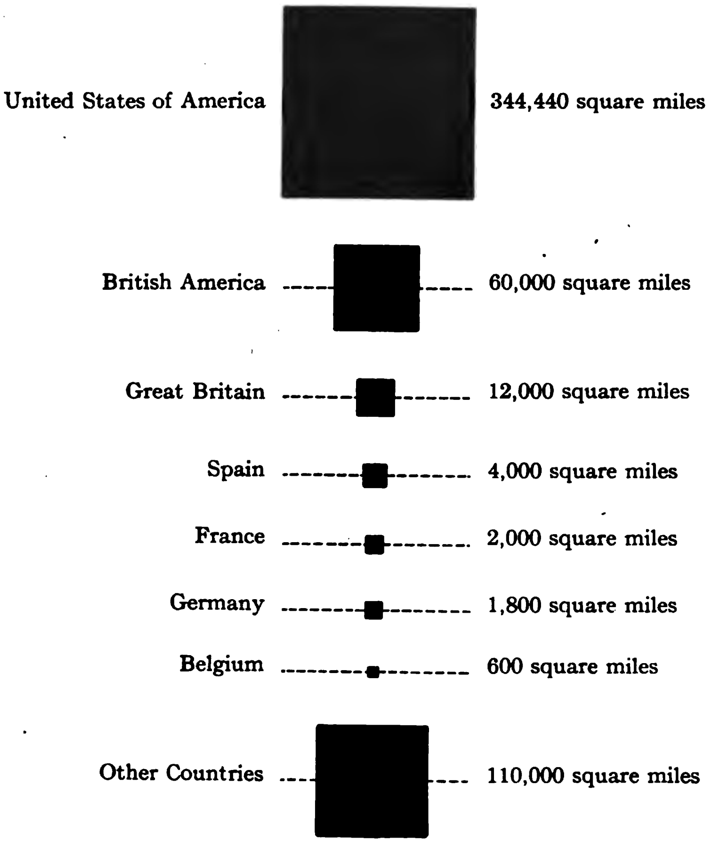
The value of this coal endowment has now become a standard by which the nations of the world are classified as to their present power and future progress. Recent experience has emphasized the vital importance of this coal supply.

From our present knowledge of the extent of the coal fields, the following graphic comparison will exhibit the relative ranks of the nations of the world in their possessions of coal.

This graphic comparison of coal areas shows that the United States of America inherits a wealth of coal, so far as developed, equal to that possessed by all the other countries of the world.

Future explorations will doubtless increase the area of coal in the United States, British America, and in the less-developed countries of foreign lands. The production represented by the square for "Other Countries" will in all probability be greatly increased in the near future as the deposits of China and Japan are opened up. The United States need be in no fear of losing first place, however, at least for a long time. In 1899 we wrested first place from Great Britain and our production is steadily increasing and widening the gap.

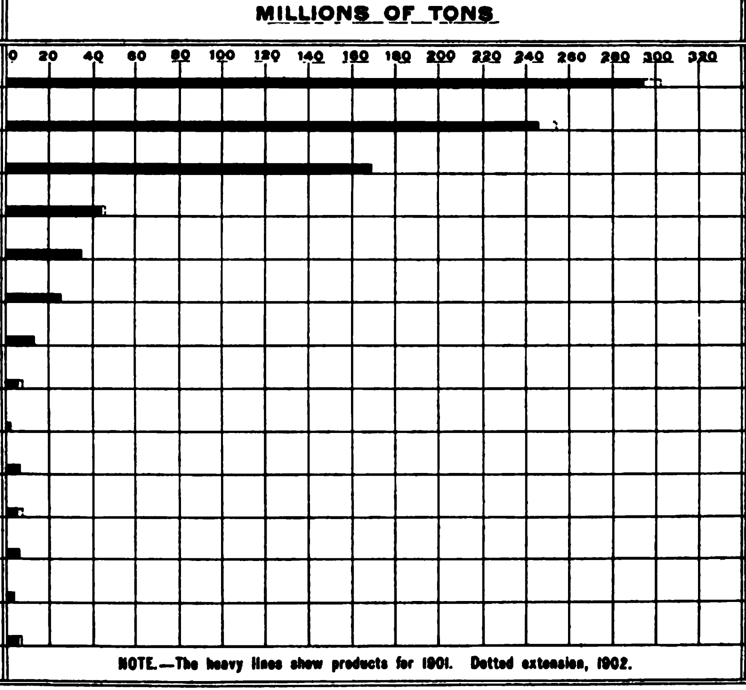
COAL FIELDS OF THE WORLD—1902



The following statistical diagram shows the relative product of coal by the several nations of the world:

THE WORLD'S PRODUCT OF COAL—1901-1902

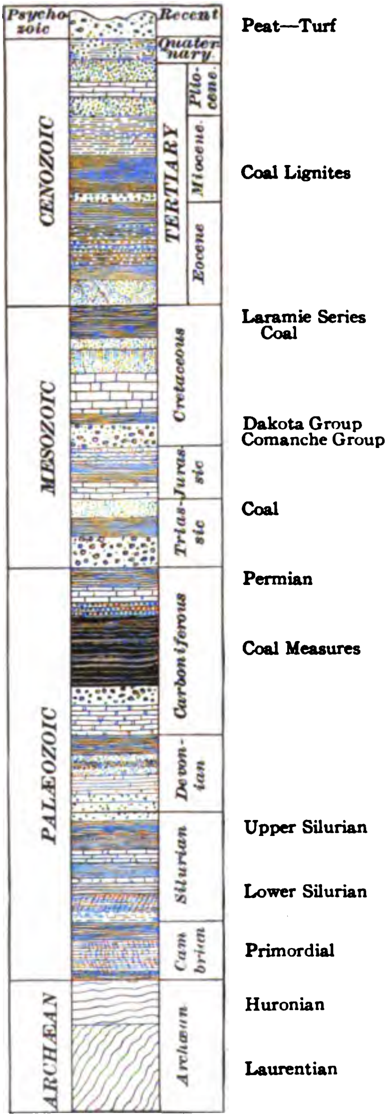
Countries	Net Tons 1901	Net Tons 1902
United States	293,298,516	301,498,148
Great Britain	245,332,578	254,346,447
Germany	168,217,082	165,826,496
Austria-Hungary	45,417,959	43,518,319
France	35,596,536	33,286,146
Belgium	24,485,842	25,622;766
Russia	17,934,201	17,090,835
Canada	6,186,286	7,639,225
Mexico		782,251
Japan	9,861,107	
India	7,432,320	8,315,418
New South Wales	6,684,637	6,655,052
Spain	3,027,992	2,916,491
Other Countries	6,632,155	7,298,073
Total	870,017,219	874,795,667



NOTE.—The heavy lines show products for 1901. Dotted extension, 1902.

The figures in this table are derived principally from the report of the United States Geological Survey. In cases where figures were not given in those reports they were taken from English sources.

The Coal Periods.—The columnar section shows the places of the coal among the rocks. While there were three periods of greatest deposit, the evidence in the remains of plants from the Laurentian to the Tertiary shows that plant life, in greater or less degree of development, accompanied all the sedimentary deposits.



SECTION SHOWING THE PLACES OF COAL IN THE ROCKS—LE CONTE

The remains of this vegetable growth are found in the Laurentian in the mineral graphite, which is usually associated with folded and flexed strata.

In the eastern part of the United States and in the lower coal measures, which are also greatly compressed and flexed, anthracite coal is the product of this old-age flora. Westward, in the Carboniferous period, under modified conditions of rock flexure, the rich bituminous coals are the crystallized remains of the luxuriant flora of this epoch. Farther westward, in the Jurassic, Cretaceous, and Tertiary periods, bituminous and lignite coals are found, as the results of the recurrences of the periods of the coal-making flora.

The more recent vegetable deposits found in the peat or turf bogs afford interesting and suggestive examples of the genesis of coal, although the flora exhibits newer forms and conditions from the old-time periods of the coal-making plants.

An example of the mode of bog or turf deposit, as it is being accumulated at present, is seen on the line of the N. N. & W. Railway, in Newfoundland. These deposits occur at intervals along the line of this railway and consist of a series of bogs in which a growth of moss and other swamp plants is accumulating. Under the cold and foggy climate and with frequent drizzling rains, the vegetable mass is being altered into black bog in the bottom and brown bog above this lowest strata, with the moss and heather on the surface. These deposits are 4 to 6 feet deep, and exhibit all the processes of growth, with the graduations from brown bog down to the dense black bog from which turf is made. It only requires a further series of conditions to compress and crystallize all this vegetable matter into true coal.

COAL FIELDS OF THE UNITED STATES

The accompanying geological map of the United States shows the approximate areas and localities, as far as determined, of the Carboniferous, Triassic, Cretaceous, and Tertiary coals, each period being distinguished by appropriate cross-sectioning.

As this map is designed for practical use, it is not considered expedient to adopt, at this time, the rather intricate classification of the great coal fields used by the United States Geological Survey in some of its latest publications.

The Appalachian field is uniform in the quality of its coal, from New York state to Alabama. It does not appear necessary to give it a double name, Northern and Southern—the same is true of the Western fields. These are distinctions without any economic differences.

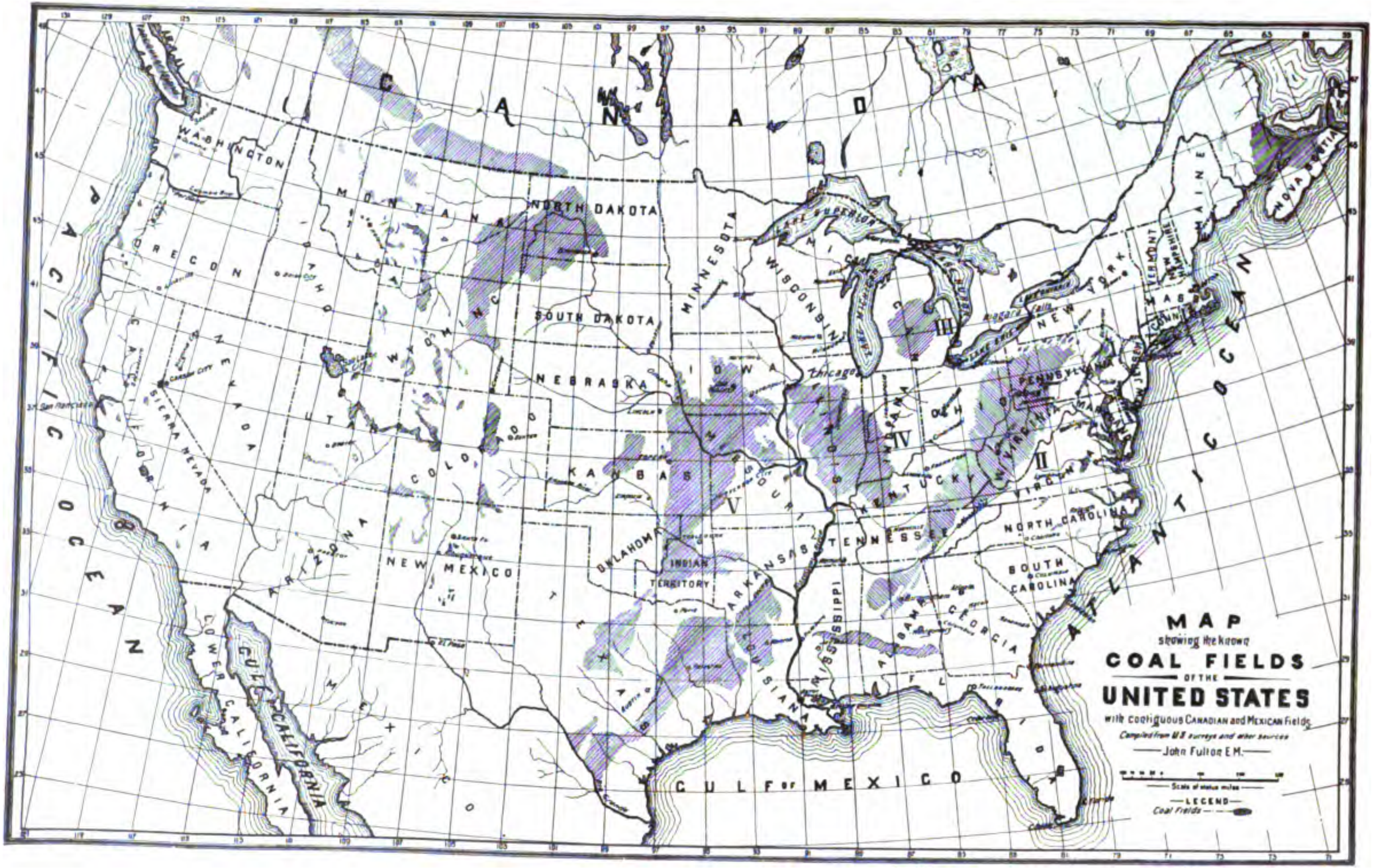
The table of outputs of coal in states and territories has also been grouped under the clear classification of the old system.

These coal fields of the United States are usually classified under eight main divisions in the following order:

I. The Anthracite Coal Fields.—These embrace in the aggregate about 1,010 square miles. The extreme eastern anthracite field, lying mainly in Rhode Island, with its north end resting in Massachusetts, contains about 500 square miles of coal measures. It affords peculiar varieties of anthracite and graphitic coals, but contributes only a small output to local markets.

In Northeastern Pennsylvania, the triple anthracite coal fields cover an aggregate area of 485 square miles. These three regions—the Schuylkill, the Lehigh, and the Wyoming—with their small annexes, contain beds of pure, glassy, anthracite coal, with thickness of seams from 3 feet to 60 feet. The total output of these fields during the year 1901 was 67,471,667 net tons, valued at $112,504,020. The small anthracite field in Sullivan County, Pennsylvania, with detached patches of anthracite in Maryland, West Virginia, Colorado, and New Mexico, cover an aggregate area of 25 square miles.

All the above coals are found in the regular Carboniferous measures. Anthracite coal is heavily compressed natural coke.


MAP
showing the known
COAL FIELDS
OF THE
UNITED STATES
with contiguous CANADIAN and MEXICAN Fields
Compiled from U.S. surveys and other sources
John Fulton E.M.
Scale of statute miles
LEGEND
Coal Fields
CANADA
WASHINGTON
OREGON
CALIFORNIA
NEVADA
SIERRA NEVADA
IDAHO
MONTANA
WYOMING
UTAH
ARIZONA
COLORADO
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
INDIAN TERRITORY
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
SOUTH CAROLINA
NORTH CAROLINA
VIRGINIA
WEST VIRGINIA
MARYLAND
PENNSYLVANIA
NEW JERSEY
NEW YORK
VERMONT
NEW HAMPSHIRE
MAINE
MASS.
CONN.
NOVA SCOTIA
LAKE SUPERIOR
LAKE MICHIGAN
LAKE HURON
LAKE ERIE
Chicago
San Francisco
Carson City
Lincoln
I
II
III
IV
V
LOWER CALIFORNIA
GULF of CALIFORNIA
MEXICO
GULF of MEXICO
PACIFIC OCEAN
ATLANTIC OCEAN

The elementary composition of the coals in the anthracite fields will be readily seen from the average proximate analysis of each section given below:

ANALYSES OF ANTHRACITE

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Rhode Island	8.36	6.09	73.23	11.68	.64
Massachusetts	2.05	4.99	76.96	15.44	.56
Pennsylvania	2.98	3.38	87.13	5.86	.65
Colorado	3.42	8.76	78.87	8.30	.65

II. The Atlantic Coast Triassic Coal Fields.—These detached coal fields are found midway between the Blue Ridge Mountains and the Atlantic Ocean. They consist of the Richmond and Farmville basins in Virginia, and the Dan River and Deep River basins in North Carolina. The aggregate area of these coal fields is 660 square miles.

The coal in the Richmond basin is bituminous, and, when properly treated, makes a medium quality of coke. The natural coke or carbonite of this basin is a peculiar product, as some sections of the coal beds have been coked by the intrusion of diabase dikes, which follow the floor or roof of the coal beds, producing a light cellular coke.

The coal beds in the Farmville field are of moderate thickness and much disturbed by flexures and faults.

The Deep River and Dan River fields are found under similar conditions to the Farmville. The Dan River region is regarded more hopefully than the others.

ANALYSES OF TRIASSIC COALS AND COKES

Locality	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Remarks
Richmond basin north side		24.57	62.39	13.04		Averages
Richmond basin, south side		34.25	62.97	3.24		Averages
Natural Coke	1.66	18.35	67.13	12.86	4.70	
Natural Coke		9.98	80.30	9.72		
Farmville	1.43	28.28	53.60	11.81	4.67	Averages
Dan River	.36	17.99	55.47	26.16	5.56	
Dan River		13.50	76.56	12.00		
Deep River Cumnock Mine	1.216	32.914	57.36	6.58	1.93	Main bench

III. The Appalachian Coal Field.—The Appalachian coal field is the largest and most liberally endowed coal field in the world. It lies along the western side of the Appalachian mountains, and has a general trend southwestwards. The northern end, with its terminal fingers and outlying coal fields, rests in Northwestern Pennsylvania, nearly touching the New York state line. The southern end rests in the state of Alabama. It has a length somewhat over 800 miles, with a width of 30 to 180 miles, and covers, in its broad southwestward course, portions of the states of Pennsylvania, Ohio, Maryland, Virginia, West Virginia, Kentucky, Tennessee, and Alabama. The general trend of its eastern border approximates to a conformity with the shore line of the Atlantic Ocean. The coal measures belong to the Carboniferous proper and vary in aggregate thickness from a few hundred feet to 3,000 or 4,000 feet.

There are two groups of coal beds in this field—the lower and upper—which are associated with the lower and upper barren measures. The Pottsville, or Seral, conglomerate is the base of these coal measures. The lower coal beds embrace a thickness of 280 feet, more or less. The lower barren measures have a thickness of 600 feet. The upper productive coal measures have a thickness of 360 feet, while the upper barren, or capping, measures are, at some localities, 1,100 feet thick. This great coal field, which includes an area of 59,370 square miles, affords the largest areas producing coal for the manufacture of coke.

The general structure of the anthracite and Appalachian coal fields consists in a series of rock waves and flexures, beginning in billows near the seaboard, moderating to waves in the middle Appalachians, and calming to mild ripples on the western flank of this longitudinal belt of some 300 miles in width.

West Virginia is credited with having the maximum depth of coal measures. The coal beds vary from a few inches to 10 feet or more in thickness and the percentage of coal to the associated rocks and shales is usually estimated as 1 foot of coal to 50 feet of slate and rock measures.

It is impossible, in a brief table, to give all the qualities of coals embraced in this large territory, but it is believed that the following tabulated analyses will give the general averages:

ANALYSES OF APPALACHIAN BITUMINOUS COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Pennsylvania—East	1.73	23.89	67.03	6.69	.66
Pennsylvania—West	1.70	39.15	46.66	10.52	1.97
Ohio	1.58	41.86	51.44	5.12	2.64
West Virginia—East	1.52	19.81	72.71	5.20	.76
West Virginia—West	1.52	37.86	53.37	6.03	1.22
Kentucky	1.80	33.00	60.10	5.10	.65
Tennessee	1.50	32.51	59.33	5.82	.84
Alabama	1.65	32.48	60.15	4.82	.90

IV. The Northern Coal Field.—The Michigan coal field, in the middle of the state, covers an area of 7,500 square miles. This coal basin lies in a rather flat country, surrounded by higher land. These coal measures belong to the true Carboniferous period. The coal seams are somewhat irregular in character and continuity. During recent years, considerable mining has been entered upon. The upper coal beds afford coking coal, the lower beds of coal are non-coking.

ANALYSES OF MICHIGAN COALS

(*From Alfred C. Lane*)

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Pere Marquette, No. 1 Saginaw....	10.15	33.14	53.95	2.76	1.10
Jackson, New Hope mine..........	5.58	46.73	45.28	2.41	2.83
Saginaw Co., Verne...............	5.82	39.79	45.15	9.24	3.83

V. The Central Coal Field.—This coal field of 46,000 square miles lies in the states of Illinois, Indiana, and Western Kentucky. It contains the three general varieties of bituminous, block, and cannel coals. The main portions of the coals of this field are rich in bituminous matter. The block coal of Indiana is a peculiar fuel; in coking, its volatile matters are expelled, leaving the normal structure of the coal intact, and in this condition it is simply a charred coal.

ANALYSES OF CENTRAL FIELD COALS

		Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Indiana	Block............	2.10	39.05	55.20	2.90	.75
	Bituminous	2.98	40.98	50.70	3.46	1.88
Illinois, Jackson County ...		2.08	37.10	52.17	7.02	1.63
Kentucky	Bituminous	4.48	32.22	54.03	7.90	1.37
	Cannel.........	1.46	45.35	45.80	6.63	.76

During recent years, the Illinois coals have been mined largely, and under careful treatment have appreciated in market value. Efforts are now being made to coke some of the coals in this field, which, with the improved machinery for crushing, classifying, and washing, afford indications of moderate success. So far, however, the efforts at coking the large bed of coal in Southern Illinois have not met the expectation of the parties in Chicago that have made a series of experiments testing the coking properties of these coals.

VI. Rocky Mountain Coal Fields.—The Rocky Mountain coal regions cover portions of the Dakotas, Montana, Idaho, Wyoming,

ANALYSES AND COKING QUALITIES OF ROCKY MOUNTAIN COALS

Twenty-Second Annual Report of the United States Geological Survey

Field	Character of Coal	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Fuel Ratio*
COLORADO							
Raton	Coking	.75	31.13	57.07	11.05		1.80
La Plata	Coking	.82	37.25	55.72	6.00		1.50
Raton	Bituminous	4.88	36.25	53.57	7.97		1.31
Canyon City	Semibituminous	6.21	31.32	52.47	11.10		1.65
South Platte	Lignite	22.95	28.64	43.31	5.10		1.51
Grand River	Anthracite	.59	6.59	88.82	4.00		13.47
WYOMING							
Hams Fork	Lignite	7.75	35.10	50.60	6.55		1.44
Black Hills	Bituminous	8.58	44.36	37.12	9.95		.84
NEW MEXICO							
Gallup	Lignite	12.14	32.81	47.63	7.42		1.45
White Oaks	Bituminous	6.66	40.13	45.56	7.65		1.14
Carillos	Anthracite	2.90	3.18	88.91	5.21		27.96
MONTANA							
Clark's Fork	Lignite	6.53	38.22	48.33	6.92		1.26
Yellowstone	Coking	1.02	38.01	48.20	11.87		1.27
Belt Mountain	Semicoking	3.68	25.43	58.05	11.71		2.28
Bull Mountain	Dry lignite	7.84	42.71	42.65	6.80		9.91

Some of these coals will make coke. The larger portion, however, do not fuse in the coke oven.

---

*Fuel Ratio $= \frac{\text{Fixed Carbon}}{\text{Volatile Matter}}$

Utah, Colorado, and New Mexico. The coal fields in this territory embrace the deposits on the flanks of the Rocky Mountains, the main areas of coal, developed at this time, being found on the eastern side of these mountains.

The qualities of these coals are quite varied, including the Permo-Carboniferous, the Jura-Trias, with the Laramie, the Cretaceous, and the Tertiary. Some of these coals make good coke, but many of them will not fuse in a coke oven. Several of the beds are quite thick, and afford valuable fuel for generating steam, and for metallurgical, manufacturing, and domestic uses.

Within the past decade, the United States government officials have investigated and thrown much favorable light on these fields, and these investigations, together with private enterprise, have disclosed the increasing value of these great coal deposits.

The following statement, from the Twenty-second Annual Report of the United States Geological Survey, will exhibit the progress in coal mining and coke making in this extensive coal region during the year 1901:

State	Coal Produced Net Tons	Coke Made Net Tons
Dakota		
Montana	1,396,081	57,001
Idaho		
Wyoming	4,485,374	
Utah	1,322,614	
Colorado	5,700,015	671,303
New Mexico	1,546,652	41,643

The coal measures in these fields cover an area of 100,110 square miles as known at the present time, but future explorations and government surveys will probably increase the area.

VII. The Western Coal Field.—The western coal field occupies the southern portion of the state of Iowa, the southeastern corner of Nebraska, the northwestern section of Missouri, the eastern side of Kansas, passing through the eastern portion of the Indian Territory and resting in a great prong in the middle of the state of Arkansas. It occupies the interior plain of the continent, and has an area of 99,800 square miles of coal measures.

Extensive mining operations are carried on in the states of Iowa, Missouri, and Kansas, and in the Indian Territory where recent explorations have developed large beds of coal fairly well adapted to the manufacture of coke. In the states of Missouri and Kansas a few coking plants are in operation, but the output is small. In the Indian Territory, several coke plants are in successful operation, the coke being marketed mainly in Mexico.

ANALYSES OF WESTERN COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Iowa	3.00	38.25	48.50	7.50	2.75
Missouri	6.50	37.71	42.17	10.56	3.06
Nebraska					
Kansas	3.25	40.96	43.98	10.71	1.10
Indian Territory East	1.05	19.04	71.73	7.53	.65
Indian Territory West	1.79	40.20	51.79	4.88	1.34
Arkansas East	1.02	10.49	76.12	9.96	2.41
Arkansas West	1.05	14.65	76.11	6.63	1.56

The Texas coal field belongs, by geographical position, to the Western field. Prof. E. T. Dumble, formerly State Geologist, in regard to these lignites, states: "It should, however, be plainly understood in the beginning, that the brown coals of Texas will be found to differ very widely in quality, and it will require analysis of each deposit to tell with certainty for what purpose it is best adapted."

ANALYSES OF BROWN COALS OF TEXAS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Stevens	10.00	5.81	48.46	4.20	1.53
Eagle Pass	5.27	37.48	44.46	10.22	2.57
Laredo	2.00	50.05	39.10	7.35	1.50
Bowie County	10.32	76.35	11.53	1.45	.35

VIII. The Pacific Coast Coal Fields.—The Pacific Coast coal fields embrace a number of detached fields in the states of Washington, Oregon, California, and Alaska. These coals are nearly all of the Tertiary age, and of the general character of lignites. The fields are of limited extent and widely separated. Their products of coal and coke during the year 1901 were as follows:

State	Coal Net Tons	Coke Net Tons
Washington	2,578,217	49,197
Oregon	69,011	
California and Alaska	151,709	

The geological survey of these fields is not yet complete. It is estimated, from what is known, that the aggregate area of these coal fields is about 30,000 square miles. The coal is mainly of the Eocene age, ranging from lignite to coking coal.

ANALYSES OF THE SEVERAL VARIETIES OF COALS IN THE PACIFIC COAST COAL FIELD

Field	Character of Coal	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
WASHINGTON							
Wilkinson	Coking	.70	23.545	56.895	18.715	.145	.009
Franklin	Coking	3.26	35.360	57.580	3.800	.097	
Newcastle	Coking	13.59	32.310	48.320	5.780	.164	
OREGON							
Coos Bay	Non-coking	17.27	44.15	32.40	6.18	1.37	
Coos Bay	Non-coking	6.88	48.69	32.05	12.38	1.50	
ALASKA							
Admiralty Island	Lignite (coking)	2.44	44.75	47.93	4.88	.67	
Admiralty Island	Lignite (coking)	2.57	55.44	29.75	12.24	.89	
Chilcat River	Semianthracite (coking)	.77	13.79	82.36	3.08		
Alaska Peninsula	Semibituminous (coking)	1.62	36.56	52.92	8.90	.75	
Shumagin Islands	Bright lignite (coking)	11.26	40.51	41.24	6.99	2.17	
Yukon Basin	Lignite (coking)	18.31	34.96	40.88	5.85		
Yukon Basin	Semibituminous (coking)	.86	25.75	66.51	6.88		

TABULATED STATEMENT EXHIBITING CLASSIFICATION AND AREAS OF THE COAL FIELDS OF THE UNITED STATES, FOR THE YEAR 1902

Name of Coal Field	Area Square Miles	Output of Coal—1900 Net Tons	Output of Coal—1901 Net Tons	Output of Coal—1902 Net Tons	Output of Coke 1900 Net Tons	Output of Coke—1901 Net Tons	Output of Coke—1902 Net Tons
I. ANTHRACITE							
New England (Rhode Island and Massachusetts)	500						
Pennsylvania	485	57,367,915	67,471,667	41,289,595[d]			
Colorado and New Mexico	25	98,404	66,869	98,937			
Totals	1,010	57,466,319	67,538,536	41,388,532			
II. BITUMINOUS[a]							
Triassic, Virginia	210			58,237			
Triassic, North Carolina	450	57,912	12,000				
Totals	660	57,912	12.000	58 237			
III. APPALACHIAN							
Pennsylvania	9,000	79,842,326	82,305,946	98,061,820	13,357,295	14,355,917	16,497,910
Ohio	12,000	18,988,150	20,943,807	23,388,334	72,116	108,774	146,099
Maryland	550	4,024,688	5,113,127	5,271,609			
Virginia	2,000	2,353,576	2,725,873	3,142,291	685,156	907,130	1,124,572
West Virginia	16,000	22,647,207	24,068,402	24,479,804	2,358,499	2,283,700	2,516,505
Eastern Kentucky	11,180	2,222,867	2,268,892	2,901,693	95,532	100,285	126,879
Tennessee	5,100	3,509,562	3,633,290	4,393,777	475,432	404,017	560,006
Georgia	200	315,557	342,825	414,083	73,928	54,550	82,064
Alabama	3,340	8,394,275	9,099,052	10,589,917	2,110,837	2,148,911	2,552,246
Totals	59,370	142,298,208	150,501,214	172,643,376	19,228,795	20,363,284	23,606,281
IV. NORTHERN							
Michigan	7,500	849,475	1,241,241	964,718			
V. CENTRAL							
Indiana	6,500	6,484,086	6,918,225	9,186,596	Ill., Ind. Mass. Mich. New York Wis., Wyo. 506,730	564,191	598,869
Western Kentucky	4,500	3,106,097	3,201,094	3,760,169			
Illinois	35,000	25,767,981	27,331,552	32,879,303			
Totals	46,000	35,358,164	37,450,871	46,790,786	506,730	564,191	598,869

VI. WESTERN							
Iowa	20,000	5,202,939	5,617,499	5,896,245			
Missouri	23,000	3,540,103	3,802,088	3,855,935	2,087	4,749	5,780
Nebraska	3,200						
Kansas	20,000	4,467,870	4,900,528	5,265,490	5,948	7,138	20,902
Arkansas	9,100	1,447,945	1,816,136	2,028,968			
Indian Territory	20,000	1,922,298	2,421,781	2,769,895	38,141	37,374	49,441
Texas	4,500	968,373	1,107,953	902,882			
Totals	99,800	17,549,528	19,665,985	20,719,415	46,176	49,261	76,123
VII. ROCKY MOUNTAIN, ETC.							
North Dakota	24,000[b]	129,883	166,601	216,871			
Montana	32,000	1,661,775	1,396,081	1,484,277	54,731	57,004	53,463
Wyoming	16,500	4,014,602	4,485,374	4,539,571			
Utah	2,000	1,147,027	1,322,614	1,574,022			
Colorado	18,100	5,182,176	5,668,886	7,961,816	618,755	671,303	1,003,393
New Mexico	2,890	1,263,083	1,050,806	1,002,437	44,774	41,643	23,296
Idaho	4,620	10		1,250			
South Dakota							
Totals	100,110	13,398,556	14,090,362	16,780,244	718,260	769,950	1,080 152
VIII. PACIFIC COAST							
Washington	Estimated	2,474,093	2,578,217	2,400,221	33,387	49,197	40,305
Oregon	25,000	58,864	69,011	63,150			
California Alaska	5,000[c]	171,708	151,079	85,896			
Totals	30,000	2,704,665	2,798,307	2,548,867	33,387	49,197	40,305
Total production, including colliery consumption	344,450	269,682,827	293,298,516	300,929,459	20,533,348	21,795,883	25,401,730

---

[a] Including lignite, brown coal, and scattering lots of anthracite.

[b] Includes South Dakota.

[c] Estimated.

[d] Strike Year.

In Western Washington, some seams of bituminous coal have recently been found which are reported as well adapted for the manufacture of coke; and, also, in Eastern Washington coking coals have been developed.

In addition to these fusing or coking coals found in this field, the chief varieties of coals are valuable for industrial and domestic purposes.

ANALYSES OF PACIFIC COAST COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Washington	2.36	41.91	48.65	7.08	
	1.74	30.70	58.30	9.26	
Oregon	20.00	32.50	41.98	5.34	
	1.53	38.33	44.94	10.71	4.49
California	15.50	40.00	29.50	15.00	
	18.08	39.30	35.61	7.01	
Alaska	2.57	55.44	29.75	12.24	.88

Evidently there is a large area of the Washington coals that, with careful preparation in crushing and washing, will make excellent coke.

COAL FIELDS OF CANADA

In the Dominion of Canada, the coal deposits have been classed in three sections:

I. The Nova Scotia and New Brunswick Fields.—These lie in the Bay of Fundy, and have a desirable location for marketing their coal on the Atlantic seaboard. The coal is similar in quality to the coal of the eastern Appalachian field. The coal measures are 13,000 feet thick, and the aggregate area of the two fields is reported to be 18,000 square miles.

The coal belongs to the Carboniferous period, and is used for coking, for iron manufacture, and for all industrial and domestic purposes.

AVERAGE ANALYSES OF NOVA SCOTIA AND NEW BRUNSWICK COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Pictou	1.20	28.43	56.98	13.39	
Joggins	1.30	37.50	56.00	5.20	
Springhill	1.10	29.10	56.60	13.20	
Nova Scotia	1.15	25.61	60.73	12.51	
Cape Breton	1.10	25.83	67.57	5.50	
Albertite	.50	57.10	42.40	.27	

II. British Columbia and Vancouver's Island Field.—The coal measures in this section belong to the Cretaceous and Tertiary formations. The coal beds are large and the quality is mainly of the better class of such coals. The amount of pressure appears to be the important factor in determining the physical properties of these coals, and consequently of their value.

ANALYSES OF BRITISH COLUMBIA AND VANCOUVER COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
a Non-coking	15.75	35.40	41.45	7.40	
b Non-coking	8.60	35.51	46.84	9.05	
c Good coking	36.065	36.065	61.29	2.645	
McKay, No. 14	4.01	40.07	51.82	4.10	
Nanaimo	1.70	38.10	48.48	11.72	

III. Eastern Rocky Mountain and Great Plains Field.—In the great plains east of the Rocky Mountains, and in the eastern flanking ridges, the coal occurs in the Cretaceous formation, including the Laramie. This field is simply the extension, northwards, of the lignite and brown coal measures of the Rocky Mountain series of the United States. Some of these coals can be used for the manufacture of coke, but the larger proportion goes to other uses.

ANALYSES OF ROCKY MOUNTAIN AND GREAT PLAINS COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
a Non-coking	20.54	33.26	41.15	5.05	
b Non-coking	10.35	34.40	39.61	15.64	
c Non-coking	6.50	38.04	47.91	7.55	
d Good coking	4.41	40.32	48.27	7.00	
e Western anthracite	.71	10.79	80.93	7.57	

MEXICAN COAL FIELDS

The Mexican coals are evidently found in the Cretaceous or Tertiary formations, probably in the former. They appear to be related in part to the Texas coals.

The Coahuila Coal Company, near Sabinas, on the Mexican International Railroad, mine coal and make a fair quality of coke from washed Alamo coal. The analyses are as follows:

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Coal	20.35	20.35	67.64	12.01	86
Coke	1 35	1.35	83.80	14.85	1.08

The coke is used mainly in smelting establishments, and commands a ready sale. It is a fairly good coke, approximating in its physical properties the Tioga coke of Pennsylvania. The coal from which it is made requires careful and intelligent work in preparing it for the coke oven.

CHAPTER II

THE FORMATION AND CHEMICAL PROPERTIES OF COAL

Formation of Coal.—The genesis of coal has now been clearly shown to have been in the swamp flora of the old-time periods of coal making, and the vegetable origin of coal is therefore no longer questioned. This conclusion has been reached from the evidences of the remains of plants of these Carboniferous periods in immediate connection with the coal beds; by the physical structure of the coal, disclosing the anatomy of the several families of plants from which it was made; and from chemical analyses tracing its derivation from vegetable matter.

Coal, therefore, was made from vegetable and woody matter, which grew luxuriantly in broad and extended marshes in the old-age times, when the Appalachian sea covered most of the continent of North America. This vegetable matter, in its decay and fall, was entombed in the waters of these swamps, which kept it from the atmosphere, and thus preserved it from oxidation or waste.

It is also evident that the more thoroughly this vegetable matter was submerged, the more perfectly the resulting coal was bituminized. This immersion in water contributed a very important element in the formation of the more highly bituminous and coking coals.

The deposit of carbonaceous matter was followed by a covering of slates, shales, sandstones, or limestone deposits, which afforded different degrees of pressure on the entombed vegetable matter, and assisted in the subsequent crystallization of the coal.

The flora of the coal-making periods consisted mainly of the large families of tree ferns, Sigillaria, Calamites, and their allies—soft, rapid-growing plants, with jointed stems and broad spear-shaped leaves, which fell in frequent showers into the waters of these marshes. These, with the mosses, ground ferns, and other plants, composed the vegetable mass that made the coal.

The atmosphere of the coal-flora periods was in large part composed of carbon dioxide, which contributed largely to the heat, and furnished plant food for the luxuriant growth of the flora.

But complementary to all these conditions of climate, rapid vegetable growth, and swamp lagoons to preserve it for coal making, great movements in the earth crust were of prime necessity in affording definite time for the accumulation of vegetable matter to make coal beds of useful thickness and to entomb them for the use of the coming age of man.

The broad geological law has been fully established, that all continents have been formed beneath the sea and then emerged from it. Not only this, but also from the way the several sedimentary formations rest upon each other, it is evident that the land has been alternately emerged and submerged many times in the process of its formation. These movements of the submergence and emergence, during the formation of the coal measures, are in entire harmony with the laws governing the formation of all the sedimentary deposits.

It will also be readily understood that in the coal-making periods, under varied conditions and extended time, a variety of coals have been made, with different degrees of purity, and with varied ratios of fixed to volatile matters. These changes have also been influenced by the subsequent movements in flexing the strata, producing the debituminization of the coal in greater or less degrees. In the greatly flexed and folded regions of the coal fields, local causes have contributed to carry the change still further, producing anthracite coal from the evolved heat in these movements. Where this metamorphosis has been carried still further, the ultimate is produced in graphite or black lead.

It is well known that all vegetable tissue contains some incombustible matter, which is designated as "ash" in coal. It ranges from 1 or 2 per cent. to 5, 10, or more per cent. in the usual varieties of coals. When coal contains more than 5 per cent. of ash, it is evidence of the deposit of mud from other sources than the vegetable matter making the coal. This additional impurity has come into coal from sediment in the waters of the marshes and from the fine muds composing the roof of the coal bed. The ratio of this fine mud or slate impurity in coal can increase until the former predominates, causing the product to lose its rank among the useful family of coals.

The usual law, with some exceptions, is that this slate impurity in coal carries with it iron pyrites, FeS_2 (a compound of sulphur and iron), so that the volumes of these undesirable impurities are usually found in a varying proportion to the amount of ash in the coal, increasing generally as the ash increases. But there are exceptions to this law.

Varieties of Coal.—It is assumed that what is now ranked as bituminous coal represents the normal condition of all true coal prior to the subsequent changes by the agencies of heat.

Fig. 1 illustrates, in a general way, the chemical and physical changes in the formation of the several varieties of coal, from its organic constituents in plant tissue to the last result in graphitic carbon.

Prof. Joseph Le Conte has given the approximate composition of these typical varieties of bituminous coal and graphite, and has constructed the following chemical formulas showing the changes under which they were formed:

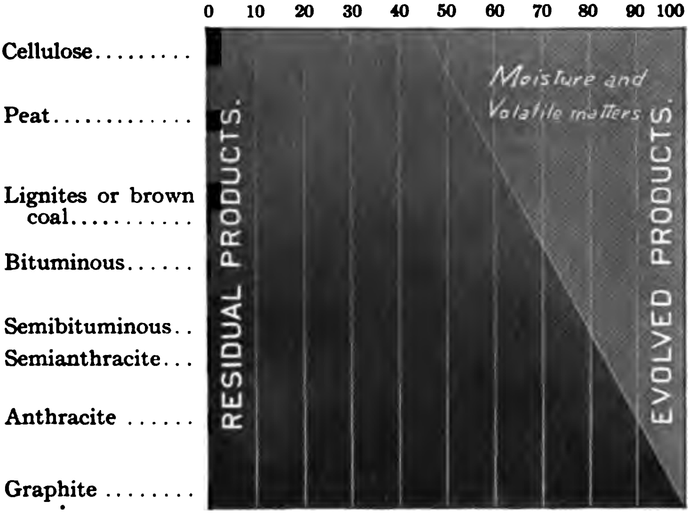


Fig. 1. Diagram Showing Genetic Relations of the Carbon Minerals, After Prof. J. S. Newberry

Vegetable matter, cellulose............ $C_{36}H_{60}O_{30}$*
Subtract 9 CO_2, 3 CH_4, 11 H_2O........ $\underline{C_{12}H_{34}O_{29}}$
And there remains.................... $C_{24}H_{26}O$ = cannel

Vegetable matter.................... $C_{36}H_{60}O_{30}$
Subtract 7 CO_2, 3 CH_4, 14 H_2O........ $\underline{C_{10}H_{40}O_{28}}$
And there remains.................... $C_{26}H_{20}O_2$ = bituminous coal

Vegetable matter.................... $C_{36}H_{60}O_{30}$
Subtract 10 CO_2, 10 CH_4, 10 H_2O...... $\underline{C_{20}H_{60}O_{30}}$
And there remains.................... C_{16} = graphite

The table on the following page exhibits the principal elements of the genesis and varieties of coals.

From this table will be noted the gradual changes effected during the lapse of time, in which plant tissue has been subjected to natural distillation. In the western coal fields we have impressive

---

*The composition of wood timber is usually given as about $C_{12}H_{18}O_8$. I have taken the formula of cellulose instead, viz., $C_6H_{10}O_5$; or, taking six equivalents for convenience of calculation, $C_{36}H_{60}O_{30}$. I believe this to be much nearer the composition of the vegetable matter of the coal period than is the formula of hardwood like oak or beech. All the results may be worked out, however, with equal ease by the use of either formula for vegetable matter.

examples of such changes, in the localities of trap outbursts, altering the Cretaceous or Tertiary coals to good bituminous and anthracite varieties. To what extent this metamorphism has affected many localities of far western coals that are now profitably used in the manufacture of coke, is not clearly made out. It is submitted by some observers, that the chief element that has altered these western coals into the many varying grades in which they are found to exist, is the pressure from upheaval and flexure.

PRINCIPAL ELEMENTS OF THE GENESIS AND VARIETIES OF COALS

Names	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
Cellulose		55.36	41.44	3.00	.20	
Peat	24.20	27.00	45.30	3.30	.20	
Lignite		27.90	66.09	4.00	1.00	
Brown coal		29.06	66.31	2.27	2.36	
Cannel	2.10	14.99	68.13	12.30	2.48	
Albertite		13.68	86.04	.10	trace	
Bituminous	1.78	35.36	58.29	3.89	.68	trace
Semibituminous	1.20	23.89	67.56	6.69	.66	.005
Semianthracite	2.27	8.83	78.83	9.39	.68	
Anthracite	2.98	3.38	87.13	5.86	.65	
Graphite			99.00	1.00		

It will be noted, however, that the evident cause of these changes in the varieties of coals, in the neighborhood of trap dikes or outbursts, with the resultant heat, is easily understood, but in large areas of coal deposits, without any evidence of eruptive heat, the cause must be sought in other conditions.

The rich bituminous coals of Western Pennsylvania, the semibituminous coals on the eastern flank of the Alleghany field, the pure, glassy anthracite of the eastern fields, and the graphitic anthracite of the state of Rhode Island all belong to the same age—the true Carboniferous period. From the analyses of these coals, it will readily appear that the largest evolved products of natural distillation occurred in Rhode Island, moderating in its action, westwardly, until the normal condition of bituminous coal is found in Western Pennsylvania and Ohio. While there may exist some conflict of opinion as to the cause of this debituminization of coal eastward, the fact that such has been consummated is not in dispute.

In considering the cause or causes that have produced the various conditions of coals, the fact is quite evident that all the anthracites in Rhode Island and in Eastern Pennsylvania are found in sections that have been violently flexed and tilted. This work of folding and flexing the eastern flank of the continent must have been accompanied with a large amount of evolved heat, as the pushing forces exerted must have been enormous. As all the measures in these sections have been baked with heat in about the proportion to the violence of the disturbance in each locality, it is evident that the cause or causes have been as extensive as the results. Hence, it has been inferred that the heat evolved in the flexing of the measures, combined with moisture and pressure, have been the chief agents in producing the conditions that have made the several varieties of coals—anthracite, semianthracite, and bituminous.

The origin of this dynamic or folding force evidently had its source mainly from a cooling globe. The rigidity of the rock belt along the Atlantic Ocean seaboard confined the main body of this force to the softer inland crust, the latter being crushed and flexed in proportion to its proximity to the rigid seaboard belt, beginning at the seaboard with the largest crust waves, moderating into ripples, and as Ohio is reached, the measures are nearly horizontal. The heat evolved in these great crust movements altered the eastern coals into graphites, anthracites, and semianthracites, the coals regaining their normal condition westward beyond this region of intense disturbance.

This general law of the bituminization of coal westward has some slight exceptions. At the summit of the Alleghany Mountains, at Bennington, the coal contains 23 per cent. of volatile matter, while an exceptional belt at Johnstown, 26 miles westward, contains less than 20 per cent. of hydrogenous matter. From Johnstown westward, the increase of volatile matter is quite regular until the maximum belt of the normal bituminous coal is reached in Western Pennsylvania and Ohio.

The coals of the eastern anthracite fields have been thoroughly coked under immense pressure, making this natural coke too dense for the best results in blast-furnace operations. This undesirable physical condition of extreme density will be fully considered later.

The manufacturer of coke can, therefore, intelligently consider the qualities of the coals in the Appalachian and western fields for use in making coke. As the dynamic force that flexed and folded the eastern side of the North American continent exerted its greatest force at the east, diminishing gradually westward, the evidence of the action of the diffused heat from these movements is seen in its effect in the hard, dry anthracite coals of Pennsylvania and Rhode Island, the dry semibituminous coals of Broad Top and Cumberland, with the increase of bituminization of the coals westward, until the normal undisturbed condition is reached in the great central plain of the continent.

The table on the following page gives the composition of the typical varieties of coals, from Rhode Island to Iowa.

It is also of interest to consider the irregular curved lines of the eastern escarpment of the great Appalachian coal field, with the deeply curved indents in Pennsylvania and Tennessee, displaying the immense forces that have flexed and pushed back bodily these portions of the field, with measures 8 to 9 miles thick. In the subsequent erosion, Tennessee and Alabama suffered most, having had the dryer sections of their coals carried away and leaving the more western sections, with their increased volumes of volatile matter, for the manufacture of coke.

TABLE EXHIBITING THE DEBITUMINIZATION OF COALS—EASTWARD

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Iowa	1.40	41.40	48.50	7.50	1.20
Illinois	1.25	41.85	48.90	7.00	1.00
Indiana	1.10	37.06	57.59	3.50	.75
Ohio	2.70	33.49	56.90	5.99	.92
Pennsylvania					
Pittsburg	1.28	38.10	54.39	5.44	.79
Connellsville	1.25	31.79	59.80	7.16	.60
Johnstown	1.03	16.49	73.84	7.97	1.97
Bennington	1.20	23.33	69.02	5.69	.76
Maryland, Cumberland	.89	15.52	74.29	8.59	.71
Pennsylvania					
Semianthracite	1.25	9.60	81.30	6.90	.85
Anthracite	1.35	3.45	89.06	5.81	.30
Rhode Island, Graphite					
Anthracite	1.18	3.80	85.70	8.52	.80

It has been noted that in the meridional sections of this coal field, if not in all fields, the qualities of the coal in the several beds approximate very closely in their chemical composition; so that if a good coking coal in found in any of the beds in a special section, all of its associated beds, above or beneath, will probably afford similar good results in coking.

COMPOSITION OF COKING COALS

While it is not yet clearly determined why one coal will fuse in the coke oven and make good coke, and another of very similar chemical composition will not fuse in coking, yet, in the Appalachian field, it has been found reasonably sure that coals, approximately equal in chemical composition, will afford similar results in the process of coking.

The following analyses will show the composition of the standard typical coking coals in the Appalachian field.

It is quite remarkable that the standard coking coal of the Connellsville region is found in a long, narrow synclinal strip, west of the Chestnut Ridge. It affords a coal with an average chemical composition between the rather dry coals to the eastward of it and the too bituminous coals westward.

ANALYSES OF STANDARD APPALACHIAN COKING COALS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Pennsylvania					
Bennington	1.73	23.89	67.03	6.69	.66
Connellsville	1.26	31.79	59.79	7.16	.60
West Virginia					
Monongah	1.52	37.96	53.27	6.03	1.22
Pocahontas	.69	19.96	73.02	5.67	.66
Kentucky	1.80	32.34	60.10	5.10	.66
Tennessee	1.50	32.51	59.33	5.82	.84
Alabama	1.65	32.48	60.15	4.82	.90

ANALYSES OF APPALACHIAN COALS

Coal Fields	Moisture at 212° F. Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Second Geological Survey of Pennsylvania
Cumberland	.893	15.522	74.289	9.296	.714	HHH, p. 101
Broad Top	.770	18.180	73.340	6.690	1.020	Kelly (D)[1]
Bennington	1.200	23.680	68.170	5.730	.620	Miller (B)
Johnstown	.720	16.490	73.840	7.970	1.970	C. I. Co. Dr. F.
Blairsville	.920	24.360	62.220	7.590	4.920	HHHH, Unwshd
Connellsville	1.260	31.800	59.790	7.160	.530	C. I. Co. Dr. F.
Greensburg	1.020	33.500	61.340	3.280	.860	MM, pp. 23, 24
Irwin	1.410	37.660	54.440	5.860	.640	MM, p. 22
Armstrong Co.	.960	38.200	52.030	5.140	3.660	MMM, p. 56

Whether this quality of coal will be found in the extensions of this strip northeastward and southwestward, paralleling the trend of the Appalachian mountain ranges, is yet to be learned. In other words, it is not yet known what were the ultimate effects of the heat diffused during the period of the flexing of the coal measures in fixing the condition of the quality of the coal as regards leanness or richness in bituminous matters.

The following shows the average composition of the celebrated Durham coking coal, England:

	Per Cent.
Moisture	.90
Volatile matter	13.00
Fixed carbon	80.80
Ash	4.39
Sulphur	.91

It is very remarkable that this Durham coal, with its very low volume of volatile matter, fuses so thoroughly in the coke oven (beehive) and produces first-class coke. Such a well-determined result adds to the perplexity of the investigation to determine the reason why one coal will coke and another will not.

TABULATED EXHIBIT OF COKING AND NON-COKING COALS

State	Locality	Geological Formation	Chemical Composition of Coals							Remarks
				Moisture at 212° F. Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.	
Pennsylvania.....	Connellsville	Upper XIV	*a*	1.26	31.80	59.79	7.16	.53	.024	Best coking coal
Virginia..........	Pocahontas	Lower XIV	*b*	1.01	18.81	72.71	5.19	.79		Best coking coal
West Virginia....	Kanawha Valley	XIII			36.58	60.37	3.06	.77	.009	Best coking coal
Pennsylvania.....	Broad Top	Lower XIV	*c*	1.28	18.40	71.12	7.50	1.70	trace	Good coking coal
Pennsylvania.....	Bennington	Lower XIV	*c*	1.20	23.68	68.77	5.73	.62	.017	Good coking coal
Pennsylvania.....	Johnstown	Lower XIV	*a*	.72	16.49	73.84	7.97	1.97		Dry coking coal
Pennsylvania.....	Greensburg	Upper XIV	*b*	1.02	33.50	61.34	3.28	.86		Good coking coal
Pennsylvania.....	Armstrong Co.	Lower XIV	*b*	.96	38.20	52.03	5.14	3.66		Pitchy coking coal
Illinois...........	Mt. Carbon	Lower XIV	*c*	2.08	38.20	53.47	8.02	.63	.027	Pitchy coking coal
Colorado.........	El Moro	Cretaceous	*d*	.95	29.82	56.41	12.82	.41		Good coking coal
Colorado.........	Crested Butte	Cretaceous	*d*	.72	23.44	71.91	3.93	.36		Good coking coal
Montana.........	Sandcoulee	Cretaceous	*c*	2.26	33.60	54.47	7.82	1.85	.009	Mainly non-coking coal
Montana.........	Belt Mountain	Cretaceous	*c*	2.98	28.71	53.31	13.34	1.65	.012	Mainly non-coking coal
Mexico..........	Coahuila Coal Co.		*a*	1.60	15.00	67.64	12.01	.86		Coking coal
British East India	Umaria	Jurassic or Cretaceous		4.84	34.07	46.33	14.76	1.08	.010	Non-coking coal
British East India	Warora	Jurassic or Cretaceous		6.00	34.00	43.04	16.96	1.20	.006	Non-coking coal
British East India	Johilla	Jurassic or Cretaceous		5.76	33.03	44.22	16.99	.42	.008	Non-coking coal
Pennsylvania.....	Indiana Co. Snyder Bank	Lower XIII		.63	25.63	62.26	11.48	.99	.012	Washed coal to make coke

It may be interesting to compare the composition of some coking and non-coking coals from the Carboniferous measures and from the Jura-Cretaceous deposits.

It is submitted as an established experience that the approximate chemical analyses of coals will not disclose their coking properties. It is therefore evident that in determining the type of coke oven, with the proportions of its chamber, walls, flues, etc., the only safe plan is to have a sufficient quantity of coal coked in the several plans of ovens, or tested in some reliable experimental plant.* In this respect it may be added that in coking the coals low in volatile combustible matters in any type of oven, it will be found of great benefit to break the coal to such sizes as will conduce to the most economic results in fixing the fusing matters in the initial operation of coking. With coal charged into the oven in large lumps, it is evident that, as the coking begins on the outside and moves slowly into the interior of the lumps, the gases in the central portion must be dissipated in more or less volume, depending on the dryness of the coal and the size of the lumps.

The oven will also be required to be kept at a maximum heat when charging the coal into it. With the disintegration of the coal and the sustained heat of the oven, the small volume of fusing matters in the coal can be promptly fixed in the coke and their dissipation with the gases prevented.

As the Appalachian coal field affords the greatest supply of coking coals, the careful study of the approximate analyses of these becomes of the first importance, so that the coke oven best adapted for the several varieties of coals can be intelligently selected.

In the Appalachian region, the analysis of the coal will, in most instances, indicate its coking properties, but westward the coals having compositions similar to good coking Appalachian coals fail to fuse in the coke oven. Pennsylvania, Virginia, West Virginia, Kentucky, Tennessee, and Alabama have been especially favored by large areas of good coking coals in this great field of 59,370 square miles. The eastern side of the field affords the coking coals best adapted for making metallurgical coke. The western side inherits too much bituminous matter to assure very good coke. This law is shown in the pitchy coals of Ohio, Indiana, and Illinois and by the small amount of coke made in these states.

The coals of Colorado, Wyoming, Montana, and the other northwestern states, belong to the Jura-Trias and Laramie-Cretaceous measures, and are independent of the Appalachian law of ratio of volatile hydrocarbons to fixed carbon, as some of these coals can be coked readily in the common beehive coke oven, as at the

---

*There are reliable establishments in the United States for testing the washing and coking properties of coals, such as the Link-Belt Machinery Company, Chicago, Illinois; Messrs. Stein & Boericke, Primos, Delaware County, Pennsylvania; Roberts, Schaefer & Company, 1275 Old Colony Building, Chicago, Illinois; and the Jeffrey Mfg. Co., Columbus, Ohio.

Trinidad or El Moro, the Crested Butte, and other coke works of Colorado, the Cambria Mining Company, of Wyoming, and the Bozeman and Gardner coke works, of Montana. On the other hand, a large portion of these northwestern coals, very high in hydrogenous mätters, cannot be coked.

It is slowly becoming evident that the solution of the coking or non-coking properties of coals is entirely confined to the relations and volumes of the elements composing the volatile combustible matters of the coal. The moisture, fixed carbon, ash, and sulphur may differ widely in good coking coals, without seriously affecting their coking properties. An example of this is seen in the very large difference existing in the volumes of carbon and ash in two of the best-known coking coals, Connellsville and Pocahontas; the former containing 59.79 per cent. of fixed carbon and the latter 72.70 per cent. The ash is neutral, exerting no influence in the fusing of coal in coking. The sulphur and phosphorus come under the same condition—they are simply undesirable elements in the metallurgical coke.

It is evident that large differences exist in the volumes of the volatile combustible matters in the coking coals of the Carboniferous age in the Appalachian field. From the percentages of volatile combustible matters in these coals, their relative coking properties can be confidently predicted. These percentages of volatile combustible matter for a coking coal range, in ordinary coke ovens, from 17 to 33 per cent.; with retort ovens and their recuperative and regenerative auxiliaries, coals inheriting much lower percentages of volatile combustible matters can be coked. The only further remark in this connection is, that in coking coals with small volumes of volatile combustible matter affording insufficient heat for coking, the balance of the heat required must come from the fixed carbon of the coal.

As a unit of carbon affords about 8,000 calories of heat, while a unit of hydrogen affords 34,000 calories, it will readily appear that coals low in hydrogenous matters must surrender, in the ordinary open ovens, an increased volume of fixed carbon to compensate for the deficiency in the reduction of the greater heat-giving hydrogen.

The loss of carbon in the open coke ovens, especially in coking the dry coals, was evidently the impelling element in the evolution of coke ovens, and in developing the retort or closed ovens with their auxiliary recuperative and regenerative appliances, and in the utilization of the gases from the coking coal in heating the oven chamber and saving the fixed carbon in coking. To assure sustained heat, as well as from the peculiar construction and length of these retort coke ovens, the charges of coke require to be drawn by mechanical appliances.

Returning to the evidence submitted, locating the fusing element or elements in coals of the Appalachian age, in their volatile combustible matters, it was shown that wide differences in the volumes of fixed carbon could exist in these coals, producing, as far as is now known, only slight modifications in their coking qualities.

It has been made evident by practical experience that in the Appalachian region coals containing 18 to 35 per cent. of volatile combustible matters can be made, with proper oven treatment, into good coke. Northwestward, among the more recent deposits of coals, the ratio of volatile hydrocarbons to the fixed carbon does not indicate, with some exceptions, their coking properties, as some of these coals inheriting 35 to 45 per cent. of these matters fail to fuse in any type of coke oven.

It has been noted in the reports of the United States Geological Survey that a coal found in Alaska, and containing the following elements, could not be coked:

ALASKA COAL	PER CENT.
Moisture, 212° F.	9.31
Volatile combustible matters	40.85
Fixed Carbon	46.14
Ash	3.70
	100.00

But in the Jura-Trias and Laramie-Cretaceous coals, this Appalachian law will not, as a general rule, be found reliable. This will be seen in the efforts to coke the large samples of the Sandcoulee and Belt Mountain coals of Montana. In comparing their volumes of volatile combustible matters with the Connellsville, their close relations will appear as follows:

Connellsville, Pennsylvania	31.80	per cent. of volatile combustible matters
Sandcoulee, Montana	33.60	per cent. of volatile combustible matters
Belt Mountain, Montana	28.71	per cent. of volatile combustible matters

Connellsville coal is the standard coking coal of the United States, as far as present knowledge has disclosed; the coals of Sandcoulee and Belt Mountain are mainly non-coking.

Tests of Sandcoulee and Belt Mountain Coals.—A shipment of coal from Sandcoulee, Cascade County, Montana, was tested at the coke works of the Cambria Iron Company, in the Connellsville region, in 1889. A general average of this coal from a bed 6 feet 6 inches to 8 feet 6 inches thick, showed the following composition:

	PER CENT.
Moisture at 212° F.	2.260
Fixed carbon	54.470
Volatile combustible matters	33.600
Ash	7.820
Sulphur	1.850
Phosphorus	.009
	100.009

The two benches of this coal bed differed in quality; the upper bench affords a dull, dry coal, the lower bench is brighter and more fusible in the coke oven. The coke was made from an average of both benches—it was analyzed as follows:

	PER CENT.
Fixed carbon	88.350
Ash	10.850
Sulphur	1.790
Phosphorus	.009
	100.009

The coke exhibited a composite structure; the coal from the upper bench did not fuse. The coking operation expelled the volatile matters, leaving the normal structure of the pieces of coal unchanged—it was simply charred coal. This coal received preparatory treatment in various ways before it was charged into the ovens—it was broken into small pieces, wetted, etc. The operations of coking were also varied, from slow, mild heat to quick, intense heat. The latter method gave the better results. The coke was made in the beehive ovens with great care and by expert cokers. The ultimate decision was that, while the Cretaceous coal is well adapted for generating steam and for domestic and other uses, it does not fuse in coking so as to produce a merchantable coke.

Another sample of coal, from the Belt Mountain, 14 miles south of Sandcoulee, Montana, was forwarded to Connellsville for test in coking. The coal bed has three benches, the average analysis of these is as follows:

BELT MOUNTAIN COAL	PER CENT.
Moisture, 212° F.	2.980
Volatile combustible matters	28.720
Fixed Carbon	53.310
Ash	13.340
Sulphur	1.650
Phosphorus	.012
	100.000

This coal, under repeated efforts in coking, came out of the oven charred; it could not be coked.

On the other side, the Trinidad and El Moro coal of Colorado, located in the Cretaceous measures, and holding 29.82 per cent. of volatile combustible matters, affords a very good coke in beehive coke ovens.

This important inquiry, as to the composition of coals that will fuse in the coke oven, has elicited and continues to invite much earnest investigation from chemists, and while some approaches have been made in ascertaining the element or elements that produce fusion of the coal in coking, yet these are not fully assured as general principles that can be relied on for universal application.

It is reported that some German chemists have made tests to ascertain the cause of the coking or fusing of bituminous coal in the coke oven under distilling heat, the conclusion being that the fusing property of the coal is produced by its richness in what is known as disposable hydrogen, or that portion which is in excess of the quantity required to form water with the oxygen present. It has been shown that such a standard for the fusing quality of coal does not correspond with observed results. So that we have in this no sure ground for such determination.

The richness of the coal in carbon does not appear to govern its fusing capabilities, the fact being that two samples of coal of practically equal carbon composition will be found to behave very differently in coking in the ovens. It is evident that if the genesis of fusing does not reside in the surplus hydrogen or fixed carbon, it certainly does not lie in the oxygen, as the latter affords no indication of the physical behavior of coal in the retort of the coke oven.

Fusibility and Coking Properties.—The following extract on the fusibility and coking property of coals is taken from the American Manufacturer—the author's name not being given:

"It has been long known that the property of coking which belongs to many coals—a property which may be observed in every degree, i. e., from a weak slagging to a complete fusion—is not a simple or partial fusion, and the fusion of mineral coal is accompanied rather by a fundamental decomposition of the same, just as is the case when sugar is subjected to a high heat, whereby are generated gases and vapors burning with a more or less luminous flame and leaving behind them a fused residue consisting chiefly of carbon.

"The very natural supposition that the fusibility or infusibility of a coal must always stand in fixed ratio to its proportional composition is not at all borne out by practice, although a number of isolated cases may seem to give it support.

"Percy (Metallurgy) found the following percentages of hydrogen, oxygen, and nitrogen in several coking and non-coking coals:

	Non-Coking		Coking			Non-Coking			
	1	2	3	4	5	6	7	8	9
H	4.75	4.95	5.49	5.85	5.91	6.34	6.12	6.04	5.99
O and N	5.28	7.36	10.86	14.52	18.07	21.15	21.13	22.15	23.42

"The following excesses of hydrogen, over what was considered necessary to combine with the oxygen to form water, were found, that is, the remaining quantities of disposable hydrogen:

	Non-Coking		Coking			Non-Coking			
	1	2	3	4	5	6	7	8	9
H	4.09	3.53	4.13	4.04	3.65	3.70	3.47	3.22	3.06

"The property of coking evidently cannot depend on this disposable hydrogen, since, for instance, in Nos. 1 and 4, non-coking and coking coals respectively, it is very nearly the same.

"The sum of hydrogen and oxygen in these nine coals is:

NON-COKING		COKING			NON-COKING			
10.03	11.81	16.35	20.37	23.98	27.49	27.35	28.59	29.41

"From this it might be inferred that a content of 7–18 per cent. of oxygen entails the property of coking. The results in the table on the opposite page, obtained from the experiments of W. Stein and of the author, however, are totally against such an inference.

"Of the Saxon coals, for instance, Nos. 7 and 8, as well as Nos. 9 and 10, while having a very similar composition, show entirely different results by the coking test. The same is true of each pair of the Westphalian coals analyzed.

"For single coal fields, it is, of course, possible to establish some limits. Richter, for instance, has done this for the coals of lower Silesia, though only in an introductory way:

"(*a*) So-called coking coals contain, with few exceptions, 40 parts of disposable hydrogen per 1,000 of carbon.

"(*b*) In case of equal content of disposable hydrogen, the coking power increases the more the combined hydrogen falls below 20 per 1,000 of carbon. Coals of 20 per 1,000 content of combined hydrogen, and even those of 17 to 18 per 1,000 do not, in lower Silesia, belong to the number of coking coals, properly speaking.

"(*c*) Although the above may be accepted as the rule, it must still be noted that sometimes coals of almost the same composition show very different coking properties.

"A sort of rule may be deduced as follows, from the analyses of several hundred Westphalian coals:

"(*a*) Coking coals (swelling in the process of fusion) contain, per 1,000 parts of carbon, over 40 of disposable hydrogen and 10 of combined hydrogen, or under 40 of disposable hydrogen and over 9 of combined hydrogen.

"(*b*) Open-burning or slagging coals (that is, fusing, but not swelling) contain, per 1,000 of carbon, over 34 of disposable hydrogen and over 9 of combined.

"(*c*) Close-burning coals contain, per 1,000 of carbon, under 40 of disposable hydrogen and under 9 of combined.

"The property of fusing or not fusing finally depends on the presence or absence of certain carbon compounds, of which intimate knowledge is probably not attainable."

Mr. Richard Thomas, in "A Paper on Coke," read before the Alabama Industrial and Scientific Society, submits a tabulated statement showing the ultimate composition of some Welsh coals, and from the coking or non-coking properties of these, infers that the fusing element in coals consists of the relations of the hydrogen to the carbon.

ANALYSES AND TESTS OF GERMAN COKING COALS

		Coals Free of Ash			Hydrogen per 1,000 Parts of Carbon			Coke	Character of the Residue
		C	H	O+N	Disposable	Combined	Total		
Saxony.......	Oberhohendorf...	83.28	4.55	12.17	36.38	18.25	54.63	67.70	Caked
	Zwickau.........	83.82	4.19	11.98	32.09	17.90	49.99	69.95	Sandy
	Zwickau.........	81.47	4.38	14.06	32.28	21.56	53.84	54.64	Caked
	Niederwurschnitz	81.17	4.67	14.15	35.71	21.80	57.51	69.73	Crumbling coke
	Niederwurschnitz	84.36	4.30	11.34	34.25	16.71	50.96	62.00	Coke weakly "fritted"
	Planitz..........	84.84	4.63	10.97	38.42	16.14	54.56	63.89	Caked
	Niederwurschnitz	82.34	4.73	12.93	37.68	19.62	57.30	66.43	Sandy
	Zwickau.........	82.59	4.76	12.65	38.50	19.13	57.63	77.29	Caked
	Zwickau.........	78.71	4.27	17.02	27.30	26.93	54.23	77.44	Caked
	Niederwurschnitz	78.71	4.51	16.75	30.73	26.54	57.27	60.81	Crumbling coke
Westphalia ...	Pluto Mine, cannel coal......	86.04	5.73	8.23	54.67	11.96	66.68	61.48	"Slagged" (gesintert)
	Mont Cenis mine, coking flame coal....	84.89	5.72	9.39	53.66	13.80	67.46	64.29	Caked
	Pluto mine, gas coal..........	83.17	5.37	11.46	47.41	17.21	64.61	66.86	Caked
	Pluto mine, gas coal..........	83.16	5.42	11.42	47.95	17.17	65.12	68.28	"Slagged"
	Alma mine.......	87.47	5.03	7.50	46.74	10.71	57.45	75.80	Partially "slagged"
	President mine...	87.79	4.97	7.24	46.36	10.30	56.66	77.60	Caked and much swollen

TABLE SHOWING COMPOSITION OF WELSH COAL

No.	C Per Cent.	H Per Cent.	N Per Cent.	O Per Cent.	S Per Cent.	Ash Per Cent.
1	91.44	3.46	.21	2.58	.79	1.52
2	84.87	3.84	.41	7.19	.45	3.24
3	89.01	4.49	1.16	1.65	1.03	2.66
4	89.78	5.15	2.16	1.02	.39	1.50
5	81.72	5.76	.56	8.76	1.16	2.04
6	87.48	5.06	.86	2.53	1.03	3.04
7	82.75	5.31	1.04	4.64	.95	5.31

TABLE SHOWING AMOUNT OF COKE AND WHAT WAS VOLATILE

No.	Coke Per Cent.	H Per Cent.	N Per Cent.	O Per Cent.	C Per Cent.	Hydrogen to Carbon
1	92.90	3.46	.21	2.58	.85	$\left\{\begin{matrix}H\,1.\\C\,26.4\end{matrix}\right\}$ Anthracite
2	85.50	3.84	.41	7.19	3.06	$\left\{\begin{matrix}H\,1.\\C\,22.1\end{matrix}\right\}$ Semianthracite
3	84.55	4.49	1.16	1.65	8.14	$\left\{\begin{matrix}H\,1.\\C\,19.8\end{matrix}\right\}$ Bituminous
4	77.50	5.15	2.16	1.02	14.18	$\left\{\begin{matrix}H\,1.\\C\,17.4\end{matrix}\right\}$ Bituminous
5	68.40	5.70	.56	8.76	16.58	$\left\{\begin{matrix}H\,1.\\C\,16\end{matrix}\right\}$ Bituminous
6	72.94	5.06	.86	2.53	18.61	$\left\{\begin{matrix}H\,1.\\C\,17.1\end{matrix}\right\}$ Bituminous
7	67.10	5.31	1.04	4.64	21.91	$\left\{\begin{matrix}H\,1.\\C\,15.6\end{matrix}\right\}$ Bituminous

Mr. Thomas gives the following descriptions of the above coals:

"*Coal No. 1, or Welsh Anthracite.*—This coal will not fuse, neither will the lump coke like the other coal. The analysis shows 92.9 per cent. of coke from the coal. In appearance, it is more like a drying up coal than coke. In place of cells, it looks more like cracks. By disintegrating the coal, and using about 6 per cent. of pitch, the latter being about 12 per cent. of hydrogen to 88 per cent. of carbon, the two combined make a very strong coke. The fracture did not show the cells the same as the coking coal, but was granulated in appearance. They claim that it works well for foundry purposes and commands a price from 3 to 4 shillings per ton more than the coke made in the same locality from the bituminous coal. The loss in volatile matter in this coal is very small. The difference in carbon from coal to coke is less than 1 per cent.; the analysis shows 3.46 per cent. of hydrogen, and 2.58 per cent. of oxygen. It seems, by the proportion of volatile carbon to the amount of oxygen, that the two had combined into carbonic oxide. Had the carbon and the hydrogen combined, it would have formed the light carbide of hydrogen, which is composed by weight of

75 per cent. of carbon to 25 per cent. of hydrogen. In that case, there would have been a loss of over 10 per cent. of carbon. On the other hand, if the amount of oxygen had combined with the hydrogen and formed water, the amount of hydrogen would not have exceeded .32 of 1 per cent. It is very clear that the hydrogen, in the anthracite, must have escaped almost in a pure state from the coal, and mixed with the oxygen of the air and formed water.

"*Coal No. 2* has a little more hydrogen, and like No. 1 it will not fuse, neither will it coke, only when mixed with pitch, or some of the other solid volatile carbons. This coal would have to be treated the same as No. 1 to make coke. The coking of No. 1 was discontinued for a time, owing to the advance in the price of pitch, there being such a demand for the article to mix with the dry non-fusible coal, to make patent fuel.

"*Coal No. 3.*—This coal is known, the world over, as the Aberdare and Merthyr smokeless steam coal. This is 2.33 less in carbon than No. 1, but higher in hydrogen, by a little over 1 per cent. It has only 1.65 per cent. of oxygen, and it shows a loss of carbon in coking of 8.14 per cent., the oxygen being so low.

"The carbon, in this instance, must have formed gas, most likely the light carbide of hydrogen. This coal has not sufficient hydrogen and carbon to fuse, but the lump makes a good furnace coke and is used very extensively. The slack of No. 3 will coke when disintegrated with richer coal, in proportion about half and half, or when the hydrogen would be about 5 per cent. in the coal—or, say, 1 per cent. of hydrogen to 17.5 carbon. The two combined will yield about 75 per cent. of coke from the coal.

"*Coal No. 4* will fuse and make a strong coke, and is a coking bituminous coal. I have noticed that, whenever it gives, say, 75 per cent. of coke from the coal, the color of the coke is dark gray and shows the cells very clearly; but it will not have a smooth, silvery gloss on it. None of the dry coals have.

"*Coal No. 5.*—This coal shows 8.06 per cent. less carbon than No. 4, but it has 7.74 per cent. more oxygen in it, and has also .61 per cent. more hydrogen. The hydrogen is 1 to 16 of carbon. This will make a bright coke of silvery appearance.

"*Coal No. 6* makes a good furnace coke, and shows the cells a little darker gray in color, the yield being rather high to be glossy.

"*Coal No. 7.*—This coal cokes more like the Connellsville, of Pennsylvania, than any I have ever seen. This coke, in appearance, has a very smooth, silvery gloss when cooled in the ovens. The best coke in this series is made from a vein called the Crepwr vein. It makes a good, strong furnace coke, and is largely used for foundry purposes. Owing to a slate roof, some of which falls in mining, the slack in some of the mines is washed, but the vein is free from all impurities, and averages about 8 feet thick."

He concludes that No. 1 coal, with a proportion of hydrogen to carbon of 1 to 26.4, will not fuse in the coke oven. No. 2 coal, with a proportion of 1 to 22.1, will not coke. No. 3, a smokeless steam coal, inheriting a proportion of hydrogen to carbon of 1 to 19.8, will not fuse readily. Nos. 4 to 7 embrace the fusing or coking coals. The best relation of hydrogen to carbon among these is found in No. 7, which is reported as producing a coke "more like the Connellsville." This coal has a proportion of 1 to 15.6; hence, it is inferred that coals inheriting ratios of hydrogen to carbon, as the series from 4 to 7 show, are good coking coals.

It may be of interest to note that the Connellsville coking coal inherits relations of hydrogen to carbon, in its composition, of 1 to 14 nearly. The Monongah coal of West Virginia contains the relations of hydrogen to carbon of 1 to 10.7. The celebrated Durham coking coal of England has a proportion of 1 to 17.2. All these coals fuse in a very thorough manner, making excellent metallurgical coke.

On the other side, a readily fusing coal from Ohio has its hydrogen to carbon as 1 to 9.8, which indicates a close relationship to the West Virginia variety.

In the Saxony and Westphalia coals, two samples of coal afford proportions of 1 to 17.4 and 1 to 17.6 respectively; the former made a crumbling coke, while the latter was "caked and much swollen."

These investigations indicate progress, but do not go far enough in embracing the different varieties of coals with their varying conditions to enable the coke manufacturer to determine accurately, from the ultimate analysis of his coal, whether it will fuse in the oven and make good metallurgical coke, or if it is a non-coking coal. So far as the more recent investigations indicate, the coking property of coal depends on the presence of certain relations of hydrogen and carbon, with the interaction of these from certain conditions not yet definitely established.

Prof. W. Carrick Anderson, of the University of Glasgow, Scotland, submits, in a paper read before the Glasgow Philosophical Society, that, in every case, the quantity of hydrogen and oxygen contained in the coal plays a more important part than the carbon. Coals very rich in hydrogen and in oxygen no longer melt, neither do those very poor in hydrogen and oxygen. He gives the table on the following page exhibiting the series of solid fuels, arranged with reference to their chemical composition and yield of coke.

He adds that it is evident from this series that the coking property is in some measure bounded by the following limits: hydrogen, 5 to 6 per cent.; oxygen, 10 per cent.; free hydrogen, 4 per cent.; and specific gravity, 1.35. Such a statement cannot, however, by any means be regarded as a rule of general application, especially seeing that cases of isomerism occur among coals in which, in two coals identical in composition, the one cokes and the other does not.

Until the exact relations of the coking elements of coal are assuredly determined, it will be the safest course, in ascertaining the coking properties of the coal, to have a sufficient quantity of it tested in a coke oven. This will settle the whole matter beyond any doubt.

SERIES OF FUELS

Kind	*C* Per Cent.	*H* Per Cent.	*O* Per Cent.	Free *H* Per Cent.	Coke Yield Per Cent.	Specific Gravity Per Cent	Time of Formation
Wood	44	6	50		15	.35	Present day
Peat	60	6	34	2	20	.60	
Brown coal	65	7	28	3	40	1.00	Tertiary and chalk
Coal (*a*) flaming	75	6	19	4	50	1.25	Carboniferous period
Coal (*b*) gas	80	6	14	4	60	1.30	
Coal (*c*) coking	85	5	10	4	70-80	1.35	
Coal (*d*) lean coal	90	4	6	3	90	1.40	
Coal (*e*) anthracite	95	2	3	1½	95	1.50	
(and coke)						(1.90)	
Graphite	100				100	2.00	Silurian

The Connellsville coal, found in the upper coal measures and at a certain distance from the eastern seaboard, is especially adapted for the manufacture of coke. It holds practically 32 per cent. of volatile matter. The bed is 8 to 10 feet thick, and the coal has a decided columnar structure. In mining, the coal crumbles into a finely divided condition, well adapted, without further preparation, for charging into the coke ovens.

The central West Virginia coals are much more bituminous than the Connellsville, the Monongah coal inheriting 38 per cent. of volatile matter, while the Pocahontas coal, in the southeastern side of the state, holds only 20 per cent. of volatile matter. These are the typical coking coals of these sections of the Appalachian field.

The Kentucky, Tennessee, and Alabama coals approach in percentage of volatile matters the Connellsville coal, and make very good coke.

In the central and western fields the coals are quite rich in bituminous matters, and as yet they have not been distinguished in the manufacture of coke. With our present inexperience in the best methods of treating these coals, in preparing them for coking, and in the use of the oven best adapted for securing good coke, few attempts have been made in these respects. It is evident that experimental work along these lines will, in the near future, become a necessity, especially in eliminating sulphur from these coals.

In the Rocky Mountain and Pacific coast regions no sure inferences can be drawn from the chemical composition of the coal as to its coking properties. In one locality the coal cokes readily, making a good marketable coke; in another, a coal with a very similar composition will not coke, but if placed in an oven it will part with its volatile matter without fusing—the result will be charred coal. The only sure method of determining the value of such coals for the manufacture of coke is, as before indicated, to have a quantity of it tested in a coke oven. This will show its coking or non-coking properties without any doubt. A few dollars expended in this preliminary work will save a great many in the end.

The kind of coke oven for these special qualities of coal can be ascertained by consulting some reliable expert in coke-oven plants.

IMPURITIES IN COAL

The impurities in coal consist of ash, sulphur, and phosphorus. The **ash** is usually a negative element, having little chemical influence in the use of coal and coke, unless it is mainly composed of silicious matter, in which case it will produce "clinkers," which are always undesirable. It has been pointed out that an excess of ash in the coal is injurious to the perfect physical development of the coke, especially in its hardness of body. Economically considered in coke for blast-furnace use, it not only displaces carbon, but requires increased charges of limestone and coke to dispose of it in the slag. Some qualification to this has been indicated in the smelting of the dry Lake Superior ores, that the ash in coke contributes somewhat to the formation of slag in the furnace—but ordinarily it is an expensive application.

The **sulphur** in coal is usually found in four principal chemical conditions; viz., sulphide of iron, FeS_2 (iron pyrites); sulphate of lime, $CaSO_4$; organic sulphur, i. e., combined with carbon, hydrogen, and oxygen; and free sulphur, i. e., sulphur not in combination with iron or other elements.

If sulphur is present in the coal united with lime, as sulphide of iron, a large proportion of it will be volatilized in coking; but if it takes the form of sulphate of lime, gypsum, it will not be volatilized in a coke oven. The organic sulphur remains, for the most part, in the coke.

The table on the opposite page shows the percentage of sulphur volatilized in coking.

This table is from volume MM of the Second Geological Survey of Pennsylvania, by Prof. Andrew S. McCreath. Professor McCreath adds: "Seven coals with an average of 63.51 per cent. of their sulphur existing as free sulphur lost 34.57 per cent. of the sulphur by coking; on the other hand, eleven coals, with an average of only 11.36 per cent. of sulphur not combined with iron, lost 37.88 per cent. Again, two coals, with an average of 74.58 per cent. of the sulphur free, lost 20.97 per cent. by coking; while two other coals, with only 2.20 per cent. of the sulphur free, lost 44.81 per cent. In the presence of such results, therefore, it would seem to be impossible to accept the statement that all the free sulphur passes off with the volatile matter in the process of coking.

PERCENTAGE OF SULPHUR VOLATILIZED IN COKING

Name of Coal	Coal Bed	Sulphur in Coal Per Cent.	Iron in Coal Per Cent.	Sulphur Required to Form Iron Pyrites (FeS_2) Per Cent.	Free Sulphur Per Cent.	Sulphur Not in Combination With Iron Free Sulphur Per Cent.	Sulphur Left in Coke Per Cent.	Sulphur in Coke Per Cent.	Sulphur Volatilized Per Cent.
L. Vernon's coal.........	Pittsburg	.982	.448	.512	.470	47.86	.452	.732	53.97
Daniel Miller's	Pittsburg	1.941	1.155	1.320	.620	31.99	1.098	1.808	43.42
P. and B. Coal & Iron Co.	Rose	4.037	3.276	3.744	293	7.25	2.694	3.590	33.26
Sharpless and Kinkead...	Lower Kittanning	.956	.448	.512	.444	46.44	.492	.840	48.53
Connellsville............	Pittsburg	.784	.567	.648	.136	17.34	.512	.746	34.69
Diamond Gas Coal Co....	Bed D	1.118	.812	.928	.190	16.99	.683	1.070	38.90
Fairmount Coal Co.......	Bed D	1.960	1.673	1.912	.048	2.45	.960	1.470	51.02
Rockhill Iron & Coal Co..	Bed C	2.483	1.960	2.240	.243	9.78	1.676	2.008	32.50
Dennison, Porter & Co...	Bed B	1.792	1.274	1.456	.336	18.75	1.012	1.391	43.52
Morris Run Coal Co......	Bed B	.583	.133	.152	.431	73.92	.497	.618	14.75
Fall Brook Coal Co.......	Bed B	.661	.133	.152	.409	61.87	.561	.696	15.12
Barclay Coal Co..........	Bed B	.776	.168	.192	.584	75.25	.565	.688	27.19
Miller's Coal (Tionesta) ..	Mercer	1.951	.721	.824	1.127	57.76	.821	1.620	57.92
Saltzburg Coal Co........	Pittsburg	2.257	1.267	1.448	.809	35.84	1.305	2.057	42.18

"In the 25 coals examined, the percentage of sulphur expelled by coking varies very much, the maximum amount being 57.92 per cent., and the minimum 14.75 per cent. The average percentage is 38.50; and the average percentage of free sulphur is 33.79.

"Where, therefore, a careful handling and subsequent washing of the coal will not remove the excess of sulphur, it is scarcely to be hoped that this can be accomplished by the usual methods in the coke ovens. And this important consideration should be borne in mind when selecting coals for the manufacture of coke for use in blast furnace or foundry."

Effect of Acetic Acid in Removing Sulphur.—An inquiry from a party in Kentucky, as to the value of acetic acid in reducing the volume of sulphur in coke, was submitted to Professor McCreath, who replied as follows:

"A sample of coal containing 3½ per cent. of sulphur was coked, and a spray of hot, diluted acetic acid was thrown on the incandescent coke. There was no evidence of the disengagement of either sulphureted hydrogen, sulphurous acid, or sulphuric acid. The latter would seem impossible.

"The test was duplicated, using a stronger solution of acetic acid. The result was equally negative.

"Two separate portions of the same coal were then coked. To the one nothing was added. This I will designate as 'regular.' To the other, a spray of diluted acetic acid was added to the incandescent coke. The coking process was continued a little, when a second application was made, completely saturating the coke. Both the resultant cokes were then weighed, and the 'treated' one yielded 1 per cent. less coke, due of course to increased oxidation of the carbon. Finally, both were fused and a determination of the sulphur made, the results obtained being as follows:

	REGULAR	TREATED WITH ACETIC ACID
Sulphur, per cent. in coke...........	2.987	2.755

"The difference is so slight that the results for all practical purposes may be considered the same, and they demonstrate that no desulphurization of the coke takes place under the treatment submitted."

Phosphorus in the coal usually goes over to the coke; it is not eliminated in the coke oven.

The investigation of the volume of phosphorus contained in coals suitable for the manufacture of coke for steel-making purposes, discloses the fact that this volume of phosphorus varies from a mere trace to a maximum of .1248 per cent. In the examination of 24 coals from the large Pittsburg bed, the average was found to be .0217 per cent., which would give to the coke an average of .0344 per cent. The great necessity of the utmost care in selecting coals for the manufacture of coke for metallurgical uses as free from the impurities of ash, sulphur, and phosphorus as possible, will readily appear. The following table of Pennsylvania coals affords some typical examples:

PERCENTAGE OF PHOSPHORUS IN PENNSYLVANIA COAL AND COKE

Name of Coal	County	Coal Bed	Phosphorus in Coal Per Cent.	Phosphorus in Coke Per Cent.
Henderson's...............	Washington	Washington	.1667	.2818
Redds'....................	Washington	Pittsburg	.0943	.1551
Penn Gas Coal Co..........	Westm'land	Pittsburg	trace	trace
Millwood..................	Westm'land	Pittsburg	.0801	.1177
Connellsville.............	Fayette	Pittsburg	.0111	.0161
Cambria Iron Co...........	Cambria	B	trace	trace

LOCALITIES OF PHOSPHORUS IN THE CONNELLSVILLE SEAM

Per Cent. of Phosphorus						
				Above 5-Foot Binder		
Roof to Bottom	Bottom*	Middle†	Top‡	Upper 12 Inches	Middle	Lower 12 Inches
	.009	.010	.023	.054	.031	.038
.019	.001	.010	.027	.033	.029	.017
.022	.001	.007	.034	.043	.035	.053
.012	.001	.004	.009			
.017	.008	.007	.018	.015	.015	.087
.019	.007	.016	.005			
.025	.002	.030	.174	.109	.060	.068
.015	.047	.016	.028	.018	§	.015
.017	.002	.008	.019	.017	§	.026
.021	.003	.044	.082	.090	.011	.010
.021	.006	.009	.029	.062	.038	.013
.020	.011	.034	.032			
.025	.004	.043	.035			
.021	.005	.006	.069	.062	.025	.003
.018	.035	.035	.006	.079	.013	.003
				.114	.022	.014
				.105	.019	.013
Average .0143	.0094	.0186	.0393	.062	.0362	.0277

* Bottom means 3-foot binder down.
† Middle means between 3- and 5-foot binder.
‡ Top means above 5-foot binder.
§ The upper and lower sample left only about 2 inches of coal between the two; consequently, no sample from the middle was taken.

Phosphorus in Connellsville Coal.—During the year 1896, Mr. O. W. Kennedy, late General Superintendent of the H. C. Frick Coke Company, had a series of tests made to determine the localities of the phosphorus in the Connellsville coal seam. The preceding table, in detail, will afford the results of these tests. It was submitted, in explanation, that "this sampling was made at mines showing phosphorus higher than the average of the region."

It is manifest from this table that the upper section of this large coal bed contains the greatest amount of phosphorus. It is also evident that the percentage of this undesirable element increases gradually from bottom to top of the coal bed.

Effect of Impurities in Coke on Pig Iron.—The sulphur, when present in coke in large volume, confers on pig metal the undesirable property of "red-shortness." Coke for use in blast-furnace work producing Bessemer pig should not contain over 1 per cent. of sulphur as a maximum volume. Coke containing .50 per cent. to .75 per cent. of this element would be much more desirable in the manufacture of pig iron for making steel. An undue volume of phosphorus produces an opposite quality in the metal made by it—the condition of "cold-shortness"—that is, metals made by coke containing an excess of these dangerous elements are found to be brittle in their hot and cold conditions. As little or none of the phosphorus in the coal is eliminated in the process of coking, it is of the utmost importance to select coals for the manufacture of coke for Bessemer uses as low as possible in this dangerous impurity. The table on page 41 shows .0111 per cent. of phosphorus in the Connellsville coal.

Portions of the ash and sulphur can be removed from the coal for coke making by the processes of crushing and washing (see Chapter III), but the phosphorus usually goes over in full to the coke and finally to the pig metal in blast-furnace work.

CHAPTER III

PREPARATION OF COALS FOR THE MANUFACTURE OF COKE

Necessity for Preliminary Preparation of Coke.—It is now quite manifest that we have reached a period, in the United States of America, in which steel is rapidly displacing iron in the arts and manufactures, especially for structural uses. This expansion of the use and manufacture of steel carries with it the necessity for a pure coke fuel, and it becomes, therefore, the duty as well as the interest of the coke manufacturer to adopt such methods in the preparation of coal for making coke as will insure the purest and best possible product.

Although there is a very great source of supply of coal for the manufacture of coke, covering an area in the United States of North America of about 344,440 square miles, it is evident that only a small portion of these coal fields affords the best coal for coke making—such as the Connellsville, Punxsutawney, Alleghany, and Broad Top in Pennsylvania; Pocahontas in Virginia; and the new regions of coking coals in West Virginia. Alabama also affords a very good coal for coke making. In Kentucky, at Pineville, and Big Stone Gap, excellent coking coals are found in abundance. At El Moro, in Colorado, very good coke is made from a large bed of coking coal. But with all these and many others yet to be developed, the aggregate ratio of the best coking coals to the whole coal area is very small.

As long as the supply of coke can be maintained from these good coking coals, the methods of coking do not urge or compel extended consideration; but when the less valuable coals for coking purposes come into use, the studies of the preparation of the coal for coking with the kind of coke oven best adapted for each quality of coal will become of vital importance. When the time approaches for these investigations to be taken up by coke makers, it will be found that three principal conditions will require careful study: (1) the preparation of coal for coking; (2) the kind of coke oven best adapted for securing the best quality of coke from each variety of coal; (3) the saving of the by-products in coking, consisting of sulphate of ammonia and tar. This will also require arrangements in coke ovens, as well as the outside conduits, condensers, etc.

The rather poor quality of coking coals on the continent of Europe has long ago compelled thorough attention to the preparation of these coals for coking, as well as to the development of the oven best suited to their wants in making from them the best possible coke, and, during the past decade, to the saving of the by-products in coking. The American coke manufacturer has before him a much easier task than the Belgium, German, or French coke makers, the larger supply of coking coal requiring no special treatment in producing the best qualities of coke. Even when the exhaustion of these good coals approaches, the second quality will be found to be superior to the continental coals. From the large and increasing use of coke, it is evident that its manufacture will demand the earnest and diligent efforts of those in charge of the several processes in its preparation and coking. Nor is this industry any exception to the general law governing all industries: small beginnings, protracted and anxious struggles for success, with the reward crowning all persistent and well-directed efforts. There is, therefore, a deep interest attached to the study of the several steps in the upward progress in the manufacture of coke, especially in its early stages and up to its present advanced progress in the industrial arts.

Large areas of the best coking coals require no special treatment, but the coals are charged into the coke ovens as they come out of the mines. In the Connellsville region, with a few exceptions, no preparatory work on the coal is attempted, and it is charged into the ovens as it comes from the mines. On account of the softness of the coal and its attenuated columnar structure, this coal is usually broken into small pieces, in mining, and this breakage, with that due to the handling into tipple bins and larries, gives pieces sufficiently small to assure good results in coking. A second type of this coal is found in the Flat Top region of Virginia. The coal is mined in more solid lumps than the Connellsville, but it is broken up, and the screenings are used in making coke. The bituminous coals of the Central and New River sections of West Virginia are usually broken and the screenings washed preparatory to coking.

The manufacture of coke from coal screenings, in the Kanawha Valley, produces a very good quality of coke, but by using the whole body of the coal bed, excluding a thin top bench of splint coal, a coke is made nearly, if not quite, equal to the best standard Connellsville. The Alleghany Mountain coals are frequently charged into the ovens as they come out of the mine, but the best results are assured by breaking the coal or by breaking and washing. From the experience gained in the use of these typical coking coals, the methods of treatment of representatives of these types will be apparent.

The annual product of coke required in blast-furnace and other metallurgical operations during the year 1902 was 25,401,730 net tons. As it requires an average of 1.6 net tons of coal to make 1 net ton of coke, the draft on the coking coal mines for the above year was 39,604,007 net tons of coal. The area of coking coals to the total coal area of the United States has not been accurately determined, but it is evidently small. As only a very limited proportion of this coking coal area can be used for coking, without preparation by crushing, classifying, and washing, it is evident that, with the present great demand for coke, this small section of pure coking coal will be exhausted within a not very extended time. At this time, coke manufacturers have invaded the areas of the second-class coking coals which require preparatory cleansing, and it is evident that the preparation of these coals for the manufacture of good metallurgical coke is now most important.

In the presence of so many varieties of coal-crushing and washing machines, evidently designed to meet the several wants in the treatment of the different qualities of coals, there can be no reasonable excuse for using slaty coals in the manufacture of coke. This essential requirement of clean coke in metallurgical operations is still more imperative when it is considered that the slates of the coal go over into the coke and carry with them the associated sulphur. In furnace operations, especially when slate in the coke is silicious, an increased charge of limestone will be required to eliminate these impurities, and this will make it further necessary to add to the fuel charge also. Besides all this, there is the danger of the presence of sulphur in the pig metal produced, if it is designed for the manufacture of steel. It is therefore evident that the only safe plan in the manufacture of coke for metallurgical uses is to use only a pure quality of coal; but in case this cannot be secured and a second quality must be used, its cleansing, by crushing and washing, becomes an absolute necessity.

In America, with its ample areas of the best qualities of coals, it is only necessary at this time to require clean mining to produce coal of great purity for manufactures and in the production of coke. At many of the coal mines in Europe, coal washing of fuel for manufacturing purposes is coming into very general favor; but in America, with its superior qualities of coals, it is only necessary to cleanse the secondary or slaty coals in preparation for the manufacture of coke.

The impurities in these coals consist of shales, iron pyrites, ferrous sulphide (FeS_2), sulphate of lime, argillaceous matter, and phosphorus. The principal element is sulphur, with its organic condition and combinations.

Sulphur is found in five principal physical conditions:

1. Pyrites is usually found in lenticular pieces as well as in balls; occasionally it forms the filling of the stems of the larger plants of the coal flora. In all these conditions it can be separated from the coal by a process of crushing or by crushing and washing.

2. Where the sulphur is found in the strata thinly interleaved in the coal, the process of separation becomes more difficult,

requiring the coal to be broken into very small sizes, with careful classification of the different sizes, in preparation for the ultimate operation in the washer.

3. Occasionally, the sulphur is found in the coal in little disks, like fish scales; these present a still more difficult condition in the process of removing the sulphur, as the sulphur disks are light and in the fine pulverized condition of the coal many of them are carried over the edge of the washer pan with the coal. The water used in washing should not be reused, as it would carry back some of these sulphur disks, increasing the undesirable element.

4. In the combination of sulphur with lime, as sulphate, gypsum, usually found in thin plates in the coal, some of it can be removed in the process of breaking and washing, but all that goes over to the coke is in a fixed or negative condition as to its action when used in blast-furnace operations.

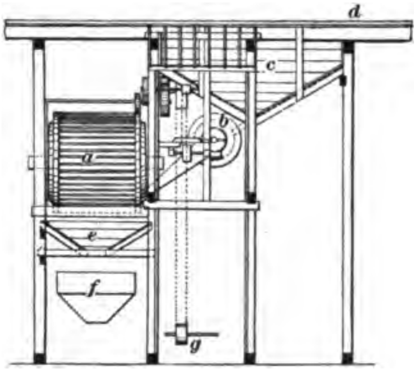
5. When sulphur is found in organic combination with the coal, supposed to be combined with carbon and hydrogen, very little of it can be removed; it goes over mainly to the coke.

CRUSHING COAL

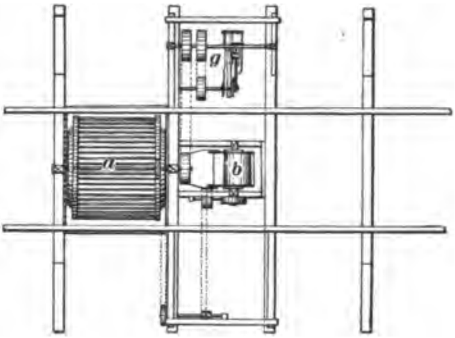
Advisability of Crushing Coal Before Coking.—In practice, it has been discovered that breaking the coal that comes from the mine in large lumps, especially when the percentage of its volatile matter is small, adds to the value of its coke. The importance of this disintegration of the coal before it is charged into the oven will readily appear when it is understood that in this condition, other things being equal, the fusing elements assumed to be in the volatile matter are utilized to the utmost. It has been found that a mixture of lumps and fine or small coal fuses unevenly in the process of coking in the oven; the fine coal fusing rapidly, while the lumps require more time for the coking process to reach the middle of the lumps. It follows, therefore, that all coals will be benefited for making a uniform quality of coke and securing the full time in the oven, by being disintegrated before being charged into the coke oven, even if they do not require the further process of washing.

In the selection of machinery for disintegrating or washing coal, or both, it will be wise to consult those experts in these processes who have made these practical operations special studies. A general principle should govern in these matters, to insist on the application of the simplest machinery with the largest practicable automatic service.

Every variety of coal will require special apparatus for its treatment, and the proper apparatus can be determined only by a careful study of the physical and chemical properties of the coal. All coal requiring washing should be carefully classified. This will insure the most efficient removal of slate or other impurities, as it will afford the best condition for their separation in the washer by the difference in their specific gravities; the coal of equal size being the lighter will rise, while the heavier matter, slates or pyrites, will sink in the pulsing water of the washers. Some coals have their slaty impurities so mixed with fireclay that they melt in the water in the washer. Efforts have been made to treat these difficult coals in the dry way, by passing the classified products through a current of air, the separation being effected, just as in water, by the difference in the specific gravities of the coal and its impurities. Other methods have been tried with indifferent success. If an examination of the character of a coal shows that it requires special and expensive appliances, with doubtful results, it will be well for the coke manufacturer to avoid attempting to use it.



(a) *Side Elevation*



(b) *Plan With Bin Removed*

FIG. 1. BRADFORD PATENT COAL BREAKER

Bradford Coal Breaker. For the disintegration of coals requiring this preparatory process, with the removal of slate and pyrites, the Bradford coal breaker, shown in section and plan in Fig. 1 (*a*) and (*b*), will be found well adapted and economical. It is simply a drum or cylinder of iron parts, having its lagging perforated to gauge the size to which it is desired to reduce the coal. This is accomplished by the percussion of the coal falling in the interior of the revolving drum from the upper to the lower sections. The length of this fall, or the diameter of the drum, is made to meet the requirements of the coal. If the coal is soft and friable, the diameter is minimum; if the coal is hard and tenacious, the diameter of the drum is increased accordingly.

The drum is fed with coal at one end and the slate and other refuse is discharged at the other end; the pure coal passes through the meshes in the lagging of the drum and is received into a pit from which it can be elevated to any desired level.

It is worthy of note that this method of disintegration, with separation of slates and pyrites, also removes bony coal, as the force of the fall in the drum is regulated to afford just sufficient concussion to break the purer portions of the coal, leaving the bony coal unbroken and discharging it with the other impurities.

The Bradford patent coal breaker as put on the market at present by Messrs. Heyl & Patterson, of Pittsburg, Pennsylvania, who control and build it, differs very materially from its original form, which consisted of a cylinder supported on stationary rollers. In this shape, it was not found very satisfactory, but was operated long enough to demonstrate the value of the principles involved. The breaker, as now constructed, has trunnions cast on both heads, which carry the entire weight. The bearings are protected from the dust and are provided with thorough lubricating devices, thus reducing the amount of power consumed to a minimum.

The elevation of the breaker shows the method of supporting it; also, the driving mechanism. The diameter of the breaker *a* varies from 7 feet to 12 feet, depending on the hardness of the coal—9 feet diameter being the general size used; the length varies with the results to be obtained. The heads, with trunnions and spreaders, are made of cast iron of proper proportions. The lagging, or mesh, which consists of steel plates perforated with holes varying from ½ inch to 2½ inches square, is securely fastened to the separators. To the plates are bolted cast-iron fingers that aid in breaking the coal as it falls on them. To one of the heads is fastened a segment gear that engages in a pinion on the countershaft placed on top of the bents supporting the breaker.

The coal passing into one end of the breaker under the trunnion, is picked up by longitudinal shelves and discharged, falling on perforated plates; that which is of proper size then passes through the mesh and the larger pieces are picked up by the next shelf and again thrown down. The coal, in falling from the shelf, has not only the force derived from its own gravity, but receives a very considerable additional force from the momentum of the breaker. The fingers not only aid in the breaking of the coal when it falls on them, but, being so designed as to form portions of spirals, can be regulated either to rapidly advance the body of the coal and impurities to the opposite end of the breaker, or to retard its progress. Fastened in the opposite head of the breaker from that at which the coal enters are wings, which discharge the substance that reaches them.

The principle involved in the separation in this machine is that the slate and sulphur are usually harder than the coal and a fall sufficient to break the coal will not break them. The bony coal is usually harder and always very much tougher, and will not break with the same fall or force as the coal. By varying the speed of the breaker, the force of the fall can be increased or decreased; and with the adjustment of the fingers, the impurities can be retained in the breaker until all the coal is freed from them.

Pieces of iron, such as miners' wedges, couplings, etc., which frequently get among the coal and cause breakage in most machines for this work, will pass through the breaker and be discharged by the wings at the end without any damage to the machinery. The speed of the breakers never exceeds 20 revolutions per minute and they require but 7 horsepower when operated to full capacity. The capacity of the breaker varies from 300 to 700 tons per day, according to the mesh, hardness of coal, and amount of impurities to be removed.

As it is necessary to have a regular supply of coal for the breakers to secure the best results, a cylinder feeder is used in connection with the breaker. This feeder *b* is placed under the bin *c* and at the end of the breaker *a*. It has two pockets, which, as it rotates, are filled and discharged into the chute that leads to the breaker. It will handle successfully the largest lump or run-of-mine coal, allowing the bin above it to be completely filled. The feeder is not only valuable for regulating the supply of coal to the breaker, but in plants where the coal is handled after leaving the breaker, it prevents the overloading of the elevators or conveyers. The coal is dumped from the tipple *d* into the bin *c*; from there it is fed into the breaker *a* by the feeder *b*; from the breaker, it passes into the bin *e*, and is then loaded into the larry *f*. The breaker is run by the engine *g*.

The cost of a plant of one 9-foot breaker, such as is illustrated in Fig. 1, and installing the same ready for operation, exclusive of boiler, does not exceed $3,000. A plant of this size requires very little attention and it is unusual for additional help to be employed other than that required for handling the coal on the tipple.

There are now eight plants comprising twelve breakers in Western Pennsylvania and three plants in other states. The largest plant is that of the Rochester and Pittsburg Coal and Iron Company at Walston, Pennsylvania, which has three breakers with a daily capacity of 1,200 tons through a 5-inch mesh, and elevators for lifting coal to a vertical height of 80 feet and discharging it into a storage bin, as well as a conveyer for removing refuse; the expense for labor operating this plant does not exceed $2.50 per day.

The Vesta Coal Company, at Lucyville, Pennsylvania, is operating one 12-foot breaker, with 1¼-inch mesh, that has a daily capacity of 750 tons. This plant, being situated in the fourth pool, Monongahela river, handles probably as hard a coal as is coked any place in the country. It does not employ any help except that necessary for the dumping of coal on tipple.

At the large works of the Cambria Steel Company, Johnstown, Pennsylvania, this breaker, as shown in Fig. 1, is capable of breaking 60 tons per hour. During a continuous run of 17 days at this plant, with the use of 3,556.7 net tons of coal as it came out of the Rolling Mill Mine, 35.5 net tons of slates and pyrites were removed in passing through the breaker, which shows a reduction of these impurities of nearly 1 per cent. Estimating the cost of engineer, oil, steam, etc., at $40 for these 17 days of trial, the expense of this work of breaking the coal is about 1⅛ cents per net ton.

The following is an estimate of the cost of this plant complete and ready for operating:

Chute and screens in place	$ 228.00
Bradford breaker, with feeder, hopper, elevator, conveyers, belts, shafting, and pulleys, in place	4,722.00
Engine pipes and fittings	1,126.60
Siphon and strainer	17.25
Foundations, bolts, etc.	1,729.51
Lumber	1,095.89
Labor, masons, carpenters, etc.	2,882.91
Total	$11,802.16

This machine is well adapted for treating coals in which the sulphur occurs in lenticular pieces or balls of pyrites. It removes pyrites, slate, and other large impurities, but its value terminates with this quality of coal. It has its main value in removing these impurities from steam coals when they are designed for use for firing boilers, especially in the preparation of coal to be used in mechanical stokers, as it can be made to reduce the coal to sizes suitable for these purposes.

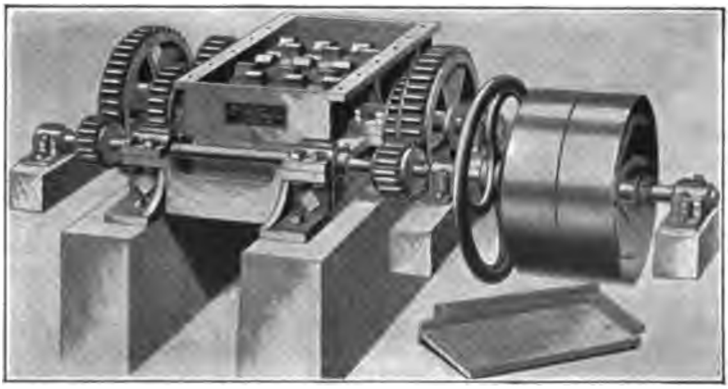


FIG. 2. STEDMAN'S COAL BREAKER

Stedman's Coal Breaker and Disintegrator.—The Stedman Foundry and Machine Works, of Aurora, Illinois, presents two machines for the treatment of coal in preparing it for coking: a coal-breaking and a coal-disintegrating appliance.

The Stedman coal breaker, Fig. 2, is designed to break the coal to the size of walnuts or marbles, to be followed by the usual processes of classification and washing to remove the slate and sulphur before charging the coal into the coke oven. It is applicable to all coals requiring cleansing by crushing and washing.

The Stedman disintegrator, Fig. 3, is a strongly made machine to pulverize coal to a uniform fineness of cracked wheat or corn meal. It is designed for use in treating the purer coals that do not require to be washed. This crushing of coal for coking is helpful in utilizing the volatile matters, especially in coals inheriting small volumes of fusing matters, as it enables the heat of the oven to be diffused simultaneously through the charge of coal, quickly fixing and securing the utmost possible fusion of the coal in the process of coking. The matter of determining the size to which the coal should be broken by either of these machines can be determined by the quality and the chemical composition of the coal. The same consideration will apply to the preparation of similar coals requiring the additional treatment of washing. These matters are mainly local and practical, and the manufacturer of coke will be called on to exercise judgment in this preparatory treatment of coal from his previous experience. The evidence of this work will be determined by the work of the coke oven.

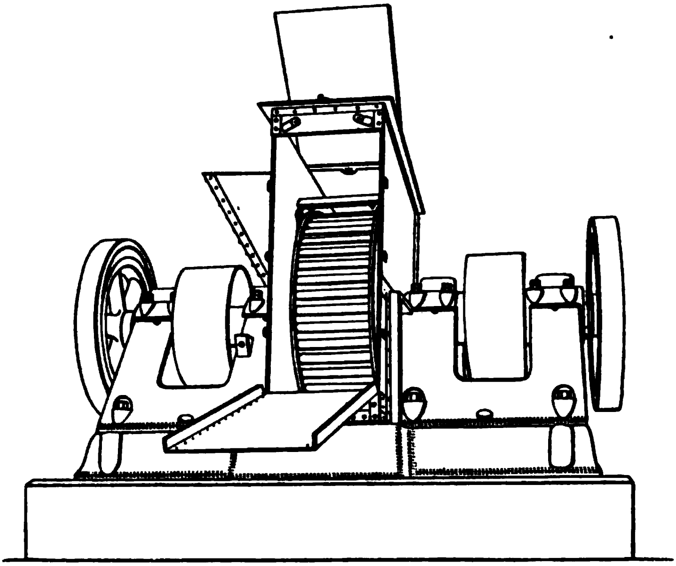


Fig. 3. Stedman's Disintegrator

The following statements exhibit the estimated cost and work of these machines:

ELEVATOR, CAPACITY 200 TONS, 10 HOURS, SINGLE STRAND

HEAD

1	Head-shaft 2$\frac{7}{16}$ inches by 48 inches long	$15.20
2	Pillow-blocks 2$\frac{7}{16}$ inches long	
2	Collars 2$\frac{7}{16}$ inches	
1	24-in. No. 108 sprocket wheel	
1	Key	

ELEVATOR BOOT

1	12″ × 7″ cast-iron boot complete with shafts, adjustable boxes, sprocket wheels, and collars	$42.00
	Price per foot for No. 108 chain and elevator buckets	3.00

CRUSHING PLANT, CAPACITY 250 TONS DAILY

1	44-inch Class A disintegrator complete. Capacity 200 to 250 tons daily. Power required, 1 horsepower for every 4 or 5 tons of coal crushed daily. Space occupied by disintegrator, 9 feet by 6 feet.	$700.00
2	11″ × 18″ engines connected at right angles with two 60-inch bandwheels on the main shaft to drive to the two pulleys on the disintegrator. Engines' speed, 150 revolutions per minute, developing from 75 to 80 horsepower. Engines are complete with two 60″ × 12″ pulleys on the main shaft, automatic stop-governor, throttle valve, spanner wrenches, cylinder, lubricator, oil cups, cylinder cocks, anchor bolts, and plates, and blueprint drawings for foundation. Price complete as described, f. o. b. cars, Aurora	738.00
1	4-inch tubular boiler, 62 inches diameter, 16 feet long, 90 horsepower, complete with chimney and breeching, guy rods, fire-front, grate bars, bearing bars, back stand, back plate, soot doors and frame, anchor bars, tie-rods, safety valve and weight, check-valve, stop-valve, and blow-off valve, whistle, water and steam gauge, feedpipe and connections. In fact, boiler with all settings and trimmings. Price delivered on cars, Aurora	895.00
1	Duplex pump to supply boiler with water and all fittings and connections to connect to boiler	175.00

COST OF MACHINERY AS DESCRIBED

1	44-inch disintegrator as described	$700.00
2	11″ × 18″ double engines, 75 to 80 horsepower	738.00
1	4-inch tubular boiler, 62 inches diameter, 16 feet long, 90 horsepower	895.00
1	Duplex pump as described	175.00
	Total cost	$2,508.00

ELEVATOR, 250 TO 275 TONS CAPACITY IN 10 HOURS, DOUBLE STRAND

HEAD

1	Head-shaft 2$\frac{7}{16}$ inches by 6 feet long	$21.50
2	2$\frac{7}{16}$-inch pillow-blocks	
2	2$\frac{7}{16}$-inch set collars	
2	24-inch No. 83 sprocket wheels	
2	Keys	

ELEVATOR BOOT

1	14″ × 7″ cast-iron boot complete with shaft, 2 sprocket wheels, adjustable bearings and collars	$47.00
	Price per foot for No. 83 double chain and buckets	3.65

CRUSHING PLANT, CAPACITY 350 TO 400 TONS DAILY

1	50-inch coal disintegrator complete	$ 900 00
	Capacity 350 to 400 tons of crushed coal daily. Power required, 1 horsepower for every 4 or 5 tons crushed coal in 10 hours. Space occupied by disintegrator, 10 feet by 8 feet; weight complete, 17,000 pounds.	
2	13″ × 20″ engines complete, connected at right angles with two bandwheels 78 inches diameter, 16-inch face on the main shaft to drive the two pulleys on the disintegrator. Engines speed at 140 revolutions per minute, developing from 110 to 120 horsepower; engines complete with bandwheels, automatic stop-governor, throttle valve, spanner wrenches, cylinder cocks, lubricator, oil cups, anchor bolts, and plates. Blueprint drawings for foundation furnished. Price complete, f. o. b. cars, Aurora	1,000.00
2	4-inch tubular boilers, 130 horsepower, 54 inches diameter, 14 feet long, complete with all necessary fittings and trimmings, consisting of fire-front, grate bars, bearing bars, back plate, soot door and frame, check, blow-off and stop-valve whistle, steam gauge, gauge-cocks, water gauge, chimney and breeching, guy rods, safety valve and weight. All pipe connections between engines and boilers are extra. Price complete, f. o. b. cars, Aurora	1,275.00
1	Duplex pump to supply boilers with water and pipes and fittings for same	150.00

SUMMARY

1	50-inch disintegrator complete as described	$ 900.00
2	13″ × 20″ engines as described	1,000.00
2	Boilers, 130 horsepower, 54 inches by 14 feet	1,275.00
1	Duplex pump to supply boiler with water	150.00
	Total	$3,325.00

ELEVATOR, 350 TO 400 TONS CAPACITY, 10 HOURS DOUBLE STRAND

HEAD

1	Head-shaft $2\frac{15}{16}$ inches diameter, 5 feet 6 inches long	$30.00
3	Pillow-blocks $2\frac{15}{16}$ inches diameter	
2	Set collars $2\frac{15}{16}$ inches diameter	
2	25-inch diameter No. 108 sprocket wheels	
2	Keys for wheels	

ELEVATOR BOOT

1	18″ × 18″ cast-iron boot complete with shaft. two No. 108 sprocket wheels, adjustable bearings and collars	$60.00
	Cost of elevator chain and buckets per running foot	5.00

ESTIMATE

1	60-inch class A coal disintegrator, complete with fly-wheels, pulleys, etc. Capacity, 500 tons in 10 hours and upwards. Weight, 18,000 pounds	$1,000.00

2	14" × 20" engines of the Houston, Stanwood & Gamble pattern, coupled at right angles with two bandwheels 84 inches diameter, 16-inch face to drive the belts running direct to disintegrator, engines run at 130 revolutions per minute, developing about 125 to 135 horsepower. Engines are complete with governor, two bandwheels, throttle valve, spanner wrenches, automatic sight-feed lubricator, oil cups, and cylinder cocks. All pipe fittings and connections are extra. Price of engine as described	$1,064.00
2	Tubular boilers 60 inches diameter, 10 feet long; rated at 160 horsepower, complete with all necessary trimmings, consisting of fire-front, grate bars, bearing bars, back plate, soot door and frame, check, blow-off and stop-valve, whistle, steam gauge, gauge-cocks, water gauge, chimney and breeching, guy rods, safety valve and weight All pipes and connections between engines and boilers are extra. Price complete, f. o. b. cars, Aurora	1,650.00
1	Duplex pump to supply boiler with water and pipe and fittings for same	175.00

SUMMARY

1	60-inch disintegrator complete as described	$1,000.00
2	14" × 20" engines as described	1,064 00
2	Boilers 160 horsepower as described	1,650.00
1	Pump to feed boiler	175.00
	Total	$3,889.00

ELEVATOR, 550 TONS CAPACITY

HEAD

1	Head-shaft $3\frac{7}{16}$ inches diameter, 6 feet long	$41.00
3	Pillow-blocks $3\frac{7}{16}$ inches diameter	
2	Collars $3\frac{7}{16}$ inches diameter	
2	30-inch No. 108 sprocket wheels	
2	Keys	

ELEVATOR BOOT

1	Cast-iron boot for 24" × 10" buckets complete with shaft, two sprocket wheels, adjustable bearings and collars	$75.00
	Price per foot for No. 108 double elevator chain and buckets	6.50

Link-Belt Coal Breaker.—The coal breaker, Fig. 4, is made by the Link-Belt Machinery Company, Chicago, Illinois.

The size and spacing of the teeth are made to suit the size to which the coal is to be broken, by which is meant the size of the largest pieces. In breaking to this size a large part will be broken finer. In general, it may be expected that the smaller the diameter of the roll the greater will be the percentage of fine, so that, if it is desired to break to a certain size without reducing much to smaller size, large diameters of rolls should be selected or a series of rolls put in, breaking first coarse, then finer, with screens between.

These rolls are made in the following sizes:

Size of Rolls		Shipping Weight Pounds	Approximate Capacity Tons per Hour	Speed Revolutions per Minute	Horsepower Required	Maximum Size of Piece That Will Enter Inches
Diameter	Length					
15	20	3,500	10	225	10	10×15
18	24	5,550	20	200	12	10×20
24	24	7,000	25	160	15	14×20
24	30	7,800	35	160	20	14×24
28	30	10,000	40	125	25	16×24
28	36	12,000	50	125	35	16×30
30	36	13,000	75	100	40	18×30

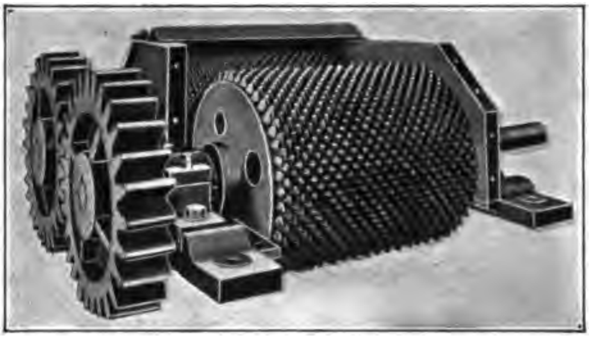


FIG. 4. LINK-BELT COAL BREAKER

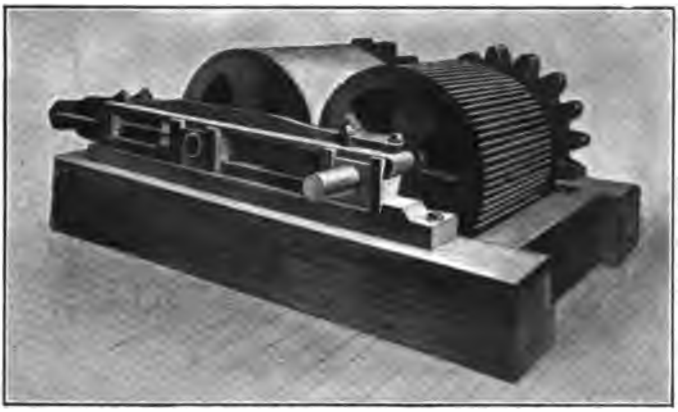


FIG. 5. LINK-BELT COAL CRUSHER

Fig. 5 shows a crusher made by this company and having one smooth and one corrugated roll. It is used for special service in coal washing.

Fig. 6 shows a disintegrator made by the same company and used for fine crushing of coal. It is made in two sizes: 36-inch diameter, 20-inch face; 48-inch diameter, 24-inch face.

COAL WASHING

Coal washing is entirely a mechanical process, and water is the main element employed in separating the coal from its impurities. The chief requirement in the coal-washing process is the reduction of the sulphur in its several conditions and of the ash, so that the coke made from this washed coal shall contain under 1 per cent. of sulphur, with ash from 6 to 10 per cent. This operation for the successful cleansing of the coal depends on the enabling law of the difference of the specific gravities of the coal and its several impurities. The average specific gravities of these are:

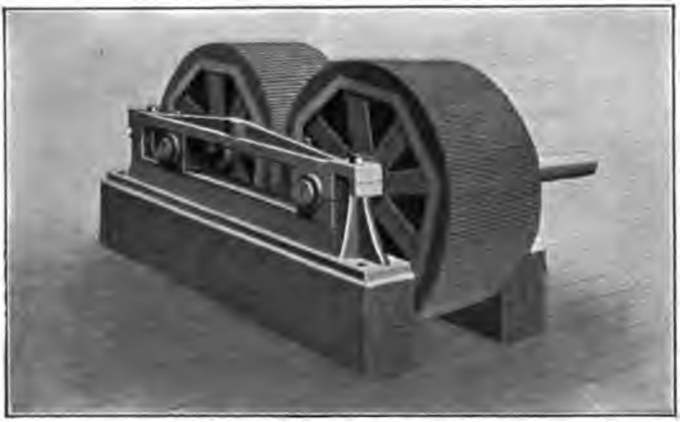


FIG. 6. LINK-BELT DISINTEGRATOR

	SPECIFIC GRAVITY
Water	1.00
Coal	1.25 to 1.50
Bone coal	1.45 to 1.80
Slate	2.25 to 2.50
Coal or slate with pyrites	3.20 to 3.60
Pyrites	5.00 to 5.20

In practice, a great variety of the combinations of these elements is found in the coal, requiring in its preparation for the washer and in the washing process special treatment for each variety.

As has been noted, the coal requires a preparation for washing by crushing or breaking and by classifying or sizing. Whether the coal is to be used in the manufacture of coke or for any other purpose, the sizing of the coal in its preparation for washing is indispensable. It has been determined that, as a general rule, the smaller the ratio of reduction of the pieces of the coal, the more complete is the process of separation. Very much, therefore, of the success of this operation depends on the proportioning of the sizes of the meshes in the classifying screens, especially for the separating of the lesser impurities in the coal under the grosser iron pyrites, which are the most readily removed.

It may be noted here that the best machinery for accurate separation or cleansing of the coal is usually the most costly, involving the greater expense in the first cost of the plant, but securing in its work the best results. As will be seen hereafter, in the preparation of the washed coal for charging into the coke oven, the coal-storage arrangement to remove some of the water or moisture from the coal is a secondary necessity.

TROUGH WASHERS

Simple Trough Washer.—During the close of the past century, especially in continental Europe, very much attention was given to mechanical appliances for washing coal. The most primitive of these consisted in a long wooden trough, divided by low cross-sectional dams at intervals along its course. The inclination of this sluice was usually made to give sufficient force to the water passing through it to separate the coal from the slate, the slate remaining in the upper recesses of the dams, while the coal was carried over, screened, and delivered into a car or other receptacle at the lower end of the sluice. The slate was removed at stated intervals by an attendant with a rake. The prepared coal and the water for its cleansing were received together at the upper end of the trough. The plan and section, Fig. 7, will make this old-time washer and its operations easily understood.

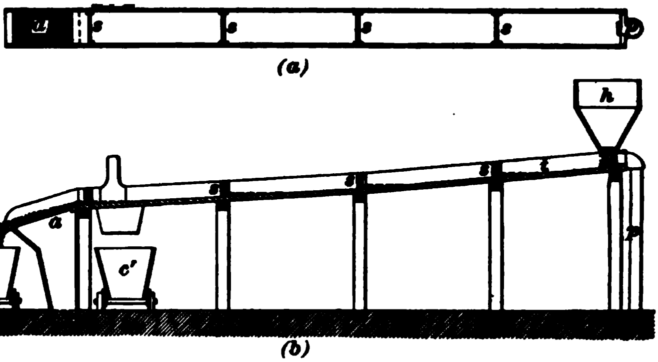


Fig. 7. Plan and Section of Trough Washer

t, trough; *s*, dams; *a*, screen; *h*, hopper for delivery of coal; *p*, stand pipe for applying water; *c*, *c′*, cars for washed coal and slates; this wooden trough is usually 30 to 100 feet long, 2 to 4 feet wide, and 12 to 15 inches deep.

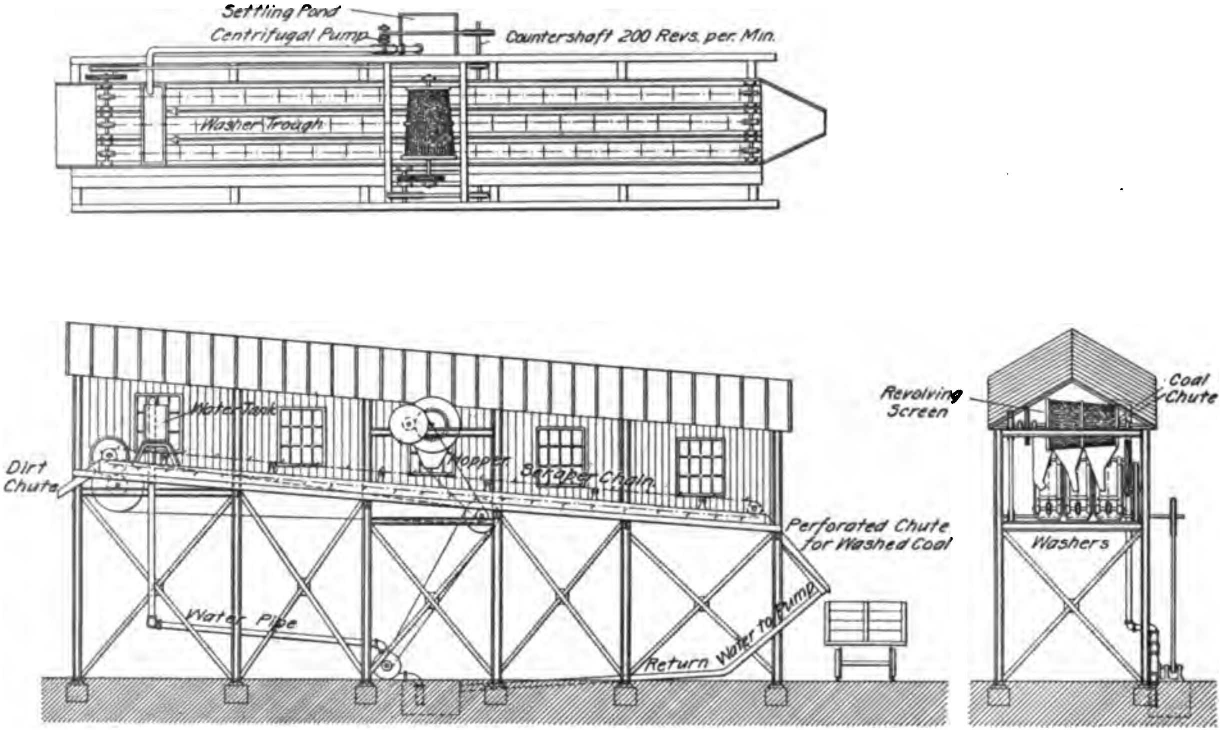
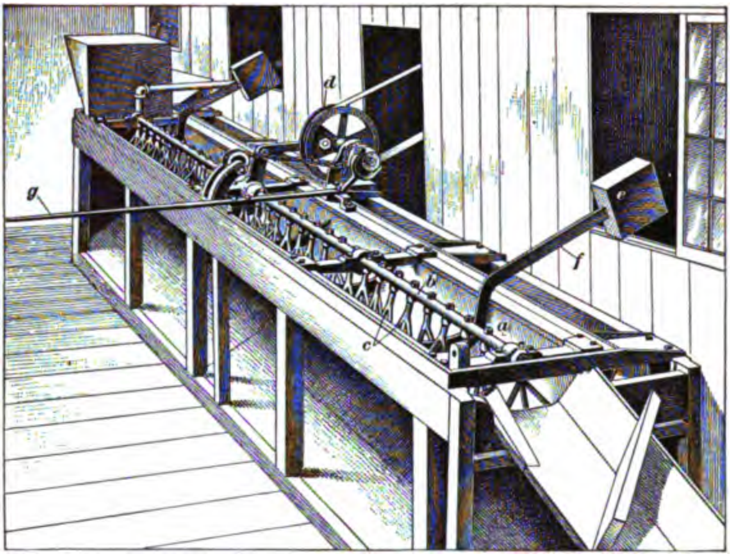


FIG. 8. THE ELLIOTT TROUGH WASHER

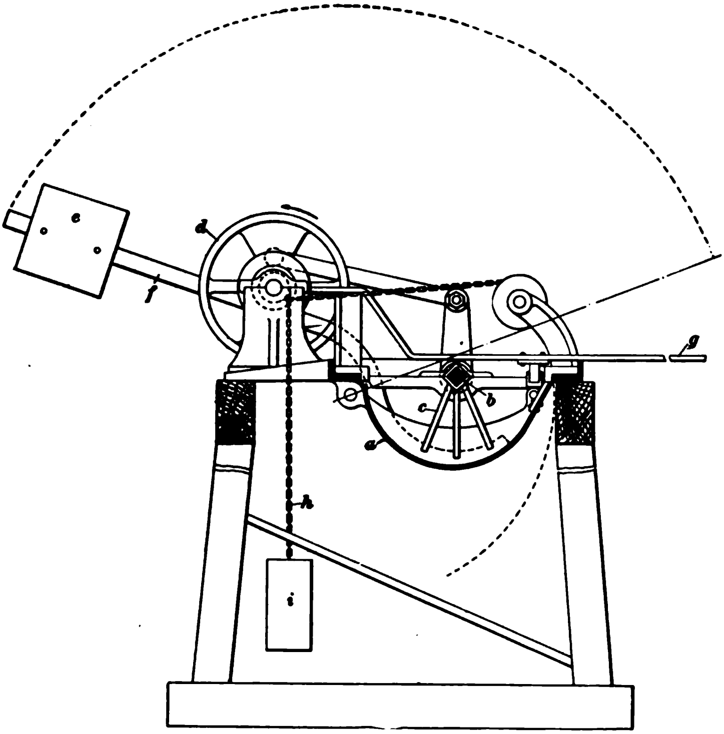
Elliott Trough Washer.—An improvement has been made on this trough washer, which adds very much to its efficiency, economizing labor and water in the process of washing. The following plan, section, and description, Fig. 8, are taken from The Colliery Guardian, London, of November 16, 1894. This machine was designed on the lines of the old trough washer, which has long been a favorite with many colliery engineers on account of its simplicity and its efficiency when in the hands of an intelligent, trustworthy attendant. In addition to the difficulty of always obtaining the necessary skill and attention, there was also in the old troughs the necessity of changing the flow of coal and water into a second trough while the dirt was being washed off and removed from the first, when the stops had become charged with it; for if this was not done at the proper time some of the dirt became mixed with the coal and the result was not satisfactory. The Elliott washer, as shown in Fig. 8, is claimed to be automatic in its action, and retains all the advantages of economy and efficiency of the old trough without any of its disadvantages; it is, moreover, independent of the skill or attention of the attendant, the operation of washing proceeding without interruption as long as is required, the coal being delivered at one end of the trough, with the water and the dirt at the opposite end.

The washer is constructed with a wrought-iron or steel trough about 18 inches wide, having sloping sides, being widest apart at the top, and narrowest at the bottom. At each end of this trough is fixed a sprocket wheel, on which rides a chain, attached to which, at suitable distances and at right angles to it, are scrapers that correspond to the inside shape of the trough. The scrapers form movable stops, or dams, that are slowly moved by the chain along the trough in the opposite direction to the way the water runs. The trough is fixed at a suitable inclination, and the coal is admitted at the center of its length and the water at its highest end or thereabouts, and as it runs to the lowest end it carries with it the coal, which is lighter than the dirt; the dirt settles in the scrapers and is conveyed by them against the stream of water and delivered at the opposite end to that at which the coal escapes. The speed of the scrapers and quantity of water are regulated to suit the material washed. The water is circulated and used continuously, so that the waste is only that which is carried away by the dirt and coal after drainage. A centrifugal or other pump is used for elevating the water to the washer. The arrangement for draining the water from the coal is such that there is no waste of coal or pollution of streams, etc. A 1-inch pipe will keep good the supply of water for each trough, or 100 tons of coal washed per day. This washer has been introduced by the Hardy Patent Pick Company, Limited, of Sheffield, England.

This class of coal washer requires large quantities of water, and its work is somewhat expensive and imperfect.



(a) *Trough Raised*



(b)

Fig. 9. Scaife Trough Washer

The **Scaife trough washer,** Fig. 9 (*a*) and (*b*), consists of an inclined trough *a* of semicircular cross-section, 2 feet in diameter and 24 feet long, provided at intervals with riffles. Lengthwise of the trough is the shaft *b* to which are attached the stirrers *c*. The shaft is given a reciprocating motion by means of an arm in its center, worked by a connecting-rod attached to the flanged driving pulley *d*. The empty trough, which is hinged to the frame on one side, is partly held in position by the adjustable counterbalance weights *e* on the arms *f* attached to the trough. A tongue on the operating lever *g* passes through an eye on the trough and firmly holds it in place.

Coal and water are fed into the upper end of the trough *a*. The combined action of the flowing water and stirrers causes the slate and other impurities to settle at the bottom of the trough, where they are caught by the riffles, while the clean coal passes over the top and out at the lower end. When the spaces between the riffles are filled with impurities, the feeding of coal is stopped, or temporarily turned into an adjacent washer, and all the remaining coal is washed over the riffles. The operating lever *g* is moved a few inches to the right, which draws the steel tongue out of the eye and releases the trough, and allows the latter to drop and dump the refuse. The trough is returned to its original position by moving the operating lever still farther to the right, which engages a clutch and causes the chain *h* to be wound up and lift the trough; the weight *i* keeps the chain taut. As soon as the trough is raised, the lever should be drawn quickly to the left until it reaches its original position. This movement releases the clutch and locks the tongue in the supporting eye of the trough. The washing is then recommenced. Where the washer is properly erected and operated, the dumping and raising will occupy less than a minute. This washer has no screen to wear and be replaced. The principal wearing parts are the stirrers, which are inexpensive and can, if desired, be made anywhere. The water may be used over and over again. The slope or fall given to the trough depends on the size of the coal and nature of the impurities; the larger the coal, the greater should be the slope and the quantity of water.

JIGS

Principle of the Jig.—To economize water and separate the impurities from the coal in a more complete and economical manner, an improved class of washing machines, called **jigs,** has been introduced. These have, in a great measure, displaced the older methods. The several classes of the broken coal previously sized are delivered into separate receptacles, or jigs, in a water bath, and the separation of the coal from the impurities is accomplished by imparting a pulsing motion to each receptacle, or jig, of such speed as to secure the best results. This pulsing motion in the modern improved machines forces the lightest matter—the coal—to the surface of the water, carrying it forwards and over the delivering edge of the jig into a car or other means of conveyance to move it to points where it is to be used. The heavier, or impure, matters sink under the coal in this pulsing movement and are dropped into special receivers under the washer for ultimate disposition.

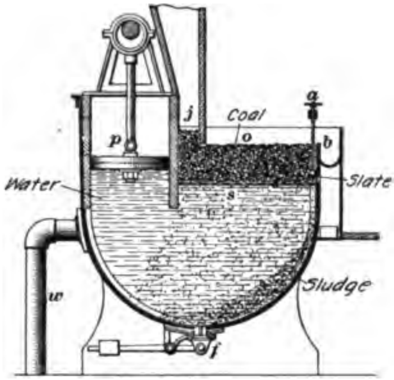


Fig. 10. Hartz Jig

p, plunger; *j*, feeder, prepared coal; *w*, water supply; *s*, water chamber; *o*, coal chamber; *a*, slate delivery; *b*, clean-coal discharge; *f*, sludge discharge.

Capacity, about 150 tons per day. Cost, about 5 cents per ton.

The force of the upward pulsing current is regulated so as to meet the requirements of the several varieties of coals, in the process of removing their impurities. If this current is too strong it will disarrange the classification of the coal; if too weak, it will fail to separate the larger pieces of coal. It is also important that the force of the upward pulsing current be uniform in its action through the mass of coal in the washer chamber of the apparatus, otherwise imperfect work will ensue.

Mr. H. Rittinger, who has given the mechanical separation of materials considerable study, has, from practical tests, deduced the following formula: The velocity of the current in feet per second is equal to $1.28\sqrt{D(d-1)}$, in which d is the density of the material, and D the diameter of the meshes in the screen, or practically the diameter of the pieces to be operated on.

The Hartz Jig.—Fig. 10 illustrates the general principles of the operations of this class of coal-washing machines.

The Lührig jig, Figs. 11 and 12, illustrates, in a brief way, the essential elements of coal washing. Fig. 11 shows the Lührig feldspar jig, which is used exclusively for the treatment of fine coal.

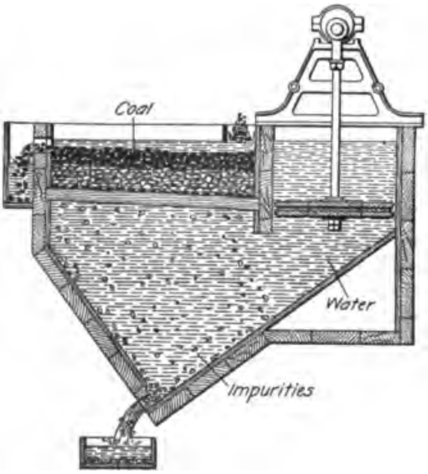


Fig. 11. Lührig Feldspar Jig

Fig. 12 shows the Lührig nut-coal jig as arranged with its machinery for automatically removing the refuse.

Berard's coal-washing machine, Fig. 13, was introduced in London in 1851, and in Paris in 1855. It was used by the Kemble Coal and Iron Company in the Broad Top region, Pennsylvania, for a few years beginning in 1873.

The coal to be cleaned is dumped from the railroad car *a* into the hopper *b* by a side door over an iron chute; thence, it is diffused on the separator *c*, which is kept in agitation by the cam *d*. The lumps that will not pass through the 3-inch square openings in *c* roll down to the screen platform *e*, where they are broken by a workman with a maul and, falling through the grating, pass to the rolls *f*. The smaller lumps pass through the 3-inch meshes in the agitator screen *c*, when they are further divided by a screen underneath *c*. The portions of the coal that will not pass through the ½-inch holes in the latter screen pass directly to the rolls *f*, while the very fine portion is carried under the rolls, down the chute *g*, into the receiver *h*. The rolls *f* have teeth, or spurs, set all over their circumference, each being about ½ inch square by ½ inch high. Their arrangement is such that the spurs of one roll mesh into those of the other. One of the crushing rolls has its pillow-blocks set with a rubber-ball spring, so as to admit a small horizontal movement, to prevent the breaking of the teeth of the rolls by the passage of hard slates or pyrites.

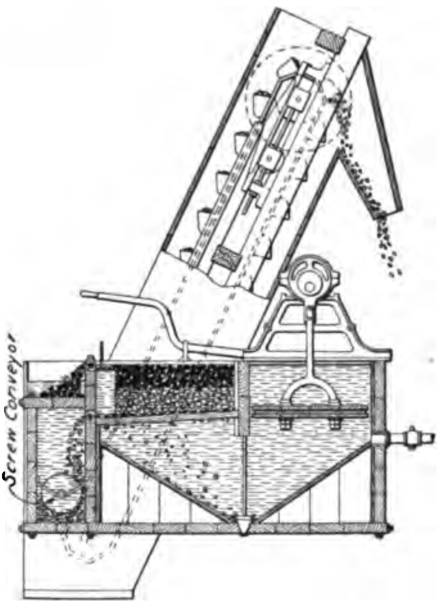


Fig. 12. Lührig Nut-Coal Jig

After passing the rolls, the crushed coal falls into the receiver *h*, whence it is elevated by the chain of buckets *i* and delivered into the chutes *j*, through which it is carried into the separating pans *k*, which are made of cast iron, with a copper plate on top of the grating, forming the bottom of the iron pan; the copper plate is perforated with ⅛-inch holes, set close together. The pans are supplied with water conveyed by troughs, through which the coal is also carried. The action of the piston *l*, which moves with quick, short strokes (120 per minute), forces the water through the coal

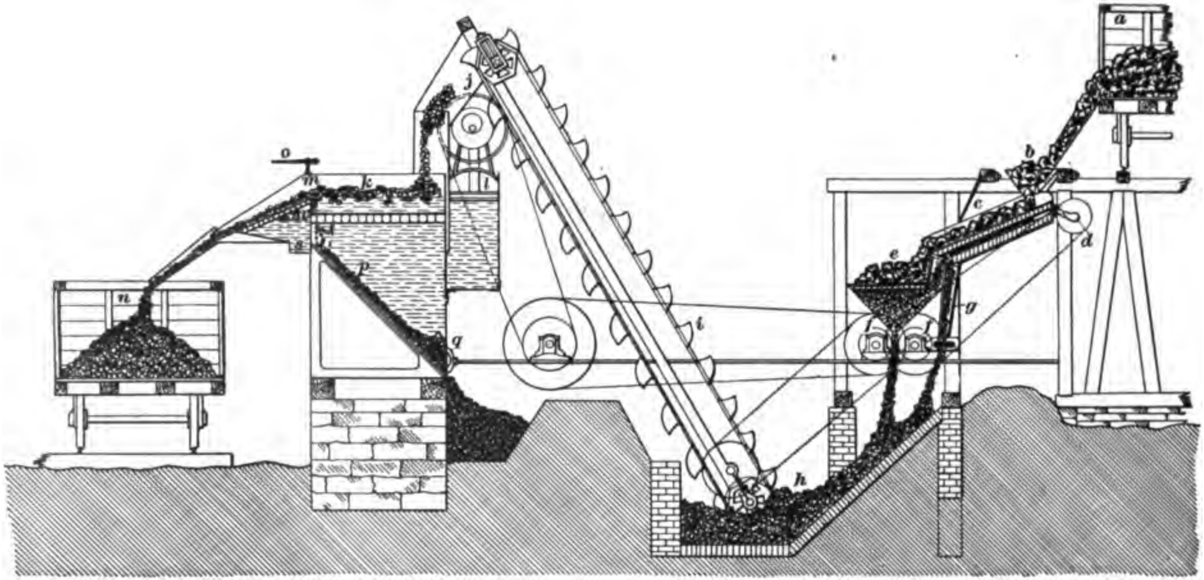


FIG. 13. BERARD'S COAL-WASHING MACHINE

and slate in rapid pulsations, lifting the pure coal upwards and onwards with the movements of the water until it is carried over the side of the pan at *m*, and thence over a grated chute into the car *n*, on the track in front of the washer.

The impurities, being heavier than coal, sink to the bottom of the pan and are carried to its front interior angle, whence they are discharged by a valve *o* into the receiver *p*, from which they can be removed by a sliding bottom *q*. The movement of the mass of coal in the pan is about 20 inches per minute, giving a continuous overflow of washed coal into the receiving cars below. This flow can be regulated by raising or lowering the front side of the wash pan at *m*.

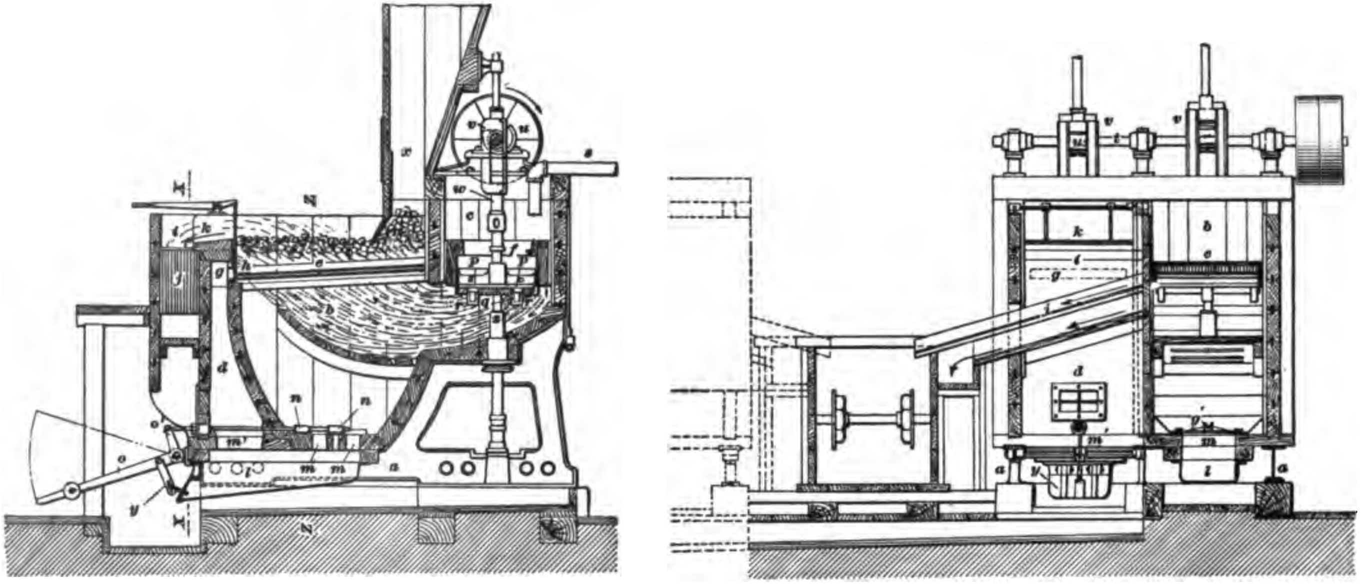
The main portion of the water in the washed coal is drained from it by a fine copper-wire screen on a chute, immediately under the discharge from the wash pan at *m*. This water, charged with the very fine coal and dust, passes through *r*, and is conveyed by a trough *s* into a large tank alongside the washer, where the fine coal is permitted to settle, and from which it is shoveled into the receiving cars along with the coarser coal and all charged into the coke ovens.

The **Stutz improved coal washer,** Fig. 14 (*a*) and (*b*), has been tested in practice during many years. It is simple in its construction, yet efficient in its operations, requiring a small force in working it. It was designed by S. Stutz, mining and mechanical engineer, of Pittsburg, Pennsylvania, who has followed up its workings, adding from time to time such improvements as appeared necessary to make its processes more complete.

Fig. 14 (*a*) is a longitudinal vertical section, and Fig. 14 (*b*) a vertical cross-section at the lines *X X* and *Z Z* of Fig. 14 (*a*).

In this figure, *a*, *a* are cast-iron brackets supporting a rectangular box divided into chambers *b*, *c*, and *d*, constituting two complete machines. Arranged within the chamber *b* is a screen or sieve *e*, while the chamber *c* contains the piston, or plunger, *f* with its mechanism to reciprocate vertically. The slate chamber *d* communicates with the separating or washing chamber *b* through an opening *g*, governed by a suitable valve *h*.

A trough, or chute, *i* provided with a screen *j* communicates with the separating chamber *b* to receive the washed coal as it passes over the bridge *k*. Beneath the slate chamber *d* and the separating chamber *b* an auxiliary receiver *l* is arranged, which communicates with both chambers by means of the openings *m′* and *m*, *m*, for the purpose of providing means to collect the sediment that passes through the meshes of the sieve *e* during the operation of the machine, and to effect its escape without wasting the water in the washing chamber *b*, thus making the operation of the washer continuous. Before letting out the fine sediment, the openings *m*, *m* are closed by the gates *n*, *n*, and the communication



(a) *Longitudinal Vertical Section*

(b) *Transverse Vertical Section*

FIG. 14. STUTZ IMPROVED COAL WASHER

with the washing chamber *b* is shut off. No water is wasted. The receiver also collects the coarse impurities from the slate chamber *d*; both kinds, coarse and fine, may be let to the outside of the machine by the levers *o*, *o'*.

The piston, or plunger, *f* is provided with large openings *p*, *p*, in its bottom; they are governed by floating valves *q* underneath, kept in proper position by guides *r*, *r*. With the improved plunger, the necessary volume of water is let into the machine from above by means of the pipe *s*, thus filling up more easily the entire space when the piston is moving upwards. Movement is imparted to the latter from the shaft *t* by means of the cam *u*, yoke *v*, and rod *w*. Coal to be washed is supplied to the screen *e* through a hopper *x*. The separation of the coal from its impurities is accomplished in the usual way. The pulsations of the water by the movements of the plunger lift the lighter coal upwards, while the slates, pyrites, etc. sink to the bottom. The stroke of the plunger can be varied to meet the wants of the different sizes of coal.

The **Stutz improved coal-jigging and washing machine,** Fig. 15, has a vertical reciprocating piston or plunger directly underneath the stationary sieve or screen; (*a*) is a longitudinal vertical section through the center of the jigger; (*b*) is a section taken at line *X X* of the top view (*c*), and a front elevation of two machines combined together.

In the figure, *a*, *a* represent cast-iron brackets supporting the separating box *b*, arranged within which is the screen or sieve *e*, with the piston, or plunger, *f* below, and the mechanism whereby the latter is caused to reciprocate vertically above. The slate chamber *d* communicates with the washing chamber *b* through the opening *g*, governed by the valve *h*. A trough or channel *i* also communicates with the washing chamber *b* and is designed to receive the washed coal as it comes over the delivery bridge *k*. An auxiliary receiver *l* is arranged beneath the chamber *b*, and communicates with the latter by means of openings *m*, *m* governed by gates *n*, *n*. The receiver *l* also communicates with the slate chamber *d*, through the opening *m'*, for the passage of the coarse impurities. The outlet gate, or door, *y* of the auxiliary receiver is connected to bell-crank levers *o*, *o* by links. Movement is imparted to piston *f* by means of eccentrics *u*, *u* keyed upon the driving shaft *t*, and yokes *v*, *v* connected to rods *z*, *z*. Coal is fed upon the screen *e* from the hopper *x*, while the supply pipe *s* furnishes the necessary volume of water for the operation.

The purpose of the auxiliary receiver *l* is to provide means for collecting the fine sulphur and slate pieces that pass through the meshes of the sieve *e* during the working of the machine, and to effect the escape of this fine sediment without wasting the water inside the washing chamber *b*, thus making the operation of the jigger absolutely continuous.

By means of the improved and special-shaped piston *f* acting at each up stroke like a wedge behind the material on the screen, the different layers of the separated substances—coal and impurities—are readily and uniformly advanced toward the delivery openings, while below the screen the filling up, or choking, by the fine sediment passing through its meshes, is also prevented.

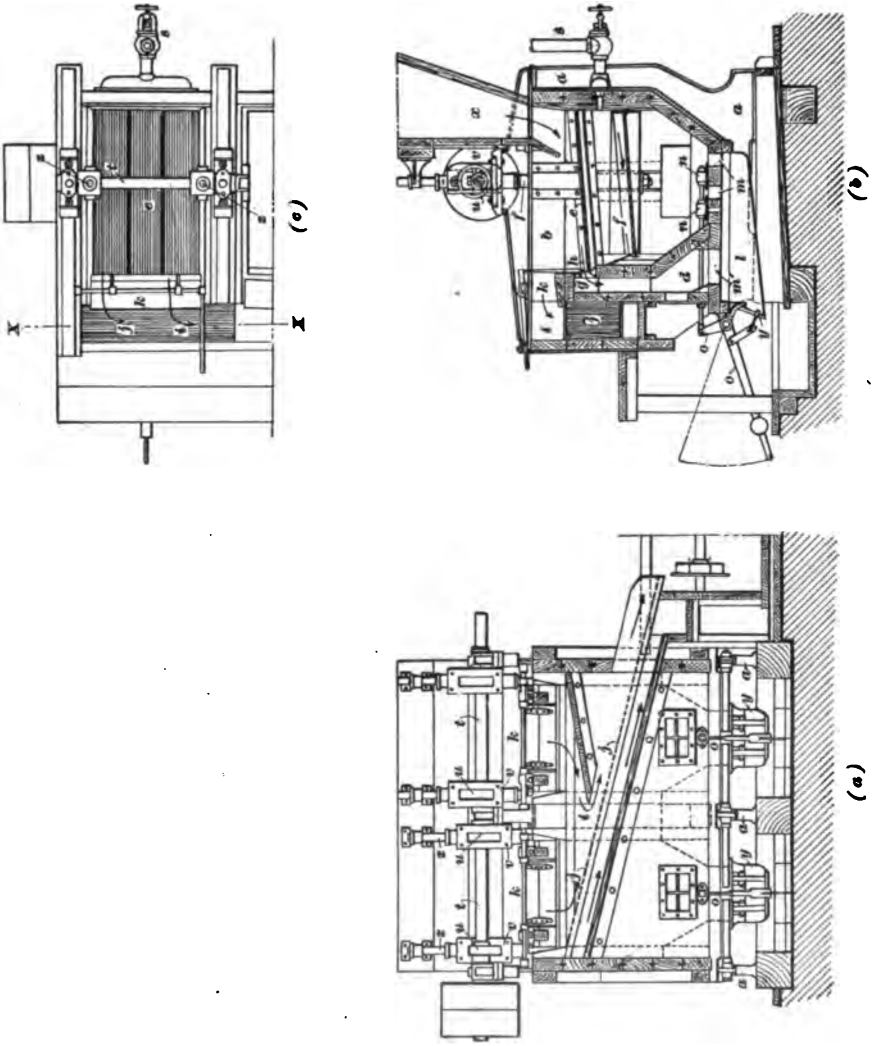


Fig. 15. Stutz Improved Coal-Jigging and Washing Machine

The cost of these coal-washing machines, for cleaning 300, 400, and 600 tons per day, will depend mainly on location, quality of coal to be treated, and the character of its impurities. Mr. Stutz has furnished estimates for the treatment of the above outputs per day of 10 hours at $11,000, $13,000, and $16,000, respectively. This estimate includes the necessary power, water, and building. It does not, however, embrace the machine for disintegrating the coal in the preparatory process; the cost of this will be found under the head of coal crushers or disintegrators. The cost of washing is given at 2 cents per ton for the work of washing alone.

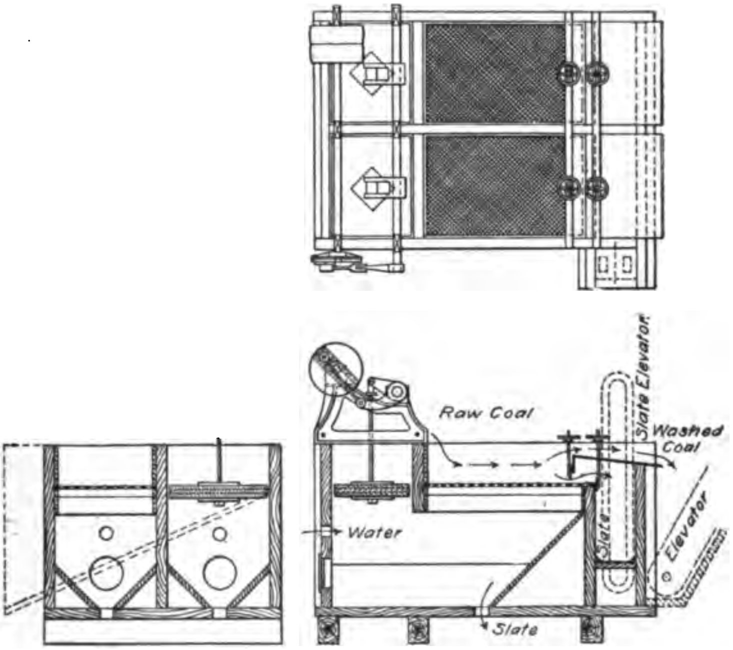


FIG. 16. STEIN'S STANDARD COARSE CORN-COAL JIG, STYLE C

The interest on investment of plant and the wear and repair of machinery must be added to show the total cost of cleaning the coal in this machine.

WALTER M. STEIN'S WASHERS

Stein Jigs.—Figs. 16, 17, and 18 show jigs, Stein standard, while Fig. 19 shows the general arrangement of a coal-washing plant designed by Mr. Walter M. Stein, of Philadelphia, for the New Glasgow Iron, Coal, and Railroad Company, of Nova Scotia.

The coal from the various mines arrives on the railroad tracks a_1, a_2 and is dumped into the pits b_1, b_2 underneath, a different kind in each pit. From these pits, the coal is taken, by means of bucket elevators c_1, c_2, to the shaking screen *d*. This shaking screen has a double eccentric motion, imitating hand screening as much as possible. The mesh of the screen plate is 3/8 inch. The material too large to pass through the perforations drops into the crusher rolls e_1, e_2, and is again taken, after the crushing, to the shaking screen *d* by means of the bucket elevator *f*. The coal passing through the shaking screen *d* is taken by means of the bucket elevator *g* to the separating screen drum *h*, which separates it into three sizes—0 to 1/8 inch, 1/8 to 1/4 inch, and 1/4 to 3/8 inch.

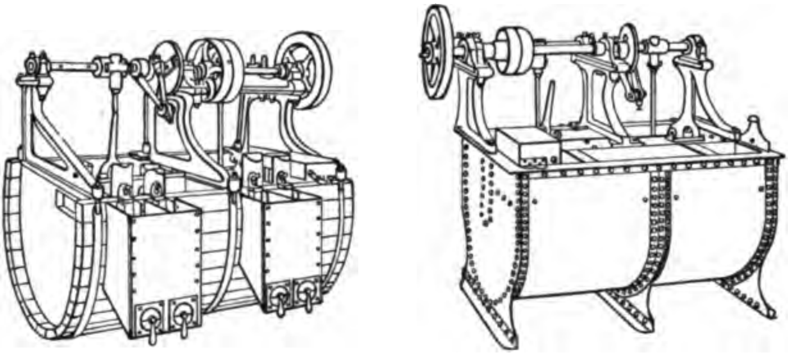


FIG. 17. STEIN'S JIG FOR COARSE SIZES, STYLE G STEIN'S JIG FOR FINE SIZES, STYLE H WOOD OR IRON TANKS

The different sizes are carried by means of chutes to the various jigs j_1 to j_8. These are all two-compartment feldspar jigs, arranged with variable stroke. Each screen compartment is 28 inches wide and 49 inches long, so that the coal must travel a distance of over 8 feet while being washed. The washed coal flows in gutters to the large elevator boot k_2, and is elevated from there to the top of the storage tower by means of the perforated bucket elevator l_2, which discharges on the distributing conveyer *m*, which carries it into the various compartments *n* of the large storage tower. The two jigs shown in dotted lines, the elevator boot k_1, and the elevator l_1, are arranged to be put in if the plant requires enlargement. The slate from jigs j_1 to j_3 is discharged into elevator boot q_1, and is taken from there by means of a perforated bucket elevator r_1, and dumped into railroad cars ready to be taken to a convenient dumping place. The centrifugal pump *t* distributes the water, which, after being used, always returns to the pump and is used over again. There is no loss in this respect except that absorbed by the coal, and enough fresh water must be added to make up for this. *u* is the steam engine of 100 horsepower to drive the entire plant.

All the elevators are of special construction and have very large buckets, automatic feed, etc., and are run at a slow speed.

The entire plant works automatically, requiring only three men to operate it. The coal before washing contains from 17 to 35 per cent. of ash, besides about 2½ to 3 per cent. of sulphur; the washed coal contains in the average 10 per cent. of ash or 1 per cent. more than the fixed ash, 9 per cent., of the coal. This is a remarkably good showing, and is seldom equaled at any washing plant in existence. The fixed ash cannot be reduced by any method. Coming within 2 per cent. of the fixed ash is ordinarily considered excellent work. The sulphur is reduced, by washing, from 2½ to 3 per cent. down to 1.35 per cent., that still left being the organic sulphur and that in combination with alumina or lime.

Jigs j_1 to j_5 were in the original plant; j_6 to j_8 were added when the additional retort coke ovens were built. The total capacity of the plant is now 300 tons of coal in 10 hours.

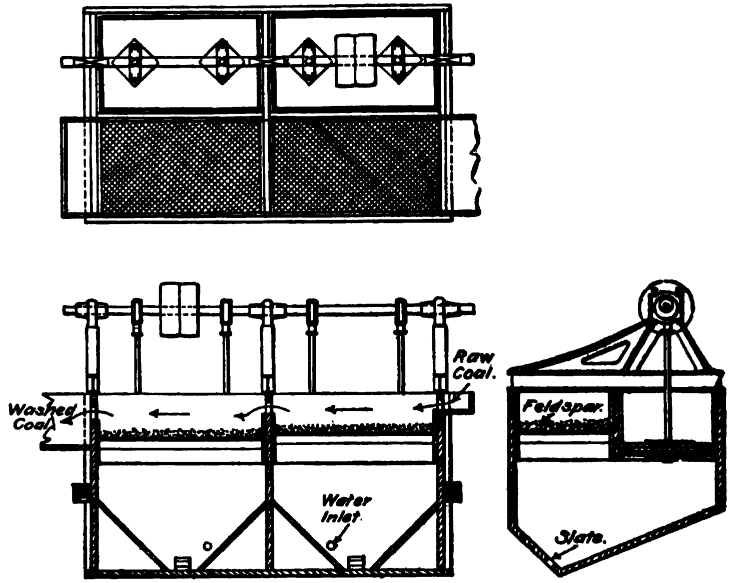
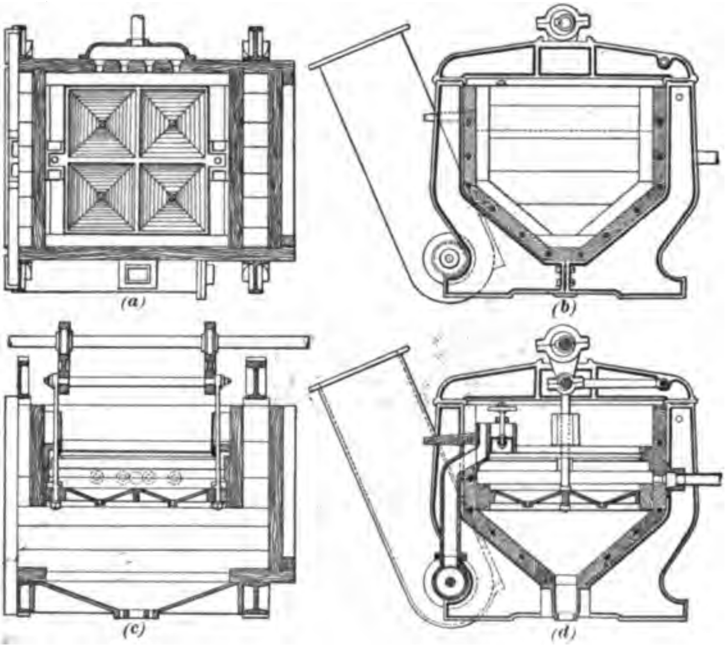


FIG. 18. STEIN'S FINE CORN-COAL JIG, STYLE A, TWO COMPARTMENTS, AUTOMATIC SLATE VALVE

The **Diescher coal washer,** Fig. 20, may be constructed with one box or with a number of boxes connecting with each other and worked by the same shaft. The boxes may either have outlets, as shown in (*d*) and on plan (*a*), with an elevator for carrying away the slate and other deleterious materials, or, where the boxes are fixed on elevated ground, they may have pyramidal receptacles into which such material falls and is discharged at intervals by its own gravity through a valve operated by a lever.

The *modus operandi* of the washer is as follows: The coal is dumped from the back upon the screen shown in section in views (*c*) and (*d*); the water is conveyed to the washer by a 3-inch pipe entering into a cast-iron box fixed at the back (*a*); this box runs along the back of the washer below the screen and delivers the water through four 2-inch holes cut out of the washer side (*a*) and (*c*). The action of the plunger forces the water through the screen, agitating the coal and carrying the cleaned coal over the wooden ledge, shown to the left and a little above the screen, into a trough that conveys it into bins; the slate and other heavy and deleterious materials, by force of their greater specific gravity, fall to the screen and escape, through the valve shown, into the discharge pipe and elevator, or into the box previously referred to.



(*a*) *Plan* (*b*) *End Elevation* (*c*) *Longitudinal Section* (*d*) *Transverse Section*

Fig. 20. Diescher Coal Washer

The washer is constructed as shown in the figure, having two cast-iron stanchions of **H** section footed out at the bottom as shown. The upper part of the stanchion has 9-inch web with 4-inch flanges, by about $\frac{7}{8}$-inch metal. The stanchions are connected together on top by means of two girders of similar section but arch-backed, having the central part of top flange level and dovetailed to receive the bearing for the main shaft. The stanchions are kept rigid by means of two 1¼-inch wrought-iron tie-bolts and distance pieces of pipe [see top of stanchion in view (*d*)], and the girders are bolted to the ends of the stanchion by four wrought-iron bolts at each end.

The body of the washer is composed of 4-inch, white-pine timbers of the widths shown, planed, tongued, and grooved. The side timbers project beyond the stanchions, as shown in views (*a*) and (*c*), the ends being let into same and further secured by an angle plate 4 inches by 4 inches (Fig. 21). It will be noticed, by reference to Fig. 20 (*c*), that only one end plate is shown. This is on account of there being a series of connected boxes in a line, the water communicating from one box to the other. The partitions of the boxes are also of 4-inch timbers reaching down to the angle of box as shown by Fig. 20 (*c*). Between the partitions and end, it will be noticed, there is a space 8 inches wide right under the stanchions (*c*); this is the equilibrium chamber, and is provided to keep the water level and prevent a vacuum being formed. Within the partition, there is a lining that can easily be renewed and serves to confine the water between the plunger and the screen. Above the plunger, an angle-iron frame 4 inches by 4 inches by ½ inch is fixed as shown in views (*c*) and (*d*), upon which the wooden frame to which the screen is connected rests; this angle iron, together with the screen, is not fixed perfectly level, but is inclined 1 inch toward the slate valve to facilitate the discharge of the coal and slate through their respective openings.

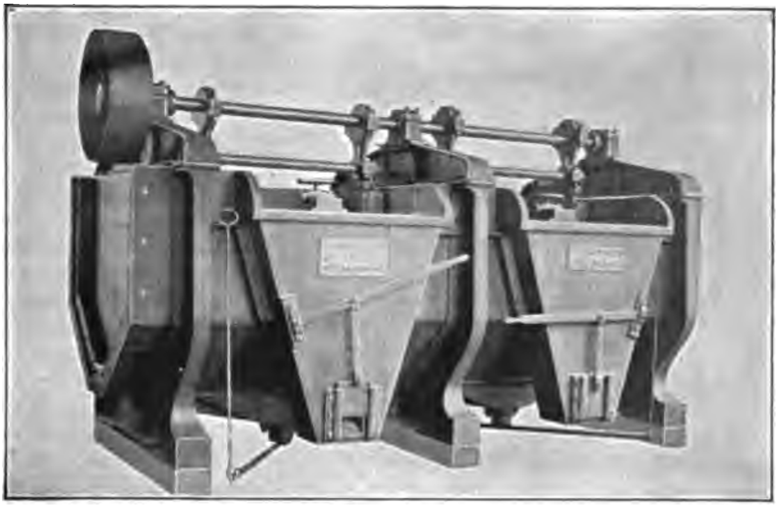


FIG. 21. DOUBLE DIESCHER WASHER

The plunger is of cast iron, ¾-inch metal, 5 feet long by 4 feet 3 inches wide, with four buckled surfaces, as shown in views (*a*), (*c*), and (*d*), in the center of each of which is a small hole to allow the discharge into the lower chamber of any fine material that may fall through the screen. The plungers are suspended by two rods of suitable size, as shown in views (*a*), (*c*), and (*d*), which are secured to plunger casting by means of collars and nuts, the casting being specially thickened for the purpose, view (*c*). The suspension rods connect with a cross-bar, as shown by view (*c*), and are shielded from the coal by two castings, view (*d*), having openings 4¾ inches by 5 inches by 7 inches deep. These castings are connected to the washer by lagscrews. The plunger has a stroke according to material operated upon, ranging from 1½ inches to 2 inches, the smaller stroke being most suitable for fine material. The 3-inch cross-shaft is suspended from eccentric or main driving shaft by means of two cast-iron eccentric yokes, as shown by views (*c*) and (*d*); the yokes are steadied by a rod, as shown in (*d*). The eccentric or main shaft is 3½ inches in diameter and turns in bronze bearings, resting on the girders previously referred to, and is generally driven by a 32-inch pulley, making 70 to 80 revolutions per minute, according to the stroke of plunger and the material operated upon. Where there are several boxes, the plungers rise and fall alternately, thereby balancing each other, and keeping the water beneath them in equilibrium. The screens of the boxes are invariably 4 feet square, composed of a rigid wrought-iron frame carrying wires of spring brass, which are placed parallel in the direction of the discharge, having a space between of about $\frac{1}{64}$ inch. These wires are fastened to the frame by means of copper wires and all the joints are protected by solder. It will readily be seen that this arrangement secures a strong, rigid, and durable screen that allows free passage to the water and to the finest pyrites only.

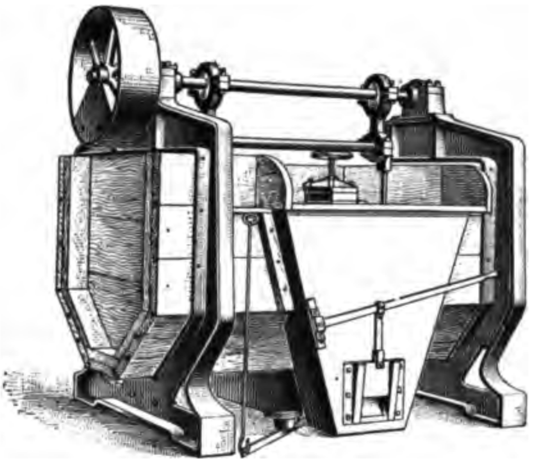


FIG. 22. SINGLE DIESCHER WASHER

The slate valve is fixed in the position shown in view (*d*); the body of the valve has an opening on both sides, 6 inches by 2 inches, the area of which can be modified at will by means of the movable valve within, which is operated by a hand wheel and screw. The size of the discharge pipe, view (*d*), varies with the kind of material operated upon. At the bottom of washer, a casting having a valve in the center for the discharge of the fine pyrites or of the water when necessary is secured as shown in views (*c*) and (*d*). Access is provided to the underside of the plunger by means of a circular manhole, about 14 inches in diameter, having a cast-iron arched door and frame.

The correctness of the principles involved in the construction of the Diescher washer is noticeable in several ways. One of its good points is that the position of the plunger is directly under the screen, which produces a uniform and energetic action of the water and an equal operation all over the screen surface, whereas, when the plunger is at the back, an unequal action of the water is produced on the screen, the effect of which is sometimes only partially obviated in other machines by means of aprons and scrapers. Another advantage of this machine is that the water enters the upper chamber between the screen and the plunger; the result of this is, as has been found in practice, that no valves are necessary in the plunger, although these are put in when especially desired.

The washing capacity of a single box varies, according to circumstances, from 75 tons of coal up to 200 tons in 10 hours, according to the amount of dirt and pyrites mixed with it. The cost of washing coal with the Diescher jig varies with the size of the plant and numerous other conditions. One man can attend to several boxes as easily as to a single-box washer. Even in the most unfavorable circumstances, the cost of washing the coal will be only a small fraction of 1 cent. per bushel. In some cases, the cost is less than $\frac{1}{10}$ cent per bushel.

The Diescher machines have been in practical use for 20 years, and are now to be found in all parts of the United States and even in Mexico. Their reputation for simplicity, durability, great capacity, and for excellence and economy of the washed coal makes them very popular and in constantly increasing demand. They are manufactured by the Scaife Foundry and Machine Company, Limited, of Pittsburg, Pennsylvania.

BROOKWOOD, ALABAMA, WASHERY

The coal-washing plant at Brookwood, Alabama, Figs. 23 and 24, was designed by Mr. Walter M. Stein, of Philadelphia, for the Standard Coal Company. The following description is by Mr. Rudolph Boericke, superintendent, and was written in response to a letter of inquiry addressed to Mr. Fred M. Jackson, secretary and treasurer of the company:

"The coal is drawn up the mine slope, by wire-rope haulage, to the top of a wooden trestle 50 feet high, where it is dumped into

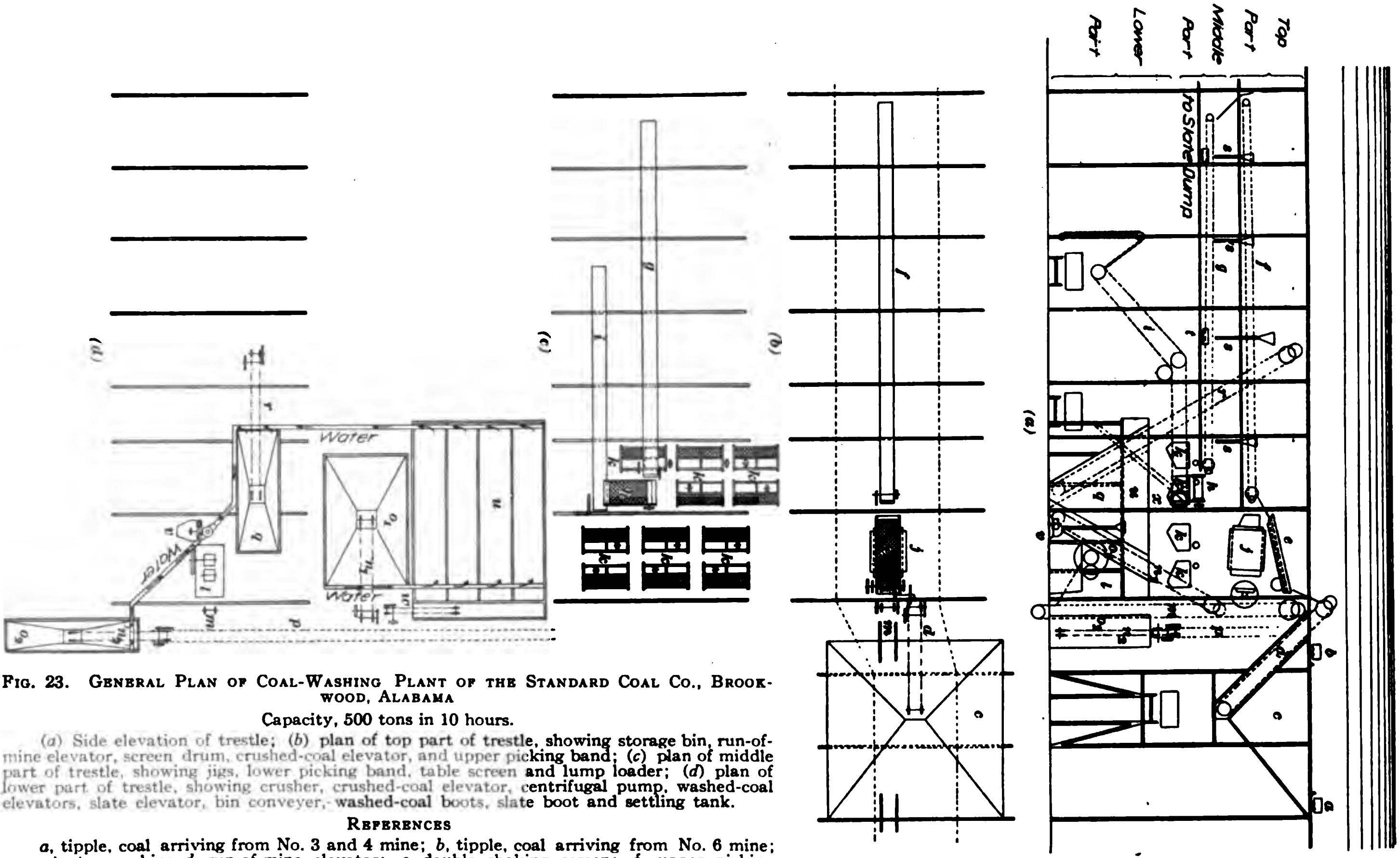


FIG. 23. GENERAL PLAN OF COAL-WASHING PLANT OF THE STANDARD COAL CO., BROOKWOOD, ALABAMA

Capacity, 500 tons in 10 hours.

(*a*) Side elevation of trestle; (*b*) plan of top part of trestle, showing storage bin, run-of-mine elevator, screen drum, crushed-coal elevator, and upper picking band; (*c*) plan of middle part of trestle, showing jigs, lower picking band, table screen and lump loader; (*d*) plan of lower part of trestle, showing crusher, crushed-coal elevator, centrifugal pump, washed-coal elevators, slate elevator, bin conveyer, washed-coal boots, slate boot and settling tank.

REFERENCES

a, tipple, coal arriving from No. 3 and 4 mine; *b*, tipple, coal arriving from No. 6 mine; *c*, coal storage bin; *d*, run-of-mine elevator; *e*, double shaking screen; *f*, upper picking band; *g*, lower picking band; *h*, single shaking screen, 3-inch mesh to separate lump and nut coal; *i*, lump loader; *j*, revolving screen drum; *k*, jigs; *l*, crusher; *m*, crushed-coal elevator; n_1, n_2, washed-coal elevator; o_1, o_2, washed-coal boots; *p*, bin conveyer; *q*, slate boot; *r*, slate elevator; *s*, chutes for taking slate to slate cars; *t*, slate cars to take slate to dump; *u*, settling tank; *v*, centrifugal pump; *w*, coal-smudge elevator; *x*, bin and chute for nut coal.

a storage bin *c*. It passes first over a double-table shaking screen *e*, which divides it into three sizes. The top screen is of 1½-inch mesh and the other of ⅝-inch mesh. The largest size, comprising nut and lump, passes over two picking bands *f* and *g*, 73 and 68 feet long, respectively, where it is hand-picked by boys, and then over another single shaking screen *h*, of 3-inch mesh, which takes out the nut, which falls into a bin *x* and is carried by a chute to the cars. The remaining lump is delivered to the lump loader *i*, which consists of a chain of buckets, or pans, moving on iron ways and in operation is exactly the reverse of an elevator—instead of raising the coal it lowers it into the car. The lower end swings on chains and can be adjusted to any height of car, or be raised clear of the train while the cars are being shifted.

"To return to the coal that passes through the first or 1½-inch mesh shaking screen *e*. That part of it that is too small for nut, yet too large for washing purposes, that is, that which passes over the ⅝-inch mesh, falls directly to the crusher *l*, where it is crushed and returned to the shaking screen. The crushed coal and all the fine coal from the mine, passing through the ⅝-inch mesh screen, is sized in a large, double, revolving drum *j* into three sizes, each size being washed through gutters to jigs *k* adapted and adjusted for it. There are eleven double-compartment plunger jigs in all, each capable of handling from 5 to 7 tons per hour. In these jigs, the raw coal enters at one end, and moves across both compartments and out at the other end as the washed product. In moving across, the slate, pyrites, barytes, and all heavier particles find their way through the bed to the bottom of the jig and flow out through the slate valve in a constant stream. The washed coal is taken to the boots o_1, o_2 and the washed slate to the boot *q*, by means of gutters. Perforated bucket elevators n_1, n_2 moving slowly to drain off the water, raise and dump the washed coal into the conveyer *p*, which carries it to the storage tower. The slate elevator *r* discharges into small cars, which the picking boys push to the slate dump. The amount of water used in this plant is very small, as the same water is used over and over. By allowing it to flow through a settling tank *u*, tolerably clear water is not only obtained, but all the sludge or finer particles of coal that are held in suspension and would otherwise be lost are saved and elevated to the washed-coal elevator n_1 by the perforated bucket elevator *w*. The water from the settling tank flows back to the centrifugal pump *v*, which again forces it to the jigs, etc."

The capacity of the washer is 500 tons per day of 10 hours, though owing to the limited output of the mines at present, it has not been handling much over 300 tons.

The table of analyses, page 79, shows the efficiency of the washer very plainly. The coke is hard and exceptionally low in ash.

To obtain the average for a day's run in this table, samples of run-of-mine and of washed coal were taken every half hour:

FIG. 24. COAL WASHER AT BROOKWOOD, ALABAMA—STORAGE TRESTLES

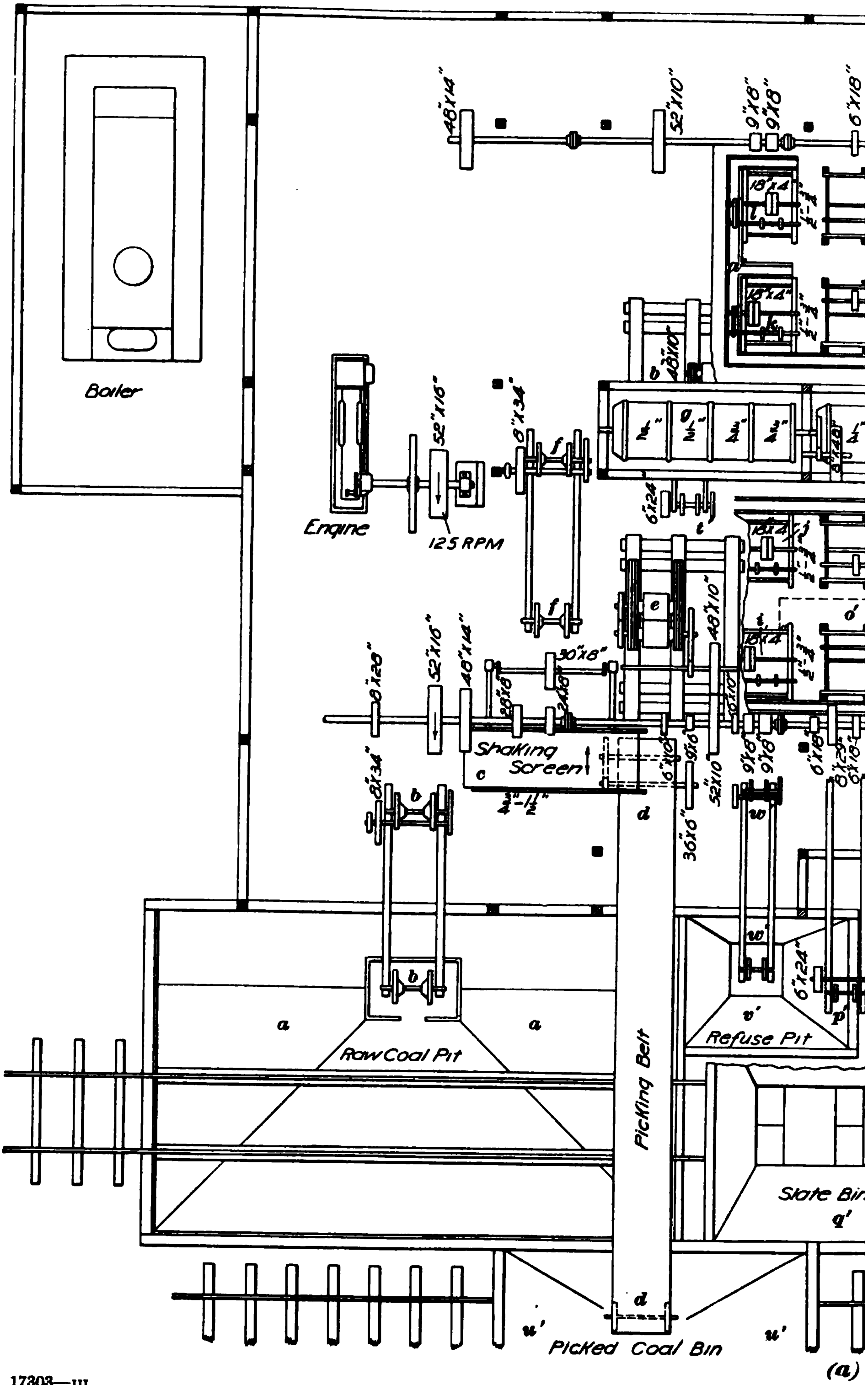
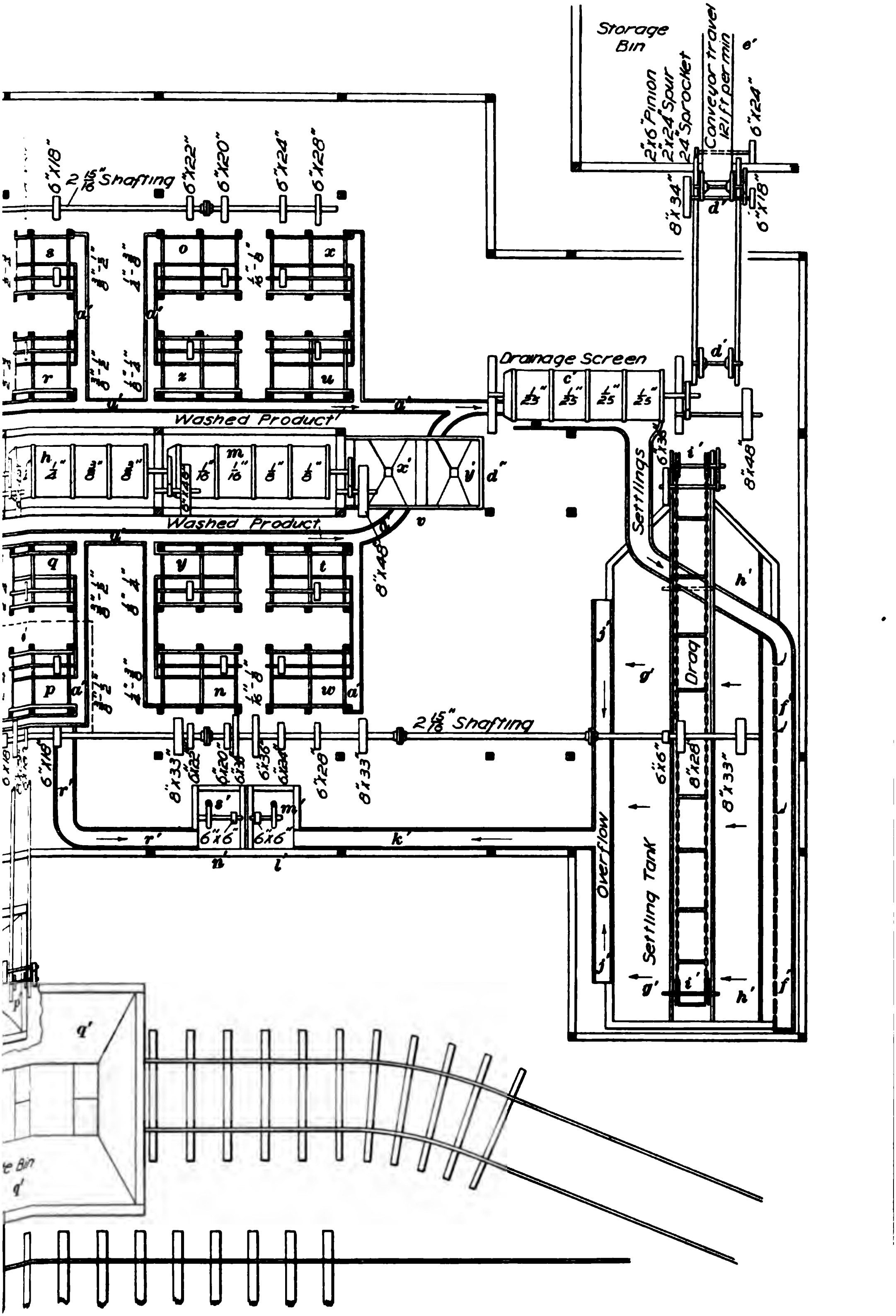


Fig. 25. Plan of Coal-Washin



(a)

NG PLANT AT COAHUILA, MEXICO

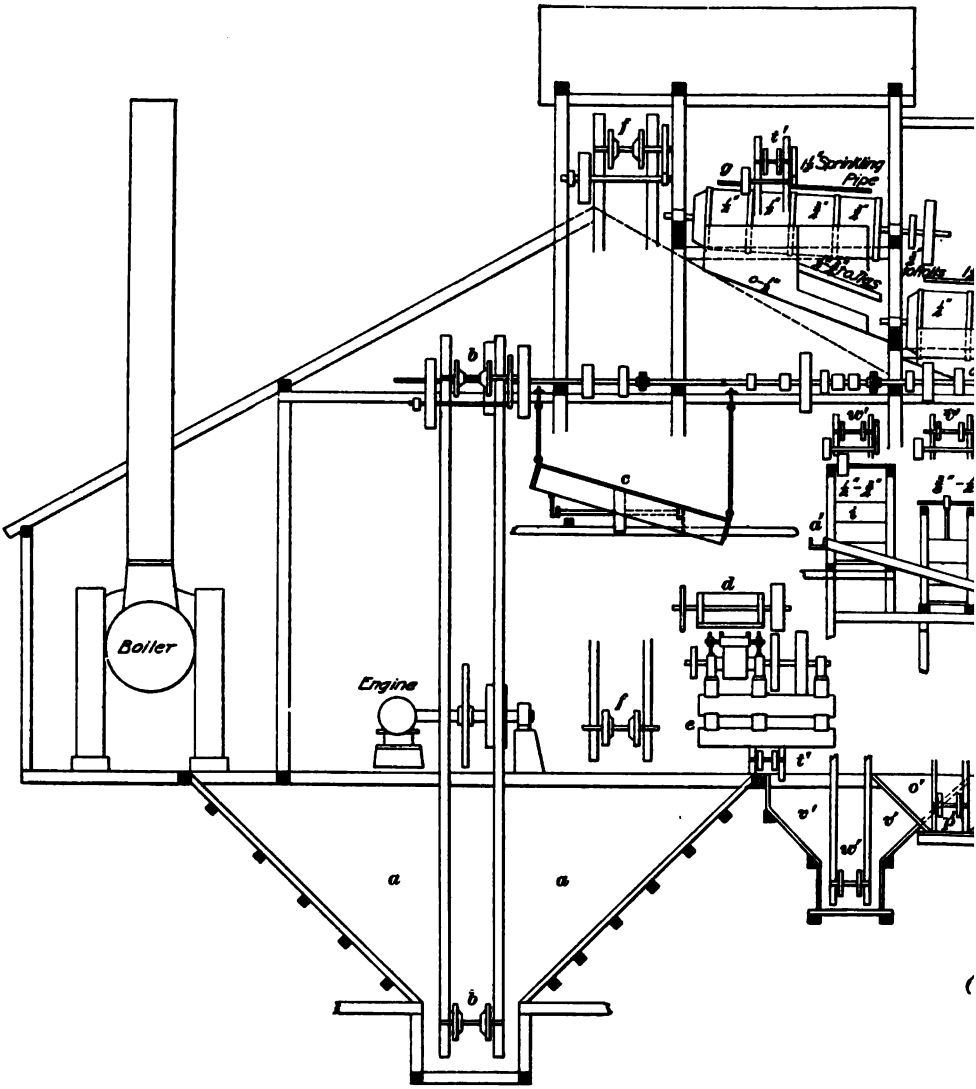
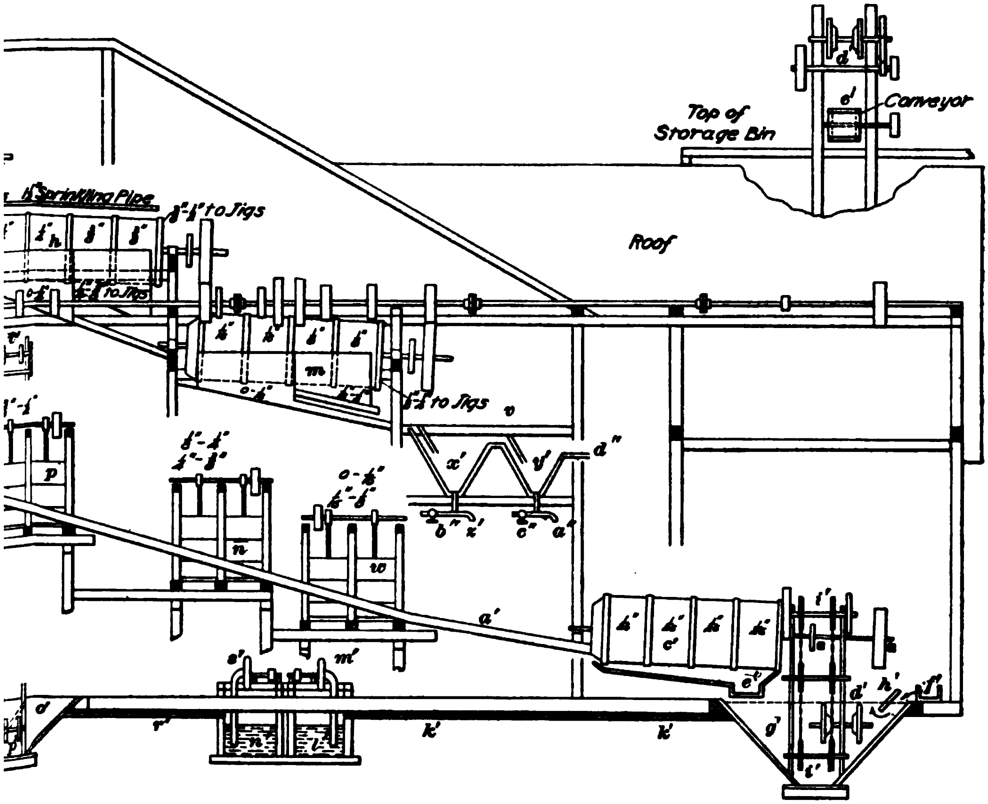


Fig. 25. Elevation of Coal-Wa



Side Elevation

(b)

Washing Plant at Coahuila, Mexico

RESULTS OF WASHING AT BROOKWOOD, ALABAMA

Date	Average Percentage of Ash in the Run-of-Mine Coal	Average Percentage of Ash in the Washed Coal	Percentage Reduction in Ash	Average Percentage of Ash in the Coke
December 21	15.32	8.15	46.9	10.10
December 23	14.10	7.50	46.9	9.50
December 31	15.07	6.50	56.8	
January 5	20.83	8.10	61.3	10.50
January 6	17.18	7.60	55.5	10.50
January 7	16.38	6.50	60.2	9.27
January 26	20.90	5.50	73.5	
January 27	17.37	5.40	69.0	
January 28	18.63	7.15	61.7	
February 13	21.12	4.81	77.5	6.10
February 14				7.40
February 17				7.80

The run-of-mine that is washed is a mixture of the No. 4 and No. 6 seams; that from No. 4 is finely interstratified with slate and contains an abundance of sulphur. There is a lack in sulphur determinations, but a casual examination of the washed slate and of the washed coal shows that it is removed almost entirely. The washer is the first of its kind in the United States, though not in America, as there is a 300-ton plant in successful operation at Ferrona, Pictou County, Nova Scotia; the New Glasgow Iron, Coal, and Railway Company operate it in connection with their blast furnace.

Mr. Stein writes that an addition will be made to the plant in the shape of a large elevator with automatic dumper for feeding coal from a storage bin; this will hold 250 tons of coal, and will enable the company to operate the washer to its fullest capacity during the day. Another perforated bucket elevator will also be added for removing the dust from the settling tank.

The sulphur has been reduced to .52, .54, and .53 per cent. from 1.65 per cent. of sulphur in the coal of one of the seams used in making coke, and 1.15 per cent. of sulphur in the coal of the other seam. This shows good work, with a very small loss of fine coal.

COAL-WASHING PLANT FOR BITUMINOUS COALS AT COAHUILA, MEXICO

I am indebted to Mr. Edgar G. Tuttle, E. M., for the following account of the Coahuila plant, which was first published in the School of Mines Quarterly, No. 4, Vol. XVII.

Fig. 25 (*a*) and (*b*) shows a coal-washing plant arranged for treating about 300 tons a day of 10 hours; the design embodies almost all of the requirements likely to be met with in coal washing.

The extent of sizing by screens and the washing are designed to treat a coal whose impurities separate with more difficulty than in the case of impurities as heavy as iron pyrites or heavy slates. For a simpler treatment, the plant can be considerably modified. The relative positions of the machines may require to be differently arranged under various circumstances connected with the location, and depending on the respective distances and directions at which the coal arrives at the plant and the point at which it is discharged. The main features of the plant can, however, be carried out to suit the above by making as many right breaks in the lines of machinery as may be necessary to bring the plant in the desired position and connect the points of receiving and delivery with its entering and terminating points. If, then, the position of any machine is such as not to permit of being driven by the main-line shafting, right-angle gears can be introduced to transmit power thereto.

In this plant, the screening is designed to be done wet; where the screening is done dry, greater fall throughout the line is necessary. Generally, where screening is done in the dry way, it is accomplished in one large revolving screen or a drum screen consisting of two or three concentric screens inside one another, each of a different mesh of perforated metal or wire cloth. Sometimes a shaking screen with several parallel screening surfaces, one above the other and each of different mesh, is used to produce as many sizes as desired. Where the screening is done dry, the jigs should be located more directly below the screen, or that part of the screen from which they receive the sized product.

The treatment of the coal in this plant is as follows: The coal received is that which usually passes through the screens in the chute at the mine tipple. This may be what falls through flat-bar screens spaced about 1½ inches apart, or through revolving or shaking screens of somewhat larger mesh. It is assumed that the coal sent to the washer will not be much larger than 3 inches at its greatest dimension, as all above this will be better hand-picked at the tipple and is not readily handled in the size of elevator buckets that are of sufficient capacity for the greater proportion of the sizes requiring treatment. The coal less than 3 inches in size is then either dumped into the pit *a* from the chute of the mine tipple, if it is located near enough to the washer plant, or it is unloaded into the pit from railroad cars. From here, the coal is lifted by the elevator *b* to the shaking screen *c*, which has an upper sheet steel screen with 1½-inch circular perforations and an under one of ¾-inch perforations. The coal is here separated into the following sizes and disposed of as indicated: All greater than 1½ inches passes over the screen and is delivered on the picking belt *d*. Coal passing through the 1½-inch screen and over the ¾-inch screen (size ¾ inch to 1½ inches) falls between the coarse rolls *e*, which reduce the coal to ¾ inch or less.

The coal passing through the ¾-inch perforations of the shaking screen (size 0 inch to ¾ inch) falls to the foot of the elevator *f*. This coal, with that from the rolls reduced to ¾ inch or less, is lifted by the elevator *f* to the revolving screen *g* at the head of a line of three screens, which are each 4 feet in diameter and about 11 feet long, and of the same construction except that they are covered with screens of different mesh. The screen *g* is divided into four sections in the direction of its length and each section is the same width; the first two are covered with sheet iron or steel with ½-inch circular perforations and the last two with screens of ¾-inch perforations.

The coal passing through the ½-inch screen openings (size 0 inch to ½ inch) falls to aprons below, which are on each side of the screen and slope into an inclined gutter directly below the screen, which leads this material (0 inch to ½ inch) into the screen *h*, with the water, which falls from a spray pipe over the length at the top of the screen to wash out particles becoming wedged in the holes and clear the coal from sticking to the sides of the screen. The water is sprayed similarly on all the screens, and falling through into the gutter, carries the coal passing through the perforations of one screen into the next screen.

The coal passing through the ¾-inch perforations (size ½ inch to ¾ inch) is spouted to the jigs *i*, *j*, *k*, and *l*, which are designed for treating coarse sizes and are provided with crank-arm or slide-yoke motion, so as to have a quick down stroke of the plunger and a slow return movement, and speeded to make about 60 strokes a minute of 3-inch to 4-inch throw, and if a middle product is to be treated the screens are arranged for drawing this off for retreatment.

If there has been any of the ¾-inch to 1½-inch coal from the shaking screen that has not been reduced to less than ¾ inch by the rolls, after this has been elevated and passed into the screen *g*, it will go over it and out at the end, and will be again fed to the rolls *e* for reduction, and will be then hoisted by the elevator *f* with the coal from the shaking screen, as already described. If the rolls *e* do not reduce this amount of coal sufficiently, it can be passed to the rolls *b′* for smaller crushing and treatment with other coal passing through these rolls.

If, however, the coal passing out of the screen *g* is not too large for washing and the impurities are sufficiently unlocked without further reduction, it may be cleaned completely by washing on jigs treating coarse sizes, or it may be sufficiently cleaned to be used for certain purposes that do not warrant its reduction to smaller sizes for what further improvement may be thus made possible. In this case the coal, as it passes out of the screen *g*, can be spouted to one or two of the first jigs treating coarse sizes, using for this purpose, say, jigs *j* and *k* (that is, for coal larger than ¾ inch), and jigs *i* and *l* for the sizes ½ inch to ¾ inch, or such proportion of these or other jigs as may be necessary for the quantity of these sizes produced.

Although a preliminary examination and test of the coal will determine the quantity of each size of the larger sizes of coal, and the number of jigs required to treat it, it is advisable, in designing the jigs and arranging them in the plant, to provide for possibilities of treating larger sizes on some of the jigs intended to treat smaller sizes, or the reverse. The points to be considered in this connection are: (1) Designing jigs so that the length of the stroke and the number per minute can be readily increased or diminished to suit the sizes treated. (2) Locating the jigs under the screens so that the material likely to be received from one or more points of the same can be readily spouted to the jigs with changes in sizes to be treated thereon. (3) Arranging the jigs so that the washed product and the refuse discharged therefrom can be readily delivered to the points desired, which may vary with the sizes produced on account of possible difference in the quality of different sizes. (4) In case a middle product results requiring treatment, the jigs should be arranged and handily located so that these can be drawn off and discharged to rolls for reduction, or else be handy to an elevator to lift this product to rolls intended for this purpose or for smaller crushing.

The 0-inch to ½-inch coal carried into screen *h* is separated into sizes as follows: Size 0 inch to ¼ inch is screened through the first two sections with ¼-inch holes, and is caught by the aprons and gutter below the screen and spouted into the screen *m*. The coal passing over the first two sections of screen *h* will be ¼ inch to ½ inch in size. This passes into the last two sections of screen *h* with ⅜-inch perforations, which separate it into two sizes, as follows: First, coal passing through the ⅜-inch holes (¼ inch to ⅜ inch), which is spouted to jigs *n* and *o*; second, coal passing over and out of the end of this screen (⅜ inch to ½ inch), which is spouted to jigs, *p*, *q*, *r*, and *s*.

The coal spouted from the gutter under the screen *h* into screen *m* (0 inch to ¼ inch) is separated as follows: The coal passing through the first two sections of this screen with 1/16-inch holes (size 0 inch to 1/16 inch), falls into the gutter below it, and if sufficiently pure, need not be treated, but can be spouted directly into the sluice boxes carrying washed coal from the jigs. If, however, it contains impurities and there is a considerable quantity of this size, it will require treatment. Generally, it will suffice to spout this coal into the jigs *t* and *u* arranged for treating this size and in the jigging thereof most of the overflow will be pure coal with possibly some light mud, which will subsequently pass off in the water overflowing from the settling tank where the fine coal will be treated for its deposition from suspension in the water from the jigs. If, however, the impurities separate with difficulty, this material 0 inch to 1/16 inch will be carried along in the gutter under the screen *m* to the hydraulic classifier *v* for treatment, as will be described.

The coal, $\frac{1}{16}$ inch to $\frac{1}{4}$ inch, passing into the last two sections of the screen *m* with $\frac{1}{8}$-inch holes, is separated as follows: That passing through the screen sections ($\frac{1}{16}$ inch to $\frac{1}{8}$ inch) is spouted to jigs *w* and *x*. The coal passing out of the end of this screen is sized $\frac{1}{8}$ inch to $\frac{1}{4}$ inch, and is spouted to jigs *y* and *z*.

The coal is spouted from screens to the jigs through troughs 6 inches square or so inside, lined with No. 12 or 14 sheet iron. Sometimes storage boxes are introduced below the screens to hold the sized screenings, and from these it is spouted to the jigs. They are, however, apt to clog up with wet screenings. A more satisfactory means of insuring a steady supply to the jigs is to arrange a regular feed to the elevator *b*, and to keep a sufficient supply of raw coal always on hand in the pit *a*.

The jigs *i*, *j*, *k*, and *l* are of one compartment about 3 feet square, and, as mentioned, are arranged to draw off a middle product, that is, material on the jig bed from a horizon between the top layer of washed coal and the bottom layers of slate. Impurities in the form of small particles closely adhering to the coal are most apt to occur among the larger sizes of coal; or, if consisting of particles of coal of an inferior quality, or of bony coal, intermediate in specific gravity between the lighter coal at the top of the bed and the slate or impurities on the bottom of the jig bed, they will occur in a layer midway between the two, whence they may be drawn off in jigs arranged for the purpose. The remaining jigs are of two compartments, each compartment being 24 inches by 32 inches. These jigs are speeded at 100 to 180 revolutions, or double strokes, per minute, and with throws of 2½ inches for the larger sizes to $\frac{1}{4}$ inch for the smallest sizes. If the impurities are with difficulty separated from the coal in the smaller sizes, it may be necessary to have three compartments instead of two in the jigs *w*, *t*, *u*, and *x*, so that the material will travel over a greater length of jig bed in being treated, thus allowing more time to effect the separation.

The coal after being washed passes out of the jigs at the overflow into the trough *a*, and is carried by the water from the jigs to the drainage screen *c'*, which is preferably covered with sheet copper of $\frac{1}{26}$-inch perforations, where the water is removed and all coal larger than $\frac{1}{26}$ inch passes over the screen and out at the end to the elevator *d'*, whence it is raised high enough for discharging either into bins or else to a point for loading.

Jigs may be used from which the water does not flow, and from which the coal is removed by elevators with perforated buckets, or if the coal overflows with water from the jigs, the water may be drained therefrom by passing over screens forming the overflow chute. In this case, there must be sufficient fall to cause flow if the coal is to be chuted dry from the jigs to the elevator *d'*, or the jigs may have less inclination or be located on the same level, provided that conveyers are introduced to convey all the coal from the jigs to the foot of the elevator *d'*.

Where coal is to be stored in bins of considerable extent a conveyer e', into which the coal from the elevator is delivered, is arranged at the top of the bins. The conveyer travels the length of the bins near their center lines, and is so designed that by means of openings in the bottom of the conveyer box, that can be opened or closed as desired, the discharge of the coal into the bin from any point thereof is effected, permitting of an even distribution of coal in the bin. The buckets of the elevator d' are perforated so as to drain as much of the water from the coal as possible. The water and coal less than $\frac{1}{26}$ inch in size, passing through the drainage screen c', fall upon an apron and into the gutter, from which they flow by the trough f' to the settling tank g'. The trough e' leads to one side of the settling tank, and, by means of small adjustable openings along the side of this trough, the discharge of the water with the fine particles of coal into the settling tank can be regulated so as to be evenly distributed, which is important to secure effective settling. The water and fine coal are discharged into the settling tank on one side of a partition h' that extends the length of the tank with its bottom 3 or 4 inches below the surface of the water; this causes the water flowing into the tank to move first in a downward current, and then across the tank, as an even, slowly moving body of water, toward the discharge side. Surface currents are thus prevented, which would otherwise occur and carry the material over the surfaces and out at the discharge without settling.

The settling tank is 12 feet wide, 32 feet long, and 4 or 5 feet deep at center, with sides sufficiently inclined that particles will not settle thereon.

The suspended coal of sand and slime sizes is thus settled, and, by means of a slowly moving drag i' with pedals or scrapers 4 feet apart, the settlings are moved gently along and finally scraped up an incline and out of the tank and dropped off at the end of the drag, which delivers the settlings at a point where they will fall and mix with the coal from the discharge end of the drainage screen c' and both be taken up by the elevator d'.

The water overflowing from the settling tank with what suspended matter it may still contain, which will be very small, overflows into the trough j'. It is important that this overflow be truly level so that the water from the settling tank will overflow in an even sheet, thus insuring a slowly moving current through the settling tank. From the overflow trough j' the water flows into the trough k' to the sump l', from which it is lifted by the centrifugal pump m' and delivered through pipes or launder boxes to screens and jigs treating the smaller sizes. Any overflow water from this sump passes to the sump n'.

The refuse, impurities, slate, etc. drawn off from the jigs, as well as the material settling through the sieves of the jig bed and released at the bottom or mud-discharge, are conveyed with the water escaping therefrom by the slate troughs to the pit *o′*. These troughs are more highly inclined for the large-sized slates to facilitate their movement to the pit *o′*. The slate troughs are best located on the floor near the base of the jigs or else below the floor line, with the flooring from all the jigs sloping thereto so as to drain off all water escaping or leaking from jigs, pipes, troughs, etc., and keep the floors clean. The slate troughs are usually made 4 inches to 6 inches square, lined with No. 12 or 14 sheet iron, curved at the bottom. The amount of water escaping with the refuse is comparatively small in comparsion to that flowing with the washed coal from the jigs. The pit *o′* need, therefore, not be very large. The one here shown is 8 feet square at top, with sides sloping about 50 degrees, and 3 to 3½ feet deep.

The refuse is removed from the pit *o′* by the elevator *p′* with perforated buckets to drain off the water taken up by them with the material. The refuse is discharged at the elevator head into the storage bin *q′* for removal by railroad or dump cars or otherwise.

If the location of the plant is on an elevation where there is considerable low land that can be filled, the refuse, escaping with water from the jigs treating the smaller sizes, can be carried in troughs with a grade of ½ or 1 foot fall per 100 feet to such points where the refuse can be disposed of to make fills. If there is sufficient fall, the refuse from the jigs treating coarser material can be likewise disposed of in troughs of steeper grade, viz., 2 per cent. to 4 per cent. fall. If there is only sufficient fall for disposing of the smaller-sized refuse as above, the heavier or larger-sized refuse may have to be removed by the elevator *p′* and disposed of as indicated.

The water, after the refuse has been settled therefrom into the pit *o′*, overflows into the trough *r′* and flows to the sump *n′*, from which it is lifted by the centrifugal pump *s′* and is delivered through pipes or water troughs to the jigs treating the coarse sizes and the rolls.

The middle product drawn off of jigs *i*, *j*, *k*, and *l* is spouted to the roll *b′* and reduced from ½ inch or ¾ inch to about ⅜ inch downwards, depending on how small it is found necessary to reduce the middle product to unlock the impurities. This material is then lifted by the elevator *t′* high enough to be discharged into the revolving screen *h* and there treated with the sizes of coal discharged into this screen from the screen *g*; this is the case if the middle product has been reduced to sizes small enough to be sized in the screen *h*. If it is not necessary to reduce all the middle products to sizes smaller than those treated in screen *g*, it is lifted by the elevator *t′* only high enough to be discharged into the elevator *f*, and from there it is handled the same as the other coal lifted by this elevator.

The coal that passes over the 1½-inch perforations of the shaking screen *c*, which will be from 1½ inches to 3 inches or so in size, is delivered on to the traveling picking band or belt *d*, where it is hand-picked by as many men or boys located along both sides of the belt as may be required to thoroughly clean the coal as it is conveyed toward the storage bin *u′*, where it is dumped for loading on railroad cars. This belt is 3 or 4 feet wide and about 40 feet long, and has a slow travel of about 30 feet a minute. It is composed of sections of wood or iron 3 inches to 6 inches wide by 3 feet or 4 feet long, whose ends are fastened to sprocket, or link, chains. The sections of wood or iron are either beveled, jointed, grooved, or hinged, so as to lay close to each other and form a flexible band readily curving around the sprocket wheels of the driving gear. If these sections are of iron they generally lap each other where their sides come in contact and form a sort of hinge joint.

If the coal treated on the picking band is of large sizes requiring sledging and slabbing, so that it is broken up in cleaning and considerable small coal results, the sections or slats of the picking band are sometimes slightly separated from each other so as to act somewhat like a screen and allow the small coal produced to fall through and thus separate it from the large lumps in loading. The impurities picked from the coal traveling on the band, which may contain more or less coal, are dropped into chutes leading to the pit *v′* or else are thrown into this pit, and from there are lifted by the elevator *w′* back to the washer building and high enough to be discharged on the rolls *e* for reduction and delivery to the elevator *f* for the usual treatment in the plant.

If there is much refuse picked from the lump coal at the mine tipple and it has considerable good coal adhering to it, it can be broken by sledging, or a special crusher may be erected for reducing it, after which it is discharged into the pit *v′* and lifted by its elevator for treatment in the plant with other coal from the pit. If this waste removed at the mine tipple is not too large and the tipple is near the washer plant, it may be chuted directly to the rolls *e*. If the tipple is located at some distance and this refuse is to be treated, it will be necessary to take it there by railroad cars, dump cars, or a conveyer, if the distance is not too great. If the amount of coal requiring hand picking is large, it may be necessary to introduce two picking belts. This is generally preferable to increasing the length of the belt with increased quantity to be treated. The maximum length for a picking belt should be 30 to 50 feet.

If the impurities in the sizes ¾ inch to 1½ inches, separated on the shaking screen, do not adhere to the coal and are readily hand-picked, they need not be reduced in the rolls, as mentioned, but can be discharged into a second picking belt that may be introduced for treating these sizes as explained for the 1½-inch to 3-inch sizes. They may be delivered into bins, if they are to be loaded for shipment, or the picking belt on which they are treated may have such a direction of travel as to finally discharge them at the foot of elevator *d′* for removal with the other coal hoisted by this elevator. Or, if the impurities are in considerable quantity in the ¾-inch to 1½-inch sizes, they may be removed by washing, if they do not adhere to the coal, so as to require crushing to liberate them. This size may then be dropped from the shaking screen with the 0-inch to ¾-inch size and hoisted with it by the elevator *f* to the screen *g* without first passing through the rolls *e*. In this case, this sized coal will, as previously explained, pass over the screen *g* and out at the end, sized ¾ inch to 1½ inches, and fall into the two jigs *j* and *k*, or others that may be required for treating it.

The hydraulic classifier *v* consists of a box of two or more compartments, 2 feet or more in width, and of such length as is determined by the number of classes of sizes it is intended to produce. The sides are sloping to insure proper discharge of the materials settled therein from the bottom, which is fitted sometimes with piping, as will be described. A partition extending 2 inches or 4 inches into the water of the classifier extends across its width so as to deflect the inflow of water and direct its current downwards, thus preventing surface currents.

The treatment of 0-inch to $\frac{1}{16}$-inch size flowing from the gutter under screen *m* to the classifier is as follows: With the diminution of the velocity of the current of water flowing from the narrow channel of the gutter into the wider channel of the classifier, there will be deposited in the first compartment *x′* of the apparatus, such smaller sizes of the heavy impurities and such larger sizes of the lighter coal as are equally settling. Likewise in the second compartment *y′*, there will be a settling of relatively smaller sizes. It will depend considerably on the nature of the impurities and coal in these smaller sizes as to what the treatment will be.

The ideal method of treating material classified as above is to submit it to treatment with water on machines of the type of the inclined table, or shaking or bumping tables, where the larger, specifically lighter particles of coal will be moved farther down the plane by the water than the smaller, specifically heavier particles of slate or impurities. In coal washing, however, the cost of this treatment is too great and the small-sized material is usually in too small a quantity and of insufficient value to warrant the expense of the treatment, or the coal may be sufficiently rich not to require treatment.

The trough washer is a machine nearest approaching the types above mentioned that it is advisable to incur the expense of, although the treatment of the coal therein is not perfect. This is used for sizes up to 1½ inches or so in rough washing, but is better adapted for the smaller sands and slime sizes or the products of the hydraulic classifier in question.

The trough washer consists of a trough inclined 1 foot in 12, from 40 to 60 feet long and 1 or 2 feet wide at bottom; sides sloping from 50° to 60°. In this, a scraper chain works, with a scraper 4 inches to 6 inches deep and 6 feet apart, closely fitting the bottom of the trough and moving slowly up the incline. The fine coal is fed into the trough midway between the two ends and 60 to 150 gallons of water a minute are fed into the trough at the upper end. The action of the water is to wash the coal down the trough and over the tops of the scrapers, while the heavier impurities settle to the bottom and are moved up the trough by the scrapers and discharged over the top. The coal discharged at the lower end of the trough with the water is drained over a screen and the water thus separated and reused, but preferably it can be discharged into the settling tank f' and there removed by the drag where this fine coal can be handled and used better when mixed with coarser coal.

Generally, however, a separation of the impurities from the classified products of the two compartments of the hydraulic classifier that will be sufficiently satisfactory where the quantities are small can be effected by allowing the settlings from the compartment x' to pass out of the spigot z' to the jig x, and those from y' flowing from the spigot a'' to pass to the jig u, where, in rapid jigging, somewhat of a separation is effected if the strokes of the jig last only during the period of accelerated velocity of fall of the particles. In this case, the larger lighter-weight particles of coal require a longer time before arriving at their maximum velocity of uniform motion than the smaller heavier particles of impurities. With strokes of the jig applied to last for $\frac{1}{8}$ or $\frac{1}{12}$ second or so, particles of coal and slate that are equally settling in the classifier may be separated to some extent on the jigs, the coal being maintained at the top of the bed and the slate settling to the bottom as usual.

If there is only a slight difference between the specific gravity of the coal and slate, it may be advisable to make the smallest size treated on the jigs from the screens $\frac{1}{25}$ inch or $\frac{1}{32}$ inch; in this case, the $\frac{1}{16}$-inch screen should be replaced by a $\frac{1}{25}$-inch or $\frac{1}{32}$-inch copper screen of perforated metal or wire cloth. In this case, the largest size treated by the classifier will be $\frac{1}{25}$ inch or $\frac{1}{32}$ inch. The use of small screens should be avoided, however, if possible, as their life is short and the value of the material rarely warrants the expense.

The classifier is arranged so that the discharge can be made continuous from the bottom by the spigots z' and a'' for drawing off the particles and what water escapes therewith. The velocity of the water traveling across the classifier from the receiving to the discharge end can be reduced according to the amount of water fed into the classifier and the amount drawn off at the bottom flow.

If it is found necessary to prevent a settling of too small sizes in the first or second compartment of the classifier and at the same time effect somewhat of a separation, an inflow of clear water can be arranged, which is admitted by the pipes at the bottom and regulated by the valves b'' and c''. This inflow is through pipes of larger area than the outflow through the spigots z' and a'', and the velocity of the inflow is not so great but that it will allow the particles of the sizes desired to settle down through its current and escape by the spigots z' and a''. This ascending current may have to be varied from $\frac{4}{10}$ inch to 3 inches a second, so that an inlet pipe of 1½ inches, 2 inches, or 3 inches may be necessary; the larger the better to provide for increasing or decreasing the sizes of the classified product desired.

A separation of the limits of sizes desired can be thus effected by maintaining just sufficient upward current so that the smaller sizes will not be permitted to settle, but the larger ones will be allowed to fall through the current and be discharged by the spigots z' and a'', which can be plugged with reducers to ¼ inch or ¾ inch, as may be required to regulate the outflow, which will depend on the rapidity with which the larger sizes accumulate. By testing the products under various flows of inlet and discharge currents, it will be determined what conditions can be produced and according to which the product can be best treated.

It may occur that the discharges from z' and a'', under an upward current, are entirely impurities and the overflow at d'' is entirely pure coal, in which case the coal can be run directly in with other washed coal to the settling tank. If this should contain much mud or small thin disks or plates of impurities, it may be possible to have these pass off as suspended matter in the overflow from the settling tank. If, however, the tendency of this form of impurities is to settle in the settling tank, they may be separated in the classifier by regulating the flow of water so that they will be carried out over the overflow thereof.

If the light-weight impurities can be thus disposed of, and if it is possible to regulate the lower inflow so as to have the heavier impurities only discharged from the spigots z' and a'', the coal may be separated therefrom and maintained in the classifier midway between the bottom discharges and the overflow.

In this case, there should be two sets of hydraulic classifiers, so that the current of water from the gutter under the last screen can be turned to a second classifier when the first has become filled. The first can then be cleaned by allowing the impurities to discharge at the spigots until the coal begins to flow. Then the washed coal can be spouted to the washed-coal trough or to the settling tank. When the classifier is emptied, it will be ready for use when the second classifier has become filled.

If the impurities are all light weight, they may be separated from the coal by adjusting the amount of the bottom discharge, or, if necessary, of the inlet current to such a point that the coal will be discharged from the bottom, while the impurities pass to the overflow d''.

SPEEDING AND GEARING OF MACHINES

	Size of Pulley on Main-Line Shaft 125 R. P. M. Inches	Pulley (1) on Machine		Pinion (2) on same Shaft as Pulley (1)		Spur (3) Driven by Pinion (2)			Machine	
		Size Inches	R. P. M.	Width Inches	Diam: Inches	Width Inches	Diam. Inches	R. P. M.	Diameter Inches	Traveling Speed Per Minute
Rolls....................	10×52	10×48	133.00	4	8	4	36	30.00	Rolls, 19½	155.0 feet
Large elevators (*b*, *f*, *d'*)...	8×28	8×34	103.00	4	5¼	4	36½	14.90	Sprocket, 30	115.0 feet
Small elevators...........	6×18	6×24	93.70	2	6	2	24	23.40	Sprocket, 18	109.0 feet
Revolving screen..........	8×34	8×48	88.00	2	6	2	24	22.00	Screen, 48	272.0 feet
Picking belt.............	6×9	6×36	31.25	4	6	4	36	5.20	Sprocket, 24	32.2 feet
Drag....................	6×6	6×36	21.00	2	6	2	24	5.20	Sprocket, 24	32.2 feet
Centrifugal pump	6×36	6×6	750.00							4-in. stroke
Shaking screen...........	8×24	8×30	100.00							
Crank-arm jig............	4×9	4×18	60.00							4-in. stroke
Conveyer *e'*.............	{ 6×18 103 R. P. M. }	6×24	77.25	2	6	2	24	19.25	Sprocket, 24	121.0 feet

In all these adjustments to regulate the amount of water admitted to the classifier, or to form an upward current, or of the amount allowed to discharge, the resulting current in compartment *y′* should be somewhat diminished from what it is in compartment *x′*, in order to allow a settling of the particles in compartment *y′*, which are smaller than those settling in compartment *x′*. If the particles treated are very small and very light weight, it is advisable to make the compartment *y′* wider than compartment *x′* to insure a diminution of the velocity of current necessary.

WATER REQUIRED IN PLANT

	Clear Water	Cubic Feet	Cubic Feet
4 Revolving screens	1 cubic foot a minute =	4.0	
2 Rolls	1 cubic foot a minute =	2.0	
4 Jigs (sand and slime sizes)	4 cubic feet a minute =	16.0	
Classifier	2 cubic feet a minute =	2.0	
	Total raised 45 feet = 180 gallons =	24.0	24.0
	Reused Water	Cubic Feet	
2 Jigs, 1/8 to 1/4 sizes	4 cubic feet a minute =	8.0	
2 Jigs, 1/4 to 3/8 sizes	5 cubic feet a minute =	10.0	
4 Jigs, 3/8 to 1/2 sizes	5 cubic feet a minute =	20.0	
4 Jigs, 1/2 to 3/4 sizes	6 cubic feet a minute =	24.0	
	Total raised 24 feet = 465 gallons =	62.0	62.0
	Total fresh and muddy water = 645 gal. =		86.0

HORSEPOWER REQUIRED

For Jigs

Number of Jigs	Size Treated	Horsepower Per Jig	Total Horsepower	Horsepower
2	0 to 1/16	1	2.0	
2	1/16 to 1/8	1	2.0	
2	1/8 to 1/4	1¼	2.5	
2	1/4 to 3/8	1¼	2.5	
4	3/8 to 1/2	1¼	5.0	
4	1/2 to 3/4	1½	6.0	
	Total		20.0	20.0

1 Shaking screen		2.5
1 Coarse rolls		8.0
1 Fine rolls		3.0
1 Picking belt		2.0
2 Revolving screens, 4 feet diameter, 11 feet long	2.5	5.0
2 Revolving screens, 4 feet diameter, 11 feet long	1.5	3.0
1 Drag for settling tank		1.5
1 Centrifugal pump, 180 gallons, 45 feet, 3-inch suction, 2-inch discharge		4.5
1 Centrifugal pump, 645 gallons, 24 feet, 5-inch suction, 4-inch discharge		7.5
1 Conveyer		2.0
1 Elevator, 400 tons, 10 hours, 42-foot lift		2.5

1 Elevator, 300 tons, 10 hours, 40-foot lift	2.0
1 Elevator, 300 tons, 10 hours, 60-foot lift	2.4
1 Small elevator, 60 tons, 10 hours, 36-foot lift (middle product)	1.0
1 Small elevator, 60 tons, 10 hours, 26-foot lift (refuse)	1.0
1 Small elevator, 60 tons, 10 hours, 30-foot lift (pickings)	1.0
Total horsepower	68.9
Add 15 per cent. for friction	10.0
Total	78.9

About an 85-horsepower engine and a 100-horsepower boiler will therefore be required.

Crushing Rolls.—The coarse rolls are 18 inches wide and 19½ inches in diameter and corrugated horizontally. They make 30 revolutions per minute, or have a tangential speed of about 155 feet, and break about 30 tons to ½-inch size or 70 tons to 1-inch size in 10 hours. If a greater amount of the larger size is to be reduced than above, either larger rolls or two of the above size are necessary. If the coal sticks to the rolls, as it will if clayey slate is present, it is preferable to use tooth rolls; or these should be used if the coal is very friable and apt to become reduced to too small sizes. Toothed rolls have a somewhat higher speed at the periphery, generally about 400 to 800 feet a minute. One of the rolls of a pair is in a movable box connected with rods to steel or rubber springs, so as to allow the rolls to yield in case of hard pieces of iron, etc. getting between the rolls that would otherwise break them. A spray of water is fed into the top of the rolls to keep them clear of adhering particles. Steel brushes are also arranged back of the rolls to scrape against them and remove particles becoming wedged between the corrugations or teeth.

The fine crushing rolls need be only about 14 inches in diameter and 12 inches wide, but it is preferable to have them as large as the coarse rolls, in the event of it being desired to change the grading of the crushing throughout the plant.

Revolving Sizing Screens.—These are 4 feet in diameter and about 11 feet long. The surface of the screen is divided into four sections by five spiders, keyed or setscrewed to a $2\frac{15}{16}$-inch shaft. Each section is covered with perforated sheet metal, requiring four sheets 32 inches by 39 inches to cover each section.

The screens have a slope of 8 inches to 12 inches in their entire length; the shaft being laid inclined. The sections of sheet metal may be either riveted or fastened by bands to the spiders, the latter method being preferable for despatch in case of repairs.

Conical screens may be used, in which case the shaft is laid level, the slope of the sides being sufficient to assist the passing of the material through it. The shape of the screen sections in this case may give more trouble in case of repairs than with cylindrical screens. The speed of screens is about 22 revolutions per minute, or the peripheral speed will be about 270 feet a minute.

The screens are sprinkled by a spray of water from a 1½-inch pipe located above the screens and having ⅛-inch holes every inch or so on the under side of the pipe.

CAPACITY OF REVOLVING SCREENS

Size of Screen Perforation Inches	Number of Square Feet of Screening Surface Required Per ton in 10 Hours
1½ to 2	.32
1 to 1½	.43
¾ to 1	.72
⅜ to ¾	3.70
⅛ to ⅜	5.40
0 to ⅛	18.00

The above capacity is variable, depending on the amount of other sizes mixed with the sizes to be screened. Shaking or flat screens have greater capacity than revolving screens and are preferable where they are not to be erected too high on the structure, where they cause jarring to the building.

Elevators.—Large elevators are best arranged when buckets are mounted on double chain formed of 12-inch or 15-inch links connected with rods into which the links on either side of the elevator buckets are bolted. The buckets are bolted to two straps hinged from one rod to the other. The elevator frame is constructed of wood with guides on either side, which may be covered with strap iron on which the elevator rods slide in the upward movement of the elevator, or the guides may have angle-iron sliding pieces, in which case the links slide therein and are guided by them. The sides of elevator buckets should be of No. 14 Otis steel and the front of No. 12 steel, with ribs at the top, front, and sides. Their shape should be somewhat rounded at the bottom to prevent material becoming wedged therein, but not too rounded, or where they discharge at the elevator head, the material may fall on the back of the bucket below it and inside of the elevator frame.

The elevators should be as far from the vertical as possible for the most perfect discharge at the elevator head, otherwise it may be necessary to introduce special devices for perfecting the discharge. The usual travel for an elevator is about 100 to 150 feet a minute, although where they are vertical or nearly so a speed of 200 or 225 feet a minute may be necessary to insure proper discharge. The slower the speed, the less the wear is on the elevator.

Small elevators may be mounted on small sprocket-chain, or link, belting with small cast- or malleable-iron buckets; their speed may be 150 to 200 feet a minute or less. The chains supporting the elevators may be operated by sprocket wheels or hexagonal or octagonal drums driven by a pulley with gearing. Either the upper or lower set of sprocket wheels or drums should be in an adjustable boxing, which will permit of moving the bearing of the sprockets by screws so as to tighten up the elevator chain as it becomes worn.

Jigs are preferably built of wood as they require less expensive foundations, and although requiring more frequent repairs than iron jigs they are moderate in first cost, and wearing parts in iron jigs being more expensively replaced than in wooden jigs, the cost of repairs in the end is not much greater in wooden than in iron jigs. Jigs treating large sizes have one compartment about 3 feet square and the stroke is given by a crank-arm movement making sixty 3-inch or 4-inch strokes per minute. The depth of the jig frame should be about 10 inches, at least, below the overflow. The jig frame may consist of an iron-bar grating or of copper cloth or perforated metal of about 8 mesh. The discharge for the lower product should be as automatic as possible and should preferably extend across the width of the bed. The coarse jigs should be arranged for treating the middle product, and the discharge should also be constructed as above.

Fine jigs should have two compartments; it is rare that three are necessary. Each compartment is about 24 inches wide and 32 inches long. These are provided with double adjustable eccentrics so that the length of the stroke can be varied as desired. The plungers make 100 to 180 strokes per minute of 2½-inch to ¼-inch throw each. The depth of the jig frame at the final overflow should be about 7 inches below it.

It is also desirable that the discharge for the lower product or slate should be automatic and arranged across the width of the jig beds, especially for the larger sizes, although the refuse in this size material can be readily withdrawn by a small slate box 3 inches or 4 inches square, located at either side of the jig, and the slate tapped at about 2 inches above the level of the jig frame. The jig frame is of wood, built of ½″ × 2½″ slats with about 2½-inch square openings. The width and length of the frame are about ½ inch less each way than the space they occupy in the jig.

Side-plunger jigs are preferable to facilitate repairs, although there is more lost motion in these than in jigs with under pistons or jigs in which the jigging is done on a movable bed. To facilitate determinations of speeding jigs it is preferable to have the plungers and the jig beds of the same area. The bottoms of the jigs should all be steeply sloping to one or more mud-discharges, and the slope sufficiently steep and the mud-valve regularly opened to prevent material clogging up the jig bottoms.

The jigs treating material from ⅜ inch downwards have sometimes a bed of feldspar through which the jigging is done. The feldspar is of such size that the particles of coal and impurities will not fall through its interstices. The mesh of the jig sieve need then only be large enough to support the feldspar.

An average estimate of the capacity of jigs is 1 ton for each inch in width per 10 hours. This is independent of the length of the jig. A safe, low estimate to provide against irregularities in the supply of coal is as follows:

CAPACITY OF JIGS

Sizes Treated by Jigs Inch	Capacity in 10 Hours Per Inch in Width Tons	Width of Jig Inches	Capacity in 10 Hours Tons
0 to 1/16	.30	24	7
1/16 to 1/8	.41	24	10
1/8 to 1/4	.60	24	14
1/4 to 3/8	.84	24	20
3/8 to 1/2	1.00	24	24
1/2 to 3/4	.83 to 1.20	36	30 to 43

SPEED AND STROKE OF JIGS FOR DIFFERENT SIZES

Size of Coal Inches	Revolutions of Jig per Minute	Length of Stroke Inches	Mesh of Wire Cloth of Jig Sieve Inches	Pulley on Jig Inches	Driving Pulley on Main Shaft Inches
2 to 3	50 to 60	5¼	1¼		
1½ to 2	50 to 60	4 to 5	1		
1 to 1½	60 to 90	3 to 4	½ to ⅞		
¾ to 1¼	100	2 to 3	6 × 6	20	16 to 18
½ to ¾	110	2¼	8 × 8	20	18
¼ to ⅜	120	2	10 × 10	20	20
⅛ to ¼	130	1½	10 × 10	20	22
1/16 to ⅛	140	⅝ to 1	16 × 16	20	24
1/30 to 1/16	150	⅜ to ¾	20 × 20	20	24
0 to 1/30	180	¼	30 × 30	20	28

Picking Bands or Belts.—These are generally 4 feet wide and travel at a speed of 30 to 60 feet a minute. For sizes from 1½ inches up, and in quantities of 30 tons per hour, belts should be 15 feet long plus 10 feet more in length for each 3 per cent. of material picked out.

For sizes from ¾ inch to 1½ inches, the belt should travel at the rate of 30 feet a minute; and for every 20 tons an hour, 15 feet length of belt is required for each 1½ per cent. of material picked out.

If these sizes contain more than 4 or 6 per cent. of impurities, it is generally preferable to treat them by washing.

Drainage Screen.—This is covered with No. 10 sheet metal, preferably copper, to avoid rapid wear, which will occur with thin sheet iron or steel if water is acid. This screen is geared the same as the other revolving screens.

Settling-Tank Drag.—This is arranged with wooden pedals about 2 inches thick, 4 inches to 6 inches deep and 2 or 3 feet long, attached to lugs on 6-inch links every 4 feet, and geared, as shown, to move slowly in the bottom of the tank and not rile up the settlings too much. The bottom and sides of these pedals have pieces of rubber or leather fastened to them, so as to keep closely in contact with the bottom of the tank along its bottom and when mounting the incline.

Shafting.—The main shafting is $2\frac{15}{16}$ inches in diameter driven at 125 revolutions per minute. It is desirable, if possible, to avoid any shafting at right angles to the main lines of shafting that will require transmission of power by bevel gears, although this cannot always be avoided.

Engine.—About an 85-horsepower engine will be required for the size of plant shown, to have a safe allowance of power. This should be mounted with a 10-inch shaft and a 16″ × 52″ driving pulley. The engine should be located as near the machinery as possible and thus reduce strain on the shafting.

Boilers.—About a 100-horsepower boiler, or two boilers of 50 horsepower each, should be provided for furnishing the power required, with a safe reserve of power. The boiler should be located handy to a point where the coal is dumped for receiving its supply. This may be near either where the raw coal or the washed coal can be had.

Location of Plant.—The arrangement of the plant can be carried out if the location is on level ground or on a hillside. Unless the material arrives at the plant from a higher elevation there is no preference in one location over the other. A hillside location permits of attaining the proper grades for lines of screens, jigs, and other machinery nearer the natural ground. It may not be necessary to support as much of the machinery in the building as on a level location, nor require as many elevators, but the building will be longer, and the increased number of floors requiring more labor for proper attention to machinery does not make a hillside location more preferable, whether its first cost is more or less, than a level location. It is important that the floor of the building and bottom of the pits be located above the general level of the ground so that they can be readily drained when desired.

Construction of Building.—Generally a frame building on stone foundations will answer all purposes, especially if there is no danger in case of fire or if the screening is done wet, and heavy machinery is not supported high in the building. In case of fire, or if the expense is warranted, an iron-frame building covered with corrugated iron is preferable. If there is much heavy machinery supported in the structure, the walls up to that height should be of stone or brick and the balance of wood or iron. It is essential that the location of the machinery and especially the jigs be such that the building can be constructed to allow light to fall on them. For this purpose the jigs and such machinery should be located near the outer walls of the building, which will have windows in the sides, or if the jigs are located inside, no machinery should be above them that will prevent the access of light thereto from windows in the roof.

COST OF PLANT

Excavation, 500 cubic yards at 20 cents	$ 100
Foundations, stonework, building 150 cubic yards at $1.50	225
Stonework of washer machinery and pits, 70 cubic yards at $2.00	140
Boiler and engine foundation and walls	500
Washer building, lumber, 80,000 feet B. M. at $10.00	800
Other finishing lumber, doors, and windows	300
Carpenter work	1,200
Iron work	300
Coal-washing machinery	10,000
Erecting (machinist labor)	1,200
Freight, teaming	800
Total	$15,565

The cost of the plant will vary considerably according to location and distance from source of supplies. The above will be the cost where material, machinery, and labor can be conveniently obtained. Present cost of this plant in the United States would range from $25,000 to $30,000.

COST OF WASHING PER TON, ON BASIS OF DAILY OUTPUT OF 300 TONS

		Cost per Ton
Labor washing		
1 foreman at $3.00	$3.00	
3 jigmen at $1.50	4.50	
2 feeders at $1.00	2.00	
1 oiler at $0.75	.75	
1 engineer and fireman at $2.00	2.00	
	$12.25÷300	= .040
Slate picking		
6 slate pickers at $1.00	$ 6.00÷300	= .020
Fuel, water, daily	4.00÷300	= .013
Oil, supplies, etc	2.00÷300	= .006
Maintenance and repairs, etc. to jigs, jig sieves, screens	1,200.00 yearly	= .010
Emergencies, renewals, and repairs to other machinery	900.00 yearly	= .015
Total cost of washing per ton		= .104

Improvement of Coal Effected by Washing.—The extent to which coal can be improved by washing will depend on the nature of the coal, the shape of its particles, the relative specific gravity of the coal and its impurities, and whether there are also present impurities of intermediate specific gravity, as bony and slaty coal. In treating a Southwestern coal of the Laramie group of the

Upper Cretaceous formation in a plant similar to the above, the results obtained were as follows:

The plant referred to contains some important additions for handling of the large coal, intermediate products and treatment and settling of the fines, as well as other improvements. The treatment in sizing and washing, however, is similar. Some of the very purest coal, which was in small quantity and friable, analyzed as shown in No. 1, its ash representing combined or fixed ash which could not be removed by any process.

No. 2 represents an analysis of selected lumps with no visible impurities adhering to them.

ANALYSES OF COAL

	No. 1 Per Cent.	No. 2 Per Cent.
Moisture		.39
Volatile combustible matter	20.35	19.75
Fixed carbon	79.30	64.36
Ash	8.35	14.65
Sulphur		.85

The analysis of ash is as follows:

	Per Cent.		Per Cent.
Silica	7.30	Lime	.83
Iron	1.01	Alumina	5.10

The specific gravity of the lightest-weight coal was 1.39; of bony and slaty coal 1.5 to 1.9; of slate and other impurities 1.8 to 2.3. There were also associated thin flakes of spar, lime, and slates. The material used for washing was screenings passing through a 1½-inch bar screen, whose analysis, as well as that of the resulting products, is shown below, when the washer was not overcrowded.

ANALYSES OF COAL, WASHED COAL, COKE, AND REFUSE

	Moisture Per Cent.	Volatile Combustible Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
Raw screenings	1.40	19.79	60.25	17.33	.85	
Washed coal	.79	19.10	69.35	10.24	.52	
Coke	.43	1.39	83.47	14.24	.82	.019
Refuse from waste box	2.22	15.76	30.96	50.12	.93	

The ash in the screenings was reduced in washing from 17.33 per cent. to 10.24 per cent. The inherent ash in the purest coal being

8.35 per cent. and somewhat higher in the average coal; the washing, therefore, reduced the ash to within 1.89 per cent. or less of the combined·ash.

The yield of washed coal from raw coal was 85 per cent., or 15 per cent. of the material was removed as impurities from the raw coal, which consisted of slate and some of the poorer quality of coal, as bony and slaty coal. The washed coal was used for coke. The yield of coke from washed coal was 70 per cent., or the yield of coke from raw coal was 59½ per cent., and contained 14.24 per cent. of ash with close washing. In other words, 4½ gross tons of raw coal, when washed, yielded 3.82 tons of coal, which was charged in a beehive coke oven 6½ feet high and 12 feet in diameter, and burned 48 hours, yielding 2.67 tons of coke.

Prior to washing, the raw screening yielded 66 to 70 per cent. of coke, much being lost as coke ashes and containing 20 to 22 per cent. of ash.

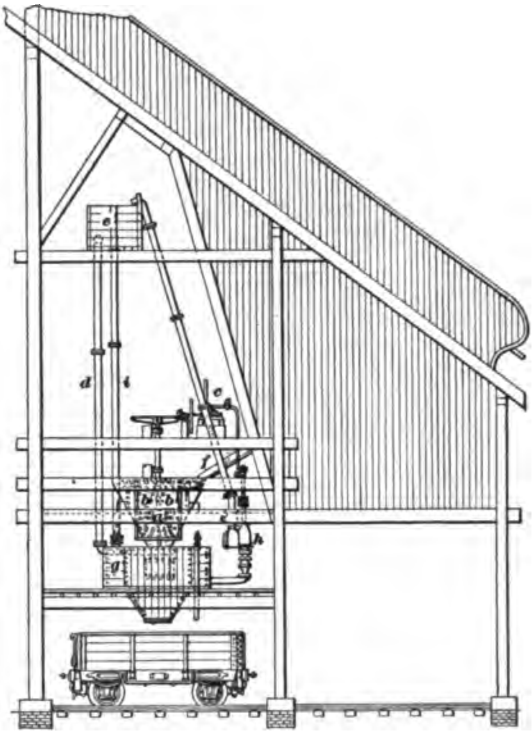


Fig. 26. Robinson Washer

ROBINSON COAL-WASHER PLANT

The **Robinson coal-washing machine,** Fig. 26, consists of a wrought-iron receptacle, the shape of an inverted cone *a*, surrounded by a jacket at the bottom, communication being made by a number of perforations by which water at considerable pressure is admitted into the cone. A vertical shaft having keyed on it four revolving arms, or agitators, *b* occupies the higher parts and sides of the cone; this part of the machine is kept in motion by a small engine of, say, 10 inches diameter, cylinder fixed at *c*. The water supply *d* from the cistern *e* to the cone through the water chamber is regulated by a valve. A supply of coal is admitted from the small-coal apparatus down the slide, or spout, *f* into the open top of the cone filled with water, the revolving or stirring motion being kept up by the agitators, and the upward flow of water being continuous; the result is that the stone and rubbish from the coal fall into a chamber. At this point, two slides connected to necessary levers are inserted, the bottom one being closed and the top one opened during the operation of washing. To discharge the rubbish, it is only necessary to shut the top slide and open the bottom and the rubbish falls into a truck below. The clean coal at the top passes down a sieve into a hopper *g* and thence into another truck below, beside the rubbish track, at will. Immediately below the sieve mentioned is fixed a collecting tank into which the water is drained from the washed coal and forced by means of a pulsometer *h* into the supply cistern *e*. An overflow pipe *i* is arranged between these two cisterns to prevent waste of water in case of the pulsometer filling the top cistern *e*.

It is estimated that the cost of all machinery complete, for a washer cleaning 300 tons of coal per day, will not exceed $2,500. To this must be added the cost of erection and the timber work, say $1,500, making in all $4,000.

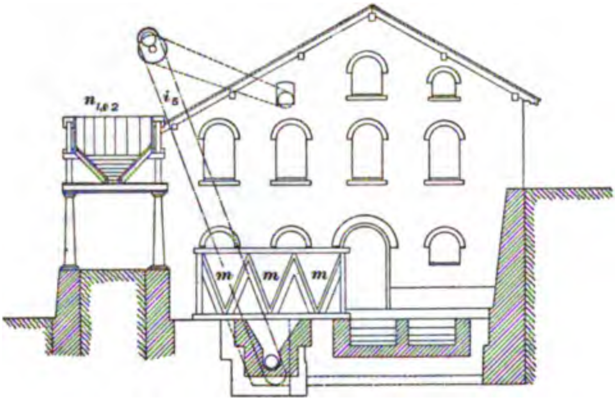
The following analyses are submitted to show its work in coal washing:

1910

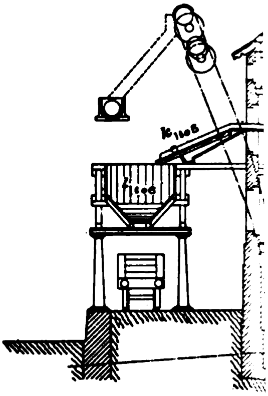
RESULTS OF WASHING WITH ROBINSON WASHER

Plant		Ash Per Cent.	Sulphur Per Cent.
Black Boy	Unwashed	11.20	2.03
	Washed	3.84	1.46
Auckland Park	Unwashed	9.35	1.18
	Washed	4.60	.86
	Unwashed	5.95	1.08
	Washed	3.60	1.00
Westerton	Unwashed	10.10	1.61
	Washed	5.70	1.18
West Auckland	Unwashed	15.40	1.14
	Washed	3.70	.76
St. Helen's	Unwashed	11.10	1.92
	Washed	2.82	1.16
New Copley Dusty Coal	Unwashed	11.28	1.50
	Washed	3.83	.84
New Copley Coarse-small	Unwashed	14.75	1.61
	Washed	2.74	.78

In kindly furnishing the foregoing information in regard to this coal-washing machine, Mr. H. S. Chamberlain, President of Roane Iron Company, of Chattanooga, Tennessee, writes: "I came across this machine in 1890 while on a trip in the north of England and



Section KL



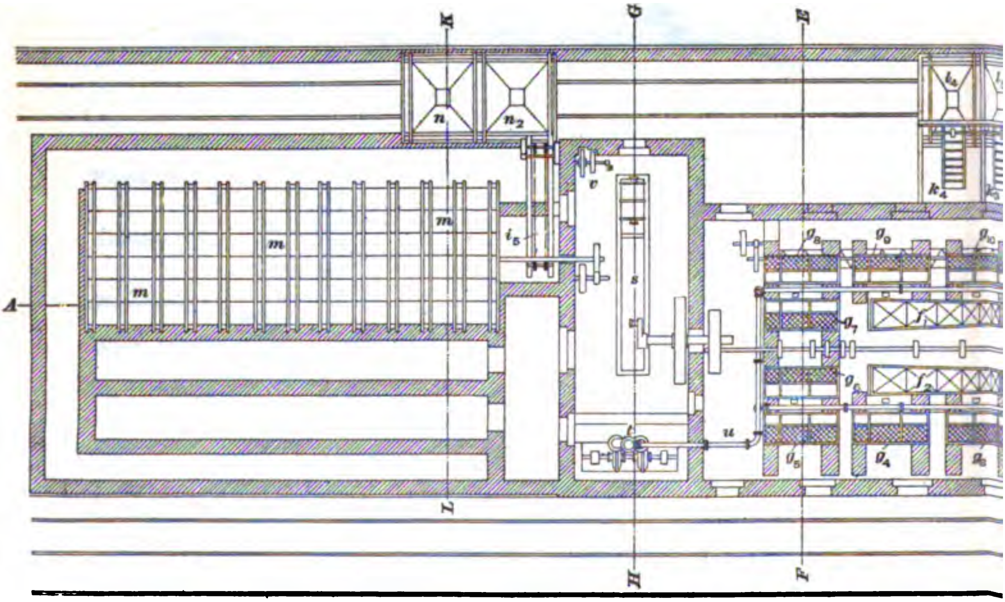
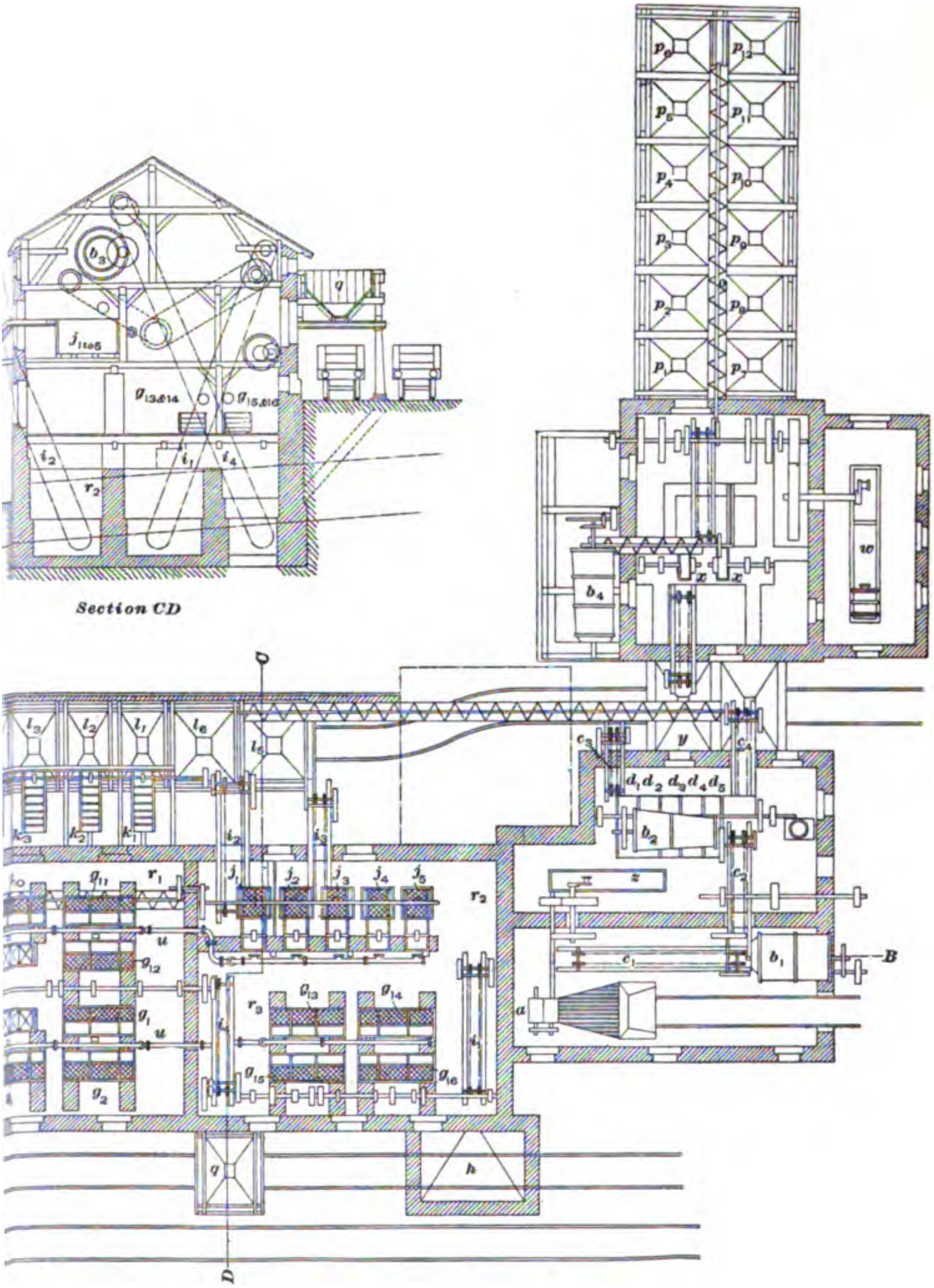


Fig. 27. Plan of Lührig Washer



ER PLANT AT DOWLAIS, WALES

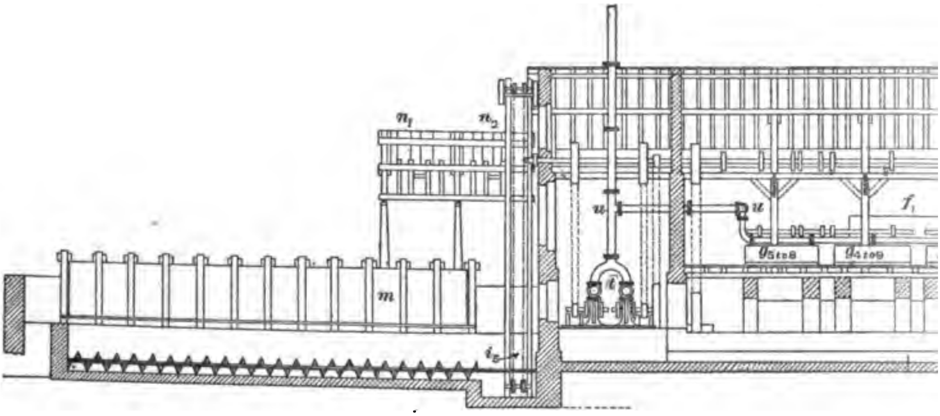
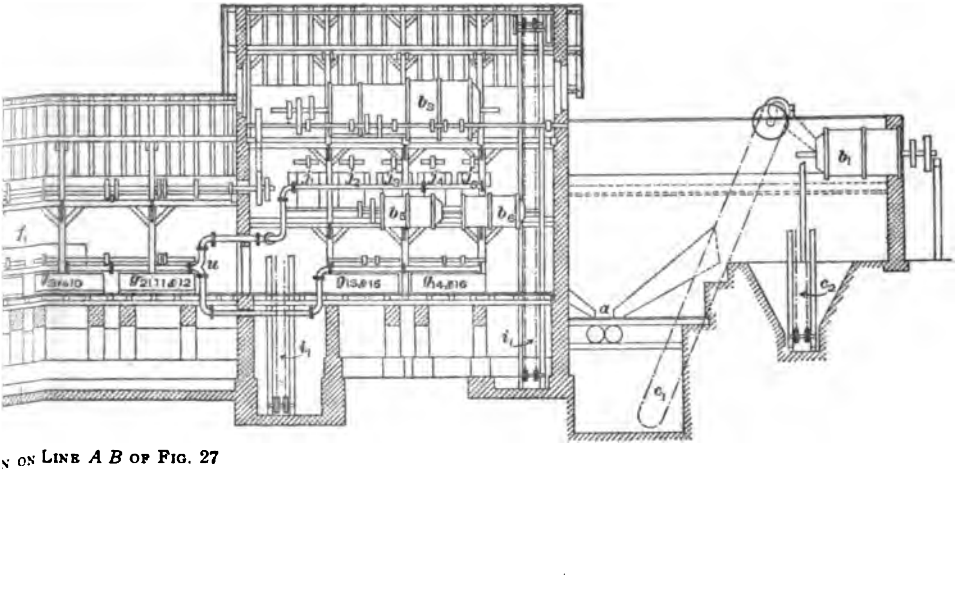


FIG. 28. SECTION ON



N ON LINE *A B* OF FIG. 27

was so struck with its simplicity and effectiveness that, after considerable negotiation, I secured the agency for the machine in this country and put one up at our colliery at Rockwood, Tennessee. The calculation is made on 10 hours' work per day; that is, a 400-ton machine will wash 400 tons of coal in 10 hours, but really will do 25 per cent. more if pushed very little."

In the foregoing description of the work of this coal-washing machine, it is understood that the coal used is the "screenings" made at the coal mine in preparing the several classes of lump, egg, and nut coal for market. If the run-of-mine coal is used for the manufacture of coke it will require the preparatory processes of disintegration and washing.

THE LÜHRIG WASHER, DOWLAIS, WALES

Figs. 27, 28, 29, and 30 will convey the general arrangements adopted at the Rybnik Collieries in the location of the Lührig coal washer in connection with the coal mine and coke ovens at that place

The plan shown in Fig. 30 is interesting, as it illustrates the method of constructing these works to secure the most economy in the several operations. The processes consist essentially in receiving from the mine, on the platform or landing of the colliery shaft, the run-of-mine coal. It is then passed over a 3-inch screen, the large lumps going to market, the screenings being deposited for further treatment in the washing section of the plant. This slack or fine coal is then classified by revolving screens and washed in the usual way. Large settling tanks are provided for the very fine sludge coal, which is usually found valuable in the manufacture of coke. Automatic arrangements have been made for storing the washed coal, so as to permit its becoming somewhat dried before being charged into the coke ovens. The plan also provides for the direct and economical handling of the coal from the mine until it is loaded into railroad cars for market or placed in the washer for the coke ovens.

This, in common with other washing machines, will require special arrangements to meet local conditions of coals to be treated. It is claimed that by this process the washed coal will not contain over 4 per cent. of ash at most, and that the tailings or refuse will retain only 3 per cent. of coal. The cost of washing alone is given at 1½ penny; in the United States the cost would be 6 to 7 cents. The capacity of this washer can be enlarged to meet the largest demands on its output.

Prof. C. Kreicher, of the Royal School of Mines, Freiberg, is quoted as having approved of this method of washing coal.

Description of the Plant.—This arrangement has been rendered more complicated owing to the machinery having to be erected on a long, narrow strip of ground, divided by an incline that had to be arched over and also by provision having to be made for washing bituminous and steam coal separately.

The arrangement therefore comprises two sets of systems, viz.: (*a*) The system for washing bituminous coals; (*b*) the system for washing steam coals.

(*a*) *The System for Washing Bituminous Coals.*—The bituminous coal is brought to the Shephard machine, which existed previous to the erection of the new washing machine, where it is crushed by means of rolls *a*, Figs. 27 and 28. It is then elevated by the elevator c_1 into a revolving screen b_1, which divides it into two sizes, viz., from $\frac{3}{8}$ inch to 0 inch, and from $\frac{3}{8}$ inch upwards.

The nut coal, from $\frac{3}{8}$ inch upwards, is raised by means of another elevator c_2 into a second revolving screen b_2 placed above the Shephard washing machines d_1 to d_5. This screen divides the coal into five sizes, which are washed each in a separate machine of Shephard's. After washing, the nut coal is raised by an elevator c_3 into bunkers *y*, situated between the building for the Shephard machines and the building for the crushers. From these bunkers the bituminous nut coals may be discharged into wagons, when required.

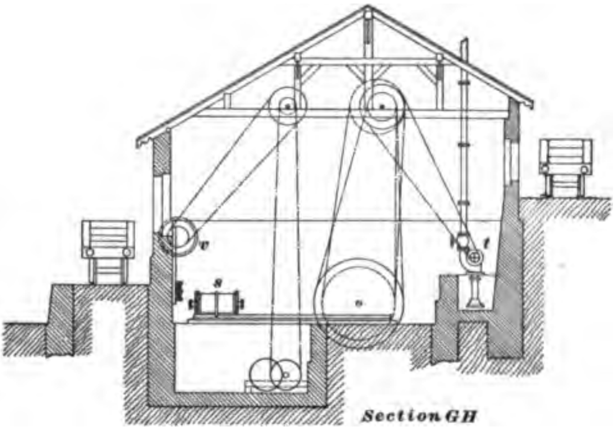


FIG. 29. SECTION ON LINE *G H* OF FIG. 27

The fine bituminous coal from $\frac{3}{8}$ inch downwards is transported by a current of water along a trough to a revolving screen b_6, situated in the building of the new washing machines erected by Messrs. Evence Coppée & Company, Engineers, Cardiff, Wales. This screen divides the coal into two sizes: from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch, and from 0 inch to $\frac{1}{4}$ inch.

The coal from $\frac{1}{4}$ inch to $\frac{3}{8}$ inch is washed in two feldspar machines g_{14} and g_{16}, Figs. 27 and 28, placed immediately below the screen;

and the coal from 0 inch to ¼ inch is conveyed in a trough by a current of water to the pointed trough f_2, shown on the plan and situated in the adjoining room of the new building. It is here divided into six sizes, each of which is washed separately in the feldspar machines g_1 to g_6 placed next to the pointed trough. The ⅜-inch and upwards bituminous coal is sent from the elevator raising the washed coal into a crusher. After being crushed, it meets the small steam coal in a bunker situated below the crusher, from which an elevator raises the coals, already partly mixed, to a screw placed on the bunkers erected in front of the crushing department. The screw *o* finally mixes the two coals and distributes them into bunkers l_5 and l_6, from which ultimately the small mixed coal is taken to the coke ovens.

(*b*) *The System for Washing Steam Coals.*—The steam coal is also treated in the new washing arrangement. Arriving in wagons, it is tipped into a bunker *h* in front of the new building, Figs. 27, 28, and 29, from whence an elevator i_1 raises it into a large revolving screen b_8; this screen divides the coal into six sizes, one of which is 0 inch to ⅜ inch, and five others varying from 1¾ inches to ⅜ inch. The last five sizes are each washed separately in five machines j_1 to j_5, ranged on the second floor, from whence the coal is run off on to reciprocating screens k_1 to k_4 for the purpose of draining off the water. The dry coal drops into bunkers l_1 to l_4, from whence it may be sent away in railway wagons.

When, however, the five sizes are required for coking, the coal is sent by a trough into a revolving screen b_4 fixed next to the crushers, from whence it is taken in a dry state, by means of a screw, to the disintegrators *x*. The water draining off, and which contains small coal in suspension, coming from the drying revolving screen and the reciprocating tables, returns to the feldspar machines.

The fine coal from 0 inch to ⅜ inch from the large revolving screen b_8 enters another revolving screen b_5, which divides it into two sizes, ⅜ inch to ¼ inch and ¼ inch to 0 inch. The first size is washed in two feldspar machines g_{13} and g_{15} situated in the large revolving screen building, while the second and smallest is carried by water in a trough to a pointed trough f_1 similar to that used for dividing the bituminous coal. The pointed trough divides the coal into six sizes, each of which is washed in separate machines g_7 to g_{16}. All the fine washed coal in a feldspar machine runs together into a large basin, from whence an elevator i_4 with perforated buckets raises it to the top of the bunker *q*. The small coal may be bunkered if desired; if not, it may be sent by a transporter to the crushing building, where it is remixed with the crushed bituminous and steam coal.

The overflow of small coal from the small-coal basin runs first into a long trough provided with a screw, and, as the small coal settles, the screw brings back the coal to the common small-coal

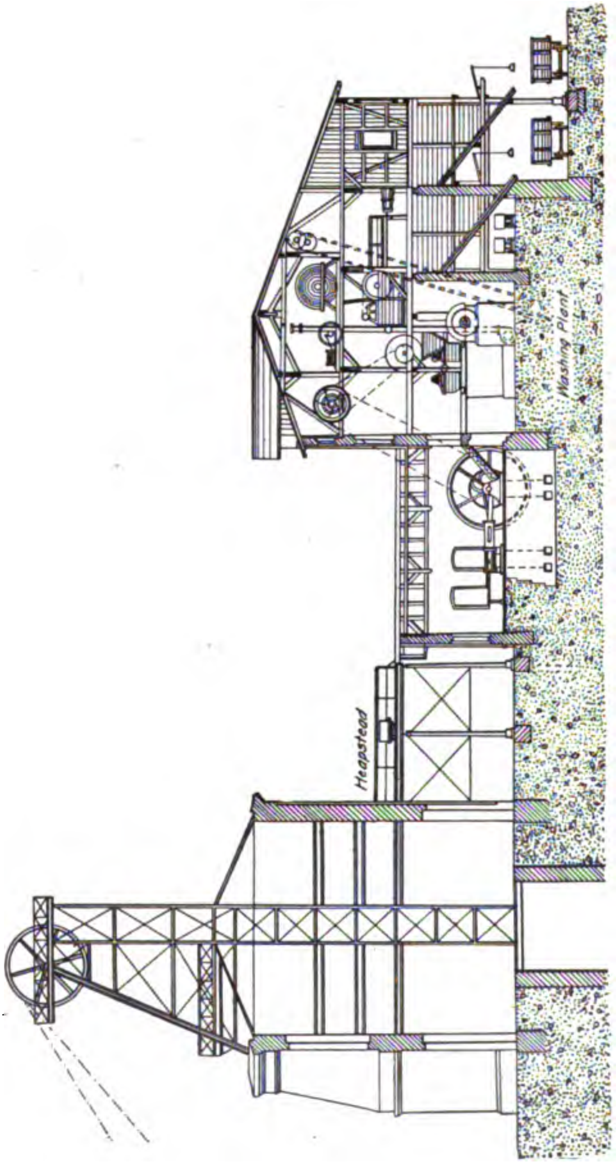


FIG. 30. SECTIONAL VIEW OF LÜHRIG WASHER AND SHAFT-HEAD FRAME AT DOWLAIS

basin, while the water runs into settling tanks or clarifiers m m. These clarifiers are three long-pointed troughs provided with a screw situated underneath. The dirty water, after having passed through the clarifiers, returns to the well of the centrifugal pump t, by which it is sent back and redistributed to the washers. The mud settling in the clarifiers drops by gravity into the trough of the screw, which transports it to the elevator i_5 situated at one end of the clarifiers, which raises the mud and drops it into bunkers n_1 and n_2.

The arrangement described above is washing 100 tons of coal per hour.

REFERENCE TO THE DOWLAIS WASHING ARRANGEMENT

On Figs. 27, 28, and 29 a, are crushing rolls; b_1, revolving screen for bituminous coal, 0 inch and ⅜ inch; b_2, revolving screen for bituminous coal, ⅜ inch and upwards; b_3, revolving screen for steam coal, 0 inch to ⅜ inch and upwards; b_5 and b_6, small revolving screens for fine coal; b_4, revolving screen for drying nuts for coking; c_1, c_2, c_3, bituminous-coal elevators; d_1, d_2, d_3, d_4, d_5, Shephard's washing machines; f_1 and f_2, spitzkasten, for classifying fine coal; g_1 to g_6, washers for fine bituminous, from 0 inch to ¼ inch, feldspar cases; g_{14} to g_{16}, washers for fine bituminous, from ¼ inch to ⅜ inch, feldspar cases; g_7 to g_{12}, feldspar washers, for fine steam coal, 0 inch to ¼ inch; g_{13} and g_{15}, feldspar washers for fine steam coal, ¼ inch to ⅜ inch; h, basin receiving steam coal from wagons; i_1, elevator raising steam coal to screen b_3; i_2, elevator raising mixed coal to transporter for crushing; i_3, elevator raising shale; i_4, elevator raising interstratified coal; i_5, elevator raising slimes from clarificator; j_1 to j_5, machines for washing coarse coal, ⅜ inch upwards; k, reciprocating screens; l_1 to l_4, bunkers for washed nut coal; l_5 to l_6, bunkers for fine washed coal, ⅜ inch and downwards; m clarificator, or settling tanks; n, slimes bunkers; o, worm for transporting coal to p_1 to p_{12} or to x; p_1 to p_{12}, bunkers for crushed washed coal to Coppée ovens; q, bunkers for interstratified coal; r_1, r_2, r_3, basins; s, driving engine for washing machines; t, centrifugal pump; u, water pipes for supply to washers, etc.; v, small engine for driving elevator and worm of clarifier; w, disintegrator engine; x, disintegrators; y, bunker for washed crushed coal delivery in wagons; z, driving engine.

Results Obtained at Dowlais Washery.—The important questions to consider in coal washing are, generally speaking, three: (1) to wash the coal clean, so as to remove all impurities, as far as that is possible; (2) not to allow any coal to pass away with the impurities; and (3) to wash the coal cheaply. As to the first point, which is very important, it would be reasonable to know the limit to which the impurity might be removed from the coal. It was thought there was only one way of settling that question, and that was to ascertain, by analysis, the yield in ash of the pure coal or the ash that could not be removed by mechanical means, as it was certain that even the purest picked coal would still contain a certain amount of impurities so intimately combined with the fuel that even with the best system of washing it would be impossible to remove it. In order to estimate the ash thus intimately combined with the coal, the best way was to pick out small lumps, or nuts, of pure coal and submit them to analysis by incineration. The method was so simple that it might be carried out by any one with a little practice, even without any knowledge of chemistry, and would enable him to estimate the contents of the ash in pure picked specimens of coal—a result that might be taken as the absolute limit of the greatest amount of purity to be obtained by washing. Some coals were so pure that pieces would not show more than 1.5 per cent. of ash; others were so dirty that the ash amounted to 10 per cent. Fortunately, the last class of coal was scarce in this country.

The table on page 107 shows the results of 4 months' coal washing in the washing machine erected at Dowlais, and described in the preceding pages.

In regard to the results of the Dowlais washing, as per details submitted in full in this table, the average figures are typical of the results of the 5 months' work. The steam coal, in its unwashed condition, contained an average of 15.9 per cent. of ash and the unwashed bituminous coal 25 per cent. of ash. The mixture of these two coals in the proportion of half and half gave an average of 20.4 per cent. of ash, and the mixed coal, after washing, contained 5.9 per cent. of ash, while the coke made with that mixture gave an average of 8.9 per cent. In the month of January the coke made with that mixture of washed coal gave only 7.5 per cent. of ash. These might be considered as fair average figures. During the first 3 months after starting—viz., September, October, and November, comprised in the table—the washing and sorting were not as perfect as in the subsequent months; therefore, the figures for the month of January were taken as being a fair statement of the result.

Now, with respect to the second point that required consideration, viz., to conduct the operation so as not to remove any portion of the free coal with impurities or with the shale itself. The best way to ascertain that the shale is practically free of coal is by taking a sample of the shale washed out, dividing it into two parts; one part is then submitted to a careful washing in an ordinary washing basin in order to remove all the particles of coal from it, and the shale, after being dried, is then incinerated; the difference between the weight of the ash and 100 will give the yield of volatile matters. Now, take the other sample of shale and dry and incinerate it; the difference between the weight of the ash and 100 will give the yield of volatile matters in the shale plus that in

FOUR MONTHS' RESULTS OF COAL WASHING IN THE DOWLAIS WASHERY

	Percentage of Ash in Washed Coal																			Percentage of Ash				
	In Nut-Coal Washers					In Feldspar Washers, to Wash Coal Below ⅜ Inch														Unwashed Steam Coal	Unwashed Bituminous Coal	Mixture of Half Steam and Half Bituminous Before Washing	Mixture of Half Steam and Half Bituminous After Washing	In Coke Made With the Mixture
	Steam Coal					Steam Coal							Bituminous Coal											
	1	2	3	4	5	6	7	8	9	10	11	12	6A	7A	8A	9A	10A	11A	12A					
1884																								
September and October	5.7	4.9	4.5	5.4	5.4	3.9	4.5	4.3	4.5	4.1	3.9	4.0	5.3	5.9	6.8	5.9	5.8	5.2	5.3	18.2	20.8		5.9	
November	3.7	3.8	3.4	4.3	3.6	3.5	3.8	3.6	4.9	3.3	3.1	3.5	–	5.2	5.9	6.2	5.5	4.7	4.9	15.6	25.0		5.8	10.7
December	5.3	3.7	2.7	3.8	4.1	3.2	2.7	3.9	4.2	3.0	2.4	2.9	3.1	4.4	5.1	5.6	6.2	5.5	4.4	14.9	29.2		5.9	8.6
1885																								
January	3.8	3.7	3.8	4.3	3.5	3.6	4.5	4.4	4.8	4.2	3.4	3.5	3.1	5.2	6.2	5.5	5.1	5.7	5.0	15.1	27.1		6.2	7.5
Average	4.6	4.2	3.6	4.4	4.1	3.5	3.8	4.0	4.6	3.6	3.2	3.4	3.8	5.1	6.0	5.8	5.6	5.2	4.9	15.9	25.0	20.4	5.9	8.9

the free coal contained in the shale. Deducting the result of the incineration of the rewashed portion of shale from the last result of incineration, the difference will show the free coal carried away with the shale.

In the feldspar washery of the Coppée system, the free coal in the shale varies from 1½ per cent. to 5 per cent. The yield in ash in the shales varies not only from district to district, but from a seam of coal to a seam of coal. However, we may state that, according to many hundreds of analyses of the shales of South Wales, the ash in them amounts to from 66 per cent. to 75 per cent. Some Lancashire shales yield only about 47 per cent. of ash. The cost of washing, including labor and all charges, except interest on capital, does not exceed 3 pence per ton of washed coal.

The following are a few analyses of the Clifton and Kersley small coal in an unwashed state—analyses that were made previous to the erection of the washery:

	PER CENT. OF ASH
Cannel coal contained	30.340
Doc mine coal contained	16.450
Pure picked nuts of cannel coal contained	8.200
Pure picked nuts of Doc mine coal contained	2.740
Mixing the two above coals in equal quantities, the average ash in the mixture was	23.395
Average of intimately connected ash with nuts in the mixture of equal parts was	5.470
After 3 months' washing, a few samples of small coal taken and analyzed gave in average	6.550

So that the washed coal differed from the absolutely pure coal by 1.08 per cent. of ash only, which may be considered an exceedingly satisfactory result.

LÜHRIG WASHER, NELSONVILLE, OHIO

The following is a description of a Lührig coal washery for fine coal screenings, designed and equipped in 1901 by the Link-Belt Machinery Company, of Chicago, Illinois, for the Buckeye Coal and Railroad Company, of Nelsonville, Ohio, that has a capacity of 100 tons per hour. The design was to assemble the screenings from a number of coal mines in the Hocking Valley field to a convenient point, unload them, wash them, and send the cleaned coal to market in fine sizes, known in the market as domestic egg, No. 1 nut, No. 2 nut, No. 3 fine, and No. 4 fine.

The coal screenings were to be delivered either in hopper-bottom or gondola cars. Hopper cars, it was believed, could be unloaded on one track at the rate of 100 tons per hour, and track No. 1, Figs. 31 and 32, was set apart for this purpose. Under this track there was constructed a concrete hopper about 40 feet long and holding a carload of coal. From this hopper, the coal was taken to the elevator *a* by means of the right-and-left screw, *b*, as it was

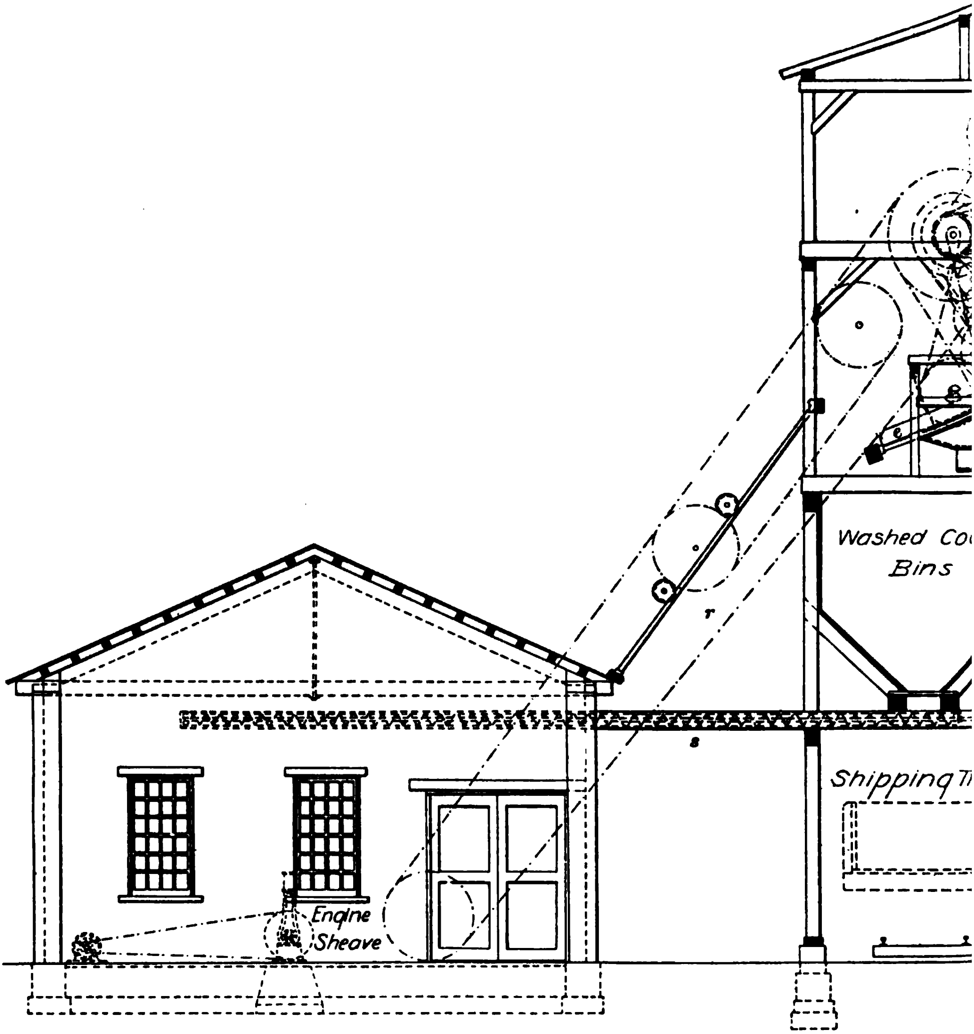
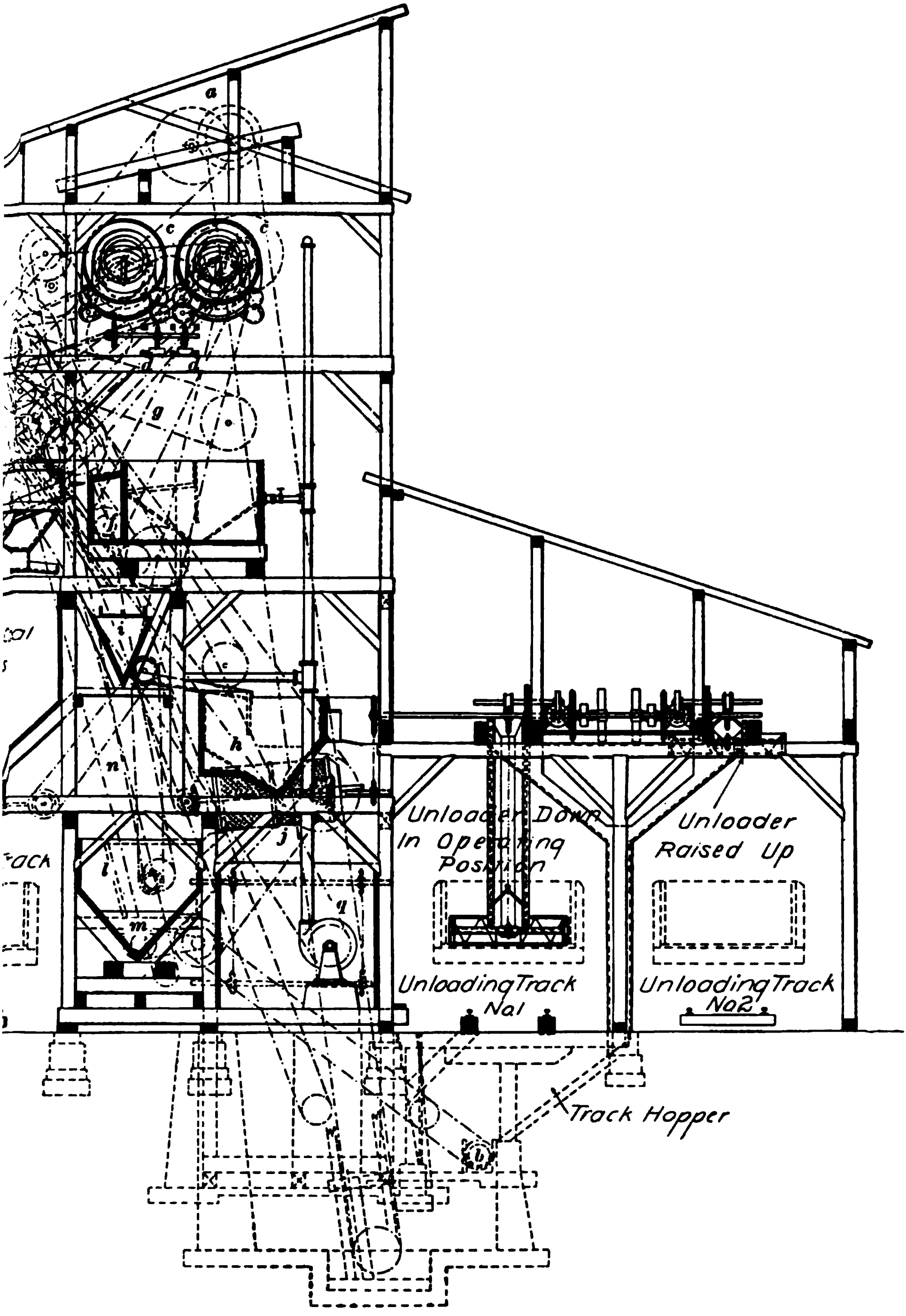
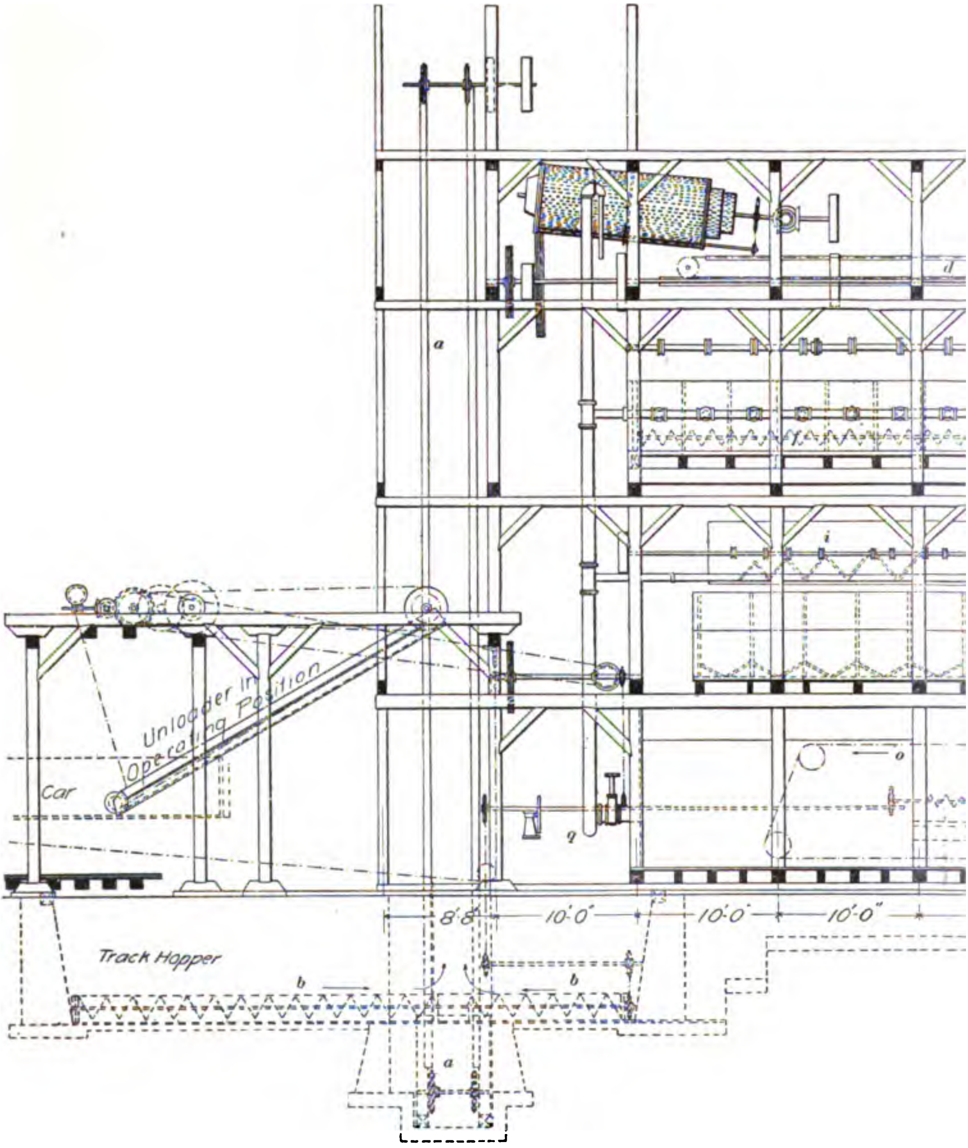


Fig. 31. Lührig Washery at Nelso

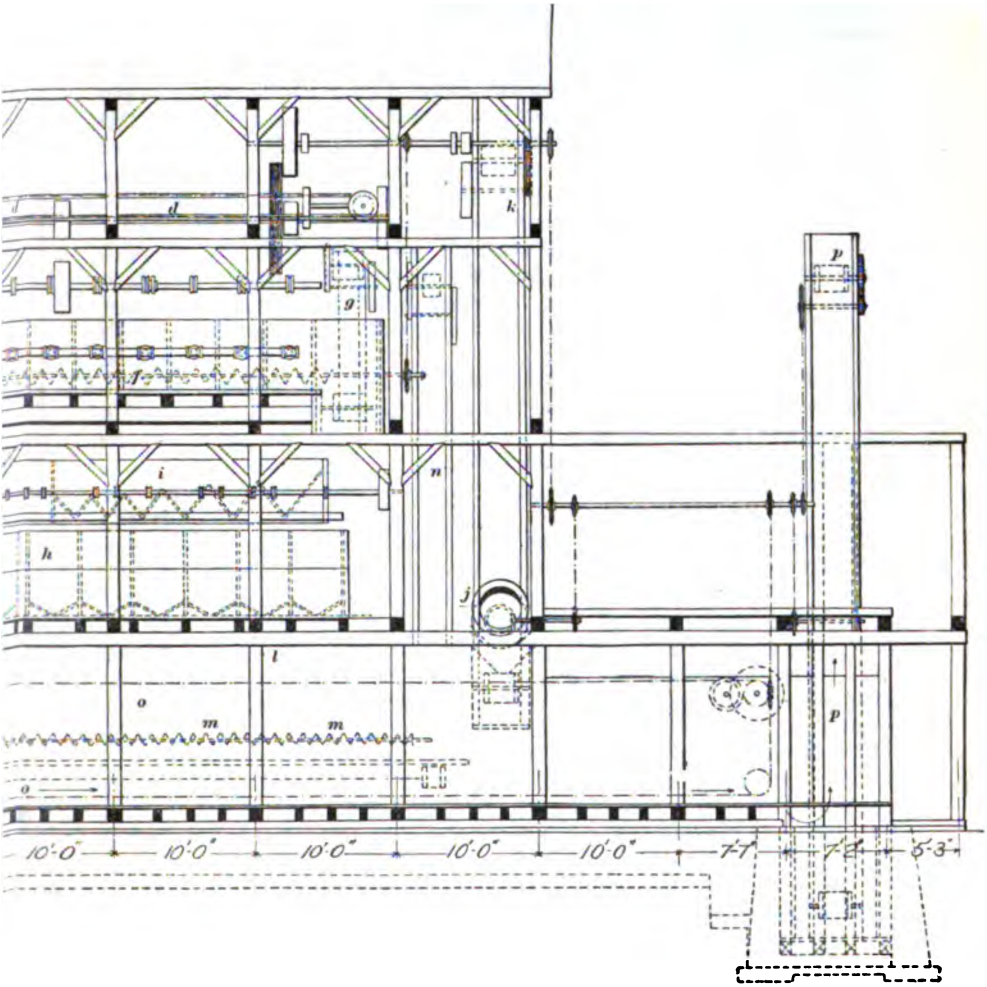


ville, Ohio. (End Elevation.)



17303—III

FIG. 32. LÜHRIG WASHERY AT NEL



SONVILLE, OHIO. (SIDE ELEVATION.)

not found possible to unload 100 tons per hour on one track. With the application of a screw unloader and an additional track, No. 2, this difficulty was removed.

Elevator *a* delivers the coal into a pair of jacketed screens *c*, *c* that classify the coal into three sizes of coarse coal and one size of fine coal. The inner jacket, with 1½-inch holes makes domestic egg; the middle jacket, with 1-inch holes, makes No. 1 nut; the outer jacket, with ⅝-inch holes, makes No. 2 nut. The domestic egg and No. 1 sizes are distributed into the respective nut-coal jigs by means of the conveyers *d*, *d* while the No. 2 nut falls direct into the nut-coal jigs. From the nut-coal jigs on the third floor, the washed nut coals are delivered direct into their respective bins by means of the bumping screens *e*, which are placed directly over the washed-coal bins, draining some of the water from the coal and allowing the clean nut coal to fall direct into the shipping bin without further handling. A spray of clean, fresh water thrown on the coal before it leaves the bumping screen brightens it considerably.

The washed-coal bins are nine in number, and are arranged in a row over the shipping track. There are two bins for each of the three coarse coals, one for No. 3, one for No. 4, and one for Nos. 3 and 4, mixed. An additional bin has been provided for the refuse, which is loaded into hopper-bottom cars and used by the railroad managers for filling. Each bin holds 30 tons and a car of nut coal can be loaded, one half from each of the two bins. The nut-coal bins need never be less than half full, reducing the breakage of the clean nut coal to a minimum.

The refuse from the jigs is gathered by the screw conveyer *f*, raised out of the water by the perforated bucket elevator *g*, and delivered direct into the refuse bin over the shipping track. The water from the nut-coal jigs, drained out of the coal by the bumping screens *e*, flumes the fine coal from the outer jackets of the screens *c*, *c* into the fine-coal jigs *h* by means of the grading box *i*, which hydraulically grades the coal to the jigs for better washing. From *h*, the clean fine coal is flumed to the draining screen *j*, which has ¼-inch holes in it. It not only drains the water from the coal, but also screens out the No. 3, ⅝-inch to ¼-inch sizes, from the No. 4 size.

The No. 3, from end of screen *j*, is lifted into its shipping bin by means of the perforated elevator *k*. The ultimate refuse from the bottom of the jigs is recovered by the refuse recovery screw *m* and lifted into the refuse bin over the shipping tracks by the perforated bucket elevator *n*. The sludge, or No. 4 coal, being all the coal below ¼ inch, is recovered by the Lührig sludge recovery *o* and lifted into its shipping bin by the sludge elevator *p*.

The water is circulated by a 10-inch centrifugal pump *q*. The power plant is located in a separate brick building from which the power is transmitted to the washery by means of rope transmission *r*. Two 66′ × 18′ boilers furnish the steam to a

150-horsepower double Erie automatic engine and to a small electric-light engine. The screw conveyer *s* takes No. 4 washed coal direct from the shipping bins to the front of the boilers.

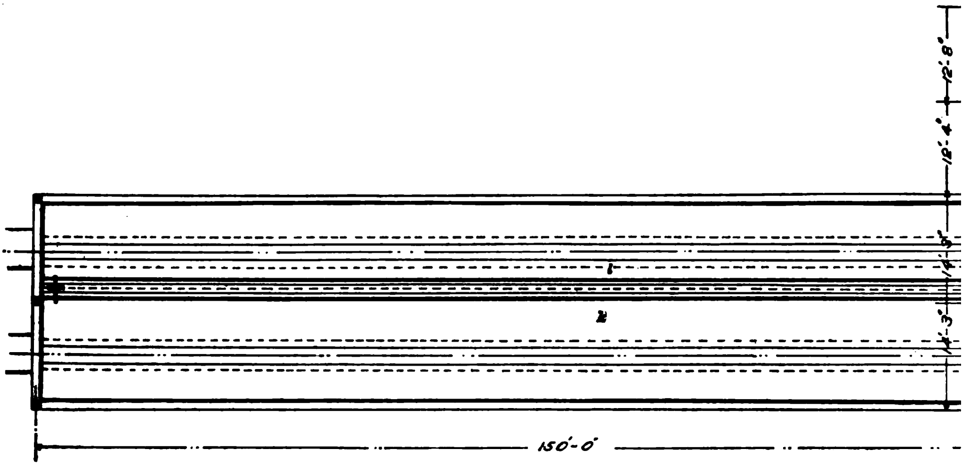
The following table summarizes some approximate figures regarding the operation of this plant:

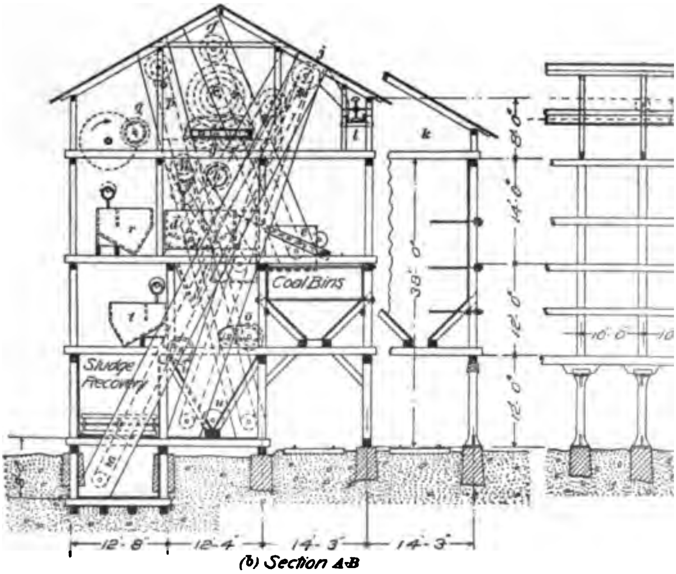
Name of Coal	Size of Screen Inches	Proportion Per Cent.	Free Water Per Cent.
Domestic egg	1½	16	1
No 1 nut	1½ to 1	21	1
No. 2 nut	1 to ⅝	17	2
No. 3 fine	⅝ to ¼	20	4
No. 4 fine	¼ to 0	14	9
Waste		12	

The amount of free water was obtained by weighing a car of wet coal as it came from the shipping bins and then allowing it to stand on a siding to drain until, by repeated tests, it no longer showed any appreciable loss in weight.

LÜHRIG WASHERY AT PUNXSUTAWNEY, PENNSYLVANIA

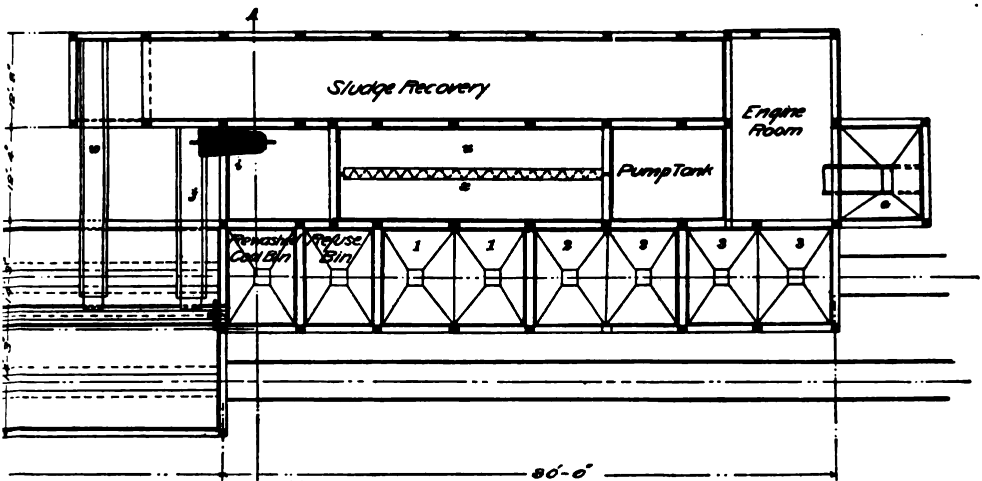
The Lührig coal washery, erected near Punxsutawney, Jefferson County, Pennsylvania, is one of the large modern washers for the cleaning of coal for the manufacture of coke. It has a capacity of 75 tons per hour as designed and equipped in 1897 by the Link-Belt Machinery Company, of Chicago, Illinois. The objects sought to be obtained in this plant are: (1) To provide clean coal for the beehive coke ovens; (2) to be prepared to ship clean nut coal for fuel purposes if the market conditions make it desirable to do so. Fig. 33, (*a*), (*b*), and (*c*), shows three views of the general arrangement of the machinery and main timbers in the supporting structure, with many details omitted to avoid confusion of lines. A raw-coal bin, not shown on the drawings, holding 2,000 tons, was provided to receive the accumulation of coal from the mine, so as to make mine and washery independent of each other to the extent of 2 days' full run. In this bin or receiver the run-of-mine coal is stored, after having been broken to nut-coal size by two Bradford breakers. From this raw-coal bin the coal is taken as required, by a Dodge chain conveyer, and placed in the raw-coal hopper *a*; from this it is taken by the elevator *b* to the top of the building and delivered into the triple jacket screen *c*. This screen has jackets with 1½-inch, 1-inch, and ½-inch holes, reading from within out, making Nos. 1, 2, and 3 nut coals and a finer coal, which is all that passes through the ½-inch holes in the outer jacket. The three sizes of coals are kept separate and are apportioned among the seven nut-coal jigs *d*, according to their respective quantities.



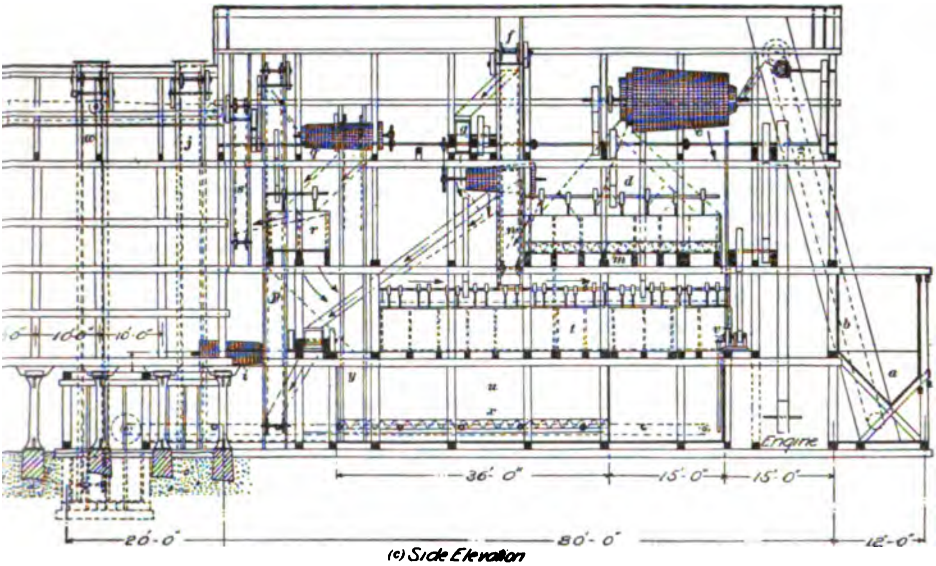


(b) Section A-B

Fig. 33. Lührig Washery at



(a) Plan



(c) Side Elevation

Punxsutawney, Pennsylvania

ii

From these nut-coal jigs, the cleaned coal is flumed direct into the six shipping bins Nos. 1, 1, 2, 2, 3, 3, in (*a*); the water being drained from the coal by means of the bumping screens *e*. If this nut coal is not to be shipped as fuel, but is to be used for making coke, it is flumed to the second nut-coal elevator *f*, which has perforated buckets, and drains the water from the coal as it is lifted to the Link-Belt coal crusher *g*. The fracture of the coal being cubical and the slate interleaved in flat condition, this crusher frees the slate from the coal, the product passing through the screen *h*; the rejections from the screen, which has ½-inch round holes, are nearly all flat slate pieces and are discarded.

It will be noticed that the nut-coal jigs are on the third floor. On the second floor is a row of twelve fine-coal jigs *t*—Lührig feldspar jigs. Six of these are used to wash the fine coal that is passed through the holes in the outer jacket of screen *c*, while the other six are used to wash the washed nut coal that has been crushed by *g* and screened through the holes in *h*.

The clean coal from the twelve fine-coal jigs is flumed to the draining screen *i*, which has ⅛-inch holes. The discharges from the end of this screen are the final clean coal and are lifted by means of the perforated bucket elevator *j* to the top of the 2,000-ton washed-coal draining bin *k*, into which it is distributed by means of the Dodge chain conveyer *l*.

The slate valves in the nut-coal jigs *d* are so set as to reject as primary refuse all pieces of coal that are contaminated with slate or other foreign matter. This refuse is gathered from the seven jigs by means of a screw conveyer *m*, and lifted out of the water by the perforated elevator *n* and dropped into crusher *o*, which is the same make as crusher *g*. From *o*, it is elevated by means of the intermediate elevator *p* and screened by *q*. Here again flat pieces of slate are separated and all that passes through the ½-inch holes in *q* is rewashed in the Lührig feldspar rewashing jigs *r*. These jigs are similar to the fine-coal jigs, but the relative areas of plungers and screen surface are different. The clean coal recovered by these jigs is lifted by elevator *s* into the rewashed-coal bin as shown on (*a*). The final refuse that passes through the feldspar bed in the fine-coal jigs *t* and the rewashing jigs *r* goes into the refuse recovery *u*.

A great quantity of water is required about this plant for washing the coal and refuse, but this water must be recovered and used over and over. If allowed to run away, it would not only require a large fresh-water supply, but it would carry away with it a quantity of fine coal, as well as damage adjoining properties by flooding them with fine coal and refuse. All the water used in the washery, therefore, except such portion as is carried away with the wet coal and dirt, is finally gathered into the sludge-recovery tank. At *v* is an 8-inch centrifugal pump taking its suction from the near end of the sludge recovery, and the main stream of water is lifted to the nut-coal jigs and used in washing the nut coal. All the water drained from the nut coal by *e* or *f* is used to flume the fine coal from the outer jacket of *c* into the fine-coal jig *t*. Some additional water from the pump *v* being required, all the water drained from the final washed coal by *i* and *s* flows into the pit at the end of the sludge recovery tank.

This sludge recovery consists of a large tank 80 feet long, 11 feet wide, and 12 feet deep. At one end, in which stands the sludge elevator *w*, the pit is 8 feet deep. In the bottom of this tank there is a scraper conveyer having three chains and scrapers of the full width of the tank; this moves very slowly and scrapes all the fine-coal settlings to the elevator pit. All the water entering the sludge recovery does so at the pit end and is taken out at the opposite end by the centrifugal pump. The fine coal thus settled consists of that which escapes through the holes in screen *i* and elevator buckets *s*, and is lifted by *w* and delivered into the coking-coal bin by conveyer *l*, thus mixing it thoroughly with the coal elevated by *j*. The water that has been used to flume the refuse from the bottoms of the jigs flows to the refuse recovery *u*. This is a **V**-shaped tank in which a screw conveyer *x* gathers the settlings to a final refuse elevator *y*, which has perforated buckets and delivers the final refuse into its bin to be removed from the plant. The water overflowing from the refuse recovery goes into the sludge tank and is again used.

The table of analyses, on page 113, of coal before and after washing, is taken from the experience of the manufacturers of the Lührig washers, the Link-Belt Machinery Company.

An excellent example of what can be accomplished through the washing of coal is furnished by the results obtained at the Montana Coal and Coke Company's plant at Aldridge, Montana, as described by Mr. J. V. Schaefer in Mines and Minerals for December, 1903. The coal there mined is very friable; and in a test, 74 per cent. of the coal passed through a ⅛-inch mesh sieve and contained 15.7 per cent. ash; 15.8 per cent. passed over a ⅛-inch mesh and through a ½-inch sieve and contained 25.6 per cent. ash; the 10 per cent. that went over the ½-inch sieve contained 40.8 per cent. ash. A test of a sample of the coal that had passed through a ½-inch mesh and over a ⅛-inch mesh shows that 32 per cent. floated in a solution having a specific gravity of 1.31 and contained 7.2 per cent. ash, while 68 per cent. sank and contained 41.5 per cent. ash.

This coal was washed in two jigs. As a result of the first jigging, 61 per cent. of the mine product was obtained that was suitable for coking and contained from 10 to 11 per cent. ash. The refuse from this first jigging was rejigged, and from this material 3 per cent. of the mine product was obtained as middlings, which was used for fuel under the boilers at the plant and contained 18 to 20 per cent. ash, while 36 per cent. of the mine product was rejected as refuse and contained 60 to 68 per cent. ash.

ANALYSES OF COAL BEFORE AND AFTER WASHING

Washery	Before Washing		After Washing	
	Ash Per Cent.	Sulphur Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Alexandria Coal Co., Greensburg, Pa.	10.60	1.139	6.21	.617
Coke made from this washed coal			9.50	.850
Rochester and Pittsburg Coal and Iron Co., Punxsutawney, Pa.	8.60	1.30	5.45	1.030
Skagit Coal and Coke Co., Cokedale, Wash.	37.04		11.00	
Central Coal and Iron Co., Central City, Ky.	12.88	3.53	7.65	2.870
New Ohio Washed Coal Co., Carterville, Ill., No. 1 mine	9.48	.78	4.85	.690
New Ohio Washed Coal Co., Carterville, Ill., No. 2 mine	9.19	1.43	8.34	1.100
Cambria Mining Co., Cambria, Wyo.	18.21	5.07	11.72	4.540
Dayton Coal and Iron Co., Dayton, Tenn.	21.75	.77	9.14	.480
Crows Nest Pass Coal Co., Fernie, B. C.	9.65		5.30	
Western American Co., Fairfax, Wash.	31.08	.34	12.25	.550
Montana Coal and Coke Co., Horr, Mont.	25.60		8.50	
Kanawha and Hocking Coal and Coke Co., Harewood, W. Va.	7.56	1.53	4.41	1.140
Northwestern Improvement Co., Roslyn, Wash.	16.30	.57	9.70	.400
Rocky Fork Coal Co., Red Lodge, Mont.	25.30		8.50	
Lührig Coal Co., Zaleski, Ohio	15.80	1.90	8.00	.870
Belt Mountain, Mont.	18.74	3.34	5.56	2.400
Wellington Colliery Co., Vancouver Island, new coal	38.00		8.90	
De Soto, Ill.	18.00		4.20	
Buckeye Coal and Railroad Co., Nelsonville, Ohio	13.77	1.05	4.30	.890
Roslyn, Wash.	16.30	.57	9.70	.400
Red Lodge, Mont.	25.00		8.00	
Reserve mine, Stein washer	5.63	1.64	2.25	1.110
Caledonia mine, Stein washer	4.69	1.50	3.25	1.680
Dominion mine, Stein washer	5.41	1.56	4.63	1.120
Coke from coal, Stein washer			6.24	1.010
Alleghany coal, Stein washer	14.29	1.32	5.72	.820

Although the ash in this coking coal is still high, as compared with some eastern coals, the coke made from it has to compete with coal on which a high freight rate is paid, and it can therefore be sold at a good profit in spite of the fact that 36 per cent. of the coal mined must be rejected as refuse.

Mr. J. V. Schaefer says: "The loss of coal in the process was not over ½ per cent., and taking into consideration the great quantity of matter that had to be removed, I think these results are remarkable, and, so far as I know, have never been surpassed."

The Stewart Coal Washer.—The Stewart type of coal washery had its origin in the desire of Mr. E. A. Stewart, the patentee, to design a plant that should be simple in its arrangement and operation, effective in its work, and at the same time have a large capacity. The jig principle was decided on as the only device that could be depended on at all times and under all circumstances to give economical results: Instead of using a large number of small jigs placed at the top of the building, Mr. Stewart adopted the idea of using a few large jigs placed on the ground. Instead of separating the coal into many sizes before washing, and keeping these sizes separate throughout the process, a system that necessitated the use of a multiplicity of elevators and conveyers, he designed to wash the coal in mixed sizes and separate afterwards, if desired. By placing the jigs on the ground he not only obtained solid foundations for his jig tanks, but he was enabled to erect above the jigs storage bins for unwashed coal, from which the coal could be fed direct into the jigs without any intermediate handling, in this way again simplifying the process, as it is absolutely essential for the economical working of any washing process to have a regular and continuous feed of coal to the machines. When these machines are placed at the top of a building two systems of elevators are required—one for elevating the raw coal into the storage bins and another for elevating out of the storage bins into the washing machines.

In order that the coal could be washed in mixed sizes effectively, Mr. Stewart designed the jig that bears his name, Fig. 34. In this jig, the downward suction that always exists to a certain extent in all eccentric-driven jigs is overcome by a peculiar arrangement of valves in the water-supply pipes. Very remarkable results have been accomplished with the use of this jig. Its first marked success was achieved in Southern Illinois. From there, Mr. Stewart moved to Birmingham, Alabama, where the Stewart washer very soon demonstrated its superiority in washing the Alabama coals.

In Fig. 34, *a* is the unwashed-coal storage bin, of any size that may be desired, holding the coal of all sizes, as the coal is not screened or sized prior to washing. *b* is a sliding cast-iron gate, operated by rope or lever, that admits the coal from *a* through *c* into *d*. *c* is a sheet-iron housing fastened to the jig box *d* and extending into the box. This is to force all coal going through *c* under the water-line, so as to prevent any fine dust from floating on top of the water and passing out over the end of the jig without its having become subjected to the action of the water. *d* is a jig box, about 5 feet × 7 feet, that is fitted into the jig tank *e* by metal plates on the four sides of jig tank and on jig. This jig box has a reciprocating movement and is worked by double eccentrics *f* and *g* keyed to shafting, lying parallel and geared into each other to run at the same speed, The jig box is hung from *f*, *g* by eight rods *h*. The coal after passing through *c* is at once immersed and goes through a complete disturbance from eight to ten times before it reaches the point of discharge for the coal *j* and for the slate *k*.

The box has, in the bottom, perforated plates that slope to the front end where there is a sliding gate *l*. The capacity of the jig is 20 to 40 tons of coal per hour. The jig tank *e* is built in size to suit the jig box so as to allow it to swing free. The tank is bushed in on four sides with iron plates to fit squarely against the same character of plates on the jig box, giving the result of a practically tight joint, but at the same time giving the jig sufficient play so that it can be moved up and down by the eccentrics *f* and *g* hung on the two pieces of shafting just over the jig. As the jig box goes down, the water is forced through the perforations in the plates with sufficient force to carry the coal of a certain specific gravity up and over the lower end of the jig, the water being sluiced through an open trough to the settling tank, or basin, *o*; the speed of the jig depends entirely on the specific gravity of the coal that is being worked.

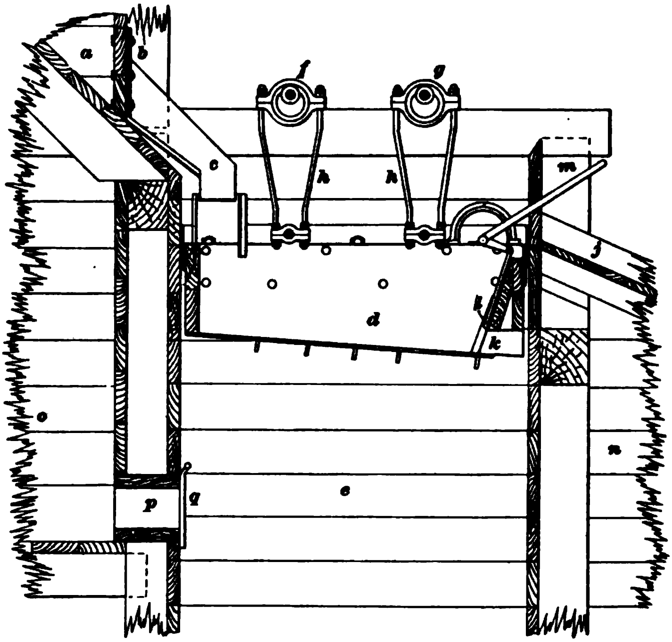


Fig. 34. Stewart Jig

The slate gate, or refuse discharge, *l* is raised and lowered at will by the lever *m*. The opening at *k* is adequate to pass a 4-inch cube, and is the entire width of the jig; the lever *m* is fitted to a radius of a half circle with slot to accommodate the opening and shutting of the gate *l*, and is fitted with handscrew so as to enable the setting of this gate at any height. The operator of the jig, after becoming familiar with his coal and the amount of

RESULTS WITH STEWART WASHER

Brookwood: Ash, 10.35 Per Cent. Sulphur, 1.433 Per Cent.		Mildale: Ash, 11.60 Per Cent. Sulphur, 1.578 Per Cent.		Carter: Ash, 10.30 Per Cent. Sulphur, 1.306 Per Cent.		Total	Contents of Washed Coal				Contents of Refuse					Washed Coal	
Tons	Per Cent.	Tons	Per Cent.	Tons	Per Cent.	Tons	Coal Per Cent.	Bony Coal Per Cent.	Slate Per Cent.	Dust	Coal Over ¼ Inch Per Cent.	Coal Under ¼ Inch Per Cent.	Bony Coal Per Cent.	Slate Per Cent.	Dust Per Cent.	Ash Per Cent.	Sulphur Per Cent.
312	47.0	291	43.9	60	9.1	663	98.4	1.41	.090			2.55	10.24	85.56	1.65	7.350	.885
252	41.2	299	48.9	60	9.9	611	95.99	4.13	.805		3.61	.45	9.54	83.64	2.76	6.900	.790
283	45.9	274	44.4	60	9.7	617	97.59	1.97	.440		.81	3.88	8.90	85.85	.56	6.850	.796

impurities it carries to the ton, very readily learns about the distance to leave his gate open, necessarily making the jig as near absolutely automatic as any jigging process that has ever been developed.

The coal, after having been separated from its impurities, passes over the top of the jig box *d* and out to *j*, into what is termed the settling basin *n*, where it is allowed to settle to the bottom, there being very little disturbance of the water in *n*; thence it is delivered by a perforated bucket elevator to any point desired.

The next important feature is the water circulation, the water being used over and over again. The only fresh water required is the water that is actually consumed or absorbed by the coal in the process of washing. The water from the basin *n*, which overflows from the top into a well is carried by any means desired—commonly a centrifugal pump on account of capacity and low duty—into what is termed the supply tank *o*, thence through the opening *p* into tank *e* to valve *q*. As the jig box *d* moves up, the valve being a cast-iron swinging check, admits the water through *p* into *e* and fills the vacancy caused by the upward motion of *d*. On the downward motion of the box *d*, the valve *q* closes and the water is forced through the perforated bottom of the jig box *d* and the same process is gone over and over as has been cited.

The gate in front of the jig box is left open at a certain point, which is governed by the amount of slate and impurities to the tonnage of coal being washed. The down motion of the jig loosens the slate bed in the bottom and works it toward the front, or discharge, side, where it is

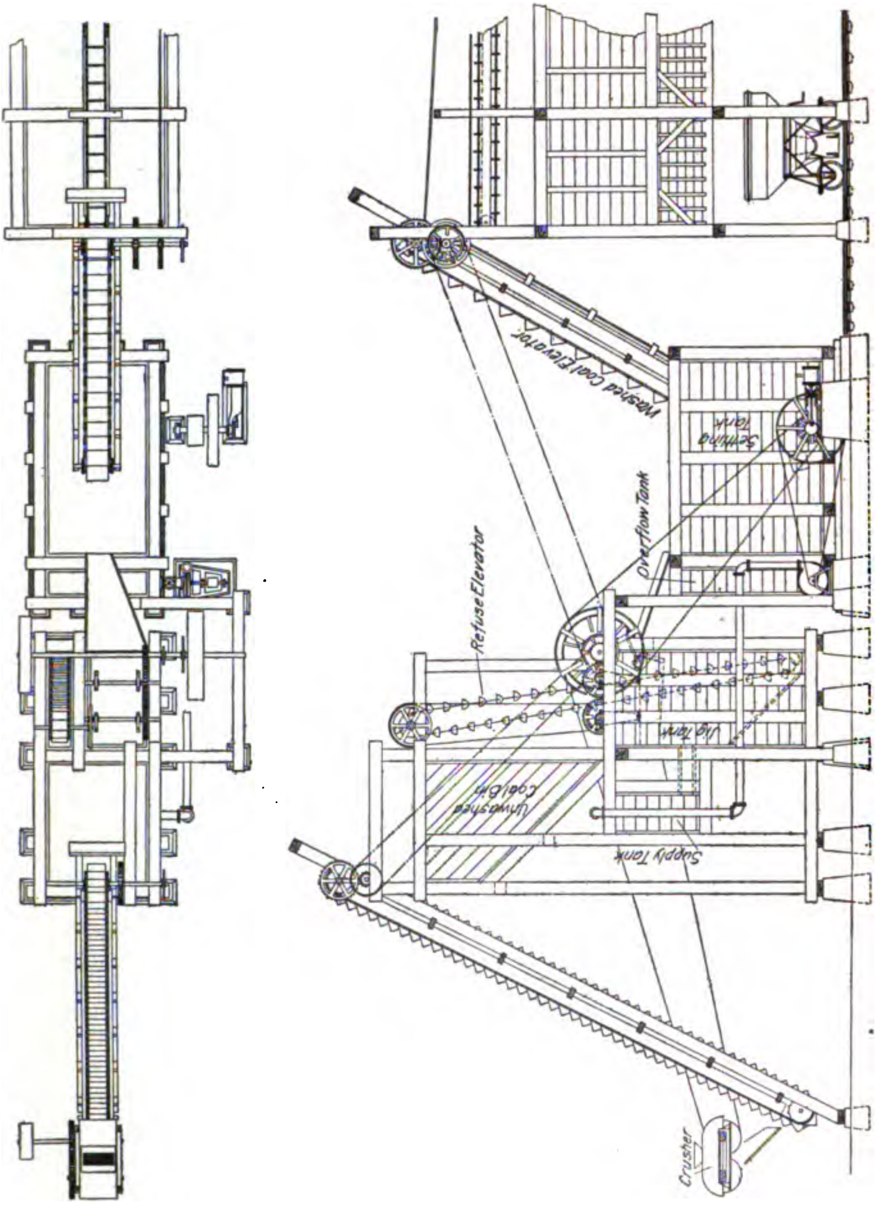


FIG. 35. SECTION AND PLAN OF STEWART WASHERY

discharged into the jig tank *e* under the jig box and is carried by a chute or hopper to a point where it is taken up by the refuse elevator and carried out. The peculiar arrangement of this jig box with the perforated bottom fitted into the tank gives a very sensitive arrangement with which the jig distinguishes the difference between materials of a very close specific gravity; for instance, in one case where the coal varies in specific gravity from 1.29 to 1.37, the bony coal from 1.38 to 1.56, the shale from 1.40 to 2.04 and the slate from 1.70 to 3.40, an average from forty-nine samples of run-of-mine coal shows the coal 82.6 per cent., bone coal, 11.4 per cent.; shale, 4.5 per cent.; slate, 1.5 per cent. The following is the result of eleven samples taken from the washed product: Coal, 92.9 per cent.; bone, 5.3 per cent.; shale, 1.8 per cent. The refuse or tailings show coal 3.8 per cent.; bone, 18.2 per cent.; slate and shale, 78.9 per cent. In another case where there is considerable fireclay to contend with, mixtures of coals from three different places were washed. The results of these washings are given in the table on page 116.

Fig. 35 shows a section and plan, and Fig. 36, a photograph of a Stewart washery of one jig; for convenience the elevators are shown in a straight line. Although the washer appears very rigid, on the contrary it is a very flexible machine, and can be made to suit almost any surroundings on account of the fact that the dry-coal elevator can be located on any one of three sides of the washer. The same conditions apply to the washed-coal elevator; it also can be located on any one of three sides. The part of the washer designated as the settling tank can be removed to any point where it can be located far enough below the level of the jig so that the water may carry the coal to it, but for convenience sake it is located very close to the jig tank.

The illustrations show the washer located on approximately level ground. The coal if screened, or if using run-of-mine, is delivered at a point where the unwashed-coal elevator will carry it up and deliver it into the unwashed-coal bin; thence, through openings over the jig box, it is allowed to empty into the jig box as freely as is desired.

The Stewart system of coal washing does not require that the coal be sized prior to the washing, and there are quite a number of cases through Illinois where it is being used very advantageously for washing coal for fuel purposes, the coal being sized after having been washed to take care of the fine dust and breaking of nut and pea coal, which necessarily goes on during the process of washing. Under those circumstances it is possible still to maintain the service of a general loss of less than 5 per cent. of free coal in the process of washing. The power required for operating the Stewart washer is approximately 10 horsepower per jig. Where there is any screening or extra conveying machinery attached to the washer the necessary horsepower required must be added to the power unit. The amount of labor required to attend to the washer is, in case of more than a two-jig washer, two men only, requiring the ordinary skill of an engineer around a mine. One man on the platform of the washer can attend to a five-jig washer, washing 1,800 tons per day of 10 hours, thee ngineer looking after the engine and oiling up the other machinery; the power required is about 100 horsepower.

Fig. 36. Stewart Washery at New Castle, Alabama

The cost of construction is a matter hard to determine, as it depends entirely on the surroundings and the length and capacity of the elevators and the additional machinery required to dispose of the coal.

This system has become quite popular throughout the Southern States, and the cost of this washer is about $20,000.

The following is a report of the results obtained with a Stewart washer at the Sayreton mines of the Republic Iron and Steel Company, made by the chemist of the company, Mr. David Hancock:

"Our run-of-mine coal, as shown by the average of forty-nine samples taken in the mine, is made up as follows:

	Per Cent.		Per Cent.
Coal	82.6	Shale	4.5
Bone coal	11.4	Slate from partings	1.5

"The average specific gravity of these portions I give below, showing also the extent of variations in parenthesis:

Coal	1.33 Specific gravity	(1.29 to 1.37)
Bone	1.45 Specific gravity	(1.38 to 1.56)
Shale	1.60 Specific gravity	(1.40 to 2.04)
Slate	1.95 Specific gravity	(1.70 to 3.40)

"The next table shows the results of 10 day's washing and is the average of eleven samples:

Washed Product	Per Cent.	Tailings	Per Cent.
Coal	87.9	Coal	3.8
Bone	10.3	Bone	18.2
Shale	1.8	Slate and Shale	78.9
Slate	.0		

"The work is even better than here shown for the reason that it is the lighter varieties of bone and shale that remain in washed coal and the heavier varieties that go to the slate dump. This point is well shown by the following analysis:

Washed Product	Per Cent. of Ash	Tailings	Per Cent. of Ash
Coal	7.50	Coal	11.90
Bone	18.00	Bone	27.90
Shale	33.40	Shale	55.00

"I give finally two representative analyses of our coke, one before the washer was installed and one showing the coke as it now is:

	Unwashed	Washed
Volatile	3.65 per cent.	2.75 per cent.
Fixed carbon	76.71 per cent.	82.55 per cent.
Ash	18.85 per cent.	14.10 per cent.
Sulphur	.79 per cent.	.65 per cent.

Fig. 37. Coal-Washing Plant of Jamison Coal and Coke Company, Greensburg, Pennsylvania

"I have inspected hundreds of cars of Sayreton washed coal and have never yet found a piece of slate of higher than 1.70 specific gravity, although Sayreton run-of-mine carries an average of 40 pounds per ton of heavy slate of this character."

Very truly yours,
David Hancock, Chemist.

STEIN AND BOERICKE WASHERY

Since 1895, the Stein washer has been built by the firm of Stein & Boericke, Limited, of Primos, Delaware County, Pennsylvania, and during this time they have made many improvements in its design. In order to give a clear idea of the extent of these improvements a description of one of the more modern plants designed by this firm is here given. We have selected for this purpose the 1,500-ton plant of the Jamison Coal and Coke Company, of Greensburg, Pennsylvania, at their No. 2 works. The plant, as it stands, is practically fireproof. The tipple is of the most modern design, is constructed entirely of iron and steel, and stands over a raw-coal bin of similar construction and having a capacity of 500 tons. All the buildings are of massive brick construction and are covered with terra-cotta tile roofing supported by steel roof trusses, the roof trusses also being made heavy enough to carry all the main shafting. The storage bins for washed coal are of steel lined with brick made impervious to water. Fig. 37 gives a general idea of the outward appearance of the plant and Fig. 38 shows a plan and elevation. The washing plant has a capacity of 1,500 tons of raw coal in 10 hours and is designed for handling either slack coal or run-of-mine, but as the tipple has about double this capacity, the washing plant is supplied mainly with the coal passing through a 3-inch bar screen, the lump coal thus prepared being loaded directly into the cars by means of a chute. The coal for the washer passes directly into the tooth crushers a, a_1, where it receives its preliminary preparation for the washing plant. From these crushers, the coal drops directly into the raw-coal bin, from which it is drawn by means of an automatic feeding device through the dampers c, from which the coal is delivered by conveyers d, d_1 to elevators e, e_1; all elevators handling the dry coal are mounted on steel frames to eliminate danger from fire. From elevators e, e_1, the coal passes into the sizing screens f, f_1, the particles too large for treatment in the washer falling directly into the special crushers g, which are of such construction as to reduce all coal and also flat and irregularly shaped slate to the desired size without any subsequent handling. The coal thus prepared is delivered by elevators h, h to the washing machines i_1 to i_{10}, on which the clean coal is separated from the slate and pyrites or other impurities, and from which it is floated to the draining elevators j, j_1, from which it is distributed by conveyers k, k_1 into

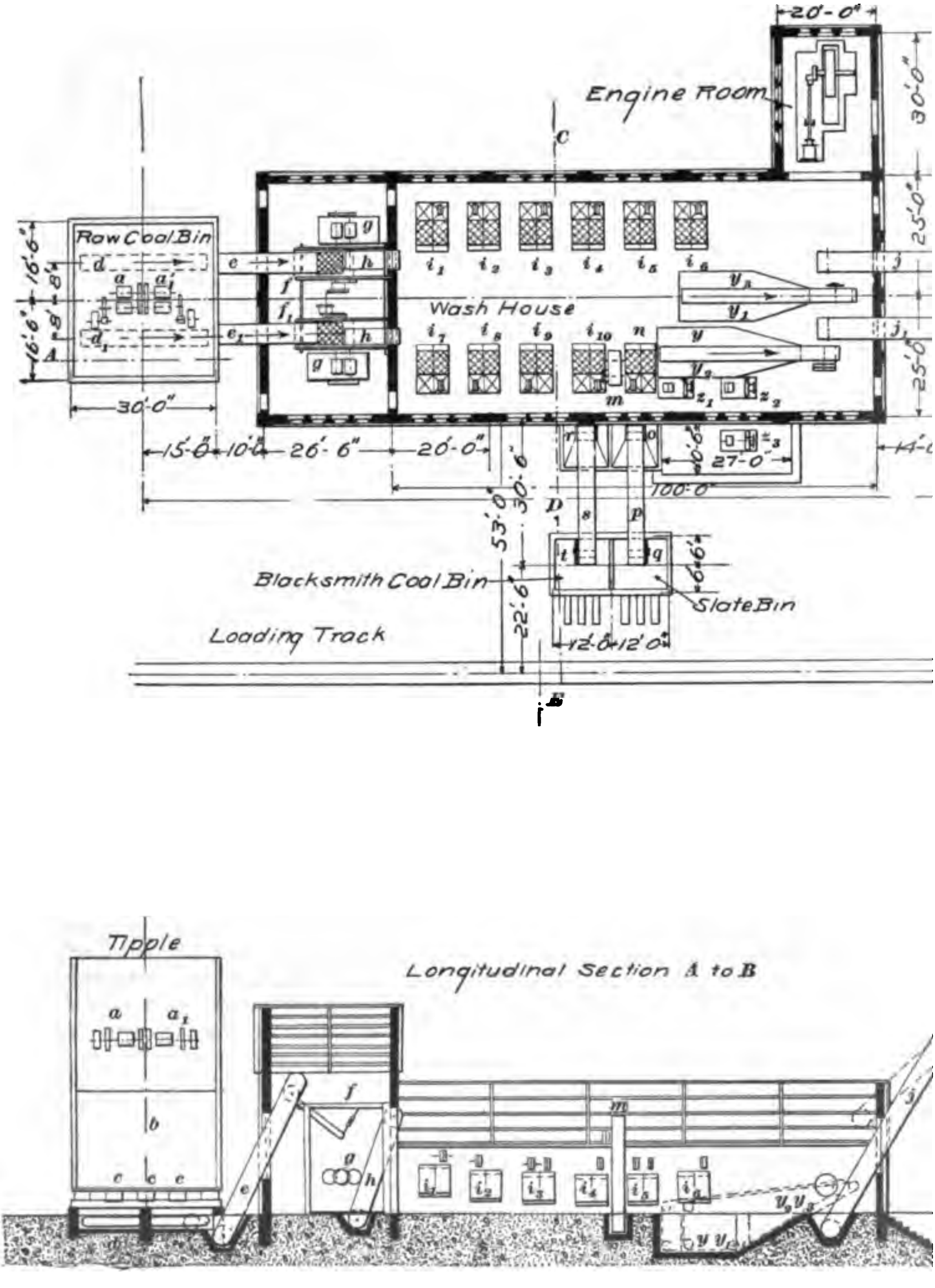
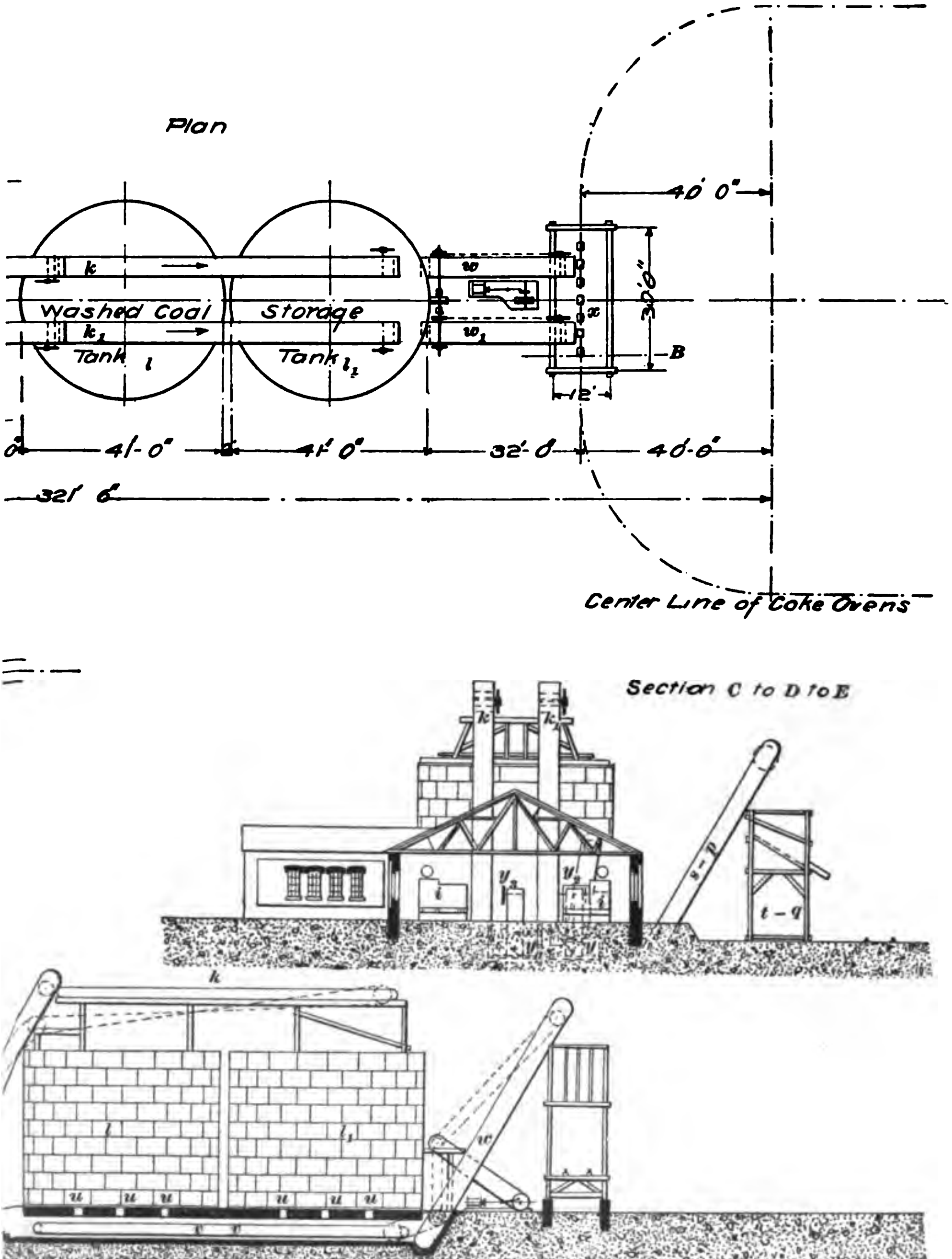


FIG. 38. PLAN AND SECTION OF WASHERY OF JAMISON



COAL AND COKE COMPANY, GREENSBURG, PENNSYLVANIA

the storage tanks l, l_1. The slate and other impurities are received from all the jigs by elevator m, which delivers the same to the jig n for rewashing, in order to recover any particles of coal that would otherwise be lost with the slate. The final slate passes into the settling tank o and thence by means of an elevator p to a slate bin q, from which it is carried away on cars. There is also provision made for diverting such washed coal from the washing plant as is suitable for blacksmith purposes, to the blacksmith-coal bin t, from which it may be loaded into cars. Each of the washed-coal storage tanks l, l_1 has a capacity of one day's run of washed coal and is provided with drainage canals in the foundations; the coal thus properly drained is taken as desired through dampers u by conveyers v and elevators w, w_1 to the bin x from which the larries carrying the coal to the coke ovens are charged. The water from the entire plant is gathered in the settling tanks y, y_1 and the clarified water is sent to the centrifugal pumps z_1, z_2, z_3 to be again circulated through the plant. The settlings in y, y_1 are removed by the conveyers y_2, y_3.

The machinery used for the preliminary crushing is driven by a separate engine, not indicated on the sketch, thus permitting the mine and washer to run independently of each other. The machinery delivering the washed coal from the storage tanks to the larries is also run by a separate engine, enabling the larries to be charged at any time irrespective of the operation of the mine or washer. All the machinery in the plant is very accessible and has been kept on the ground floor, as also the storage tanks and raw-coal bin, which, as will be readily understood, is far more desirable than to have these parts of the plant supported on trestle work or in a high building. Cement floors are used throughout all buildings, which greatly facilitates the work of keeping the plant clean.

Mr. John M. Jamison, president and treasurer, kindly gives the following information as to the cost and work of this washery: (1) The cost of the washer plant designed to wash 1,500 tons of coal in 10 hours is, in round figures, $65,000. We might add in explanation that our plant was built at a time when high prices on all material as well as labor prevailed. (2) The percentage of impurities removed from our coal in washing is approximately 4 per cent. (3) Our experience in washing coal leads us to the conclusion that 10 cents per ton of 2,000 pounds is a reasonably safe estimate to put upon the cost of washing coal; this, of course, includes all the waste.

BAUM WASHER

The **Baum Washer,** Fig 39, is one that washes from 0 inch to 3½ inches without preliminary classification. In its general construction, the washing machine on the Baum system is similar to that of the well-known pulsating washers, with much larger dimensions, but the essential difference is that the pulsating motion is obtained by the action of a compressed-air, 4-foot water gauge, which acts on the surface of the water in compartment *a*, in such a manner that the movement is more elastic, but nevertheless more energetic, than that obtained by a piston. The pulsating motion in the front compartment of the washing machine is

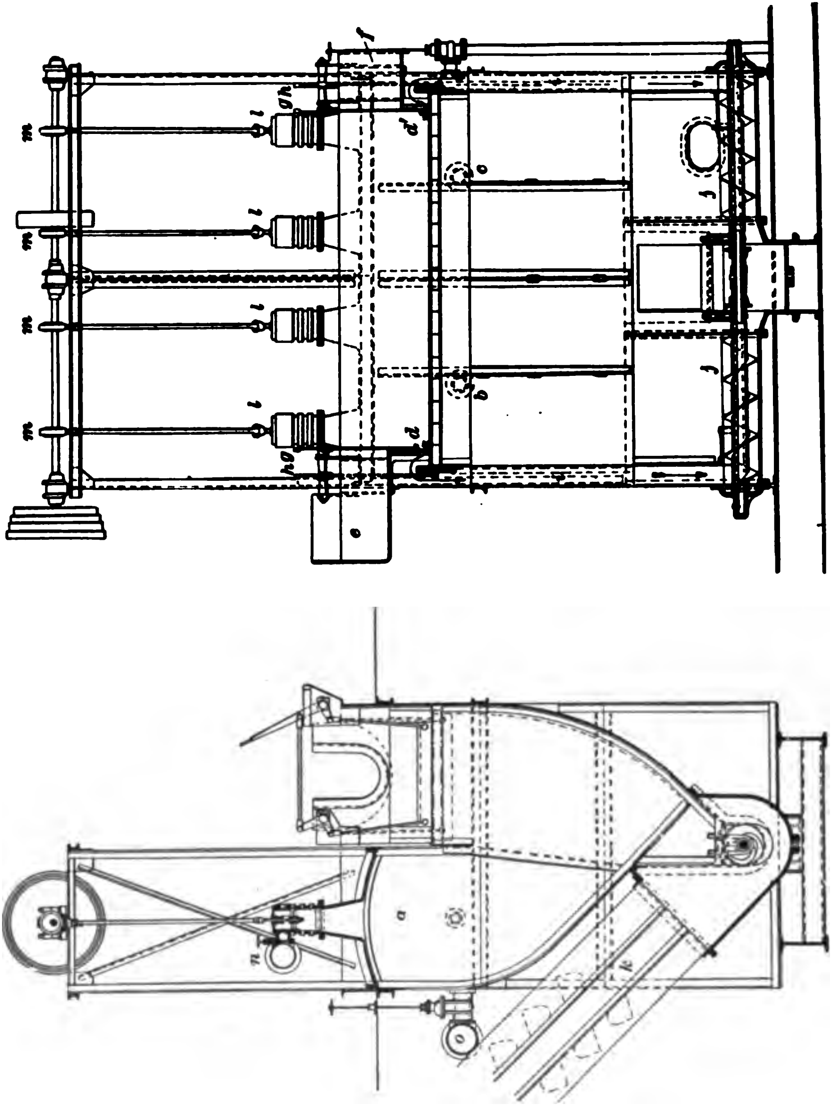


FIG. 39. THE BAUM WASHER

quicker in the upward than in the downward movement. This is effected by a constant inlet of water into the compartment *a* at *b* and *c*. The pulsating motion combined with the movement of the water running through the washer is such that the coal when passing into the front compartment of the washing machine on the top of the sieve *d*, *d'* and going from *e* toward *f* is classified in layers according to specific gravity, the heavier particles sinking to the bottom. The lower layer, composed of dirt and shale, is mechanically taken out at *d* and *d'* through apertures, the height of which is regulated by levers *g*. After having passed through these apertures, the shale has to pass over a dam, the height of which is regulated by means of levers *h*. Having passed through the apertures *d* and *d'* (see the arrows on the drawing), the dirt falls to the bottom of the washing machine through the openings *i* and *i'*. From there it is taken by two Archimedean screws *j* and an elevator *k* with perforated buckets to allow the water to run off.

The admission and exhaust of the compressed air are regulated by sliding valves *l* actuated by the eccentrics *m*. These valves are situated between the pipe *n*, conveying the compressed air, and the compartment *a*.

The coal is introduced, by means of a current of water, into the front compartment of the washing machine at *e*. The water necessary for the washing process is clarified and carried by the pipe *o* that introduces it at *b* and *c*.

Classifying Drum.—The exit of the washing water and of the washed coal is effected at *f* through a trough that leads the whole to a classifying drum of large diameter, and with superimposed sieves where the screening is facilitated by a current of water that forces the coal through the holes of the different sieves of the drum; this peculiarity explains the good results obtained by this apparatus. The drum classifies into as many sizes as may be desired. Each size of coal is then led through troughs to the bunkers for loading into wagons, after having received a quick rinsing with fresh water and a passage over metallic gauze, which allows the water to run off.

Rewashing of Fine Coal.—The fine coal under, say, ½ inch is taken with the washing water underneath the classifying drum by a centrifugal pump that sends it to a washing machine similar to the one described above, where it is washed again before being sent to the draining conveyer.

Separation of Intergrown Coal.—If the quantity of coal contained in the intergrown coal and dirt is only insignificant, the intergrown coal is allowed to go away with the dirt. If, however, the quantity is important, the intergrown coal is separated from the dirt, in which case the coal, after having passed through the first washing machine, is sent to a second washing machine similar to the first, in which the lower layer will be formed by the intergrown coal, which is recovered as described above.

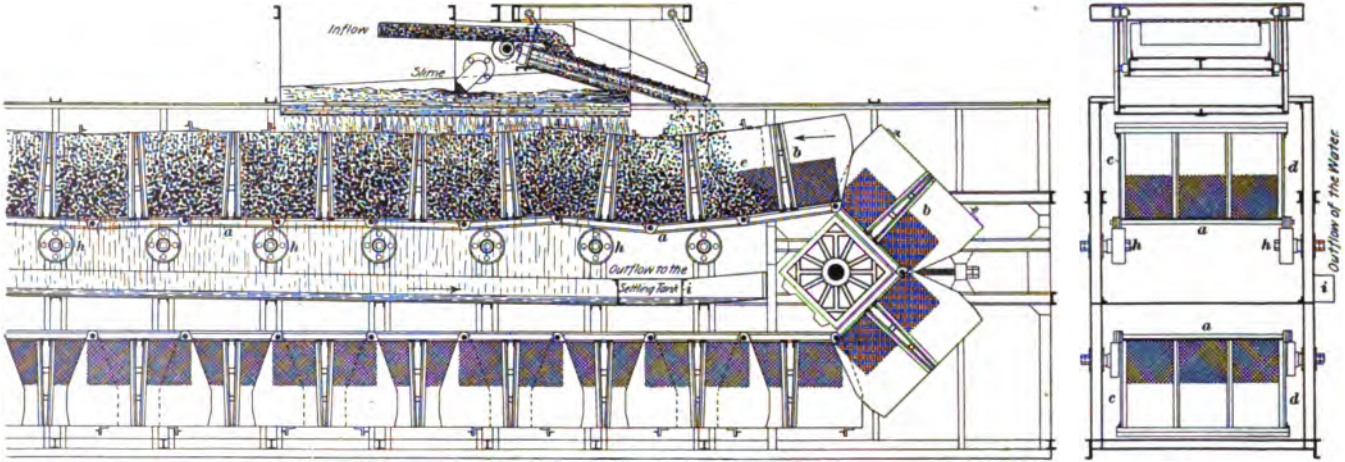


FIG. 40. DRAINING CONVEYER

Separation of the Dirt Out of the Intergrown Coal.—It is sometimes advisable to crush the intergrown coal in order to effectively separate the dirt from it; in that case the crushed intergrown coal is mixed with the fine coal before it enters into the last washing machine.

Draining Plant.—The draining plant, Fig. 40, is able to reduce the added moisture in the coal to such reasonable percentage as may be desired; at the same time, it clarifies the washing water by extracting a great part of the slurry by filtration through a constantly renewed layer of fine coal. This draining plant consists of an extremely strong conveyer, carrying about 2 tons of coal per yard. The conveyer is made with perforated plates *a*, hinged one to the other, and carrying on the middle a double vertical partition *b* of perforated sheets, strengthened with angle irons, and slightly separated from each other to allow the water to run between them; the two upright sides *c* and *d* are also perforated. The conveyer thus presents an aspect of a series of boxes hinged one to the other in the middle of the bottom.

The washing water comes with the fine coal on especially arranged swinging sieves of metallic gauze, which, as indicated in Fig. 40, allow the water, the slurry, and the very fine coal to pass through, while the coarser coal slides down to the conveyer at *e*. The finer coal and the slurry, separated as just mentioned, then fall on top of the coarser coal from *f* to *g*. The coal is now in the best condition for draining.

As the conveyer moves, it passes over the supporting rollers ***h***, the distances and the difference of height between which are calculated so as to let the conveyer bend under the load of coal between one roller and the other. The effect of this sagging of the conveyer is to press the coal between the vertical partitions *b* when it arrives between the rollers, or above the lower rollers, and to open these partitions one from the other as it arrives above the higher rollers. The coal is in this way submitted to a process of pressure and expansion that compels the separation of the water from the coal. This water, in passing through the layer of coarser coal at the bottom of the boxes, leaves a great part of the slurry on the draining conveyer. It is afterwards recovered at *i*, and sent through especially designed settling tanks insuring its thorough clarification. After clarification, the water is used over again in the washer.

Regulation of Moisture.—The percentage of water left in the coal may be regulated by the speed of the conveyer, which has a length of about 22 yards, and generally a speed of about 8 inches per minute. If it is run more rapidly, the percentage of water is larger, the coal having thus less time for draining, and vice versa.

Settling Tanks.—The settling tanks, Fig. 41, are established in such a manner that the slurry still contained in the washing water, after its passage through the draining conveyer, is automatically and continuously recovered. In the latest plants there is only one settling tank of large diameter (33 feet diameter and 39 feet deep), which is constructed in iron and supported by a brick tower outside the washer building. In some plants, the settling tanks are placed inside the washer building on the same floor as the coal hopper. Their object is always the same, facilitating the deposit of the slurry by a sudden stoppage in the speed of the current of water.

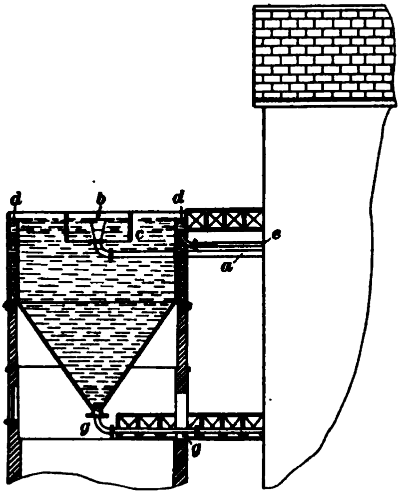


Fig. 41. Settling Tank

The tank is the shape of a cone, with the point downwards. The water containing the slurry is pumped through the pipe *a*, Fig. 41, at the point *b*. It meets the shield *c* and is then compelled to cross the tank from the center to the circumference, and consequently with a speed decreasing in geometrical progression, before it falls into the gutter *d* that surrounds the tank. The water is thus recovered in a clarified state in this gutter, and is taken away by the pipe *e* to the washer. The slurry falling to the bottom of the tank is continuously extracted in the form of a liquid mud through the pipe *g*, which takes it again to the draining plant if it is clean, and where it remains with the fine coal; or, if it is too dirty, it is sent into tanks of small area outside the washer, where it is collected and used when and where the colliery finds it advantageous.

A Baum Washing Plant.—The coal washer, Fig. 42, erected at Gladbeck, Westphalia, may be considered as a standard washer on the Baum system. The coal is brought from the screening plant *a* through jigging screens *b* passing everything under 3 inches into the hopper *c*. It is then lifted by an elevator *d* to the top of the washer building. It receives at *e* a current of water that pushes it into the first washing machine *f*. The shale falls to the bottom of this washing machine and is caught by an elevator with perforated buckets *g*, and dropped along chutes into the hopper *h*. The washed coal is then conducted to the classifying drum *i*, which classifies into five, or as many sizes as may be desired. Each size is delivered into hoppers *j* by means of chutes *k* and spirals, which take the nuts without breakage up to the loading hoppers, each having a capacity of 50 tons.

The fine coal from 0 inch to ½ inch falls with the washing water into a centrifugal pump *l*, which lifts it into a second washing

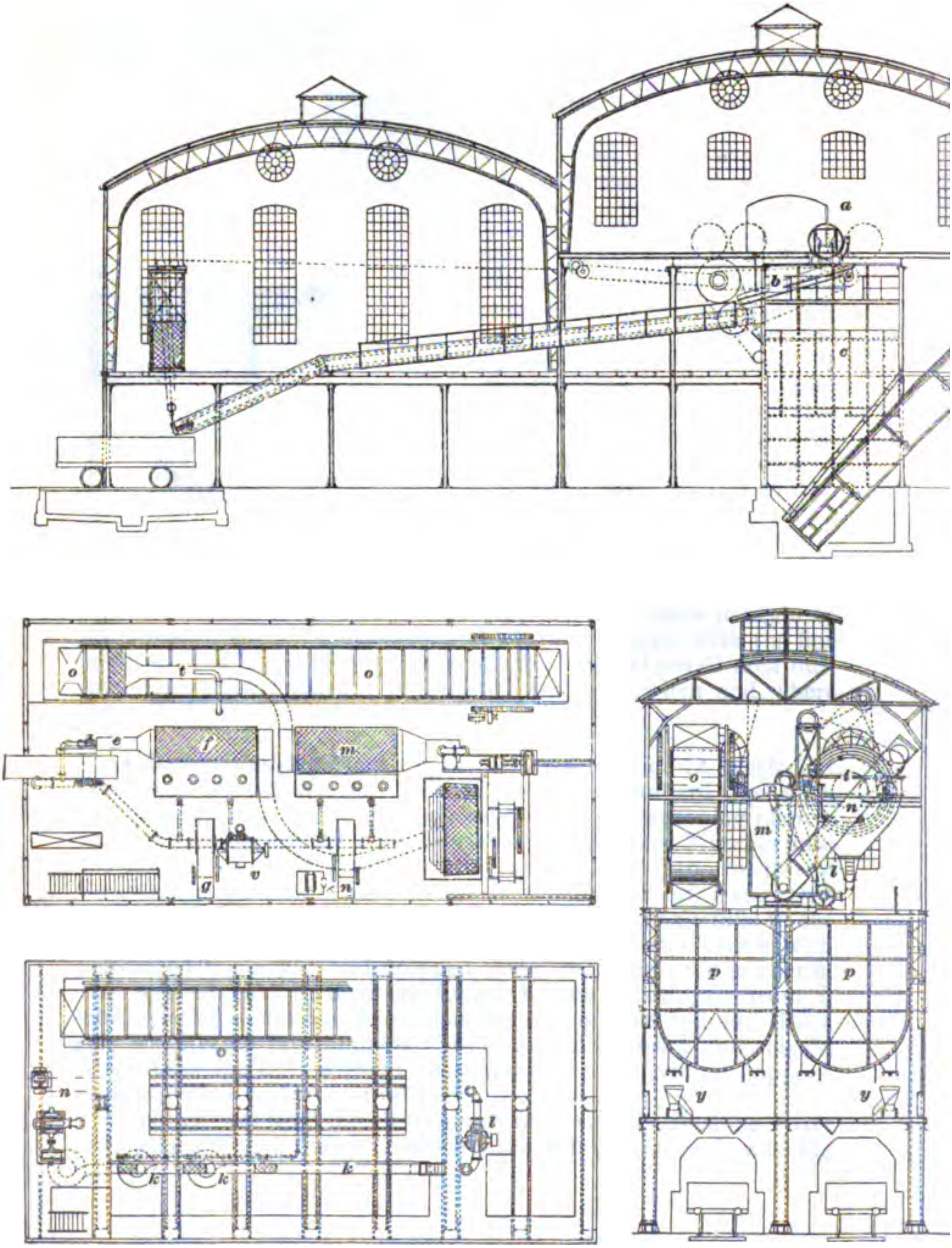
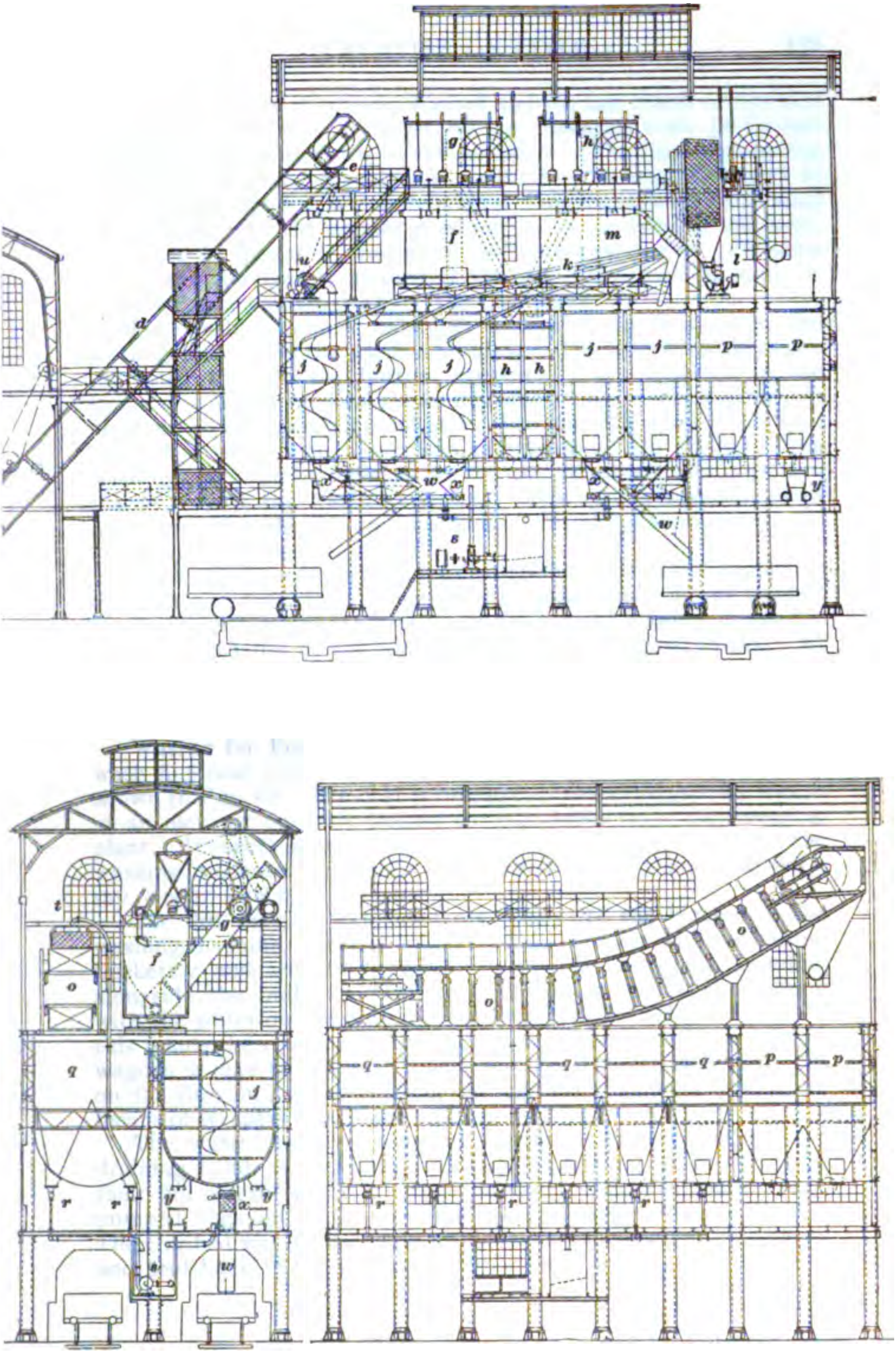


FIG. 42. WASHING PLANT ON BAUM



System at Gladbeck, Westphalia

machine *m*, where it is again washed and the last traces of fine dirt extracted. The dirt is lifted by an elevator with perforated buckets *n* and sent down to the hopper *h*. The fine coal leaving the second washing machine is carried by the washing water to the draining band *o*, which delivers it with the desired percentage of moisture into the hopper *p*, which has a capacity of 200 tons, where it is spread by means of Archimedean screws. In some plants this fine coal is crushed at the end of the draining band by a disintegrator situated above the bunkers *p*.

The washing water undergoes a second clarification in the settling tanks *q* in the washer building. The slurry continuously extracted through the bottom apertures *r* is conducted in the shape of a liquid mud to the centrifugal pump *s*, which pumps it again on to the draining band at *t*. The clarified water is pumped through a centrifugal pump and sent back to the washer. The settling tanks can be replaced by the one previously described and placed outside the washer building. Such an arrangement gives more room for the fine-coal bunkers. The compressed air is provided by the rotary blower *v*.

The washed sized coal is loaded directly into the railway wagons by the chutes *w*, provided at *x* with rinsing apparatus, and the washed fine coal is either loaded directly into the railway wagons or into the larries *y*, situated at the level of the top of the coke ovens. All the motors of this washer are electric, having a total power of 140 horsepower. This washer deals with 100 tons per hour of raw coal.

Washer for Fine Coal.—In cases where it is only required to wash fine coal without sizing, the arrangement of the plant is as shown in Fig. 43. The coal is brought to point *a* either by means of an elevator or by a creeper coming direct from the screening plant. It meets at *a* a current of water that pushes it into the washing machine *b*, suitably constructed to wash fine coal only, say, under $\frac{1}{2}$ inch or $\frac{5}{8}$ inch.

The dirt falls, as explained previously, to the bottom of the washing machine, where it is taken by an elevator with perforated buckets *c* and sent from there into the dirt wagons *d* standing alongside the building. The washed coal is then carried along with the water on the draining band *e* and delivered dry at *f*. At this point, the coal may either be loaded directly into the railway wagons or may be delivered by the elevator *g* shown in dotted lines on the drawing, which takes it through the disintegrator and, by means of scrapers *h*, into the coal bunkers.

The water, having undergone a first clarification through the draining band, is compelled to cross the settling tanks *i* through their full length, where it drops the slurry, which is continuously pumped back on to the draining band by a centrifugal pump *j*. The clarified water is pumped at point *k* by the centrifugal pump *l* and sent back to the washer.

The compressed air is provided by the blower *m*.

The power for driving may be either steam or electricity, and varies from 40 to 60 horsepower according to the size of the plant. The engine or motor is in the engine room *n*, together with the different pumps. The building, partly supported by cast-iron pillars, is of brickwork for the first story, and above the first story, of iron filled in with brickwork.

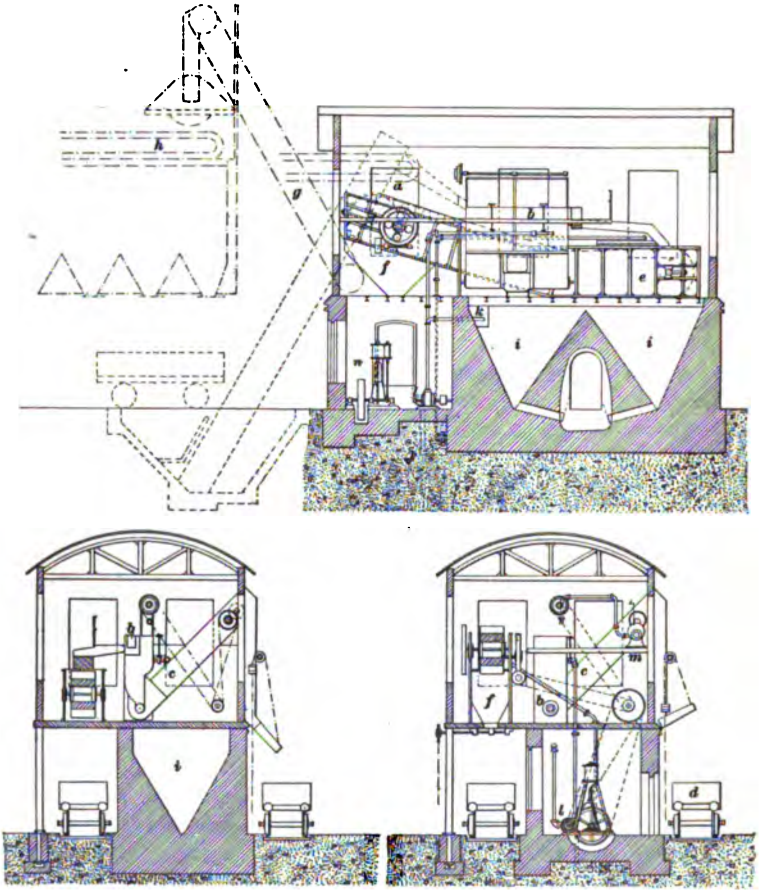


Fig. 43

This very efficient washing plant is made in three different sizes, to treat from 20 to 40 tons of coal per hour, and can be erected and started to work within six months. Above that capacity some alterations are made to the plant.

CHAPTER IV

HISTORY AND DEVELOPMENT OF THE COKE INDUSTRY

History.—Authorities are not in harmony as to the time of the beginning of coke manufacture in England. In 1735, Darby is reported as using coke successfully at Coalbrookdale, in Shropshire; but little was accomplished, however, until 1750, when its use became extended as a blast-furnace fuel. Evidently the same economic conditions that subsequently expanded the use of coke in the United States of America had their earlier force in England, for the scarcity of wood for making charcoal and its increasing cost forced iron manufacturers to search for and use a less expensive fuel. The late Mr. Joseph D. Weeks has called attention to the fact that from the abundance of wood for making charcoal in the United States and the encouragement given to the exportation of charcoal metal to England, it is quite improbable that much, if any, coke was manufactured prior to the Revolution.

In May, 1813, an advertisement appeared in the Pittsburg Mercury, indicating that John Beal, an English emigrant, who possessed the knowledge "of converting stone coal into coak," would, under certain conditions, communicate the same "to proprietors of blast furnaces." It is not on record whether this offer led to the introduction of the manufacture of coke in America.

Shortly after this, however, in 1816-17, Col. Isaac Meason built the first rolling mill, west of the Alleghany Mountains, to puddle iron and roll it into bars, in Fayette County, Pennsylvania; this mill went into operation in September, 1817. Shortly after this time, general attention was directed to the rapid disappearance of the forests of Pennsylvania, accompanied by the discovery of large deposits of coal, all pointing to the necessity of its manufacture into coke for use in the growing iron industry.

In 1825, the acting committee of the Pennsylvania Society for the Promotion of Internal Improvements sent Mr. William Strickland to England, as their agent, to study various subjects relating to internal improvements, and to investigate the methods employed in the manufacture of iron. His letter of instruction was as follows:

"Attempts of the most costly kind have been made to use the coal of the western part of our state in the production of iron. Furnaces have been constructed according to the plan said to be adopted in Wales and elsewhere; persons claiming experience in the business have been employed, but all has been unsuccessful.

In large sections of our state, ore of the finest quality, coal in the utmost abundance, limestone of the best kind, lie in immediate contiguity, and water-power is within the shortest distance of these mines of future wealth.

"The prices which are obtained for iron on the western waters are double those of England, the demand is always greater than the supply, and thus nothing but knowledge of the art of using these rich possessions is wanted.

"We desire your attention to the following inquiries on the subject of the manufacture of iron:

"1. What is the most approved and frequent process for coking coal, and what is the expense per ton or caldron?

"2. In what manner are the arrangements or buildings, if any, constructed for the coking of coal, obtaining drawings and profiles thereof?

"3. Are there different modes for coking coal; and if they have any difference in principle, what are they?

"4. In what manner are the most approved furnaces for the smelting of ore constructed? Drawings and sections of the same to accompany the information that may be obtained upon this inquiry."

Mr. Strickland reported intelligently, with full drawings, illustrating the methods of coke making and the construction of blast furnaces for using this new fuel.

As these investigations were completed in 1825, it is inferred that coke had been in use before this time. A paragraph in the history of Fayette County refers to the use of coke in the Alleghany furnace in Blair County in 1811.

Mr. James M. Swank, general manager of the American Iron and Steel Association, Philadelphia, suggests that the early efforts in the use of coke in blast furnaces were made in mixtures with charcoal.

In 1835, the Franklin Institute of Pennsylvania offered a premium of a gold medal to "the person who shall manufacture in the United States the greatest quantity of iron from the ore during the year, using no other fuel than bituminous coal or coke, the quantity to be not less than 20 tons." In the same year, Mr. William Firmstone was successful in making good gray forge iron for about 1 month at the Mary Anne furnace, in Huntingdon County, Pennsylvania, with coke made from Broad Top coal.

In 1837, F. H. Oliphant made about 100 tons of coke iron at his Fairchance furnace, near Uniontown, Fayette County, Pennsylvania; and in the same year coke was successfully used in the Lonaconing furnace, Frostburg, Maryland.

These early efforts in the use of coke in blast furnaces were not very successful. Probably this came from the imperfect methods of making coke and the insufficient blast to the furnace. The latter was, perhaps, the most retarding cause in the early efforts in smelting pig iron with coke. While these experimental tests in the use of coke were carried forward in Pennsylvania and Maryland, other states were also making efforts in the same direction. Coke did not come into use rapidly. In 1849, Prof. J. P. Lesley failed to record a single coke furnace in blast in Pennsylvania. In 1856, however, he reported 21 furnaces in blast in Pennsylvania and 3 in Maryland using coke.

The early history of coke making in the Connellsville region is involved in some obscurity; but Colonel Meason used coke at his refinery in 1819. In 1841, two carpenters, Provence McCormick and James Campbell, united with a stone mason, Mr. John Taylor, in a coking enterprise. The mason was to build the coke ovens and the carpenters would construct the arks to convey the coke by river to market at Cincinnati. Two ovens were built about 10 feet in diameter. The coal charge was about 80 bushels. In the spring of 1842 enough coke was made to load two boats 90 feet long, about 800 bushels each. These were taken to Cincinnati, but the demand was trifling and the parties, losing heavily in the enterprise, became disgusted with the outlook for marketing coke. This was the beginning of the manufacture of coke in the great Connellsville field, which now sends to market annually over 14 millions of tons.

The growth of the coke industry was undoubtedly greatly assisted by the excellent product of Connellsville, but the manufacture struggled along up to 1880 without impressing its value as of sufficient importance to give it a place in the statistics of the products of the industries of the United States. It has now attained a position and magnitude of prime importance in all metallurgical operations.

The following table will show the number of coke establishments in the United States, indicating the growth of the manufacture of coke from 1850 to 1903.

STATISTICS SHOWING DEVELOPMENT OF COKE INDUSTRY

Year		Number of Establishments	Year		Number of Establishments
1850	Census Year	4	1890	December 31	253
1860	Census Year	21	1891	December 31	243
1870	Census Year	25	1892	December 31	261
1880	Census Year	149	1893	December 31	258
1880	December 31	186	1894	December 31	260
1881	December 31	197	1895	December 31	265
1882	December 31	215	1896	December 31	341
1883	December 31	231	1897	December 31	336
1884	December 31	250	1898	December 31	341
1885	December 31	233	1899	December 31	343
1886	December 31	222	1900	December 31	388
1887	December 31	270	1901	December 31	423
1888	December 31	261	1902	December 31	456
1889	December 31	252			

NOTE.—The above and several following statistical tables are taken from the United States Geological Survey, Department of Mineral Resources.

NUMBER OF COKE OVENS, BEEHIVE AND BY-PRODUCT, IN THE UNITED STATES ON DECEMBER 31 OF EACH YEAR FROM 1880 TO 1902, WITH THEIR ANNUAL OUTPUTS

Year	Number of Ovens	Output Net Tons	Year	Number of Ovens	Output Net Tons
1880	12,372	3,338,300	1892	42,002	12,010,829
1881	14,119	4,113,760	1893	44,201	9,477,580
1882	16,356	4,793,321	1894	44,772	9,203,632
1883	18,304	5,464,721	1895	45,565	13,333,714
1884	19,557	4,873,805	1896	46,944	11,788,773
1885	20,116	5,106,696	1897	47,668	13,288,984
1886	22,597	6,845,369	1898	48,383	16,047,209
1887	26,001	7,611,705	1899	49,603	19,668,569
1888	30,059	8,540,030	1900	58,484	20,533,348
1889	34,165	10,258,022	1901	64,001	21,795,883
1890	37,158	11,508,021	1902	69,069	25,401,730
1891	40,057	10,352,688			

The year 1880 marks the first great appreciation of the value of coke for the manufacture of Bessemer pig iron. It marked an era of rapid uplift in the values of coke and coking-coal lands. It is well to note that the number of ovens at the close of each year represents those in existence, but it does not mean that there were that many in active operation. In this connection it is interesting to note the increase in the productive capacity of the coke ovens in the United States. It is not possible to compare the number of ovens in actual operation each year, and the averages must be

RECORD OF BY-PRODUCT COKE MAKING FROM 1893 TO 1902

Year	Ovens		Production Net Tons
	Built	Building	
1893	12		12,850
1894	12	60	16,500
1895	72	60	18,521
1896	160	120	83,038
1897	280	240	261,912
1898	520	500	294,445
1899	1,020	65	906,534
1900	1,085	1,096	1,075,727
1901	1,165	1,533	1,179,900
1902	*1,663	†1,346	‡1,403,588

*Includes 525 Semet-Solvay, 1,067 Otto-Hoffman, 15 Schniewind, and 56 Newton Chamber's ovens; †Includes 210 Semet-Solvay, 664 Otto-Hoffman, 412 Schniewind, and 60 Retort Coke Company ovens; ‡By-product coke embraced in general table of coke production in the United States.

based on the number of ovens in existence at the close of each year. In 1880, the number of ovens in existence was 12,372 and the total coke production was 3,338,300 net tons, an average of 278 tons of coke per oven. In 1890, the total number of ovens reported was 37,158 and the production of coke was 11,508,021 net tons, an average of 310 tons of coke per oven. In 1900, the total number of ovens reported was 58,484 and the production was 20,533,348 net tons, an average of 351 tons of coke per oven. The number of ovens in use in 1900 was 4.7 times those in existence in 1880. The output of coke in 1900 was 6.2 times that of 1880. The increase of production in 1901, as compared with the preceding year, was 1,262,535 net tons, or 6.15 per cent. Coke production in 1902 overtopped all previous records; it was 25,401,730 net tons, exhibiting an increase over 1901 of 3,605,847 net tons or 16.5 per cent. The inability of railroads to furnish cars and motive power materially reduced this year's output, increasing the expense of production.

RECORD OF BY-PRODUCT COKE OVENS BY STATES, AT THE CLOSE OF 1900, 1901, AND 1902

States	Ovens, December 31, 1900		Ovens, December 31, 1901		Ovens, December 31, 1902	
	Completed	Building	Completed	Building	Completed	Building
Alabama	120	120	120	120	240	40
Maryland				200		200
Massachusetts	400		400		400	
Michigan		30	30	45	75	60
New Jersey		100		100	100	
New York	30	564	30	564	30	574
Ohio		50	50		50	60
Pennsylvania	355	232	355	504	592	412
Virginia	60		60		56	
West Virginia	120		120		120	
Totals	1,085	1,096	1,165	1,533	1,663	1,346

The records of the number of by-product coke ovens in the above table are accumulative; the whole number of these ovens completed and building in the United States at the close of the year 1902 is given in the last two columns, 1,663 built and 1,346 building.

By the term **yield** is meant the percentage of merchantable coke that has been obtained from the coal used in its manufacture. The table shows that the general average for most of the years given is about 64 per cent., but in most instances this indicates the value of the coke oven used and the care afforded the coking operations. Until recent years, these elements in securing full

AMOUNT OF COKE PRODUCED IN THE UNITED STATES FROM 1896 TO 1902, INCLUSIVE, BY STATES AND TERRITORIES (NET TONS)

State or Territory	1896	1897	1898	1899	1900	1901	1902
Alabama	1,479,437	1,443,017	1,663,020	1,787,809	2,110,837	2,148,911	2,552,246
Colorado	343,313	319,036	445,982	530,424[a]	618.755[a]	671.303[a]	1,003,393[a]
Georgia	53,673	33,000	49,529	50,907	73,928	54,550	82,064
Illinois	2,600	1,549	2,325	2,370	2,631	[d]	[d]
Indiana	4,353	2,904	1,825				
Indian Territory	21,021	30,364	34,110	24,339	38,141	37,374	49,441
Kansas	4,785	6,181	4,180	14,476	5,948	7,138	20,902
Kentucky	27,107	32,117	22,242	81,095	95,532	100,285	126,879
Massachusetts				[b]	[d]	[d]	[d]
Missouri	2,500	2,503	740	2,860	2,087	4,749	5.780
Montana	60,078	67,849	52,009	56,376	54,731	57,004	53,463
New Mexico	24,228	1,438	6,980	44,134	44,774	41,643	23,296
New York[b]							
Ohio	80,868	95,087	85,535	83,878	72,116	108,774	146,099
Pennsylvania	7,356,502	8,966,924[c]	10,715,302[c]	13,577,870[c]	13,798,893	14,355,917	16,497,910
Tennessee	339,202	368,769	394,545	435,308	475,432	404,017	560,006
Texas		394					
Utah	20,447	23,617	28,826	[a]	[a]	[a]	[a]
Virginia	268,081	354,067	531,161	618,707	685,156	907,130	1,124,572
Washington	25,949	26,189	30.197	30,372	33,387	49,197	40,305
West Virginia	1,649,755	1,472,666	1,925,071	2,278,577	2,358,499	2,283,700	2,516,505
Wisconsin	5,332	17,216	35,280	33,437	48,000	564,191	598,869
Wyoming	19,542	24,007	18,350	15,630	14,501		
Totals	11,788,773	13,288,984	16,047,209	19,668,569	20,533,348	21,795,883	25,401,730

[a] Colorado includes Utah.

[b] Included with Pennsylvania.

[c] Includes production of New York; and of Massachusetts also in 1899.

[d] Included in Wisconsin and Wyoming.

APPROXIMATE STATEMENT OF AMOUNT OF COAL REQUIRED TO PRODUCE 1 TON OF COKE IN EACH YEAR SINCE 1880, WITH PERCENTAGE OF YIELD (NET TONS)*

Year	Tons	Pounds	Per Cent. Yield	Year	Tons	Pounds	Per Cent. Yield
1880	1.57	3,140	63.0	1892	1.57	3,140	64.0
1881	1.59	3,180	63.0	1893	1.57	3,140	63.5
1882	1.58	3,160	63.0	1894	1.56	3,120	64.0
1883	1.56	3,120	64.0	1895	1.56	3,120	64 0
1884	1.63	3,260	61.0	1896	1.58½	3,170	63.0
1885	1.58	3,160	63.0	1897	1.57	3,140	63.5
1886	1 56	3,120	64.0	1898	1.57	3,140	63.6
1887	1.56	3,120	64.2	1899	1.54	3,080	65.1
1888	1.51	3,020	66.0	1900	1.57	3,140	63.9
1889	1.55	3,100	64 0	1901	1.57	3,140	63.9
1890	1.56	3,120	64.0	1902	1.56	3,129	64.1
1891	1.58	3,100	63.0				

*These figures include both beehive and by-product coke.

PERCENTAGE OF YIELD OF COKE FROM THE SEVERAL QUALITIES OF COALS USED IN ITS MANUFACTURE IN EACH STATE AND TERRITORY DURING 1896-1902

State or Territory	1896	1897	1898	1899	1900	1901	1902
Alabama	57.5	58.8	59.0	59.0	58.9	55.8	60.2
Colorado[a]	56.9	55.6	59.1	59.0	62.0	58.4	59.2
Georgia	49.0	49.3	61.0	65.2	52.4	60.7	63.3
Illinois	66.7	43.0	35.0	56.2	57.1		
Indiana	49.0	41.4	44.9				
Indian Territory	40.0	44.3	46.5	41.0	48.0	50.0	44.6
Kansas	53.5	52.5	53.0	53.6	57.7	61.4	58.3
Kentucky	48.6	50.0	50.0	53.5	50.2	49.0	47.8
Massachusetts							
Missouri	55.9	56.0	49.3	53.8	55.3	52.5	55.4
Montana	53.0	48.5	56.0	51.0	50.3	55.4	53.7
New Mexico	61.7	55.6	55.6	64.3	60.3	57.5	56.9
New York							
Ohio	62.7	62.7	63.5	58.8	62.5	66.9	66.6
Pennsylvania[b]	66.1	66.2	65.7	68.1	66.2	66.0	65.9
Tennessee	56.5	55.0	54.6	55.8	55.6	54.6	54.6
Texas		56.3					
Utah							
Virginia	58.9	61.6	62.0	62.2	63.2	64.7	65.5
Washington	67.0	67.0	62.2	59.8	61.5	62.7	58.8
West Virginia	61.4	61.0	61.2	60.0	60.9	61.1	61.7
Wisconsin	62.0	59.0	59.0	60.8	60.0	71.1[c]	70.2[c]
Wyoming	47.6	43.7	51.9	48.7	44.7		
Total average	63.	63.5	63.6	65.1	63.9	63.7	64.1

[a] Average, including Utah.

[b] Average, including New York, also Massachusetts for 1899.

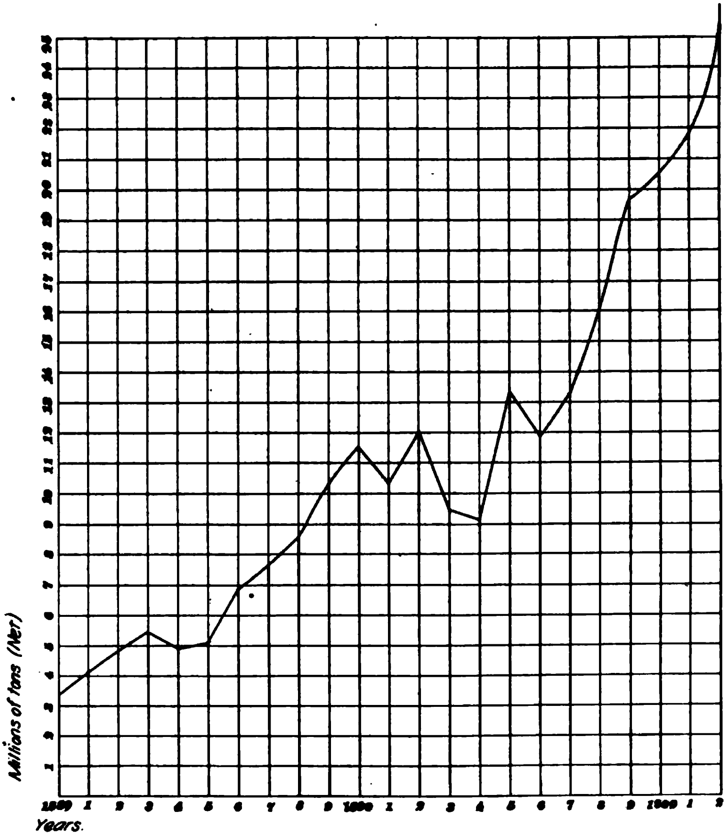
[c] Includes Illinois, Indiana, Massachusetts, Michigan, New York, Wisconsin, and Wyoming.

yields from the several qualities of the coals have not received the consideration that their importance demanded.

Two elements must be harmonized to secure the largest percentage of merchantable coke in the different types of coke ovens: (1) properly applied skill; (2) correct knowledge of the quality of the coking coal. It may be added that in all dry coals inheriting a large percentage of fixed carbon, with a correspondingly low volume of hydrogenous matter, some of this fixed carbon must be consumed in the coking process; while, on the other hand, coking coal with a large volume of volatile combustible matter will require very little of its fixed carbon in the process of coking.

The table on page 137 indicates a slight general average increase of percentage of coke product during 1902 over that of 1901, but there is evidently room for further increased percentage of coke.

DIAGRAM ILLUSTRATING THE GROWTH OF THE MANUFACTURE OF COKE IN THE UNITED STATES FROM 1880 TO 1902, INCLUSIVE



AMOUNT OF COKE PRODUCED IN THE UNITED STATES FROM 1880 TO 1902

Year	Net Tons	Year	Net Tons	Year	Net Tons
1880	3,338,300	1888	8,540,030	1896	11,788,773
1881	4,113,760	1889	10,258,022	1897	13,288,984
1882	4,793,321	1890	11,508,021	1898	16,047,209
1883	5,464,721	1891	10,352,688	1899	19,668,569
1884	4,873,805	1892	12,010,829	1900	20,533,348
1885	5,106,696	1893	9,477,580	1901	21,795,883
1886	6,845,369	1894	9,203,632	1902	25,401,730
1887	7,611,705	1895	13,333,714		

COKE IMPORTED AND ENTERED FOR CONSUMPTION IN THE UNITED STATES FROM 1869 TO 1902 (NET TONS)

Year Ending June 30	Quantity	Value	Year Ending Dec. 31	Quantity	Value
1869		$ 2,053	1886	28,124	$ 84,801
1870		6,388	1887	35,320	100,312
1871		19,528	1888	35,210	107,914
1872	9,575	9,217	1889	28,608	88,088
1873	1,091	1,366	1890	20,808	101,767
1874	634	4,588	1891	50,753	223,184
1875	1,046	9,648	1892	27,420	86,350
1876	2,065	8,657	1893	37,183	99,683
1877	4,068	16,686	1894	32,566	70,359
1878	6,616	24,186	1895	29,622	71,366
1879	6,035	24,748	1896	43,372	114,712
1880	5,047	18,406	1897	34,937	98,077
1881	15,210	64,987	1898	46,127	142,334
1882	14,924	53,244	1899	31,197	142,504
1883	20,634	113,114	1900	115,556	371,341
1884	14,483	36,278	1901	72,727	266,075
1885	20,876	64,814	1902	140,488	423,775

From the above it will be seen that this imported coke cost per ton as follows: 1872, $.962; 1880, $3.645; 1890, $4.8975; 1900, $3.215; 1902, $3.165.

COKE EXPORTED FROM THE UNITED STATES SINCE 1895 (NET TONS)

Year	Quantity	Value	Year	Quantity	Value
1895	131,368	$425,174	1899	280,196	$ 858,856
1896	169,189	553,600	1900	422,239	1,358,968
1897	173,034	546,066	1901	430,450	1,561,898
1898	199,562	600,931	1902	439,590	1,785,188

The amount and value of coke exported from the United States have increased each year since 1895, as seen in the above table.

The prices obtained for this coke per ton, are as follows: 1895, $3.2375; 1898, $3.01; 1900, $3.2175; 1902, $4.06.

AMOUNT OF COAL USED IN THE MANUFACTURE OF COKE IN THE UNITED STATES, FROM 1896 TO 1902, INCLUSIVE, BY STATES AND TERRITORIES (NET TONS)

State or Territory	1896	1897	1898	1899	1900	1901	1902
Alabama	2,573,713	2,451,475	2,814,615	3,028,472	3,582,547	3,849,908	4,237,491
Colorado[a]	639,238	616,592	803,686	898,207	997,861	1,148,901	1,695,188
Georgia	109,655	67,000	81,108	78,098	140,988	89,919	129,642
Illinois	3,900	3,591	6,650	4,217	4,605	[f]	[f]
Indiana	8,956	7,022	4,065				
Indian Territory	53,028	68,495	73,330	59,255	79,534	74,746	110,931
Kansas	8,940	11,772	7,856	26,988	10,303	11,629	35,827
Kentucky	55,719	64,234	44,484	151,503	190,268	204,297	265,121
Massachusetts				[b]	[f]	[f]	[f]
Missouri	4,471	4,627	1,500	5,320	3,775	9,041	10,430
Montana	113,165	139,907	92,552	110,274	108,710	102,950	99,628
New Mexico	39,286	2,585	12,557	68,594	74,261	72,350	40,943
New York	[b]	[b]	[b]	[b]	[f]	[f]	[f]
Ohio	128,923	151,545	134,757	142,678	115,269	162,624	219,401
Pennsylvania	11,124,610[c]	13,538,646[c]	16,307,841[c]	19,930,419[d]	20,831,196	21,736,467	25,017,326
Tennessee	600,379	667,996	722,356	779,995	854,789	739,246	1,025,864
Texas		700					
Utah[e]							
Virginia	454,964	574,542	852,972	994,635	1,083,827	1,400,231	1,716,110
Washington	38,685	39,124	48,559	50,813	54,310	78,393	68,546
West Virginia	2,687,104	2,413,283	3,145,398	3,802,825	3,868,840	3,734,076	4,078,579
Wisconsin	8,648	29,207	59,900	54,950	[d] 80,000	793,187[d]	852,977[d]
Wyoming	41,038	54,976	35,384	32,100	32,400		
Totals	18,694,422	20,907,319	25,249,570	30,219,343	32,113,543	34,207,965	39,604,007

[a] Includes coal coked in Utah.

[b] Included with Pennsylvania in 1898 to 1902.

[c] Includes New York

[d] Includes Massachusetts and New York.

[e] Included with Colorado.

[f] Included with Wisconsin and Wyoming.

CONDITION OF COAL CHARGED INTO COKE OVENS, WHETHER RUN-OF-MINE, SLACK OR SCREENED, WASHED OR UNWASHED, DURING THE YEAR 1902

State or Territory	Run-of-Mine		Slack or Screened		Total
	Unwashed	Washed	Unwashed	Washed	
Alabama	1,233,117	509,376	290	2,494,708	4,237,491
Colorado[a]	831		641,422	1,052,935	1,695,188
Georgia	28,600			101,042	129,642
Illinois[b]					
Indiana[b]					
Indian Territory		3,947		106,987	110,934
Kansas		1,766	14,126	19,935	35,827
Kentucky	5,000	28,159	91,496	140,466	265,121
Massachusetts[b]					
Missouri			10,430		10,430
Montana		99,628			99,628
New Mexico			208	40,735	40,943
New York					
Ohio	161,783		19,618	38,000	219,401
Pennsylvania	21,615,568	602,287	1,623,624	1,175,847	25,017,326
Tennessee	287,064	334,109	47,161	357,530	1,025,864
Utah					
Virginia	1,018,148		697,962		1,716,110
Washington		68,546			68,546
West Virginia	1,262,393		2,517,223	298,963	4,078,579
Wisconsin Wyoming	[b]735,194		117,528	255	852,977
Totals	26,347,698	1,647,818	5,781,088	5,827,403	39,604,007

[a] Includes Utah.
[b] Includes Illinois, Indiana, and Massachusetts.

The above table shows that, as a general average with all kinds of coal, it required 1.5591 tons of coal to make 1 ton of coke.

CONDITION OF COAL USED IN THE MANUFACTURE OF COKE IN THE UNITED STATES, FROM THE YEAR 1890 TO 1902, INCLUSIVE (NET TONS)

Year	Run-of-Mine		Slack or Screened		Total
	Unwashed	Washed	Unwashed	Washed	
1890	14,060,907	338,563	2,674,492	931,247	18,005,209
1891	12,255,415	290,807	2,945,359	852,959	16,344,540
1892	14,453,638	324,050	3,256,493	779,156	18,813,337
1893	10,306,082	350,112	3,049,075	1,211,877	14,917,146
1894	9,648,750	405,266	3,102,652	1,192,082	14,348,750
1895	15,609,875	237,468	3,052,246	1,948,734	20,848,323
1896	11,307,905	763,244	4,685,832	1,937,441	18,694,422
1897	13,234,985	1,037,830	4,180,575	2,453,929	20,907,319
1898	16,758,244	1,672,972	4,487,949	2,330,405	25,249,570
1899	20,870,915	1,457,961	4,796,737	2,913,730	30,219,343
1900	21,062,090	1,369,698	5,677,006	4,004,749	32,113,543
1901	23,751,468	1,600,714	4,546,201	4,309,582	34,207,965
1902	26,347,698	1,647,818	5,781,088	5,287,403	39,604,007

In the preceding table, the columns of washed coal indicate in a marked manner that coke makers have entered into an era of washed coal in the manufacture of coke. This gradual increase in coal washing also indicates the reduction of the areas of coking-coal lands whose coal required no washing for use in coke ovens.

AVERAGE VALUE PER NET TON OF COKE, AT THE OVENS, MADE IN THE UNITED STATES, FROM 1897 TO 1902, BY STATES AND TERRITORIES

State or Territory	1897	1898	1899	1900	1901	1902
Alabama	$2.140	$2.030	$2.03	$2.667	$2.820	$3.250
Colorado[a]	2.916	2.590	2.51	2.820	2.420	2.740
Georgia	1.280	1.560	2.30	2.849	2.830	3.643
Indian Territory	3.450	2.833	2.96	3.990	4.140	4.100
Kansas	1.500	1.544	2.13	2.520	2.110	2.617
Kentucky	1.410	1.448	1.99	2.465	2.070	2.505
Missouri	1.500	1.420	1.93	2 520	2 099	2.500
Montana	6.890	6.906	6.32	6.159	5.918	6.750
New Mexico	2.250	2.095	2.25	2.909	2.840	3.178
Ohio	2.480	2.470	3.04	2.690	2.750	3.370
Pennsylvania	1.530[b]	1.500[b]	1.69[b]	2.220	1.885	2.330
Tennessee	1.810	1.630	1.95	2.670	2.358	2.850
Utah[c]						
Virginia	1.400	1.317	1.73	2.137	1.635	2.065
Washington	4.420	4.270	4 98	4.797	4.858	4.940
West Virginia	1.310	1.260	1.53	2.010	1.800	2.318
Illinois	1.870	2.020	2.35	2.870	2.849	3.446
Indiana	1.995	1.750				
Massachusetts			[d]			
Michigan						
New York		[d]	[d]			
Wisconsin	4.300	3.500	3.75			
Wyoming	3.000	3.500	2.46			
Average	$1.663	$1.594	$1.76	$2.310	$2.039	$2.490

[a] Includes Utah.

[b] Average value, including New York, and also Massachusetts in 1899.

[c] Included with Colorado.

[d] Included with Pennsylvania.

NOTE.—The great majority of prices secured for coke at ovens in the above table shows that, excepting the brief boom times, very little if any margin of profit has been secured; in fact, during some of these years coal was receiving prices equal to, if not above, that of coke.—ED.

TOTAL VALUE OF COKE, AT THE OVENS, MADE IN THE UNITED STATES, FROM 1880 TO 1902

Year	Value	Year	Value	Year	Value
1880	$ 6,631.265	1888	$12,445,963	1896	$21,660,729
1881	7,725,175	1889	16,630,301	1897	22,102,514
1882	8,462,167	1890	23.215.302	1898	25,586,699
1883	8,121,607	1891	20,393,216	1899	34,670,417
1884	7,242,878	1892	23,536,141	1900	47,443,331
1885	7,629,118	1893	16,523,714	1901	44,445,923
1886	11,153,366	1894	12.328.856	1902	63,339,167
1887	15,321,116	1895	19,234,319		

RANK OF STATES AND TERRITORIES IN THE PRODUCTION OF COKE FROM 1890 TO 1902

State or Territory	1890	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900	1901	1902
Pennsylvania	1	1	1	1	1	1	1	1	1	1	1	1	1
Alabama	2	2	2	2	3	2	3	3	3	3	3	3	2
West Virginia	3	3	3	3	2	3	2	2	2	2	2	2	3
Virginia	4	6	6	6	6	6	6	5	4	4	4	4	4
Colorado	6	5	4	4	4	5	4	6	5	5	5	5	5
Tennessee	5	4	5	5	5	4	5	4	6	6	6	7	6
Massachusetts										7	7	6	7
Ohio	8	8	8	10	8	8	7	7	7	8	10	8	8
Kentucky	7	10	9	8	9	9	10	10	15	9	8	9	9
Utah	19	14	13	11	12	11	14	15	13	16	15	12	10
Georgia	10	7	7	7	7	7	9	9	9	11	9	11	11
Wisconsin	14	9	11	12	18	17	17	16	10	13	12	13	12
Montana	11	11	10	9	10	10	8	8	8	10	11	10	13
Michigan												20	14
Indian Territory	17	13	16	15	19	16	13	11	11	17	14	17	15
New York				13	11	12	16	12	14	15	16	16	16
Washington		16	15	16	16	13	11	13	12	14	17	14	17
New Mexico	9	20		18	15	14	12	21	17	12	13	15	18
Kansas	12	12	12	14	13	15	18	17	18	19	19	19	19
Wyoming		19		20	17	18	15	14	16	18	18	18	20
Missouri	16	15	14	17	20	21	21	19	21	20	20	21	21
Illinois	18	17	18	21	21	20	20	20	19	22	22	22	22
Indiana	15	18	17	19	14	19	19	18	20	21	21		
Texas						22	22	22					

In the preceding tables a steady increase both in the number of plants and ovens, as well as in total output, will be noticed. It is of interest also to notice the increased capacity of the individual ovens. In 1880, 12,372 ovens produced a total output of 3,338,300 short tons of coke, an average of 270 short tons per oven. During the year 1902, there were in active operation 67,124 ovens, which produced 25,401,730 short tons of coke, an average of 378.4 tons per oven. In 1901, the total number of active ovens was 61,396 which produced 21,795,883 tons of coke, an average of 355 tons per oven, showing that the average productive capacity of each oven in 1902 exceeded that of the preceding year by 23.4 tons.

CHAPTER V

MANUFACTURE OF COKE

Methods of Coking Coal.—Coking is the art of preparing from bituminous or other coal a fuel adapted for metallurgical and other special uses. The operation consists in expelling by heat the gaseous elements from coking coals, leaving the fixed and deposited carbon, ash, and the residue of sulphur and phosphorus. These constitute what is known as coke. There are three principal methods now in general use in the manufacture of coke: (1) Coking the coal in heaps or mounds, in the open air; (2) coking the coal in the beehive or round oven partly enclosed, with the air partially excluded; (3) coking in retort or closed ovens, with air almost entirely excluded. In these methods there are some modifications, but the governing principles are maintained in whole or part. The open-pit method is rapidly disappearing, as it is wasteful of the coal and tedious in operation. The beehive coke oven holds its place firmly from its moderate cost in construction and simplicity in operation, with its product of the best possible metallurgical fuel. The retort coke oven, with its supplemental apparatus for saving of by-products, affords many advantages in special localities and under favorable conditions, but from its large cost in construction and installation, with the expert agencies required in its operations, it cannot hope for general application.

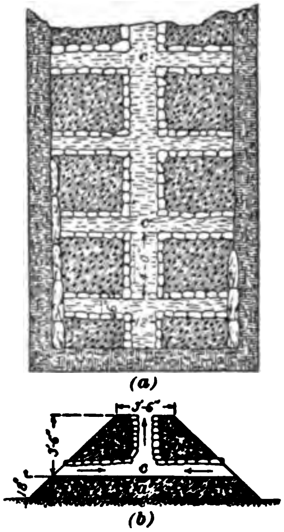


Fig. 1. Bennington Coke Pits

Coking Coal in Heaps or Mounds.—The open-air coking in heaps or mounds has been copied from the mounds of the charcoal burners. This primitive and wasteful mode of coking requires a yard made by leveling the ground and surfacing it with coal dust. The coal to be coked is then arranged in rectangular heaps or mounds, Fig. 1, with longitudinal transverse, and vertical flues; sufficient wood having been distributed in these to ignite the mass of coal.

Beginning on the prepared floor, a base of coal *a* 14 feet broad is spread to a height of 18 inches. On this base the flues are arranged and constructed as shown in the plan (*a*), the flues being built of refuse coke and lump coal and covered with suitable billets of wood. The coal is piled up as shown in the cross-section (*b*). When the mound is ready for coking, fire is applied at the base of the vertical flues *c*, *c*, igniting the kindling wood at each alternate flue. As the process advances, the fire is extended in every direction, until the whole mass is ignited.

Considerable attention is required in this method of coking in constructing the mounds, in diffusing the fire evenly through the mass, in preventing waste by admitting the proper volume of air, and in banking up the mounds with fine dust as the coking operation is completed from base to top.

When the gaseous matters have been expelled, which is seen when flames cease to appear, the whole heap is closed up with fine dust and partially smothered out. The final operation consists in the application of small quantities of water delivered by a hose down the flues, which is quickly converted into steam permeating the whole mass of coke. This gives coke with freedom to develop cells and, under careful management, with a small percentage of moisture. The time required for coking a mound of the dimensions given, without limiting its length, is from 5 to 8 days, depending on the state of the weather.

The yield of coke, at the Bennington yard, is as follows:

	GROSS TONS
Coal used in mound	56.87
Coke drawn from mound	33.63
Loss in coking	23.24

This primitive method of coking is very wasteful of the coal and slow in operation.

Some efforts at progress, in methods of coking to secure greater economy in the coal, have been made in the early period of evolution, by a plan for coking in open-top, rectangular masonry enclosures. These were made with side walls, 5 to 8 feet in height, having air ports along their longer sides.

The method of coking in these rectangular kilns was very similar to those used in the mound coking, but has little to commend it in the economy of its work. All that can be urged in its favor is that it was a step in the progress of improvement toward the modern coke ovens.

The beehive coke oven followed. The following analyses will exhibit the result of its work with the Connellsville coal:

ANALYSES OF CONNELLSVILLE COAL AND COKE

	Coal Per Cent.	Coke Per Cent.
Moisture	1.25	.88
Volatile matter	31.80	.67
Fixed carbon	59.79	87.05
Ash	7.16	10.60
Sulphur	.53	.74

To Determine Loss of Carbon in Process of Coking.—To determine the waste in coking by this system, the fixed carbon, ash, and sulphur go to make the coke. Allowing for the volatilization of sulphur in coking, then 59.75 + 7.16 + .44 = 67.39. Then 100 ÷ 67.39 = 1.484 tons of coal to make 1 ton of coke.

The fixed carbon in the coke should therefore be, 1.484 × 59.79 = 88.728 per cent.; but it is only 87.05 per cent., exhibiting a loss of fixed carbon in coking of 1.882 per cent.

Two additional elements enter into this result; the percentage of fixed carbon deposited from the volatile hydrocarbon of the coal, giving the coke the silvery glaze that distinguishes it so prominently. The other element is the moisture in the coke; the percentage of this depends on the care exercised in quenching or cooling the incandescent coke in the beehive oven, ranging from 1 to 3 per cent.

The actual loss of fixed carbon in coking would be the calculated loss plus the deposited carbon minus the moisture remaining in the coke. Some of the volatile matter in the slates and shales forming the ash will be volatilized in the process of coking, but this is so small an element that practically it is disregarded. The conditions of carbon deposit, with the percentage of moisture in the coke, will hold in all the methods of coking. It is also evident that the higher the percentages of fixed carbon and ash in any coal, the greater the aggregate percentage of the product in coke.

A recent test of a sample of the Kanawha Valley coke, made from the rich bituminous coal of that region, will further illustrate the method of determining the loss of fixed carbon and other elements in the coal in the coking process.

ANALYSES OF KANAWHA VALLEY COAL AND COKE

	Coal Per Cent.	Coke Per Cent.
Volatile matter	34.7900	.000
Fixed carbon	57.8600	89.200
Ash	6.2000	9.500
Sulphur	1.1500	1.300
Phosphorus	.0157	.024

From the foregoing analyses it is evident that, taking the fixed carbon, ash, and 74 per cent. of sulphur, we have 57.96 + 6.20 + .85 = 64.91. Hence, 100 ÷ 64.91 = 1.540 tons of coal to make 1 ton of coke.

The fixed carbon in the coke is therefore 57.86 × 1.540 = 89.10 per cent.; but by analysis it is 89.20 per cent., exhibiting a slight gain of this element. This is secured from the large deposit of carbon glaze from this very rich bituminous coal. The other elements in the coke can be determined on the above general principles.

BEEHIVE COKE OVEN

The name beehive evidently had its genesis in the close resemblance of the internal form of this oven to the ancient dome-shaped beehive.

The initial form of the beehive coke oven is given in Fig. 2, which shows the effort to introduce a partially enclosed oven early in the manufacture of coke. It is not very clear whether this plan of oven was suggested by the form of the dome-shaped mound method of coking coal or from the charcoal kilns. It was built with refractory materials and in some instances had flues in its heavy walls.

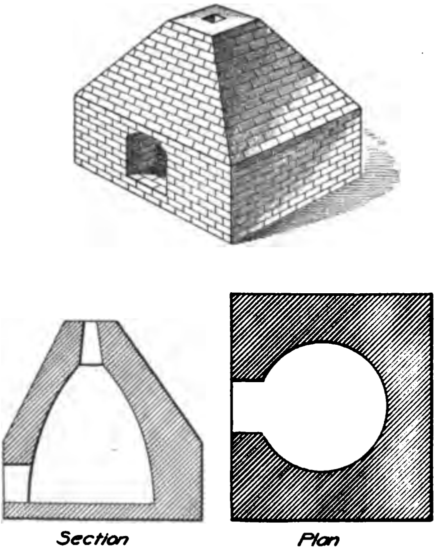


FIG. 2. PLAN OF COKE OVENS NEAR NEWCASTLE-UPON-TYNE*

The product of this oven could not differ much from that of the modern beehive oven of 1880, 1890, and 1902, only the waste of carbon in the former was much more than in the improved oven. The ancient beehive oven was originally constructed on a diminutive scale in the "day of small things," but it has continued to grow in size through a century and a half until it has attained dimensions of 12 feet to 13 feet in diameter, with a height of dome above the floor of 7 feet to 8 feet. The height of the door of this oven has been increased so as to admit the air at a level somewhat above the charge of coking coal to prevent the waste formerly

---

*From Mr. A. L. Steavenson, in Vol. VIII., North of England Mining Engineers, 1860

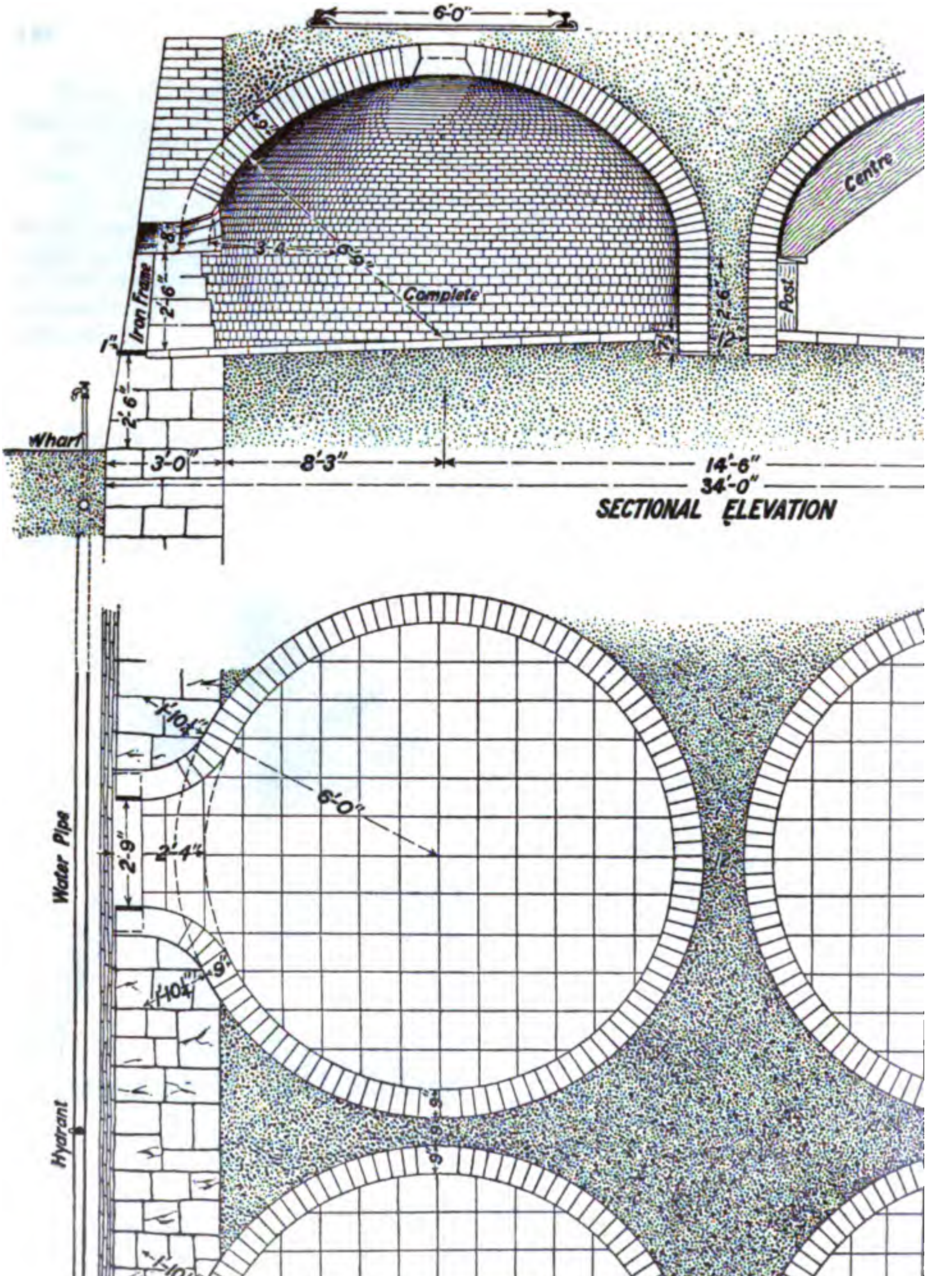
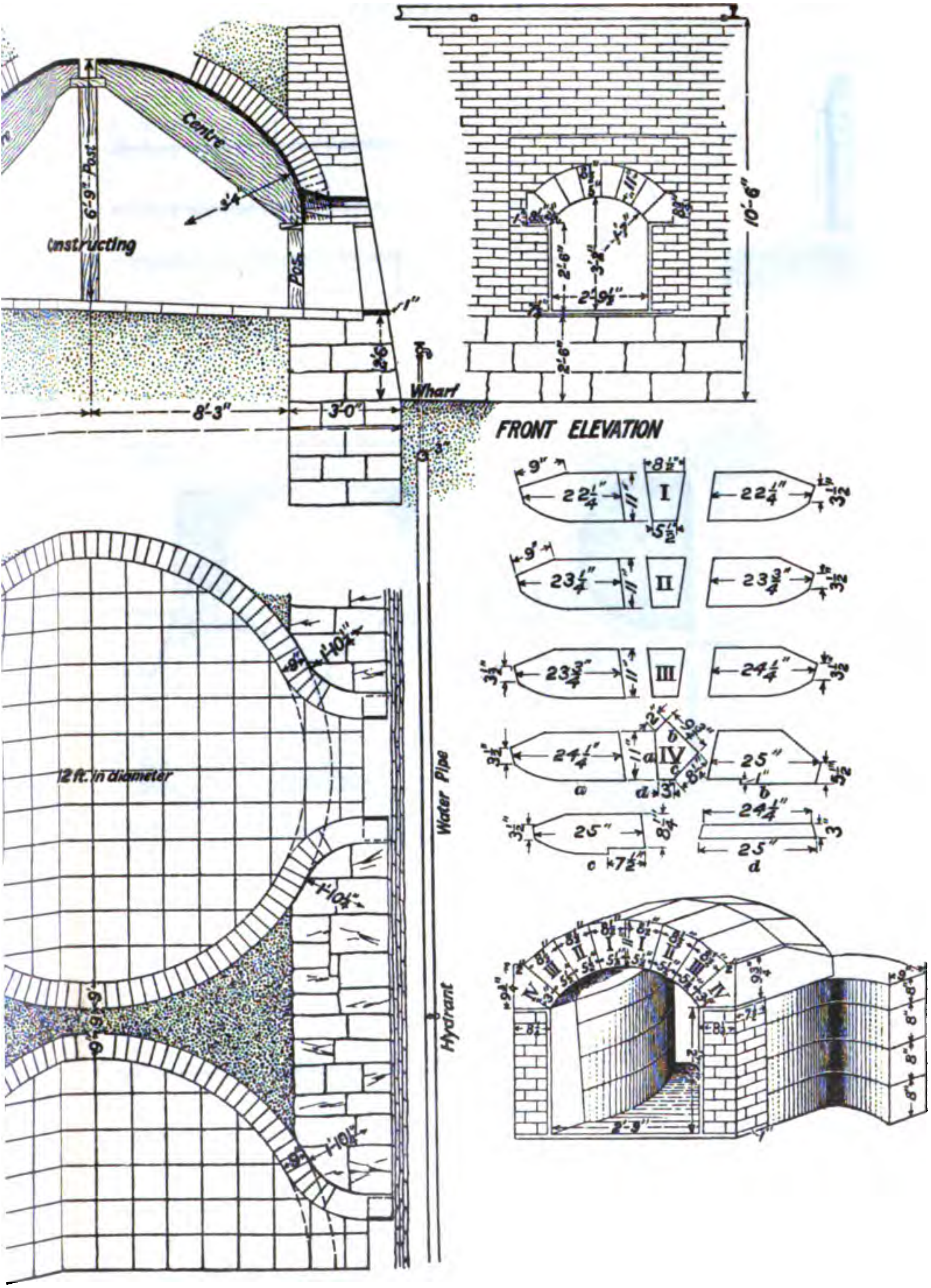


Fig. 3. Working Plan for the Con



Construction of Beehive Ovens, Oliver Plant

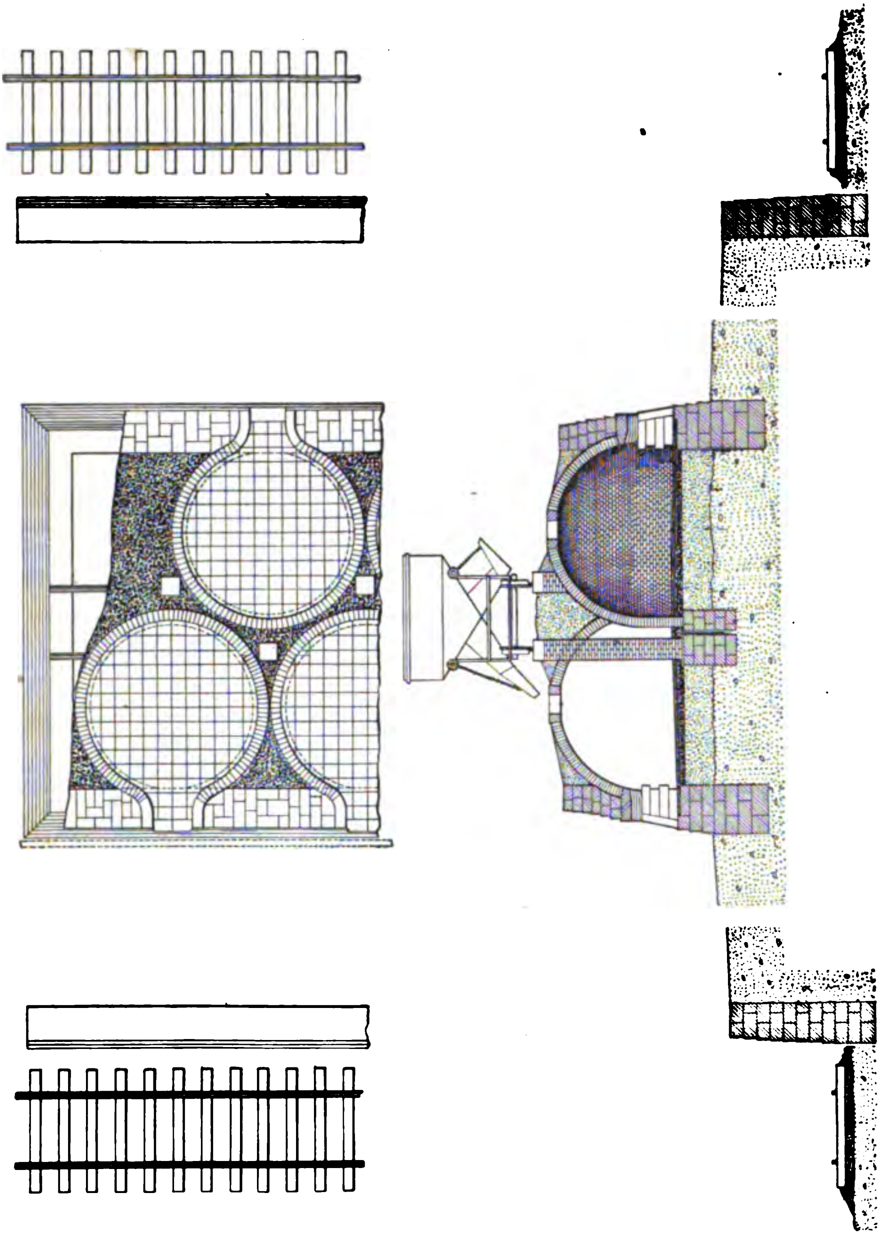


Fig. 4. Beehive Ovens, Interlocking Plan of Arrangement

sustained at this place by contact of the air with the coke in low-door ovens, leaving a deposit of ashes along the line of this air draft.

A number of improvements have been made in the construction of this oven, especially in the preparation of shaped firebrick for doors, jambs, dome, and charging port. In addition to these improvements, recent practice has secured the use of silica brick for the dome, increasing greatly the wearing properties of the oven, especially in this portion of it, which is subjected to the most intense heat in the coking operations. Mr. O. W. Kennedy introduced the use of silica brick and estimates that they will wear three to four times as long as the fireclay brick.

In some ovens, an annular passage for the admission of air, with perforations for its equal distribution above the level of the charge of coal, has been tried with increased economy in saving the burning of the carbon of the coal.

BEEHIVE OVEN OF 1894

Beehive Oven, 1894 Type.—Fig. 3 exhibits working plan with details of the usual method of constructing this oven, dating about the year 1894. A bank of a double row of this class of ovens was constructed near Gallitzin on the Alleghany Mountain. The design was to coke coals from the Upper Kittanning (B) and the Upper Freeport (E) seams. As these coals are only medium in fusing matter, the moderate size of this oven answered the purpose very successfully.

Beehive Oven at Oliver Plant.—A plan and section given in Fig. 4 illustrate the larger beehive coke ovens more recently constructed at the Oliver plant, near Uniontown, in the Connellsville region. These have been kindly furnished by Messrs. Wilkins and Davison, engineers, Pittsburg, Pennsylvania, who are experts in this and kindred constructions.

The interlocking plan shown in the bank of coke ovens, Fig. 4, is sometimes used to compact more closely the group of ovens; at other localities, it is adopted to economize space where the ground for the ovens is limited.

Continental Coke Oven.—Fig. 5 exhibits plans and sections with detailed drawings of the coke ovens of the Continental Coke Company's works, No. 1, near Uniontown, Fayette County, Pennsylvania. These ovens are in the Connellsville coke region and are of the modern enlarged plan of the beehive coke oven.

The section in Fig. 6 shows an arrangement for an extended works where ample ground can be secured. These two figures show plans and sections of the coke ovens, wharves, and railroad sidings, with dimensions given in full details. These several banks of ovens with their respective coke wharves have been built

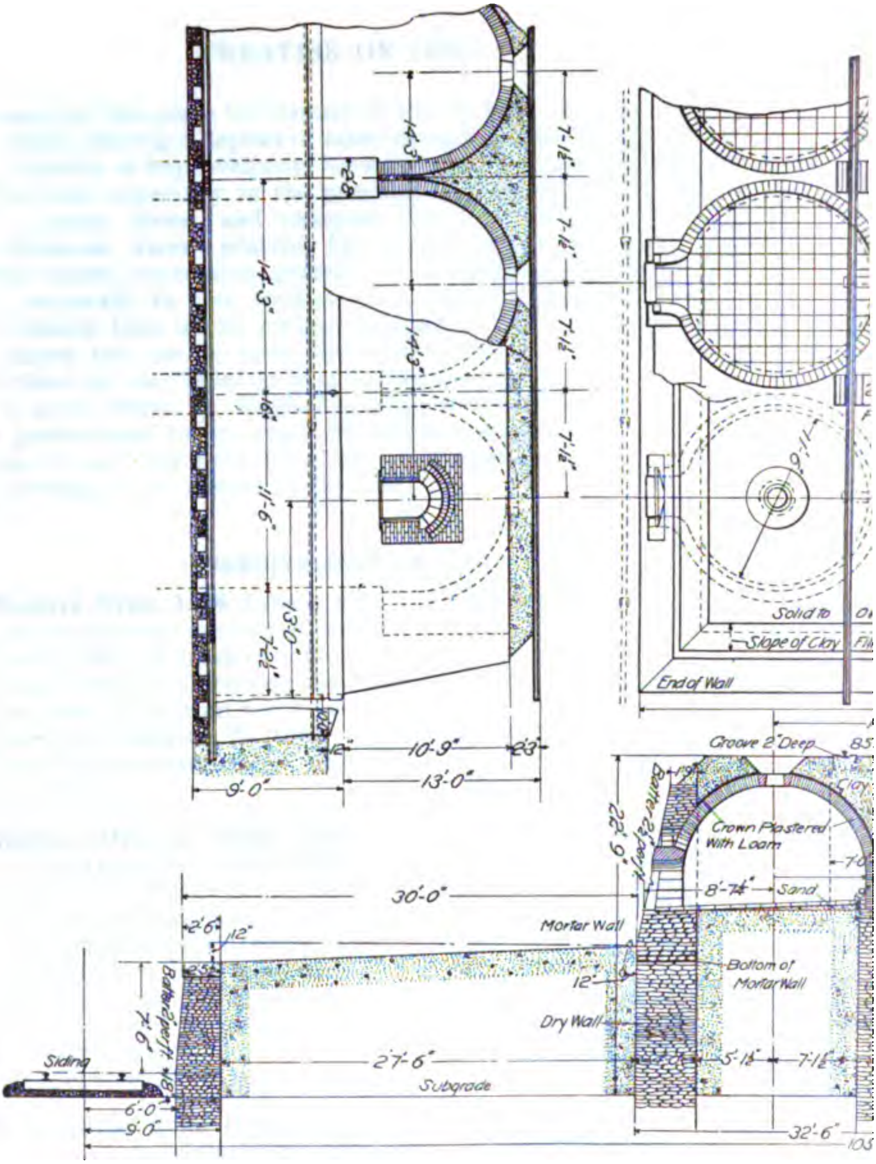


FIG. 5. BEEHIVE OVE

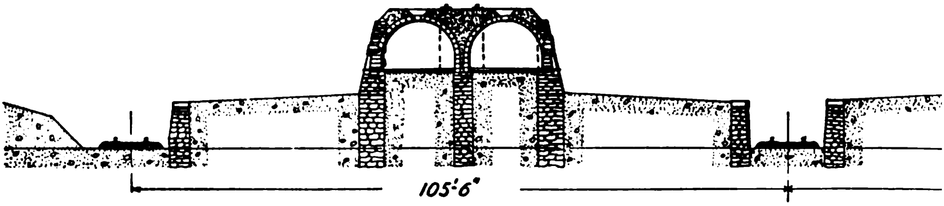
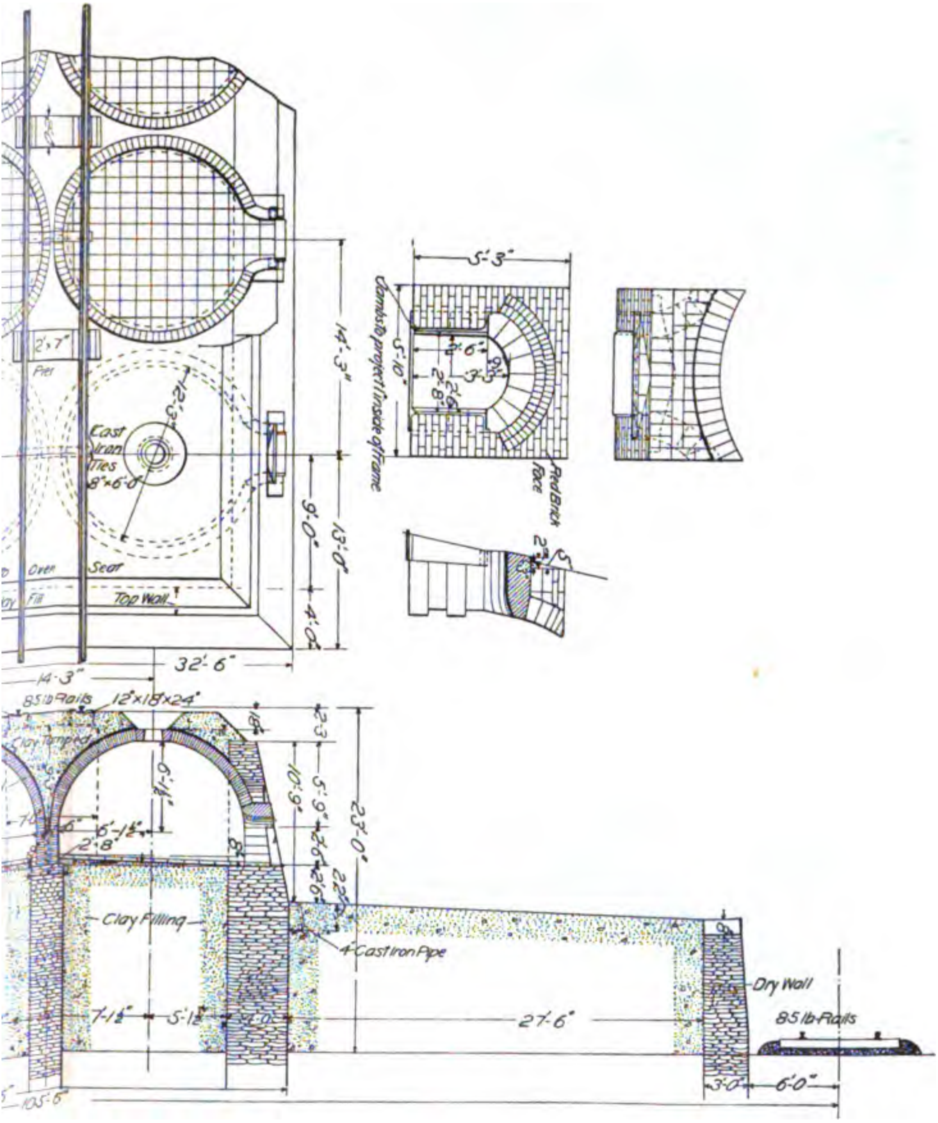
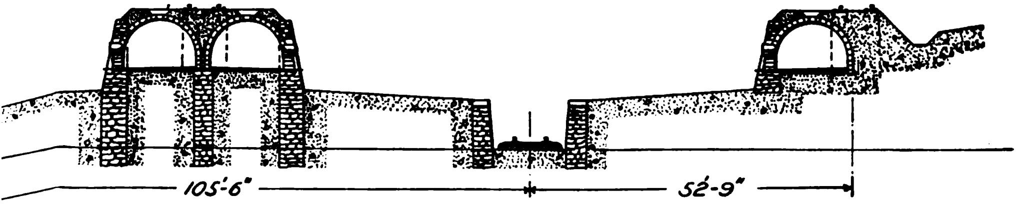


FIG. 6. ARRANGEMENT OF OVENS AT



E OVENS CONTINENTAL COKE CO.



INS AT WORKS OF THE CONTINENTAL COKE CO.

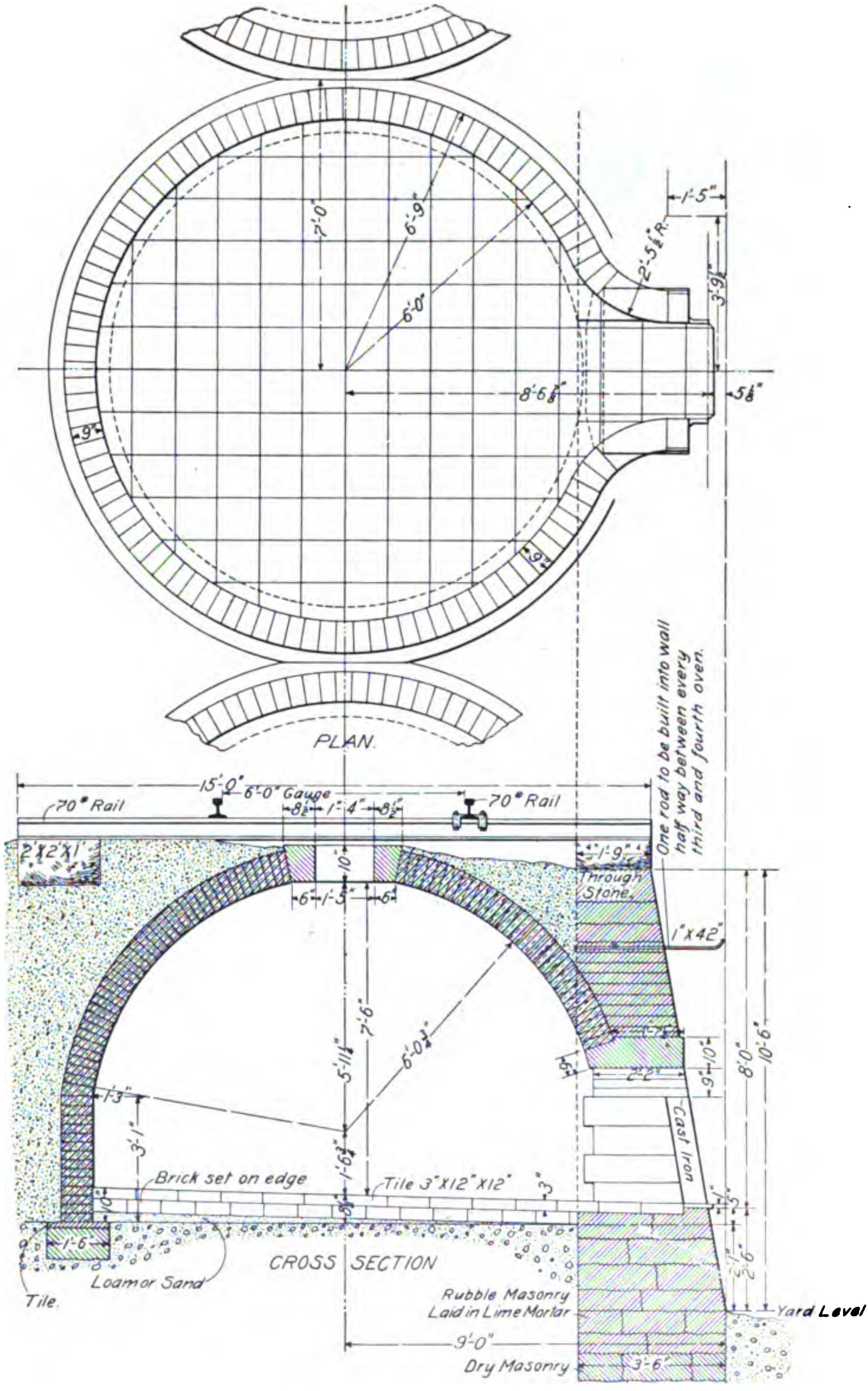

7'-0"
6'-9"
6'-0"
2'-5½" R.
1'-5"
3'-9½"
8'-6⅝"
5⅛"
9"
9"
PLAN.
15'-0"
6'-0" Gauge
70# Rail
70# Rail
8½"
1'-4"
8½"
2'x2'x1'
10"
6"
1'-3"
6"
1'-9"
Through Stone.
One rod to be built into wall half way between every third and fourth oven.
1"x42"
7'-6"
5'-11"
6'-0¾"
1'-3"
3'-1"
1'-6¾"
1'-7"
2'-2"
9"
10"
9"
8'-0"
10'-6"
Cast Iron
Brick set on edge
Tile 3"x12"x12"
3"
10"
5"
1"
3"
1'-6"
Tile.
Loam or Sand
CROSS SECTION
2'-6"
Rubble Masonry Laid in Lime Mortar
Yard Level
9'-0"
Dry Masonry
3'-6"

FIG. 7 (a)

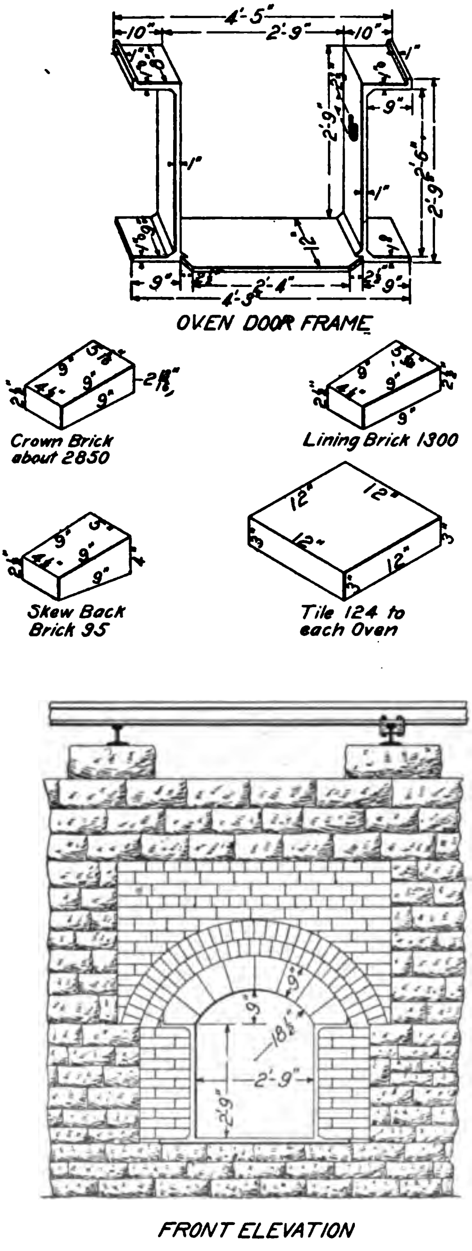


Fig. 7 (b)

up from the low ground and involve considerable masonry work as well as much embanking. While this method of construction is expensive in first cost, since the ovens are raised high above the ground, they are free from dampness and assure the best results in their coke product.

Wharton Coke Oven. Fig. 7 exhibits a modern plan of the beehive coke oven as it has been constructed in a plant of 300 ovens at the Joseph Wharton Coke Works at Coral, Indiana County, Pennsylvania.

The general design is given in the drawing with some details. The oven is 12 feet by 7½ feet. It was planned mainly for coking coal from the upper Freeport bed (E). This coal, as well as all others in Indiana County, requires a preparation for use in manufacturing merchantable coke for metallurgical uses. The fusing matter is not as high in this coal as in the Connellsville. At these works, to avoid the production of black ends, so undesirable in blast-furnace work, a subfloor of red brick has been laid under the usual tile floor of these ovens; this additional floor stores heat and prevents the production of black ends, the coke coming out of the oven with a silvery clearness to the floor of oven. Another peculiarity of the construction of these ovens is the second sustaining arch over and supplementary to the heavy jamb brick arch over the door of the oven. This higher arch is designed to sustain the front of the oven structure while repairs are being made to the large shaped brick in the arch and jambs of the ovens, without the labor and expense of tearing down a large section of the oven. Silica brick were used exclusively in the domes or crowns of these ovens. This will conduce greatly to the length of their work and economy in their repairs.

The section shown in Fig. 8 illustrates the arrangements of the ovens with the ample wharf room, the retaining wall, and railroad siding, with related elevations to secure the utmost facilities in the manufacture and shipment of the coke.

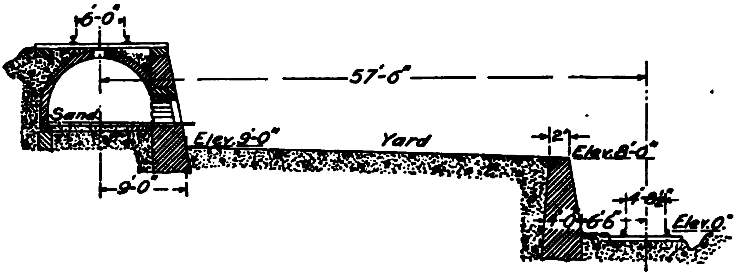


Fig. 8

It may be noted here that the operations of the modern beehive coke oven secure two desirable properties in metallurgical coke, viz.: its full cellular developments, assuring the maximum calorific energy in its combustion, and its dry condition with minimum percentage of moisture.

It may be conceded, however, that the cost of labor and waste of carbon in coking in the beehive oven are somewhat in excess of similar work in some of the modern retort coke ovens.

This plant of beehive coke ovens at the Wharton works is very complete in all its parts and is a model in its design and construction.

The general plan of this large plant of coke ovens was matured by Mr. Harry McCreary, general superintendent, ably assisted by Mr. R. M. Mullen, civil engineer. The estimated cost of one oven of the Wharton type, in 1903, is given in table on page 154.

CONSTRUCTION OF THE MODERN BEEHIVE OVEN

Excavation for Foundations.—The excavation for all foundations for masonry work should be cut to such depth beneath the surface of the ground as will assure stability to the masonry and exemption from its disturbance by frost. The depth and general foundation conditions must be studied in each locality, and should be under the direction of a competent engineer, or such agent as the management may appoint.

Masonry of Retaining Walls.—The masonry of the retaining walls of the coke ovens should be laid dry with sound sandstones, of even beds and of such thickness as hereafter described. This dry-laid foundation should be carried to the level of the coke wharf in front of the coke ovens. Above this foundation course the masonry should be laid in lime mortar or cement, composed of two parts of clean, sharp sand and one part of good slacked lime or cement, the whole carefully mixed to secure a thorough blending of these materials. The building stones should be sufficiently large and broad-bedded for this purpose to assure good bond and strong work to resist the alternating pressures from the heat changes in the coking operations. Flagstones with good beds, having an average thickness of 6 inches to 8 inches, should be used in the retaining wall above the level of the floor of the oven.

ESTIMATED COST OF ONE WHARTON COKE OVEN

	Price	Amount
1,254 lining brick	$18.00	$22.57
2,487 crown brick, silica brick	18.00	44.76
113 tile 12 in.×12 in.×3 in	55.00	6.22
1 set arches and jambs	8.00	8.00
770 paving brick in bottom of oven	8.00	6.16
660 mill brick in front of oven	8.00	5.28
1 ring	2.00	2.00
1 cast-iron door frame	5.00	5.00
30 lineal feet, 70-pound cross-rail to carry larry rail—700 pounds	30.00	10.50
29 lineal feet, 70-pound larry rail, 655 pounds	30.00	9.80
14 lineal feet, cast-iron water pipe, 434 pounds	.02	8.68
13.4 cubic yards mortar wall	2.75	36.85
1.5 cubic yards brickwork in front of oven	4.90	7.35
Building oven complete	29.25	29.25
125 cubic yards excavation for oven seat, yard, and railroad	.40	50.00
7 railroad ties	.35	2.45
28 lineal feet, 70-pound rail for railroad track—655 pounds	30.00	9.83
20 cubic yards of dry wall per oven	2.35	47.00
Total cost of oven		$311.70

The outer face of the masonry should be neatly trimmed and the bedding of the stones dressed to lie firmly on each other without the aid of chips or pinners. The face of this wall should be carried up with a uniform batter of at least 2 inches to the vertical foot. Great care should be taken in embedding the stones in the mortar and thoroughly filling all joints and interstices. Seats for the bases of the iron door frames of the oven should be carefully dressed to an even surface to assure stability at this important part of the ovens. The arch piece of this iron door frame is to be omitted, as its expansion under heat has been found to be a disturbing element to the jambs and supplementary arches.

Building the Coke Oven.—The foundation under the oven should be cleared of all vegetable or combustible matter and the foundation of the circular wall should begin on firm materials—whether on rammed embanking ground or in excavations under the surface. The building of the oven should conform accurately to the plan selected for the locality. It should be built of shaped firebrick and silica brick composed of materials especially adapted for the service demanded in their use in the oven—strong heats with water contact in the quenching or cooling of the coke charge in the oven.

The circular section of the oven, from the foundation to the springing of the arch of the dome or crown, should be built with firebrick shaped to conform to the radial lines of this portion of the oven. The physical composition of these firebrick should consist of coarsely ground fireclay to provide for the expansion by heat and the shrinkage by water under these conditions in the coking operations. The dome or crown of the oven should be built with silica brick, holding not over 2 per cent. of lime in combination. They should be shaped to conform to the radial planes of this portion of the oven to secure compactness and stability, and the whole should be keyed firmly by the charging port ring in the crown of the oven.

The lines of the oven should be defined by sweeps from a central pivoted stake. The oven door jambs, with shaped arch brick connections, should be neatly and carefully laid. The supplementary brick arch to maintain the front wall of the oven above its door should be constructed on firmly set skew backs at the springings of this arch. The mortar to be used in setting the firebrick work of the oven should be composed of loam, or loamed clay, in such proportions as may be deemed most serviceable. A mortar of ground fireclay and loam may be used in this work.

The tiles on the bottom of the oven should have a rise from the door to the back of the oven of 6 inches. They should rest on a thin stratum of sand on top of the subfloor of the oven. This subfloor is to be built of red brick, laid on edge, in a sand bed on a firmly compacted foundation. The use of this red-brick subfloor is to store heat to prevent the production of "black ends" in the coke.

The filling under and around the oven should be made with selected earth, and all vegetable or unsuitable matters removed. The filling should be made in horizontal layers, not exceeding 1 foot in thickness. It should be thoroughly wet and packed solidly with rammers or rollers to prevent shrinking and settling. To assure stability in this filling sufficient time should be allowed it to settle and to partially dry.

Fig. 9. Constructing Beehive Ovens

The *larry track* should be made with T rails, weighing 70 to 80 pounds per lineal yard, to be laid on iron cross-ties or iron girders with necessary chair fastenings. When a double row of coke ovens is constructed, the larry track should be placed midway between the charging ports of the ovens. In this case, the larry should have discharging chutes on each side.

Cast-Iron Water Pipe.—A cast-iron water pipe 4 inches in diameter, weighing at least 18½ pounds per lineal foot, should be laid with its top surface 18 inches below wharf level, with taps for coke-oven valve for each two coke ovens, with Powell's star coke-oven valve on top.

Coke Wharf.—The level of the coke wharf should be 2 feet 6 inches below the sill of the iron door of the oven, with a moderate inclination to the edge of the wharf wall. The width of the coke wharf should be at least 40 feet. The level of heads of rails, on the railroad siding, should be made of such grade under the level of the wharf as to secure ample height for loading the coke into the railroad cars, from 7 feet to 12 feet. The grade of the cove ovens should be 1 foot to 100 feet (1 per cent.) where it is practicable, and the railroad sidings of similar gradients. This will secure descending gradients with the tonnage and secure easy handling of railroad cars without the necessity of a locomotive.

Measurements.—All the stone masonry necessary to the completion of the coke ovens is measured in the wall with the dimensions as given on the plan. All masonry is measured and paid for by the cubic yard of 27 cubic feet. These measurements are the actual cubical contents without any allowances.

The brickwork in the coke ovens is paid for by the oven. This includes the laying of the jamb brick, facing brick, tiles, silica brick, and all other work of this description in the complete construction of the coke ovens. All excavation and filling are paid for by the cubic yard.

The engineer or agent should issue directions from time to time as the work progresses, and these should be carried out strictly in accordance with his instructions. In all cases, the decision of the engineer or agent, in the method of the construction of the work and in the estimate of quantities, should be final and conclusive between the contracting parties.

Fig. 9 will be interesting as showing the process of the construction of these beehive coke ovens.

THE COKING PROCESS

For the purpose of determining its exact percentage of coke product, an exhaustive series of experiments was made at the large coking plants of the Cambria Iron Company, in 12′ × 6′ beehive ovens, in the Connellsville region under the care of Mr. Isaac Taylor.

The cross-sections of 48- and 72-hour charges of coal in these ovens, Figs. 10 and 11, will show the process of coking from top of charge to floor of oven, with the enlargement and shrinkage of the resultant coke carefully and accurately defined from the actual work of these ovens.

From the sections, Figs. 10 and 11, and the Tables I and II, it will be readily seen that the average charge of coal for 48-hour coke is 9,910 pounds, or 5 net tons nearly. It occupies a depth in the coke oven of 23 inches. The charge of coal for 72-hour coke is 11,915 pounds, or 6 net tons nearly. It has a depth in the oven of 26½ inches. These sections show. in a graphic way, the heights of 48- and 72-hour coke in the ovens at "best," and its reduced altitude after being cooled by watering in the oven. The process of fusing and coking begins on the top surface of the charge of coal, and goes down through the mass of coal at the rates shown in the margins of the sections, until it reaches the bottoms of the ovens.

It will also be seen that in this process of coking hydrocarbon gas will be evolved from the coal, which gas, passing up through the fissures of the incandescent section of coked coal, deposits some of its carbon. This gives the coke the bright silvery coating that distinguishes the best cokes and partly protects them from dissolution in the upper region of blast furnaces from the action of the ascending gases.

The tables of careful tests, I and II, show in accurate detail two series of determinations to learn the exact percentage of coke produced, under careful management in the beehive coke oven. They give the average results from an equal number of tests of 48- and 72-hour charges of coal in the product of coke.

Table I shows the usual and practical percentage of coke made in these ovens in the usual way with the moisture from cooling in the oven included. Table II shows the exact percentage of coke as it has been drawn in a red-hot condition and exempt, or nearly so, from moisture. This latter determination is impracticable, but it was made to ascertain the ratio of carbon waste by the beehive-oven method of coking.

In all these experimental tests, the coal charged into ovens and the products in marketable coke, fine coke, or breeze, and ashes, have been carefully separated and accurately weighed.

In the preparation of these tables, samplings of the coal used and coke made were analyzed by the late Dr. James J. Fronheiser, in the Cambria Iron Company's laboratory at Johnstown, Pennsylvania, with the following results:

	CONNELLSVILLE COAL	CONNELLSVILLE COKE
Moisture at 212° F	1.25	.63
Volatile matter	31.27	1.37
Fixed carbon	59.79	85.99
Ash	7.16	11.12
Sulphur	.53	.89

Height of coke 4 hours after charging oven

PROGRESS OF COKING

2 hours after charging oven— 3½ inches
10 hours after charging oven— 6⅝ inches
14 hours after charging oven— 9¾ inches
21 hours after charging oven—12¾ inches
25 hours after charging oven—16 inches
30 hours after charging oven—19⅛ inches
$32\frac{11}{16}$ hours after charging oven—23 inches

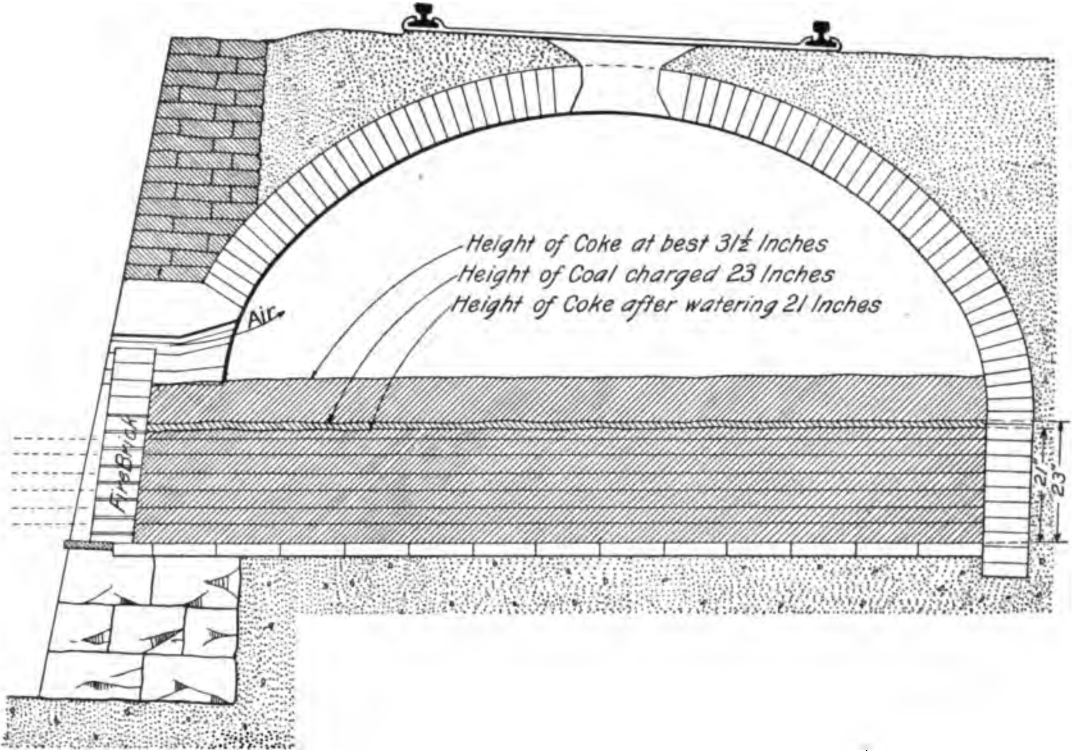


FIG. 10. 48-HOUR COKE CHARGE

TABLE I

TEST EXPERIMENTS IN COKING

CONNELLSVILLE REGION, 1892

No. of Test	When Charged			When Drawn			Time in Oven Hours	Coal Charged Pounds	Ash Made Pounds	Fine Coke Made Pounds	Market Coke Made Pounds	Total Coke Made Pounds	Per Cent. of Yield				Per Cent. Lost	Remarks
	Month	Day	Hour	Month	Day	Hour							Ash	Fine Coke	Market Coke	Total Coke		
1	Dec.	14	11 A. M.	Dec.	16	7 A. M.	44	10,400	84	209	6,922	7,131	.81	2.01	66.56	68.57	30.62	Watered in oven
2	Dec.	16	10 A. M.	Dec.	19	8 A. M.	70	12,400	103	264	8,060	8,324	.83	2.13	65.00	67.13	32.04	Watered in oven
3	Dec.	17	9 A. M.	Dec.	20	7 A. M.	70	11,430	94	282	7,640	7,922	.82	2.47	66.84	69.31	29.87	Watered in oven
4	Dec.	19	11 A. M.	Dec.	21	7 A. M.	44	9,420	75	249	6,260	6,509	.80	2.64	66.45	69.09	30.11	Watered in oven
Totals and averages........................								43,650	356	1,004	28,882	29,886	.82	2.30	66.17	68.47	30.71	

TABLE II

TEST EXPERIMENTS IN COKING

CONNELLSVILLE REGION, 1892

No. of Test	When Charged			When Drawn			Time in Oven Hours	Coal Charged Pounds	Ash Made Pounds	Fine Coke Made Pounds	Market Coke Made Pounds	Total Coke Made Pounds	Per Cent. of Yield				Per Cent. Lost	Remarks
	Month	Day	Hour	Month	Day	Hour							Ash	Fine Coke	Market Coke	Total Coke		
1	Dec.	16	12 M.	Dec.	19	7 A. M.	67	12,420	99	385	7,518	7,903	.80	3.10	60.53	63.63	35.57	Hot or dry tests
2	Dec.	17	11 A. M.	Dec.	20	7 A. M.	68	11,090	90	359	6,580	6,939	.81	3.24	59.33	62.57	36.62	Hot or dry tests
3	Dec.	19	10 A. M.	Dec.	21	7 A. M.	45	9,120	77	272	5,418	5,690	.84	2.98	59.41	62.39	36.77	Hot or dry tests
4	Dec.	20	10 A. M.	Dec.	22	7 A. M.	45	9,020	74	349	5,334	5,683	.82	3.87	59.13	63.00	36.18	Hot or dry tests
Totals and averages........................								41,650	340	1,365	24,850	26,215	.82	3.28	59.66	62.94	36.24	

Height of coke at 3 hours' burning

PROGRESS OF COKING

3 hours after charging oven— 2 inches
6 hours after charging oven— 5¼ inches
9 hours after charging oven— 8¾ inches
14 hours after charging oven—11¾ inches
22 hours after charging oven—15 inches
32 hours after charging oven—18¼ inches

36 hours after charging oven—24¾ inches
55 hours after charging oven—26½ inches

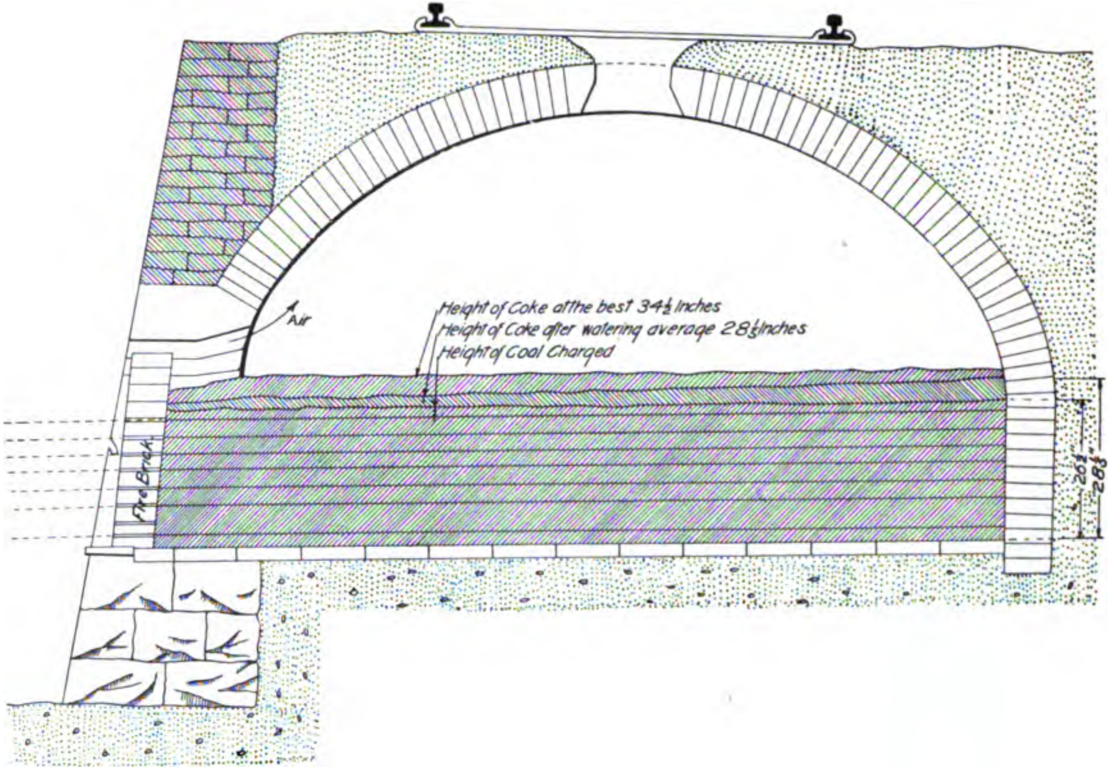


Fig. 11. 72-Hour Coke Charge

TABLE III

TEST EXPERIMENTS IN COKING

ALLEGHANY MOUNTAIN

No. of Test	When Charged			When Drawn			Time in Oven		Coal Charged Pounds	Market Coke Made Pounds	Small Coke or Breeze Pounds	Ashes Made Pounds	Total Coke Made Pounds	Per Cent. of Yield				Per Cent. Lost
	Month	Day	Hour A. M.	Month	Day	Hour A. M.	Hours	Minutes						Market Coke	Small Coke	Ash	Total Coke	
1	Feb.	12	7.40	Feb.	14	7.10	47	30	10,625	7,260	125	320	7,385	68.33	1.17	3.01	69.50	27.49
2	Feb.	17	7.30	Feb.	19	9.40	50	10	10,700	7,180	115	380	7,295	67.10	1.07	3.55	68.17	28.28
3	Feb.	12	7.30	Feb.	15	7.20	71	50	12,375	8,525	95	330	8,620	68.88	.76	2.67	69.60	27.79
4	Feb.	14	8.10	Feb.	17	9.50	73	40	12,900	8,680	85	400	8,765	67.28	.66	3.10	67.90	28.96
Totals and averages..................									46,600	31,645	420	1,430	32,065	67.91	.91	3.07	68.80	28.11

From the analysis of Connellsville coal given on page 158, used in these coking tests, as shown in Tables I and II, it will be seen that the loss in the coking operation, in the wet and dry ways, is 30.71 and 36.24 per cent., respectively. This loss arises from the expulsion of moisture, volatile matter, and some of the fixed carbon. The loss of the fixed carbon is the most important element in the consideration of the work of the beehive and all other coke ovens. The fixed carbon, ash, and sulphur constitute the coke. The sum of these in this instance amounts to 67.48. Dividing 100 by this number gives 1.481, the number of tons of coal to make 1 ton of coke. Then the fixed carbon in the coal, 59.79, multiplied by 1.481, gives 88.549, the theoretic volume of carbon in the coke. Hence, 88.549 : 100 = 85.99 : 97.11, or 2.89 per cent. of loss of fixed carbon. Practically, it is more than this, depending on the care in coking and cooling the coke in the oven.

In Table II, the coke was drawn from the oven hot and weighed in this condition, showing that the loss of carbon was substantially the same as in the former case, but the loss in moisture and volatile matter was 36.24, exhibiting a reduction in moisture of 5.26 per cent.

A similar test on a bank of beehive ovens at Gallitzin, on the Alleghany Mountains, running on coal from the Upper Freeport seam, required 1.383 tons of coal to make 1 ton of coke. The loss in fixed carbon was 4.42 per cent. Another test, under similar conditions, at a coking plant in Elk County, Pennsylvania, using coal from the Upper Kittanning seam, required 1.459 tons of coal to make 1 ton of coke. The loss in fixed carbon was 2.71 per cent.

Practically, Table I shows that Connellsville coal, coked in the modern beehive oven, will produce under careful and intelligent management 66.17 per cent. of marketable coke, 2.30 per cent. of small coke or breeze, and .82 per cent. of ashes. This enlarged product of coke, 66.17 per cent., has been obtained by improved methods in coking, by reducing the waste of fixed carbon at doors of ovens, and by increasing their height so as to admit air above the charge of coal in the oven, thus avoiding the old-time wastage at this place. There is also a deposit of carbon from the expelled volatile hydrocarbons of the coal in coking in their upward passage through the incandescent coke, especially noticeable in the upper section of coke.

Just how much carbon is deposited under the varying conditions in coking 48- and 72-hour coke has not yet been accurately determined. After some experiments, in a crucible, in coking Connellsville coal, it was found that, under conditions similar to those of the beehive oven, and admitting a proportional volume of air, the resultant dry coke was 67.56 per cent., which is slightly in excess of the theoretical or calculated yield of coke from this coal, 67.27 per cent. A second experiment consisted in the exclusion of air, using the true retort method in coking. This gave 79.20 per cent. of coke. We have, therefore, the two results: (1) by admitting air, 67.56 per cent.; (2) by excluding air, 79.20 per cent.; exhibiting an increase by the latter method of 11.64 per cent.

As the first coking test gives the full theoretic result of coke, it is evident that there was no burning or waste of fixed carbon, or if any was wasted an equal amount of deposited carbon must have replaced it. In the second test, there was evidently a large deposit of carbon from the gases of the coal, at least 14.71 per cent., assuming that no fixed carbon has been burned in this retort test.

Practically, no construction of coke oven could afford the precision of admitting air and absolutely excluding it, as in these laboratory tests. They show, however, that the retort-oven methods of coking afford a larger yield of coke than can be obtained by the beehive- or air-oven methods of coking. The relative calorific values of the coke made in these two principal methods will be taken up in a subsequent chapter.

Old Welsh Oven.—In the progress of the manufacture of coke, the elements of cost appear to have invited attention to the laborious and expensive methods of drawing coke from the old and cramped beehive ovens. The main effort in reducing cost was directed to a new plan of coke oven, retaining the principles of the beehive, but planning the new oven so as to draw the coke by mechanical appliances.

The Welsh oven consists of an arched chamber 12 feet long, 7 feet broad, and about 6 feet high. One end of this oven is walled up, the other end or front has doors or luted walls. A flue chimney at the closed end of the oven affords egress to the gases.

The coke is drawn out by a drag composed of a main iron bar running the length of the oven and having a crosspiece at the inner end. The whole drag is placed in the bottom of the oven before the charge of coal is placed in it, and it remains under the charge of coal until it is coked and ready for drawing out, when a chain is attached to an eye in the drag at front of oven, and the coke pulled out in mass, by windlass or engine power. The coke is usually quenched or cooled outside the oven.

With skill, this method of coke manufacture possesses some advantages in the economy of the work in drawing the coke out of oven, without injuriously affecting the physical condition of the coke. The cooling outside the oven by watering is the chief objectionable feature in this section of the work of coking, as coke watered in this way, if done in a clumsy manner, will contain from 8 to 15 per cent. of water, which neutralizes the advantage secured in the rapid drawing of the coke by mechanical means. This effort at the improvement in the coke oven to save labor has been followed by other plans on the same general principles, but mainly designed at improvement in the details of these methods of the several operations in coking.

The **Thomas oven** is simply an improved Welsh oven, preserving the desirable properties of the beehive oven in coking the coal. It secures some economy over the latter by its mechanical method of drawing the coke. It retains, however, the undesirable method of cooling the coke by watering it outside the oven.

This oven has been fully described in a paper prepared by Mr. J. T. Hill, manager of the Coalburg mine, and read at the meeting of the Alabama Industrial and Scientific Society, in 1891. Fig. 12 illustrates its main features.

The descriptive text is as follows: "The essential difference between the old Welsh oven and the Thomas oven exists in the fact that the latter is much longer, affording greater capacity, and that both ends are movable, thus doing away with the necessity of placing the drag in the oven prior to charging. In nearly every other respect the ovens are identical.

"At Coalburg there are sixty-four Thomas ovens arranged in one single continuous battery. In construction, the same principles are carried out and materials used as in the beehive ovens, except that the bottoms are of hard red brick, upon the theory that they resist wear of the drag better than the firebrick. In detail they are described as follows: length, 36 feet; width inside, 7 feet 3 inches at back, and 7 feet 9 inches at front; height over all, 8 feet; height of door, 4 feet; height inside, 5 feet to crown of arch.

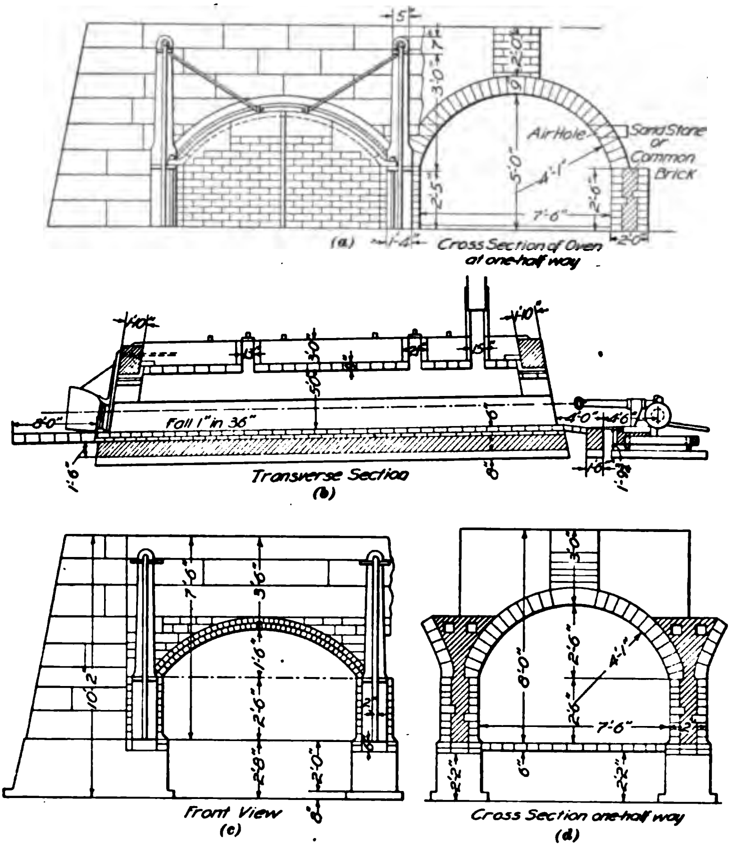


Fig. 12. Thomas Oven

"Fall in bottom from back door to front, 1 inch in 3 feet, or 1 foot in the whole length of oven. Both back and front are movable and have swinging doors, which are in two sections, and built of firebrick of special design, laid in iron frames.

"There are three openings on top, two funnel heads and one draft stack near the back end of the oven. In front of it and on a level with the floor of the ovens is an apron of stone and brick masonry, 8 feet wide and running the entire length of the battery.

Four feet below this masonry or apron is another piece of masonry 7 feet wide, which also runs the entire length of the battery, on which the truck of the dinky containing the machinery for drawing the coke is located. Still farther below is the railroad track, on which are placed the cars for the receipt and shipment of the coke. At the rear of the battery is another track, on which runs a car used for conveying the drag from oven to oven, and on this car is permanently fixed a crab for pulling the drag back after discharging, Fig. 13.

"Twelve tons of coal are charged from 6-ton larries, through the funnel heads, and the leveling is done from both ends.

"When ready to draw, the doors at both ends of the ovens are swung open and an iron rod passed through the oven over the top of the hot coke, and attached to the drag at the rear. The hot coke is thus drawn in a body out of the front end of the oven, and over a screen attached to the dinky, at which point the fire is quenched with water falling from a tank, situated above the screen, no water whatever being thrown into the oven. From the screen it falls in broken pieces to the railroad car below and is ready for shipment."

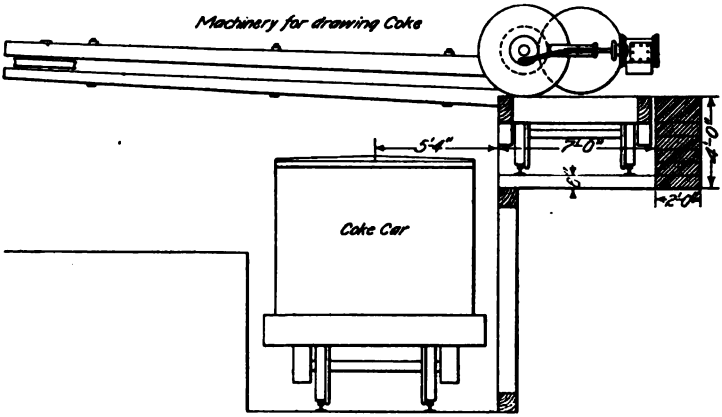


FIG. 13. COKE DRAWER

The yield is practically the same as from the beehive ovens under skilful management, and the quality of the product, so far as can be determined by analyses and observation, is fully up to the standard. I regret that I cannot present data showing its relation to the beehive coke in furnace practice, but the conditions of consumption are such that it has not been practicable to make such a test. The claim for economy in reducing the labor in making coke in this oven requires more data to define the exact amount. The relative original costs of this and the beehive oven, to produce a given output per month, with the cost of repairs of each kind of oven, should have been submitted in order to have a fair comparison of merits.

It will readily appear that in all these ovens, with admission of air through doors, or by special ports, the true principle of coking is retained—freedom of the coal, by the shallow charges, to develop the best physical structure in coking, as the pressure of these coal charges in these broad horizontal ovens is so slight as not to materially compress the fusing mass in forming the cells in making coke. On the other side, there is some waste by the admission of air in burning the expelled gases in the crowns of the ovens above, and in contact with the coking coal.

This is all that can be urged against the use of these types of coke ovens in the manufacture of coke. With care in cooling the coke, especially when watered in the oven, a product is obtained in best condition for affording the utmost calorific energy in metallurgical operations.

Browney Coke Plant.—Desiring to learn the condition of the beehive coke oven, in the celebrated Durham coke district in England, and to be advised as to the progress of the introduction of the narrow or retort coke oven there, with the status of efforts in the saving of the by-products of tar and sulphate of ammonia, I wrote Sir Isaac Lowthian Bell, the eminent authority on all matters connected with the iron and steel industries, who kindly sent the drawings, shown in Fig. 14, of the Browney colliery coke plant of Messrs. Bell Brothers,* with the following note covering my inquiries:

Rounton Grange, Northallerton, May 22, 1893.

My Dear Mr. Fulton:

Various circumstances, my own engagements not being the least, have conspired to delay my reply to your letter of 10th ult.

I enclose the tracing of our own ovens, by means of the waste heat of which we supply our collieries with steam power. In these, by-products are wasted, as you no doubt will see. It is difficult, I may say impossible, to give a categorical reply to your inquiry in respect to the narrow ovens in which combustion in the ovenself is avoided and where, in consequence, ammonia and tar escape decomposition. In certain districts, even in England, they are successful, the difficulty being their maintenance in good repair.

In South Wales they seem to do very well; with us, in the county of Durham, and in Yorkshire, the reverse has frequently been the result. My own opinion is that the richness in combustion gas lies at the root of the evil, the consequence being an elevation of temperature in the outside flues which is incompatible with stability.

My own firm has spent large sums in pursuit of a plan of obtaining ammonia, etc., and the firm of Messrs. Pease and Company is continuing the process with perfect success as regards the by-products; but they, or their customers, find, as we found, the coke not so suitable for blast-furnace work as that burnt in the old-fashioned beehive oven.

I am very sorry that I find it impossible to see your exhibition at Chicago. I must therefore be content to hear what others have to say on the subject.

With my kindest regards to all my good and faithful friends in Johnstown, believe me yours faithfully, I. Lowthian Bell.

---

*The chimney for these ovens, the base of which is shown in the end elevation, Fig. 14, extends 80 feet above the top of the ovens, and is battered 1 in 27.

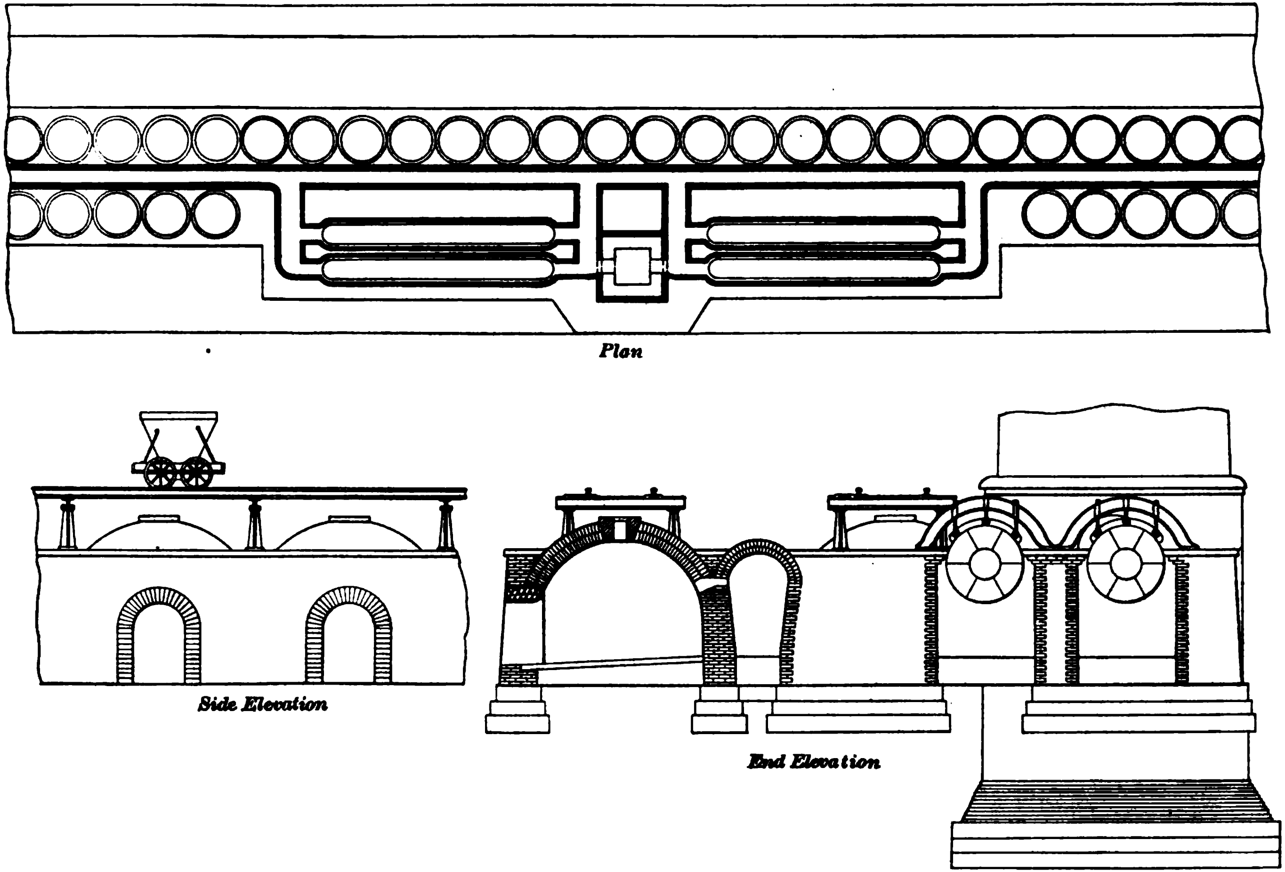


FIG. 14. COKE OVENS AT BROWNEY COLLIERY

I enclose a letter also from our engineer, Mr. Steavenson.

Mr. Steavenson's letter reads as follows: By the narrow ovens, I presume Mr. Fulton means those which are discharged by ram and cooled by water outside; this, we have always found, causes an excess of moisture amounting to 4 or 5 per cent., whereas with the round oven it does not exceed the half of 1 per cent., when cooled before being drawn.

If the narrow ovens are burned close so as to produce by-products, it gives a solid lumpy material which works badly in the blast furnace.

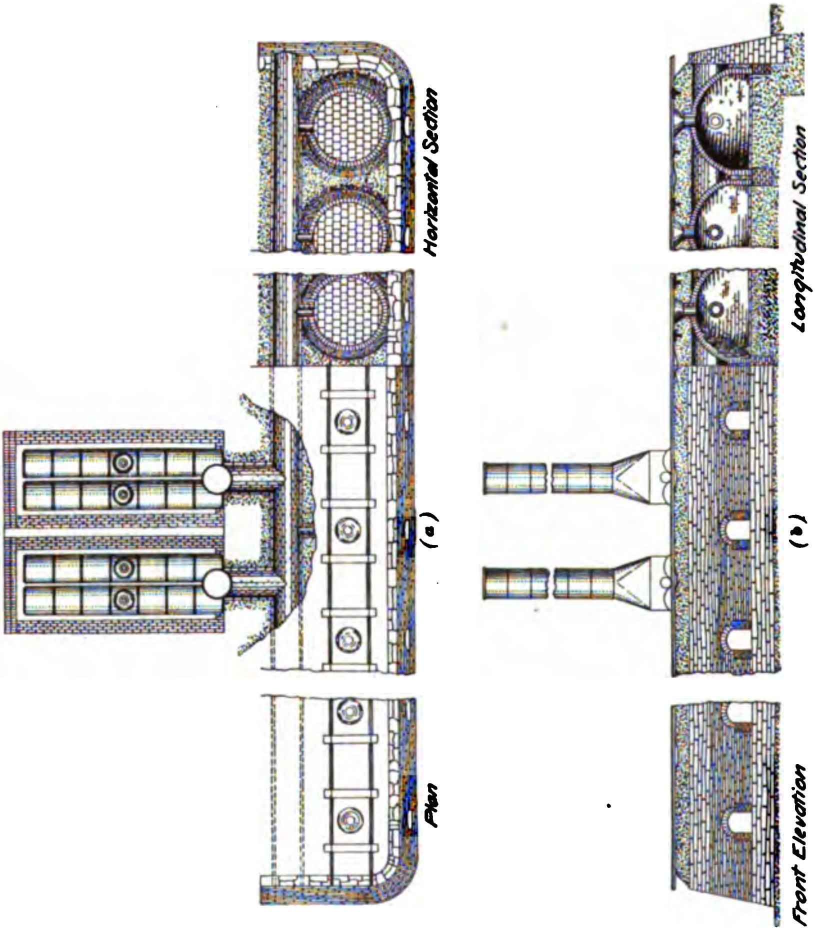
Messrs. Newton, Chambers and Company, of Sheffield, say they are successfully drawing off the by-products from the floor of the open burning beehive oven; this may depend on their having an open free-burning coal, but we have not yet succeeded in doing it with the rich-burning coal of Durham, and when we get 64 per cent. of good coke and all the steam which is required for drawing 1,000 tons per day, and pumping a large feeder of water from 600 feet, we seem to have accomplished a fairly satisfactory result. A. L. Steavenson.

From the arrangements of the beehive coke ovens of the Messrs. Bell Brothers, England, it will be seen that the hot gases from these ovens are conveyed through a central conduit and carried under boilers, affording steam for winding coal, pumping water, and other uses. Similar applications of the waste heat of coke ovens have been made in Scotland and on the continent of Europe.

Since the above was written, very commendable progress has been made in England and Scotland in improving the beehive coke ovens, and in the introduction of several plans of the retort coke ovens with the saving of the by-products.

Use of Waste Gases for Steaming at Pratt Mines, Alabama.—In America, these waste gases have been utilized at a few plants in a similar service—generating steam. Mr. E. Ramsay, mining engineer of the Tennessee Coal, Iron, and Railroad Company, describes, in a paper read before the Alabama Industrial and Scientific Society, the method in use at the Pratt mines:

"In order that the construction and mode of operation of the plants now in operation may be readily understood, I have prepared plans of one of the plants to which reference will be made in this paper, Fig. 15. As noted heretofore, the ovens from which the gases and heat are derived were built some years ago and were in operation at the time work was commenced. The first part of the work undertaken was the construction of the longitudinal main flue, which is cylindrical in section and placed immediately to the rear of the ovens. A few ovens were blown out at a time, and as the flue was built and connection made to each oven, these ovens were again put in blast and others blown out, and so on until the flue had been built and connections made to the entire battery of twenty-five ovens. This main flue is 3 feet 6 inches internal diameter, has 4-inch walls on bottom half and 9-inch walls on top half, and is built of firebrick furnished by the Bessemer Firebrick Company, of Bessemer, Alabama. At first thought, it may seem that the walls are too light for a flue of such diameter, but when one reasons that this flue is cylindrical in shape, which gives the greatest possible strength for the amount of material used, the objection does not have the same force. At all events, it has given no trouble except on two occasions, when a few bricks fell out of the walls and into the flue at the juncture of one of the small flues which connect it with the ovens. When the clay and earth filling was removed from the rear of the ovens to make room for the main flue, it was found, as was expected, to be quite hard burned, and especially that part resting on the oven walls proper, which was as hard burned as an ordinary red brick. This hard material was nicely cut out to a section equal to the half circle of the external diameter of the flue, the bottom half of which was laid in it, using the cut-out section as a form and a loamy clay as mortar.



(*a*) *Top View and Horizontal Section.* (*b*) *Front Elevation and Longitudinal Section*

FIG. 15. OVENS AT PRATT MINES, ALABAMA, USING GASES FOR STEAMING PURPOSES

The upper half of the flue was then laid, using the ordinary wood centers, which were moved along as the flue was completed. Over the upper half of the flue, a layer of about 6 inches thick of well-puddled clay was put on, which, when the heat was turned on, was burned into the hardness of a red brick. This plan was adopted as a cheap means of reenforcing and adding strength to the walls of the flue and making it so that, if a brick or two did fall out, it would be quite probable that the flue would continue to do duty until a convenient time for making repairs could be had. In both of the instances where the flue gave way, work was continued for several days before repairs were made. As is shown by the plan, in transverse and longitudinal sections, the main flue is built in contact with the rear walls of the ovens and a connection is made to each oven at the point of contact by a cylindrical firebrick flue 12 inches in diameter and about 20 inches long.

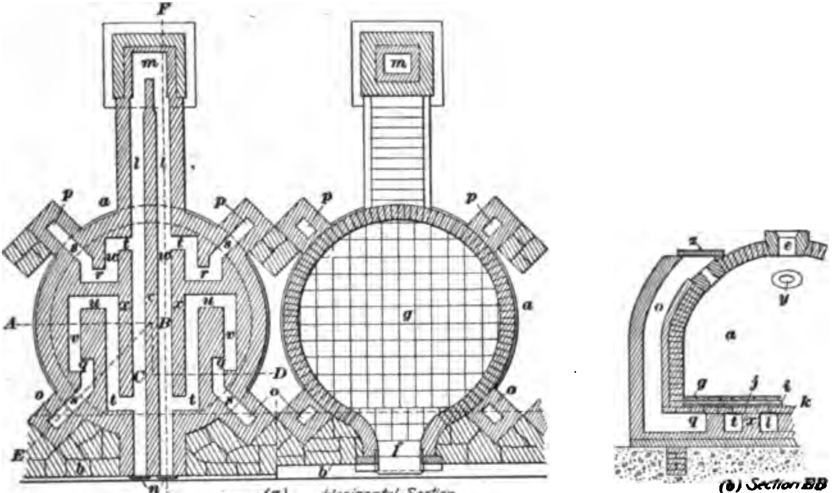
"There are two boiler plants of the design, size, and construction shown in plan in operation at Pratt mines, and each receives the heat and gases from its individual battery of 12-foot bank beehive ovens of the usual American construction. Each plant consists of two batteries of 46″ × 26′ boilers, with two 16-inch flues each, and is situated midway and to the rear of the ovens in such a position that the transverse center line which passes through the center of the thirteenth oven, counted from either end, is also the center line of the boiler plant. The boilers were placed in the center of the bank of ovens for the reason that the closer they were placed to the ovens the less the distance would be which the gases would have to travel, and consequently the less would be the loss of the initial heat of the gases by radiation. To illustrate: the boilers might be placed so far from the ovens as to cause the gases to part with all the initial oven heat before arriving at the boilers, and in such a case the benefit derived would be alone in the combustion of the gases at the boilers, with the proper admixture of air, in a manner similar to the burning of gases from the blast furnaces under boilers and in hot-blast stoves. This being the case, it is apparent that, unless the conditions will not admit of it, the boilers should be placed as close to the ovens as possible. The boiler settings, as will be seen from the drawings, are of the ordinary type, with the boiler fronts and grate bars omitted. To have used grate bars, in order to allow of hand firing with coal, would have complicated the plant to an extent which the benefits to be derived would not have warranted. As noted in a previous portion of this paper, grate bars were used in the first experimental plant erected at Pratt mines, and in that case they were rapidly destroyed by the incandescent gases passing over them. To have obviated this trouble it would have been necessary to admit the gases back of the grate bars, and in such a case that part of the boiler immediately over the bars would have been practically dead space; or a furnace might have been built, to one or both sides of the boilers, in such a manner as to admit the heat and gases at the same point as they are now admitted in the plant described in this paper.

"In order that each battery might be worked separately, or both at one time, an independent flue from the main flue and discharging under the battery is provided, as shown in the plan, and in each of these branch flues, which are of the same diameter as the main flue, a damper was placed in the first plant built; but after working practically for several months it was found to be almost unnecessary, as the opening of the breeching and cleaning doors at once stops the draft and, consequently, the flow of gases, and if the shut-down was to be for any length of time, it would be an easy matter to close one of the flues with a temporary brick wall, such as is used in closing coke-oven doors at each drawing. That it is only a matter of a few minutes' work to open these doors and take off the oven dampers has been demonstrated on several occasions when it was desired to stop the flow of gas and heat to the boilers. In fact, this can be done as expeditiously almost as a damper, large and unwieldy as it would necessarily be, could be manipulated.

"The amount of steam-actuated machinery at this mine, shaft No. 1, is very large, and requires a great amount of steam for its operation. Before the utilization of the waste heat and coke-oven gases in the making of steam, this plant used monthly about 1,500 tons of coal, or 7½ per cent. of the entire output of the mine for boiler use. This, at $1 per ton, represented a monthly loss of $1,500 for boiler coal, or about 7½ cents per ton of coal on the entire output. So long as the selling price of coal was reasonably remunerative, this large outlay for boiler fuel was not felt so much, but as the selling price constantly became less and less, it was imperative that something should be done. Then work was commenced on the boiler plants at the bank coke ovens, and so successful has been their operation that the coal used at the old boilers has been reduced to 300 tons per month. When the amount of labor used at the coal-fired boilers for firemen and ash wheelers, together with the expense of grate bars and general wear and tear is considered, it is no exaggeration to say that the coke-oven boilers have effected a monthly saving of $1,500, or $18,000 per annum. By utilizing the gas from another block of twenty-five ovens, the entire plant could be supplied with steam without using any coal whatever, except a little on Monday mornings, when the ovens are cold from standing over Sunday; and even this could be obviated by drawing and charging a few of the ovens on that day."

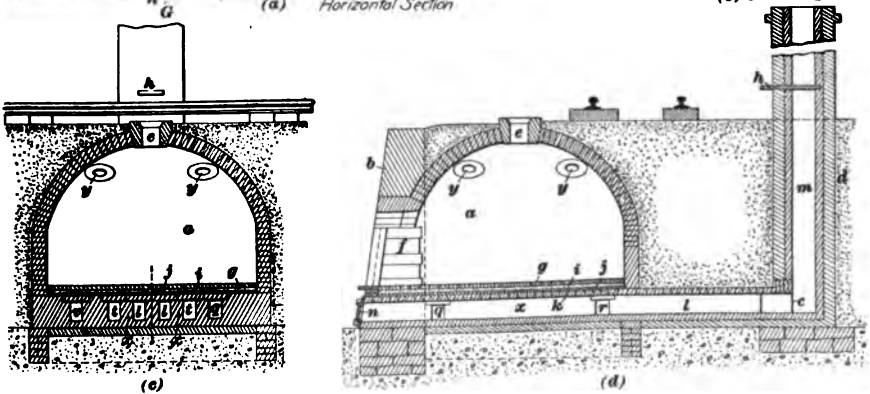
From the evidence of the economy in these methods of utilizing the waste gases from plants of beehive coke ovens in affording heat for generating steam, it is evident that it will be well to consider these examples on the lines of economy, especially in erecting new plants of coke ovens.

The Ramsay Patent Beehive Coke Oven.—The design of the Ramsay oven is to secure a hard-bodied coke, to prevent the production of black ends in the coke, and, by means of its bottom flues affording increased heat, to coke the dry coals or coals low in volatile matter. The high temperature of this oven assures a hard-bodied coke, which



(a) Horizontal Section

(b) Section BB



(c) Section ABCD

(d) Section FG

Fig. 16. Ramsay Patent Beehive Oven

is most desirable for use in blast-furnace operations, as it resists dissolution, in its downward passage in the furnace, from the ascending hot carbonic-acid gas. This hard-bodied coke is secured by the use of all the gas evolved in coking and burned in the oven flues.

Fig. 16 shows the detail of this oven as built at Byrendale Coke Works, in Elk County, Pennsylvania; (*a*) is a plan showing the arrangement of the flues; (*b*), (*c*), and (*d*) are cross-sections.

TABLE IV

EXPERIMENTS IN COKING BY THE SHAWMUT MINING COMPANY IN ELK COUNTY, PENNSYLVANIA, IN RAMSAY AND BEEHIVE OVENS

No. of Test	When Charged			When Drawn			Time in Oven		Coal Charged Pounds	Market Coke Made Pounds	Small Coke or Breeze Pounds	Ashes Made Pounds	Total Coke Made Pounds	Percentage of Yield				Per Cent. Lost	Remarks
	Month	Day	Hour A. M.	Month	Day	Hour A. M.	Hours	Min-utes						Market Coke	Small Coke	Ash	Total Coke		
1	June	25	7.35	June	27	6.30	46	55	19,700	13,000	130	130	13,130	66.00	.66	.66	60.65	33.35	Ramsay ovens
2	June	25	6.25	June	27	6.00	47	35	20,615	13,399	123	174	13,522	65.00	.59	.85	65.59	34.41	Ramsay ovens
3	June	25	8.20	June	27	7.25	47	5	20,211	13,400	111	134	13,511	66.30	.55	.66	66.85	33.16	Ramsay ovens
4	June	25	9.25	June	27	8.00	46	35	11,250	7,200	72	144	7,272	64.00	.64	1.28	64.64	35.36	Beehive ovens
5	June	25	9.40	June	27	7.45	46	5	10,769	7,000	74	126	7,074	65.00	.68	1.17	65.68	34.32	Beehive ovens
6	June	25	10.00	June	27	9.40	47	40	11,137	7,150	72	130	7,222	64.20	.65	1.17	64.85	35.15	Beehive ovens

The following is the explanation of the reference letters used in connection with the drawings, Fig. 16, showing the construction of the Ramsay patent beehive oven: *a*, body of oven; *b*, front wall of oven; *c*, wall between center flue; *d*, stack in rear of oven; *e*, trunnel ring; *f*, oven door; *g*, top tile bottom of oven; *h*, damper in stack; *i*, *j*, composition air-tight packing; *k*, bottom tile of oven; *l*, two horizontal flues extending from front of oven to stack at back of oven; *m*, stack in rear of oven; *n*, covering of the double flues *l*; *o*, inlet front flues from bottom of outlet flues; *p*, inlet back flues from bottom of outlet flues; *q*, *r*, *s*, *t*, *u*, *v*, *w*, radiating flues under oven; *x*, pillars between flues under oven; *y*, four inlet flues from oven to flues; *z*, top covering tile on top of flues.

Mode of Operation.—Coal is charged the same as in a common beehive oven at *e* and leveled, the opening *e* and door *f* are closed, and the damper *h* is partially closed when ignition takes place. *f* and *h* are regulated as occasion demands. The operation of the flues is as follows: the gases generated in the oven enter flues *y*, descend *o*, radiate through *s*, *q*, *r*, *u*, and *t* into parallel flues *l*, and escape through the stack *m*; when the oven is burned off, the coke is watered in the oven and then drawn by hand in the manner commonly employed in drawing the ordinary beehive oven.

COMPARATIVE AVERAGE ANALYSES OF COKE MADE IN RAMSAY AND COMMON BEEHIVE OVENS

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
Ramsay..........	.02	.75	89.28	9.95	1.05	.024
Beehive..........	.17	1.58	87.53	10.72	1.12	.025

NOTE.—These analyses were made by the Metallurgical Laboratory, 545 Liberty Avenue, Pittsburg, Pennsylvania.

Comparison of Wages.—*Ramsay.*—Charging, .05; leveling, .12; drawing, .99; total, $1.16. The average charge per drawing is 6.645 tons, then $1.16 ÷ 6.645 = 17.5 cents per ton.

Beehive.—Charging, .05; leveling, .11; drawing, .77; total, $.93. Average charge per drawing is 3.55 tons, then .93 ÷ 3.55 = 26.2 cents per ton, a saving of 8.7 cents per ton in favor of the Ramsay oven.

In considering the relative economy of operating different types of ovens, the first cost is an important item which must be taken into account.

The following is an estimate of materials and cost of the beehive and Ramsay coke ovens:*

---

*The relative work of the beehive and Ramsay ovens, with all other matter, has been furnished by Mr. Geo. S. Ramsay.

STATEMENT OF MATERIAL AND COST FOR THE BEEHIVE OVEN

3,100 crown brick at $32	$ 99 20
1,800 liners at $32	57 60
1 set of fronts at $11 per set	11.00
900 red brick at $9	8.10
500 red brick for ring wall at $9	4.50
118 floor tile at $95	11.21
1 trunnel head at $3	3.00
1 trunnel-head ring at $3	3.00
Frame	6.00
Labor	239.21
Extra labor and supplies not mentioned above	59.70
Total	$502.52

MATERIAL NECESSARY FOR ONE RAMSAY PATENT COKE OVEN

FIREBRICKS

3,000	9-inch quartzite bricks for bottom flues	
2,500	9-inch quartzite bricks for side flues	
5,500	9-inch Q. T. Z. at $21 per M	$115.50
1,900	12-inch Juniata liners at $35	66.50
2,900	12-inch Q. T. Z. crown bricks at $45	130.50
190	8″ × 3″ × 18″ Q. T. Z. covering and bridge tiles at 13 cents	24.70
20	6″ × 6″ × 18″ Q. T. Z. blocks at 20 cents	4.00
130	12″ × 12″ × 2¾″ floor bricks at 10 cents	13.00
56	12-inch Q. T. Z. special arch bricks for flues at 20 cents	11.20
8	Juniata jamb blocks at $2.50	20.00
2	Juniata R. and L. skews at $2	4.00
5	Juniata arch bricks at $2	10.00
1	trunnel ring	3.00
	Total	$402.40

RED BRICKS

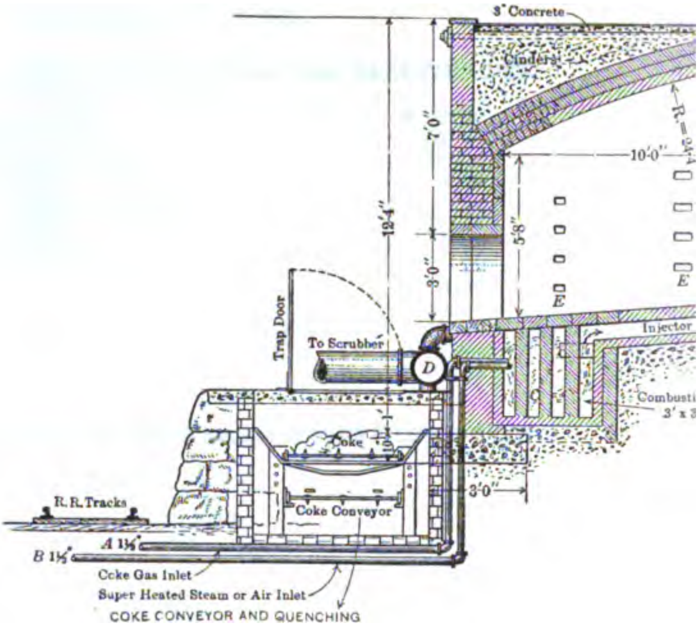
1,000	bricks for bottom ring	5,400 at $10	$ 54.00
3,500	bricks for chimney		
700	bricks for pier		
200	bricks around door		

FIRECLAY—BRICKLAYING AND ASBESTOS

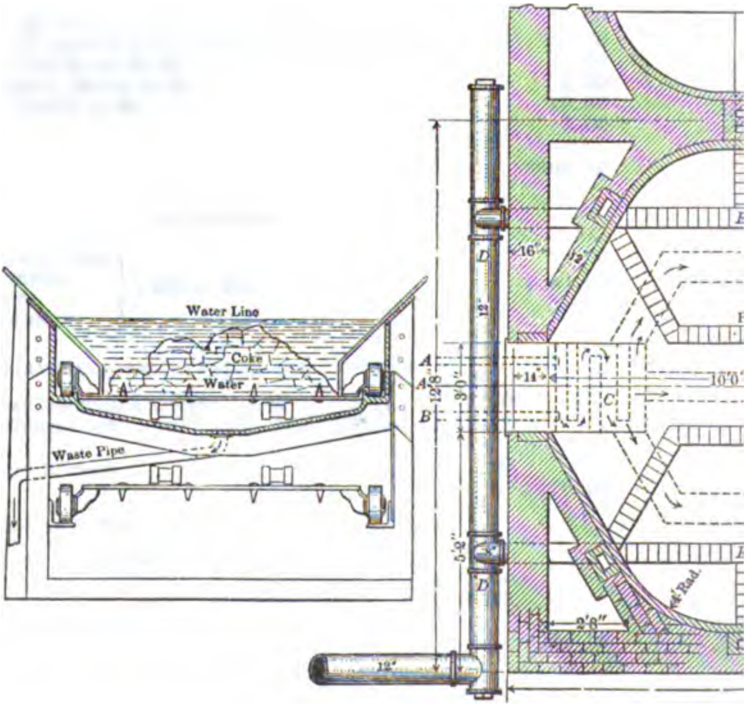
10	tons of fireclay, including freight, at $7	$ 70	
7	sheets of asbestos 44″ × 44″ × ¼″, 360 pounds at 5 cents	18	
	Bricklayer and helpers	90	
			178.00

STONEWORK—EXCAVATION AND FILLING

40	perches of stone work at $4	$160	
10	yards of excavation at $1	10	
45	yards of filling at $1	45	
1	capstone for pier	1	
			216.00

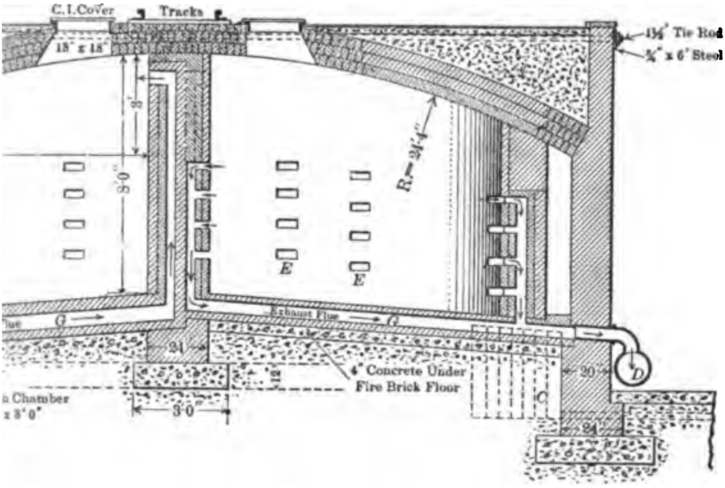


(a) El

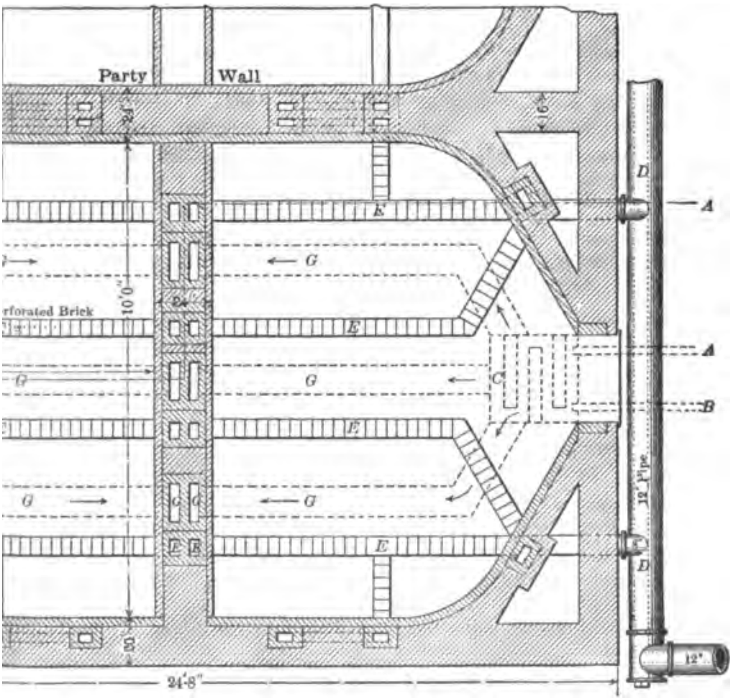


(b) I

FIG. 17. DAUBE'S DO



vation



lan

N-Draft Coke Oven

IRONWORK

4 6-inch I beams at 6 feet long—24 feet at 15 pounds	360 pounds	
1 20′ × 9″ girder rail with distance pieces	900 pounds	
1 cast-iron door frame	360 pounds	
1 cast-iron cover-plate	50 pounds	
4 wrought-iron anchors	30 pounds	
	1700 pounds at 3 cents	51.00
Total		$901.40

Mr. Ramsay estimates that under ordinary conditions this oven can be built for $675. Under normal conditions the beehive oven costs $250 to $300.

Daube's Economic Down-Draft Coke Oven.*—The accompanying illustrations, Fig. 17, show the details of a coking oven invented by Oscar Daube, of New York, having for its object an improvement in the quality of by-product coke. The oven is built on a beehive plan. Under each one is located a combustion chamber operated under forced draft with coke-oven gas or fuel. This results in coking from the bottom up, while the waste gases from the combustion chamber pass up the rear, entering the oven above the coke bed under pressure, which causes the coking to take place from the top down and from rear to center. The gases generated in the coking process are drawn through flues that pass down the sides and also under the floor of the ovens, giving off their radiant heat on their outward passage to the coke in the oven. It will thus be seen that the coking process takes place from the bottom up, top down, and from sides to center. The process is claimed to be rapid, completing in 24 hours a charge of 6½ long tons. The coke obtained is said to be of first-class quality, running from 88 to 92 per cent. carbon and yielding 67 to 72½ per cent. of coke.

The manner of withdrawing the gases at the side and bottom of the oven has for its object the decomposition of the heavy hydrocarbons. These, coming in contact with the incandescent coke, decompose on their outward passage, adding a percentage of carbon to the coke; hence, the large yield of coke per ton of coal. The yield of tar is correspondingly reduced from 12 to 14 gallons per ton to from 4 to 5 gallons. The quantity of gas recovered is approximately 5,000 cubic feet per ton, the balance being used for heating the ovens. This recovery compares favorably with the amount now being obtained by other by-product coke ovens. The ammonia saved amounts to from 25 to 35 pounds per ton of coal, depending, of course, on the percentage of nitrogen in the coal coked. The above results are on a basis of a good coking coal, capable of coking by any process. There are, however, large areas of so-called

---

*Engineering and Mining Journal, November, 1902.

non-coking or poor-coking coal that up to date none of the present coke ovens have successfully coked.

The economic down-draft coking process has been developed on the opinion held by Sir I. Lowthian Bell, and others, that the cause of the poor-coking or non-coking qualities of coals lay in the fact that they are low in disposable hydrogen, and which in slow ovens volatilizes before the coking stage is reached. This theory is claimed to have been proved correct in this process, which, owing to its ability to generate a high uniform heat at the beginning of the coking operation, brings about the fusing or coking stage before the disposable hydrogen is volatilized. The inventor states that a number of western coals heretofore considered non-coking have been successfully coked by the economic process. The cost of these ovens, independent of by-product recovery plant, is said to be only slightly higher than that of the ordinary beehive oven.

IMPROVED HEMINWAY PROCESS*

This improvement relates to the method of coking in a beehive oven, and has for its object not only the production of a good sound metallurgical coke from so-called non-coking coals, but also the improvement of the practice of coking the well-known grades of coking coal.

It is generally admitted that a good coking coal must contain from 20 to 30 per cent. of volatile matter; it must be low in ash and sulphur, and when subjected to a coking heat must fuse or become pasty, and while in this pasty condition it must give up its volatile matter in such form that during its evolution from the pasty mass of coal it will push a number of carbon particles together so as to form strong cell walls, separated from one another by pores.

Suppose that the volatile matter in a coal is over 40 per cent.; it naturally follows that one must change or modify the ordinary practice followed in beehive ovens, because the greater volume of volatile matter would increase the size of the pores and thus weaken the carrying strength of the coke, unless the strength of the cell walls was correspondingly increased; that is, provided that the rate of evolution of volatile matter was the same in both cases. But suppose that the volatile matter in the latter case is evolved at a much greater rate, might not this rapid evolution have a tendency to cause more pressure in the oven and thus close the pores; in fact, might it not even change the shape and regularity of the cells as well, thus producing a coke too dense and one that would not absorb the hot gases in the blast furnace under usual conditions? I consider it possible to obtain good results from coke whose cell structure is not exactly similar to the recognized form. I also

---

*Dr. R. S. Moss in Mines and Minerals, April, 1901.

consider it possible to alter the cell structure of a coke at will during the time of coking by an intelligent manipulation of the pressure in the oven, which can very easily be accomplished by the use of my improved method of coking.

It is well known that the fusibility of a coal does not depend on the volume of volatile matter present in the coal; however, the greater the fusibility of a coal, the greater is the range to which it lends itself for easy change of the size and arrangement of its cells; but what effect does this have on the carbon regarding its efficiency for blast-furnace work? Suppose that I produce a very porous and a very dense coke from the same coal, does it not follow that, although the percentage of fixed carbon is the same in both cases, the efficiency under the same conditions in a blast furnace will vary between wide limits; but is this the fault of the material or the method of operating the blast furnace? The same heat units are represented in both the porous and the dense coke, they are both strong enough to bear the usual burden of ore, and yet the proportion of coke to ore is very much greater in one case than in the other; this assumes that carbon in all its various forms, as found in coke, will develop the same efficiency. But does it? If oxidized directly to carbonic acid its efficiency must necessarily be the same, but as a matter of fact two cokes of exactly similar analyses give different efficiencies; what is the cause? Clearly this can be readily ascertained by making a simple analysis of the gases escaping from the blast furnace. It will be found that the ratio of carbonic acid to carbon monoxide is higher in the gases from the coke showing the highest efficiency, and vice versa; but why should one coke give a higher efficiency than another where the fixed carbon in both is equal? Obviously, oxidation of the fixed carbon is not equal, and as oxidation depends on the air supply, all other conditions being the same, the pressure of air, or the volume, or both, must be changed; but here again is a limit to which we can either increase or decrease pressure, or volume, or both, to advantage; but as the limit lies within very wide margins it will be found, in practice, that equally good results may be obtained with either a dense or a porous coke, provided that they both hold the burden, by manipulating the air supply either as regards pressure or volume to suit the coke.

Let us return to our coke ovens. When I took charge of the Universal Fuel Company's plant I found a battery of four experimental ovens in operation under the Heminway process; to these ovens a by-product plant had been attached; the arrangement was such that the gas was taken off from the trunnel head, thence to a small hydraulic main placed at some considerable distance from the ovens, thence through a Root exhauster to a Pelouze & Audouin's condenser, from there through a scrubber, and thence measured through a proportional meter to a purifier and on to the holder. I found this arrangement both useless and dangerous.

Good hard coke was being made from western coals and everything appeared favorable as regards the matter of coking.

By the Heminway process, air, hot or cold, was blown into the oven just above the top of the coal. If the oven was rather cold, or the charge did not readily ignite, hot air was used; the air was heated to 600 or 700° F. by being passed through firebrick checker work in a furnace external to the oven, thus aiding combustion. The amount or volume of air, either hot or cold, was not regulated in proportion to the amount or volume of the volatile matter that was given off from the coal; hence, the object aimed at was not gained at all times. If an oven appeared hot, the air was put in and the oven was blown continuously, resulting in nothing more than further heating the air, which, passing off from the trunnel head, carried considerable heat from the brickwork, hence cooling down the oven so much that after the expiration of a few hours the oven was very much cooler than when charged. The coal did not coke, and the inevitable result of an oven making breeze and not coke was obtained. This had been the case time and again; the cause assigned by those in charge was deterioration of the coal used, due to the weather, or perhaps it might be the effect of a few days longer on the road from the mine to the works, or it might have got wet in transit, etc.; be that as it may, while we all know that coal does deteriorate if exposed to atmospheric changes, yet I have never heard of any coal undergoing such remarkable changes in such a short time.

It has been found that, while the Heminway method does increase rapidity of combustion, the rate of coking is seriously disturbed throughout the mass of coal; for instance, the top layer of coal is coked long before the bottom, hence, at the high temperature maintained by this method, the coke or carbon in the upper part of the oven is burned while waiting for the lower layer to coke. This is as might be expected; coal and coke are bad conductors of heat, hence the rate of heat penetration throughout the mass of coal is disturbed. The upper layers coke rapidly without giving a corresponding increase to the lower layers.

Let us assume the normal conditions found in beehive ovens: 5 to 7 tons of coal are charged into the oven, the coal is leveled off and the door walled up, coking takes place in the usual way and the oven is drawn, we will say, in 48 hours; black ends are noticed on the bottom; therefore, the coal has not been thoroughly coked. If a sample of this coke is taken from top to bottom, we shall find that the volatile matter will increase from above downwards. Now suppose that this same oven is attached to the Heminway process, again charging the same amount of coal—in fact with all conditions remaining the same—hot or cold air or both are blown into the oven as deemed best under the circumstances, so that complete combustion takes place inside the oven; it naturally follows that the temperature of the oven, at least the space within the area of combustion, will increase at a much quicker rate than in the first case; hence, all other conditions remaining the same, it follows as a matter of course that the increased disproportion of heat distribution in the latter case must tend to set up an unequal rate of coking throughout the mass. Supposing that the oven is drawn just as soon as the top is well coked, the yield of coke will be high, yet it will vary in hardness and amount of volatile matter from above downwards, showing large black ends, practically nothing but fused coal on the bottom; then again, if we continue to coke until the whole of this volatile matter has been eliminated and the coal is thoroughly coked to the bottom, we shall find our yield much less than the loss of volatile matter above would indicate, due, in this case, to the coke having been consumed on top. This teaches that the ideal coke oven must, if possible, be evenly heated; it must evenly maintain that heat so that the whole mass may be completely coked, as nearly as possible at one and the same time. If our material were a good conductor of heat the problem would be very much easier, but as we must depend on the heat radiated from the firebrick walls and bottom of our oven, it takes considerable time before that heat and the heat of combustion combined penetrate through the mass of coal; this in a beehive oven; in a closed oven the trouble is not exactly the same, as this latter method is one of distillation by means of a furnace external to the oven. To overcome the difficulties met with in the Heminway process I have made a number of improvements, which are herein set forth and discussed.

Instead of blowing air direct from an opening having the exact diameter of the pipe through which it is conveyed, I enlarge the exit by making it elliptical in shape, raised slightly on the lower side instead of horizontal, thus blowing the air in a slightly upward direction in the oven and at a sufficient height above the mass of coal to protect combustion of the fixed carbon, by a cushion or layer of volatile matter between the coal and the air supply; at a point 3 feet at least from the center of the air exit I add a second air supply also elliptical in shape and placed almost in a horizontal plane, thus completing combustion of the volatile matter that escaped the lower supply of air. It is obvious at once that the form of my exit will insure a better and more even mixture of air and combustible gas than when the exit is round. It prevents cutting or channeling of the volatile matter and gives a better diffusion; then again, it is well known that to obtain complete combustion a considerable excess of air is required; hence, if we depend entirely on one air supply, a considerable volume of inert nitrogen must be thrown into the oven, thus absorbing heat and carrying it off at the trunnel head. If complete combustion is not obtained, a large amount of combustible volatile matter will pass out of the trunnel head and be consumed in the open air without giving any heat to the brickwork in the oven. By adding a secondary air supply it does not become necessary to blow as much air into the oven from the lower pipe. Combustion of part of the volatile matter takes place; the heat produced by this combustion is transferred to the whole of the gases; hence, the unconsumed volatile matter reaches the secondary air supply at a higher temperature than would otherwise be the case; hence, such an excess of air is not required to obtain complete combustion as is the case with only one air supply, and the whole of the combustible matter is consumed inside the oven, thus preventing loss of heat due to combustion on the outside of the oven. This is all very well so far as it goes, yet it alone only increases the disproportion of rate of coking throughout the mass of coal in the oven, and hence aggravates rather than lessens the trouble met with in the Heminway process of coking; for, with this increased heat above the coal, the top layer of coal is coked much more quickly than in the Heminway process, and even long before the coal on the bottom of the oven has given off its volatile matter; hence, we must either draw an oven with coal on the bottom not coked at all, or we must run it until coked, when the fixed carbon on the top, or rather the coke, is being consumed and the top is ashed over, reducing our yield very seriously, as well as increasing the percentage of ash; therefore, one can see that this improvement in itself is useless. To overcome this difficulty I have built a flue from the inside of the oven just below the trunnel head, carrying it down the outside of the oven and under the bottom, starting near the front of the oven and continuing along the bottom to the back, and again passing outside to a main flue built between the ovens, where the gases may be utilized for raising steam, and thence to a chimney discharging into the outer atmosphere. I have built twelve flues under the oven, and thus equalized the heat from front to back; the front being the coolest part of the oven in a battery built back to back decided my taking, or rather starting, in from the front, because the protection of the other ovens on the sides and back maintains a slightly higher temperature than in front where the oven is not protected; hence, the gases at their highest temperature enter the bottom flues at the coolest part of the oven. By carrying the waste gases from the top underneath the floor of the oven, I equalize, to a great extent, the difference in temperature between the top and bottom of the oven; not only this, but I also increase the rapidity of evolution of the volatile matter from the bottom, and thus in a given time remove a greater volume of combustible matter than is possible in the Heminway or old process. This increased combustible matter requires a large volume of air for its combustion; hence, I open the top and bottom valves connected with the air supply and thus add the required increase of air. This increased amount of air and gas, by their combustion, increases the amount of heat produced; hence, the waste gases passing under the bottom of the oven carry a corresponding increase of heat; the greater volume of air and gas gives a greater volume of waste gases, all of which are conveyed under the bottom of the oven, not only equalizing the heat in the mass of coal, but also increasing the rapidity of coking the coal, thus materially reducing the time of coking, in addition to obtaining a more even coke and one entirely free from black ends, to say nothing of the increased yield which I obtain. I find it an advantage to build a double floor on the bottom of the oven because of the increased amount of heat retained than when single. One must also build the floor of the flues of sufficient thickness to prevent undue loss of heat below; it must be protected by a sufficient thickness from the effect of atmospheric changes, as well as climatic conditions, such as difference in temperature between winter and summer, excessive rains, etc. The place and location of the ovens will readily determine what precautions are necessary to retain the heat on the bottom so as to obtain the most effective work.

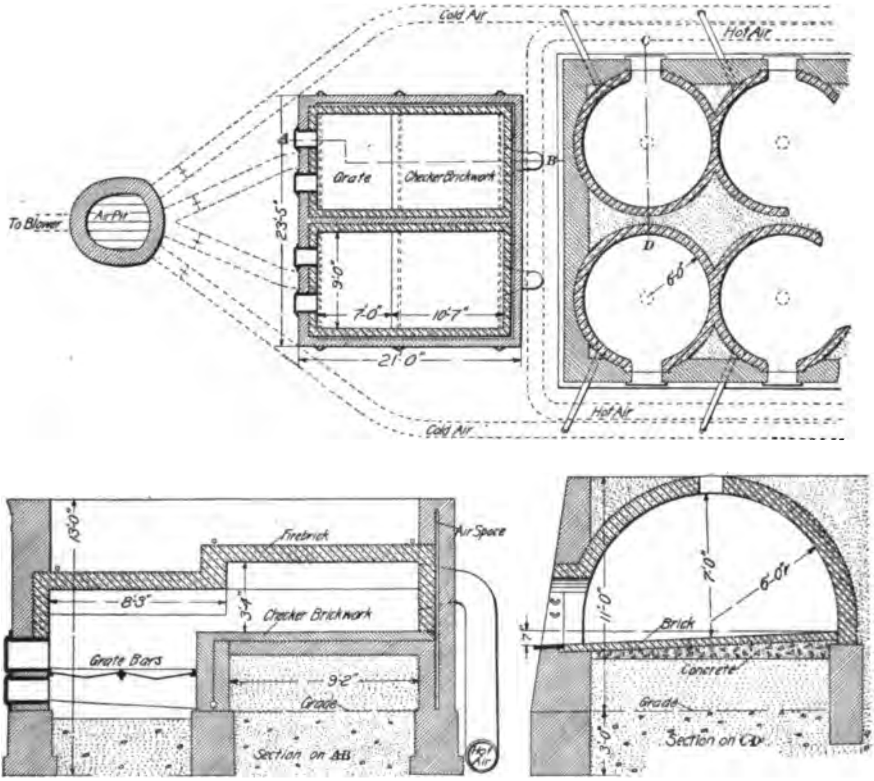


Fig. 18. Heminway Process Improved Beehive Coke Ovens

To still further obtain a more intimate mixture of air and gas in the oven, I have added four openings in the oven on a level with and in favor of the one lower oval-shaped opening. I thus throw air into the oven at four separate points equidistant from each other, thus reducing the danger of unequal and incomplete combustion; the directions of these four openings are such that a line drawn from the lower side of each opening will strike a point just below the trunnel head in the oven. One can easily see that a very complete mixture of air and gas is obtained. If necessary, two more openings for the admission of air may be added in favor of the one upper opening, these openings to be directly opposite each other and almost horizontal with the face of the oven; this will insure a secondary air supply that will thoroughly and evenly mix with the gases coming from below and result in complete combustion of all volatile combustible matter escaping from the lower part or strata of combustion.

While this is a great advance over the old method, yet the rate of coking through the mass is not as even as might be desired. We have, in this case, our oven hotter at all times on top than on the bottom and less toward the center than on the bottom; to overcome this I have arranged to pass either air alone, or air and waste gas, or waste gas alone, under the bottom and up through the mass of coal in the oven by means of flues or perforated tile, or any arrangement that will allow the air or gases to pass up through the whole bottom of the oven; for instance, in my first trial of this I used the flues built in the bottom of the oven which I designed for drawing off gas, tar, and liquor; the flues, two in number, are 6 inches wide and 9 feet from back to front; in a 12-foot oven they are arranged at equal distances apart and are covered with perforated brick ¼ inch wide on top and ½ inch on the bottom. Air was blown in the bottom through these flues and, as might naturally be expected, combustion was very intense over the flues, so much so that it channeled and rapidly consumed the volatile matter in the coal directly over the flues. The coal along this line coked very rapidly, leaving a depression the shape and length of the flue on the top of the coke due to the quicker coking over the flues and consequently quicker contraction. Near the front of the oven or at the point of least resistance to the passage of air, large holes appeared, through which the air passed readily to the top of the oven; however, even with this crude arrangement, the coke came out good; black ends in this case appearing on top and not on the bottom of the coke. The time of coking was still further reduced, and I consider, with the perforated bottom and intelligent management of all the improvements herein set forth, we shall still further reduce the number of so-called non-coking coals, besides reducing time of coking of all coals now coked, coking a 7-ton charge in 36 hours equal to 72-hour coke, improving the quality and increasing the yield so that it runs very close to what is found on analysis.

The importance of this perforated bottom for the admission of air or waste gases, or a mixture, cannot be overestimated; but like all improvements, it can be made worse than useless by ignorant operation. When air is blown into the bottom of the oven the volatile matter in the coal is consumed; at the point of combustion considerable heat is produced which, passing from below upwards, distills the volatile matter above, and this increased yield of volatile matter increases the volume of combustible gases; hence, a greater volume of air is required. This air is supplied either through the air flue on the top, or, if the heat is not fairly even, a part or the whole of the combustible gases is carried to the bottom of the oven where they come in contact with air blown into the bottom; hence, combustion of the volatile matter takes place, protecting the fixed carbon on the bottom of the oven; and yet by the passage of this hot burned gas it distills the volatile matter remaining in the mass of coal above the coke on the bottom, and the heat passing rapidly and evenly from top to bottom and from bottom to top, produces an even rate of coking throughout the mass of coal. I was led to this improvement through chemical methods which I have

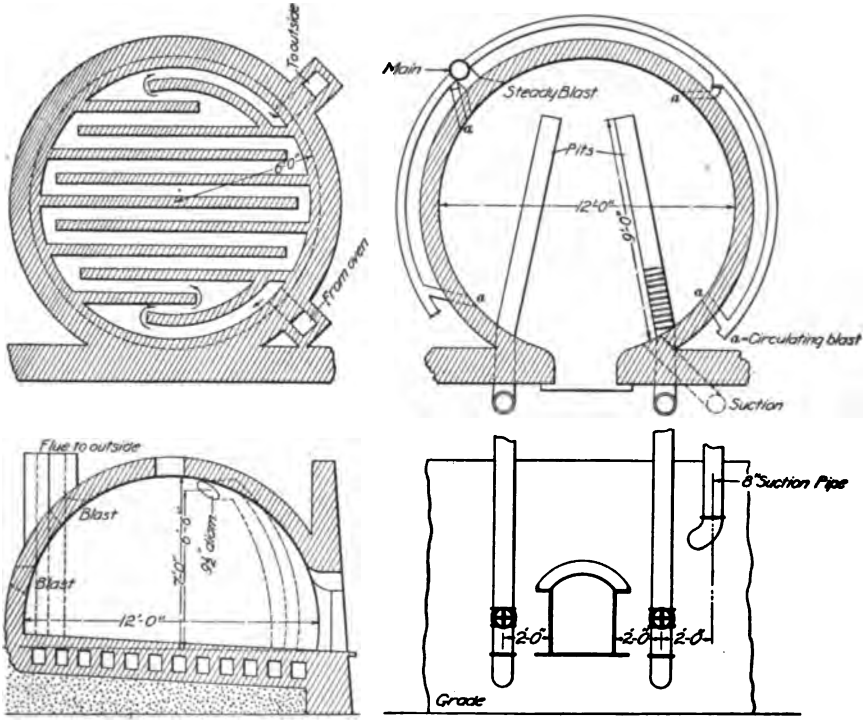


FIG. 19. ARRANGEMENT OF FLUES IN IMPROVED BEEHIVE OVENS

devised for the removal of sulphur and which demand a quick temperature throughout the mass of coal to decompose the chemicals used and bring about the necessary chemical reactions, without injury to the fixed carbon.

The battery of twenty-four ovens has been built after the plans of the writer, as shown in Figs. 18 and 19. These ovens are now in operation producing results which excel even my anticipations. I am able to coke a 5-ton charge of so-called non-coking Illinois coal in 24 hours, and the coke is superior in quality. I am able to use duff which costs 25 cents per ton at the mine, but am now using pea coal on account of the moisture in washed duff at this time of the year, about 30 per cent., which is frozen and takes too long to draw off in the oven.

The following are analyses of the coal and the coke:

ANALYSES OF ILLINOIS COAL

Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
2.30	33.58	56.93	7.19	1.32
5.71	32.61	52.26	9.42	1.93
4.50	31.60	56.90	7.00	1.10
4.35	31.16	56.79	7.70	1.30
4.57	31.53	55.06	8.84	1.13

COKE ANALYSES

Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur
.10	.80	87.37	11.73	.90
.09	.64	88.89	10.38	.76
.08	1.03	88.71	10.18	.35
.10	1.64	87.45	10.81	

The whole of this work, which I have devised and carried into practice at this plant, has been especially arranged to treat all kinds of coal, and is working with the greatest possible success. All my improvements herein described are the sole property of Mr. L. Z. Leiter; my by-product gas plant is working with the greatest success. It is the first time coal gas, tar, and ammonia, in addition to the metallurgical coke, have been successfully produced in a beehive form of oven.

Newton-Chambers System.—In 1895, thirty Newton-Chambers beehive coke ovens were put in operation by the Latrobe Coal and Coke Company, near Latrobe, Pennsylvania. For a time, they were operated as by-product saving ovens, but after a brief period the saving of by-products was abandoned. The ovens are now being operated in the usual way as beehive ovens. They are of about the same dimensions as the standard class of these ovens in the Connellsville field, only the doors have been greatly widened to introduce a system of mechanical coke drawing, from the design of Mr. Thomas Smith, of the Thorncliffe Iron Works, near Sheffield, England, patented in 1891.

Fig. 20 shows a portion of a bank of thirty beehive coke ovens with the appliances for saving by-products. As has been stated, the effort at saving by-products has been discontinued. It is not, therefore, necessary to enter into a description of these appliances, as it was found undesirable to continue the effort for saving the by-products of ammonia salts, oil, or tar products, and gas.

Many efforts have been made to supersede the heavy and hot manual labor of drawing coke, by automatic machines, in the round or beehive coke ovens. So far, little progress has been made in a practical way in coke drawing. The machine for drawing coke at the Latrobe coke ovens, shown in Fig. 20, is the most successful effort thus far made in this direction. It is reported that a single man operating this extractor can draw four of the large 12-foot ovens per hour.

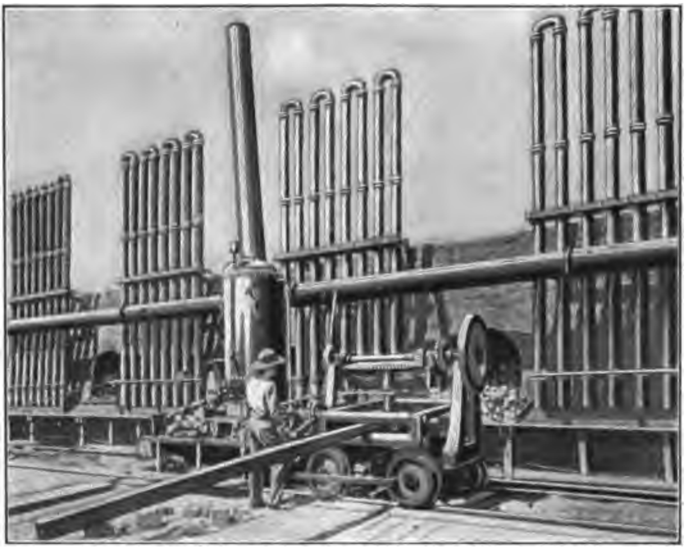


FIG. 20. LATROBE COKE OVENS

The **Smith coke drawer,** Fig. 21, consists of an extractor or coke drawer on one truck, coupled with a second truck carrying a small upright boiler, which runs on a track parallel to the coke ovens. The extractor consists of an engine, operating a bar *a* with a wedge-shaped plate or shovel *b*.

This shovel is pushed under the coke in the oven, the coke falling over the back surface of the wedge. The engine is then reversed and the bar with its shovel drawn out, bringing the coke with it. Along the front of the ovens there is an apron or endless conveyer into which the coke falls. The coke is then conveyed to the end of the block of ovens and delivered into railroad cars.

The **Hebb coke drawer*** is the invention of Mr. John A. Hebb, of Hopwood, Pennsylvania, and is in successful operation at the Continental, No. 1 plant, of the H. C. Frick Coke Company. In building this machine, it has been the inventor's object to incorporate in the mechanism the movements made by a man in pulling coke from an oven.

In Fig. 22 (*a*), the small house at the right of the machine contains the electric motor, which, together with the coke-drawing mechanism, is mounted on a truck adapted to run on a track along the yard in front of the ovens.

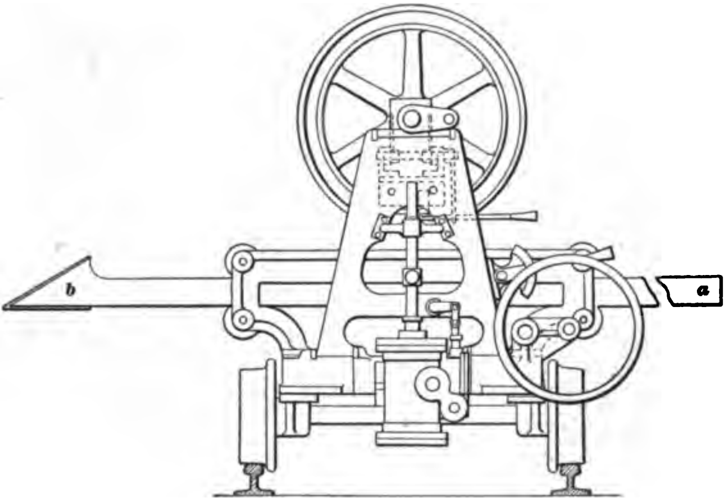


FIG. 21. SMITH COKE DRAWER

The mechanical details of this coke drawer are best shown in Fig. 22 (*b*) and (*c*), the former being a vertical section on the line of the scraper or rake beam, transversely of the track on which the machine runs; and Fig. 22 (*c*) is a vertical section at right angles to that of Fig. 22 (*b*), and also through the center of parts mounted on the revolving table. Referring to Fig. 22 (*b*) and (*c*), the main truck *a* supports a revolving table *b* that runs on rollers *c*, the table being provided with a circular track *d*. Connected with the electric motor is main shaft *e*, which by means of bevel pinion *f* drives vertical shaft *e'* by meshing with bevel wheel *f'*. Extending at right angles with shaft *e*, and on about the same level, is shaft *g*.

---

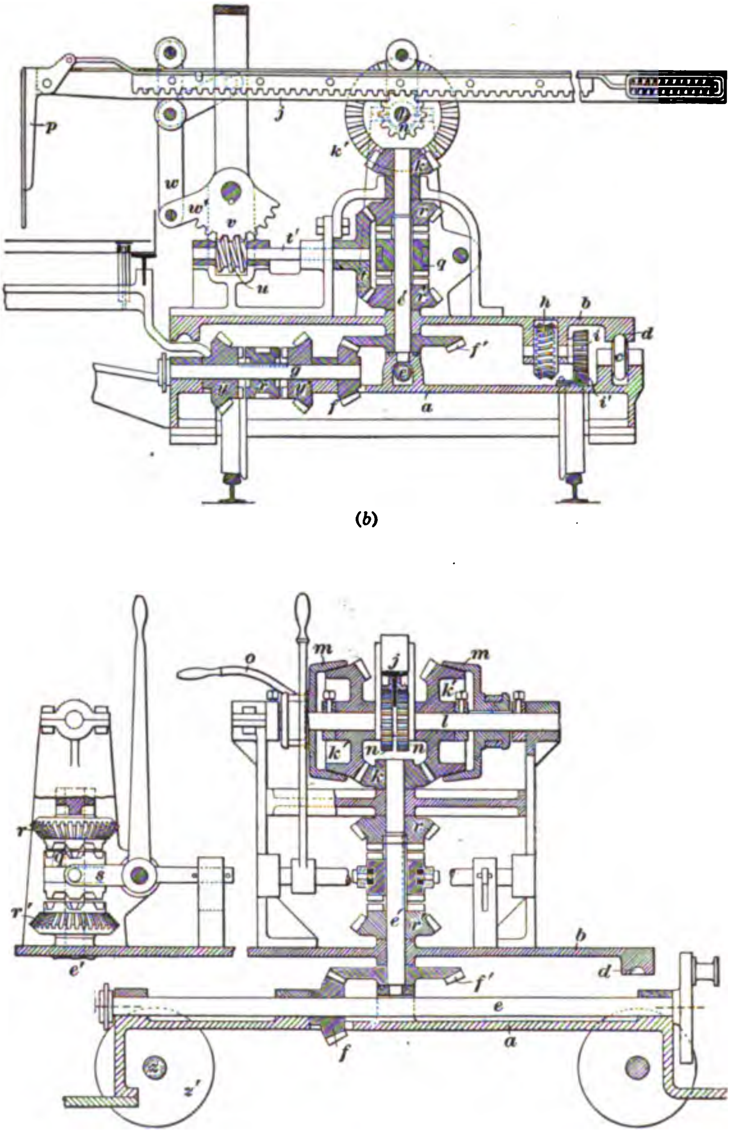
*Extracted from Mines and Minerals for February, 1904, p. 304.

From these main shafts all of the various operations of the machine are transmitted through gearing, clutches, and levers.

The turntable *b* is rotated in either direction by a hand wheel connected by gearing meshing into worm-wheel *h*. Mounted on the shaft with *h* is a pinion *i* which engages a circular rack *i'* mounted upon truck *a*.

The description of the scraper or rake mechanism is readily apparent upon reference to the illustrations. The rake beam *j* is supported on rollers mounted on standards, at each side of central shaft *e'*, and which are secured to turntable *b*. At the upper end of shaft *e'* is keyed a bevel pinion *k* that meshes with bevel gears *k'*, one on either side, and running in opposite directions, loosely on shaft *l*. Beyond gears *k'* on each side is a friction drum *m* keyed to shaft *l*. Also keyed to the same shaft are driving pinions *n* that engage racks secured to each side of the rake beam *j*. When either friction drum *m* is brought into frictional engagements with its adjacent gear *k'* it will transmit motion to shaft *l*, in one direction or the other, according to which drum is utilized. The shifting operation of the drums is secured through lever *o*, which, in an intermediate position, holds the friction drums clear of the gears. By this means, upon holding one of the clutches in contact, the beam may be extended into the oven to the desired distance, and upon using the other clutch it may be withdrawn. Beam *j* rests on rollers, so that its weight is not carried by pinions *n*. Above the beam is a roller that provides an upper bearing for the beam and holds it in engagement with the driving

(*a*)
FIG. 22. HEBB COKE DRAWER



(b)

(c)

FIG. 22. HEBB COKE DRAWER

pinions. The forward end of the beam is provided with a pivotally attached rake head *p*, adapted to fold backwards on coming in contact with the coke when it enters the oven, and to be automatically extended to its upright position [as shown in Fig. 22 (*b*)] by the tension of a spring at the back end of beam. A rod connects rake head *p* with the spring.

The inner (end nearest oven) end of beam is raised and lowered as follows, shown in detail at the left of Fig. 22 (*c*): Clutch *q*, which is keyed to the constantly moving shaft *e'*, is adapted to engage bevel gears *r* and *r'*, these latter being loosely mounted on shaft *e'*. Clutch *q* is raised or lowered by lever *s* provided with a hand lever. Gears *r* and *r'* engage bevel gear *t* keyed to shaft *t'*, on which is worm *u*, Fig. 22 (*b*). The worm engages toothed segment *v* having a lever arm. Upward or downward movement is imparted to the inner end of the rake beam through lever arm *w'* and arms *w*, the latter carrying under and upper rollers as shown. Thus, the parts described permit the machine to reach any part of the oven for the removal of the coke.

Other devices are employed for the purpose of moving the entire apparatus along the track either for the purpose of locating it to the right or left of the central position in front of an oven or for transporting it from one oven to another. The gear to accomplish this result is connected with shaft *g*, which is constantly revolved by shaft *e* by means of bevel gears. On shaft *g* is keyed clutch *x*; gears *y* and *y'* are loosely mounted and revolve when brought into engagement with clutch *x*. Meshing with gears *y* and *y'* is another bevel, not shown, through which, by suitable connections with a worm on axle *z*, motion is imparted to wheel *z'* and the truck moved one way or the other according to which bevel clutch *x* engages. A lever within easy reach of the machine operator controls this actuating mechanism.

The removal of the coke raked out by the scraper is effected by a conveyer shown in Fig. 22 (*a*).

The operation of the machine is effected by one man who stands on the turntable *b* and faces the oven door. All the levers are within easy reach, so that he can control any of the movements of the machine without changing his position.

Silica Brick.—The following letter from O. W. Kennedy, formerly general manager H. C. Frick Coke Company, in regard to the introduction of silica brick, is self-explanatory:

UNIONTOWN, PA., March 16, 1904.

JOHN FULTON, ESQ.

My Dear Sir:—Absence from home has delayed reply to yours of 5th. A man named Bradley, who was superintendent of a silica brick works at Layton, Pennsylvania, claimed recently to have been the first to suggest their use to me and to others. He did so, but some time prior to that a man named Drum had insisted that they would answer the purpose, but no one paid any attention to them until I took the matter up with Bradley and began their use against the protest of brick manufacturers, oven builders, and about everybody connected with the business. It was two years or more after this beginning before some brick makers in this region could be persuaded to abandon the manufacture of clay brick, and then only after they saw their trade leaving them.

I do not know how many others besides Drum and Bradley thought they would answer the purpose, but the fact is that I fought the battle for silica brick in coke-oven construction against odds and opposition that would have caused many a one to abandon the project, and persisted until their use became general.

I would estimate the life of a silica crown at from 12 to 15 years. Some clay crowns have lasted that long, but the instances are rare and were made many years ago. In the past 10 or 12 years they have ranged from 2 months to 3 or 4 years. I think it would be entirely safe to say that an average life would be less than 3 years. This, of course, applies to the Connellsville and Klondike fields. In some other coking districts I believe they get along with the clay crowns fairly well. Yours truly,

O. W. Kennedy.

Coking Experiments and Results.—The following is a synopsis of experiments, with practical conclusions, made in the manufacture of coke in beehive coke ovens in the Connellsville region, Pennsylvania. These experiments consisted of tests at two coke works; one had its coal treated in a Heyl & Patterson breaker, the other was crushed by a pair of rolls; the former separated the rough slates, the latter broke coal and slate together. Special attention was given to the effects on the coke from coal treated in these ways as well as from coal as it came from the mine. Conclusions from these tests were arrived at as to the management of the ovens to assure the best results in the time used in coking and in the quality of the coke.

To determine the downward rate of progress in the coking of the coal, measurements were carefully made showing the following rate of carbonization:

TABLE V

RATE OF CARBONIZATION

Length of Time in Oven Hours	Thickness of Coal Coked Inches	Thickness of Coal Coked in 1 Hour Inch	Length of Time in Oven Hours	Thickness of Coal Coked Inches	Thickness of Coal Coked in 1 Hour Inch
3	3	1	28	17½	⅜
12	8½	½+	48	25	⅜
20	13	½−	72	28	⅛
24	16	¾			

It will be seen from this table, as well as from the two illustrations of the downward progress in coking, Figs. 10 and 11, pages 159 and 161, that this process in its beginning is rather slow, decreasing until the twentieth hour, then increasing until the twenty-fourth hour, moderating at the twenty-eighth hour, after which the progress is slow until the close of the operation at the seventy-second hour. An examination of the coke products of 48-, 72-, and 96-hour coke shows that the silvery glaze on the coke is deposited carbon. Occasionally this carbon is thrown on the coke as soot. These deposits are mainly found on the coke on the uppermost 15 to 18 inches of the coke made.

The walling up of the door of the oven and closing the charging port give the following beneficial effects: valuable heat is retained in the oven and the best results in coking are assured.

The want of sustained heat in the oven from insufficient air will produce inferior coke accompanied by the undesirable black ends in the coke. It is manifest that air is admitted into the oven to supply the necessary oxygen to secure the complete combustion of the gases evolved from the coal in the coking process. Hence, the importance of adjusting the supply of air into the oven to meet this necessity. Too much air will have the effect of cooling the oven. The largest amount of gas is liberated in the initial operations of coking, requiring the most ample supply of air, say up to the twenty-fourth hour; after this the supply of air should be gradually diminished until the flaming ceases, when the oven should be entirely closed until drawn.

In these experimental tests, some ovens were intentionally cooled by allowing them to stand, while others were heated by covering the charging ports with dampers. The coke from the cooled ovens was inflated in cellular structure and had nearly an inch of black ends. The whole charge showed irregular coking, with a poor quality of coke. The hot ovens produced a first quality of coke, with good cell structure and the absence of black ends. Two experiments showed conclusively that the ovens in which the heat was retained by walled-up doors and closed charging ports produced coke, 72 hours after charging, that was thoroughly carbonized and showed little black ends. From these tests it follows that a high degree of heat in the oven, maintained throughout the process of coking, is essential to securing the best results in hardness of body of coke, in developing its cellular structure, and in preventing the production of black ends.

Another very interesting test of two ovens was made. Two adjacent ovens were selected, A and B. Oven A was closed at door and port hole as soon as the charge of coke was drawn out; it was then allowed to stand 5 hours before recharging. Oven B was treated in the usual way; that is, it stood about 2 hours before it was recharged. No damper was used on the charging port and the door was not walled up until after leveling the charge of coal. The charges of coal were equal in these ovens, about 145 bushels or 5.62 tons each. Oven A ignited 8 minutes after charging, starting off with brisk combustion, becoming quite hot 10 minutes after ignition. Oven B ignited 32 minutes after charging, starting off with feeble combustion, becoming quite hot 30 minutes after ignition. Oven A was completely burned off in 8 hours less time after charging than oven B. This comparative test, which is most important in the manufacture of coke, was kept up and the reliability of results, as stated, assured.

It was demonstrated that, by using dampers on the charging ports and walling up the oven doors immediately after the coke was drawn, the heat was retained and the best results in the quality of the coke secured.

With increased charges, oven A made its coke during the same time that oven B, with less charge, completed its operation. The charge was 5.62 tons, and as there are about 9,000 cubic feet of gas in 1 ton of this coal and it required 72 hours in oven B to burn the 50,000 cubic feet of gas, it burned this at the average rate of 694.4 cubic feet per hour, a slow condition of combustion. Oven A burned its gas in 64 hours, or at the average rate of 781.2 cubic feet per hour, which emphasizes the value of the hot oven.

TABLE VI

No. of Test	Time of Coking No. 1 Oven, Dampered and Sealed 3 Hours Before Charging—72-Hour Coke		Time of Coking No. 2 Oven, Charged Immediately After Drawing—72-Hour Coke		Time of Coking No. 3 Oven, Charged in Usual Way 2 Hours and 10 minutes After Drawing—72-Hour Coke	
	Hours	Minutes	Hours	Minutes	Hours	Minutes
1	53	7	52	2	59	
2	54	16	57	37	60	
3	58		60	2	60	
4	53	27	63	34	58	
5	56	20	56	41	63	30
6	52	17	60	50	70	
7	55	9	61	5	59	30
8	64	40	62	7	60	
9	59	15	59	34	65	
10	53	30	58	32	64	
11	59	41	63	51	65	30
12	56	1	72	20	59	
13	54	30	59	11	66	
14	54	30	63	4	60	
15	55	25	63	14	63	30
16			63	44	58	30
17			61		60	
18			59	40	55	
19			67	10	63	
20			59	50	60	
Average	56	22	61	16	61	30

In addition to the exclusion of outside air in retaining or storing the heat of the oven, by walling up the doors to the leveling line and dampering the charging port, it is also important to charge the oven quickly after the first charge of coke has been removed. This affords the charge of coal full time in the oven to secure the best results in 48- and 72-hour products of coke. Any loss of heat or time in recharging detracts from the quality and value of the coke.

In harmony with the foregoing tests, three additional tests were made to determine the effects of these methods in the manufacture of coke:

1. The first set of ovens was sealed immediately after the drawing of the coke, and allowed to stand 3 hours before charging.
2. The second set was charged immediately after the coke was drawn out.
3. The third set was treated in the usual way, that is, charged in its regular turn, but not dampered. This was on an average of 2 hours and 10 minutes after drawing the coke.

The charge of coal in each oven averaged 142.7 bushels. The average time that elapsed between the charging of the oven and its ignition was as follows: (1) first set, 24 minutes; (2) second set, 51 minutes; (3) third set, 1 hour and 8 minutes.

The time required in coking in these ovens will be seen in Tables VI and VII.

It was observed that the ovens in the first series maintained a more rigorous combustion, especially toward the end of each burning, gaining 5 hours in time over the Nos. 2 and 3 series of ovens. An additional test was made in the No. 1 ovens, by increasing the charge of coal 5 bushels. The time of burning was as follows:

TABLE VII

No. of Test	Time of Coking No. 4 Oven, Dampered and Sealed 3 Hours Before Charging—72-Hour Coke		No. of Test	Time of Coking No. 4 Oven, Dampered and Sealed 3 Hours Before Charging—72-Hour Coke	
	Hours	Minutes		Hours	Minutes
1	57	30	4	65	15
2	61	30	5	66	19
3	55	15	Average	61	10

With the coal charge increased 5 bushels, these ovens were burned off in about the same time as the ovens in Nos. 2 and 3.

Effects in Physical Properties of Coke Produced by Crushing the Coal.—Investigations were also made to ascertain the effects produced on the physical properties of the coke from crushed coal. (See conditions of crushing coal on page 192.) These tests were made at two plants, one using coal crushed with slate separated; the other using coal and its slate crushed together. We will designate these tests A and B.

Under the conditions of crushing the coal at the coke works A, it was observed that the lower section of the coke in the oven had an inflated cellular structure. This led to the belief that the ovens were overcharged and could not burn off as heavy charges of the fine coal as they could of the run-of-mine. To test this the 72-hour charge was reduced from 145 to 138 bushels, but this instead of improving the physical structure of the coke made it more spongy, causing the ovens to burn off from 10 to 12 hours before the time of drawing the coke. The coke was also brittle and imperfectly coked. Complaints of this coke came from several parties. The charges were restored to 142.7 bushels, very decidedly improving the physical condition of the coke. The reduction of the charges worked badly as to the quality of the coke and the losing of heat in the oven. These tests exhibited the difficulty in keeping the ovens that are charged with broken coal to the desired high standard of heat.

The average weight of the coal as it comes from the mine is 78.6 pounds per bushel, while the average weight of the broken coal is 75.9 pounds per bushel. It is therefore evident that a bushel of the run-of-mine coal is 3.55 per cent. heavier than a bushel of the broken coal, which means that 1 bushel of run-of-mine coal makes 1.0355 bushels of broken coal, after the coal has been finely broken and the refuse separated. It was decided from these experiments, considering the relative bulks of run-of-mine and breaker coal, that it requires a hotter oven in using the latter coal to assure equally satisfactory results with the use of the run-of-mine coal.

Swelling of the Charge.—Measurements were made to ascertain the relative amounts of the swelling of the charges of run-of-mine and broken coal. These measurements were taken every 30 minutes for 5 hours and it was found that the greatest swelling of the charge took place about 3½ hours after ignition. It was found that the maximum swelling was the same in both series, being 2½ inches in each. It was considered that this expansion of the charge of coal in coking is mainly due to the swelling of the upper 3 or 4 inches of the charge, and is not due to the swelling of the whole body of the charge.

Shrinkage of Charge.—Another test was made to determine the shrinkage in the height of the coke due to watering or cooling in the oven. It was found that the shrinkage of a 72-hour charge of coke is about $\frac{9}{16}$ inch.

Another test was made to determine the relative shrinkage in cooling the coke in ovens that have been charged with run-of-mine coal and broken coal. The former showed an average shrinkage of 5.36 inches, the latter an average shrinkage of 7 inches. The height of the charge in the former was 26 inches, and in the latter 27 inches. In the first series, run-of-mine coal, the average shrinkage was 20.70 per cent. of the total height of the charge; and in the second series, 25.95 per cent. of the total height of the charge.

Cell Structure.—A test was made to determine the relative cellular structure in the coke from lump coal and from finely pulverized coal. The large lump coal made a coke weighing 72.50 pounds per cubic foot, and the finely powdered coal gave a coke weighing 53.17 pounds per cubic foot, a reduction in the weight of a cubic foot of coke of 19.33 pounds. Other lumps of coal were subsequently coked, and the coke from these was correspondingly heavy and evidently of closer cellular structure than the coke made from the broken coal and pulverized coal. It follows from these tests that the coarser coal produced a heavier and denser coke, the lighter and more developed structure being secured from the powdered coal.

Relative Weight of Coke.—The crushed coal, the crushing having removed some of the slate and other impurities, produced the best quality of coke in its physical and chemical properties. Fifty samples of run-of-mine coke gave a weight of 61.61 pounds per cubic foot. An equal number of samplings of broken-coal coke gave a weight of 60.59 pounds per cubic foot, exhibiting a difference of 91.02 pounds in favor of the latter Doubtless some of the difference in the weight of a cubic foot of each product is accounted for in the difference of the cellular structure, but the main element consists in the purer coke from the broken coal with its impurities removed.

A test made to determine the relative weights of coke made from run-of-mine and broken coal, and also to enable a comparison to be made between 48- and 72-hour coke, gave the weight of a cubic foot of run-of-mine 48-hour coke as 58.65 pounds, and the weight of 48-hour coke from broken coal as 56.21 pounds per cubic foot, or 2.44 pounds per cubic foot lighter than the coke from run-of-mine coal. The run-of-mine 72-hour coke weighed 61.61 pounds per cubic foot, and the 48-hour coke weighed 58.11 pounds, or 3.5 pounds lighter per cubic foot.

The following results were obtained from crushed coal, in which the coal and its impurities were broken together without any attempt at separation: The weight of 72-hour coke from this broken coal was 70.88 pounds per cubic foot, and from run-of-mine coal, 66.81 pounds per cubic foot. It is evident that the broken coal makes coke 4.07 pounds heavier than that made from run-of-mine coal. The crushed coal at this place makes a denser coke than that made from run-of-mine coal. It may be noted that at one of these works, in the coal-crushing operation, much of the bone and slate are removed, while at the other both are crushed together.

A test was made to endeavor to account for the difference in weight of the coke made from the coal in its two different treatments in the coke oven. The bone and slate separated at one of the works were collected and after being finely broken with a hammer were restored to the charge of cleaned coal, thoroughly mixed and charged into the oven. It was found that the coke produced with this mixture afforded substantially the same weight of coke as that from the broken coal and its slate from the other works. Careful test showed that, in 28.70 cubic feet of run-of-mine coal, 1.8 cubic feet of refuse was taken, or 6.27 per cent. Now, 6.27 per cent. of a charge of 145 bushels of coal would be 9.09 bushels, which equals the amount of refuse existing in a 145-bushel charge. A cubic foot of coke made from this crushed coal and slate gave a weight of 62.73 pounds. Comparing this weight of 62.73 with 61.61, the weight of a cubic foot of coke from run-of-mine coal, it shows also that the weight of coke from cleaned coal is increased 1.12 pounds per cubic foot above that of run-of-mine coal by giving the crushed coal the same quality as when crushed en masse—coal and slate.

At one of these works, the crushed coal and slate give an additional weight of 4.07 pounds, while at the other, under like conditions, the increased weight of the coal is only 1.12 pounds per cubic foot. The difference in the methods of crushing the coal at these two works does not fully account for the difference in the weight of the coke produced. Evidently the difference in the bone and slate at these two mines will suggest the main cause of the divergence in the weight of coke produced.

The evidence of these tests shows that the presence of finely crushed bone coal and slate in the charge of coal will produce a more restricted cellular structure in the coke. The variations of cellular structure, as shown by the previous tests, must also involve variations in the amount of shrinkage, the uncleaned coal at one works giving a reduced shrinkage below the cleaned coal of 2 inches.

Tests of Coking Properties of Different Portions of Connellsville Coal Seam.—A series of tests was made to determine the quality and physical properties of coke made from the three natural divisions of the Connellsville bed of coal. These divisions are as follows: (1) the coal between the 3-foot binder and floor, or bottom of the seam; (2) the coal between the 5-foot binder and the 3-foot binder; (3) the coal between the 5-foot binder and roof.

The coal for this test was secured from points in the mine sufficiently distant to secure a general average. The coke produced afforded the following weights per cubic foot: (1) from bottom bench of seam, 57.86 pounds; (2) from middle bench of seam, 72.50 pounds; (3) from upper bench of seam, 82.07 pounds.

Coke from fine coal from the same localities in the mine and from the same benches of seam weighed as follows: (1) from bottom bench of seam, 53.20 pounds; (2) from middle bench of seam, 58.21 pounds; (3) from top bench of seam, 61.79 pounds.

Comparing the above results, it is evident that the weight of coke made from lump coal is heavier than coke made from fine coal, all taken from the same localities in the mine. It is also evident that the coal from the top bench of the seam affords the heaviest coke, the middle bench the next heaviest, and the bottom the lightest.

The analyses of the coke made from three benches of this large bed are as follows:

	Fixed Carbon Per Cent.	Volatile Matter Per Cent.	Ash Per Cent.	Phosphorus Per Cent.	Sulphur Per Cent.
Bottom of seam	91.09	1.36	7.55	.010	.558
Middle seam	88.78	3.08	8.14	.016	.690
Top seam	81.28	1.70	17.02	.028	.973

As to purity, the coke decreases in quality from the bottom to the top of the seam.

Axioms.—Diminutive cellular structure in the coke is caused by insufficient heat in the ovens, and, conversely, a high heat maintained throughout the period of the coking process is essential to the best cellular structure, hardness of body, with the absence of black ends.

It is a decided benefit to exclude the outside air as much as possible from the oven while it is standing over between charges, either by walling up the door or using a sheet-iron shield; also, it is an advantage to make this interval at least 2 hours, provided that the outside air is excluded.

It requires a hotter oven to secure the best results in coke when using broken coal than it does when using run-of-mine coal.

The coarser the coal, the heavier is the coke, and the finer the coal, the lighter is its coke; the purer the coal, the lighter is the coke. This is self-evident, as the impurities of the coal are mainly heavier than the pure coal.

These experiences are from the practice of coking in the Connellsville seam. Other regions will require special studies to secure the best result in the coke produced.

Where impurities exist in coal, it should have a preparation for coking by crushing and washing.

CHAPTER VI

THE RETORT AND BY-PRODUCT-SAVING COKE OVENS

Introduction.—Two conditions combined to introduce the modern retort or closed coke ovens in Continental Europe: (1) Some of the coals in these countries inherit a small percentage of the fusing matter so essential in the manufacture of coke for metallurgical uses; hence, the retort oven with its quick heat, utilizing the small portion of this fusing matter in these qualities of coal, supplied this important requirement. (2) The desire for supplementing the profits of coke making, by saving the by-products of tar, ammoniacal liquor, and gas, from the gaseous products discharged from the coking chambers of the ovens in the manufacture of coke.

Evidently this new departure was suggested to coke makers and oven builders from the operations in the manufacture of illuminating gas, for the gas makers, in the process of purifying their product, required the elimination of tar and ammoniacal liquor. It thus became evident to coke makers that the gases evolved from the coke ovens contained similar products and logically suggested additional profit in saving them.

It is recorded that the first coke ovens producing tar and ammonia as by-products were constructed at Sulzbach, near Saarbrücken, in 1766. These first attempts were very crude and of little practical value. In 1781, Sir Archibald Cochrane, Count of Dundonald, obtained a patent on the production of tar, volatile oils, alkalies, acids, pitch, and coke, from bituminous coal. Very slow progress was made in the saving of by-products; their practical manufacture and sale in market was not assured until about the year 1883. The reason for this slow progress has been attributed to two principal causes: the low price of these products in market, on account of the supply from the gasworks, under the method in use, until recently, of making illuminating gas from bituminous coal; besides, the early efforts at the coke works were expensive and unsatisfactory, both in quality of coke and value of by-products secured.

In 1856, Knab, of the Department Allier, France, built a group of retort coke ovens in which a double purpose is evident: the saving of the by-products of tar and aqua ammonia, and the manufacture of illuminating gas. The gases freed from tar and ammonia were returned to the ovens and burned in the flues to reenforce the heat for coking. These ovens are described as having narrow vertical chambers, 23 feet long, 6 feet 6¾ inches high, and 3 feet 3⅓ inches wide. They were also provided with bottom draft.

The principal difficulty in extending the use of these ovens, and which has only recently been corrected, consisted in the neglect of proportioning the several parts of the oven to the requirements of the quality of the coals to be coked. With the advent of correct dimensions in the retort coke ovens, to meet the wants of the various qualities of coal, their increased use in the manufacture of coke and saving of by-products has been largely extended.

Jones and Blackwell took out patents in 1861 to produce tar and ammonia by converting coal into coke in kilns, but the experiment failed.

In 1862, Simon and Carvés, of France, made very valuable improvements in the original plan of the Knab oven. They introduced side horizontal flues, in addition to the bottom flues in the Knab oven. The gases from this closed oven were drawn into condensers and scrubbers by an exhaust engine, the tar and ammonia separated, and the remaining gas returned to supplement the oven heat. The construction of this Knab-Carvés coke oven, with important improvements, in 1873, to assure the better distribution of heat, afforded a model for subsequent coke ovens, and this model was soon appropriated by Albert Hüessner, who is credited with the practical introduction of a successful oven and apparatus for securing by-products from the coke-oven gases. Hüessner built 100 ovens in 1881, establishing the by-product industry on a sound basis in Germany.

The quality of the coke made in these ovens was regarded as inferior, on account of the rapid exhaustion of the gases by suction, and it required many years with considerable improvements in the ovens to overcome the objection.

The G. Seibel coke oven was introduced in France in 1881. It has horizontal flues in the middle of the walls of the coking chambers, with gas reservoir after the Simon-Carvés plan, and was the first oven built without grates for saving by-products. At one plant in France the surplus gas, after the extraction of by-products, is used for illuminating purposes. The temperature obtained in this oven is fully equal to the Otto-Hoffman oven with its expensive regenerators.

The main element in the design of this oven is to maintain the process of coking so successfully in use in the beehive ovens; that is, the carbonization of the charge of coal in the oven, beginning at the upper surface and going downwards to the bottom of the oven, proportioning the heat as the coking progresses from top to floor of oven. This secures the deposition of the maximum quantity of carbon from the evolved hydrocarbon gas from the coal in coking. About 11 per cent. of deposited carbon has been secured under this method in this coke oven, which not only glazes the coke with nearly pure carbon, but also adds very materially to the percentage of the carbon in the coke, reducing, relatively, the ratio of impurities to the carbon in the coke.

The principles under which this oven was designed by Mr. G. Seibel are undoubtedly correct, and should afford excellent results in the quality of coke and saving of by-products.

About the time of the introduction of the Seibel oven, the earnest attention of coke manufacturers was directed from previous experience to the two prime requirements in the manufacture of retort coke: the production of good coke, and the securing of the by-products. The first consisted in the necessity of proportioning the size of the oven chamber to meet the requirements of the different qualities of coking coals, the coals rich in volatile matters requiring treatment in wider ovens, while the dry coals or those low in volatile matters demanded narrow ovens for the best products in coke.

The previous inattention to these prime requirements, especially in coking the continental coals of Germany, Belgium, and France, caused the retort cokes to be regarded with suspicion as to their adaptability for producing coke for metallurgical purposes. It required considerable time to remove this prejudice. The ultimate credit of doing so is attributed to Dr. C. Otto and Company, of Dahlhausen on the Ruhr, who, in 1881, erected ten trial ovens, which laid the foundation of a system coming later into favorable use. But it required the addition of the Siemens regenerator, in order to heat the air required for the complete combustion of gas to as high a degree as possible, before a successful condition was assured. This addition was patented by Gustave Hoffman in 1883, constituting the Otto-Hoffman coke oven.

Some criticism has been made questioning the value of the addition of the Siemens regenerators to the Otto-Hoffman oven, with the increased cost involved by these appendages. The arrangement of vertical side flues is also regarded as objectionable, from the difficulty of distributing the heat evenly, with the reduced amount of it secured.

This Otto-Hoffman coke oven was further improved by E. Festner, of Gottesburg, who made an important change in the position of the flues in the oven side walls, by using the horizontal in place of the vertical position. He also abandoned the Siemens regenerator, replacing it with the Ponsard gas furnace. In establishing these improvements, he is reported as having the cooperation of Hoffman, and the oven has been named the Festner-Hoffman coke oven.

The Semet-Solvay oven came into appreciative notice in 1887. It is designed for coking dry coals or a mixture of pitchy and dry coals. Its side walls are made with flued and jointed tiles in horizontal position. This secures a maximum heat which can be evenly distributed so as to avoid the destruction of firebrick lining by concentrated heat at certain localities. The dimensions of this oven are made to meet the requirements of the several qualities of coking coals or mixtures of such coals. It has two simple heat reservoirs and avoids the rather expensive regenerators and recuperators of some other ovens. It is usually regarded as a plain economical oven, well adapted to the saving of by-products.

In Scotland, Mr. Henry Aitken, of Falkirk, introduced important improvements in the method of coking in the beehive oven, and subsequently added appliances for the saving of by-products from the gases of this oven. The first improvement, of 1874, consisted in the application of hot air into the dome of the oven, so as to increase the heat by the thorough combustion of the gases evolved from the coking coal beneath. This augmented heat supply was designed to save the burning of the fixed carbon in the coking coal. In 1880, he introduced apparatus for the saving of the by-products in the beehive ovens. This consists in the placing of a triple radial perforated conduit in the bottom of the oven, connected with an exhaust pipe leading to condenser and scrubber to secure the by-products. These inventions were quite successful and approached at the time very nearly to the best results in retort-oven practice.

In England, in 1883, Mr. John Jamison devised methods very similar to Aitken's for saving by-products in coking in beehive ovens. He introduced no change in the form of the ordinary beehive oven, except to place channels or conduits in its bottom, through which to extract the gases of carbonization by a slight suction exhaust. He has obtained in this way good results in both coke and by-products.

Simon and Carvés introduced in England, about the year 1880, the improved retort, recuperative coke oven, bearing their names. This plan is a decided improvement on the Coppée model in simplicity of design and efficiency in work, but the Coppée oven afforded the base for the Otto-Hoffman and the Simon-Carvés. It has horizontal flues with attached apparatus for securing the by-products, and this plan of oven has been quite successful in producing a large percentage of good coke at a moderate cost.

In Great Britain, with its excellent coking coals, the continental retort oven was slow in finding general favor. This condition existed from the fact that the beehive oven produced excellent coke for metallurgical purposes. The small wastage of carbon by this method was not regarded as of prime importance, as it was urged that the physical structure of the coke made in the beehive oven under slight pressure developed a cell structure that conferred superior calorific energy on this kind of coke. And it was further submitted that the smaller product of the beehive oven, in blast-furnace use, was equal to the work of the larger product of the denser retort coke.

Doubtless in the early efforts for the introduction of the retort coke ovens the importance of proportioning their several parts for the coking of coals of different qualities was not so well understood as in more recent times. Besides, the value of the by-products from the coke ovens was not considered in a manner commensurate with its importance.

In the United States of America, with its great coal fields, embracing so large areas of excellent coking coals, the introduction of retort coke ovens has been slow. This arises mainly from the large cost of these ovens, especially when supplied with an equipment for saving by-products. A secondary hindrance consists in the expensive labor cost in small experimental plants. A maximum number of coke ovens is required to assure minimum cost in the labor of coke making.

However, since the decline of the production of tar and ammoniacal liquor in the gasworks, the by-products from coke works have realized a revival of their importance, especially the sulphate of ammonia as a valuable farm manure, which, in the progress of improved agricultural operations, is coming largely into demand. These have given retort coke ovens renewed attention and importance, and this will be further reenforced as the use of coke enlarges, requiring the use of some of the secondary qualities of coals to maintain the necessary supply of this valuable metallurgical fuel.

As a sequence of the requirements of coke manufacture on the continent of Europe, demanding for successful treatment the use of the closed or retort coke ovens, the auxiliary apparatus for saving the by-products was adjusted to these types of ovens, and some ovens were designed with a view mainly for the securing of the by-products. In Great Britain, with the satisfactory beehive-coke-oven manufacture, the appliances for saving the by-products had their first application on this plan of oven, graduating in recent years to the retort type of coke ovens. In the European countries, the use of sulphate of ammonia as a manure has received careful attention, as this salt is an excellent fertilizing agent and is largely used in farming operations. The tar affords elements that are widely used in many of the industrial arts.

The large areas of superior coals for making coke found in the United States and in Great Britain afford the best metallurgical coke in the beehive oven. This condition, even with its expensive labor and waste of fixed carbon, restrained efforts in improvements in the coke oven, except in the single direction of economy in the labor of drawing the coke from the oven by mechanical appliances in place of manual labor, as noticed in the instance of the Welsh coke oven.

But in Belgium the conditions are quite different. The coals there are poor in quality and low in the elements that fuse the coal in coking. In this busy little kingdom, with the expanding use of coke, it early became a very urgent requirement to devise ovens to coke their inferior coking coals. The Belgian coke oven was the result of efforts in this direction. It was followed by a number of ovens of similar construction bearing its name.

NUMBER OF BY-PRODUCT COKE OVENS IN USE AND UNDER CONSTRUCTION IN THE UNITED STATES AT THE CLOSE OF YEAR 1902, BY STATES

State	Ovens, December 31, 1902		State	Ovens, December 31, 1902	
	Completed	Building		Completed	Building
Alabama	240	40	Ohio	50	60
Maryland		200	Pennsylvania	592	412
Massachusetts	400		Virginia	56	
Michigan	75	60	West Virginia	120	
New Jersey	100				
New York	30	574	Total	1,663	1,346

TABLE EXHIBITING THE USE OF RETORT OR BY-PRODUCT COKE OVENS IN THE UNITED STATES FROM 1893 TO 1902, INCLUSIVE

Year	Ovens		Product Net Tons
	Built	Building	
1893	12		12,850
1894	12	60	16,500
1895	72	60	18,521
1896	160	120	83,038
1897	280	240	261,912
1898	520	500	294,445
1899	1,020	65	906,534
1900	1,085	1,096	1,075,727
1901	1,165	1,533	1,179,900
1902	1,663*	1,346†	1,403,588

*Includes 525 Semet-Solvay, 1,067 Otto-Hoffman, 15 Schniewind, and 56 Newton-Chambers.

†Includes 210 Semet-Solvay, 664 Otto-Hoffman, 412 Schniewind, and 60 Retort Coke Oven Company.

The Belgian oven was succeeded by a large variety of closed or retort ovens in Germany, Belgium, France, and recently in England. As we shall consider these ovens in their proper order, we will endeavor to unfold the main designs of their authors in each plan of oven. It may be submitted here that the chief and imperative requirement in all of these ovens is the economy of heat in the operation of coking. To satisfy this prime demand, passages and flues have been introduced in the bottoms and walls of the ovens to utilize the heat of the gases expelled from the coal in coking, returning it through these passages and flues to maintain the necessary oven heat in coking.

During the past decade, auxiliary apparatus has been attached to some of these ovens and has been successful in saving the chief by-products of tar and sulphate of ammonia from the gases evolved from the coal in coking. After these by-products have been secured, the gases are returned to regenerators and used in the usual way in heating the coke ovens. Any surplus heat from these gases is frequently utilized under the boilers in making steam.

Belgian Oven.—The Belgian coke oven was evidently designed to satisfy three principal requirements:

1. To meet the condition of coking coals of inferior quality, requiring the economy of heat from the gases by returning them under and around the coking chamber of the oven, through passages and flues, and to retain the oven heat by the rapid discharge of the coke, cooling it outside the oven.

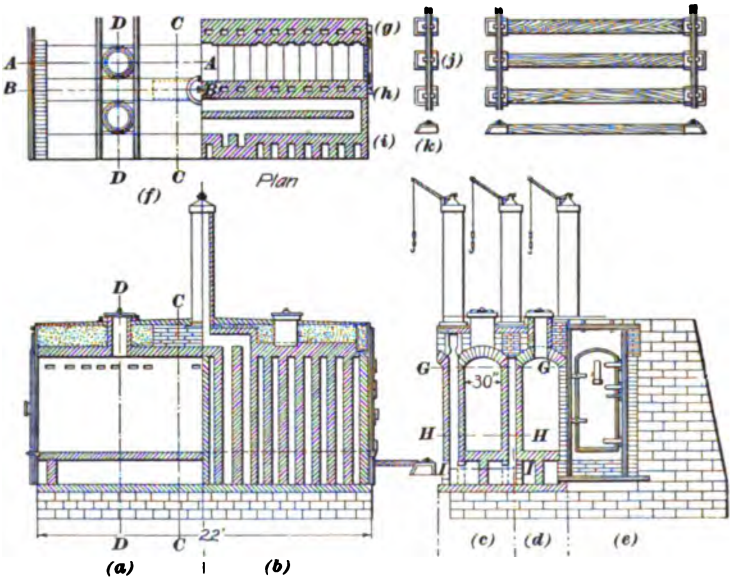


Fig. 1. Ordinary Belgian Coke Oven

(a) Section through $A\ A$; (b) section through $B\ B$; (c) section through $C\ C$; (d) section through $D\ D$; (e) end elevation; (f) plan of top of ovens; (g) plan of section through $G\ G$; (h) plan of section through $H\ H$; (i) plan of section through $I\ I$; (j) plan of pusher track; (k) elevation of pusher track.

2. To economize the work of drawing or discharging the coke from the oven by mechanical appliances in place of the

rather slow and expensive methods of performing this work by manual labor.

3. To exclude the air in coking the coal as much as practical, so as to save the waste of fixed carbon usually made in ovens admitting the admixture of air in the coking chamber, and in affording an increased percentage of coke from the coal charged into the oven.

The inferior dry coals of Continental Europe can only be coked to best advantage in closed ovens. This involves, however, the necessity of cooling the coke outside the oven, leaving in this coke 4 to 8 per cent. of moisture, under ordinary conditions. Whether the increased product of coke from the coal charged in these ovens will compensate for the augmented moisture in the coke, from the necessity of watering it outside the oven, will be considered hereafter in detail. On the other side, by this rapid discharge of coke, the oven's heat is retained and acts quickly on the newly charged coal, utilizing the small volume of fusing matters in the dry coals.

Fig. 1 shows the main features of the early Belgian coke oven; references to its parts are given on the drawing. Its general design consisted in the economy of heat in coking the inferior dry coals. The width and height of the oven chamber were usually proportioned to meet the requirements of the coals to be coked; the dryer the quality of the coal, the narrower the chamber of the oven, and, conversely, the oven was made wider when coals inheriting more hydrogenous matter were to be used in coke making.

During the working of the bank of Belgian coke ovens, by the Blair Iron and Coal Company, at Hollidaysburg, Pennsylvania, the coal used was from the Miller (B) seam in the Bennington mine. It was composed as follows:

	Per Cent.
Volatile matter	22.38
Fixed carbon	68.50
Ash	8.00
Sulphur	1.12
Total	100.00

The theoretic coke from the above coal, assuming 40 per cent. of the sulphur to have been volatilized in coking, is 77.17 per cent.

The Belgian coke ovens, using this Miller coal, gave the following results: coal charged, 6.86 gross tons; coke made, 4.81 gross tons; difference, 2.05 gross tons.

In the large bank of Belgian ovens, formerly in use at the blast furnaces of the Cambria Iron Company, at Johnstown, Pennsylvania, and using the Miller seam coal, the yield of coke was 70.3 per cent., indicating a loss of fixed carbon of 30.02 per cent. This coal was washed in preparing it for coking in these ovens.

At the Bennington bank of one hundred beehive coke ovens, using the Miller coal (B), from the same mine and of similar quality as formerly supplied to the Belgian ovens at Hollidaysburg, the product gave an average yield of coke of 64 per cent., requiring 1.56 tons of coal to make 1 ton of coke. As previously shown, this coal affords 77.17 per cent. of theoretic coke. The beehive ovens yield 64 per cent. of coke, showing a loss of fixed carbon of 17.06 per cent. Equating the relative conditions of moisture in the Belgian oven, coke watered outside the oven, and the dryer coke of the beehive oven, watered inside it, the increased yield of coke from the Belgian oven over the beehive oven is about 10 per cent.

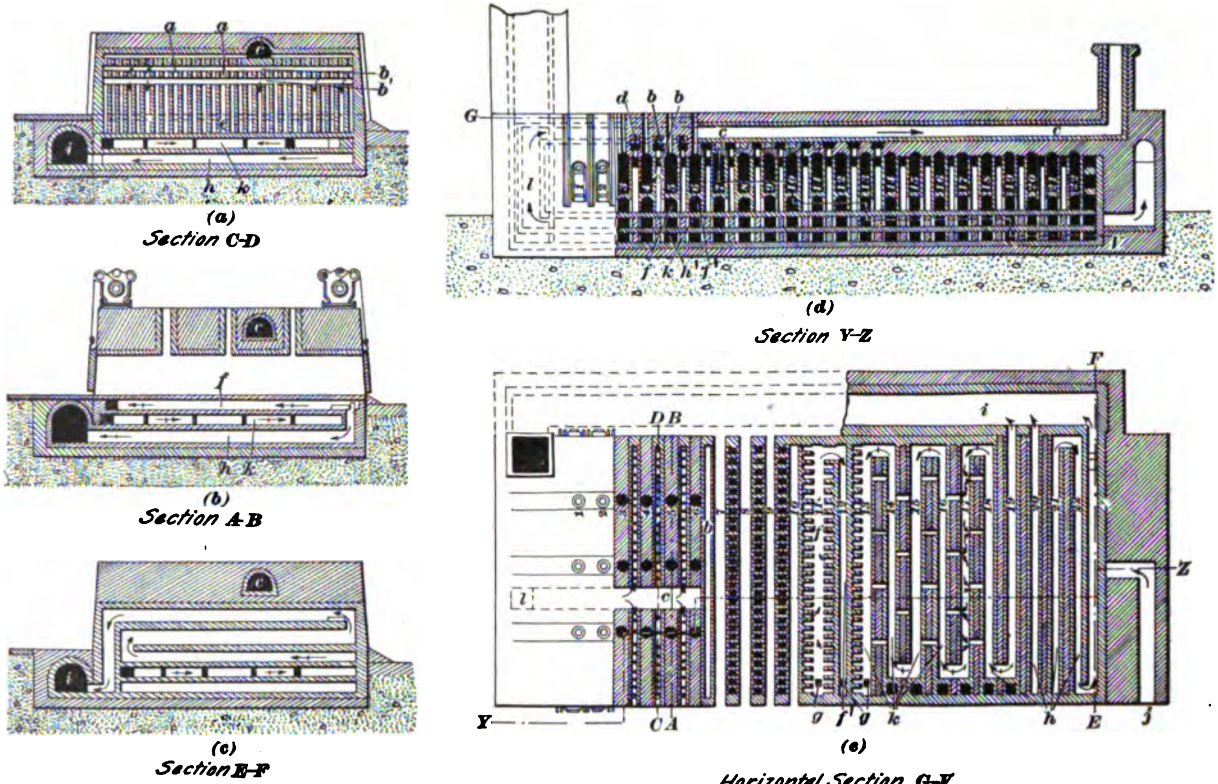
The modifications and additions to this family of coke ovens are quite numerous; even a brief description of their various forms would exceed the limits of this work. The main principles of the original Belgian oven have been retained in its successors, though not always bearing the family name.

The ovens selected for illustration and description will be taken from the most practical types for the manufacture of coke at this time, and also those specially designed for supplementary apparatus in saving the by-products of dry distillation in the coking process.

Coppée Coke Oven.—This oven is also a Belgian invention and was in use on the continent prior to 1861. In 1873 and 1874 it was introduced in England, and has also been used in a few localities in the United States. The main principles embraced in the design of the Belgian coke oven are preserved in the plan of the Coppée oven, but the latter is much more complex in its structure and operation than the former. Fig. 2 shows its general design.

The Coppée coke ovens are usually built in blocks of twenty to thirty ovens, and the plans and sections referred to in the following description embrace a block of twenty-two ovens with draft chimney and other appliances. View (*a*) represents a longitudinal section passing through the middle of a side wall of an oven, on line *C D* of the plan (*e*); (*b*) shows a longitudinal section through the middle of an oven, on line *A B* of plan (*e*); (*c*) shows section passing through the middle of an end side wall, on line *E F* of plan (*e*); (*d*) shows cross-section and elevation, on line *Y Z* of plan (*e*); (*e*) is a plan from the line *G V* of section (*d*); the courses of the gases are shown by plain arrows, while the way of air-courses is shown by crossed arrows.

The gas escapes from the oven through twenty-eight openings *a* situated on both sides of the oven, into the horizontal flue *b*, where it meets and mingles with the hot air brought by the flue *c* and small flues *d*. The perfect combustion of the gases takes place in the horizontal flues *b*, *b′*. The inflamed gases descend through twenty-eight vertical flues *e* into the flue *f* situated under the floor of the odd-numbered oven; in this flue *f* the gases of the two side walls, communicating with the flue under the floor, mix together.



(a) Section C-D

(b) Section A-B

(c) Section E-F

(d) Section Y-Z

(e) Horizontal Section G-V

FIG. 2. COPPÉE COKE OVEN

The gases run from one end of the flue to the other in the flue *f* and then pass into the flue *f′* situated under the floor of an even-numbered oven; next, the gases go through the opening *g*, reach the flue *h′* situated under the regenerating air flues, and ultimately flow into the main flue *i*. This main flue takes the gases to the boilers, or to the chimney, as the case may be.

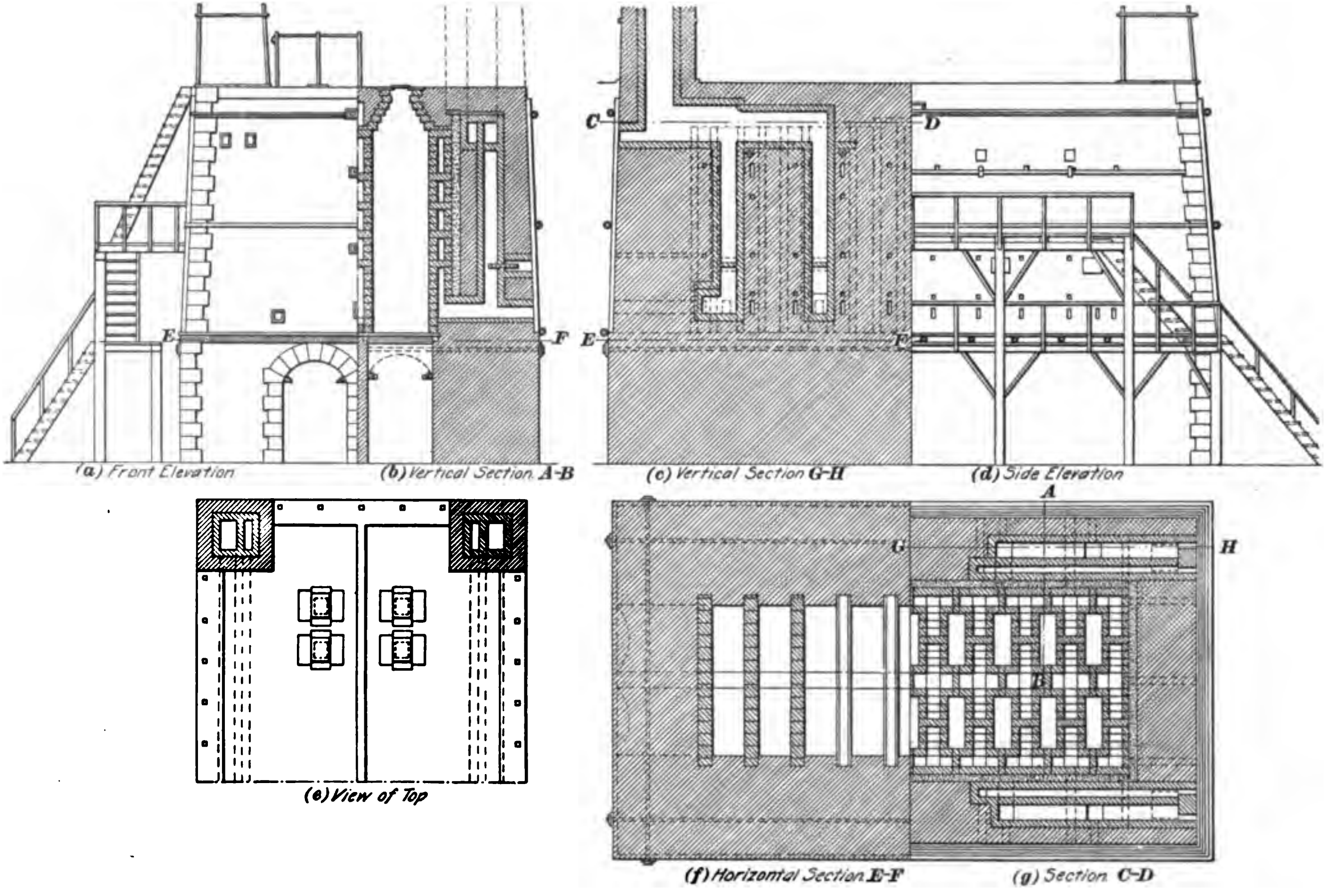
In the flues *f* situated under the floor of the odd-numbered ovens, an opening *g* is provided with a damper which regulates the admission of gases into the lower flues *h* and *h′*.

The requisite air for the combustion of gases is taken from the outside by an opening *j* situated in the end buttress wall, then it descends to reach the regenerating flues *k*, from one end of the batch to the other end of it. These air flues are situated between gas flues *f*, *f′*, and *h*, *h′*, The air that enters from the outside by the opening *j* leaves the flues *k* through the opening *l*, having been raised to a temperature of 600° to 800° F. This hot air ascends the shaft *l* and reaches the flue *c* situated on top of ovens. Out of this flue *c* the hot air is divided by the small flues *d*, situated above each side wall, into the flues *b*, *b′*, also situated above the side walls and immediately under the flues *d*.

The discharging of the ovens is made by a ram engine, which pushes the coke, first out of the odd-numbered ovens, so that each newly charged oven finds itself between two others in full operation; therefore, between two highly heated ovens. These alternate new charges generate gases at once which escape on both sides through twenty-eight openings, enter the flues *b*, *b′*, mingling with the hot gases of the adjoining ovens and the hot air supplied through the flues *d*.

From the foregoing description of the operations of this oven, it is evident that in using very dry coals the alternate charging and discharging of the ovens is necessary to the diffusion and maintenance of the oven heat. With coals richer in volatile combustible matters, the ovens could be drawn in sections, thus avoiding any injurious pressure on the walls of the ovens by the swelling of the coal in coking. These ovens are usually constructed of such width and height as may be required in coking coals inheriting different volumes of hydrogenous matters, varying in width from 15 inches to 13 inches, with heights governed by the same elements in the coal to be coked.

It is claimed that the Coppée oven affords 70 to 83 per cent. of coke in Belgium, and 67 to 75 per cent. in England. A bank of thirty Coppée coke ovens, formerly in use at the Conemaugh furnace of the Cambria Iron Company, constructed with some modifications from the foregoing plan, especially in the arrangements of the crown flues, gave the following results in their work in coking a moderately dry coal during the fiscal year 1886. The amount of coal charged into the ovens during the year was 12,630 gross tons; the coke produced, 8,680 tons, exhibiting a product of coke, weighed



(a) Front Elevation (b) Vertical Section A-B (c) Vertical Section G-H (d) Side Elevation

(e) View of Top (f) Horizontal Section E-F (g) Section C-D

FIG. 3. APPOLT COKE OVEN. EIGHT RETORTS

after having been watered outside the ovens, of 68.72 per cent.; using 1.22 tons of coal to make 1 ton of coke. The coal used was constituted as follows:

	Per Cent.
Moisture 212° F	.560
Volatile matter	17.700
Fixed carbon	73.980
Ash	7.360
Sulphur	.820
Phosphorus	.006

It may be noted that this coal is very low in its volatile combustible elements, requiring the burning of some of the fixed carbon of the coal to sustain the oven heat in coking. The leanness of volatile hydrocarbons in the coals at the city of Johnstown is quite remarkable and exceptional, as the Appalachian coals east and west of this belt inherit normal volumes of these matters, with their usual increase westwardly.

The work of the old Belgian coke ovens on the dry coals at Johnstown, and the results at Hollidaysburg on the second quality of coking coal from the Miller (B) seam at Bennington, have been considered in a former section. The average result of a full year's work of a bank of thirty Coppée coke ovens at the Conemaugh furnace, supplied with the dry coal from the Lemon seam in the Johnstown basin, has also been submitted. The use of all these ovens was discontinued some years ago, for reasons that cannot be wholly attributed to the work of the ovens.

The full comparison of the economies of the open and closed ovens, with cost of construction and adaptability of plans for special coals, will be considered hereafter.

Appolt Coke Oven.—A radical departure from its predecessors, in its general plan, is the Appolt coke oven. It was evidently designed to meet the general conditions covered by the Belgian oven, with additional elements in the economy of the work of coking, and was particularly adapted for coking dry coals, which require a rapid exposure to a high temperature in the initial stage of coking, to utilize the small ratio of fusing matters in such coals.

This oven, Fig. 3, is described as *"consisting essentially of a series of upright rectangular retorts, the longer sides of the rectangle being two or three times the length of the shorter. The retort is wider at the bottom than at the top to facilitate the discharge of the coke. These retorts are grouped in companies of twelve, eighteen, or twenty-four, as the requirements may be; the whole enclosed in a large rectangular brick chamber, which may be termed the combustion chamber, the retorts being surrounded on all sides by air spaces, these spaces being in communication, and the walls that form the sides of the retorts connected together by solid blocks of firebrick.

---

*From Report of J. D. Weeks, Esq., to Census Office, 1885.

"Between the firebrick walls of the combustion chamber and an outside brick wall is a space filled loosely with some powdered substance, as sand or other poor conductor of heat, which allows a certain degree of expansion and contraction of the firebrick wall of the combustion chamber within. This combustion chamber for a group of twelve retorts would be about 17 feet long, by 11 feet 6 inches wide, and 13 feet high.

"Each retort is about 4 feet long and 1 foot 6 inches wide at the base, and 3 feet 8 inches long and 13 inches wide at the upper part, the walls being about 4¾ inches thick.

"The ovens are placed in two rows, back to back, the bottoms being provided with cast-iron doors strengthened by transverse bars of wrought iron. The partition walls of each chamber, at a distance of from 16 inches to 2 feet from the base, are traversed by two rows of small horizontal openings 5½ inches long and about 3½ inches high, nine on the wide side and three on the narrow side. At the upper part there are three similar openings on the wide side only.

"Through these openings the volatile products evolved during the coking of the coal pass into the surrounding open spaces of the combustion chamber, where they are burned by mixture with atmospheric air admitted through holes in the wide sides of the outer wall of the oven."

The designs of these ovens are very complete, especially on the lines of rapid and economical work. The yields of coke as given by the Messrs. Appolt are as follows: Each retort contains about 1½ tons of coal. The coking is usually completed in 24 hours. Belgian coking coal gave from 80 to 82 per cent. of coke, and English coking coal 72 to 73 per cent. No analyses are given with these statements and we can learn little of the actual work of this oven.

Theoretically, this is a very perfect oven, yet it has not come into as general use as some of its competitors. The two chief elements in retarding its more general use consist: (1) in its large original cost and in the expensive cost of repairs; (2) the great height of the oven, 13 feet, compelling coking under much pressure and producing in the middle and lower sections of oven coke of objectionably dense physical structure. This dense product of two-thirds of its coke must be injurious to its character, especially in blast-furnace use.

It is probable that the adverse conclusion of Sir I. Lowthian Bell, in 1871, regarding the value of Appolt and other flued-oven cokes, was induced by the dense physical structure of these cokes, as it is difficult to understand how their chemical composition could invite criticism, for the reason that, in the beehive and other open or non-flued ovens, some of the fixed carbon of the coal is consumed in coking, reducing its volume in the coke.

Comparison of Oven Types.—It would exceed the limits of this volume, at this time, to follow up, in order, the several types of ovens from the ancient beehive to the modern retort oven, but it is designed to submit the chief successful and practical types of these ovens with their individual desirable elements.

It may be again noted here, that, in the progress of development of the by-product industry, three special root types of ovens have been used: (1) The beehive, into which air is moderately admitted and its heat maintained by burning a portion of the fixed carbon of the coal. Its by-products were moderate in quantity as well as in value. Aitken, of Scotland, and Jamison, of England, have successfully applied to this type of coke oven, appliances for the saving of by-products of tar and ammonia. (2) The Belgian, Coppée, and related ovens and improvements on the Knab, which are closed or retort ovens with vertical flues. (3) The Simon-Carvés oven is a closed retort oven with horizontal flues and recuperator.

These two types of closed ovens utilize the oven gases, after having been deprived of by-products, by retaining them to heat the chambers of the ovens, thus saving the burning of the fixed carbon of the coal in coking. This utilization of the gases evolved in coking, by returning them to supplement the oven heat, is the distinctive characteristic of the family of retort coke ovens.

The positions of the coal in the chambers of these three typical coke ovens have been clearly defined by the three postures in which a common brick can be placed. Laying it horizontally on its broadest side shows the posture of the charge of coal in the beehive oven; placing the brick vertically on its side illustrates the shape in which the coal is coked in the Belgian ovens; and by placing the brick vertically on its end, the posture of the charge of coal in the Appolt oven is accurately represented.

It has been pointed out that the designs of the coke ovens following the original beehive were chiefly made to satisfy the three principal conditions of the manufacture of coke: (1) to coke inferior coking coals; (2) to economize the work of coking, by mechanical appliances; (3) to secure a large percentage of coke from the coal charged into oven.

The relative ultimate economies of each system of coking will hereafter be considered in detail, embracing capital invested in construction of each type of oven plant, the percentage of coke obtained, cost of making it, and the quality and value of the coke produced.

With the expansion of the use of coke in metallurgical operations on the one side, and the gradual exhaustion of the areas of the best coking coals on the other, it becomes evident that to meet the coking requirements of the lower qualities of coking coals special plans of coke ovens will be required to assure the best possible product of coke.

Modifications of Appolt Coke Ovens at Blanzy.—We make the subjoined extracts from a communication to the Societe de l'Industrie Minerale, by M. Marle, engineer at the Blanzy collieries. Several types of ovens have been employed at Blanzy, where from 20,000 to 25,000 tons of coke are made each year, but of different types only two remain, the horizontal Coppée and the Appolt type.

"A few modifications have been introduced in the Appolt ovens in order to utilize the waste heat for firing the boilers or to take off the gas for other purposes. The Appolt oven generally consists of eighteen vertical retorts, arranged in two rows in a large heating chamber. The gases issuing from the retorts by narrow horizontal apertures at the bottom are ignited and permeate through the heating chamber, air entering by orifices at different levels. The products of combustion escape through eight passages at the level of the lower part of the retorts, communicating by horizontal flues with vertical chimneys at the four corners of the oven. Eight other and smaller orifices at the top of the heating chamber may also serve to take off the waste flames; but they are not generally employed, as their use leads to a cooling down of the lower part of the oven. The outlet passages, below the level of the gas exits, must draw along a portion of these gases before their complete combustion, and without their having contributed to heating the oven; so that, in the chimneys, and especially where the passage is throttled by dampers, the temperature is very high, rendering maintenance costly and difficult. Moreover, this arrangement gives but little facility for graduating the temperatures, which are always too high in the middle of the oven and too low at the two ends, thus delaying the operation of coking in the retorts at the corners, which cannot be drawn every 24 hours.

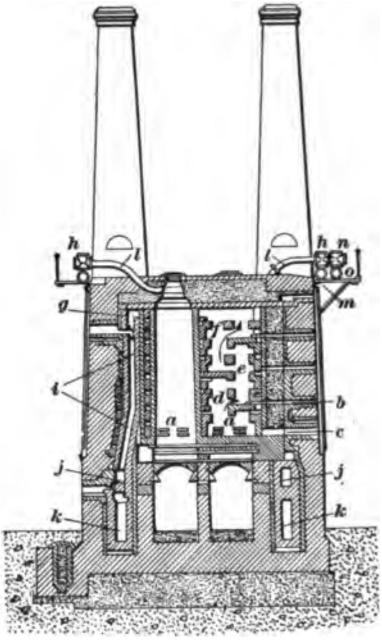


Fig. 4. Modifications of Appolt Coke Ovens at Blanzy

"In order to improve this state of things, the direction of the gases has been completely changed. The gases leave the retorts by the narrow apertures *a*, *a*, Fig. 4, at the bottom, and air for combustion enters by the passages *b*, *c* at different levels as before; but the products of combustion are entirely evacuated at the upper portion of the heating chamber, and the gases, before arriving there, are obliged to follow a course *d*, *e*, *f* that forces the gas and air to mingle and enter into combustion, thus heating as evenly as possible all the parts of the oven, while apertures with dampers are provided in the partitions for still better regulating the temperature.

"In the long sides of the oven there are as many evacuation apertures *g* as there are retorts; and, besides, at each end there are four apertures in the shorter sides, so as to heat the corner compartments, which, since this modification, coke as rapidly as the others. Each of these apertures is fitted with a damper, which permits of regulating at will the temperature of coking; and they communicate with a descending chimney *i*, traversing the whole height of the oven, and then enter the horizontal collector *j*, divided in the middle by a vertical partition into two equal parts.

"Owing to this arrangement, the heating chamber is itself surrounded by all these chimneys *i*, which heat it still further and protect it from external cooling, while the chimneys themselves are separated from the outer masonry by an air space, which also protects them. From the collector *j*, the gases pass into another flue *k* by means of four apertures fitted with dampers, and, when they reach this flue, the gases may be sent at will under the boilers and thence up their chimneys, or directly, on the other side, up other chimneys, dampers serving to direct the gases to one or other end, according to requirements.

"This double direction was rendered necessary by the intermittent working of the boilers, which are only in use by day, while it also permits of a complete stoppage, so far as the boilers are concerned, for cleaning and repairing them. The object of the collector *j* is to regulate the draft in the descending chimneys *i*, which, without such an arrangement, would always have too strong a draft on the side where the gases were directed. Lastly, the oven may be completely closed by the dampers on Sundays and holidays, when the ovens are not drawn.

"The flues *j* and *k* and descending chimneys *i* are, for a considerable distance, surrounded by air, which is raised to a tolerably high temperature; and this heated air may, if required, be used for the combustion of the gases in the heating chamber by suitably regulating the dampers. It was, however, necessary to discontinue the use of this hot air until the excess of gas produced by the oven was taken off, as the temperature which it produced was too high and might damage the bricks of the oven.

"The boilers are vertical and provided below with a series of Mac-Nicol tubes, which greatly increase their evaporating power. They supply steam for driving the lifts, the coke breakers, and a washing apparatus. On Mondays, when there is no gas in the ovens, it becomes necessary to heat them so as to have steam enough to begin work; and for this purpose they are provided with grates, so that they may be fired like ordinary boilers.

"The first two Appolt furnaces constructed by the Blanzy Company in 1862 were built, as usual, of burnt bricks, which it was necessary to cut and square carefully; but, noticing the difficulty caused and length of time required by this work, the late M. Jules Chagot, who then managed the Blanzy Colliery, conceived the idea of building the ovens with unburnt bricks, as practiced in the furnaces of glass works. Accordingly, since 1866, all the ovens have been constructed in this manner, except one, in which case there was no time to wait for the bricks. One consequence of the use of unburnt bricks is that they must be made on the spot, as they cannot be transported easily.

"This system possesses the following advantages: (1) facility for squaring the bricks, which is done with a scraper instead of by hammer and chisel, thus economizing about one-sixth of the labor; (2) the faculty of the unburnt bricks to adhere together, so as to make of each retort a monolith, the joints of which cannot be detected; (3) saving of the burning, which is effected when firing up the oven, which must always be heated very slowly, whatever be the method of construction.

"In addition to the above, the manufacture of the bricks on the spot has the advantage of leaving no doubt as to their quality and composition, or the manner in which they may be expected to behave in the fire, and it also permits of varying the composition according to the position occupied by an individual brick, of using very large bricks and of thus diminishing the number required. In the ovens built at Blanzy, the bricks are at least 25 centimeters (10 inches) high; each course of a compartment is built of six bricks; four courses of the upper portion are made, each in a single piece, and each course of the descending chimneys, also in a single piece, so that it may be laid very rapidly. In cases where the bricks are not required to adhere, in order to prevent displacement, a piece of wood or cardboard is introduced into the joint during construction and this packing piece is consumed when firing up. Actual experiment has shown the amount of clearance that must be left, which is greater in proportion to the quantity of quartz entering into the composition of the brick.

"Before charging the oven it must be fired up with great precaution for at least 3 weeks; and it is necessary to keep a watch on the expansion, and unscrew the nuts of the tie-rods as required. All the nuts must be provided with lead washers, the squeezing out of which gives warning of the moment when they must be slacked. Thanks to all these precautions, it was found possible to construct the last oven with twenty-two compartments instead of eighteen, without the slightest fracture being perceptible in the retort. There is an advantage in getting as many compartments as possible in the same bank, because the cost of the two heads of the chimneys and of the boilers is spread over a larger number of retorts, and therefore over a greater production of coke.

"On noticing what happens in the retorts after charging, it will be seen that, during the greater portion of the carbonization, the gas attains considerable pressure inside, and has a tendency to escape, not only by the narrow apertures intended for this purpose at the bottom of the retort, but also at the upper and lower joints if they are not made well. If, therefore, during this period, the gas be put in communication with a gasometer, the pressure of which is regulated very low, the gasometer will be filled without air entering the retort. As, in the present instance, the gasometer of the gasworks is 250 meters (273 yards) from the oven, an exhauster will be added for drawing off the gas from the retort, while leaving behind it sufficient pressure to prevent the possibility of a vacuum being formed in the retort. It will be possible, with practice, to determine the time during which communication must be maintained, and at the end of this period a valve must be closed, allowing the gas to escape by the apertures *a*, *a*, Fig. 4, for taking off the gases. The gas will be taken off by the pipes *l*, the valves *h*, and the general pipes *m*, in communication with the exhauster. If, later on, it be found advisable to take off all the gas for recovering the tar and the ammoniacal liquor, the apertures *a* will be closed, and a second valve *n* and pipe *o* will be added for collecting the gas not intended for lighting. After their tar and ammoniacal liquor are condensed, they will be sent into the flues *b*, *c*, where they will burn with the hot air, serving to maintain the heat of the ovens. The flues *b* and *c* are, in fact, already arranged for receiving the gas pipes.

"With Appolt ovens, more labor is required than in any others. For 17 or 18 hectoliters (mean 62 cubic feet) of coal charged, 2 hectoliters (7 cubic feet) of coke dust must be charged in for closing the apertures at top and bottom, and also at least half that quantity of small coke for protecting the gas exits *a a* and preventing them from being obstructed by the coal. When the coke is drawn, this dust and small coke must again be withdrawn from the batch, which is a double work, increasing the volumes to be handled by three-eighteenths on charging, and the same on drawing, making one-third together. Hitherto the drawn coke, received in a tram, has been quenched and tipped on a floor, where the separation, screening, and loading up were effected by hand.

"To lessen these expenses, the company put up a mechanical screen. Trams of the drawn and quenched coke are brought by an endless chain in front of a pit into which the coke is tipped, and then raised by a Jacob's ladder to the top of the shed, whence it falls into a screen, with bars 5 centimeters (2 inches) apart, which keeps back the large coke. The latter falls into a hopper, where it is stored, and whence it may be charged directly into wagons

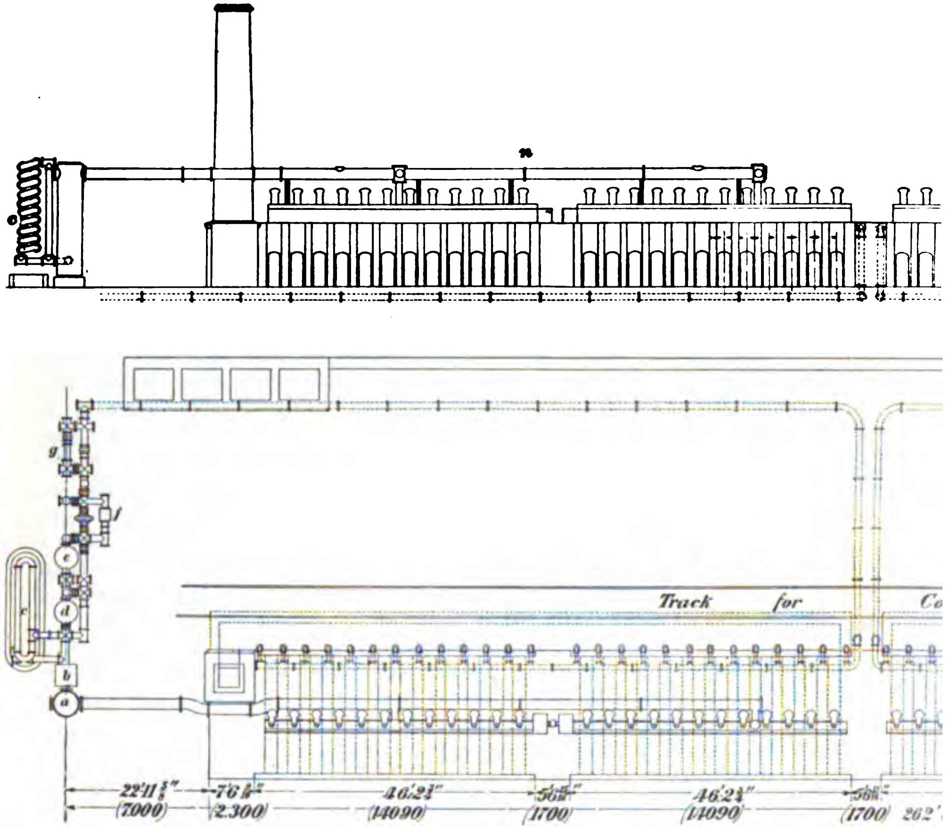
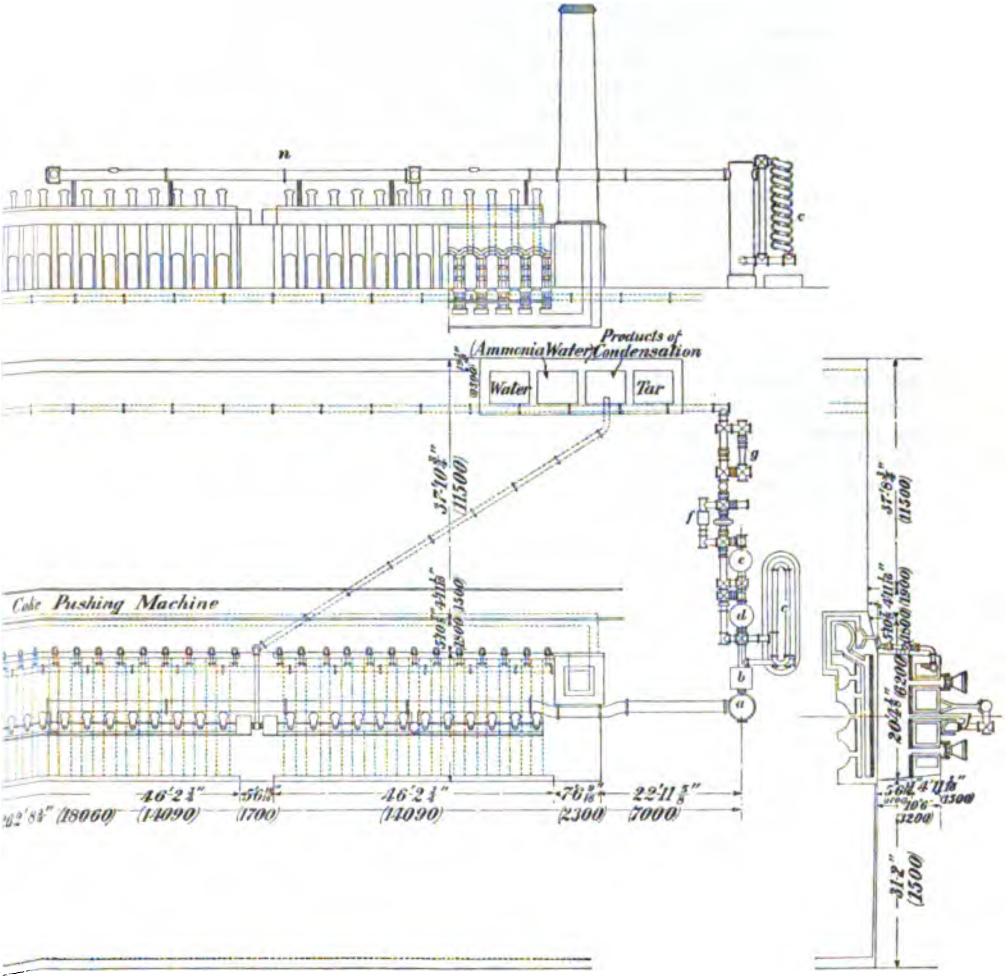


FIG. 7. SEIBEL SYSTEM. PLANT FOR CONDENSING AND COLLECTING

a, Expansion regulating tank; *b*, condenser or refrigerating



NG By-Products From a Double Battery of Twenty-Four Coke Ovens
ting tank; *c*, pipe; *d*, *e*, scrubbers; *f*, tar condensers; *g*, exhauster

running on rails by a sliding door at the bottom, the overplus being directed into a trommel or revolving drum, which divides it into four sizes, from dust to 40 millimeters ($1\frac{9}{16}$ inches).

"As the quantities of small coke produced are not sufficient for the demand, part of the large coke, instead of falling into the loading hopper, will be sent to a breaker and divided by a similar trommel into the same classes as those referred to above. It is expected that this arrangement will permit of reducing by more than half the labor required. The dust and the small coke required for charging into the retorts with the coal will be led to hoppers at the side of the ovens, whence they will be taken by the charging trams.

"The coal used for coking is of the long-flame bituminous variety containing: carbon, 77.82 per cent.; hydrogen, 5.2; oxygen, 9.17; and nitrogen, 1.31; with an average of 6.5 per cent. of ash, yielding in the crucible a mean of 63.71 per cent. of coke, which is adhesive and rather soft, its structure showing long bright needles.

"For some usages a harder coke is made from a mixture of bituminous and anthracitous coal. The latter, obtained from the west of the concession, contains: carbon, 82.48 per cent.; hydrogen, 3.88; oxygen and nitrogen, 6.14; with a mean content of 7.5 per cent. of ash, yielding in the crucible 83.5 per cent. of pulverulent coke, but the mixture of this coal with the bituminous produces a large and dense coke, in which the above-named needles are absent."

It is quite probable that this type of coke oven will be found to be well adapted for the successful coking of the western coals, rich in bituminous matter. The dimensions of the coking chambers will require enlargement for the best results from these coals.

Simon-Carvés Oven.—About the middle of the 18th century, efforts were made in France and England to extract the by-products of tar and ammonia from the gases evolved in coking coal. This was stimulated at that time by the increasing use of coke in the presence of a declining supply of charcoal. These efforts were made prior to the practical introduction of works for making illuminating gas from coal.

It is on record that Bolton and Watts first erected private gasworks in 1798; this was followed by the construction of public gasworks in London in 1813, Paris in 1815, and in Berlin in 1826. The by-products of tar and ammonia, at these early gasworks, were regarded as very undesirable resultants, which required removal in purifying the illuminating gas, as at this time no useful place appeared for them in the industrial arts.

A limited application was provided for the use of tar in Germany in 1846, in the manufacture of roofing felt. In England, tar was used in a small way, in 1838, for the preservation of timbers.

This was followed by the utilization of the sulphate of ammonia as a fertilizer, thus affording additional revenue to the gas makers and coke manufacturers.

A long interval of slow progress followed the early production of these by-products in the coke-making industry. This arose, in part, from the feeling entertained at this period that ovens making by-products could only produce an inferior quality of coke. Doubtless this judgment was induced by the poor quality of gas-house coke for metallurgical purposes, and by the fact that coke for blast-furnace use could only be made in beehive or similar types of coke ovens, untrammeled by the cumbersome apparatus for saving these by-products.

The foundation of ultimate success in making a good quality of coke and at the same time securing the by-products was laid in France by Knab's retort coke oven in 1856; but the condensation of tar and ammonia from the gases from these ovens was only practically successful by the Haupart and Carvés oven about the year 1881. This success imparted to the saving of by-products renewed interest and gave the coke-making industry additional value in France, Germany, and England. The most important improvement in the Carvés oven, from the Knab, consists in the addition of side flues. The Knab oven had only bottom flues.

Mr. H. Simon, in England, improved the Carvés oven very materially by adding recuperating flues in front of the ovens. This recuperator affords ample heat in the process of coking and overcomes the necessity of using a portion of the fixed carbon of the coal for supplemental heat in coking.

The Simon-Carvés retort coke oven is a closed oven with horizontal flues and apparatus for saving by-products. Its introduction was followed by a large number of retort coke ovens with and without appliances for securing by-products.

The Simon-Carves coke ovens, Fig. 5, are constructed to produce coke suitable for all industrial purposes, with an economy of coal, and at the same time to collect all the by-products in the distillation of coal. These by-products serve for the manufacture of ammonia and ammonia compounds, tar and all its derivatives, benzol, carbolic acid, anthracene, coloring matter, etc.

In the Simon-Carves oven, the carbonization takes place in a closed retort, and there is neither introduction of air nor combustion in the interior of the oven. To convert the coal into coke, the heat is applied externally through flues passing under the floor and along the sides of the ovens. The heat is generated from the gases obtained in the ovens from the coal, but only after these gases have been deprived of every particle utilizable as a by-product. Hot air is employed to render the combustion more effective, waste heat from the ovens being utilized to heat the air. Fig. 5 illustrates the main operations of this oven.

The coal to be coked is conveyed to the top of the ovens by the coal larry *o*; by opening the doors of these larries, the coal falls into the oven through the ports *a*. These openings and the doors *b* and *c* at each end of oven are then tightly closed and luted, so as to prevent the admission of air. The valve *d* is then opened, putting the interior of the ovens in communication with the exhauster pipe *e*. This conveys the gases evolved from the coking coal to the condensers and scrubbers, where they are deprived of the by-products and returned to be burned with hot air in the oven flues. When the carbonization is completed, the doors of the ovens are opened and the coke pushed on the platform or

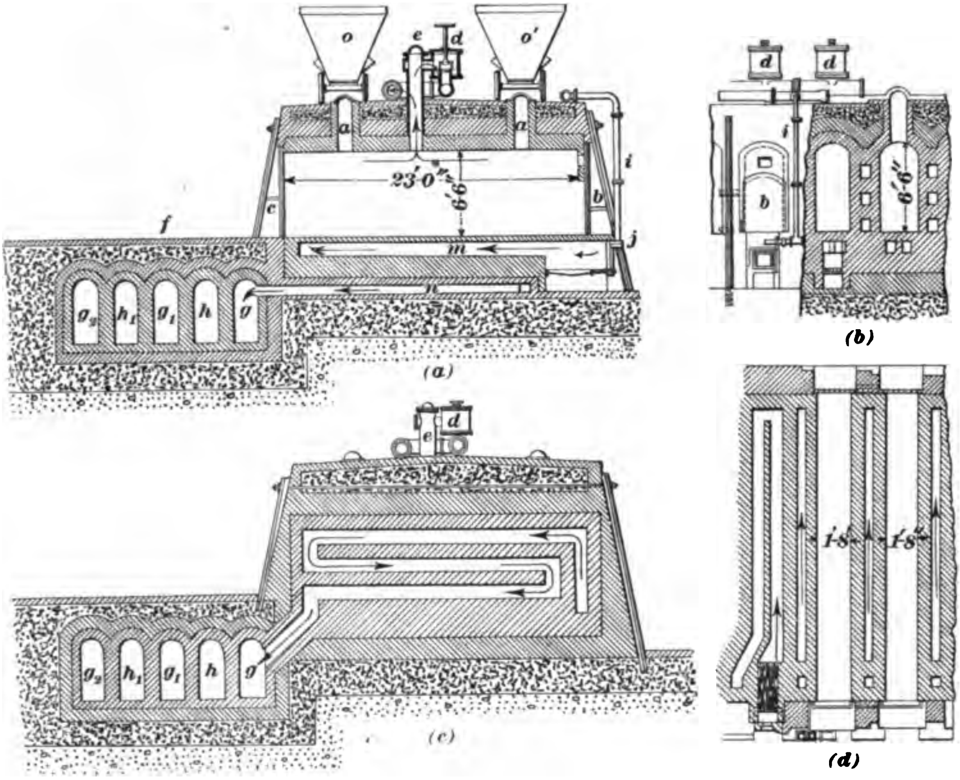


FIG. 5. THE SIMON-CARVÈS COKE OVEN

o, *o'*, charging larries; *a*, *a*, charging ports to ovens; *b*, *c*, doors to each end of ovens; *i*, pipe and tuyères for transmitting gases; *m*, flues under ovens for gases and heated air; *j*, nozzle to mix gases with air in flues *m*; g, h, g_1, h_1, g_2, recuperator for smoke and waste heat from flues *n*; h, h_1, flues to allow the gaseous products to escape to chimney; g, g_1, g_2, flues for passage of air, which is heated on its way by contact with the hot walls of the flues h, h_1; *e*, opening on top of oven to collect the gases; *d*, valve to regulate the gases; *f*, coke wharf where the coke is cooled.

wharf *f* by a steam ram. The cooling of the coke is done on this wharf. The interior dimensions of this oven are as follows: length, 23 feet; width, 18 to 20 inches; height, 6 feet 6 inches.

The recuperator is an important and later element in this oven; it is described as follows: Externally to the brickwork of the ovens are provided five longitudinal flues g, h, g_1, h_1, g_2; two of these flues, h and h_1, allow the gaseous products of combustion to escape to the chimney, the other three flues, g, g_1, g_2, contiguous to the former ones, serve as passages for the air, which is heated on its way by contact with the walls of the flues h and h_1. The flues h and h_1 communicate respectively with the chimney and the steam boilers, which can be placed at each end of the row of ovens, to further utilize the waste heat of the products of combustion.

The charge of coal for each oven is 5½ net tons. The coking requires about 48 hours with the usual quality of coals. With coal affording 75 per cent. of coke, the production of an oven is 2.1 to 2.2 tons of coke per day, and about 10 per cent. of ammoniacal water and 3 per cent. of tar.

A battery of fifty ovens at Bearspark Colliery, England, makes about 900 net tons of coke per week from coal constituted as follows:

	Per Cent.
Moisture	.84
Volatile matter	26.85
Fixed carbon	68.44
Ash	3.10
Sulphur	.77
Total	100.00

The theoretic coke from the above coal is 72 per cent. The charge into the oven is 5½ net tons of coal, yielding about 4⅛ tons of coke in 48 hours. Deducting for ashes and breeze, the product of marketable coke is practically 75 per cent. This shows a small accretion from the deposit of carbon in the process of coking, about 4 per cent.

The cost of labor in coking and collecting by-products is estimated at 48 cents per net ton of coke made in a battery of fifty ovens, producing together 105 tons of coke per 24 hours. The annual product of fifty ovens of marketable coke would be about 34,000 net tons. The value of the by-products of tar and ammonia is estimated at 68 cents per net ton of coke made.

The cost of a plant of fifty Simon-Carvés ovens with appliances for saving the by-products would be about as follows in the United States, depending somewhat on locality:

Fifty ovens at $1,300 each	$ 65,000.00
By-products appliances, tracks, houses, elevators, etc.	50,000.00
Total	$115,000.00

This estimate does not embrace a coal-washing plant. If such is required, an additional sum must be added to the above, depending on the character of the coal and the impurities to be removed.

With coals inheriting 26 per cent. of volatile matter the saving of by-products becomes more assured, but with the large expense of the apparatus for saving by-products in the original cost of the coking plant, and in its continuous and expensive operation and maintenance, it becomes a matter demanding careful investigation whether at this time it is an auxiliary that will surely afford to the coke manufacturer an income that will compensate for investments in this addition to the plant, and afford a return to cover the additional labor and repairs of apparatus. A thorough test of the coal, for its value in affording by-products, should be made as a prime element in the investigation of this matter.

These Simon-Carvés ovens can be used in the manufacture of coke, with or without appliances for the saving of the by-products of tar and ammonia. Their system of horizontal flues is commended for efficiency and economy of repairs.

G. Seibel's Rètort Coke Oven.—*By-Product Oven.*—The Seibel retort coke oven was patented by its inventor, Georges Seibel, in France, in 1881, in England, in 1882, and in the United States of America, in 1883. Two main principles appear to have been kept in view by Mr. Seibel in the planning of this oven. (1) To preserve the mode of carbonization that secures a maximum deposit of carbon from the hydrocarbon gases in their ascent through the upper incandescent coking portion of the charge. (2) To arrange tuyères and horizontal flues for the utmost economy in maintaining oven heat by combustion of the returned gases, deprived of the by-products, without the use of grates or complicated regenerators. The details of this oven are all in harmony with these principles, exhibiting practical skill in the design of the retort coke oven and its by-product-saving appliances.

Through the courtesy of Mr. W. M. Stein, of Primos, Pennsylvania, I am enabled to submit the considerations that guided Mr. Seibel, the inventor, in designing this oven, from his own notes, with a description of the oven and its mode of operation.

"Until recent years, the method of coking in hermetically closed ovens, permitting the saving of tar and ammonia, was not considered a good one by the best engineers. It was generally believed that, at best, only coke of inferior quality could be obtained, hardly comparable with that of gasworks.

"For a long time, the coke ovens of the works of Marais, near St. Etienne, Loire, modified according to the Knab system, failed to find imitation. Today this method of carbonization with saving of by-products is more appreciated, its advantages recognized, and the prejudice entertained against the process is given up, especially in Europe.

"Experience has demonstrated that the coke thus obtained is not inferior in quality to that obtained from the same coal in ovens of the other systems. Germany has adopted ovens heated with regenerated gas for saving of tar and manufacturing sulphate of ammonia.

"The engineers today study and apply the different systems. Belgium has ovens heated with gas and arranged to gather tar and aqua ammonia, producing at the same time perfect coke, suitable for all metallurgical purposes.

"In France, on the contrary, this question seems to have remained indifferent to the interested parties. One large iron company only, the company of Terrenoir Savoutte and Besseges, had adopted the ovens of the system Carvés and Company, in 1867. In three intervals, in 1867, 1873, and 1875, this company has built at Besseges, eighty-five ovens of this type, being perfectly satisfied with the results. A group of these ovens is also in operation for the past few years at Terrenoir.

"Such is the condition of carbonization with saving of by-products in the principal coal centers of Europe.

"It may be said, however, that, though this question met with little interest in France, it is beyond dispute that the improvement originated in this country. In this direction, the Company of the Mines of Campagnac located at Crausac, Aveyron, has been quite successful, effecting a remarkable improvement in the coking industry. In 1878 and 1879, this company built a first battery of nine ovens, modifying the previously adopted method of carbonization. The result obtained surpassed all expectation. In 1882, the company added ten ovens to its first battery, which have given the same satisfaction as the first. The mere enumeration of these results will be amply sufficient to emphasize the progress accomplished.

"The coal of the Company of the Mines of Campagnac gives theoretically an average yield of 64 per cent. of coke, ashes included, and 36 per cent. of volatile matter. The actual yield of these ovens (Seibel) proved to be 75 per cent. The results obtained during the whole year 1883 were, as above noted, 75 per cent., that is, 11 per cent. in excess of the theoretical yield.

"The production of tar was 54 pounds per each gross ton of coal charged. From these results the following figures exhibit the working of these ovens during the year 1883: coal charged into ovens, 14,675 gross tons; production of coke, 11,006¼ gross tons; saving of tar, 360¾ gross tons.

"The Company of Campagnac commenced to save the aqua ammonia and manufacture sulphate of ammonia only after the beginning of the year 1883. The yield of sulphate of ammonia is 11 pounds for each gross ton of coal charged. The company then increased the surface of the condensing apparatus of the gases. The tar production showed the effect immediately, increasing to 66 pounds for each gross ton of coal charged.

"It follows from these figures that a coke oven of this system, using this or a similar quality of coal, will produce yearly as follows: 648.81 net tons of coke, 25.99 net tons of tar, and 4.325 net tons of sulphate of ammonia.

"These results require no comment, I shall therefore not dwell upon them, but complete the information by adding that the coke made from this coal is superior in quality to that obtained from similar coal in either the Appolt or Coppée ovens.

"We have during several months made coke regularly with our coal in those two types of ovens and ours, and could therefore determine the difference in the products, which was very easily perceptible.

"The coke obtained from our ovens is harder and denser than that obtained in the ovens named above. This improvement is the consequence of the increase of yield, which surpasses the theoretical yield by 11 per cent. This increase is obtained at the expense of the carbon of the hydrocarbons of the gases, which, dissociating, deposit part of their carbon in the pores of the coke. In short, there is, during the period of distillation, a dissociation of the gases, whereby a part of their carbon, being now in elementary form, unites itself with the coke or fixed carbon, enriching it and increasing its quantity and quality.

"Before describing the ovens, I will sum up the reasons which have been guiding me in their construction.

"It has been proved long ago that the hydrocarbon gases produced by the distillation of the coal give up, under certain favorable conditions, a larger or smaller proportion of their combined carbon. The formation of graphite in the retorts of gasworks is due to this cause. On the other hand, if one compares carefully the coke produced in a beehive oven with the coke from the same coal produced in ovens of the other types, it will be recognized that the coke from the beehive ovens is denser, harder, and in thicker pieces than that produced by ovens of other systems. The difference is especially marked in coke from coals rich in volatile matter like those of the basin Decazeville and Aubin. This difference in quality was formerly so well known in the basin of Decazeville that the foundry owners would take only beehive coke for smelting in cupolas, excluding coke from the ovens Semet, Appolt, and Coppée, which was formerly used simultaneously with beehive coke in these works. The difference in quality can only be due to the manner of carbonization. In the beehive ovens formerly used, the process of coking commences at the top and then goes downwards. Now, if a charge of coal is put in a heated beehive oven, all parts of the oven with which the coal comes in contact, walls and bottom, cool immediately, the dome only retaining its heat. The latter radiates heat over the charge and starts the distillation there. This distillation continues downwards in the mass of coal, and the gases produced in the lower portions are forced to traverse a porous mass during the formation of coke, in order to escape through the only opening in the roof. The hydrocarbon gases traversing in the early stage of the coking process through a spongy mass are consequently surrounded by conditions very favorable to their dissociation, and give up to the upper regions of the charge a certain proportion of their carbon. This fact can be proved by a careful examination of a coke needle. These needles are formed vertically in the beehive ovens; at the lower part of the needle, where it touches the bottom of the oven, the grain of the coke is porous, puffed up, coarse; while it gradually becomes finer and denser, approaching the top of the needle. The only possible explanation of this difference in the condition of the same needle is the one given above; it gives, therefore, a valuable hint as to the dimensions and particular arrangement that must be observed in designing the oven. In spite of the quality of the coke produced in the beehive ovens in the basin of Decazeville and Aubin, they have been abandoned. They yielded too small a quantity of coke.

"Assisted by the observations just related and information gained in the position of managing engineer at the mines of Decazeville, I had, when called upon to construct coke ovens for the Company of the Mines of Campagnac, already studied up a type of oven reproducing the method of carbonization in use in the beehive oven, that is, where carbonization commences at the top and extends downwards, but avoiding the losses that are incurred by combustion of the fixed carbon.

"The retort coke ovens of the Company of the Mines of Campagnac carbonize from the top downwards and are hermetically sealed.

"The following very simple arrangement was adopted. As mentioned above, the Company of the Mines of Campagnac possesses a group of nineteen ovens constructed in two batteries. The first experimental battery of nine ovens and, in addition to these, ten others have been built, the south end of the first battery being the north end of the second. Each retort oven is a long, narrow, arched chamber, 19 feet 8¼ inches long, 6 feet 6¾ inches high, and 27½ inches wide between the side walls.

"The dimensions of a more modern oven are given in Fig. 6. The walls separating each oven from its neighboring one are 15¾ inches thick and are built of first-class firebrick. The walls between the ovens contain three horizontal flues, connected with each other at their ends, so as to form a continuous flue, as indicated by *a*, *b*, *c*, which is continued in *d*, under the sole of the oven, and finally leads through the flue *e* into the main gas flue *f*. The latter takes the gases to the chimneys, built at the ends of the battery of ovens. The upper flue *a* has an opening at *g*, going through the wall to the outside of the oven in which the gas burner is placed and which will be described further on.

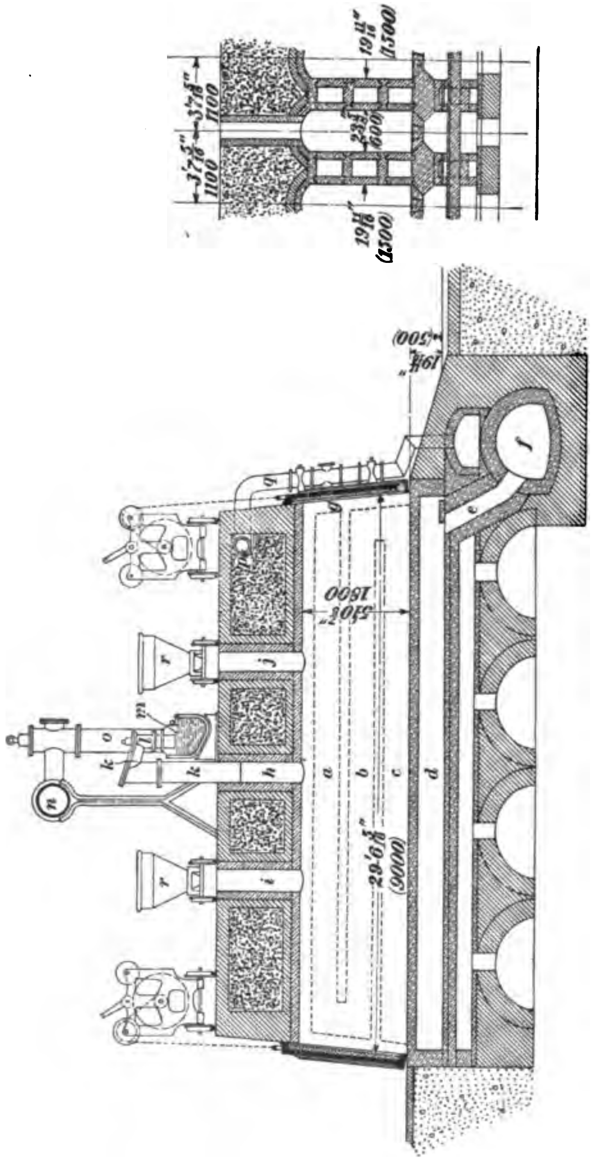


Fig. 6. Seibel's Retort Coke Ovens for Saving of By-Products

"In the middle of the retort of each oven, there is in the arch an opening *h* that allows the gases of distillation to escape. To the right and left are placed symmetrically the two other openings *i* and *j* for charging the coal.

"The ovens are closed at their ends by cast-iron doors. Two swinging doors are placed over these. The doors, as well as the charging ports, are hermetically sealed by a clay point. Above the opening *h*, which allows the gases of distillation to escape, a vertical cast-iron pipe *k* is placed, which, by a branch *k*, connects with a small barrel *l*, the opening of which can be closed by a valve *m*. It is only necessary to lift the latter by its handle to effect the stoppage. The gases of the distillation escape by means of the pipes *k* and *k* into the hydraulic main, common to each battery.

"The hydraulic main is connected with a collecting pipe *n*, by a vertical pipe *o*, which is also provided with a valve. Each battery has its hydraulic main connected with the collecting pipe *n*, which leads the gases of all the ovens to the condensing apparatus. An exhauster worked by steam, which absorbs these gases, forces them to traverse the various apparatuses with gradually decreasing pressure. The gas gives up its tar and ammoniacal water, and is then returned to heat the ovens.

"The purified gas is driven back by the exhauster to the pipe *p* which extends along the top of the ovens. From this pipe, the gases are distributed equally to the tuyères by secondary pipes *q*, which take to the burners the quantity of gas necessary for each. The pipes *q* are supplied with valves that regulate or stop the flow of gas to the burners. These burners consist of two tubes, one within the other, and closed at the outer end by a flange. The inner one is a little smaller than the outer one, so as to have a circular space of .039 inch. Thus joined with the flanges put together, and the outer tube connected with the feeding pipe by a special small tube, it will be seen that the arriving gas flows in the upper part of the circular aperture between the tubes in the form of an elongated crown. The air necessary for this crown of gas reaches the circular aperture by means of openings in the inner tube. The supply of air can be regulated by shutting these openings more or less.

"These are the general arrangements of the oven; it will now be easy to understand its operation.

"When an oven is charged and cut off from the battery by closing the valve *m* in the small barrel *l*, it is then recharged with coal through the openings *i*, *j*, by means of the larries *r*, *r*. The charge of coal is piled up as high as possible in the oven, nearly to the spring of the arch, and is then leveled from both sides through the upper opening of the doors, which remain open while the coal is charged. This being done, the charging ports *i*, *j* are closed by lids and the upper openings of the doors shut, both being hermetically sealed with clay.

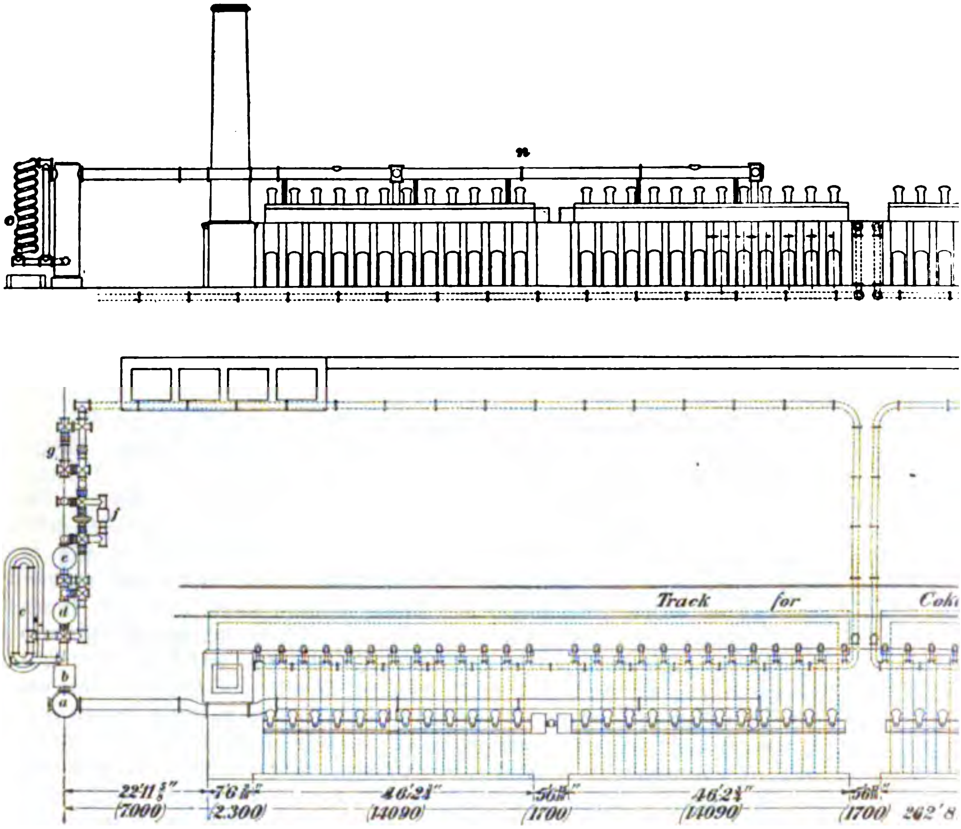
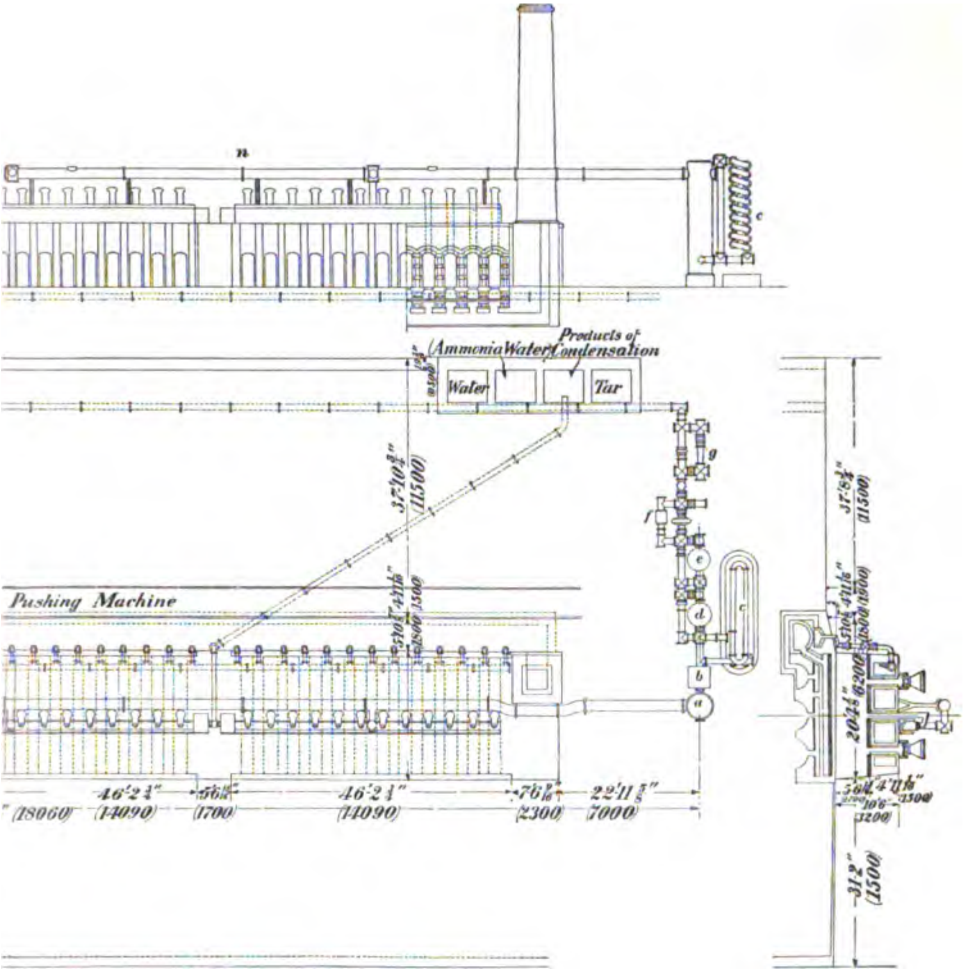


FIG. 7. SEIBEL SYSTEM. PLANT FOR CONDENSING AND COLLECTING B
a, Expansion regulating tank; *b*, condenser or refrigerating

17303—VI



-Products From a Double Battery of Twenty-Four Coke Ovens
nk; *c*, pipe; *d*, *e*, scrubbers; *f*, tar condensers; *g*, exhauster

"At the same time, the valve *m* of the barrel *l* is opened and the communication of the oven with the hydraulic main restored. The carbonization now proceeds regularly, the gases of distillation escaping under a small pressure through the opening *h*, and, by means of the pipe *k*, *k*, to the hydraulic main, from whence they go to the condensing apparatus.

"The coal charged being wet, the walls and floor of the oven in contact with it are considerably cooled. The arch is the only part of the oven remaining hot.

"On the other hand, the two burners have continued heating the wall flues *a*, which, in their function as combustion chambers of the gases, have a higher temperature than the flues *b*, *c*. It is, therefore, easily understood that the upper part of the charge will receive from the flues *a*, as well as from the hot arches by radiation, the greatest amount of heat.

"The distillation begins therefore very actively at the top of the charge and progresses downwards. It will be seen from this that the carbonization begins at the top and goes downwards, exactly as in the beehive ovens. The gases generated in the lower part of the charge must, in order to escape through the only opening *h* in the oven, traverse the upper regions, which are ready settled and have been brought to a high temperature. This shifting of the gases causes them to give up part of their combined carbon, which settles in the pores of the coke already formed and in the fissures between the coke needles.

"I have endeavored to give the ovens such dimensions as are most likely to facilitate the dissociation of the hydrocarbon gases, which is such an essential part in the method of carbonization just described.

"The general arrangement of the condensing apparatus at the mines of Campagnac is shown in Fig. 7, which gives, at the same time, their connection with coke ovens. At each end of the oven batteries, a boiler is heated with the products of combustion resulting from the heating gases, which must pass under the boiler on their way to the chimney. These boilers work alternately, just as one or the other chimney takes the products of combustion. Should it, however, be found necessary, both boilers and chimneys can be used.

"The by-product-saving apparatuses are as follows: Fig. 7, *a*, expansion regulating tank; *b*, condenser; *c*, pipe condenser; *d*, *e*, scrubbers; *f*, tar condenser; *g*, exhauster.

"These apparatuses work in the manner explained below.

"(*a*) This expansion regulating tank is a simple cylinder of sheet iron, 4 feet 3 inches in diameter and 16 feet 5 inches high, standing vertically. The gases of distillation arrive at the upper part, through the collecting pipe *n*, Fig. 7, and leave the cylinder at the lower part. Arriving at this large tank, from the tube *n*, the gas expands, and this is sufficient to cause it to abandon a certain proportion of tar and ammoniacal water. The temperature of the gas in this reservoir varies with the external temperature and the amount of gas produced by the ovens; it is between 70° and 90° centigrade (158° to 194° F.). The pressure on the contrary remains constant and is 0.

"(*b*) From the expansion tank the gas goes to the square condenser—a rectangular tank, 6½ feet high, 3 feet 4 inches wide, and 3 feet deep. This tank is placed in another, open at the top, of 1 foot high, 4 feet wide, and 3 feet 7 inches deep, filled with water to the height of an overflow, which permits the discharge of the condensed liquids. The first tank is divided into six compartments by vertical hollow partitions, in which cold water circulates. These partitions are so arranged that the gas, in order to circulate, must pass from one compartment to the other and bubble through the condensation water. Traversing this apparatus the temperature of the gases falls about 11° to 13° centigrade (52° to 55.4° F.), and they lose a considerable quantity of tar and ammoniacal water, the cooling surface of the tank being 258 square feet. Leaving the apparatus, the gases have attained a depression of .08 to .18 meter (3⅛ to 7 inches) of water.

"(*c*) From the square condenser the gas passes through the pipe condenser—a series of wrought-iron serpentine pipes, water-cooled from the top by a water spray. The condensing surface of these pipes is 1,115 square feet, the decrease of temperature 20° to 26° centigrade (68° to 79° F.).

"(*d*), (*e*) Two scrubbers follow the pipe condensers; they are cylinders of 3 feet 4 inches diameter and 16 feet 5 inches in height, and contain a series of plates so arranged that the gas entering these cylinders at the bottom meets the water coming from the top and is methodically washed. The cylinders are filled over two-fifths of their height with crushed coke. In one of the scrubbers, the gases are washed with ammoniacal waters in order to enrich the latter, in the other with pure water in order to extract as much ammonia as possible. After the first washing, the depression of the gases is .15 to .22 meter (5 to 8¾ inches) of water; after the second washing .20 to .27 meter (8 to 10½ inches). The first washing lowers the temperature 10° to 15° centigrade (50° to 59° F.); the second, 5° to 6° centigrade (41° to 43° F.).

"(*f*) The tar condenser is built according to the principle of Pelouze and Andouin, and is used in large gas works to deprive the gases of the last particle of tar which they may yet hold. It consists of a series of metallic curtains arranged vertically one behind the other. These curtains are construced of pieces of wire about ¾ inch in diameter, placed vertically in frames, ¾ inch apart. Each curtain is placed behind the other in such a manner that the wire strings of one correspond to the space between the wires of the other. The gas, passing these obstacles, is subjected to a succession of shocks that cause it to yield up the last particle of tar it contains. To work properly, the needed depression of this apparatus must be .04 to .05 meter (1½ to 2 inches) of water. This is regulated by augmenting or decreasing the passage surface of the gases. The frame bearing the series of metallic curtains is enclosed in a case on three sides. On the fourth side, the bottom, the seal is effected by the waters of condensation and the tar. By raising and lowering this frame in the waters, which have a constant level, the passage surface of the gases is increased or diminished, and correspondingly the depression of the gases is increased or decreased.

"(*g*) The exhauster is of Bourdon's system, exhausting the gases by means of a jet of steam. The force of the same can be regulated by the introduction of a needle in a conical opening. The exhauster is set so that there is neither pressure nor depression in the expansive tank, the first of the condensing apparatus. In this way a slight pressure of gas is maintained in the ovens, excluding the air entirely. The exhauster produces a total depression of .25 to .30 meter (10 to 12 inches) of water, measured before the gas enters it; it leaves the exhauster with a pressure of .08 to .10 meter (3⅛ to 4 inches) of water.

"We have just seen that the gas is drawn through the condensing apparatus by the exhauster, with a depression of .25 to .30 meter (10 to 12 inches) of water, and that the latter forces it back to the special burners, already described, in order to heat the ovens. With the coals of the Company of the Mines of Campagnac, containing 35 to 36 per cent. of volatile matter, it was thought that it would not endanger the perfect operation of the ovens if 4,000 to 5,000 cubic feet of gas were taken for lighting the plant. This gasometer, of 2,119 cubic feet capacity, is placed to the left and back of the ovens. It feeds about 200 burners distributed over the buildings for separating, washing, unloading, etc. The gasometer is filled at the times when the gas production is greatest, that is, after the last charge. To effect this, it is only necessary to shut off the gases from going back to the ovens, at the same time establishing communication with the gasometer. The latter is filled in a few minutes; it is then isolated and the gas from the exhauster goes again to the ovens. The whole operation takes about 7 to 8 minutes, during which time the coke ovens are not disturbed. This gas for illuminating purposes is purified by lime in two ordinary purifiers, after leaving the gasometer. The whole plant is thus well and economically lighted, as this gas costs a trifle.

"The products of condensation, tar and ammoniacal water, as they come from the various condensing apparatuses and the hydraulic main, are all conducted into a series of settling tanks where the difference in density permits an easy separation. The tar is drawn off by a hand pump and put into barrels direct, ready to be sent to market. The ammoniacal waters are taken up by a pump, driven by a steam engine, and lifted to a reservoir, the level of which is higher than any of the apparatus of the plant. From this reservoir these waters go back to the first scrubber to be concentrated.

Manufacture of Sulphate of Ammonia.—"The distilling apparatus for the treatment of ammoniacal waters is a modification of the apparatus of Mallet. About 70½ cubic feet of these waters are treated at a time. This quantity arrives in two sheet-iron receivers, which are placed side by side over a stone pier, in order to be heated at the same time in the same heating chamber. Before heating, a small quantity of lime water is put in each receiver. During this process, which lasts about 4 hours, the mixture is agitated from time to time with agitators for this purpose, and the disengaged gases go over into a third receiver containing 70 cubic feet of ammoniacal waters.

"This third receiver is heated by the return flame of the others and also by the vapors of ammonia introduced into it. These vapors of ammonia, however, disengage themselves as soon as the temperature becomes high enough, and are conducted into lead tanks that contain sulphuric acid, and uniting with the latter yield sulphate of ammonia. During this process the sulphuric acid absorbs also the steam that the vapors of ammonia carry with them. The sulphuric acid of 60° uniting with the water yields the sulphate of ammonia in solution. The solution being evaporated, a white salt, sulphate of ammonia, is obtained with 20 per cent. of nitrogen.

"The crystallization is effected in large tanks of sheet iron, lined with lead, and having a small bottom. These tanks are 13 feet 2 inches long, 5 feet 9 inches wide, and 1 foot 4 inches deep. Two of these permit, with a crystallization surface of 55 square feet, the crystallization of 660 pounds of sulphate of ammonia in 24 hours. In the double bottom of the tank steam is introduced, furnished by the boilers of the ovens. Usually 660 to 770 pounds of sulphuric acid of 60° is used, and a weight about equal to that of sulphate of ammonia is obtained. The work is very easy; a single man can attend to the manufacture of the sulphate of ammonia that 40 to 50 tons of coal will produce. This is the quantity that is coked daily. A boy suffices to put the manufactured tar in barrels. These two can be employed besides this for other work.

"Such are the arrangements of the works of the Company of the Mines of Campagnac.

"The following statements show the cost of this plant, with the expense of making coke and saving the by-products:

Cost of Plant—Nineteen Coke Ovens. France

Construction of nineteen ovens	$13,177.07
Cost of each oven, $693.53	
Cost of condensing plant	10,216.45
Cost of apparatus—tar and ammonia	3,973.67
Cost per oven—apparatus for by-products of tar and ammonia—$746.85, $1,440.38	
Total cost of plant.	$27,367.19

The Work of Ovens in the Year 1883

	Tons
Coal charged into ovens	14,675
Coke produced	11,006¼

Showing product of coke, 75 per cent.

Cost of labor and supplies per ton of coke and its by-products produced, 73⅛ cents.

Note.—The cost of such a plant in the United States would be about as follows:

Ovens, each	$1,000 to	$1,250
Condensing apparatus per oven	700 to	750
Tar and ammonia plant	325 to	350

Making the total cost of each oven, including chemical plant, $2,025 to $2,350, depending on localities. In France the cost would be $1,700 per oven and apparatus.

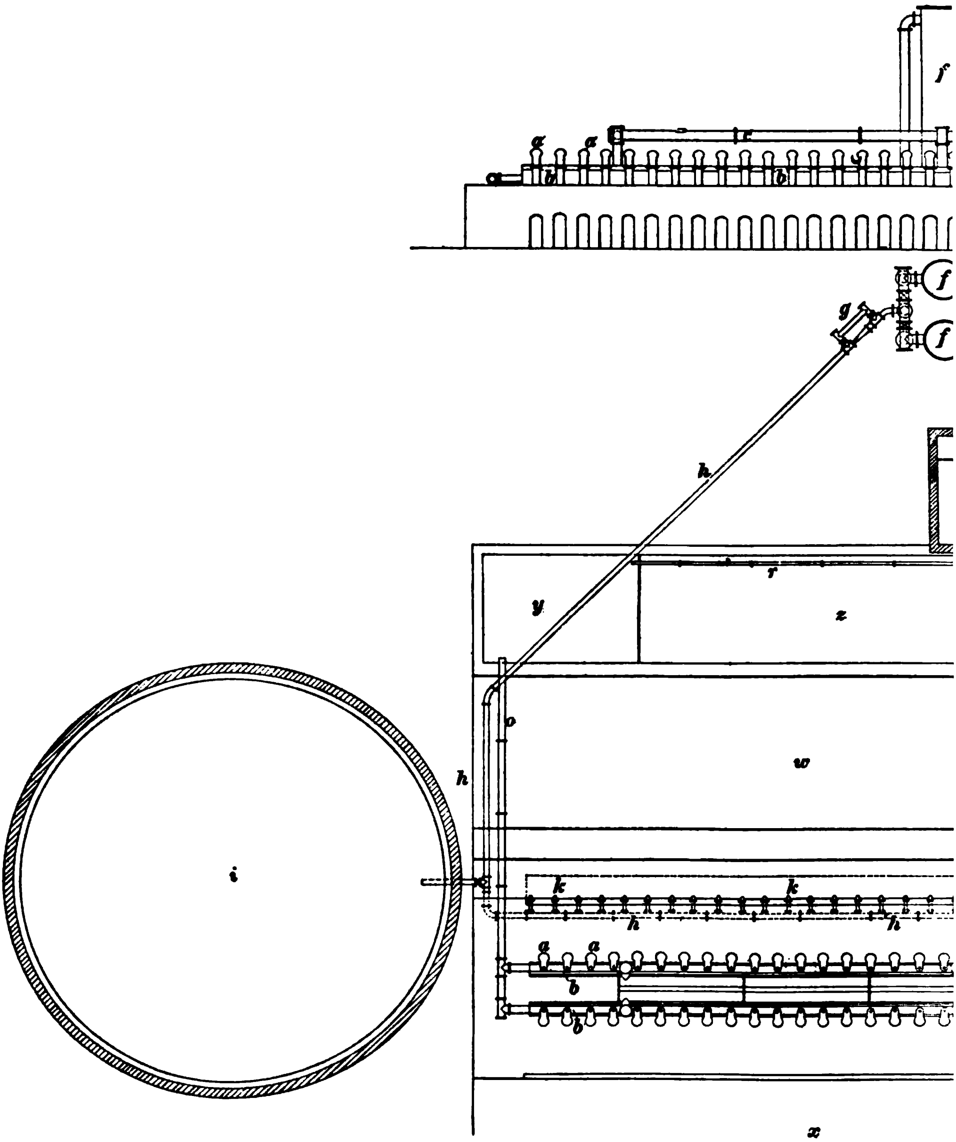
"The question may now be raised, if this mode of carbonization from top down, giving such good results with coals rich in volatile matters, may also be applied to any other coals that will coke. We are convinced that it will be advantageous to coke coal containing the 24 to 25 per cent. of volatile matter. The coals of Campagnac contain 22 per cent. of combined carbon, of which 50 per cent. remains in the coke. It is difficult to estimate beforehand what amount of the combined carbon of a given coal will become disengaged and unite with the coke. As to coals having less than 24 to 25 per cent. of volatile matter and yet capable of coking, the ovens of Campagnac will give excellent results, if used as an ordinary oven, dispensing with the gas-condensing and by-product-saving plant. In fact, they will always be better than the ordinary ovens, as they develop fully the coking qualities of the coal, especially if communication be established on either side, between the retort proper and the top wall flue *a*. This communication should be established as near the outside as possible, at *g*. Each oven will thus have two openings through which the gases of distillation are emptied into the top wall flue, and their coming in contact with air, drawn into the flue by the depression of the chimney, will ignite them. If the doors and charging holes are hermetically sealed with clay, the coking process will proceed exactly in the same manner as if the ovens were heated with purified gas from the condensing plant. As the carbonization goes from the top downwards in a sealed retort that has only two openings for the gas to escape, the dissociation of the gases and deposits of part of their combined carbon with the coke is exactly the same as in the ovens at Campagnac. As it is easy to control the amount of air necessary for combustion, and all the gases of distillation yielded by the charge of coal are forced to pass through all the flues, it is easily understood that in such an oven the maximum temperature is reached which the volatile matter of the coal can furnish.

"We can also arrange a group of mixed ovens for carbonizing coals of 20 to 25 per cent. of volatile matter, and save the by-products of only a number of the ovens. It will thus be seen that these ovens give better results than many other systems, especially when coal fairly well adapted for coking is used. By a most simple arrangement, which does not cause any additional cost in the construction of the ovens, hot air can be introduced into the combustion chambers instead of cold air. We would always recommend this arrangement, when coals not rich in volatile matter are carbonized. The results obtained from hot air have been entirely conclusive."

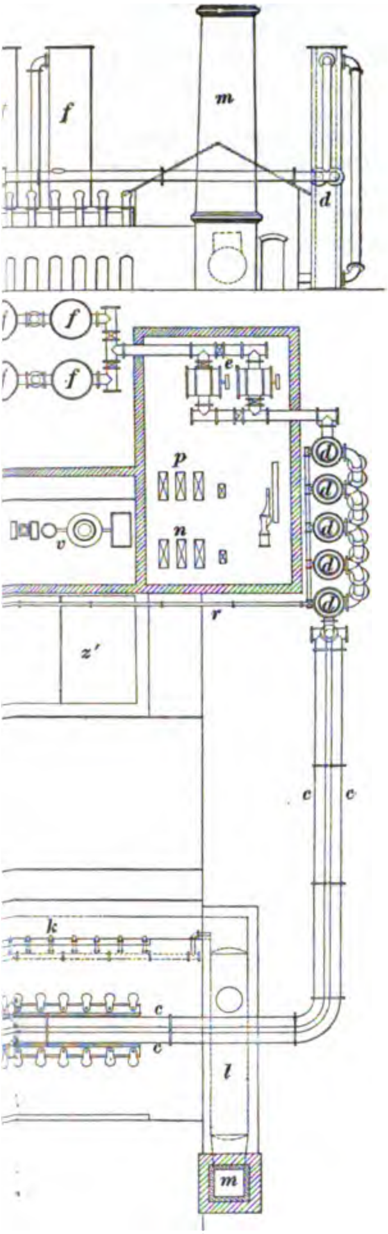
From the preceding statements of the cost and work of this coke oven, it is evident that it is well designed for coking coals inheriting medium volumes of volatile combustible matters, securing a maximum quantity of deposited carbon from the hydrocarbons evolved in coking. As previously noted, it can be used to full advantage in the manufacture of coke without the saving of by-products, as well as in making coke with the saving of tar and ammonia, at the option of the management.

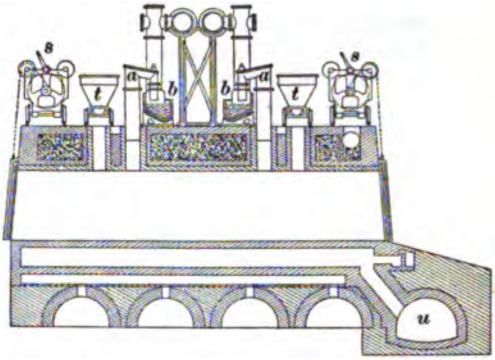
Through the courtesy of Mr. Walter M. Stein, metallurgical engineer, of Primos, Pennsylvania, we present in Fig. 8 a general plan of twenty-four retort coke ovens with saving of by-products, with the following description:

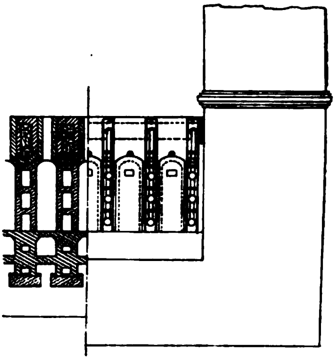
"Each oven has two escape pipes *a* by means of which the gases reach the hydraulic main *b* and are then drawn by a Beale exhauster through the pipe line *c* into the five condensers *d*, consisting of concentric cylinders. The Beale exhausters are provided in duplicate to prevent any stoppage of the plant; each one, however, is sufficient to exhaust the entire gas of the twenty-four ovens. From the Beale exhauster, the gas is forced through the scrubbers *f*. Two of these are ordinarily used and two are reserve scrubbers. After the scrubbers follows the steam exhauster *g*. The pipe line *h* conveys the gas back to the ovens to heat the same. A branch connection is used to fill the gas holder *i*, which has a capacity of 52,000 cubic feet; this gas can be used for heating or illuminating purposes. The small branch pipes *k* of the pipe line *h* take the gas into the horizontal wall flues of the ovens, the gas being admitted either into the top flue only or into all of the three wall flues. The boiler *l* is heated with the waste gases, while the surplus gas may also be used for this purpose. *m* is the chimney; *n*, three steam pumps; *p*, three reserve pumps; *o*, the pipe line to take the products of condensation to the reservoirs from the hydraulic main; *r*, the pipe line from the condensers to the reservoir; *s*, the windlass for raising the door of the ovens; *t*, *t*, the charging larries; *u*, the main gas flue; and *v* the ammonia machine for making sulphate of ammonia. If the gas is used for illuminating purposes, a purifier is inserted before the gas holder. *x* is the coke-discharge side of the ovens; *w*, the machine side where pusher works; *y* is the reservoir for tar, and *z* the reservoir for strong water of ammonia; while *z'* is the reservoir for weak water of ammonia."



17303—vi FIG. 8. GENERAL PLAN OF TWENTY-FOUR RETORT COKE OVENS, WITH SAVING OF BY-PRODU







CTS. **Seibel's System. Walter M. Stein, Metallurgical Engineer, Primos, Pennsylvania**

Otto-Hoffman Retort Coke Oven.—In the manufacture of coke for metallurgical uses the main effort is usually directed to the production of hard-bodied coke, with a full developed cellular structure. It adds materially to the value of such coke, both as regards purity and calorific vigor in the blast furnace, to cause as large a deposit of carbon, from the volatile hydrocarbon gases evolved in coking, as is possible from the quality of the coal used in making the coke; hence, in all retort coke ovens, two special requirements are demanded, the saving of the fixed carbon of the coal in coking and the securing of a deposit of carbon from the evolved gases.

In addition to these points, during the past decade much attention has been given in Germany, France, and England to saving the by-products of tar and sulphate of ammonia, which are carried out in the gases during the process of coking the coal.

The initial efforts in this direction were greatly retarded by prejudices against the quality of the coke produced. It is quite probable that these had some foundation, as the early retort coke ovens were incomplete in their operations and their product of coke somewhat below the standard requirements. Besides, gas-house coke was looked upon as a retort coke and considered inferior, as it was in fact, for metallurgical uses, as compared with the carbon-glazed coke from the beehive ovens.

The recent improvements in retort coke ovens have nearly, if not quite, removed some of these objections, and retort-oven coke is now afforded an unprejudiced test on its merits.

In the European countries, with agricultural conditions requiring concentrated manures, the by-product of sulphate of ammonia has become a valuable adjunct in the manufacture of coke, with the assurance of a home market for all that can be produced.

In the United States of America the conditions requiring the use of concentrated manures are somewhat different, as there is still a large proportion of virgin soil that requires little manure; yet in many sections of the country the sulphate of ammonia could be used to advantage by the agriculturists. Just how far the American coke manufacturers desire to invest in by-product appliances to their coke-oven plants, is a business inquiry demanding earnest and exhaustive consideration. In the presence of a gradually approaching time when the use of the secondary qualities of coking coals becomes necessary, it is evident that the retort coke ovens will come into more general use, in the manufacture of coke for blast-furnace and kindred uses. Many of these ovens can be used either with or without the auxiliary appliances for saving by-products.

We are further indebted to Dr. C. Otto and Company, of Dahlhausen on the Ruhr, for developing the Otto-Hoffman retort coke oven, which has in a great measure removed the prejudices against retort coke previously noted.

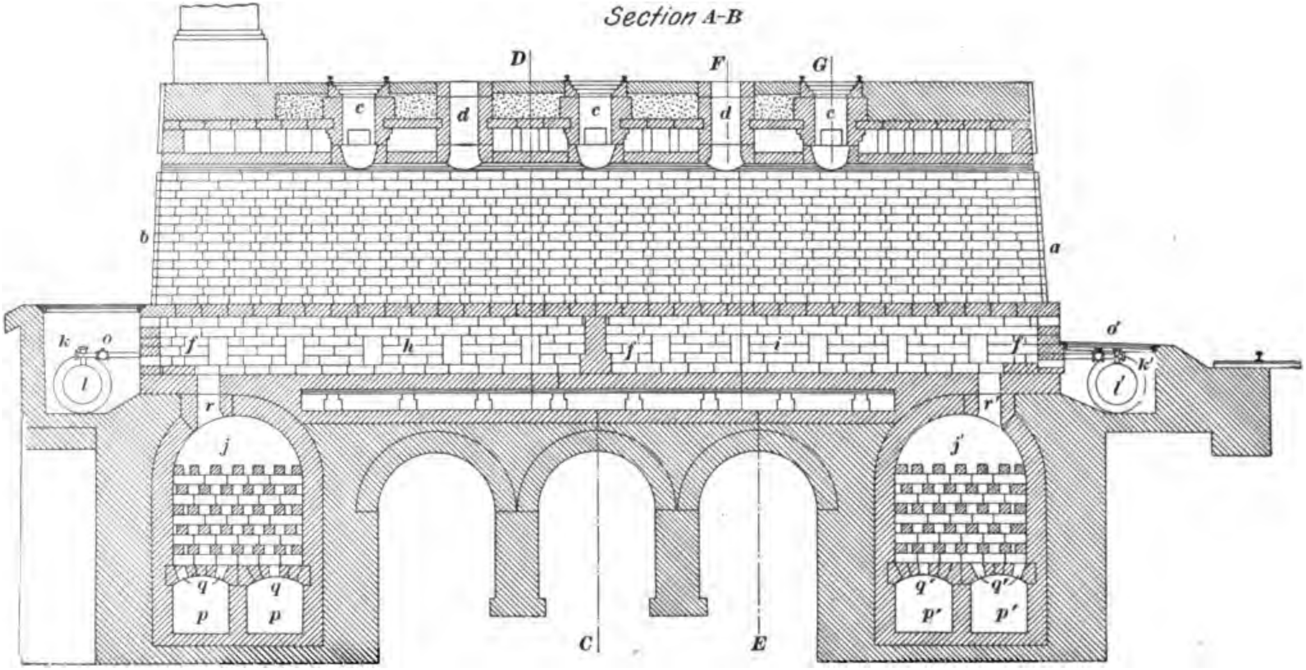


Fig. 9. Longitudinal Section of an Otto-Hoffman Coke Oven Along Line A-B, Fig. 10

The following description of this oven is taken mainly from the paper of B. Leistikow, general director of the Wilhelmshuette.*

The coking chambers of the Otto-Hoffman ovens are narrow chambers, 16 to 24 inches wide, 33 feet long, and 5 feet 3 inches high to the base of the arch, and are closed at both ends by air-tight doors.

The construction of these ovens is based on a combination of the Siemens regenerator according to Hoffman, with the ordinary Otto oven as a model, to which a large number of improvements have been made.

Fig. 9 exhibits a longitudinal section of an Otto-Hoffman coke oven. The pushing engine is on the side *a*; the coke is discharged on the side *b*, where it is cooled.

There is no direct connection between the coking chamber and the side flues. In the covering arch there are three openings *c*, which are ports for charging coal into the ovens, and two openings *d* through which the gases evolved in coking pass off.

Under the base of the arch, in the side walls, there are horizontal flues *e*, Fig. 10, that connect the entire vertical draft system.

The base flues *f* running lengthwise of the oven between the side walls *g*, are divided into two equal parts *h* and *i*. These halves are connected with regenerators *j*, *j'*, used for preheating the air necessary for the combustion of the gases. To each half of these base flues, tuyère pipes *k* and *k'* are connected, which are fed through the gas-supply pipes *l* and *l'*.

The regenerators are long, latticed, brick flues, running across the whole coking chambers. They are connected at one end, by means of a reversing valve, either with the air-distributing pipe *m* of the condensation plant in Fig. 11, or back with the chimney.

As soon as the oven is heated and the coking process in operation, the gases evolved escape through the openings *d*, *d* into the supply pipe, similar to the retorts in gas plants, and thence through the opened valve into the gas receiver, from which they pass to the condensation plant. From the latter, the gases, freed from their by-products—tar, ammonia, and benzol—are returned to be burned around the ovens. On the way to the latter, is a reversing valve, that leads the gas at will into the supply pipe *l* or *l'*.

When the gas enters through the pipe *l* and passes through the tuyère *k* by means of the cock *o*, into the half *h* of the base canal, the valve is so set that blast enters the flue *p* and thence through the small openings *q* into the regenerator *j* and is heated there, passing upwards through the small openings *r* into the base flue *h*, where combustion takes place. The heated products of combustion pass through the side vertical flues, then to the horizontal flues *e* and quickly downwards through the other vertical

---

*Address delivered on September 5, 1892, at the fifth general meeting of the German Mining Engineers.

half to the base flue *i*, thence through the opening *r'* into the regenerator *j'*, heating it and passing through the small openings *q'* into

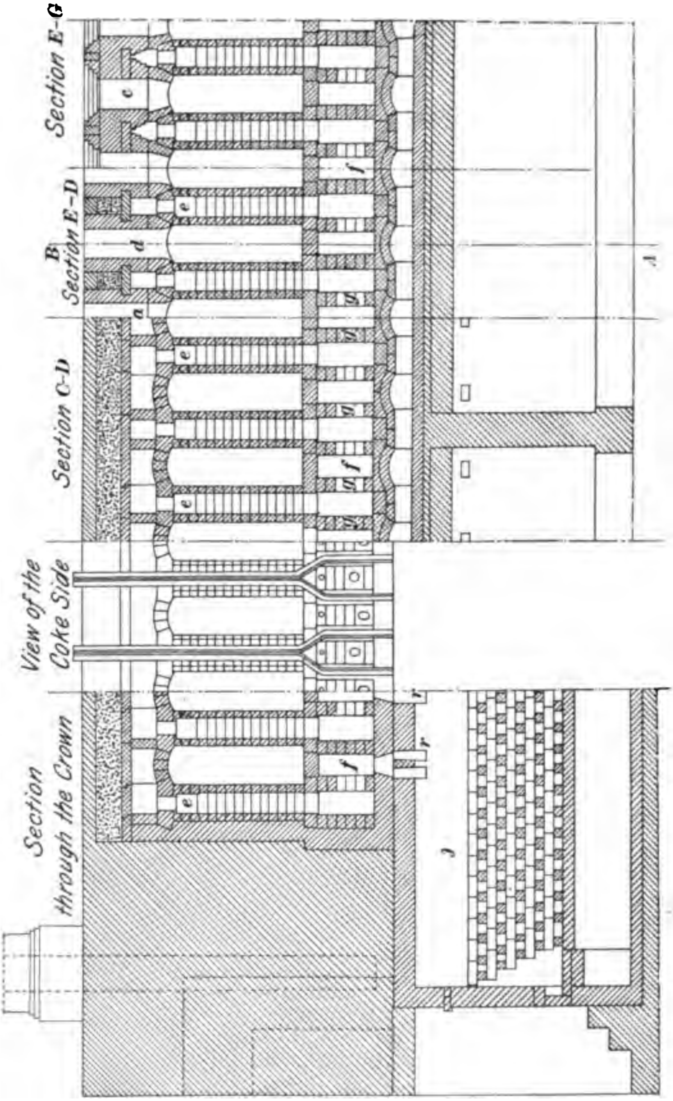


FIG. 10. TRANSVERSE SECTIONS OF AN OTTO-HOFFMAN COKE OVEN

the flues *p p'*, and thence through the air valves to the chimney. The valve is reversed after a certain time, and the gas takes exactly the opposite direction.

In the earlier work of this oven, it was thought necessary to preheat the gas as well as the air; for this purpose a second regenerator was arranged on each side of the oven; this, however, was

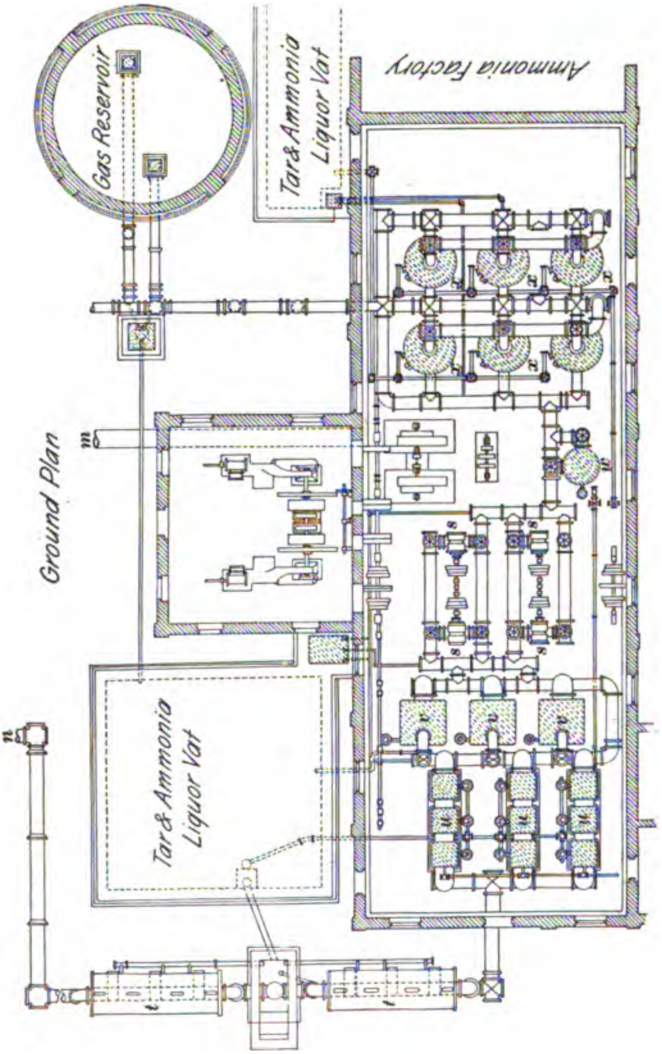


Fig. 11. Condensation Plant at the Julienhuette

discontinued, as it was found to be better to heat the necessary air, amounting probably to ten times the volume of the gas, to a high temperature, than to heat the comparatively small volume of gas, thereby running the risk of explosions. In all later plants, there is arranged on each side of the ovens, only one regenerator, as shown in the accompanying drawings, by which change this oven has been much simplified without impairing its utility.

The air is first preheated in these regenerators to about 1,000° centigrade, thereby reducing the amount of gas necessary to heat the ovens, leaving the excess for other purposes.

The gases evolved from the ovens pass through the valve into the receiver and are aspirated into the condenser by the aspirator *s*, Fig. 11; on its way to the condenser the gas passes into an apparatus *t* wherein it is cooled and separated from particles of coal dust and a great deal of the tar.

The gases now pass into the condenser *u*, consisting of a vertical, four-cornered, wrought-iron box, supplied at the top and bottom with false floors, on which are arranged a large number of wrought-iron tubes, through which cold water flows. The gases travel around the tubes in opposite directions, while the products of condensation, tar and ammonia, continually run off below. The water of the coal passes off as steam, absorbing about 50 per cent. of the ammonia.

After the gases have passed the cooler, they arrive at the purifier *v*, which is quadrangular, and the gas divides itself into a number of tubes that are immersed in water. In the purifier the gas is first washed with pure water and then with weak ammonia water, and the remainder of the tar is separated. The apparatus is so constructed that the water flows in from above and out below continuously. This water, together with the condensed products of the air and water coolers, passes into a large vat, where the tar separates by virtue of its specific gravity.

The same aspirator can be used for forcing out the last particles of gas, which becoming heated several degrees by the sudden compression must be passed through another cooler *w* to be reduced to a minimum temperature 13° to 18° centigrade.

After leaving cooler *w*, the gas streams below into the bell washer *x*, where it is distributed among a number of bells, which have a toothed diaphragm extending under the water, whereby it receives a thorough scrubbing. The washer contains four to six shelves, one under another, and the water flows from above downwards, the gas takes the opposite direction and always is driven against the fresh stream of descending water, whereby it is completely separated from the least traces of tar and ammonia.

The purified gas may now be conducted to the ovens for combustion, unless it is desired to separate further products, notably benzol, which is done in some works, the process, however, being secret.

The gas, before being forced into the pipes *l* and *l'*, Fig. 9, is led through a small reservoir, which acts as a pressure regulator, and indicates to the inspector whether the pressure is constant, which is necessary to insure constant temperature in the ovens.

The temperature was found to be as follows:

	Degrees Centigrade
In the hearth flue	1,200 to 1,400
In the side walls	1,100 to 1,200
In the regenerators at the beginning of the air supply	1,000
In the regenerators at their ends	720
In the chimney	420

The tar that separates at the bottom of the vat by reason of its weight is conveyed by a wall pump operating a spiral conveyer to the high receiver *y*, Fig. 12, from which it may be run directly into cars and taken to the refineries.

The ammonia water, which has collected in the vats, is pumped to the receiver *z*, Fig. 13, from whence it is piped to the distilling room of the ammonia factory. In this latter are two Colonnen apparatuses *a*, *a'*, of the Grueneberg-Blum system (in other works they use Doctor Feldmann's apparatus with equally good results), each capable of working 30,000 liters, in which the water passes downwards from column to column, coming in contact with a current of dry steam which takes out the ammonia and carries it with it. The ammonia is set free from its compounds by milk of lime in the space above the cascade column, which is pumped into the apparatus from the lime reservoir *b'*.

The steam, saturated with ammonia, is led into sulphuric acid in the lead-lined chambers *c'* where it is converted to ammonium sulphate, or into the condenser *d'* where it is taken out as ammonia water. When the chamber acid is neutralized, the liquor is drawn off and the salt removed to the dropping board *z*, from whence, when the lye has entirely drained, it will be transferred to the lead-lined salt chambers. On the other hand, if the ammonia water is simply condensed in the cooler *d'*, it runs into the receiver *e'* (holding about 10 tons), whence it may be piped into tank cars for transportation.

The sulphuric acid may be stored in the receiver *f*, to be run off by means of air pumps or siphons as needed, into the boxes *c'*. The waste water that runs off from the apparatus *a'* is led into vats, where the lime settles out.

The plan and sections in Figs. 12 and 13 exhibit a view of Plant 3 of the Julienhuette, at Buethen, in East Silesia.

The cost of this oven and the distillation apparatus in Germany is as follows:

The cost of oven	$1,168.75
By-products apparatus, per oven	1,636.25
Total	$2,805.00

The cost would be largely increased in the United States, especially as the apparatus for the saving of the by-products is erected in duplicate. This duplicate apparatus affords the opportunity of cleaning and repairing the several parts of these appliances without interruption to the continuous work of the ovens. It adds to the expense in the construction of the plant, but is found to be an element of economy in the working of these retort ovens.

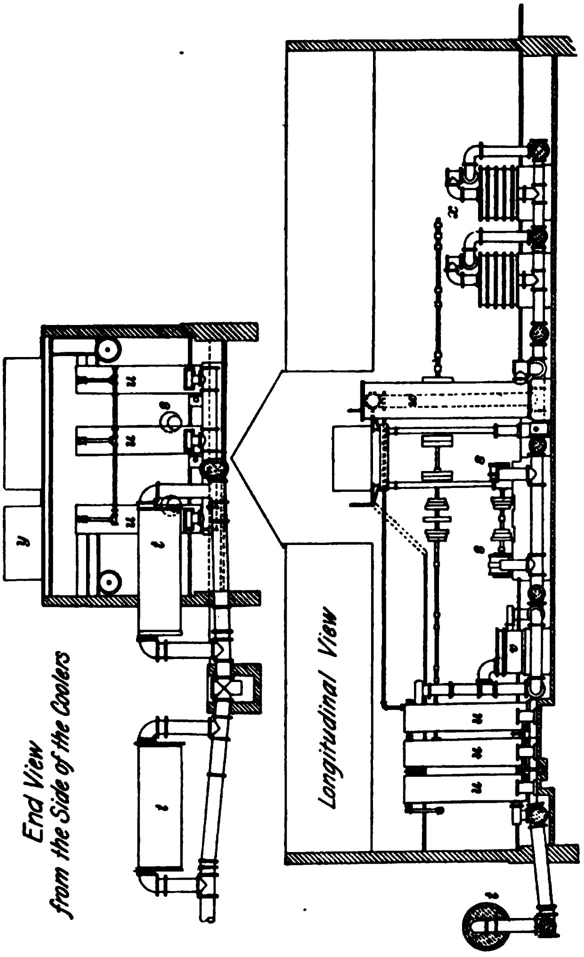


Fig. 12. Condensation Plant at the Julienhuette

The Otto-Hoffman oven is usually constructed in sections of sixty ovens each. A duplicate apparatus for condensing and exhausting will serve for two sections of ovens.

The cost of these ovens in the United States has been estimated at $3,300 each. This includes the necessary apparatus for the saving of the by-products of tar and ammonia sulphate, but does not cover the patent charge for using this oven.

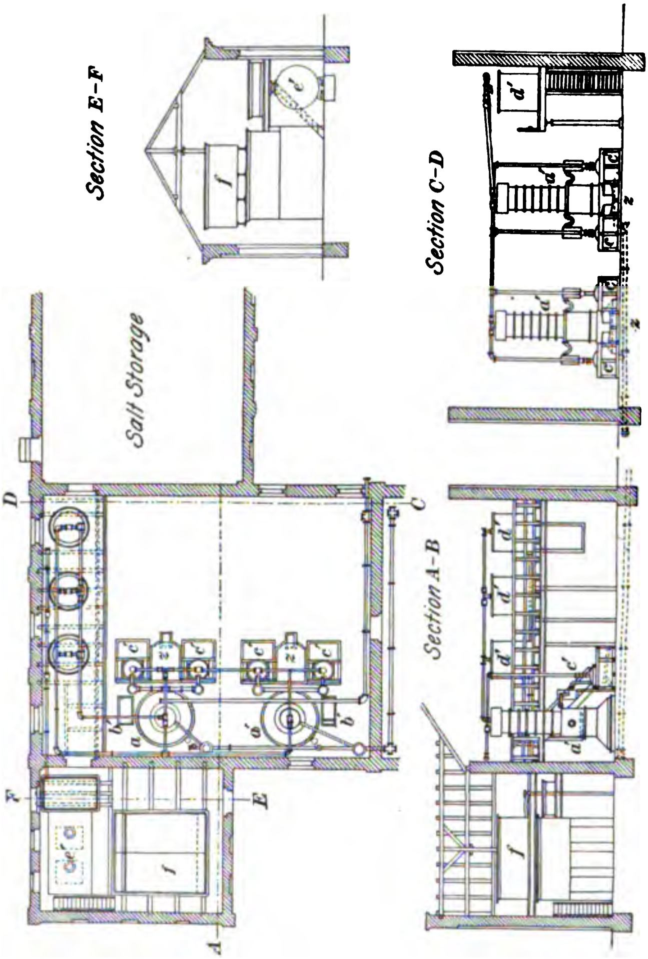


Fig. 13. Ammonia Factory at the Coke-Oven Plant of the Julienhuette

In the estimates of the value of the by-products secured, per ton of coke made, very large claims have been submitted. With the use of good coking coal, the net profits have been estimated as high as $1.52 per net ton of coke produced. It may be pointed out that this estimate includes the value of 40 per cent. of surplus gas for heating purposes, which is calculated at 14 cents per ton of coke. It is evident that such an estimate is misleading, when it is considered that tar is now worth at the coke ovens $5 per ton, and ammonia sulphate $55 to $60 per ton in the market.

An average product of about 1 per cent, of ammonia sulphate and 3 per cent. of tar can be secured from the carbonization of coal to make 100 tons of coke. Under present conditions the value of these at the coke works is $50 and $15, making in all $65, less the cost of manufacturing the sulphate of ammonia, $34 per ton, leaving as the maximum net profit per 100 tons of coke made, $36; or 36 cents per ton.

The value per ton of coke of surplus gas from the ovens will be somewhat different, depending on the value of coal in the locality of the coke ovens. An average of 5 cents per ton would be a safe estimate. This, added to the value of the by-products of tar and ammonia sulphate, affords a net saving of about 41 cents per ton of coke produced.

A reference to the table on page 398, Chapter X, will afford full details.

Dr. F. Schniewind, of New York City, who represents this oven in the United States, writes:

"As to the life of the plant, the construction of the ovens in all details is most substantial, reducing repairs to a minimum. At Hoerde, Westphalia, there is a plant making coke without saving by-products, that has been running the past 13 years and requiring very moderate repairs. The coking coal used in Germany is very different in quality from the American standard, the Connellsville coal. It is, as regards coking qualities, poorer throughout.

"In Westphalia, in the Ruhr basin, the most important coal and coke district in Germany, the coal varies in its character in a similar way as in the Appalachian field; the coal becoming more bituminous in a gradual increase from the east to the west. This gives a variety of qualities of coal for coking, depending on the locality of the coal supply. The yield of coke varies from 70 to 85 per cent. of coal charged into ovens.

"The following may be considered an average analysis of Westphalian coking coal washed:

	Per Cent.
Volatile matter	23.00
Fixed carbon	67.70
Ash	8.00
Sulphur	1.30

"The theoretic yield of coke would be about 76.48 per cent. The washed coal is charged into the ovens in a very moist condition, holding about 12 per cent. of water. The coke, though it cannot be compared as to luster with the Connellsville coke, is an excellent blast-furnace fuel, which stands a heavy burden in the furnace.

"The fuel results of the German blast furnace are very good indeed if the poor quality of the coke-making coals is considered.

"In Silesia, the coking coal is of very poor quality. In some instances, extraordinary measures have to be resorted to in order to produce coke; the coal has to be disintegrated finely and then while moist stamped by hand into large sheet-iron casks and charged into the ovens. It is only in this way, and by the use of the Otto-Hoffman ovens at a very high temperature, that a coke suitable for blast-furnace use can be made.

"In the Saar district the coal is also very poor."

Test of the Connellsville Coal in the Otto-Hoffman Ovens.—In order to investigate the results that might be expected from these ovens when running on Connellsville coal, I went over to Europe early in the summer of 1893, in the company of a competent American blast-furnace engineer, who was sent by some capitalists who had become interested in this matter.

We had sent to Europe about 18 tons of Connellsville coal, with which, after some preliminary tests, we charged whole ovens. The coke made was of most excellent quality, very hard, with metallic ring and silvery luster.

Some of this coke was placed on exhibition in the mining exposition at Gelsenkirchen, where it caused general admiration, as not a single brand of Westphalian coke could compare with it.

The Connellsville coal was composed as follows:

	PER CENT.
Moisture	1.59
Volatile matter	29.18
Fixed carbon	58.84
Ash	9.40
Sulphur	.99
Total	100.00

The theoretic yield of coke from the above coal is about 68.84 per cent.; in the Otto-Hoffman ovens the products were:

	PER CENT.
Large coke	71.1
Small coke	1.2
Breeze	1.3
Total	73.6

This result shows, assuming that no fixed carbon has been burned in coking, a deposit of 4.76 per cent. of carbon from the hydrocarbons in coking. The result is evidently correct, as the rich coking coals of Connellsville or West Virginia secure carbon deposits in the coke oven.

The time occupied in coking Connellsville coal in the Otto-Hoffman oven was from 28 to 32 hours.

As to the yield of by-products, the Connellsville proved to be equal to the richest German coals, as will be seen from the following figures based upon dry coal:

Locality	Coke and Breeze Per Cent.	Tar Per Cent.	Sulphate of Ammonia Per Cent.	Cubic Feet Gas, Per Net Ton of Coal
Connellsville coal..	73.6	4.0	1.07	9,321
Westphalian coal..	76.0	3.0	1.15	8,744
Silesian coal.......	67.0	4.2	1.12	10,057

In regard to benzol, the yield from Connellsville coal will be found richer than that from German coals, which yield from .3 to .7 per cent. from dry coal. It is difficult, however, to make any accurate statement, as analytical research is insufficient. The quality of the by-products obtained from Connellsville coal was excellent.

The excess of gas, about 40 per cent. of the total production, is of great value for illuminating and heating purposes. As a source of light, it has only about one-half the illuminating power of best illuminating gas, if used with ordinary burners; but if used with the modern incandescent burners, its light equals in brilliancy the electric incandescent lamp. The fuel value may be judged from the following comparative table:

TABLE OF ANALYSES OF DIFFERENT GASES

Percentage by Volume	Gas From Otto-Hoffman Ovens 1	Coal Gas, Average American 2	Coal Gas, Cologne, Germany 3	Natural Gas 4	Water Gas 5	Producer Gas		Gas From Improved Bee-hive Ovens 8
						Anthracite 6	Bituminous 7	
Hydrogen......	53.32	46.0	55.00	2.18	45.0	12.0	12.0	2.3
Methylene......	36.11	40.0	36.00	92.60	2.4	1.2	2.5	13.7
Ethylene.......	1.63	4.0	1.19	.31			.4	.9
Benzol..........	.61	?	1.54					
Carbon monoxide	6.49	6.0	5.40	.50	45.0	27.0	27.0	2.6
Carbon dioxide..	1.41	.5	.87	.26	4.0	2.5	2.5	9.8
Sulph. hydrogen	.43	?	?					
Nitrogen........		1.5		3.61	2.0	57.0	56.2	70.0
Oxygen.........		.5		.34	.5	.3	.3	.7
Vapor.........		1.5			1.5			
	100.00	100.0	100.00	99.80	100.4	100.0	100.9	100.0

Analyses 1 and 3, by Doctor Knublanch; 2, 4, 5, 6, 7, by W. J. Taylor, A. I. M. E., Vol. XVIII, page 881; No. 8, by the agents of the English or Smith oven.

The comparison, especially of the percentage of nitrogen, will show the efficiency of the Otto-Hoffman oven.

At most plants the surplus gas is used for generating steam in boilers, together with the off heat from the regenerators. The

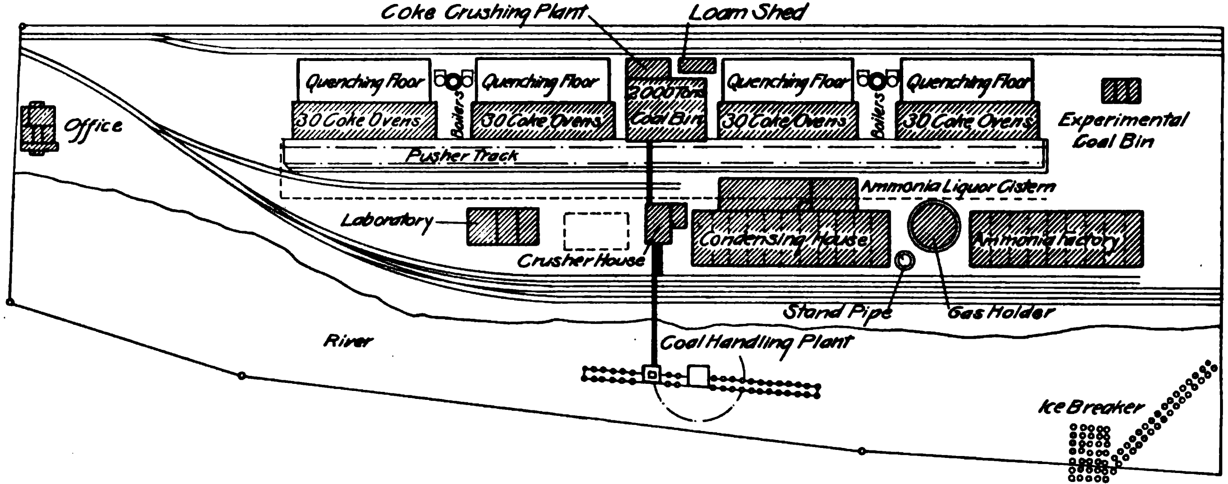


FIG. 14. GENERAL PLAN OF THE COKE-OVEN PLANT AT OTTO STATION, PENNSYLVANIA

steam produced is .9 pound of four to five atmospheres pressure for each pound of dry coal coked in the ovens. This is the average result of 48 hours run (if the time of coking is reduced, the evaporation of water increases) and after all the by-products, including benzol, have been recovered.

Tar has found two principal uses in addition to its former applications. The manufacture of tar paper utilizes a fair proportion of this product; the coming briquet industry will in the future greatly enlarge the demand for tar.

The market for the by-products of tar and the sulphate of ammonia is reported as fairly good, with an upward tendency.

FIG. 15. OTTO-HOFFMAN BY-PRODUCT PLANT, OTTO STATION, PENNSYLVANIA

The demand for tar has been increased by the change in the methods of making illuminating gas at the gasworks.

It is submitted that Philadelphia, Cleveland, and Chicago afford a good market for these by-products.

OTTO-HOFFMAN COKE OVENS AND BY-PRODUCT APPARATUS OF THE PITTSBURG GAS AND COKE COMPANY*

This plant is shown in plan in Fig. 14 and a photograph of it in Fig. 15. The ovens, built in four sets of thirty each, are arranged symmetrically on two sides of the coal-storage building. The two portions of the coking plant being duplicates, only one of them will be described. Between the two sets of ovens constituting one-half of the plant is a 25-foot

---

*W L. Affelder in Mines and Minerals, February, 1899.

space containing four Cahall vertical boilers of 100-horsepower capacity each, while in the similar space in the other half of the plant there is one 200-horsepower Babcock & Wilcox boiler. Their combined capacity is 450 horsepower, and they furnish all the steam power needed at the plant. Each oven is 33 feet long, 6 feet high, and 22 inches wide, with 12-inch walls. The ovens are built of sandstone and are lined with firebrick. Through the arched roof there are five circular openings, three being for the introduction of coal, and the other two for the egress of the volatile materials. The ends are covered with cast-iron doors that are raised or lowered by means of a portable windlass on the top of the oven. Directly below the oven floor extends a narrow, brick-lined flue crossed midway between the ends by a transverse partition. This flue communicates with the vertical flues in the side walls, which are joined at the top of each wall by a narrow, horizontal flue. Beneath the ends of the ovens and extending along the entire set are Siemens' regenerators.

Each oven is charged through the openings in the top with 7 tons of coal, crushed to ½ inch and less. A stream of gas that has been recovered as a by-product from coal that has been previously coked is introduced at one end of the flue that extends beneath the floor of the oven through a 2-inch pipe. Here it meets air that, by passing through the heated regenerator, has a temperature of about 2,000° F. The influx of air is accelerated by a fan situated in the space between the two sets of ovens. The hot air and burning gas pass through the horizontal flue and up the vertical flues of the front half of the oven into the horizontal flue near the top of each wall. They then pass down the other vertical flues and out through the bottom horizontal flue of the rear half of the oven into the second regenerator. After passing through the second regenerator the gases are still very hot, and a portion of their heat is utilized in the boilers before they are allowed to pass up the chimney. The heat imparted to the coal by the highly heated floors and walls drives from it all the volatile matter, and at the end of from 24 to 36 hours, the time depending principally on the nature of the coal, a mass of red-hot coke, weighing from 75 per cent. to 78 per cent. of the weight of the coal charged, is removed from the oven by means of a steam ram.

Recovery of the By-Products.—Although many of the German plants recover tar, gas, ammonia, and benzol, no attempt is made at this plant to separate the latter from the tar.

Extending along the top of each set of ovens and sloping at a small angle toward the space between the two sets of ovens are two 24-inch cast-iron pipes, called tar pipes, into which the volatile matter passes through double-elbowed pipes extending from two openings in the top of each oven. The elbows are intended to catch the greater portion of the soot, thereby preventing its being collected with the tar. A third pipe, 18 inches in diameter, between and above the other two, communicates with both of them near their ends in order to equalize the pressure, which would otherwise differ greatly because of the suction applied at their lower ends to accelerate the flow of their contents. The several tar pipes unite to form one 36-inch main, which discharges its contents into a bottomless tank, with its lower part immersed in tar. Almost all the tar separates, by virtue of its specific gravity, from the gases with which it is mixed, and flows in a slow, but steady, stream into a brick-walled cistern 100 by 20 feet, while the gases pass into the condensing house directly beyond this cistern.

The gases pass up through three tall, cylindrical, sheet-iron washing tanks, in which sprays of cold water wash out most of the tar still present, together with a considerable portion of the ammonia. The gases are then led through several cooling tanks, which are nearly filled with pipes containing circulating water. Three small washers, or scrubbers, are next employed to remove the last traces of tar and almost all the remaining ammonia. The gases, which now consist of the ordinary coal gas, with a very small percentage of ammonia, are run through compressors in order that the pressure will meet the requirements of Wood's mill, in McKeesport, to which the gas is piped. After having been compressed, the gases are again cooled and washed, this final washing taking out the remaining traces of ammonia. Besides being used in McKeesport, the gas is used at the coking plant both for heating the ovens and for illuminating purposes.

The tar is pumped from the cistern into a large storage tank, from which it is run into tank cars and shipped to refineries. Since all the water employed in washing the gases is run into the tar cistern, the ammoniacal liquor must be pumped continually from above the tar into a storage tank, in order to prevent its being carried away with the tar. From the ammonia tank, the liquor flows through pipes to the ammonia house, which adjoins the gas-washing plant. It is introduced at the top of two cylindrical, cast-iron tanks, together with lime water, while a jet of steam is admitted at the bottom. The heat supplied by the steam accelerates the liberation of ammonia gas, caused by the lime uniting with the acid radical of the various ammonia salts present. The excess of steam carries off the ammonia as NH_4OH, through a pipe at the top of each tank. The ammonia then passes into vats containing hot sulphuric acid, in which the following reaction takes place:

$$2NH_4OH + H_2SO_4 = (NH_4)_2SO_4 + H_2O$$

When the solution becomes saturated with ammonium sulphate, the latter settles to the bottom of the vats and is removed by means of perforated ladles, and is dried in a centrifugal dryer. A small portion of the ammonia is sold as aqua ammonia, instead of converting it into the sulphate.

Not only does the company obtain a greater yield of good coke than is obtainable from the same coal when used in beehive ovens, but it also obtains a large quantity of valuable by-products. According to the statement of the superintendent of the plant, the yield of coke varies from 75 per cent. to 78 per cent.; of tar, 5 per cent. to 6 per cent.; of ammonium sulphate, 1.25 per cent. to 1.45 per cent.; and the amount of gas is 10,000 cubic feet per ton of coal. He also stated that a number of the consumers of the coke made at the plant preferred it to that made in the Connellsville region. The fact that the coke finds a market as far west as Kansas City, Missouri, speaks well for its quality. That the by-products are of superior quality is shown by the large and ready market for them.

A few words might well be said in this connection by way of comparing the relative merits of the Otto-Hoffman and the beehive oven as coke producers. It has been shown by actual experiment that the yield from Connellsville coal in an Otto-Hoffman oven was 73.6 per cent., while the theoretic yield was only 68.84 per cent. The United States Geological Survey reports show the actual yield from the beehive ovens in the Connellsville region to have been but 66.84 per cent. in the years 1880 to 1896, inclusive. Even at the lower limit claimed by the superintendent, the company is obtaining from its ovens an amount of coke exceeding the amount that it could obtain from beehive ovens by more than 8 per cent. of the weight of the coal charged.

Eight men in two shifts of 12 hours each are employed. The total coal consumption is between 600 and 700 tons per day.

I am indebted to Mr. Wm. L. Elkins, Jr., President of the United Coke and Gas Company, and to Mr. W. P. Parsons, Superintendent of the Pittsburg Gas and Coke Company, through whose courtesy I was enabled to make a careful study of the plant.

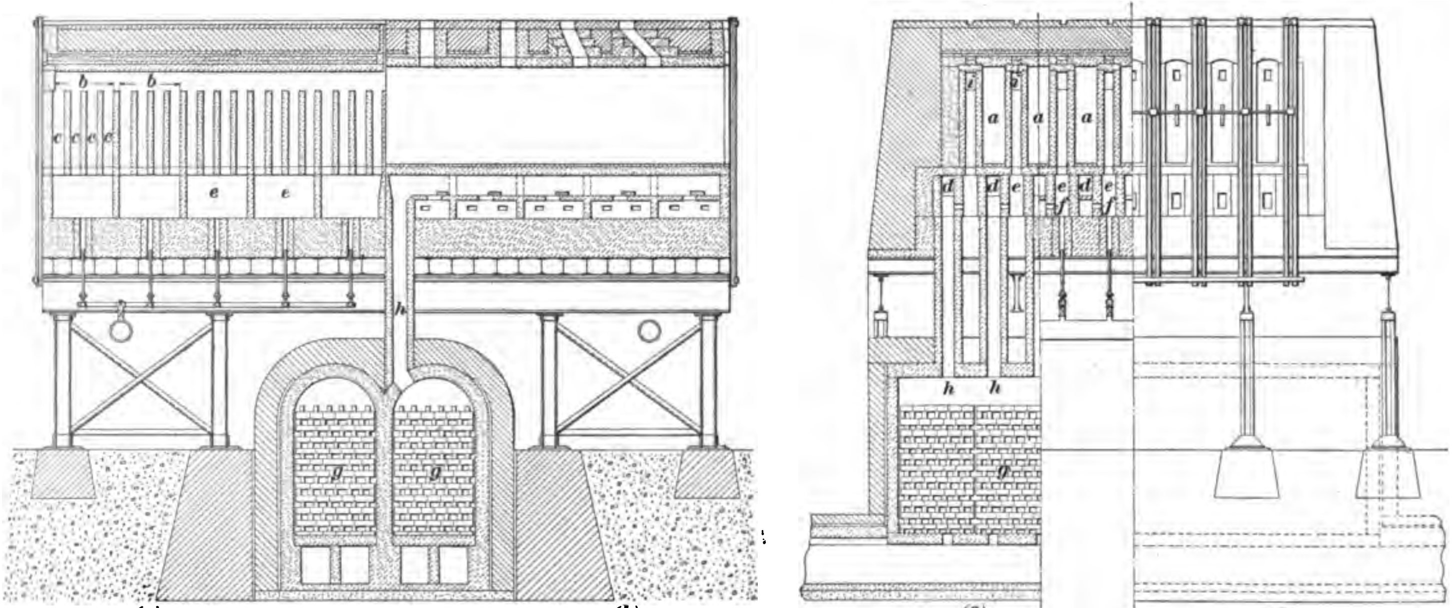
SCHNIEWIND OVEN

Description of a Plant of 100 Coke Ovens.*—In order to adapt the Otto-Hoffman process, as practiced in Germany, to the new requirements, it has had to undergo many changes. I will describe a plant consisting of one hundred by-product coke ovens of the latest type of the United Coke and Gas Company. (See Fig. 16.)

Ovens.—The ovens are arranged in two groups of batteries of fifty ovens each. Each oven *a* is an air-tight retort, consisting of a rectangular chamber 43 feet 6 inches long, 17 inches wide, and 6 feet 6 inches high. The ovens are placed side by side, and are supported on a steel structure, consisting of light I beams, running the length of the battery, that rest on cross-girders supported by steel columns. (United States patents Nos. 627,595, 644,368,

---

*Article by Dr. F. Schniewind.



(a) Cross-Section Through Flues

(b) Cross-Section Through Oven

(c) Longitudinal Section

(d) Elevation

FIG. 16. DIAGRAM SHOWING SCHNIEWIND TYPE OF OVEN

644,369, 668,225, 673,928. British patents Nos. 13,325, 1899; 3,335, 1900; 10,589, 1900; 993, 1901. Further patents pending.)

The construction allows the brickwork to be inspected at all points. The primary object, however, is the uniform distribution of fuel gas to the combustion chambers for heating the oven retorts. The retorts are separated by hollow walls that are divided into ten compartments *b*, each compartment containing four, preferably vertical, flues *c*. An air chamber *d* is located directly under the retort. Alongside this chamber and directly under the vertical flues above referred to are ten combustion chambers *e*. The gas supply to each of the chambers is controlled independently, and a uniform heat is maintained throughout the entire length of the oven. The air for combustion is admitted through openings *f* in the wall between the air and the combustion chambers. The air is heated to 1,800° F. by a pair of regenerators *g* placed together under the center of the battery and running its entire length. A vertical flue *h* conducts the air from the regenerator to the air chamber *d* under the oven.

The well-known Siemens principle is used in operating the air regenerators, with reversals every 30 minutes. The fuel gas is reversed at the same time as the air by means of a suitable valve; but the gas is not regenerated. The gas unites with the hot air in five combustion chambers *e*, ascends through the vertical flues *c* to a horizontal flue *i* above, through which it passes and descends through the five chambers in the other end of the oven, thence through the air chamber *d* and vertical flue connection *h* to the regenerator *g*, and through the reversing valves to the stack. The regenerators are built entirely independent of the oven structure, so that their expansion does not affect the oven brickwork.

Coal Handling.—A steel coal-storage bin of a capacity equivalent to about 2 days' coal consumption is placed between the batteries. The coal is elevated to the bin from a hopper placed under the coal-receiving track by a belt or other type of conveyer. A coal larry of 8 tons capacity runs on a track on the top of the batteries and under the coal bin. The larry consists of a long, narrow bin with eight spouts in the bottom, through which the coal is run into the oven retort through holes in the top of it, and is leveled by means of a bar worked through a small opening in the doors at the ends of the oven. The larry is operated by an electric motor and receives its load of coal from the storage bin, under which it passes. A very dense metallurgical coke can be produced and the output of an oven largely increased by compressing the coal into a mold slightly smaller than the retort and charging the mass through the oven door.

Coke Handling.—On the completion of the coking process, the oven doors are raised and the mass of 6 tons of coke is pushed on to a movable platform by means of a ram. The pushing ram, as well as the machine on which it is mounted, are operated by electric motors. The coke, after being pushed upon the platform, is quenched and allowed to cool. The platform is then tilted by an electric motor and the coke slid off into cars that run on a track at the back of the machine.

Gas Mains.—The gas distilled from the coal during the coking process is conducted to the condensing house by two independent systems of mains that run on top of the battery the entire length, one on each side. Each oven is connected to each main by a vertical pipe and valve.

During the first part of the process, the rich gas is taken off through the rich-gas main. The valve to this main is then closed and the balance of the gas is taken off through the poor-gas main. When the coking is completed, the valve to the poor-gas main is closed, disconnecting the oven from both mains.

Condensing Plant.—The gas leaving the coke ovens is divided into two fractions; viz., the first fraction or rich gas, which is sent out as illuminating gas, and the second fraction or poor gas, which is used for heating the ovens. The cooling of the gas and the removal of tar and ammonia are done in the usual apparatus; hence, it is not necessary to discuss it here in detail. Both the rich and poor gases are treated in the same manner. The following is the sequence of the apparatus as shown in the general sketch of a gas plant for coke ovens, Fig. 17: *a*, *a'* are air coolers; *b*, *b'* are multitubular water coolers; *c*, *c'* are tar extractors; *d*, *d'* are exhausters; *e*, *e'* are second coolers intended to remove the heat produced by the compression of the gas in the exhausters; and *f*, *f'* are ammonia washers.

The rich gas when freed of tar and ammonia leaves the condensing plant and passes through pipe *g* into the purifying plant *h*, and from there into a large storage gas holder for illuminating gas, from which it goes into the city. The poor gas, after being treated in the same manner as the rich gas, leaves the ammonia washers *f* and passes through two benzol scrubbers *i*, *i'*. After having been freed of its benzol, it flows through pipe *j* into the oven-gas holder *k*. Here it is mixed with producer gas, when necessary, which will be discussed later, and carried to the ovens for heating by the pipe *l*. The benzol extracted from the poor gas is then transferred to the rich gas, so as to increase its candlepower.

The tar oil by which the gas is washed runs first from tank *n*, through the second benzol scrubber *i*, into tank *m*. From here it is supplied by pump *m'* into the first benzol scrubber *i*. The tar oil enters from tank *n* with about 5 per cent. of benzol, and finally leaves washer *i* with about 15 per cent. of benzol. It is collected in tank *o*. From here it is fed by pump *o'* into still *p*, in which the benzol is reduced again to about 5 per cent. The exhausted oil collects in tank *q*. From here it is taken by pump *q'* through the oil cooler *r*, in order to be again supplied to tank *n* for a new absorption.

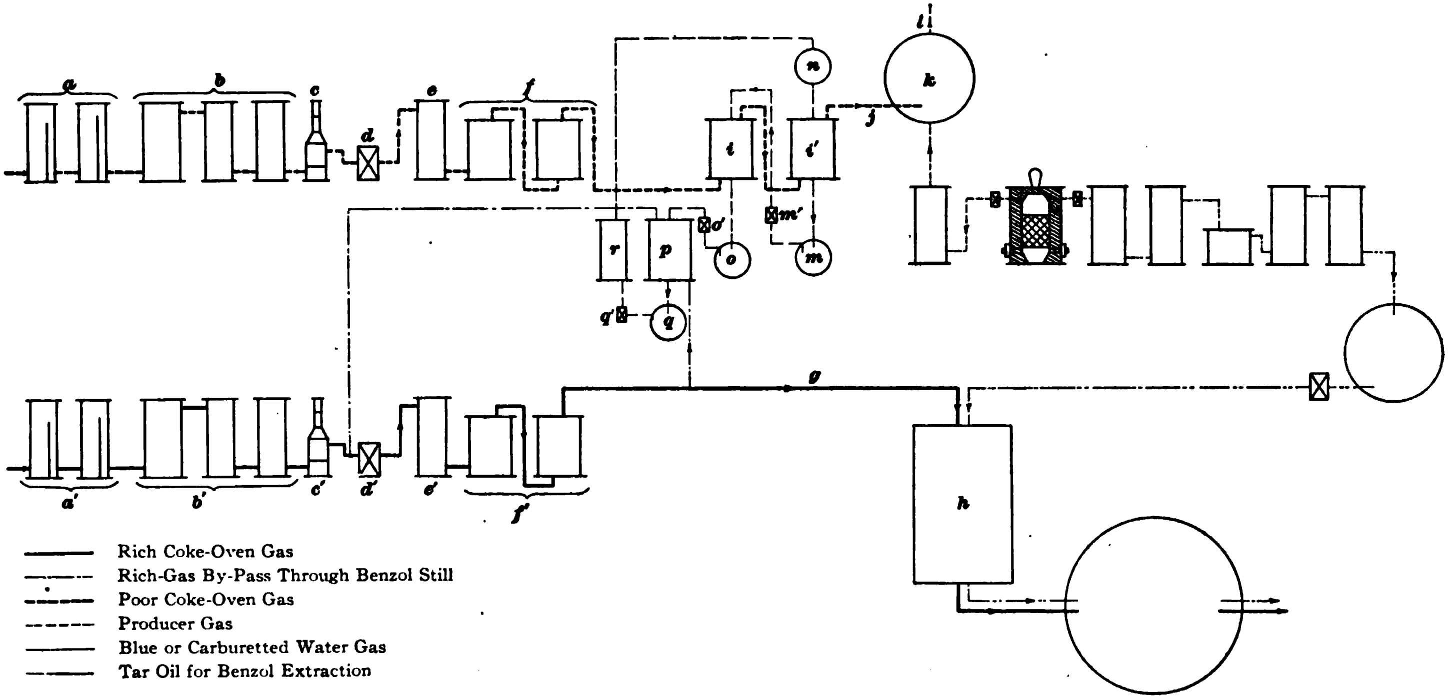


Fig. 17. Condensing Plant for Schniewind Ovens

The Utilization of the By-Products of the Coke Industry.—The following valuable paper of Dr. Bruno Terne was read before the chemical section of the Franklin Institute, Philadelphia, Pennsylvania, October 20, 1891. It exhibits Doctor Otto's efforts in utilizing the beehive type of coke oven for saving the by-products of tar and ammonia.

"About a year ago I had the honor to speak, in the lecture course of the Franklin Institute, on ammonia, its sources and technical uses. I dwelt, for reasons that I thought of sufficient importance, especially on the production of ammonia as a by-product of the coke industry.

"We have now entered on the beneficial workings of the new policy of furthering industrial developments in new branches in a period that requires the technical men in all branches, and especially in the chemical industries, to call the attention of the capitalists to the points in which we are behind the times in our developments, to the points where the resources of our own land are neglected, and we are far behind the more progressive European manufacturers.

"I thought it of sufficient importance to ventilate the same question before the chemical section of the institute in order to create an interest in the circle of the members of the institute, who are the best judges of such questions, in order to provoke criticism of my views. I have revised the part of my lecture referring to the development of the ammonia industry for this purpose, not in the expectation of claiming new and original ideas, but to secure your attention to a point that I consider of great importance for the development of an important branch of the chemical industries.

"We are surrounded by an immeasurable quantity of nitrogen gas in the atmospheric air. The weight of the atmosphere surrounding our earth is calculated to be 10 trillions of pounds, of which 7.77 trillion pounds is nitrogen; but, in spite of this inexhaustible source of nitrogen, we are not able, in a direct way, to use a single pound for the production of ammonia. It has long been the endeavor of the technical chemist to convert the nitrogen of the air into ammonia, but up to this hour none has succeeded in doing it with practical results. We are still compelled to use as sources for the production of ammonia the products of plant or animal life.

"The nitrogen of the air must pass through the channels of plant life to reach, in the products of the animal body, their highest degree of concentration. Hoofs and horns, with 15 to 16 per cent.; dried blood, with 19 per cent.; hair and wool waste, with 10 per cent.; and bones, with 5 per cent. of ammonia, are the richest sources.

"But the products of animal life, however, even if they were not too valuable otherwise, are by no means sufficient to satisfy the wants of the present day for the products of ammonia. But nature has provided an inexhaustible source for hundreds of years to come, in the residuum of plant life of former periods. In the bituminous coal fields and in the deposits of brown coal are lying stored up billions of pounds of nitrogen waiting to be converted into ammonia.

"The process of gaining this ammonia is incidental to the production of illuminating gas, to the production of coke, and to the production of animal charcoal. In distilling the bituminous coal we obtain of the weight of coal used, 4 to 6 per cent. of tar and 6 to 10 per cent. of ammoniacal water of 1.8° B.

"As Professor Lunge has shown, the nitrogen contained in the coal does not yield the amount of ammonia that we might expect:

Name of Coal	Yield of Nitrogen Per Cent.	Possible Yield of Ammonia Per Cent.	Possible Yield of Ammonia Water 1.020 Specific Gravity Per Ton of Coal Gallons
Wales	.71	1.10	142
Lancashire	1.25	1.52	196
Newcastle	1.32	1.60	206
Scotland	1.44	1.75	226

"But instead of these figures, the practical yield per ton of coal at the best is only 45 gallons of gas water of 1.020 specific gravity, generally only 25 gallons, and in some instances, as low as 13 gallons.

"The ammoniacal liquors from distillation of animal refuse are much richer, but the small quantity produced allows us to ignore the same as a very insignificant factor in the production of ammonia salts. The consumption of ammonia in its various forms has grown enormously in the last 20 years, and the manufacture of illuminating gas is no longer sufficient to supply the increasing demand for ammoniacal liquors. On the other hand, the inroad that electrical plants for illumination have been making yearly on the production of illuminating gas has already been felt, and will be more so from year to year. The production of water gas and oil gas are other factors that are cutting down the amount of ammoniacal waters produced.

"But there is another source for tar and ammonia, which, so far as my knowledge goes, has, with a single exception, not been worked in our country.

"Rich as are our resources, we are not rich enough to waste continually. It seems strange, and nevertheless it is a fact, with all the ingenuity of the American people in the advancement of the purely mechanical part of the technical industries, we have been and are yet slow in the development of the chemical industries.

"The acid manufacturer of Europe, especially of England and Germany, had commenced, in the beginning of this century, to make himself independent of the sulphur mines of Sicily by using the sulphurous ores of his immediate neighborhood and to utilize the pyrites for making his sulphuric acid. It has been only within the last 20 years that our people commenced to use the ores that had been lying under their feet, and today even, the United States consumes more sulphur for the manufacture of sulphuric acid than any other nation.

"It is the same with productions of tar and ammonia as a by-product of the manufacture of coke. If you will visit our coal region today, you will find the nightly sky illuminated from the fires of the coke ovens, and every one of the brilliant fires bears testimony that we are wasting the richness of our land in order to pay the wiser European coke manufacturer, who saves his ammonia and sends it to us in the form of sulphate of ammonia; and who also saves his tar, which, after passing through the complex processes of modern organic chemistry, reaches our shores in the form of aniline dyes, saccharin, nitrobenzol, etc.

"As far back as 1768, tar had been produced as a by-product of the coke industry by a chemical process at Fishbach, in the coal district of Saarbrücken on the Rhineland. The general opinion of the consumer there was then, and most likely will be here at the present time, that the coke produced will be of inferior quality. Against this opinion of the practical coke men, it has always been held by technical chemists, that the process can be so conducted as to yield all the by-products and still make a first-class coke.

"Since about 1850, the producers of coke in France, Belgium, England, and Germany commenced simultaneously the saving of the by-products.

"At St. Étienne, in France, a system of furnaces was at work in 1862 for which great success was claimed at that time. The gas and other volatile products of the coke oven were conducted to an air condenser, in which the tar and ammonia were condensed; the non-condensable gases were returned to the furnace as fuel.

"Scrubbers and condensers have been improved to insure complete condensation.

"The following average results have been claimed:

	Per Cent.
Coarse coke	70.00
Small coke	1.50
Waste coke	2.50
Graphite	.50
Tars	4.00
Ammonia water	9.00
Gas	10.58
Loss	1.92

"The net gain after deducting all expenses and without reckoning in the coke was, per oven, in Bességes, which has eighty-five ovens in operation, 111,446 francs. For eighty-five ovens this saving amounts to 94,990 francs or about $18,938.

"I give you in the table on page 259 the results reported from two establishments in France.

RESULTS OF BY-PRODUCT PLANTS IN FRANCE

Name of Works	No. of Ovens	Tons of Coal Consumed	Yield of Coke			Tar			Ammonia Water		Sulphate of Ammonia		
			Total Tons	Practical Per Cent.	Per Oven	Total Tons	Per Cent.	Per Oven	Hectoliters	Per Cent.	Kilograms Per Hectoliter	Tons Per Oven	Kilograms Per Ton of Coal
Bességes, in 1879	85	46,902	33.092	70.55	389.3	1,096	2.23	12.89	44,932	9.6	6.5	3,435	6.22
Terrenoire, April 1 to December 31, 1879	100	38.427	26,293	68.42		966	2.50		36,205	9.72	7.6		
Per annum calculated.....					350.57	1,288		12.88				3,374	6.54

"I will not endeavor to cover the development of the coke industries of Europe for the whole period since 1850. I have had occasion to familiarize myself with all the conditions of this industry, and am in possession of figures and plans of Doctor Otto's successful ovens, a view of which I show you. (See Figs. 9 and 10.)

"In 1883, a system of twenty ovens was built at the coke works of Gottesburg, Silesia, the results from which were so encouraging that in the following year 120 ovens were built.

"I will give you a report from a manufacturer, who, two summers ago, visited the Dahlhausen works of Doctor Otto, at the mines of Millensiven near Dortmund. Here there are two sets of thirty ovens each, which are charged alternately every other day. The gases are conducted by large iron pipes to a large basin, where a part of the tar will be condensed. From there it is led to the coolers, where the remaining tar and ammoniacal products are absorbed, and the gas, purified, is returned to a gas holder, and from there is redistributed to the coke ovens, to the boiler fires, and utilized as illuminating gas throughout the works. The gas returning to the coke ovens is mixed with hot air and enters the flues of the bottom and sides. The coke produced is an excellent product and finds a ready market everywhere. It has not the silver gray or steel color of our Connellsville coke, but it is quite as good in quality as ours."

Festner-Hoffman Coke Oven.—The general design of the Festner-Hoffman coke oven is to simplify construction and operation in the manufacture of coke and saving of by-products. The recuperative compartments of this oven are somewhat simpler than the double regenerators of the Otto oven.

In the treatment of dry coals, it is evident that a high heat with quick application is required in coking such coals; it is also manifest that an efficient method of heating the air, for mixture with the returned gas, is absolutely necessary. But the recuperators and regenerators should be designed in as simple and inexpensive a manner as possible, consistent with efficiency in performing this part of the work in coking. The Festner oven has the advantage of direct and continuous work, removing the necessity of reversing the air and gas currents, as in the Otto oven, thus avoiding the risk of explosions.

The most important improvement appears in the horizontal posture of the side flues in this oven. In practical operations, it has been made very plain that the oven heat from the combustion of the returned gas can be regulated much more readily in ovens having horizontal flues than in those using the vertical posture. The danger in the latter arises from the tendency to the concentration of excessive heat at certain localities in the oven flues, destroying the firebrick conduits and lining.

From the study of this oven, it is evident that in its design some progress has been made in the right direction in reducing its cost of construction and expense of operation. It is further manifest that additional study along these lines would be helpful in the introduction of these retort coke ovens in the United States.

Mr. E. Festner, Director, Silesia Coal and Coke Works, in a paper read before the German Mining Engineers, September 5, 1892, describes this oven, shown in Fig. 18, as follows:

"The well-known Otto-Hoffman oven is called the regenerative oven; in distinction to this I will call my Festner-Hoffman oven the recuperative oven (referring to the similarly constructed Ponsard gas furnace), the purpose of which is to dispense with the continual reversing of the regenerative ovens and to effect a permanent heating of the air necessary for combustion. In this work I was assisted by Coke Inspector Hoffman, a very able engineer and the father of the Otto-Hoffman ovens.

"During long experience with the coking process, I have always found the horizontal flues and the somewhat strong side-walled ovens better than the Coppée ovens with vertical flues. The former can be worked at a higher heat and can be examined more readily, particularly in the flues; therefore, I equipped my ovens last year with horizontal drafts similar to the Simon-Carvés system, which is used to great advantage at Bulmke, near Gelsenkirchen.

"In building this new plant I arranged my appliances for the saving of by-products, as their advantages are evident. As the

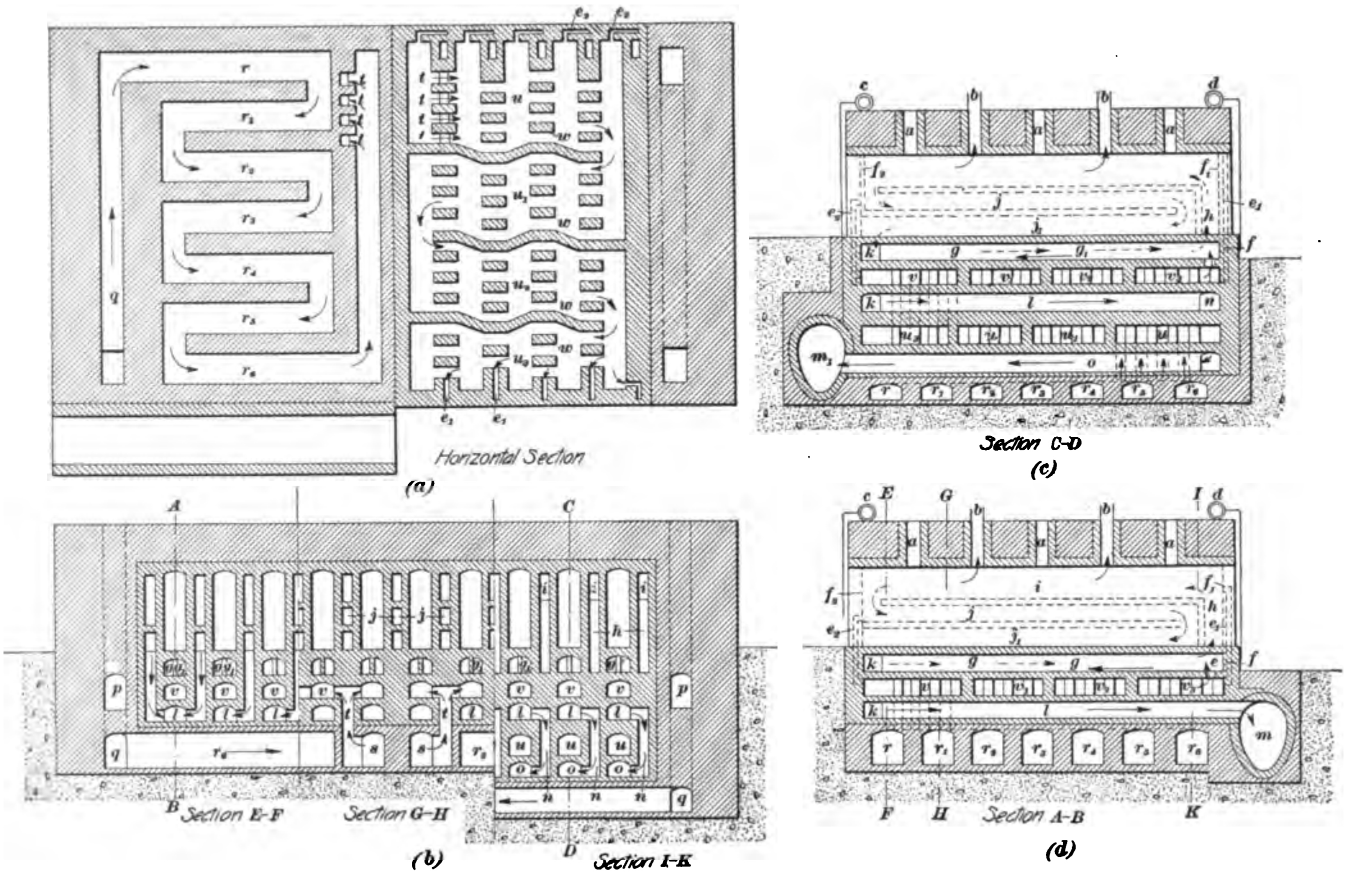


FIG. 18. THE FESTNER-HOFFMAN COKE OVEN WITH THE BY-PRODUCT-SAVING AND CONTINUOUS AIR-HEATING APPARATUS

quality of the dry coal used required a very high heat, it became necessary to heat the air for combustion as high as possible, and as grave defects appeared in the reversing process, the recuperative oven was suggested more from necessity than inclination.

"In explanation I will say that I call the chamber where the coal is placed for coking and the side of oven where the coke pusher operates, the front side; and the other, where the coke is discharged and cooled, the rear side. The chamber of this oven is 29½ feet long, 23 inches wide, and 5 feet 11 inches high. The oven contains, when full, 6½ tons of washed coal for a 48-hour charge. The chamber walls are 6 inches thick, and the flue walls about the same thickness.

"The ovens are combined in groups of thirty each. The hot-air flues, lying underground, consist of two systems for a battery of thirty ovens.

"The coking chamber is filled with coal through the three charging ports *a*. The gas is conveyed through the flues *b* into the condensing apparatus. The exhausted gases return through the pipes *c* and *d* and are sent by the hot-air current that enters at e, e_1, e_2, through the dividing pipes f, f_1, on the front, and f_2 on the back. The gases are first led forwards and back in the hot flues g and g_1, under the oven bottom; they then rise in the vertical hot flue *h* on the rear side, passing through the horizontal flue *i* to the front side; they then go backwards in *j*, and forwards again in j_1, falling through *k* to the lowest horizontal hot flue *l* in order to reach the central flue *m*, which leads the gas under the boilers. After the heating they receive in passing through these two levels, the gases are led through *n*, *o*, and m_1.

"The air to be heated enters from the outside at *p*, falls to the horizontal air canal *q*, through the flue system r, r_1, r_2, r_3, r_4, r_5, and r_6, as seen in drawing, and is easily warmed in this system by means of the hot flue *l*. From here the air is led through the horizontal air flue *s* to the vertical flues *t* in order to get to the main system u, u_1, u_2, and also to v, v_1, v_2, v_3, from whence it is led as hot air through the vertical drafts e, e_1, and e_2, to be used in the combustion. The heating that the air in the flue system undergoes, through continually impinging against the small piles *w*, etc., is excellent and the heat of combustion rises to 1,650° F. In the latter-described arrangement is the characteristic of our oven, for which Hoffman and I have applied for a patent.

"According to the results in question, from this new oven in Gottesburg, nothing remains to be desired; they can be heated very high, are easily regulated, and are, according to experiments that I made with similar ones built by me in Hermsdorf, almost indestructible, so that these new ovens can be recommended as the best.

"The waste gas from flue *m* supplies five boilers of 45 horsepower. With this heat, the boilers not only supply the necessary steam for the condensing apparatus, but power for electric lighting of the whole works, as well as for running various small machines.

"In order to have as small a depression as possible in the hot flue, a ventilator plant is necessary, which, as in the Otto-Hoffman oven, helps to regulate the supply of air and leads to a uniform heating of the hot flue. The slight depression in the hot flue stops the gas in the chamber from passing through the cracks in the walls directly into the hot flue and thereby being lost to condensation.

"The cost of the oven proper, from the excavation to the time of firing the oven, is estimated, in Germany, at $935. The cost of oven and by-product apparatus would therefore be as follows, in Germany:

Oven	$935.00
By-product apparatus	1,600.00
Total	$2,535.00

"In the United States, the cost would be somewhat more, approaching about $3,000 per oven."

No record is given of the work of this oven, but it is fair to estimate its coke and by-products about the same as the Otto-Hoffman oven, a charge of 6.889 net tons of dry coal every 48 hours giving 5.166 net tons of coke every 2 days, or 2.583 net tons daily.

The coal used is given as an average of its quality in the district referred to in the foregoing article as follows:

	Per Cent.
Moisture	.74
Carbon	84.29
Hydrogen	4.61
Nitrogen	1.62
Oxygen	4.77
Ash	3.97
Total	100.00

Semet-Solvay Coke Oven.—The Semet-Solvay retort coke oven, Fig. 19, came into appreciative notice in Europe, in 1887. This oven was evidently designed to secure three chief elements in the coking of coal and saving its by-products.

1. To coke dry coals, such as inherit only 15 to 17 per cent. of volatile combustible matter; this is secured by the quickly applied heat during the initial operation of coking, thus obtaining the full benefit of the fusing matters in the coal and producing the hardest-bodied coke possible with such quality of coal.

2. To store heat in the oven walls, to be made available in starting the coke operation after a fresh charge of coal has been placed in the oven, avoiding the expensive auxiliary arrangements of regenerators or recuperators.

3. To secure in a direct and simple manner the by-products of tar and ammonia in coking, enhancing the profit of the coke manufacturer.

An examination of the accompanying plans and sections of this coke oven will show the general scope of its design. The oven chamber is usually 30 feet long, 1 foot 4½ inches wide, and 5 feet 6 inches high. These dimensions may be increased or diminished to meet the requirements of coking each quality of coal. Its side walls are faced with flued and jointed tiles in horizontal posture, which affords the best condition for the regulation of the heat and its proper distribution, so as to avoid its destructive concentration at any part of the oven.

These flued tiles are quite thin, quickly transmitting the heat from the combustion of the returned gases to the charge of coal. This heat is sustained by drawing on the heat stored between the flued lining of the ovens in the dividing walls. This stored heat is maintained by the return of the surplus heat toward the close of the coking of each charge, and is ready to be used in supplementing the heat of ovens on the introduction of each fresh charge of coal, avoiding the chilling of the fusing matter in the coal by a slow process of coking.

In this oven, the massive arch and covering *A* afford a very important second heat-storage reservoir for each oven, which insures the maximum heat at the upper portion of the charge of coking coal. These two repositories for heat storage, the walls and the arch, obviate the necessity of auxiliary appliances for heating the air for combustion of the gases, which are essential in other systems.

The oven is capable of coking the richer or pitchy coals, but its chief merit consists in its successful treatment of coals low in hydrogenous matters, which are difficult to coke in ordinary ovens. It, therefore, measurably anticipates a time when the chief sources of the best coking coals shall have been reduced in extent, and when the coke manufacturer will be compelled to fall back on the less valuable or dry coking coals to maintain the coke supply.

The design for an oven to coke the rich or pitchy coals will, in time, engage the attention of oven builders, reversing the heat conditions of the Semet-Solvay oven, to produce coke without the usual inflated cellular structure now barring the use of such coals for the manufacture of metallurgical coke.

It may be noted that the Semet-Solvay ovens afford sufficient surplus heat to make steam in boilers, located near the ovens, for all purposes of all the operations of the manufacture of coke and saving of the by-products.

Mr. E. Festner, director of the Selician Coal Works, Gottesburg, reports that a Semet-Solvay oven will coke 1,440 tons of coal, producing 1,125 tons of coke per year. About 78 per cent. of coke

is obtained from the coal charged; all 24-hour coke. He further gives the cost of this oven and its appliances, in Europe, as follows:

Cost of oven complete	$1,168.75
Apparatus for saving by-products	1,402.50
Boiler plant, heated with gas	490 87
Storage bin and coal mixer	420 75
Total cost per oven	$3,482 87

In the United States, the cost, per oven, of such a plant would exceed the above.

It has been suggested that the use of silica material in the flued tiles in the oven lining would add to their permanence in performing their important functions in the oven and reduce expenses of repairs.

A plant of twelve Semet-Solvay retort coke ovens is now in operation at the works of the Solvay Process Company, near Syracuse, New York. This plant has been constructed in a very perfect and substantial manner with improved appliances for extracting and saving the by-products of tar and ammonia. It is designed at some future time to add twelve more ovens to the present plant, making in all twenty-four ovens. The exhauster and apparatus for securing the by-products are sufficiently large to take care of the products of twenty-four ovens or more. The main design is to obtain coke as free as possible from sulphur, and at the same time secure the by-products of tar and ammonia.

The plan of this oven is shown in Fig. 19, which has been kindly furnished by W. B. Coggswell, Esq., general manager of the Solvay Process Company, of Syracuse. The cost of this plant is as follows:

Ammonia concentrator	$ 1,584.74
Boilers	10,210.56
Coal trestle	3,039.58
Coal-house plant	5,027.23
Chimneys	3,107.93
Pusher	3,112.46
Producer	701.00
Ovens (12)	28,685.30
By-product building	7,365.74
Washers (2)	2,856.69
Exhausters (2)	2,511.16
Shafting	841.47
Hydraulic mains (2)	2,281.84
Gas condensers (4)	6,521 42
Piping and other contingencies	10,167.32
Total	$88,014.44

From this it will be seen that the ovens cost $2,390.45 each; the ovens with the appliances and pusher will cost $7,334.53 each. Increasing this plant to twenty-four ovens, and estimating the cost of the twelve additional ovens at $2,000 each, the aggregate cost of the plant will be $112,014.44. The average cost of the ovens is $2,195.23 each. The average cost of the by-product-saving apparatus is $2,472.04 for each oven. It is quite probable that with a still further increase of ovens the average cost of ovens and by-product appliances would be much reduced.

The coal used in these ovens is small or fine coal procured from the Morris Run Coal Company, Tioga County, Pennsylvania. It is constituted as follows:

	Per Cent.
Moisture	.1600
Volatile matter	19.1200
Fixed carbon	70.7800
Ash	8.9100
Sulphur	.7318

The theoretic coke in the above coal is 80.12 per cent.

During the month of June, 1895, 1,656½ net tons of coal was used in the twelve coke ovens, producing 1,273½ net tons of large coke and 46½ tons of breeze, exhibiting a total product of 1,320 tons of coke and breeze. The total product of coke is 79.68½ per cent. of the coal charged into ovens; of this 2.80 per cent. is breeze, or small coke, leaving of marketable coke 76.87½ per cent. As the theoretic coke from this coal is 80.12 per cent., it is evident that very little waste of fixed carbon has been made in coking. On the other side it appears that very little carbon has been deposited from the volatile hydrocarbons in coking; this is further confirmed by the absence of the bright silver glaze that evidences this deposit on coke.

The daily charge for each oven is 4.6 net tons of coal. The coke and breeze produced are 3.67 net tons. One oven produces 106.12 net tons of marketable coke per month or 1,273.44 net tons per year.

The by-products of tar and sulphate of ammonia made during the month of June, are as follows:

	Per Ton of Coal
Tar	43.6 pounds
Sulphate of ammonia	9.88 pounds

The revised cost of labor in making coke and saving by-products is given at $1.08 per net ton. It is estimated that with a twenty-four oven plant this cost would not greatly exceed 60 cents per net ton of coke made and by-products saved. These ovens are run continuously with three shifts of men, making the cost of the work somewhat above other types of ovens. The value of the by-products, per ton of coke made, is placed at 48 cents.

With the dry quality of coking coal used in these ovens, inheriting only 17 to 19 per cent. of volatile combustible matter, it is evident that the results of the retort coke ovens clearly indicate that this is the best oven for coking this rather inferior coal. The percentage of coke made, 76.875, with its hardness of body and its consequent condition to resist dissolution in its passage down a blast furnace by the action of the ascending gases, gives it additional commendation in producing metallurgical coke.

A similar quality of coal coked in the beehive oven afforded only 61 per cent. of coke rather softer in body than the retort coke, and consequently less valuable as a fuel in metallurgical operations.

When the several types of coke ovens shall have been considered, with cost of plant, expenses of operating, and physical properties of their products of coke compared, a general review of the merits and demerits of each kind of oven will be submitted. At this time it can only be pointed out that such an analysis of coking will embrace two lines of determinations: (1) Whether metallurgical coke is the prime requirement, with or without by-products as a secondary matter; (2) when the by-products are the chief product, with coke only a secondary interest.

With the largely increased cost of a coking plant for saving by-products, and its increased cost in labor above the coke plants without the saving of by-products, it becomes a serious consideration whether the market value of the by-products will secure increased profits to cover increased investment in plant and extra labor expenses to the coke manufacturer.

In a communication, July 10, 1894, F. R. Hazard, Esq., treasurer of the Solvay Process Company, of Syracuse, New York, states:

"In the matter of the present results of the block of Semet-Solvay ovens, in Syracuse, we would say that, running on Morris Run coal, the percentage of marketable coke to coal used was 78.2 per cent. In addition to the coke there is from 2 to 3 per cent. of breeze. The by-products amount to 42¼ pounds of tar per ton of coke, and 16.12 pounds of sulphate of ammonia per net ton of coke. We will be obliged if you will make this correction in the revision of your articles.

"We cannot use our small block of twelve ovens for a fair criterion of either original or operating cost. By the European practice, the cost of a Semet-Solvay oven is $1,000 against $1,200 for an Otto-Hoffman oven; and the Semet-Solvay oven will produce double the quantity of coke, requiring but 22 hours against 48 hours for the Otto-Hoffman oven. The cost is for the oven only, not the by-products. The cost of operating a block of twenty-five Semet-Solvay ovens, making twenty-eight charges of 4½ net tons each in 24 hours, equal to 126 net tons of coal producing 101.5 net tons of coke, is two engineers and twenty laborers. At $2.25 per day per engineer, and $1.40 per day for laborers, this would amount to $32.50, operating cost for 101.5 net tons of coke, or 32 cents per net ton of coke. One extra man will attend to the by-product works."

For the large class of dry coals, this oven is admirably adapted to produce very good metallurgical coke, as good as can be made from this dry coking coal. It may be submitted here, as a general principle, that first-class coke cannot be made from second-class coals. Twelve Semet-Solvay coke ovens with apparatus for saving the by-products of tar and ammonia sulphate have been in operation during the year 1894 at the large chemical works of the Solvay Process Company, Syracuse, New York. Mr. W. B. Coggswell, the managing director, has kindly furnished the statement on this and the following page of the year's product of coke, breeze, and by-products. The large output of coke is remarkable, as it greatly exceeds the best record of retort ovens that has come to our notice. From the strikes at the coal mines during the year, the output of coke was reduced owing to the insufficient supply of coal.

Experiments in these ovens with Connellsville coal, for the Illinois Steel Company, afforded remarkable results in the increased product of coke. It was shown that coke could be made from this coal in 16 hours that in quality was satisfactory to the representative of this company, Mr Whiting, who remained at ovens during the time of the experiments. This indicates a daily output of coke of nearly 6 tons. During two visits of the writer to these works, very full statements of the work of the ovens were kindly furnished.

COKE-OVEN STATEMENT SOLVAY PROCESS COMPANY FOR 1894

Coal used, total short tons, 2,000 pounds	21,825.60
Coal used per oven, short tons	1,818.80
Coke produced, total short tons	17,531 20
Coke produced per oven, short tons	1,460.90
Breeze produced, total short tons	678.10
Breeze produced per oven, short tons	56.50
Percentage of large coke to coal	80.33
Percentage of breeze	3.17
Percentage total coke to coal	83.50
Ammonia sulphate, total pounds	309,385.00
Ammonia sulphate per oven, pounds	25,782.00
Ammonia sulphate per ton of coal, pounds	14.27
Tar produced, total pounds	917,230.00
Tar produced per oven, pounds	76.435.00
Tar produced per ton of coal, pounds	42.20

Owing to insufficient supply during the strike, the production was limited by the receipts of coal.

WEST VIRGINIA COALS IN SEMET-SOLVAY OVENS

The following figures are the results of a test of Davis, and Thomas, West Virginia, coals made in Semet-Solvay ovens at Syracuse, February 23 to 27, 1899. Four ovens were coked for the by-product test. Duration of coking 24 hours. One oven was coked 20 hours, and another 22 hours, and in both cases the volatile

COKE-OVEN STATEMENT, SOLVAY PROCESS COMPANY, FOR THE YEAR 1894

Coal and Products	January	February	March	April	May	June
Morris Run, Pa., tons	1,327.60	1,373.90	1,786.70	1,012.90	850.00	786.00
Clearfield, Pa., tons						654.90
Reynoldsville, tons	291.60	262.10				
Pocahontas, tons					434.80	213.30
Benton, tons	137.50					
Phillips, tons				813.60	444.10	
Coal used, total tons	1,756.70	1,636.00	1,786.70	1,826.50	1,728.90	1,654.20
Coke, large, total tons	1,374.60	1,282.40	1,421.50	1,454.20	1,409.80	1,382.60
Coke, large, per cent. of coal	78.20	78.40	79.50	79.60	81.30	83.50
Breeze, total tons	62.20	56.40	51.70	41.10	36.90	30.30
Breeze, per cent. of coal	3.50	3.40	2.90	2.20	2.13	1.83
Ammonia (sulphate), pounds	28,327.00	25,592.00	24,413.00	27,066.00	23,315.00	27,501.00
Ammonia (sulphate), per ton of coal, pounds	16.12	15.64	13.66	14.81	13.50	16.62
Tar total, pounds	74,240.00	75,310.00	77,440.00	83,540.00	82,050.00	83,500.00
Tar per ton of coal, pounds	42.20	46.00	43.30	45.70	47.40	50.40

Coal and Products	July	August	September	October	November	December
Reynoldsville, tons		973.30				
Morris Run, tons		421.10	1,847.20	1,900.20	1,883.00	1,721.70
English steam, tons	139.00	13.80				
Belgian, tons	1,698.40	501.90				
Indiana, Illinois, and Pennsylvania (sample)						337.00
Coal used, total tons	1,837.40	1,910.10	1,847.20	1,900.20	1,883.00	2,058.70
Coke, large, total tons	1,531.80	1,543.10	1,495.80	1,569.70	1,537.00	1,528.70
Coke, per cent of coal	83.30	80.78	80.70	82.60	81.60	74.25
Breeze, total tons	83.20	66.32	55.60	64.80	64.30	65.30
Breeze, per cent. of coal	4.53	3.47	3.01	3.41	3.41	3.17
Ammonia (sulphate), pounds	22,987.00	27,827.00	22,659.00	27,060.00	25,766.00	26,872.00
Ammonia (sulphate), per ton of coal, pounds	12.50	14.60	12.20	14.42	13.67	13 05
Tar, total pounds	63,750.00	81,800.00	73,060.00	76,960.00	83,740.00	61,840.00
Tar, per ton of coal, pounds	34.60	42.80	39.60	40.00	44.40	30.00

matter was practically all driven off. The following are the figures as to yield of coke, ammonia, and tar from the Davis coal:

	Pounds	Per Cent.
Weight of coal used in four ovens at 8,825 pounds	35,300	
Weight of coke produced	27,400	
Coke yielded		77.62
Moisture in coal		4.21
Moisture in coke		2.89
Breeze produced	1,270	
Breeze equal		3.60
Moisture in breeze		20.00

Taking into consideration the moisture in the coal and coke, the figures are as follows:

	Pounds	Moisture Per Cent.	Coal Per Cent.
Weight of coal charged	35,300	4.21	
Weight of dry coal	33,814		
Weight of coke produced	27,400	2.89	
Weight of dry coke	26,609		
Yield of large coke			78.69
Weight of breeze	1,270	20.00	
Weight of dry breeze	1,016		
Yield of breeze			3.00
Total yield			81.69

The by-products per 2,000 pounds of coal are: sulphate of ammonia, 18.51 pounds; tar, 41.14 pounds; gas, 8,000 cubic feet.

ANALYSIS OF DAVIS COAL AND COKE

	Coal Per Cent.	Coke Per Cent.
Volatile matter	23.720	1.1200
Fixed carbon	68.370	88.6000
Ash	7.910	10.2800
Sulphur	.737	.6890
Phosphorus		.0092

The following is the test of Thomas coal:

	Pounds	Per Cent.
Weight of coal used in three ovens at 9,945 pounds	29,835	
Weight of coke produced	22,760	
Coke yielded		76.28
Moisture in coal		3.00
Moisture in coke		2.00
Breeze produced	1,215	
Breeze equal		4.07
Moisture in breeze		25.00

Taking into consideration the moisture in the coal and coke, the figures are as follows:

	Pounds	Moisture Per Cent.	Coal Per Cent.
Weight of coal charged	29,835	3.00	
Weight of dry coal	28,940		
Weight of large coal	22,760	2.07	
Weight of dry coke	22,305		
Yield of large coke			77.01
Weight of breeze	1,215	25.00	
Weight of dry breeze	912		
Yield of breeze			3.10
Total yield			80.11

The by-products for 2,000 pounds of coal are: sulphate of ammonia, 20.66 pounds; tar, 47.96 pounds; gas, 8,500 cubic feet.

ANALYSIS OF THOMAS COAL AND COKE

	Coal Per Cent.	Coke Per Cent.
Volatile matter	25 420	1.200
Fixed carbon	63 400	85.450
Ash	11.180	13.350
Sulphur	.678	.663
Phosphorus		
Crushing strength		

COMPARISON OF SEMET-SOLVAY TESTS

	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
Connellsville coal	29.02	61.61	9 37	.770	
Connellsville coke	1.85	87.07	11.08	750	.0180
Davis coal	23.72	63.57	7.91	.737	
Davis coke	1.12	88.60	10.28	.669	.0092
Thomas coal	25.42	63.40	11.18	.672	
Thomas coke	1.20	85.45	13.35	.665	

The above analysis of Connellsville coal is fully 2 per cent. below the average of usual volatile matter, and the phosphorus is also higher than usual. The yield of large coke from Connellsville coal was smaller than that from West Virginia coal, due to the higher percentage of volatile matter. The tests show that not only none of the fixed carbon is lost in the retort type of ovens,

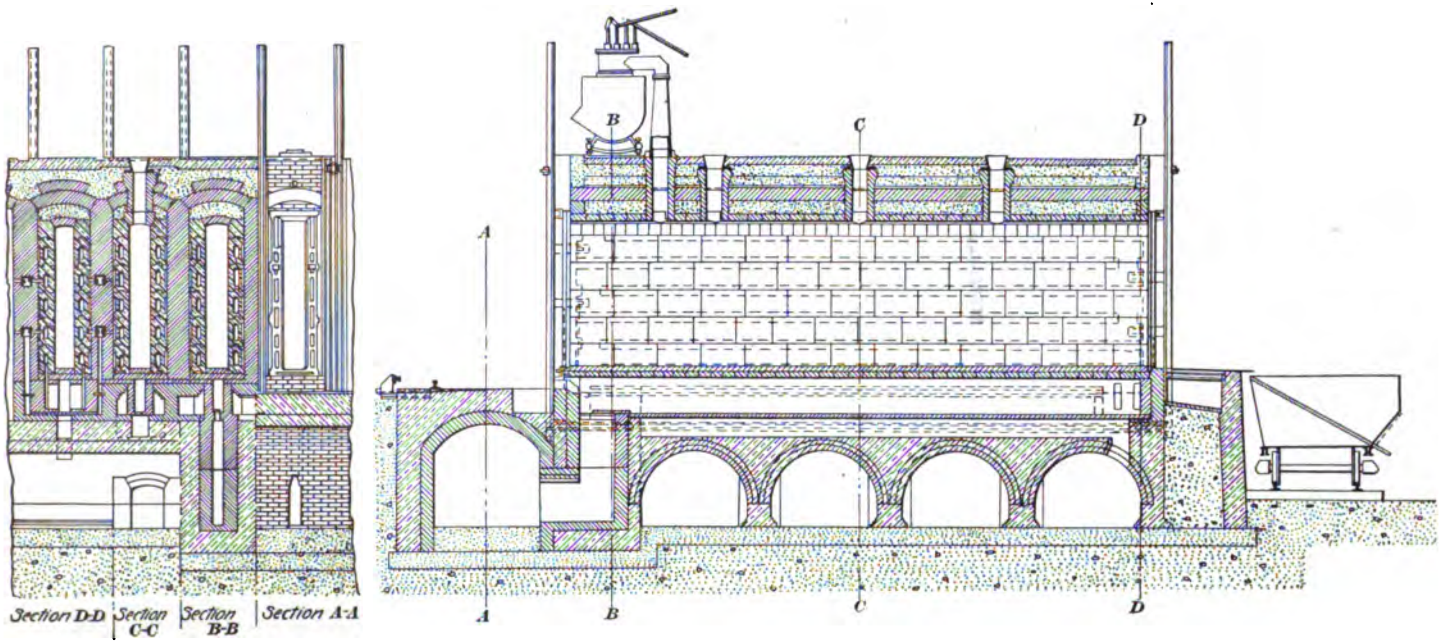


FIG. 20. IMPROVED SEMET-SOLVAY OVEN

but that there is an increase over the theoretical yield; this is probably deposited by the escaping gases. The same results are obtained from all coals.

Recent Improvements in Semet-Solvay Ovens.—The following description of the recent improvements in the Semet-Solvay coke oven has been furnished by the general manager and engineer of the Semet-Solvay Company, Mr. W. H. Blauvelt:

Fig. 19 exhibits the longitudinal and cross-sections of this oven in its normal condition as constructed at the experimental plant at the Solvay-Chemical Works, Syracuse, New York. Since its installation at these works this normal type has been mainly followed in the construction of coking plants in various localities in the United States. These ovens had four horizontal lines of heating flues. The coking chambers were 30 feet long, 16½ inches wide, and 5½ feet high, affording a daily output of marketable coke of 4.4 tons.

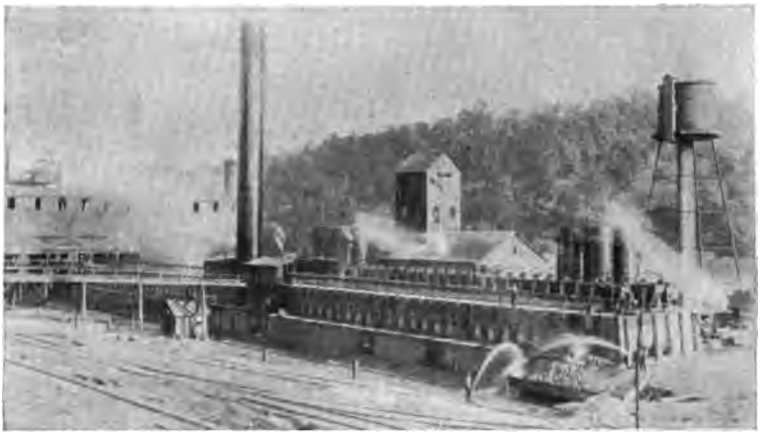


FIG. 21 (a). VIEW OF REAR END OF SEMET-SOLVAY COKE PLANT AT DUNBAR, PENNSYLVANIA

Fig. 20 shows the longitudinal and cross-sections of the enlarged and improved oven. It will be evident that an additional heating flue has been added to the height of this oven, giving it five heating flues. Its length has been increased from 30 to 35 feet. The output of marketable coke from this enlarged oven is given as 7 to 9 tons per day. The largely increased capacity of this oven has evidently been secured by the enlargement of its length and height, as well as from the compression of the charge of coal from its increased height. The width, 16½ inches, remains unchanged.

Semet-Solvay Plant at Dunbar, Pennsylvania.—Fig. 21 shows three views of the Semet-Solvay plant of fifty by-product ovens built in 1895, adjoining the plant of the Dunbar Furnace Company.

The coal used is Connellsville coal. This plant was one of the earliest Semet-Solvay plants in the United States and the ovens are built of the early type illustrated in Fig. 19. There are two symmetrical batteries of twenty-five ovens each. A detailed description of these ovens will be found in Mines and Minerals, February, 1900, page 297.

Fig. 21 (*b*). View of Ram and Front of Ovens

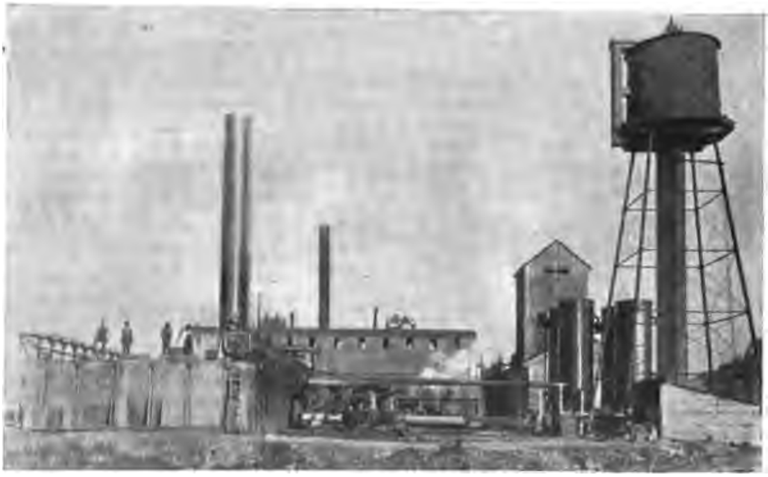


Fig. 21 (*c*). View Showing Arrangement of By-Product Apparatus

The following is Mr. Blauvelt's letter in regard to the present status of the Semet-Solvay oven:

SYRACUSE, N. Y., June 19, 1903.

MR. JOHN FULTON, 136 Park Place, Johnstown, Pa.

Dear Sir:—Since the last edition of your book was published, the growth of the Semet-Solvay oven has been very rapid and there are now in this country nearly 1,100 ovens, either in operation or under construction. The principal advance has been in the size of the units, that is, the size of the ovens and the number of ovens in a block. In 1895, the standard block of Semet-Solvay ovens was twenty-five ovens, each having a capacity of 4.4 tons of coal. Now the ovens are built forty in a block, with a capacity of from 7 to 9 tons each, so the unit has risen from 110 tons of coal per day to 360 tons per day. The increase in the capacity of the ovens has been obtained mainly by increasing the height. The height of the charge was formerly 4 feet 11$\frac{1}{16}$ inches; now the standard is 6 feet 2$\frac{3}{8}$ inches, and we have successfully operated ovens 9 feet high, and 130 of these largest ovens are in the course of construction. The length has also been increased from 30 feet to 35 feet. It was thought that the increased height might have some effect on the physical quality of the coke, making it more dense near the bottom of the oven, but it has not been found to be the case. There is no visible increase in density in the coke on account of the higher ovens. We have not found it desirable to change the width of oven originally adopted in this country, namely an average of 16$\frac{1}{2}$ inches. This width permits almost all coals to be coked thoroughly in from 22 to 24 hours, and all things considered, this is found to be the most advantageous coking time. Wider ovens have been tried up to 20 inches, but the output of coke per day has proved to be less than with the standard width.

Other improvements about the ovens themselves have been of a minor nature, mainly the perfecting of details, looking to more economical and efficient construction. Electricity has been substituted for steam on the pushers and for man power in the handling of the charging larries. There has been no opportunity for improvement in the control of the gas in the flues or the regulation of the heat on the ovens, as these essential points have always been thoroughly under control and entirely satisfactory. The introduction of our inclined coke car, which permits the very even distribution of the coke as it is pushed from the oven, over a large surface, thus permitting prompt and efficient quenching with a minimum of moisture, has entirely overcome one of the former handicaps of retort-oven coke, namely, the high moisture, and in combination with our system of quenching by the use of a large stream of water, the coke may be kept quite as dry as in the best beehive practice. By the use of this coke car the handling of the coke is reduced to an absolute minimum, and when the furnace stock house is sufficiently nearby, the coke is delivered directly from the quenching car into stock-house bins with a minimum of breakage.

Our experience has fully demonstrated the superior merits of the Semet-Solvay system of main division walls between the ovens carrying the roof structure in a permanent manner and removing all load from the thin flue walls, as well as acting as a reservoir of heat, which is drawn upon whenever the oven becomes cooled by the charge of fresh coal. The independence of the flue system in respect to the main structure of the oven permits repairs to any oven flue to be made without shutting down any of the adjacent ovens. This is an important point in cases where the coal is of a nature to injure the flues, necessitating comparatively frequent repairs. Some of the American coals that have been developed since your first edition have proved to be quite injurious to the bricks forming the flues. In such conditions this independence of each oven produces quite an important effect on the average output of a plant.

The rapid exhaustion of the Connellsville field has awakened new interest in the retort oven, since such a large number of coals throughout this country are not capable of producing a good coke in the beehive oven, and the coke users must turn to the retort oven for aid. Many of the coals, while sufficiently pure, chemically, do not give, even in the retort oven, a structure sufficiently dense to support the furnace burden and resist the dissolving action of the hot gases in the top of the furnace. Experiments have proved that this structure can be improved and made entirely satisfactory by grinding the coal to a size of $\frac{1}{4}$ inch or $\frac{3}{16}$ inch and under, and compressing the coal either by ramming or pressure. The Semet-Solvay Company has followed this line of investigation very thoroughly and has developed a compression machine that gives very satisfactory results, overcoming many of the difficulties that have made the use of the machines that have been employed on the continent of Europe very unsatisfactory, and at the same time having a capacity as to time of compression very much superior to any other machine. These machines are being installed at a number of the Semet-Solvay plants. In addition to the improvement in the physical quality of the coke, the use of compression increases the output of the oven from 10 per cent. to 15 per cent. on account of the increased amount of coal that can be charged.

During the last 3 years, the production of illuminating gas from by-product ovens has developed remarkably, and now the process is operated very successfully in a number of places. The Semet-Solvay Company has been delivering illuminating gas of 18 candlepower to the Detroit City Gas Company for about a year, and two other plants are being fitted up for this purpose. The coke oven has an important advantage over the old retort system for the production of illuminating gas, namely, that in the coke oven it is possible to make use of the well-known fact that in the distillation of coal the portions of the gas coming from it during the early part of distillation contain much the greater part of the illuminating bodies; the latter portion of distillation yields mainly carbonic oxide and hydrogen. In the coke oven, it is easily possible to use the gases low in illuminating power for fuel for the heating of the ovens, reserving the higher illuminating gas for distribution. In the ordinary gas retorts this separation is not possible.

In the by-product side of the operation, improvements have been mainly along the lines of greater efficiency, increased yield of by-products owing to greater perfection of apparatus and better knowledge of the conditions that produce the largest yield of by-products consistent with the always primary point of the best possible quality of coke. The distillation of the ammonia has been very greatly developed, so that now all apparatus is of much higher economic efficiency, while permitting the easy production of crude ammonia liquor up to 25 per cent. ammonia with consequent saving in transportation costs. The manufacture of aqua ammonia has also been developed and the many practical difficulties attendant on this manufacture have been successfully solved, so that we are producing at several of our plants aqua ammonia of the highest commercial quality.

The successful development of the by-product oven is, of course, dependent on the ability of the country to utilize the by-products, so as to equal in consumption the very rapid increase in production. With the great increase in the cost of material and labor, since your first edition was published, the costs of construction and operation of plants of by-product ovens have, of course, increased proportionately, and it is necessary that the values of the principal by-products, namely, tar and ammonia, should be maintained at approximately the present figures in order that the construction and operation of these ovens may continue to be attractive. Those interested in the markets of these by-products are giving the most careful study to the development of their use in new fields, but at present there is unquestionable danger that the very large amount of tar and ammonia that will come on the market in the next year will seriously affect prices. There is no doubt that the consumption of the country will in time catch up with the production, as the history of such products has always shown this to be the case, but it is quite possible that there will be a considerable period during which practically all profit is cut off from those operations, of which the by-products are one of the important sources of profit.

Yours very truly,
W. H. Blauvelt.

Connellsville Coke From Semet-Solvay Ovens.—The following report of tests in coking Connellsville coal in Semet-Solvay retort ovens, and furnace tests of the coke produced, which were made for the Johnson Company, of Lorain, Ohio, is published by the special permission of A. J. Moxham, Esq.:

A. J. Moxham, Esq.,
President The Johnson Company,
Lorain, Ohio.

Dear Sir:—In harmony with your instructions, dated March 26, 1895, I have conducted a series of experiments of coking Connellsville coal in Semet-Solvay retort ovens, at the works of the Solvay Process Company, near Syracuse, New York. The coke made in the ovens was shipped to the large blast furnace of the Buffalo Furnace Company, at Buffalo, New York, and its value as a metallurgical fuel tested in this blast furnace in comparison with the best quality of the Connellsville beehive-oven coke, from the H. C. Frick Coke Company.

The main scope of these practical experiments was to determine, from actual accomplished work, the relative economies of the manufacture of coke in these two types of coke ovens, with their comparative calorific values in the work of manufacturing pig iron in a modern well-equipped blast furnace.

At this time, considerable attention is being directed to the economies in the manufacture of coke, with the saving of by-products in retort or closed ovens. The investigation is stimulated by the more recent improvements made in the construction of these ovens, mainly along the elements of securing good metallurgical coke by increased internal heat in the ovens, in the profits secured by saving the by-products of tar and ammonia, and by the increased percentage of coke made from the coal, reducing, in proportion, the percentage of impurities in the coke.

In addition to these, the plan of these ovens has been simplified and the cumbersome and expensive regenerators and recuperators omitted; increased oven heat has been secured by thinning the inside walls through which the flue heat is transmitted into the coking chamber of the oven.

With the use of the best coking coals, the competition between the open and closed ovens is quite close and difficult of exact determination. Other things being equal, the main effort in the manufacture of metallurgical coke in the retort ovens is to equal in calorific value, in blast-furnace work, the standard beehive-oven coke. But in the manufacture of coke from the lower qualities of coals, especially those low in fusing matters, the narrow ovens have undoubtedly established their superior value in this respect.

The large cost of the retort ovens, as compared with the open or beehive, is the main barrier to their more rapid introduction. This is as $3,100 in the former to $325 in the latter.

To make the tests in a fairly comprehensive plan, $2{,}058\frac{13}{20}$ tons of Connellsville coal was shipped from the Valley mines of the H. C. Frick Coke Company to Syracuse, for the initial coking test in the small experimental plant of twelve Semet-Solvay ovens at this place. These coking tests, as well as the subsequent blast-furnace ones, were made with great care, as the importance of such determinations evidently demanded. It was the first time in the industrial records that beehive and retort-oven coke, from Connellsville coal, were compared as to economy in cost of coking and relative value in blast-furnace work, on fairly equated conditions.

The following analysis of the Connellsville coal used in the coking tests at Syracuse, in the Semet-Solvay retort coke ovens, exhibits a fair average of the coal used:

	Per Cent.
Moisture, 212° F	.840
Volatile combustible matter	31.600
Fixed carbon	59.860
Ash	7.700
Sulphur	.820
Phosphorus	.008

The theoretic percentage of coke that can be obtained from the above coal is 68 per cent. This assumes that no fixed carbon is consumed in coking and that no carbon is deposited from the tar gas in the oven. In the modern beehive oven, 12 feet by 7 feet, some of the fixed carbon is consumed in the oven by the admission of air. At the same time, the percentage of its coke is increased by the bright glaze of deposited carbon.

Two very careful tests were made to determine the percentage of coke made in the Semet-Solvay oven from Connellsville coal.

No. 1 test charge, 9,200 pounds of coal, produced 6,580 pounds large coke, 164 pounds breeze, and 256 pounds dust and refuse.

No. 2 test charge, 9,000 pounds of coal, produced 6,349 pounds large coke, 80 pounds breeze, and 198 pounds dust and refuse.

	Test No. 1 Per Cent.	Test No. 2 Per Cent.
Large coke	71.52	70.55
Breeze	1.78	.88
Refuse, pitch, etc	2.63	2.20
Total coke	73.30	71.43
Average large coke	71.035	

From accurate determinations of the percentage of furnace coke produced from Connellsville coal in the beehive and Semet-Solvay coke ovens, it was found as follows: beehive, 66 per cent. of large coke; Semet-Solvay, 71 per cent. of large coke.

Taking the theoretic coke at 68 per cent., it is evident that a loss of 4.22 per cent. of carbon has been made in coking in the beehive oven. The Semet-Solvay, considered from the same standard, has gained 4.41 per cent. of carbon, or a total gain of 8.63 per cent. of carbon over the beehive product.

In the beehive, however, the carbon deposit consists of a bright silvery coating, affording efficient protection to this fuel from carbon-dioxide gas in its descent in a blast furnace. The carbon deposit in the Semet-Solvay oven is a dull-colored deposit of carbonaceous matter from the tar of the coal in coking. Much more carbon is deposited in the beehive oven than in the Solvay, but at the same time much more carbon is consumed in the open oven.

The Semet-Solvay oven is 30 feet long, 16½ inches wide inside coking chamber, and 5 feet 6 inches high. The accompanying cross-section, Fig. 22, will show its general features. It is constructed with dividing walls, arches, and superstructure of red brick. It is noticeable that the flue tiles with their connecting arch, composing the coking chamber, are entirely independent of and separate from the red-brick incasing structure; this secures freedom and room for expansion in the lining firebrick work of the coking chamber.

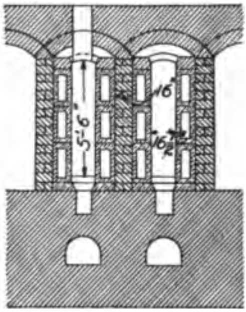


Fig. 22. Cross-Section Semet-Solvay Ovens

The 16-inch dividing and sustaining walls perform a double office by supporting the structure and in storing heat. The slight cooling of the oven during the few minutes occupied in discharging the coke is quickly restored by the heat stored in these incasing red-brick walls. The 2¾ inches in thickness of the inside face of the flue tiles transmits the heat from the combustion of the returned gas in the horizontal flues of the oven. The circuit of this heat is continuous in one direction and can be regulated at pleasure.

The hot gas from the ovens is carried under boilers to generate the necessary steam for the condensing plant, and for the engine in discharging the coke from the ovens. The surplus gas can be used in lighting the works, or in any other way that may be required.

The horizontal flues in this oven can be readily examined and cleaned. They convey the heat in an even and direct manner, avoiding any liability to the injurious concentration of heat that is sometimes found in vertical-flue ovens.

In considering the economies of this type of oven, it is important to inquire into its wearing properties. It is evident that the red-brick walls, arches, and superstructure are quite permanent, requiring no special attention in their repairs. The firebrick flue lining of the oven is the most liable to breakage and wear. The twelve ovens at Syracuse have been in use about 2 years, and are now in good condition. During this time one end flue tile had to be replaced from a crack found in it. It is quite evident that the end flue tiles are liable to break or crack from the frequent changes in temperature at the doors of the ovens. The inside flues are kept at a nearly uniform heat and are not so liable to crack.

As the coke is cooled on the outside of the oven, the difference in temperature inside should not seriously affect the life of the flued lining tiles. In case of crack or breakage of these jointed lining tiles, their renewal at the ends of the oven can be made at a small cost and in a short time. The renewal of the inner flues will require the cooling of the oven as well as the ovens on either side of it. This is the most serious aspect of repairs, involving considerable expense in time and labor. It may be said, however, that the renewal of the inside tiles is infrequent.

The coking test in these ovens was conducted mainly to determine the minimum time required with maximum heat to produce good blast-furnace coke. The various tests included coking periods ranging from 18 to 26 hours. It appeared that, with well-sustained oven heat, good blast-furnace coke could be made in 20 hours. This was the standard minimum time used in producing the coke for furnace test. Some coke was made by continuing it in oven 26 hours; this produced a bright hard coke evidently equal in hardness of body to the beehive coke of 72 hours. From subsequent experience in the furnace test it is quite probable that 23 to 24 hours would secure a firmer coke, which would bear faster furnace driving.

The coking tests began April 16, and closed May 17, 1895.

As before noted, there are only twelve Semet-Solvay ovens at the Solvay Process Works, at Syracuse, New York.

The analyses of Connellsville and Solvay cokes, made at the laboratory of the Buffalo furnace, by Mr. O. O. Laudig, chemist, are as follows:

	CONNELLSVILLE PER CENT.	SOLVAY PER CENT.
Moisture, 212° F.	.19	1.25
Volatile matter	1.17	1.61
Fixed carbon	89.02	86.66
Ash	9.62	10.48
Sulphur	.90	.77

Analyses of Connellsville coal and the coke made from it in Semet-Solvay ovens, from laboratory of the Solvay Process Company, by Mr. J. D. Pennock, chief chemist, are as follows:

	No. 3		No. 9		Breeze Per Cent.
	Coal Used Per Cent.	Coke Made Per Cent.	Coal Used Per Cent.	Coke Made Per Cent.	
Moisture, 212° F.	.470	.200	000	.070	4.73
Volatile matter	30.460	2.520	29 020	1.850	
Fixed carbon	62 920	87.480	61.610	87 070	78.57
Ash	6.620	10.000	9.370	11.080	16.70
Sulphur	.900	.850	.770	.750	
Phosphorus	025	.037	017	023	

In several tests in these ovens, the coal was moistened with 1, 2, and 3 per cent. and up to 5 per cent. of water, without apparent change in the quality of the coke produced or in the quantity produced from this coal.

The effect of the temperature of the oven in the manufacture of coke is well understood. For dry coals, a quickly applied high temperature produces the best possible coke. In the case of the richer coals, such as the Connellsville, a more moderate heat secures the best results in the coke.

During the progress of coking at Syracuse, in the Semet-Solvay ovens, frequent tests of the temperature in the flues and interiors of these ovens were determined by the use of the German Segar Cones. These have been recorded as follows:

	Degrees Fahrenheit		Degrees Fahrenheit
East flue, top	2,130	East flue, bottom	2,138
West flue, top	2,112	West flue, bottom	2,174
East flue, center	2,222	Within the mass of coke	1,994
West flue, center	2,354	Above the mass of coke	1,958

Temperature tests taken in the beehive oven immediately above the coking coal gave the maximum heat, 2,778° F., from 48-hour or furnace coke.

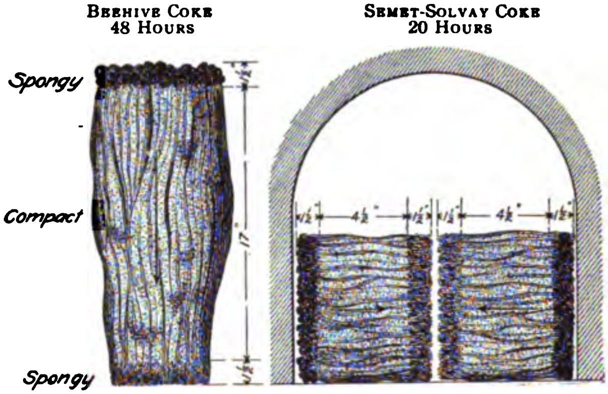
From the foregoing, it will be readily seen that in the coking operations of these ovens the application of heat is quite different. The long time required in drawing the coke from the beehive oven reduces its temperature to 300° or 400° F. The operation of coking, therefore, begins under a mild heat, increasing gradually until the high maximum is reached midway in the operation, producing a hard-bodied coke with fully developed cells.

On the other side, the rapid discharge of the coke in the Semet-Solvay oven by a steam-engine pusher reduces the temperature very slightly, and on closing the doors of the oven for a fresh charge of coal the average heat is rapidly restored. The oven heat is, therefore, applied quickly and maintained throughout the time of coking.

In the open, or beehive, oven the coking of the charge of coal begins on the upper horizontal surface, reaching down through the charge gradually to the floor of the oven. The coke crystallizes in a vertical columnar structure in surfaces at right angles to the horizontal plane of the oven. In the Semet-Solvay oven the planes of crystallization are at right angles to the vertical side walls of the oven, and consequently in horizontal postures. The coking begins at the oven side walls, moving gradually to the central longitudinal plane of the oven, where a line of demarcation is developed in a shelly section of coke of inflated physical structure. The pressure of the charge of coal in the narrow oven compresses the cell structure of its coke, making it more dense than the broad oven with shallow charges.

The general structure of beehive and Semet-Solvay coke will be noticed in the sketches, Fig. 23.

A beehive oven of 12 feet in diameter, taking the inflated structure of coke at top and bottom of charge at 3 inches, will afford 85 per cent. of good coke and 15 per cent. of spongy coke. The Semet-Solvay oven makes 3 inches of spongy shattered coke in the middle of the charge, producing 81 per cent. of compact coke and 19 per cent. of spongy coke. The beehive oven will make an average of 2 net tons of coke per day. The Solvay will afford a product of 4 tons per day.


BEEHIVE COKE
48 HOURS

SEMET-SOLVAY COKE
20 HOURS

Dense coke, 3 inches.
Average coke, 9 inches.

Spongy coke, 3 inches.
Arrows show direction of coking.

FIG. 23

The table on page 283 will exhibit, in detail, the physical and chemical properties of cokes made in these typical ovens.

It will be noted that the Connellsville coke, used at the Buffalo furnace during the test, was from the Adelaide works of the H. C. Frick Coke Company. The coal used in making coke in the Semet-Solvay ovens at Syracuse, New York, was shipped from the Valley mines of the H. C. Frick Company.

The physical determinations of the Adelaide coke exhibit a most excellent structure, equaling the standard coke of this region. The analysis shows its superior chemical purity, excelling in this respect the standard coke.

The physical tests of the Semet-Solvay coke exhibit the increase of density in the retort coke as compared to the beehive. These are typical examples and indicate in a clear and definite manner the condition of coke made in the two principal types of coke ovens. The increase of cell space will be noticed in the Solvay coke, from the walls of the coking chamber to the middle of the oven. The average increase in density of the Solvay coke over the standard beehive is 12.7 per cent. The compression of cell structure is 11½ per cent.

FULTON'S TABLE EXHIBITING THE PHYSICAL AND CHEMICAL PROPERTIES OF COKE

REVISED SERIES

Connellsville	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Per Cubic Inch ¼ Ultimate Strength	Height of Furnace Charge, Supported Without Crushing	Order in Cellular Space	Hardness	Specific Gravity	Chemical Analysis						Remarks
	Dry	Wet	Dry	Wet	Coke	Cells						Fixed Carbon Per Cent.	Moisture Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.	Volatile Matter Per Cent.	
Beehive	12.51	21.62	47.69	82.20	43.93	56.07	272	108	1	3	1.74	86.88	.79	11.54	.695	.005	1.31	(*a*) Standard average
Beehive	13.66	23.31	52.02	88.72	43.91	56.09	315	125	1	3	1.80	89.02	.19	9.62	.940	.019	1.17	(*b*) Adelaide, H. C. Frick Co. Buffalo
Semet-Solvay	16.48	24.29	61.59	92.47	56.16	43.84												(*c*) Section at oven walls
Semet-Solvay	14.92	23.47	55.80	89.51	47.61	52.39												Intermediate section
Semet-Solvay	15.40	25.48	59.29	96.20	46.60	53.40												Middle section
Semet-Solvay, average	15.43	24.18	58.12	91.92	49.49	50.51	370	147	1	3	1.90	86.66	1.25	10.48	.770	.018	1.61	(*d*) Used at Buffalo

NOTE.—The above cokes were all made from Connellsville coal. The coke used at the furnace test at Buffalo consisted of beehive and Semet-Solvay, made in the open and retort ovens. (*a*) T. T. Morrell, chemist; (*b*) O. O. Laudig, chemist, Buffalo Furnace Company; (*d*) J. D. Pennock, chief chemist, The Solvay Process Company, Syracuse, New York.

TABLE EXHIBITING THE RELATIVE ULTIMATE ECONOMY OF PLANTS OF BEEHIVE AND SEMET-SOLVAY COKE OVENS

Name of Oven	Cost Per Oven Dollars	Cost of Condensing Plant Per Oven Dollars	Total Cost Per Oven Dollars	Daily Output Per Oven Net Tons	Number of Ovens to Make 300,000 Net Tons Per Year	Total Cost of Plant Dollars	Interest on Investment 5 Per Cent. Per Year Dollars	Interest Per Ton of Coke Cents	Sinking Plant in 20 Years, Per Ton Cents	Labor Making Coke and Saving By-Products . . Cents	Total Cost Per Net Ton Cents	Percentage of Coke Produced	Value of Units of Coke Over 66 Per Cent. Cents	Value of By-Products Per Net Ton Coke Cents	Net Ultimate Cost of Coke Per Ton Cents	Remarks
Beehive..........	325		325	2	500	162,500	8,125	2.75	2.75	35	40.5	66			40.50	By-products not saved
Semet-Solvay.....	1,550	1,550	3,100	4	250	775,000	38,750	12.90	12.90	40	65.8	71	07	40	18.75	By-products saved

NOTE.—The by-products are estimated as affording net profits as follows: ammonia sulphate, 25 cents per net ton of coke made; tar, 6 cents; and surplus gas, 9 cents. In the above comparison of relative cost and work of ovens no estimate has been made of the cost of repairs for each type of coke oven; it is assumed that these will not vary much in a term of 20 years.

The chemical analysis shows a fairly clean coke, but exceeding the Adelaide coke in the percentage of ash. This analysis discloses the fact that the Solvay coke retained 1.61 per cent. of volatile combustible matter, as against only 1.17 per cent. in the Adelaide coke, an increase of 3.76 per cent. This indicates the requirement of a longer time in the coke oven, or an increase of heat to reduce this volatile element.

Retort coke should be somewhat harder bodied than open-oven or beehive, coke. But in the table on page 283 they are just equal, which sustains the demand for more oven heat or longer time in coking in the retort oven. It is also important to reduce the percentage of the inflated sections of coke in the middle of the oven. It is submitted that by widening the oven chamber to 20 inches, the ratio of shattered to solid coke would be largely reduced.

The tabulated statement on this page will exhibit the relative costs and economies in plants of beehive and Semet-Solvay coke ovens, to produce 300,000 net tons of blast-furnace coke per year, using Connellsville coal.

The breeze from handling the Solvay coke is much less than that from the beehive coke. Little waste is found in careful handling of Semet-Solvay coke.

The Buffalo furnace, of the Buffalo Furnace Company, is a modern blast furnace, 18 feet at bosh and 80 feet high. It has three hot-blast stoves, 18 feet by 70 feet, of the Cowper-Kennedy type. The blowing engines have surplus power and can increase the pressure of blast to meet the requirements of different densities of fuels. The plant is located on the bank of the Buffalo River, on the west end of Hamburg Street, and receives its ore stock direct from the lake boats.

The limestone for fluxing comes from Canada, from the upper members of the Helderberg formation, and is most excellent for this purpose. Many of its sections are highly saturated with petroleum. The composition of limestone is as follows:

	Per Cent.
Carbonate of lime	97.45
Carbonate of magnesia	1.40
Oxide of iron, alumina, etc	.50

The coke used at this furnace is supplied by the H. C. Frick Coke Company. It was especially noted as the very best quality of furnace coke; evidently it had been carefully selected, as no black ends were visible in the supply examined. It was, therefore, quite manifest that the best Connellsville beehive coke would be used in the competitive test with the Semet-Solvay coke. The whole furnace plant is ably managed by Mr. F. E. Bachman.

Immediately before the commencement of the coke tests, the furnace was banked a short time to give opportunity for cleaning the hot-blast stoves. It was assumed that a few days after resumption of work, the furnace would regain its normal condition. It did not, however, attain uniform work throughout most of the time of these tests, but it is proper to submit that the irregularities in its working were about equally distributed over the periods of the use of beehive and Semet-Solvay cokes; possibly somewhat more during the use of the Semet-Solvay coke.

This furnace is run chiefly to make open foundry pig iron, and this was its product during the time of these coke tests, with some exceptions, when a denser metal, denominated "holly," was produced.

The mixture was changed slightly during the tests, but was on an average as follows:

	Pounds
Marquette iron ore	17,000
Winthrop iron ore	878
Rex iron ore	636
Florence iron ore	1,050
Queen iron ore	672
Total	20,236

This mixture gave an average product of 57.29 per cent. of foundry pig iron.

The weights of the coke charges averaged as follows:

	Pounds
Beehive, Connellsville	10,923
Retort, Semet-Solvay	11,830

The limestone charges averaged as follows:

	Pounds
For Connellsville coke	3,300
For Semet-Solvay	3,600

The general table of blast-furnace operations, on page 287, will exhibit the results of these tests, with Connellsville beehive and Semet-Solvay cokes.

These general results require and will be adjusted subsequently, so as to give to each test the true results of its work as accurately as can be determined.

The test of the Connellsville beehive coke began May 12, at 6 o'clock A. M., and closed May 16, at 5 o'clock P. M. The Semet-Solvay coke test began at the close of the beehive coke and ended May 22, at 2 o'clock A. M. Approximately 5 days were allotted to each kind of coke.

Samples of each kind of coke were submitted to severe tests for moisture, in a neighboring foundry core oven, and resulted as follows: Connellsville beehive coke, 973½ pounds dried to 956 pounds; loss, 1.830 per cent. Semet-Solvay coke, 1,174¼ pounds dried to 1,114¼ pounds; loss, 5.385 per cent. The heat of the core oven was not determined, but it was estimated, approximately, as approaching 300° F.

Referring to the analyses of the beehive and Semet-Solvay cokes, made in the laboratory of the Buffalo Furnace Company and at the Solvay Process Works, it will be noted that the beehive coke has been made from much cleaner coal than that from which the Solvay was made. Taking the average of these two determinations for the Semet-Solvay coke would give it, in round numbers, 88 per cent. of carbon, and the beehive 89 per cent. as charged into the furnace. Equating these cokes for the moisture, it will reduce the carbon in the Semet-Solvay coke to 84 per cent. and the beehive to 88 per cent. of efficient available carbon for furnace use, allowing for the volatile matters in these cokes.

The table shows that there was little waste from soft coke, as the relations of the two gases, $CO_2 : CO$, were found to be as 1 : 2.47 in the beehive coke, and as 1 : 2.27 in the Semet-Solvay product. Sir I. Lowthian Bell found the relations of these gases in a large test of Durham beehive coke as 1 : 2.28, and in Simon-Carvés' retort-oven coke as 1 : 3.32.

The heat in the furnace during these tests was fairly well sustained. Closing the Connellsville beehive test, a disarrangement

TESTS OF BEEHIVE AND SEMET-SOLVAY OVEN COKE, FROM CONNELLSVILLE COAL, MADE IN THE BUFFALO FURNACE, MAY, 1895

Date, 1895	Kind of Coke	Furnace Charges—24 Hours Pounds			Iron Made, Tons—2,300 Pounds					Total Tons Daily	Stock Per Ton of Metal			Average Pressure of Blast Pounds	Heat of Blast at Furnace Degrees F.	Gases, Top of Furnace		Ratio, $CO_2 : CO$	Average	Silica in Metal Per Cent.	Cinder		Remarks
		L.S.Ore	Lime-stone	Coke	No. 1	No. 2	No. 2 Plain	No. 3	Rag-ged		Ore Pounds	Lime Pounds	Coke Pounds			CO_2 Per Cent.	CO Per Cent.				SiO_2 Per Cent.	Al_2O_3 Per Cent.	
May 12	Connellsville Beehive	920,760	158,000	524,300	8	92	110	16	9	235	3,918	672	2,231	7.75	1,088	10.0	21.900	1:2.19	1:2.47	3.00	30.82	22.40	Furnace working irregular
May 13		968,540	167,000	546,150	6	94	91	11	5	207	4,679	806	2,657	7.75	1,093	8.8	22.536	1:2.56		2.86	31.20	20.00	Furnace working irregular
May 14		1,012,960	171,600	568,000	6	68	117	62	6	259	3,911	662	2,208	8.00	1,125	9.0	23.200	1:2.59		1.91	36.80	20.06	Improved working
May 15		972,000	165,000	546,150	8	66	138	34	7	253	3,845	652	2,174	8.20	1,159	10.2	26.600	1:2.60		2.22	37.20	20.04	Becoming more regular
May 16		385,820	67,800	218,460		69	61	110	5	245	3,600	643	2,184	7.33	1,226	8.5	21.000	1:2.47		2.32	32.44	21.30	Cooled furnace, reduced lime
May 16	Semet-Solvay Retort	489,380	89,800	295,730																			Furnace cool
May 17		890,880	158,720	532,350		94	95	50	5	244	3,248	650	2,181	8.00	1,167	9.1	21.900	1:2.40	1:2.27	3.05	29.00	21.15	Slipping; not down to regular work
May 18		901,800	157,500	532,350		61	99	66	5	231	3,904	682	2,304	7.50	1,218	9.1	21.800	1:2.28		1.93	33.80	17.70	Two slips today—cooling furnace
May 19		854,700	152,480	496,860	10	113	84	16	5	228	3,749	669	2,179	6.50	1,234	10.7	22.500	1:2.10		2.25	30.40	18.10	Furnace gaining heat
May 20		966,900	150,800	496,860	18	99	73	12	5	207	4,140	728	2,475	7.32	1,240	9.4	21.000	1:2.23		2.49	30.15	19.70	Improved working
May 21		707,530	130,575	421,463	45	148	133	25	9	260	2,721	503	1,621	7.00	1,251	8.8	20.700	1:2.35		2.42	33.80	16.00	Working steadily

of the stock scale reduced the limestone, causing a slight lowering of temperature of furnace at the opening of the Solvay coke test.

The analyses of six casts of beehive and Solvay iron will afford comparison of heat of furnace and quality of pig metal produced, all of which was No. 2 pig.

	Connellsville Coke	Semet-Solvay Coke
Graphite carbon	3.760	3.600
Combined carbon	.170	.180
Silicon	2.770	2.150
Phosphorus	.283	.284
Sulphur	.049	.039
Manganese	.780	.780

The following condensed statement will show the stock used and pig iron produced from beehive and Semet-Solvay cokes, during these tests:

	Beehive Coke Test	Semet-Solvay Coke Test
Iron ore used	4,260,080 pounds	4,711,190 pounds
Limestone used	729,400 pounds	870,700 pounds
Coke used	2,403,060 pounds	2,775,613 pounds
Pig metal made	1,122 tons (of 2,300 pounds)	1,205 tons
Coke per pound of iron	.956 pound	1.028 pounds

Equating the conditions of these cokes and eliminating excess of moisture, the coke per pound of iron will be for beehive .938 pound, and for the Semet-Solvay .972 pound.

When the further fact is taken into consideration that the Semet-Solvay coke contained an average of 10.17 per cent. of ash, while the beehive had only 9.62 per cent. of this impurity, the quantity of each kind of coke to smelt 1 ton of foundry metal is substantially equal, and the amount of coal used as Semet-Solvay coke is proportionably reduced.

Introducing the factor of relative proportions of coke made from a pound of coal in the two types of ovens, the comparison becomes as follows: beehive, 1.421; Semet-Solvay, 1.389.

The different grades of foundry metal made during the 5-day test by each kind of coke are as follows:

	No. 1 Tons	No. 2 Tons	No. 2 Plain Tons	No. 3 Tons	Ragged Tons	Total Tons
Beehive	20	357	480	237	28	1,122
Solvay	73	487	461	156	28	1,205

It will be noted that the Solvay coke products in pig iron, Nos. 1 and 2, give 560 tons, and the beehive, 377 tons. The lower products of Solvay coke in No. 2 Plain, No. 3, and Ragged give 645 tons, against 745 tons from the beehive coke. The difference, therefore, in the heats afforded in the metal made by beehive and Solvay coke is fairly in favor of the latter.

The most vital inquiry, in these competitive tests, consists in the relative physical properties of these cokes to stand rapid driving in the furnace. It was found that usually the Connellsville beehive coke could take a blast from 51 revolutions of engine, while the Solvay coke reached its maximum at 48 revolutions, a reduction of 5.88 per cent.

The tabulated statement of furnace operations during these tests shows that the largest output of pig iron from beehive coke was 259 tons, and from Solvay coke 244 tons; a decrease in daily product of the latter of 5.79 per cent., which is in harmony with the reduction of blast when using the Solvay coke. It is true, however, that the Connellsville beehive coke requires to be reduced occasionally to 48 revolutions in the blast, but this is the exception rather than the rule.

The analyses of the gases at top of furnace show that there is no loss in the Solvay coke from dissolution in its passage down the furnace, from carbon dioxide; but on the other side it resists this gas with more firmness than the Adelaide coke. No temperature tests were taken as to the heat of the gases at top of furnace, but the relations of CO_2 to CO are assuring that no waste from dissolution from the soft or spongy portions of the fuel had taken place.

From the denser physical properties of the Solvay coke, it was anticipated that an increased pressure of furnace blast would be required to develop its best qualities, but in this we were somewhat disappointed, as the furnace test reversed the order of blast in a direction just opposite to the one anticipated. The conclusion is evident that the Solvay coke requires more heat or more time in the oven to enable it to stand the blast in driving the furnace equal to the beehive coke.

In making the coking tests at Syracuse, all needed facilities were cheerfully afforded by the chief officials of the Solvay Process Company. To Mr. Thomas Morris, superintendent of the coke ovens, I am indebted for many helpful suggestions and other favors.

During the progress of these tests at Buffalo, we were favored with the presence of Mr. W. B. Coggswell, managing director of the Solvay Process Company, as well as by Mr. W. H. Blauvelt, fuel engineer, of this company. The Carnegie Company was represented by Mr. James Scott, the superintendent of the Lucy Furnaces in Pittsburg; also, Mr. Charles McCrery, manager of the Dunbar Furnaces.

Mr. T. B. Baird, vice-president of the Buffalo Furnace Company, and its manager, Mr. F. E. Bachman, afforded full opportunity to secure results of tests. Mr. Baird was especially courteous in extending to the visitors many favors.

Mr. W. T. Richards, of Cleveland, who directs the management of the M. A. Hanna Furnaces, was very helpful in these tests.

In conclusion, it may be submitted that, while the testing time of these cokes in the blast furnace has been necessarily limited, yet it has afforded some reliable indications of the relative values of retort and beehive coal in the manufacture of pig iron.

It has been established that the denser coke of the retort oven could not be driven as fast in the furnace as the more open-celled beehive coke, in relations of 48 to 51.

It has yet to be shown that the denser retort coke, hardened by increased heat and time in the oven, can be made to stand a blast, proportionally stronger than that of the beehive fuel, to equal the furnace output of the latter in pig metal.

In the relations of density of fuel to speed in a blast furnace, the fact has been definitely settled that, other conditions being equal, the speed is in proportion to the density of the fuel. This is found in the use of anthracite coal (which is a natural coke), in blast-furnace operations, in its slow calorific energy, as compared with open-celled beehive coke. The output in pig iron of the former to the latter is as 3,000 to 8,000 tons per month, or as 1 : 2.66.

The retort oven, however, affords advantages, as from the Connellsville coal it will yield 71 per cent. of large coke for furnace use, against 66 per cent. of a similar product of the beehive. This, with the saving of by-products by the retort oven, compensates for the difference in its energy or speed in a blast furnace, as compared with the beehive fuel.

The Semet-Solvay coke oven has been designed under correct principles, as regards wearing properties and output. Its most distinguishing property is in its rapid work in coking, which is 30 per cent. shorter in time than its chief competitors.

Very respectfully,
Jno. Fulton,
Mining Engineer.

Johnstown, Pa., July 2, 1895.

The **Rothberg by-product coke oven,** Fig. 24, belongs to the well-known horizontal-flue type of which the Semet-Solvay oven can be considered the prototype. This oven differs from the Semet-Solvay in that a vertical wall *a*, Fig. 24 (*b*), divides the flues in the center into separate parts and that standard brick are used instead of special tile. Also, one set of flues serves two adjacent ovens, while the Semet-Solvay has a solid wall between two ovens, which necessitates separate flues. The oven chamber is about 33 feet long, 16 inches wide, and 6 feet 6 inches high, having a capacity of 7 tons of compressed coal or 5½ tons of loose coal per charge. The average coking period is 30 hours, but has been reduced to 24 hours on test. No regenerator chamber or hot stove is used, the air, which is taken in through openings *b*, *b*, being heated in the recuperative flues *c* and *d*.

Fig. 24 (*b*) shows the flues and dampers. From the recuperative flues, the air passes through vertical flue *e* and meets the gas from the first burner at *f*. From this point, the flame is either forced through the horizontal flue to the center of the oven and back in the next lower flue, or is allowed to pass directly to the next lower

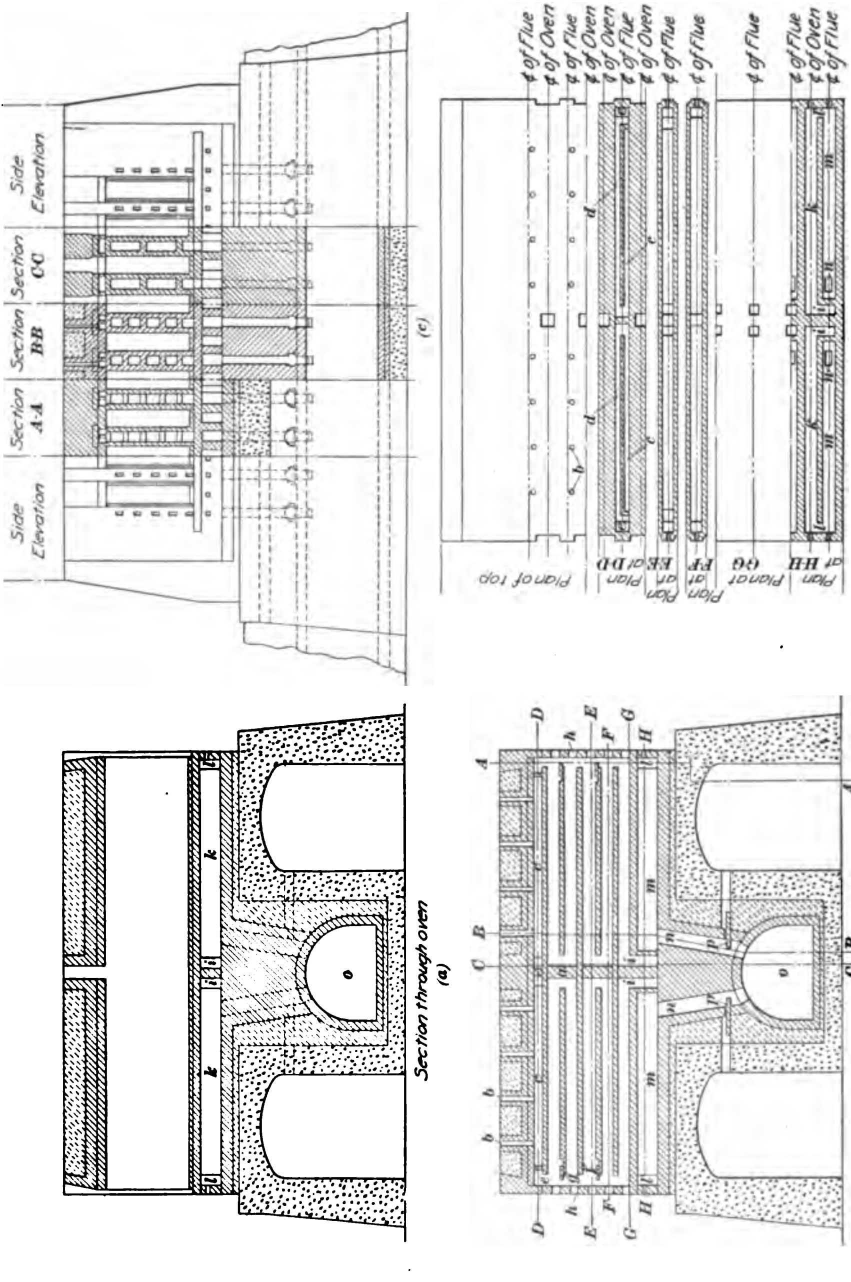


FIG. 24. THE ROTHBERG BY-PRODUCT OVEN

flue by opening the damper *g* in the vertical flue. By observation through peep hole *h*, it is easily determined which course the gas should take to keep the heat of the oven uniform. The second damper, below the second burner, is adjusted in a similar manner. The gas of combustion is led through flues *i* and *k* under the oven and back through *l* and *m* to the stack through *n* and the gas sewer *o*. The stack draft is regulated on any oven by damper *p*. By admitting the gas into the different flues, and by using the regulating dampers, a very uniform temperature is maintained. Air can be admitted through any of the peep holes in case it is necessary for the combustion of the gas.

The advantages claimed for these ovens are: (1) The cost of construction is reduced by the elimination of the regenerators and hot-air fans, and the air is sufficiently heated in the inexpensive recuperative flues. (2) The ovens are easily operated. A uniform temperature is maintained without difficulty by the use of the regulating dampers, as every part of the oven is under complete and independent control. (3) Operating expense is reduced by cutting out the elaborate hot-air system.

This type of oven was first used at the Lackawanna Iron and Steel Company's plant at Lebanon, Pennsylvania, in 1903, where an experimental battery of five ovens was erected. The results obtained from this small battery caused the Lackawanna Company to install the oven at their Buffalo plant; 282 ovens have been built and 470 more are in course of construction at that place.

The A. Hüssner Coke Oven.*—This is one of the forms of coke ovens built mainly for the saving of by-products in coking. Mr. Hüssner, the inventor, is one of the early experts in the successful work of securing these products.

The flues in this oven are horizontal; similar in this respect to Simon-Carvés and the Semet-Solvay ovens. This oven differs from the Coppée and Hoffman types in the posture of its flues, as they have the vertical posture. The horizontal-flued ovens afford a very uniform diffusion of heat in a simple and direct manner.

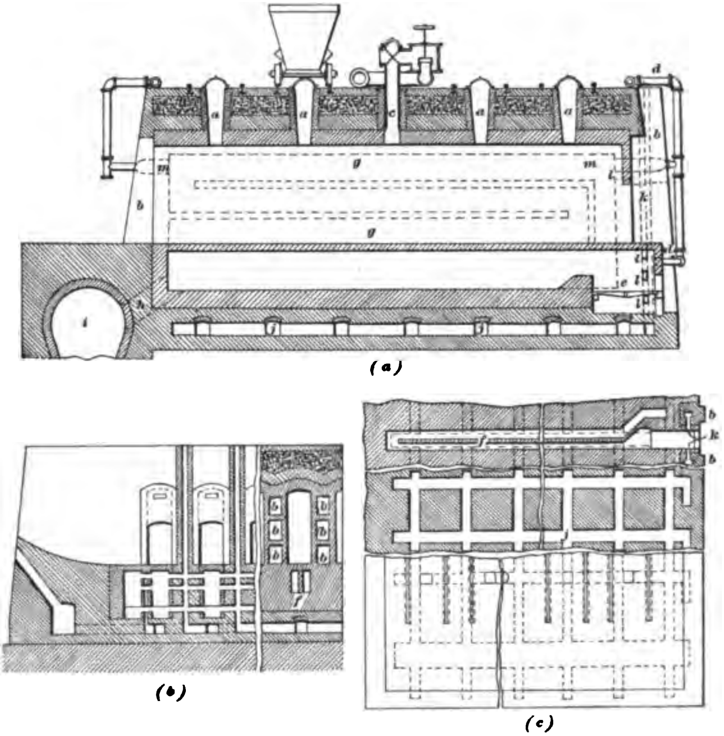
The dimensions of the flues are: length, 29 feet 6⅜ inches; width, in the middle, 1 foot 10⅜ inches, with a certain taper to facilitate the mechanical discharge of the coke; height, 5 feet 10⅛ inches. (The original Carvés oven is 19 feet 8¼ inches, by 2 feet 5⅜ inches, by 4 feet 9 inches high.) The available space in the Hüssner ovens is 88 per cent. of the total space, and they have a charge of 5½ tons of finely sifted, dry coking coal.

The charging takes place by four holes *a*, *a*; the ends are closed by doors turning on hinges; the discharging takes place by the usual steam pushing machine. The end walls between each two ovens are strengthened by buttresses *b*, Fig. 25 (*a*), which at the same time prevent air from entering the flues.

---

*Lunge, 1887.

The gases are aspirated by means of an exhauster through the outlet *c*, and are forced through the condensers and scrubbers, then return to the ovens and issue by the tube *d* over the fire-grate *e*, where they take fire. The fire gases travel around the partition *f*, rise at one end and up to the top flue *g*, and descend through three horizontal flues and the snore hole *h* into the main flue *i*. The mouth of the gas-inlet pipe *d* is an annular double tube, like a Bunsen burner; while the inner tube conveys the air for combustion, the combustible gas issues through the annular space, and both enter at the same time into *e*. Owing to the distance that the products of combustion have to travel before they reach the main flue *i* (about 100 feet in Carvés oven), they were formerly cooled too much, while the oven bottoms were fluxed. To avoid this, Hüssner (about the same time that Carvés took out his new patent in 1883) introduced a previous heating of the air to about 300° centigrade in the flues *j*; it is then conveyed through the small flue *k*, contained in the buttress *b*, partly through *l* into the grate space *e*, partly through *l* into the top flue *g*, and in both



(a)

(b)

(c)

Fig. 25. Hüssner Coke Oven

places gets mixed with gas. This does not seem to have met with complete success; but after adding further gas inlets at *m* and *m*, the fire on the grate *e* could be left out, the gases sufficing for heating the retorts.

The cost of erecting a set of one hundred Hüssner ovens in Gelsenkirchen, Westphalia, according to a published balance sheet, was: For ovens, buildings, machinery and iron wall, railroads and water supply, £300 per oven ($1,500). The ovens are charged, at intervals of 60 hours, with 5½ tons of coking coal.

They are stated by Hüssner to yield from good coking coal as follows:

	PER CENT.
Large coke	75.00
Small coke	.80
Coke breeze	1.20
Tar	2.77
Sulphate of ammonia	1.10

A recent statement claims that, from a charge of 7 tons of coking coal, 5 tons of coke is obtained in 48 hours; this shows a product of 71.43 per cent. of coke.

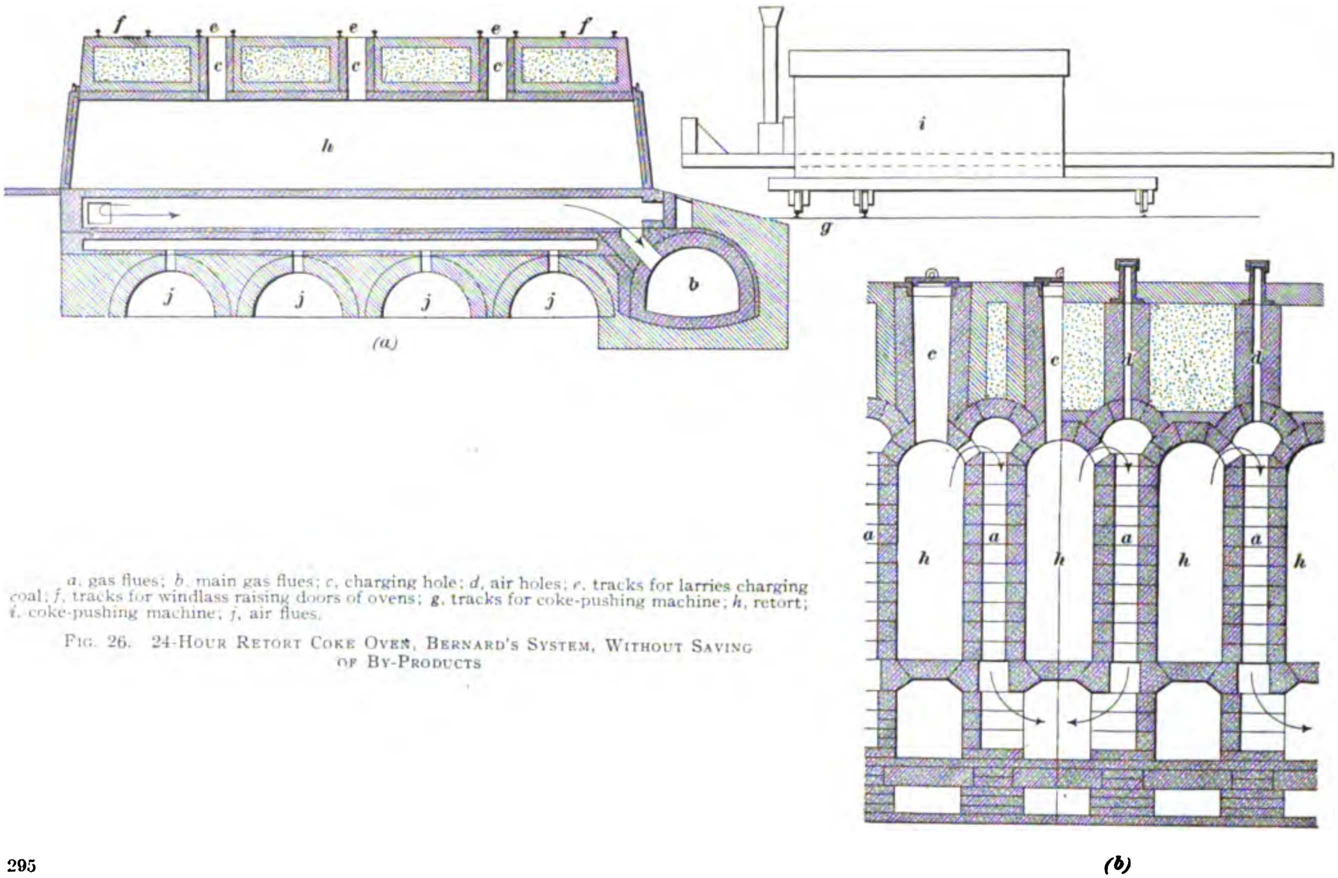
It is also submitted that all the surplus heat from the ovens can be returned to the steam boilers, or other uses, affording a much greater heat supply than is usually obtained by the use of a portion of the gas, deprived of the by-products, to the steam boilers. In the Otto-Hoffman ovens, 40 per cent. is estimated for use in generating steam.

It is evident that this oven, from the substantial method of its construction, its horizontal flues and its simple requirements in its operation, is destined to meet the wants in the coking of a wide range of the several qualities of coking coal, with slight revision in its dimensions.

The Bernard Coke Oven.—Fig. 26 shows the Bernard system of retort coke ovens. This oven was designed for producing coke only, but when it is further desired to save the by-products of tar and ammonia, the arrangement of the flues is changed from the vertical to a horizontal position.

The first trial battery of these ovens consisted of thirty-six ovens; the second and more recently completed addition has eighteen ovens, making in all fifty-four coke ovens at this plant. These ovens were built by Mr. Walter M. Stein, of Primos, Pennsylvania, for the New Glasgow Iron, Coal, and Railway Company, of Nova Scotia.

The coke is discharged from the ovens by a steam ram every 40 to 48 hours, according to the regularity or irregularity of the supply of coal for charging. Each oven is charged with 6 gross tons of crushed and washed coal, containing 12 per cent. of moisture. The total daily charge for the fifty-four ovens is 162 gross tons of coal.



a, gas flues; *b*, main gas flues; *c*, charging hole; *d*, air holes; *e*, tracks for larries charging coal; *f*, tracks for windlass raising doors of ovens; *g*, tracks for coke-pushing machine; *h*, retort; *i*, coke-pushing machine; *j*, air flues.

FIG. 26. 24-HOUR RETORT COKE OVEN, BERNARD'S SYSTEM, WITHOUT SAVING OF BY-PRODUCTS

The one-half of the ovens, twenty-seven, discharged daily, gives from each oven 2¼ tons of marketable coke, with less than 3 per cent. of moisture; the aggregate daily product is therefore 60¾ gross tons of coke. This exhibits a yield of good coke of fully

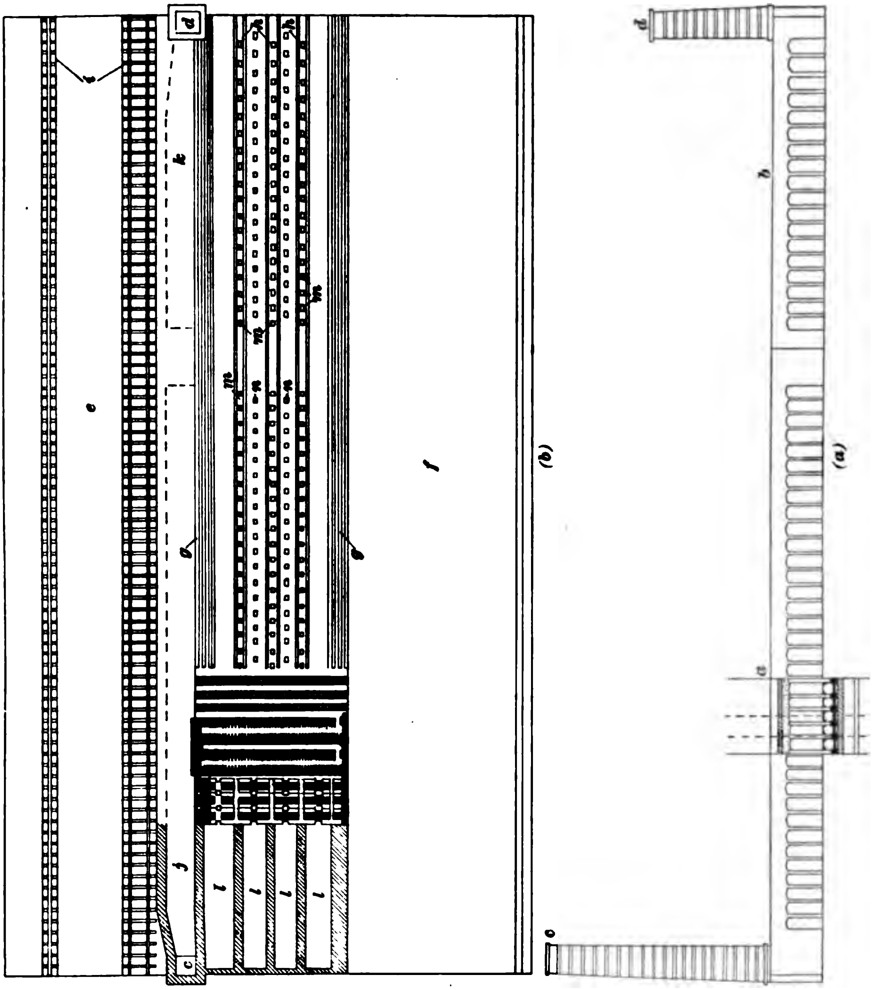


Fig. 27. General Plan of Fifty-Four Retort Coke Ovens, Bernard's System, Patented. Built by Walter M. Stein

a, battery of thirty-six retort coke ovens, Bernard system; *b*, battery of eighteen retort coke ovens, Bernard system; *c*, chimney for *a*; *d*, chimney for *b*; *e*, side of coke-pushing machine; *f*, coke-discharge side; *g*, tracks for windlass for raising doors of ovens; *h*, tracks for larries for charging ovens; *i*, tracks for coke-pushing machine; *j*, main gas flue of *a*; *k*, main gas flue of *b*; *l*, air flues; *m*, charging holes; *n*, air holes.

75 per cent., which has been carefully ascertained by coal charged into the ovens and the merchantable coke produced.

As Mr. Stein writes: "The cost of coke making at Nova Scotia is, on an average, 15 cents per ton; this includes taking the coal from the storage bin, charging it into the ovens, pushing the coke out of ovens, closing the oven doors, sealing them with loam and watering the coke. This work is performed by a party of nine men; they could with ease take care of six ovens more if necessary. These nine men are all ordinary laborers, with the exception of one, who has charge of the pushing engine. The coke is loaded on charging buggies by additional men, and conveyed to the blast furnace by an endless rope. It will be noted that a force of nine men is required for a plant of retort coke ovens, whether it consists of ten or sixty ovens. For more than sixty ovens, an additional force of nine men is necessary. It will thus be seen that the maximum economy in the manufacture of coke in these ovens is only secured by a battery of sixty ovens.

"The nine men operating this plant of fifty-four ovens are distributed as follows. Three fillers on top of ovens. Two on coke side and two on pusher side to clear the doors, level the charges of coal in the ovens, and seal the doors with loam. One man is required to cool the coke with water as it is pushed out of the ovens. The ninth man is in charge of the engine for pushing the coke out of the ovens. A bank of sixty coke ovens is considered as affording a fair daily amount of work for the nine attending workmen."

The cost of washing the coal is somewhat below 5 cents per ton in summer and 10 cents per ton in winter, indicating a yearly average for this work of 7½ cents per ton.

The whole cost of labor in making one ton of coke is as follows: work at washing plant, 7½ cents; work at coking plant, 15 cents; making a total of 22½ cents. This is exclusive of repairs to ovens or machinery, supplies, etc.

Mr. Stein further adds, in regard to the cost of repairs to the ovens per ton of coke: "I beg to say that these ovens have not cost in repairs $100 since they were started; the only repairs that will be required are the door blocks on the discharge side, where some scaling of brick corners occurs by the use of water in cooling the coke. Occasionally, a hole is burned in bottom of oven by an irregular supply of air. At long intervals, a door will crack, but this is infrequent.

"As a general rule, retort coke ovens, well constructed and skilfully operated, will require very little repairs during the first 10 years. Three years ago, during a long strike of miners in Germany, I had the privilege of examining the inside of numerous ovens of various types, and they generally looked well inside, though all or nearly all of them had been in continuous use for about 10 years; they appeared to be good for at least 5 years of additional work."

I have examined a sample of this Nova Scotia coke; it is quite firm and hard-bodied and is a fairly good furnace coke. This result has been mainly secured by the admirable preparatory work in washing the coal, a description of which, by Mr. Stein, is given on page 69.

In reference to the cost of this bank of retort coke ovens, with coke-discharge engine, it is somewhat difficult to say, as the materials for the experimental plant of thirty-six ovens were imported, which would add to the cost. The principal elements of cost were as follows:

One coke-discharging engine	$ 3,000
Iron parts of coke ovens, complete	9,000
Foundation of ovens and red brick	8,000
Firebrick, all imported	30,000
Superintendence, plans, etc	5,000
Total	$55,000

The cost per oven is therefore about $1,000. In the states of Pennsylvania, Ohio, West Virginia, Missouri, Illinois, Alabama, and Kentucky, where excellent firebrick is readily and cheaply obtained, the cost of these ovens should be somewhat under the cost above stated.

The Brunck Coke Ovens.*—Since the time of the experimental plant described by the inventor (the late Franz Brunck), in 1894, a number of installations have been laid down on this system in Rhenish-Westphalia and elsewhere. In general, the original form of the ovens and conduits has been retained, but a great improvement adopted in the arrangement of the double flue, whereby the following advantages have been secured: the two halves of the oven can be heated independently of each other, the waste gases from each half being led away separately. Furthermore, the air of combustion can be heated to a very high degree by being directed upwards through the checkerwork of firebrick situated between the two flues, which are maintained at a high temperature by the waste gases from the oven; the air is then led over the arch of the flue and traverses the cooling channels in a direction contrary to that taken by the furnace gases. In this manner, a large part of the heat escaping from the ovens is returned to them in the most direct manner, without any loss by radiation, while on the other hand, the heating and fusing of the firebrick of the flues are prevented.

A vertical section of the oven and heating conduits is shown in Fig. 28, path of heating gas and air for support of combustion being indicated by arrows. This illustration represents one of the ovens in a battery of one hundred and twenty at the Minister Stein pit, Gelsenkirchen. Each half of the oven is heated from the bottom and the two sides, the flames being readily accessible,

---

*R. Brunck in "Stahl und Eisen."

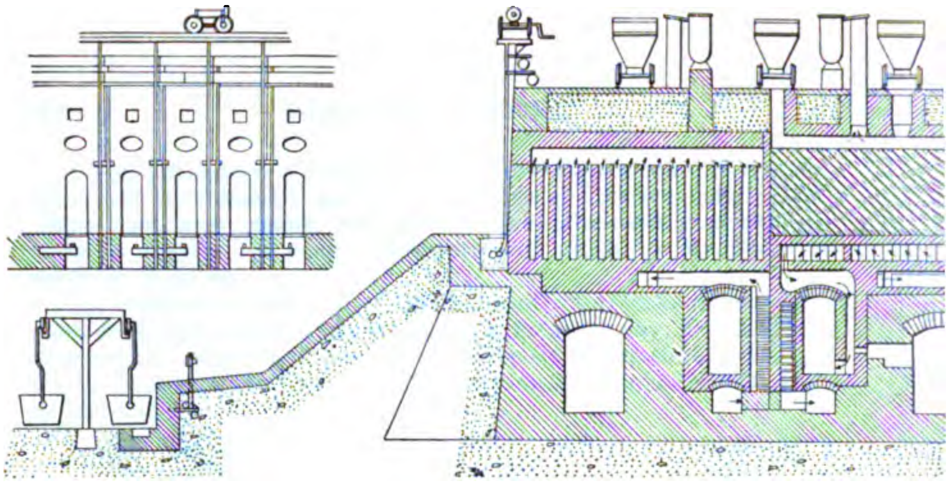


FIG. 28. THE BRU

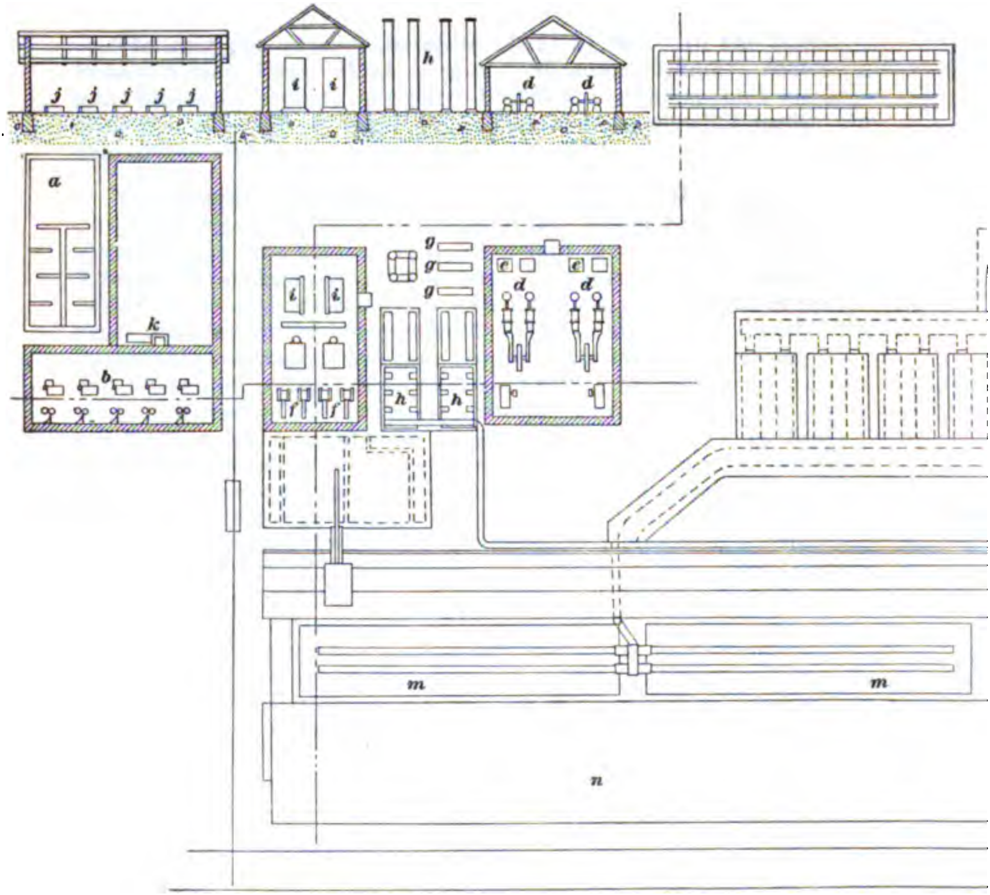
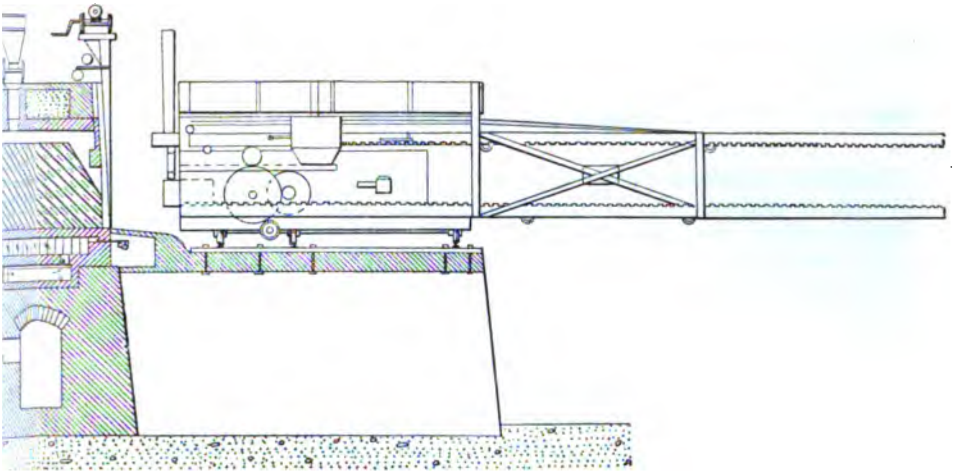
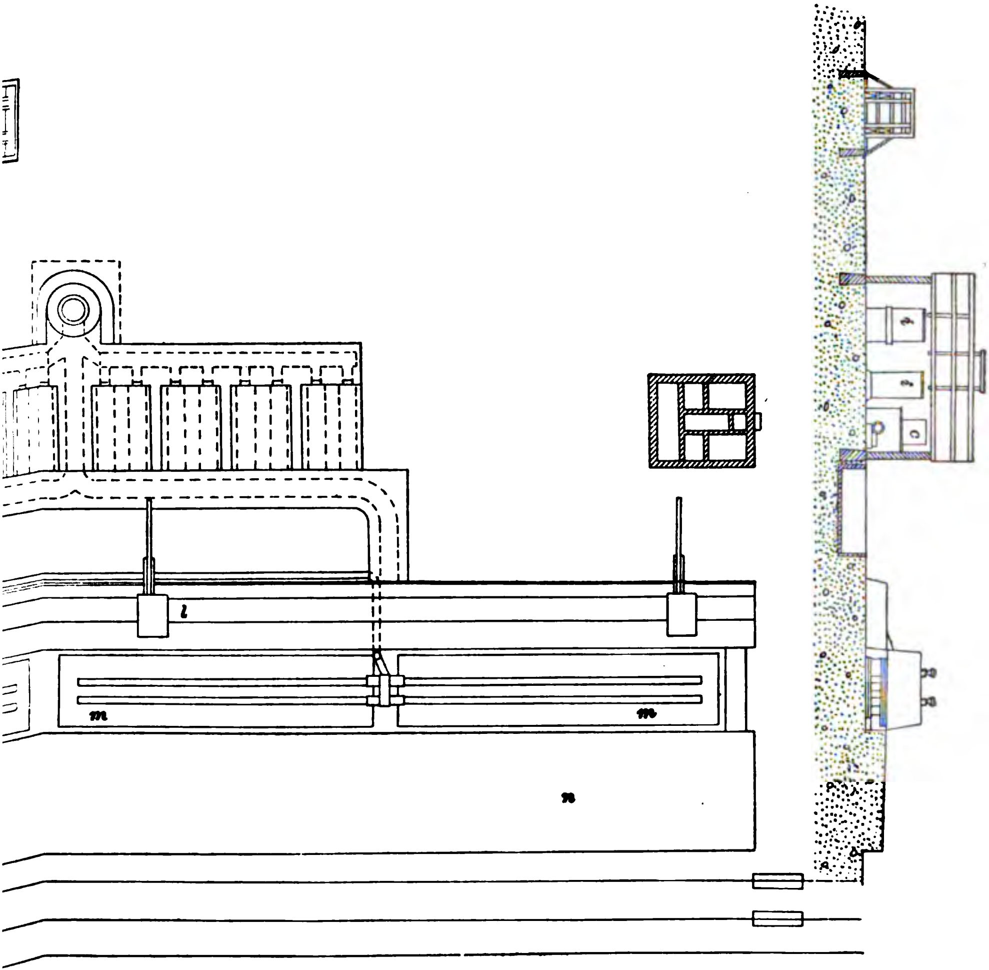


FIG. 29. INSTALLATION OF 120 BRUNCK COKE OVE

a, Clarifying tank; *b*, ammonia works; *c*, tar and ammonia tanks; *d*, steam engine; *e*, water pu
k, centrifugal separator; *l*, coke pusher; *m*, oven



E BRUNCK COKE OVEN



OVENS AT THE MINISTER STEIN PIT, GELSENKIRCHEN

ter pumps; *f*, tar and ammonia water pumps; *g*, cooler; *h*, cooler; *i*, washer; *j*, saturation boxes; vens, in batteries of thirty; *n*, quenching ramp

easy to regulate, and enabling the heat to be distributed uniformly over the oven. This thorough control of the heating is highly important for the supply of heat to the upper part of the charge of coal, since there the application of heat is from the sides only, whereas in the lower part of the oven, heat is applied from both sides and bottom. Again, in consequence of the separate removal of the waste gases the draft for each half of the oven can be regulated independently.

As can be seen in the drawing, the heating is effected from both ends symmetrically toward the central portion. The result of this method of conducting the heating gases, in conjunction with the central position of the flue underneath the oven, is that the gas in the oven has a shorter distance to traverse than is the case in ovens with horizontal, or even vertical, heating flues. This plays an important part in the question of the recovery of by-products and the yield of same, since the longer the path traversed by the gases through the heating conduits the greater must be the difference between the initial and final pressure to overcome the resistance opposed to the movement of the current. As, on the other hand, the pressure of gas within the oven is nearly constant throughout, there occurs either an escape of gaseous distillation products from the oven into the heating conduits or of air and products of combustion from the latter into the oven, it being impossible to keep the oven walls gas-tight. Both these occurrences lead to waste—combustion—of coke and by-products and to overheating. Owing, however, to the short distance the gas has to traverse in the Brunck oven, it becomes possible to maintain the pressure in the oven and heating conduits at an approximate equilibrium, and thus prevent injurious communication and transfusion. The maintenance of this condition of equilibrium is also greatly facilitated by the system of blowing in the air of combustion by means of ventilating fans, this procedure rendering the air supply independent of the natural chimney draft, and enabling the pressure to be adjusted to suit requirements throughout the entire system.

The structural arrangement of strong central pillars between the heating conduits of each pair of ovens has proved successful during an experience extending over seven years. These pillars take up the weight of the oven top and protect the oven from abstraction of heat by the adjacent oven when the two are in different stages of the coking process. As explained by the inventor, one of the advantages of the method of heating by means of single and double conduits in the walls is that, being relieved of the weight of the oven top by the central pillar, the walls can be built thinner and the ovens higher than is possible with systems wherein the oven walls have to support the roof. Owing to the more rapid conduction of heat and the reduced thickness of the charge of coal to be coked, the operation proceeds more rapidly, weight for weight, and the capacity of the ovens is therefore heightened without the fireproof fittings being exposed to as much wear and tear as in wider ovens with thicker walls. Thanks to these favorable conditions and the uniformity of heating, the Brunck ovens that have been at work in the Kaiserstuhl pit for the last 7 years have needed but very little repair. The removal and replacement of portions of the walls and sole of the ovens can be effected without affecting the skeleton; i. e., the central pillars and roof, owing to the fact that the method of setting the brickwork has been chosen with a view to such contingency.

In addition to preventing the overheating and fusion of the brickwork in the walls, the preliminary heating of the air to a high degree entails the advantage of enabling an excess of gas to be produced even in the case of coals somewhat deficient in gas-forming constituents; whereas, in ovens where the air is but slightly heated, if at all, the whole of the gas is consumed in heating the ovens themselves. This excess production naturally extends the limits of the by-product recovery. The excess of gas obtained when the gas content is 19 to 20 per cent. forms a useful reserve in the event of the ovens failing by reason of wet coal, bad weather, or the intervention of Sundays and holidays. Under normal working conditions the gas finds employment for lighting, heating, or, more recently, as a source of motive power. For the latter purpose, the gaseous distillation products of the Brunck coke oven are particularly adapted, since, in consequence of the aforesaid equilibrium of internal pressures, the gas is not contaminated with products of combustion, but contains its high calorific power.

In comparing two systems of coke ovens, it is evident that preference should be given to the one that, given the same coal in both cases, furnishes an excess of gas in addition to waste heat. If from the gas consumed waste heat alone is produced, the degree of efficiency of the plant is lower, because waste heat is only suitable for steam raising, and even when devoted to that use is subject to loss on the way between the ovens and the boilers. Moreover, the thorough utilization of the waste heat entails a much larger heating surface for the boilers than is required by gas fuel. The importance of heating the air for supporting combustion in the ovens led to the adoption of a method for utilizing the heat of the distillation products from the latter. To this end the air and hot gases are conducted in contrary directions through the special apparatus, wherein the latter give up their heat to the former; and as the volume of air required is seven to eight times that of the gas to be consumed, the large quantity of gaseous products formed in the coking process is suitably cooled, while the air is correspondingly heated. There is thus a considerable saving in condensing water, or in the expense of recooling the water used in the condensers.

All coking plants of the Brunck system are provided with a mechanical leveling apparatus combined with the coke pusher (see Fig. 28), and set in motion from the latter by a train of cog gearing. This does away with the old laborious task of leveling the charge by hand, and the attendant inconvenience occasioned the workmen by the gases escaping from the oven. When the machine is used, the surface of the charge of coal is leveled perfectly throughout the oven, whereas, when the work is done by hand, the upper surface generally retains some of the conical form assumed by the charge in filling. The bar of the machine travels backwards and forwards the whole length of the oven while the charge is being introduced, and, by its weight, compresses the charge to some extent, besides doing the work three times as quick as by hand labor. As a result of this compression, the weight of the charge in each oven is increased, and at the same time the labor of three or four hands per shift is saved in each battery of sixty ovens.

The set of Brunck coke ovens erected at the works of Jules Chagot and Company, Montceau-les-Mines, is noteworthy on account of the provision of a special device for fractionating the oven gases. The illuminating power of these gases being highest in those given off in the earlier stages of distillation, these first fractions are drawn off through a special conduit to the gasworks, where they are purified and utilized for lighting the town. On the other hand, during the second period of the coking operation the valve leading to the gasworks conduit is closed, the gases being delivered to the condensing plant.

The arrangement of the newest large installation of Brunck plant, viz., one hundred and twenty ovens at the Minister Stein pit, Gelsenkirchen, is shown in Fig. 29. The engines exhaust the total output of gas from the ovens, about 300,000 cubic meters per 24 hours, and also supply power for the ventilating fans. The blast engines supplied with the Brunck plant are characterized by smoothness of running and low requirements in respect to repairs, being thereby superior to most of the usual rotary exhausts, three or four of which will be required to deal with the above quantity of gas. Being compounded, the engines maintain the gas at such a constant pressure that the employment of a gasometer for equalizing the pressure becomes superfluous.

As shown in Fig. 29, four washers are sufficient to deal with the ammonia in the gas from the whole one hundred and twenty ovens at the Gelsenkirchen works, and replace the usual numerous small washers. This simplifies the arrangement of the necessary conduits and facilitates supervision and ease of working. The various machines being driven direct without intermediate shafting, the work is less subject to interruption in the event of repairs being necessary in any part.

The grouping of this plant is as simple for one hundred and twenty ovens as generally for half that number. The Gelsenkirchen plant is capable of coking 250,000 to 260,000 tons of coal, with 10 to 12 per cent. of moisture per annum, and of turning out 2,800 to 2,900 tons of sulphate of ammonia, and 7,500 to 7,800 tons of tar. The steam boilers for utilizing the waste gases and excess of coke-oven gas have a total heating surface of 1,400 square meters, and their favorable situation immediately behind the center of the four groups of ovens greatly facilitates that utilization, besides insuring the production of sufficient steam to furnish 550 tons per diem for working the pit, in addition to satisfying the requirements of the condensing plant.

The Bauer By-Product Coke Oven.—By means of the accompanying illustrations and description, which appeared in "Stahl und Eisen," a new form of retort coke oven, devised by Doctor von Bauer, which has been adopted by the firm of Fried. Krupp after a year's trial at the Hanover colliery, owned by the firm, is shown. Fig. 30 (*a*) is a cross-section through the center; (*b*) is a longitudinal section; (*c*) is a section through the center; (*d*) is a section through the flues; (*e*) is a partial section, on a larger scale, through the top of the flues. It is known that most varieties of coal contain more gas than is required in order to transform them into coke; hence, not only is all the gas unnecessarily consumed, but also air is admitted toward the end of the process through the peep holes in the doors, which helps to lower the temperature at the expense of the charge; that is to say, at the commencement there is too much gas and too little air, and at the end of the process the reverse condition obtains, notwithstanding that the whole of the gas is consumed. It is a very difficult matter to regulate the supply of air and give the proper dimensions to the gas flues. If, however, there is a means of supplying the gas in a uniform manner these defects are removed, and in addition there is a surplus of unconsumed gas, which is of more value than spent gas. The system under consideration enables one to heat the air in an equally uniform manner, and to increase the supply of air and gas as the increasing temperature of the oven renders it necessary, thus adapting itself to the exigencies of the coking process, which at first requires less, and later more, of air and gas.

The method can also be applied to the ovens with by-product recovery in which gas is delivered in uniform quantities from the gasometer.

A glance at the drawings, Fig. 30, and the perusal of their description will show that the Bauer oven can be worked (1) as an ordinary oven; (2) as an oven with condensing apparatus; (3) as an oven worked on the duplex principle; viz., of abstracting the gases during that period in the process when they are most rich in by-products, and allowing subsequently the less valuable

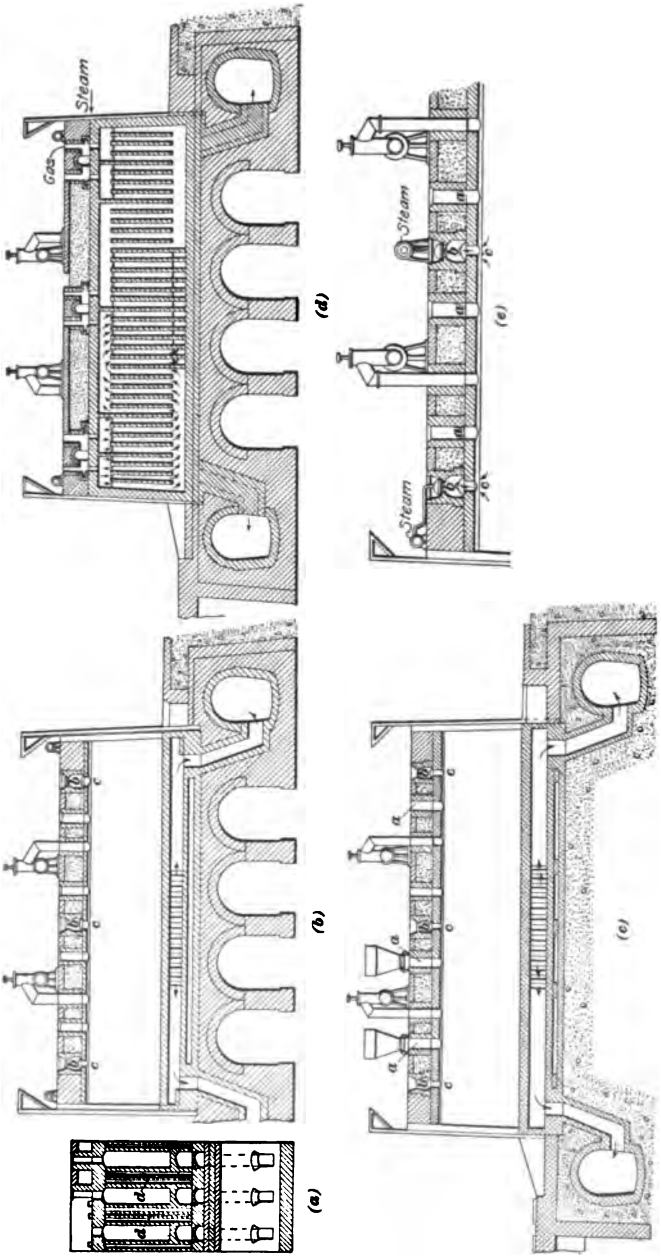


FIG. 30. THE BAUER BY-PRODUCT OVEN

gas to pass, without being cooled and afterwards rekindled, direct into the flues. By this method, an economy of both heat and of gas is effected, and the cost of the by-product plant is reduced, as the hottest and poorest gas is not treated.

The Bauer ovens will take a charge of from 9 to 10 tons, and the average coking time is from 30 to 36 hours. Considering their output, it is claimed that they occupy less space, and the cost of working is less than is the case with some of the other systems.

The ovens are filled through the charging holes *a*, unless it is preferred to introduce a pressed or pounded cake of coal with the aid of machinery, and thus do away with these apertures. (1) When used without by-product recovery the valves to the exhauster are closed and the stones that close the main flues are lifted. (2) When used with by-product recovery apparatus the valves to the exhauster are open and the stones that shut the flues are down. (3) The duplex principle of working is when methods (1) and (2) are combined; viz., at first with and afterwards without by-product recovery. When the oven is without the by-product system the gases reach the main flues *b* through three apertures *c* and thence pass on to the combustion flues. With the by-product recovery plant in operation, the purified gases from the gasometer pass into the mains, and thence into the flues through six openings. With the union of the two methods, the gases from the gasometer mix with those of the ovens in which the exhauster is not working, and then flow into the flues through six apertures. In each case the flues receive gases or gas mixtures of uniform composition, either the crude gas disengaged at each particular phase of the coking process, or the return gas, or else the return gas mixed with the gases of the ovens that are in operation.

The gases enter at the top ends of the ovens, pass downwards, then underneath the bottom of the flues, then upwards, and finally, having received an addition to the quantity from the mains, pass once more in a downward direction to reach the bottom flue, situated in the middle of the oven, and thence flow to the boilers through the outlet pipes. The ovens operate, therefore, on both sides, namely, from the ends toward the center, and there are on that account two inlets for the gas. Below the combustion flues there is situated, between the air flues that are underneath the bottom flues of the oven, a main air flue; this receives from outside and from the air flues both cool air and hot air. This air passes up through airways that are located between the combustion flues, and then through certain small ports reaches the gases that, from the main flues, have passed into the chamber above the gas flues. The coal in the oven is on a level with the chamber where the gas and air are commingled. In places where the gases flow in a downward direction, the previously heated air is introduced through small holes underneath the flues, and in order to admit fresh air certain small air passages are effected in the top of the oven or of the air chambers.

In each half of the oven, in the gas flues, the fresh air is admitted from below twice and emitted from above as hot air, and once from above to be emitted below in the same condition. Those surplus gases that are not consumed in the combustion flues pass direct from the mains, previous to ignition, into a transverse duct, which for every ten retorts connects the three mains together, and from this duct pass through the main outlet to the boilers, or reach the latter by a separate conduit in order not to become mixed with the spent gases. Parallel with the return gas pipes, there run steam pipes for the purpose of moderating, in case of necessity, any excessive temperature in the gas mains, or in order to maintain any particular degree of heat that may be desired. These pipes, which are of small diameter and are placed above the oven, are furnished at certain intervals with nozzle-shaped branches, furnished with taps that lead into the mains. The position of these steam pipes is shown in the elevation, although they are too small to be distinctly indicated.

The battery of Bauer ovens consists of eight, with a capacity of 9 tons. The coal used contains 12 per cent. of water and 67 to 69 per cent. of fixed carbon and ash. The coke yield was, taking the average of the year during which the ovens were worked experimentally, 73.2 per cent. Batteries of some other systems in the vicinity were worked with precisely the same coal, and the highest yield of the old or the most recent ovens was 68 per cent.

The normal coking time for one of Bauer's ovens is 30 hours. For about 2 months it was from 32 to 34 hours, and for the rest of the time, as special men were not told off to attend to so small a battery, the time has been 48 hours; as soon, however, as the new installation is complete, the period of 30 hours will be adhered to.

An oven with 48-hour charges will yield in 1 year (360 days) 1,186.5 metric tons of coke, and with 30-hour charges it will yield 1,898.4 tons of coke; that is, when worked without by-product apparatus. The theoretical yield of coke has been given above as 67 to 69 per cent., or as smaller than the actual. Such discrepancies are, however, not infrequent. At Creusot, in Bauer's vertical ovens, working with a mixture of coal and anthracite, we have a yield of 81½ per cent., although theoretically the coke contents are put down as 82 per cent.; at the Hanover colliery, we have a yield of 4 per cent. above the theoretical one as before stated, namely, 73.2 per cent. It is, therefore, not correct to merely indicate the charge for 24 hours, in instituting comparisons. The excess of over 4 per cent. above the theoretical yield has been maintained by Bauer's ovens regularly throughout the whole time they have been in operation, that is to say, for about 15 months; and these figures are not simply the result of an analysis effected in the laboratory, but have for their basis the total amount of the coke production since the ovens started working. At the Hanover colliery, Doctor Kassner, Doctor von Bauer, and others, are of opinion that this excess in the yield is due to the precipitation of volatile carbon, which is absorbed by the glowing coke in the last stages of the process. Notwithstanding the experiments of Kassner, many are skeptical on this point, and further investigations are to be made. The fact of this excess of the yield above the estimate is, however, well established.

The advantages claimed for these coke ovens are the surplus of gas unconsumed, the smaller space that they occupy, the low working expenses, and the absence of any smoke.

Lowe Coke Oven.—In response to a request for information about the Lowe oven, the following has been received from the inventor, Mr. T. S. C. Lowe:

NORRISTOWN, PA., July 14, 1903.

MR. JOHN FULTON, 136 Park Place, Johnstown, Pa.

Dear Sir:—Your letter of June 26, to Mr. Herbert Cutler Brown, of Los Angeles, has been sent to me with the request to write you concerning my new system of coke and gas production, and it gives me much pleasure to send you herewith an article recently published in the Progressive Age.

I have been much interested in your former publications, and if possible would be glad to furnish you with accurate tests of my system, but so far there have only been experimental plants built, the most important being that of the Jones & Laughlin Steel Company, and unfortunately it will take a longer time to get accurate information from that source than you will probably have before issuing your proposed publication, for the reason that it has been found necessary to let down heats to arrange some parts of the apparatus, increasing flue space and stack draft, as well as to arrange to prevent the indrafts of air caused by warping of door and other frames of the outer casing. This is easily done, as soon as they can shut down the ovens long enough to do the work.

These first ovens have been in operation 3 months, and it is desired to continue them, since it serves to give them information as to all the parts that are found defective, as you know in all new matters something will arise that can be bettered. The principle, however, works perfectly, and cannot be improved on, either in the production of a superior quality of coke, or the saving of the gases.

In about 2 weeks from now, however, we shall start up a new plant better arranged for making tests, at Rockaway Beach, Long Island, and if you think that your work will be delayed long enough, I shall be pleased to send you an invitation to go and see this plant operated, for I am sure it would be an interesting feature for your book, and afford just the information that is now needed more than ever concerning the production of metallurgical coke and gases suitable for open-hearth steel work, power, etc.

Very sincerely yours,
T. S. C. LOWE.

New Lowe Coke-Oven and Gas-Making System.*—This new process of gas making has now passed the experimental stages, and it is a proved fact that a superior, hard, heavy, smokeless fuel, fully equal to the best anthracite, can be made in any locality in the

---

*By John Haug in the Progressive Age, April 1, 1903: further information upon this new process will be furnished by the author at or from his office, 536 Bourse Building, Philadelphia, Pennsylvania.

world, from cheap soft coals, and while doing this a larger volume of gas is saved than by any process heretofore practiced. This coke, sold under the name of "Lowe anthracite," has been tested for all purposes for which anthracite has been employed, and in no instance has it proved inferior, but in many cases far superior to the natural anthracite. To devise a system to accomplish this has required, on the part of the inventor, an immense amount of work and study and the possession of an unusual amount of scientific knowledge. To create a perfect system required, first, a thorough study of the older methods. The old beehive system was found to produce a good hard metallurgical coke, but, as a rule, the yield is only from 50 to 60 per cent. of the coal employed, all the rest going off in volatile form. It was noticed that, when care was taken to admit air in the best proportions for securing high heats, the coke was harder and better and the yield of that oven was greater than when this care had not been exercised. The reason for this slight increase in the weight of coke was found to come from the deposit, on the upper portions of the charge, of carbon dissociated by the high temperatures from the heavy hydrocarbons. Under the best conditions of beehive coke making, more than 50 per cent. of the combustible gases escape from the tunnel head of the oven unconsumed, which of course accounts for the immense volume of black smoke always arising from coke ovens operated in this way. It was this knowledge of what was going on at the different stages of coking under this system, as well as the knowledge of what kind of coke would give the best results in blast furnaces, cupolas, and for domestic and other uses, that showed the necessity of a radical change in this most important line of industry.

Without going into the various stages of how he arrived at his final conclusions, it is evident that Professor Lowe has devised a system of coke and gas making that is of considerable interest.

The first requisite was to retain all the valuable features of the beehive ovens, whereby the coal is coked by reflected heat from the arches of the ovens; second, to maintain continuously the highest possible degree of heat that the best brickwork would stand without injury, that all of the heavy hydrocarbons might be deposited in solid form during their passage upwards and through the hottest part of the coke; and third, to save all combustible gases not needed in keeping up the necessary heats.

If fairly good coke could be made in the old way without actually burning more than half the gases arising therefrom, it was certain that, with a properly constructed apparatus by which the ovens are never cooled while charging coal or discharging coke, and where the air admitted for burning gases comes in at from 2,000° to 3,000° temperature instead of cold air as in the old system, it would be easy to figure that a much larger percentage of the gas arising from the coking coals could be taken away unburned, and either enriched and sold as illuminating gas or employed for metallurgical heating and power purposes without carbureting. But this required an entirely new construction, and the plan was adopted which resulted in the ovens being heated by internal combustion taking place directly over the coal to be coked.

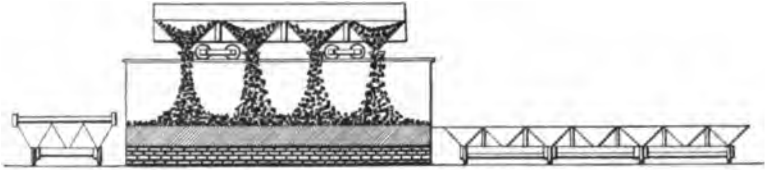
In following out this idea, Professor Lowe has devised a series of ovens *a* built within a single steel casing, all having connecting flues *b*, with large regenerator chambers *c* at each end of the battery of ovens, and also a steam generator *d* and stack *e* at each end connected by flues *f* and *g* to the superheaters, as shown in Fig. 31.

To properly heat a large plant under this system requires about a week, but after the heats are once established the operation is very simple, and, so far as the brickwork and apparatus generally are concerned, there is no reason why they should not last 10 to 15 years without repairs. Blast furnaces often run from 7 to 10 years without closing down for repairs, and their work is much more severe than that of coke ovens.

Under Professor Lowe's system, a much deeper charge of coal is thoroughly coked in 24 hours than in the beehive oven in 48 hours.

From four to twelve of these ovens are built in each battery. Therefore, in a four-oven plant, one oven is discharged and recharged every six hours; in a six-oven plant, every 4 hours; in an eight-oven plant, every 3 hours; and in a twelve-oven plant, one oven every 2 hours. The greater the number of ovens in one battery, up to eight or twelve, the more evenly are the heats maintained, although most excellent results have been obtained in a four-oven apparatus.

In order that the reader may understand how the gas is saved by this system when it is impossible to do so in the beehive oven, we would state that the heating of the Lowe ovens and taking off gases therefrom are alternating operations, while the coking process is continuous. The gas arising from the coking coals is burned under the arches of the ovens and over the coking coal, by the admission of the highly heated atmosphere from one of the regenerators, say, for 30 minutes, and the combustion of these gases is completed while passing from the last oven into and among the brick checkerwork of the regenerators at the other end, and the last heats are taken up while passing through open iron checkerwork in entering the stack, say, for 30 minutes; then the stack valve is closed, and water being sprayed over the piled cast-iron work, large volumes of steam are generated, which, while passing through the checkerwork brick, is so highly superheated that it does not in the least check the coking operations of the coal; and while this steam passes along from one oven to another through the series of flues, it not only carries with it the volatile hydrocarbons being given off in immense quantities, but the steam itself is decomposed while coming in contact with the heavier hydrocarbons and the flocculent carbon in the form of lampblack or soot, when passing through the highly heated brickwork.



CROSS-SECTION

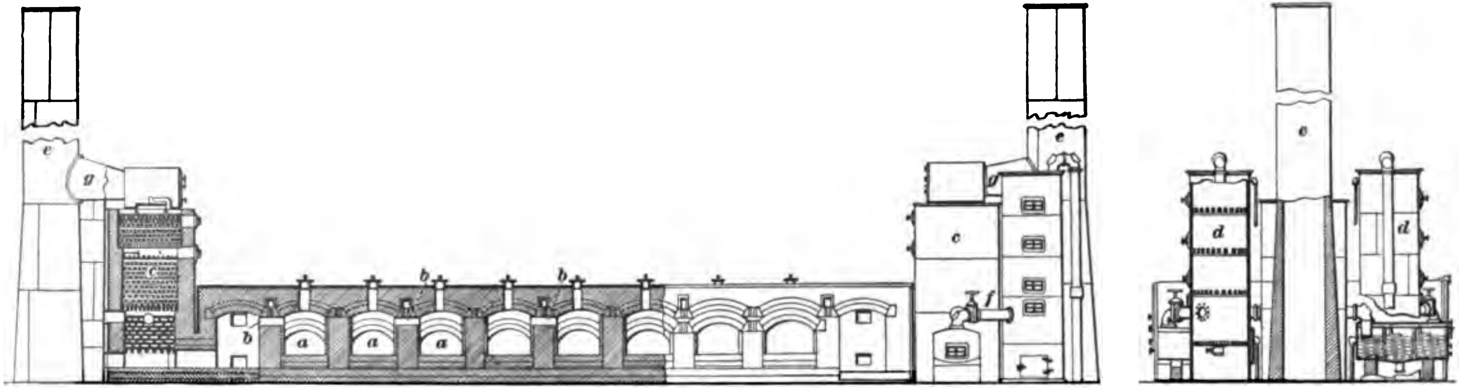


FIG. 31. LONGITUDINAL SECTION THROUGH OVENS, REGENERATORS, AND STACK, WITH CROSS-SECTIONS THROUGH OVEN SHOWING CHARGING HOPPERS

It is believed that in the larger batteries of ovens, for every 30 minutes the gas is burned in the ovens, the gas-recovering period can be extended to 40 minutes; thus, over 57 per cent. of all the gas arising from the coking coals is saved, in addition to all the water gas that the more solid and condensed portions will produce by their admixture under these high heats, leaving no tar to be provided for. In fact, the inventor's aim has been to convert everything about the coal into either a high grade of coke or gas in a combustible form. He says that, in apparatus making tar, it is always at the expense of good coke and large volumes of gas, and there could be no better illustration of this than in the results obtained in distilling coal in the ordinary gas-house retorts, for there they get tar in such quantities that the gas engineer is continually hunting better methods of burning the tar, either under retorts or steam boilers. The quality of Lowe-oven coke is much superior to that of gasworks coke. The writer is now superintending the erection of a number of Lowe coke-oven plants, on both the Pacific and Atlantic coasts. The largest battery of ovens yet built is that at the Jones & Laughlin Steel Company's plant at Pittsburg. They are built inside a gas-tight steel casing, having a ground space for the ovens and superheaters of 40 by 80 feet, and contain eight ovens, each 6 feet 6 inches wide by 38 feet in length. Each oven will take a charge of coal weighing 16 tons. The brick required for this battery of ovens was about 500,000, including the regenerators and checkerwork, but it is found that in future construction this can be considerably reduced without impairing the efficiency of the ovens.

The steel company has built a large gas holder, and gas mains are being laid to their various open-hearth steel furnaces. This gas will either mix with or supplement the natural gas of which their supply is now so short and the price so high that they have been compelled for a number of years to make producer gas to help them out—which is both troublesome and expensive. These ovens were designed to be ready to go into regular operation some time in April, 1903.

A test of the ovens in producing coke was made about the middle of January, principally to settle the questions: (1) concerning the ability to thoroughly coke so thick a mass of coal (30 inches) and at the same time produce a satisfactory quality of coke; and (2) to ascertain whether or not the coke could be discharged from ovens of this size and length without piling up in the ovens. Much to the surprise of all, the coke pusher designed for this purpose discharged the entire mass of coke in a solid block, without the least stoppage or hitch.

These were two very important points to a concern whose coke production was 3,000 tons daily, and who planned to increase that output to 4,000 tons. To make 4,000 tons of coke daily in beehive ovens would require the maintenance of fully 1,800 of them, and as it required one man to three ovens, it would mean a force under the old system of 600 men daily, as it is nearly all hand labor. By this new system, fifty men will be amply sufficient to do all of this work, leaving 550 to go into other more useful branches.

While making the short test of the ovens, it was difficult to ascertain the exact increase in percentage of coke, but enough was shown to satisfy Professor Lowe that the increase over the beehive yield would be fully 20 per cent., and that about 15,000 cubic feet of mixed coal and water gas would be saved per ton of coke made; or 60,000,000 cubic feet of gas while producing 4,000 tons of coke, which, counted at selling rates of natural gas (10 cents per 1,000) per equal number of heat units, would amount to $6,000 daily. This, with the 800 tons daily of pure, solid carbon saved in the coke, and the labor of 550 men, is sufficient to give any large concern like this a great advantage over its competitors.

The time consumed in discharging coke from the ovens and recharging the coal, and quenching and loading the coke into cars, is estimated, under favorable conditions, to require for each oven about 2½ minutes. The coke, as it is discharged from the ovens, drops into an immense cage capable of holding 13 tons of coke, the cage itself weighing 6 tons. This is picked up by a traveling crane operated on an elevated railway, and run to a tank of water in which it is immersed for about 15 seconds. It is then lifted out, and by the time the cage is swung round over a car, the internal heat in the coke has so driven out all the moisture that the coke is much drier than when quenched with hose in the old and tedious way. To see this cage with its load handled by this machinery one would think it had but a feather's weight.

An advantage in handling coke in this manner is that there is no waste in the form of breeze, as in the case of the beehive ovens, where it has to be pried out with bars, and consequently broken up considerably.

The coke pusher is an admirable piece of machinery, and was designed by W. B. Hasbrouck, who at present has charge of the Lowe coke-oven construction work, while W. Larramie Jones, of the Jones & Laughlin Steel Company, was, I believe, the originator of the new method of handling and quenching the coke by machinery. It is certain that they are taking a great interest in this new system, and it will not be surprising if in time it will supersede, not only all their beehive coke ovens, but the entire coke-making systems the world over.

Beehive By-Product Oven.—During the past few years efforts have been made to use the beehive, or round, coke oven in the saving of by-products. The results thus far have not been assuring. Some of them have exhibited considerable ingenuity, but the section of this oven is not the true form of a retort It is undoubtedly much more economical in first cost than any of the standard retort ovens with by-product-saving attachments; but it cannot secure as good results along this line as do the standard retort coke ovens. It is evident, however, that the coke produced in this round oven will inherit a much more desirable physical structure in its coke than that of any of the narrow retort coke-oven products.

Fig. 32 shows the method of construction of these round by-product-saving coke ovens.

Doctor Otto builds these ovens at his own expense, runs them for 12 years, taking the coal from the mines and delivering the coke to the mine company, for the yield of tar and ammonia, and at the end of the term surrenders the whole plant to the mine owners. He must make in this time, from the value of the products alone, the cost of the ovens, the interest of the capital invested, and the legitimate profit of a manufacturer, and he is successful in doing it.

MANUFACTURE OF COKE FROM COMPRESSED FUEL*

It will probably be admitted that the best coking coals on the continent, and also those of Great Britain, have for years past been getting scarcer, and various devices have been employed to improve the quality of the result in coke when made from inferior seams. A few years ago several works, chiefly in the Saarbrücken district, came under the author's notice, where a systematic attempt was being made to improve the quality of the coke by compressing the fuel before coking, and he was so impressed with the improved results obtained with poor coking fuels that he undertook experiments on the same lines. It is proposed in this paper to embody a short account of the results of these experiments and the benefits derived. It may be said at once that the result of the trials made showed that the advantages of compression were by no means confined to the poorest coking fuels.

The idea of compressing fuel for coking purposes originated on the continent, where many of the coals coked so indifferently that it was of the greatest importance to adopt any method that gave a prospect of improving the quality of the resulting coke. It had been observed that the coke produced from the lower portions of retort ovens, compressed by the weight of the superincumbent fuel, was superior to that produced from the upper portions of the charge, and this led to experiments in compressing the fuel by various means: first, by stamping in the oven by hand; in other cases by weighting the charge; and from this the practice of compressing in a box outside the ovens was gradually evolved, the stamped cake being afterwards moved out of the box into the oven by mechanical means.

---

*By John H. Darby, Journal Iron and Steel Institute, Vol. 1, 1902, page 26.

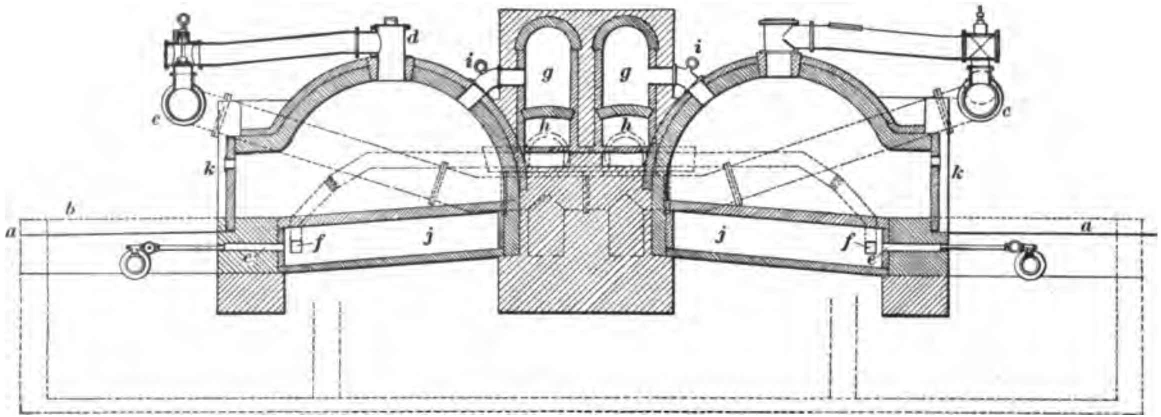


Fig. 32. Doctor Otto's Improved Coke Furnace

a, floor; *b*, edge of basin; *c*, receiver; *d*, supply opening; *e*, gas inlet; *f*, air inlet and exhaust of products of combustion; *g*, *g*, generators; *h*, air channel for distribution of air; *i*, valve for heating the ovens; *j*, sole, heated to 1200° centigrade; *k*, door fastening. Product: 75 per cent. coke; 1 per cent. SO_3NH_3; 2½ to 3 per cent. tar.

A number of samples taken from coking fuels in various parts of Great Britain were experimented with. The degree to which slack may be compressed varies with its character, state of division, contents of moisture, and other conditions; and, generally speaking, it was found that the weight of a given bulk of compressed fuel in an oven was 50 per cent. greater than fuel charged in the ordinary way through the holes in the upper portion of the oven and leveled by hand. Taking into account the side clearance that has to be allowed in introducing a cake of fuel into an oven, the net gain in weight that an oven of given capacity would hold varied from 25 to 30 per cent. in favor of compressed fuel. But it was found that the compressed fuel coked more slowly than the uncompressed, and the net gain in production of coke per oven finally amounted to between 10 and 12 per cent. in favor of the compressed charge.

To ascertain the difference in the character of the coke from compressed fuel compared with uncompressed, the weight of a cubic foot from a solid lump of coke was estimated, and it was found, in the case of three samples of fuel from Durham, that the average weight per cubic foot for uncompressed coke was 63.37 pounds and for compressed, 80.88 pounds; for North Welsh uncompressed coke the average weight was 56 pounds per cubic foot, compressed, 60.57 pounds; South Yorkshire uncompressed coke, 53.9 pounds, compressed, 57.9 pounds; West Lancashire uncompressed, 58 pounds, compressed, 66.4 pounds. It will be seen that compressed coke is considerably denser, in addition to which the following advantages were noted: (1) The breeze or small coke was very much reduced in quantity, the lumps of coke were larger and firmer and in a marked degree bore handling without very much breakage. (2) The process of charging an oven by the mechanical means in use, where compression of fuel is adopted, occupies much less time than the old method of charging by hand through holes in the top of the oven; in fact, the time is reduced from 10 or 12 minutes to 3 or 4 minutes, so that the objectionable smoke is largely prevented and the loss of by-products is less; in fact, in some cases, the yield of ammonia has been increased 25 per cent. (3) Less hand labor is employed, and the laborious work of forcing the wet fuel out of the tubs into the ovens and leveling the charge in the ovens is entirely abolished, while the clearance between the cake of fuel and the side of the oven allows the free escape of the gases and tends to prevent undue deterioration of the oven walls.

The results obtained show that the quality of the coke is distinctly improved by compression. Such improvement is naturally more marked in some fuels than in others; but from a large number of trials made with many of the English fuels, the writer is able to say that he has not seen any instance in which the improvement made by compression has not been apparent. Indeed, he is aware of a case in which compressed coke is being sold in the open market at a substantial advance on coke previously made from similar uncompressed fuel. Even with the best coking fuels the results obtained seem to justify the outlay in equipping a plant for compressed fuel, as well as the special case in which it is essential that the fuel should be compressed in order to produce a marketable coke.

In reference to the apparatus employed, it is unnecessary to mention the machine in which stamping is done by hand, or to describe the earlier forms of mechanical stamps in use, and it will be sufficient to illustrate two of the later types.

The essential parts of the appliances used are the stamping machines and compression boxes. These can be combined in a variety of ways as the surroundings may demand. For example, there are the combinations, first, of a compression box and charger, built with a superstructure carrying the stamping machine; secondly, a compression box and charger with stationary stamping machine. The first combination may be described generally as suitable where the machine has to travel for a considerable distance and take its supply of slack for compression at a number of stopping places, stamping operations proceeding during the traveling of the machine. The second combination, having a fixed point for the fuel supply, allows of the application of a fuel-feeding device as presently described, and offers opportunities for saving both time and labor. In fact, under favorable conditions, this type of machine will compress and charge fifty ovens per 24 hours, and it is probable that this is not the limit of the modern machines. With both these types of machines, in many instances, a coke-discharging arm may be conveniently combined with the compression box, in which case two men are able to control the operations of pushing the coke out of the oven and charging it with compressed fuel.

NOTE.—If the principles submitted in Chapter VII are correct, that is, that the calorific energy of blast-furnace fuels is in proportion to the extent of surface presented to the action of the oxidation gases in the zone of combustion in the blast furnace, and as it has been demonstrated that the most dense fuel—anthracite—is the lowest in value for rapid heat giving it follows that, if a vigorous fuel is a desideratum for use in a blast furnace, then any element of compression in the charge of coal, tending to densify the coke, or in any way to render it more like anthracite, should be avoided.—ED.

CHARGING AND COKE-PUSHING MACHINERY

The following description of coke pushers and ramming machines is taken from articles by Alfred Ernst and Dr. W. B. Rothberg, describing the by-product coke plant of the Lackawanna Iron and Steel Company, at Lebanon, Pennsylvania, appearing in Mines and Minerals, March, 1904.

Coal-Ramming or Compacting Machines.—Eight coal-ramming machines *K*, Fig. 33, are used at this plant, consisting of hammers working in steel guides, and actuated by means of an electric motor. The rammers are supported on the framework of the coal bin, in which a sufficient allowance is made for strain due to same. The rammers can be operated in any desired height without changing the stroke of the machine. A controller of sufficient capacity is placed in a convenient position for the operator.

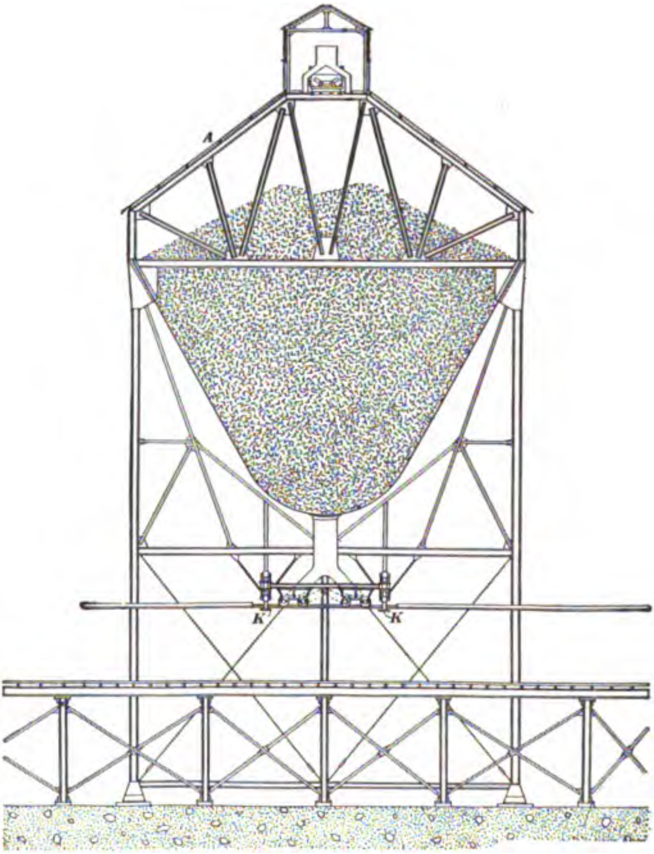


FIG. 33. COAL BIN AND RAMMERS

Coal-Charging Boxes.—Four coal-charging boxes *B*, Fig. 34, are provided, each of which consists of a base plate or peel, resting on rollers, having a rack attached thereto, and engaging with suitable pinions and gearing for moving the peel into the oven with a cake of compressed coal. The sides and ends of the box are of sufficient height to form a cake of coal for the ovens. The

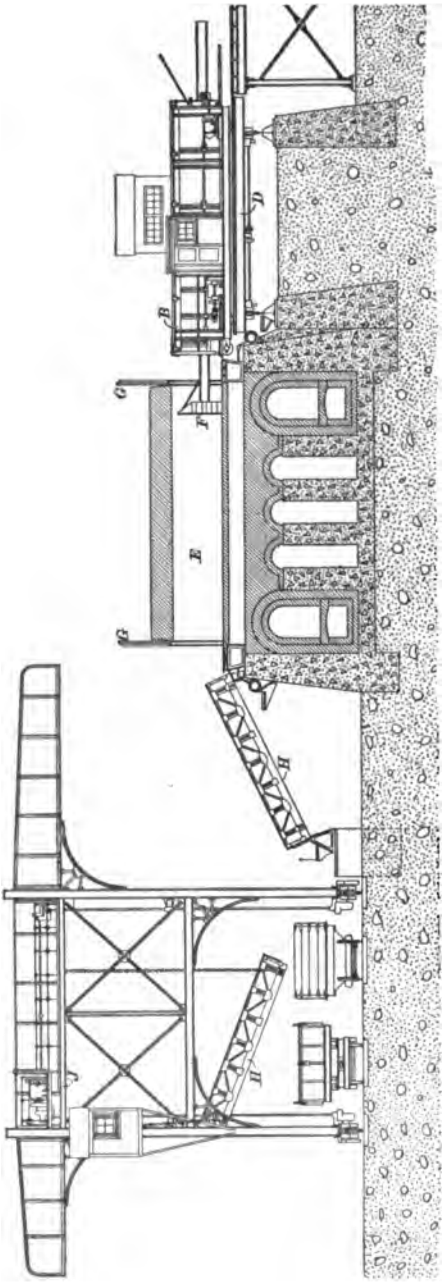


Fig. 34. General Section Through Crane, Ovens, Pusher

front end, or end nearest the ovens, is formed of two doors with a suitable locking device connected directly to the operator's cab by means of locking levers. The rear end is stationary and is built up rigidly on the lower framework of the machine. The sides of the box are supported by short links, with pin joints, attached to side posts, which form part of the solid framework of the machine. To the lower corner of the rear end of each side plate is fastened a pin and roller that engages with a cam on either side of the peel. After the box has been filled and rammed, it is placed on the pusher platform *D* and moved to the oven. When the oven has been emptied and the coal box brought into position, the front door of the box is opened from the cab, and the peel set in motion. This starts the peel toward the oven, pushing forwards on the sides, causing them to rotate about their several points of support, thus relieving the cake of coal from any side pressure. The coal is then placed in the oven on the peel and the doors closed. The door on the end of the oven nearest the coal box is lowered to the peel and the peel withdrawn, leaving the cake of compressed coal in the oven. The cams on the peel on their return engage with the pins on the rear end of the side plates, and draw them into their original position, locking them. The front doors are then closed and the coal box returned to the ramming station for a fresh charge. The machine is mounted on heavy trucks that are driven by a 50-horsepower electric motor, which also operates the peel. By means of these trucks and motor, the box is run underneath the bin to receive its charge, or back on to the platform of the coke pusher. The box is held on the pusher by rail clamps operated from the cab.

Coke Pusher.—The two coke pushers at this plant are operated as follows: The coke is pushed from the ovens by means of a heavy ram *F*, Fig. 34, carrying a cast-steel rack that is driven by a pinion, connected by means of suitable gearing to a 50-horsepower electric motor. This ram is guided by means of rollers, a sufficient number being used to hold it properly in place. On the framework of this machine are also provided tracks for a coal-charging box. The whole mechanism is carried on a massive steel framework *D* resting on four track wheels that are connected by means of suitable gearing and clutches to the 50-horsepower motor used to operate the ram.

Situated on this steel framework in a convenient position is the operator's cab, built up of steel framework and covered with corrugated galvanized iron, and also containing a sufficient number of windows to allow the operator a good view of all the operations of the machine. The operator's cab contains the controllers, etc. for all the operations of this machine, which are as follows: The pusher is run along the tracks parallel to the line of coke ovens, until the tracks on the pusher platform are directly opposite those from the coal bin. The coal-charging box is run on to the pusher platform and clamped there by means of rail clamps on the coal box. The whole machine is then moved to a position in front of the oven

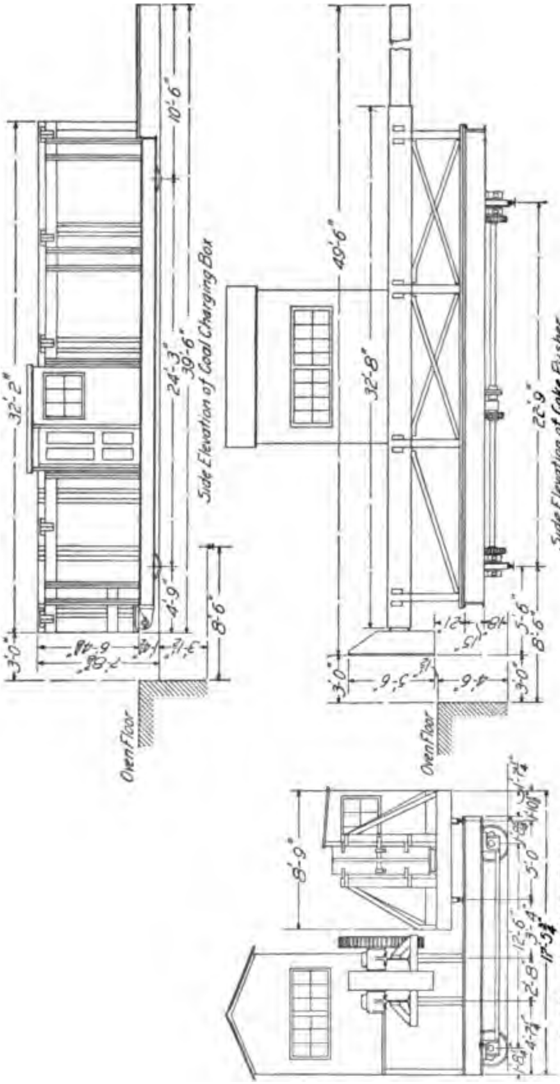


Fig. 35. Details of Coke Pusher and Charging Box

to be drawn. The clutch connecting the motor with the pinion driving the ram is engaged and the coke pushed out of the oven. The coal-charging box is then placed in front of oven as described above.

For carrying the boxes underneath the bins and rammers, four platforms and tracks are provided. These platforms consist of a steel framework supported on columns and carrying a plate floor, resting on beams, and also two lines of rails, forming tracks for the charging boxes to pass backwards and forwards underneath the rammers when the coal is being compacted. The platform has a factor of safety of six, on account of vibration during the process of compacting.

Details of the construction of the coal-charging box and coke pusher are shown in Fig. 35.

PLANT FOR SAVING COKE BY-PRODUCTS*

The Extension of the Coal-Distillation Plant at the Matthias Stinnes Mine in Carnap, Germany.—The following is taken from an article by Doctor Bertelsmann appearing in the Zeitschrift für Berg-Hütten und Salinenwesen for 1901, page 481:

At the Matthias Stinnes bituminous coal mines there have hitherto been but thirty coke ovens; these were of the under-fired type and were arranged to recover the tar and ammonia from the gas, which was used exclusively for heating the ovens. During the 4 years in which they have been in operation, a series of tests were carried out in order to obtain exact data on the following points: (1) how to obtain the best coke from a high volatile bituminous coal; (2) how to obtain the largest amount of surplus gas of high calorific and candlepower, fit for illuminating and power purposes; (3) what by-products can be recovered from the gas, in what quantities, and into what form can they be most profitably worked up.

The results of these tests afforded the data in accordance with which the extension of the existing plant was laid out. They were as follows: (1) a coal-mixing plant; (2) thirty-five coke ovens, with gas producers, reversing gear and regenerators, apparatus for the separation of the coke-oven gas, also pushing and charging machines and coal-compressing apparatus; (3) condensing plant for washing the gas and recovering the by-products; (4) an ammonia plant; (5) a benzol plant; (6) a cyanide plant; (7) an office building, with eating hall and bathrooms. With the exception of the cyanide plant, the above are either completed or in process of erection and will be hereafter described. A description of the cyanide plant cannot be given, as the details are as yet undecided.

Coal-Mixing Plant.—The coke made from a high volatile coal, in consequence of its coarse-grained structure and the large amount of the evolved gas, is very porous, brittle, and apt to be full of cracks and therefore ill adapted to stand the burden in the blast

---

*Mines and Minerals, December, 1902, page 214.

furnace. It may be improved by crushing the coal and pressing it into a solid cake before charging into the oven. Tests were made to ascertain whether a mixture of different coals would improve the coke, and it was found that, with the addition of from 10 to 20 per cent. (weicher staubiger Kohle) lean, dry coal, the strength and density of the coke were notably increased. In order to do this on a large scale, the coal-mixing plant was installed. The coking coal, coming direct from the mines to the washer, and drained of most of its water in the storage bins, is brought to the plant by a chain conveyer, while the outside coal is brought in by rail and unloaded by hand. The two kinds of coal are elevated to separate hoppers, of which there are four, placed on the four corners of a square. Each hopper ends in a conical spout, which is provided at its lower end with a loose sleeve, adjustable vertically. Beneath these spouts is a horizontal mixing table that revolves about a central vertical axis. As the adjustable sleeves are raised, a certain amount of the coal runs out of the spouts on to the moving table, and is scraped from there by an adjustable arm into a mixing screw. The proportion of each coal in the mixture is controlled by the adjustable sleeve and scraping arm. The screw discharges to a disintegrator, which still further mixes and crushes the coal, and it is then elevated to two large coal hoppers above the ovens. Power for the mixing plant is furnished by a single-cylinder steam engine.

Ovens.—As already stated, it was desired to select an oven system that would afford the largest possible amount of surplus gas, this gas to be suitable for use in gas engines at the adjoining coal mines. For this reason it was inevitable that a return should be made to the method of recovering the heat of the chimney gases by means of the regenerative system. The newly constructed ovens are thirty-five in number and of the double-wall type with vertical flues, each flue being separately heated, and connected with the other flues only by the common off-head canal. Canals and pipes laid beneath the coke platform bring the heated air and the gas to their respective canals, lying beneath the oven floor and the heating flues, each serving for the two oven walls. From these canals the air and gas are admitted to each separate vertical heating flue. As insufficient air is admitted, only a partial combustion ensues, in order to avoid local overheating, complete combustion taking place on the entrance of additional air, entering at a point in the middle of each heating flue. The burned gases from all the flues pass to a common horizontal canal above and descend from this through three vertical off-head flues to the chimney canal, on the pusher side of the ovens. The admission of the primary and secondary air and the gas is regulated for each two walls, and the draft opening to the chimney canal for each wall by dampers. The heated gases from all the ovens pass through a reversing valve to one of two regenerators, where the heat is absorbed by checkerwork, passing thence through a second smaller reversing apparatus to the stack. The air for combustion is forced through the other regenerator in the reverse direction by a motor-driven fan placed at the small reversing valve, is heated by the checkerwork, and passes through the large reversing valve to the before-mentioned air canal. At the end of each reversal period, the valves are moved 120° and the regenerators interchange their functions. The charging of the coking chamber can be done through the customary openings above, but consists usually in pushing the cake of compressed coal into the oven from the pusher side. For this purpose an electrically driven charging machine, having two stamping boxes, is used. Over each box is an electrically driven stamper. The coal to be stamped can be delivered to the boxes at any point along the battery by overhead conveyers.

Each oven is provided with a riser pipe in the middle to conduct away the gas. These risers connect with two **U**-shaped mains, and are on each side for the rich and poor gas respectively. The connection to these mains is made by movable valves dipping into a seal to make them gas-tight. The rich gas is given off only during the first part of the coking time, the remainder being classed poor gas. Separate pipes take the two gases to the condensing house, there being a tar drain from each to a common reservoir.

Condensing Plant.—In accordance with the plan of handling two qualities of gas, the condensing plant consists of two identical, but entirely distinct, systems. The gases coming hot from the oven pass first through high annular air coolers, then to rectangular water coolers, leaving them at atmospheric temperature. They are then forced by exhausters into the tar scrubber, then to a series of rotating slat washers, one after the other. In these, the ammonia, benzol, and cyanide are absorbed by suitable liquids, the sulphureted hydrogen being removed from the rich gas as well. This completes the washing process, the gases passing directly to where they are used, as already described. The air coolers, as has been stated, are annular in form, that is to say, having an inner air-shaft so that the air-cooling effect takes place from both sides at once. All the coolers are divided by partition walls so that the inlets and outlets are at the bottom, allowing several coolers to be connected with little space between, thus avoiding long pipe connections and one-sided loads on the cooler shells. The water-tube coolers are so arranged that the gas and water pass through in opposite directions. The warm water passes under its own pressure to an open cooler of wooden latticework, when it is cooled by evaporation, and is raised from a collecting basin to the elevated tank over the water coolers by rotary pumps, to be used again. The tar and ammoniacal liquor condensed in the coolers is led to a gravity separating tank and is carried by pumps to be worked up.

Each of the nine rotating slat washers consists of a large cast-iron drum having an outside flange near each end, traveling on two pair of grooved rollers, which drive it by friction. The entrance and exit of the gas is through stuffingboxes. The drum is divided by thin cast-iron partitions having a central opening into four equal chambers, each being again divided by a wooden partition, so that communication is along the periphery only. The space in the chambers is then filled with closely fitting gratings of wood. The washing liquid enters and leaves through stuffingboxes at either end, the direction of its passage being opposed to that of the gas. The upper half of the washer is, therefore, always filled with gas and the lower part with wash liquor, both moving in opposite directions, and, by the rotation of the drum, the gas is forced to pass continually over freshly wetted and dripping surfaces, so that an intimate contact between gas and liquid is assured. No gate valves are employed on the gas mains and by-passes, seal pots with dip pipes or partitions being used, which can be made gas-tight at any time by filling with water.

The motive power for the condensing house is supplied by two single-cylinder steam engines with poppet valves, used alternately. These drive the apparatus already mentioned, and, in addition, six horizontal piston pumps for circulating the waste liquors, a gas compressor, and two dynamos for light and power purposes.

Ammonia Plant.—The ammonia is removed by washing the gas with water after it has been freed of tar. The liquor from the washers and the condensate from the coolers are collected in one reservoir and raised by a piston pump to an elevated tank, from which the mixture flows by gravity to the ammonia house. In order to obtain ammonia in a salable form it must first of all be separated from the liquor and to some extent purified. This process may be divided into four parts: (*a*) the preheating of the liquor; (*b*) the driving off of the carbonic acid and the sulphureted hydrogen; (*c*) the driving off of the free ammonia; (*d*) the driving off of the fixed ammonia.

(*a*) The preheating of the liquor is done in an apparatus in which a part of the water that has given up its free ammonia is used to heat the raw ammonia liquor. The apparatus consists of a series of cast-iron chambers placed one above the other, and divided by thin steel plates, the first, third, fifth, etc., and the second, fourth, sixth, etc., being connected, so that two entirely separate circulation systems of alternate raw liquor and hot water are formed. The flow is in opposite directions, the transmission of heat being through the partitions.

(*b*) The liquor, thus warmed, passes upwards under pressure and flows down through a small column. In this it encounters a current of fresh steam, or of escaping steam from the apparatus below, described later, which in either case is sufficient to drive off the carbonic acid and sulphureted hydrogen, but not the ammonia. The gases so driven off are returned to the unwashed oven gas.

(*c*) The partially purified water now comes to the upper portion of the large column apparatus. As it passes downwards through the latter, it encounters enough steam to free it of all its volatile ammonia. A part of the heated water is then removed to pass through the before-mentioned preheater, to warm the raw liquor, and after serving this purpose is used again in the slat washer for condensing purposes. In this way the incrustation of the washer slats with scale, which is generally the result of constantly using spring or river water, is avoided.

(*d*) The liquor passing down through the column enters the lime chamber by a seal pipe and is then mixed with milk of lime, forced into the chamber by a pump. Passing thence to the lower part of the column it encounters fresh steam and is deprived of the ammonia set free by the lime. The waste liquor, now free of ammonia, is allowed to settle in the lime tanks and runs to waste.

The ammonia thus obtained in gaseous form is still mixed with a good deal of steam, and can easily be transformed into ammonium sulphate or strong ammonia liquor, as desired. The manufacture of aqua and liquefied anhydrous ammonia is also contemplated.

In making ammonium sulphate, elevated lead-lined wooden boxes, reenforced with iron and set above the floor, are used. The arched lid is of cast iron, lead covered, and carries a number of lead-covered connections that allow ammonia vapor, acid, and mother liquor to be introduced and the waste vapors to escape. The ammonia vapors are admitted through dip pipes, beneath circular toothed hoods, allowing an intimate contact between vapor and liquid. The vapors given off escape through one of the connections to a condenser overhead, the baffles in which catch and hold any entrained liquid, and pass thence to the foul-gas main. The bottom of the box slopes from all sides toward the middle and is furnished with an opening, closed by a hard-lead cone worked by levers from the outside. Under each saturating box is a lead-lined receiver. The operation is as follows: Through one of the connections certain quantities of 60° sulphuric acid and mother liquor from the last operation are introduced and saturated by the passage of ammonia gas. When the saturation is complete, the contents of the box are run into the vessel below, through the opening, and then allowed to settle. The clear mother liquor is drawn off and the salt is dried in a centrifugal separator. The latter is then ready for market. The mother liquor is drained to a collecting basin and then raised by a hard-lead injector to an overhead tank, from which it flows to the saturating boxes again. If the ammonia vapor is to be worked up into concentrated liquor, it is deprived of a certain portion of its water in a return-flow condenser and then entirely cooled, the finally condensed strong liquor being drawn off and marketed in that form. The floor and walls of the ammonia house are covered with asphalt, so as to resist the action of the acid and mother liquor.

Benzol Plant.—The benzol and its homologues are absorbed from the gas by washing it with dead oil in one of the rotary slat washers already described, the saturated oil being pumped to the benzol plant. Here it flows first through preheaters, like those in the ammonia works, supplied with hot dead oil from the other apparatus. From the preheater it comes to the column apparatus, and passing downwards through this is exposed to the action of ascending steam and is deprived of its benzol, etc. The action of the steam is enhanced by arranging the columns in a circle about a central shaft, from which they are all directly heated by gas. The oil leaving the column serves, as already stated, to preheat the incoming oil, is then entirely cooled in water coolers, and passes again to the gas washer. The vapors recovered from the oil in this process consist of water and benzol hydrocarbons. After condensing, they are separated into water and raw benzol and the latter collected in a tank. From this it is redistilled by means of a still provided with column and returns condenser, so operated, first with indirect and then with direct steam and by regulating the condenser, as to deliver 90-per-cent. or 50-per-cent. or other degree benzol, as desired. The separate fractions are run into separate receivers and pass thence to the storage reservoirs. It is also intended to install apparatus for rectification with sulphuric acid, and further fractional distillation.

CHAPTER VII

PHYSICAL PROPERTIES OF CHARCOAL, ANTHRACITE, AND COKE, AND A COMPARISON OF BEEHIVE AND BY-PRODUCT COKE

The law of progress is universal. Beginning with the blade, then the ear, and ultimately the full corn in the ear. The iron manufacturers have studied, under many years of practical experience, the properties and values of the principal fuels in general use for iron smelting—charcoal, anthracite, and coke.

The following table, from J. M. Swank's "Iron in All Ages," will exhibit in a very interesting way the struggle of these fuels for supremacy, with their present ranks, the coke leading all others:

TABLE I

Years	Charcoal Net Tons	Anthracite and Coke Net Tons	Coke Net Tons	Remarks
1854	342,298	339,435	54,485	
1855	339,922	381,866	62,390	Anthracite leads charcoal
1869	392,150	971,150	553,341	Coke leads charcoal
1875	410,990	908,046	947,545	Coke leads anthracite
1880	703,522	2,448,781	7,154,725	Era of coke
1900	339,874	1,636,366	11,727,712	Era of coke
1901	360,147	1,668,808	13,782,386	Era of coke
1902	378,504	1,096,040	16,315,891	Era of coke

This exhibit establishes the fact that the use of coke in smelting iron is largely on the increase, and that the use of anthracite is decreasing, especially when used alone in blast furnaces; while charcoal, in its limited use, appears to be nearly stationary.

As coke is now the chief fuel in the metallurgy of iron and steel, and its use is steadily increasing, it is evident that it is destined to maintain its prominent place of usefulness in the coming ages, increasing in largest proportion with the expansion of the manufacture of iron and steel.

The table also shows that coke has superseded anthracite in blast-furnace operations. Where the relative cost of coke to anthracite does not largely exceed 25 to 30 per cent., the former fuel would probably obtain the preference, from its greater calorific energy in the production of a larger output of pig iron in the furnace.

At present, furnaces within the borders of the economic bounds of coke are using this fuel mainly and obtaining supplies from the Connellsville, Alleghany, and Clearfield regions.

Mixtures of coke with anthracite are made at some furnaces, ranging from one-eighth to one-half of the fuel charge. It is evident, however, that the use of coke in blast furnaces is steadily on the increase and will continue to enlarge the bounds of its usefulness, displacing the less energetic anthracite fuel.

From the limited area of the chief anthracite fields in the East, containing in the aggregate only 488 square miles of coal measures, and from its present large annual output of 53,967,543 net tons in 1893, with a deeper and increasing cost of mining, it cannot long profitably continue to supply furnace fuel at very low rates.

The charcoal fuel for blast-furnace use, under the rapid cutting down of the primeval forests, must continue to afford only a limited supply and its use be confined to the smelting of pig metal for special purposes.

From all the foregoing it will be seen that the present and future manufacture of coke demands and should receive increased and earnest attention.

The following table exhibits the decrease and increase of the use of the fuels used in blast-furnace operations, in detail:*

TABLE II

Fuel Used Gross Tons	1898	1899	1900	1901	1902
Bituminous, chiefly coke	10,273,911	11,736,385	11,727,712	13,782,386	16,315,891
Anthracite and coke ..	1,180,999	1,558,521	1,636,366	1,668,808	1,096,040
Anthracite alone.....	22,274	41,031	40,682	43,719	19,207
Charcoal....	296,750	284,766	339,874	360,147	378,504
Charcoal and coke			44,608	23,294	11,665
Totals....	11,773,934	13,620,703	13,789,242	15,878,354	17,821,307

This table shows in a very emphatic manner that coke is the principal fuel now in use in blast-furnace and other metallurgical operations, and that anthracite alone holds a small and vanishing place in these great industries.

---

*From statistical tables by James M. Swank, general manager American Iron and Steel Association, 1903.

Charcoal, in use mainly for special purposes, maintains its small place among these fuels.

In these fuels, especially for blast-furnace and kindred uses, the prime requisites are hardness of body, to sustain the weight of furnace charges, to resist dissolution in the upper portion of the furnace, and full cellular structure to afford combustion with the utmost energy at the proper zone in the furnace. These elements in the fuels are essential in the economical and vigorous working of the furnace.

Charcoal was, in the early times of iron making, the principal, if not the only fuel used in forges and blast furnaces. From its softness of body it could only be used in the old-time forges and low furnaces with feeble blast in the initial operations of iron smelting. It was the educating fuel in the early operations of iron smelting and iron working.

Anthracite is a natural coke. From its hardness of body it is abundantly able to sustain the pressure of the highest furnace charges, as well as to resist the dissolving action of hot carbon-dioxide gas, but its extreme density of physical structure renders its combustion slow, and its calorific energy moderate.

Between these extremes of blast-furnace fuels, coke comes to the iron manufacturer inheriting in harmonious combination the good properties of charcoal and anthracite. It has hardness of body to sustain the burden of the highest furnace, and this hardness enables it to resist dissolution in its passage down the furnace to the zone of combustion. Its large surface space from its cellular structure affords full preparation before reaching the zone of fusion, which assures great calorific energy in its combustion.

Beginning with 1850, the three fuels at the service of the iron manufacturer consisted of wood charcoal, anthracite, and coke. These are composed as follows:

TABLE III

Fuel	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
Charcoal	3.50	6.490	87.00	3.00		.020
Anthracite	2.50	4.000	87.00	6.00	.50	.020
Coke	.49	.011	87.46	11.32	.69	.029

It required time to assure furnace managers of the special fuel best adapted for their use, considering cost, energy of fuel, and quality of pig iron made.

During the past two decades the examination of furnace fuels embraced not only their chemical constituents, but also their physical properties. This has led to the conclusion that the physical structure is a very important factor in conferring energy in the combustion of the fuel. Rapid combustion in the furnace results in increased output with corresponding reduction of cost of pig iron.

This intelligent study of the physical as well as the chemical properties of these fuels in furnace use did not end here; but the correlated study of the form and size of the furnace, the heat and pressure of blast, have been put into successful practice in the smelting of iron. This has led to the development of the fuel best adapted to these metallurgical operations, especially in the large blast furnaces for the production of Bessemer pig iron.

It becomes, therefore, most important to the coke manufacturer to consider the essential elements in coke that have conferred on it the most distinguished place in the iron industry, so as to maintain in its manufacture these desirable properties. If the physical structure of these fuels is examined, it will be found that charcoal consists of a series of longitudinal tubes, uniting with each other and affording ready passage to the furnace gases. The walls of these tubes are readily oxidized. Charcoal is, therefore, a pure and moderately energetic furnace fuel.

Anthracite is a natural coke, made under immense pressure, and very dense in its physical structure. It inherits no cellular structure, as it has been fused into a dense vitreous mass by the pressure and heat under which it was made, this great pressure repressing the cell development. It is, from its physical structure, the least energetic of the fuels under consideration. Its action in a blast furnace is somewhat relieved, as under heat it decrepitates, and thus increases the extent of surfaces exposed to the oxidizing gases of the furnace, compensating in a measure for its density.

Coke, on the other side, has a structure made of a series of irregular, promiscuously disposed cells, with vitreous walls; these cells are connected by diminutive passages that afford free courses for the oxidizing gases of the blast furnace. It is these hard vitreous cell walls in coke that give it the superior value as an energetic fuel in blast furnaces.

From the foregoing, it will be evident that the physical structure of coke, other things being equal, is the main element that confers on it the superior place it holds among blast-furnace fuels. The same is true, in a modified way, of charcoal fuel. The anthracite holds the lowest rank.

The factor of the cost of these fuels is also an important element in determining their use in each locality. This, however, does not enter into the present investigation, except as a qualifying clause.

PROPERTIES OF COKE

The main inquiry at this place is to determine the nature of the physical and chemical properties that are most desirable in coke for blast-furnace use, and to meet, as far as possible, these requirements in the manufacture of coke. These requirements in coke fuel are clearly defined under five distinct elements in its manufacture: hardness of body; fully developed cell structure; purity; uniform quality of coke; and coherence in handling.

In the further consideration of these valuable properties in metallurgical coke, it may be helpful to the manufacturer to consider these five essentials in detail.

Hardness of Body.—The best cokes possess a hardness of body of 2 to 3 per cent. By this is meant hardness of body or cell walls, not density, for dense cokes are usually soft or punky; while hard-bodied cokes are generally well developed in cellular structure. These two physical properties, hardness of body of coke and full cell spaces, are correlated, just as softness of body and density are associated.

The coal from which soft coke is made lacks the element that fuses and hardens and is therefore deficient in these prime essential qualities. The nature of this fusing element or elements in coking coals has not been clearly defined, at least such information has not come under the notice of the writer.

The following table of careful tests of hardness of body and development of cells will prove interesting:

TABLE IV

Locality	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Per Cubic Inch, One-Fourth Ultimate Strength	Height of Furnace Charge, Supported Without Crushing	Order in Cellular Space	Hardness Per Cent.	Specific Gravity
	Dry	Wet	Dry	Wet	Coke	Cells	Pounds	Feet			
Standard Coke											
Connellsville..........	12.14	21.34	46.30	81.25	43.73	56.27	236	94	1	3.0	1.69
Syracuse, New York..	15.02	23.41	57.20	89.20	47.68	52.32	340	136	1	2.6	1.91
Morris Run, Pa.......	13.02	22.41	49.03	85.37	41.82	58.18	246	97	1	2.3	1.90

NOTE.—The Connellsville coal was coked in beehive ovens. Morris Run coal, Tioga County, Pennsylvania, was coked in Semet-Solvay ovens, at Syracuse, New York, and the same quality of Morris Run coal was coked in beehive coke ovens near the mines.

In the treatment of dry coals, the hardness of the body of the coke can be increased by coking such coal in the narrow or retort coke ovens. The cell structure in this kind of oven is always more or less depressed as compared with the full cellular development in coke made in the beehive class of oven.

In any type of oven, maximum heat is required to produce the hardest-bodied coke, but it is not conducive to the largest output of by-products.

The solution of this question, the elements in coal that contribute to its fusion in a coke oven and assure hardness of body with large cell spaces, is most important; for, if they were known, equivalent elements could be supplied to coals deficient in them, thus improving the quality of coke in its most essential requirements.

This prime necessity of hardness of the body of coke will be evident when the conditions of its combustion in a blast furnace are considered. In its movement down the furnace to a short distance above the tuyères, it is enveloped in the ascending currents of hot gases, mainly carbon dioxide; this gas possesses the power of dissolving carbon or coke, and is especially destructive to the soft variety.

Sir I. Lowthian Bell, in his treatise on the "Manufacture of Iron and Steel," page 287, gives the following:

Hard coke, soft coke, and charcoal pounded as nearly as possible to the same size were placed in a hard-glass tube, which they filled, and were then raised to a good, red heat in a Hoffman double furnace. During the space of 30 minutes, 800 cubic centimeters of carefully dried carbonic acid was passed over each specimen. The issuing gases had the following volumetric composition:

	HARD COKE PER CENT.	SOFT COKE PER CENT.	CHARCOAL PER CENT.
Carbonic acid	94.56	69.81	35.20
Carbonic oxide	5.44	30.19	64.80
	100.00	100.00	100.00

It will thus be evident that every pound of coke dissolved by this gas, before reaching the efficient zone of combustion, is a double loss, reducing the heat of the furnace and disarranging its regular operations.

It is evident that an equal amount of fixed carbon in these three principal fuels, used in blast-furnace operations, will afford equal volumes in heat units; but it is also evident that the time required to produce these heat units will be in proportion to the extent of surface exposed to the oxidation gases in the blast furnace or similar heating operations. A pertinent example has been witnessed in the old-time "back-log." It contained a certain number of heat units, but they came out very slowly. It was mainly designed to "hold fire," but when energetic heat was required the log had to be split into small pieces to afford a greatly enlarged surface to the oxidation agency in its combustion. This foundation principle holds practically true in the combustion of these fuels, the anthracite representing the "back log"; the charcoal and coke, the rapid-burning fire in front of the "back log."

It follows, therefore, that in all coking operations any element in the plan of the chamber of the oven that restrains the liberty of the coal in its fusing to make fully developed cells, reduces in such proportion the energy of the fuel; in other words, every approach to the dense anthracite structure is inimical to the value of the fuel for rapid and energetic combustion. This principle, not generally well developed, is one of the chief elements that has held the product of the round or beehive coke oven in such acceptance with blast-furnace managers, and enabled it to maintain its place of usefulness in the presence of criticism and sarcasm as to its wastefulness and antiquated condition.

It will be seen from the tabulated statements that, at the close of the year 1902, there were 69,069 beehive coke ovens in operation in the United States, against 1,663 retort ovens of all forms.

Well-Developed Cell Structure.—The coals best adapted for coke making will usually afford, in conjunction, ample cellular development and hardness of body. The value of full cell structure in coke will be readily appreciated when it is considered that such fuel presents the largest surface for oxidation in a blast furnace. The desirable ratio of cellular space to the cell walls or body of the coke has been carefully determined, and found to be as 44 to 56, nearly. That is, the cubic contents of coke body to cell space is as 43.73 per cent. of coke to 56.27 per cent. of cells.

The evidence, by filling these cell spaces with water under the receiver of an air pump, clearly shows the thorough connections by passages of all the cells in the coke. The calorific energy of the coke fuel in the crucible of a blast furnace also shows how easily and thoroughly the blast penetrates these cell spaces and maintains rapid combustion.

TABLE V

Locality	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Per Cubic Inch, One-Fourth Ultimate Strength	Height of Furnace Charge, Supported Without Crushing	Order in Cellular Space	Hardness Per Cent.	Specific Gravity
	Dry	Wet	Dry	Wet	Coke	Cells	Pounds	Feet			
Standard Coke											
(*a*) Connellsville......	12.51	21.62	47.69	82.20	43.93	56.07	301	110	1	3.0	1.74
(*b*) Otto-Hoffman oven	14.64	21.02	55.79	80.07	61.13	38.87	465	186	1	3.1	1.80
(*c*) Otto-Hoffman oven	20.49	24.23	78.07	92.30	77.22	22.78	940	376	1	3.5	1.82

NOTE.—(*a*) Coke made from Connellsville coal in beehive ovens; (*b*) coke from sides of Otto-Hoffman oven, from Connellsville coal; (*c*) coke from bottom of Otto-Hoffman oven, from Connellsville coal.

It is impossible, however, to make good coke from coal that is wanting in the elements that assure thorough fusion in the coke oven. Inferior coking coals can be coked by special oven treatment, but the coke from such coal is always of a lower quality. No condition of oven treatment can make good coke from bad coking coal.

Table V exhibits, in a marked manner, the repression of cell development when Connellsville coal has been coked in Otto-Hoffman retort coke ovens, as compared with the structure of coke made from same quality of Connellsville coal and coked in the modern beehive coke oven.

In the presence of these facts, in regard to the repression of cell development in retort coke ovens, it becomes a matter of great interest to determine whether the increased hardness of body of the retort-oven coke will compensate in blast-furnace work for the greatly diminished cell space in this coke. It will require furnace determinations to adjust the relative loss and gain from these related physical conditions.

Purity.—Carbon is the source of heat in coke. Other properties being equal, the larger the percentage of carbon the greater is the volume of heat.

As coal has had its genesis in vegetable matter, it usually inherits 3 per cent. to 7 per cent. of ash. A coke, therefore, not greatly exceeding 10 per cent of ash can be regarded as an average clean fuel. Cokes inheriting only 5 per cent. to 7 per cent. of ash are regarded as exceptionally pure.

The sulphur in coke should be under 1 per cent., if the fuel is to be used in metallurgical operations. The best coke contains only ½ to ¾ per cent. of this impurity. Ordinarily, the volume of sulphur in coal is in a certain proportion to its slate or ash, but there are exceptions to this relationship where coal high in ash is quite low in sulphur. The reduction of the slate in coal by washing or picking generally reduces the percentage of sulphur. About 40 per cent. of it is volatilized in the coke oven.

A reference to Chapter III will show the great progress that has been accomplished in the last decade in cleaning coal from its impurities by crushing, classifying, and washing. The manufacturer of coke has now all kinds of washers at his service, so that no valid excuse can be urged to cover the production of impure coke. But it may be submitted here that, while most coking coals can be successfully treated in washeries, yet there are some that cannot be cleaned by the best modern appliances. The exceptions, however, are so limited that the coke manufacturer need not hesitate to submit samplings of his coal for washing tests to the reliable firms, before noted, for definite determinations in the capability of the washing process in removing slate, sulphur, and other impurities from the coal.

Phosphorus is found present in coke. In the purest varieties it runs from .012 per cent. to .029 per cent. As a general experience, the phosphorus in the coal goes over to the coke; but there are occasional exceptions to this. When coal is washed preparatory to coking, some of the phosphorus goes out in the slates and refuse.

Uniform Quality of Coke.—The uniform quality of the coke is one of the important requirements in view of what has been noted of the destructive action of hot carbon-dioxide gas on the soft portions of the coke.

The black ends that are sometimes made in coking have to be included in weighing charges for the blast furnace, and their ready dissolution reduces the heat power in the proper zone in the furnace. As this defect can be controlled by the manufacturer of coke, no reasonable defence can be urged for the presence of black ends in coke made for furnace use.

It has been shown that the use of coke as a metallurgical fuel is not only quite large, but increasing in the manufacture of iron and steel. The large number of establishments for the manufacture of coke in the United States assure the truth of the foregoing statement.

Table VI will show the physical as well as the chemical properties of American and Mexican cokes. In examining this table it will readily appear that in the best coke the aggregate of cell space to body of coke is in the relation of 44 to 56, nearly. It is not submitted that all coking coals can be made to assure this ratio of cells to body of coke, but in the coals best adapted for making good coke, a close approximation to these physical relations should be found.

Coherence in Handling.—In blast-furnace practice, it has recently been determined that cokes vary widely in breakage in handling in the railroad cars and at the furnace, making breeze that is undesirable, and which, if in large proportion, congests the furnace, reducing the output. This fine material from brittle coke is generally thrown aside as worthless. In careful tests recently made of three principal qualities of blast-furnace cokes, which can be designated as A, B, and C, 5 tons of average shipments of each variety were taken just as received in railroad cars at the furnace; these classes were carefully separated into large, medium, and breeze. All these tests were made by volume, with the following results:

	A Per Cent	B Per Cent.	C Per Cent.
Large coke	45.71	56.81	54.40
Medium coke	25.71	40.90	44.00
Breeze	28.58	2.29	1.60

From the above, the great loss in fuel and freight in the breeze produced from the class A will readily appear. The cokes B and C vary little in the loss from breeze. But the medium coke in the class A, from its brittle property, would reduce its value in

TAB

FULTON'S TABLE EXHIBITING THE PHYSI

REVISE

Locality	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Lb. Per Cubic Inch, ¼ Ultimate Strength	Ft. Height of Furnace Charge, Supported Without Crushing	Order in Cellular Space
	Dry	Wet	Dry	Wet	Coke	Cells			
Connellsville—Standard Coke..	**15.47**	**23.67**	**59.09**	**90.28**	**52.78**	**47.22**	**301**	**120**	**1**
Caledonia, Pa.	12.10	21.80	46.12	83.07	40.83	59.17	149	60	1
Caledonia, Pa.	13.57	22.41	51.69	85.38	46.07	53.93	209	84	1
Walston, Pa.	13.77	22.58	52.61	86.01	46.25	53.75	316	126	1
Reynoldsville, Pa.	12.44	22.17	47.39	84.48	40.63	59.37	181	73	1
Richland, Pa.	12.38	22.05	46.59	84.02	41.05	58.95	245	98	1
Bennington, Pa.	10.89	20.98	41.49	79.94	38.43	61.57	212	85	1
Gallitzin, Pa.	11.91	21.99	45.37	83.79	38.49	61.51	213	85	1
Lilly, Pa.	13.39	20.61	51.02	78.54	55.95	44.05	170	68	1¼
Indian Creek, Pa.	23.35	27.48	88.94	104.68	78.80	25.20	933	373	1½
Coosa, Ala.	12.34	22.19	50.94	86.37	39.93	60.07	192	77	1
Blocton, Ala.	14.32	22.52	54.56	85.80	49.97	50.03	409	164	1¼
Pineville, Ky.	13.31	19.90	50.71	75.82	59.80	40.20	274	109	1½
Pineville, Ky.	14.10	22.24	53.73	84.73	50.37	49.63	227	91	1½
Powelton, W. Va.	14.16	22.93	53.88	87.33	46.48	53.52	381	151	1¼
Montana, W. Va.	14.28	22.82	54.39	86.95	47.87	52.13	327	131	1
Monongah, W. Va.	12.63	22.05	48.11	84.02	42.33	57 67	306	122	1
Big Stone Gap, Va.	11.89	21.18	45.31	80.70	43.34	56.66	245	98	1¼
Big Stone Gap, Va.	12.20	21.02	46.49	80.09	46.22	53.78	326	131	1½
Pocahontas, Va.	15.67	23.53	59.68	89.64	52.07	47.93	236	94	1
Salville, Va.	11.64	21.87	44.35	83.32	37.61	62.39	200	80	1
Lonaconing, Md.	10.22	21.29	38.92	81.12	32.43	67.57	90	36	1½
Hondo, Mex.	9.78	20.69	37.89	78.85	34.41	65.59	158	63	1¼
Alamo, Mex.	12.04	22.09	45.88	84.18	38.67	61.33	146	58	1¼
Cardiff, Wales.	12.90	22.27	49.16	84.86	42.76	57.24	231	92	1
Syracuse, N. Y.	15.02	23.41	57.20	89.20	47.68	52.32	340	136	1
Morris Run, Pa.	15.02	22.41	49.03	85.37	41.82	58.18	246	97	1
Anthracite, Pa.						100 00		100	
Glassport, Pa.	17.34	25.01	66.45	95.59	53.73	46.67	804	322	1
Indian Territory.	12.49	21.46	47.60	81.75	45.31	54.69	217	87	1
Graceton, Indiana Co., Pa.	10.24	20.92	39.02	79.72	34.84	65.16	240	96	1
Jameson Coal & Coke Co.	12.04	21.92	45.87	83.50	39.76	60.24	316	126	1
Pinnickinnick, W. Va.	12.50	22.18	47.95	84.18	41.40	58.60	280	115	1
Coal City, Ala.	12.93	22.64	49.28	86.25	40.79	59 21	300	120	1
Cumberland, Tenn.	14.88	22.31	56.68	85.00	50.39	49.61	431	172	1
Marytown, W. Va.	11.90	22.00	45.32	83.84	38.45	61.55	213	85	1
Alleghany coke.	11.91	21.99	45.37	83.79	38.49	61.51	216	90	1
Kentucky coke.	14.11	22.25	53.72	84.74	50.40	49.60	250	103	1
Kentucky coke.	13.30	20.00	50.70	75.83	59.90	40.10	274	110	1
West Virginia coke.	12.25	21.20	46.50	80.10	42.22	57.78	286	113	1
Kanawha & Hocking Valley Coal & Coke Co.	12.45	22.18	47.38	84.49	42.68	57.32	296	118	1
Great Kanawha Colliery Co.	12.42	22.19	47.35	84.52	40.60	59.40	300	119	1

NOTE.—Chemical analyses by T. T. Morrell, Prof. Andrew S. McCreath, Doctor Rothberg, Hugo C

TABLE VI

HYSICAL AND CHEMICAL PROPERTIES OF COKE

VISED SERIES

Order in Cellular Space	Hardness Per Cent.	Specific Gravity	Chemical Analysis Per Cent.						Remarks
			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Phosphorus	
1	**3.0**	**1.80**	**.42**	**.80**	**87.46**	**11.32**	**.69**	**.015**	Average Standard
1	3.0	1.80	.130	.990	87.890	9.420	1.570	.0240	Beehive oven, 48 hours
1	3.0	1.81							Beehive oven, 72 hours
1	3.0	1.82	.310	2.610	85.080	12.000	2.050	.0060	Beehive oven
1	3.0	1.87		1.120	87.110	11.770	1.800	.0110	Beehive oven
1	3.0	1.84	.500	1.130	80.480	16.470	1.420	.0140	Beehive oven
1	2.4	1.74		1.200	87.400	11.550	1.890	.0130	Beehive oven, B seam
1	2.9	1.89		1.200	89.250	9.550	1.460	.0160	Beehive oven, B seam
1½	2.4	1.47		1.500	89.800	8.210	.460	.0300	Beehive oven, B seam
1½	2.6	1.92	.220	.736	86.100	11.970	1.700		Latrobe coal, coked in Germany retort oven
1	3.0	1.88	.094	.174	85.753	11.544	2.435	.0640	Beehive
1½	2.6	1.75	.153	.810	92.760	6.940	.740	.0066	Beehive
1½	2.5	1.37	.430	1.040	91.560	6.360	.610	.0130	Beehive, Hull, Wyman, & Cairns
1½	2.6	1.77	1.140	.410	94.660	3.780	.590	.0070	Beehive, Cumberland colliery
1½	2.6	1.86	.017	2.900	91.048	7.548	.626	.0070	Beehive, 48-hour coke
1	3.0	1.82	4.000	2.900	84.330	8.770	1.670	.0100	Beehive, 48-hour, unwashed coal
1	3.1	1.82	.230	.800	89.770	9.800	.976	.0390	Beehive, 72-hour, washed coal
1½	2.5	1.67	.290	1.320	92.050	5.600	.740	.0090	Beehive, 48-hour coke
1½	2.7	1.61	.630	1.930	93.810	3.630	1.010	.0050	Beehive, 72-hour coke
1	2.5	1.83	.345	.341	92.694	5.822	.738	.0063	Beehive
1	2.8	1.89	.130	.376	87.930	10.270	.790		Beehive
1½	2.1	1.92	.614	1.020	84.667	12.234	1.465	.0241	Beehive
1½	2.1	1.77	.430	1.390	83.070	14.240	.820	.0190	Beehive, washed coal
1½	2.5	1.89		1.350	83.800	14.850	1.080	.0050	Beehive, washed coal
1	2.5	1.84	.060		95.000	4.260	.685	.0180	
1	2.6	1.91	.230	.920	86.040	12.810	.560	.0050	Semet-Solvay oven
1	2.3	1.90	.360	1.290	89.360	8.990	.760	.0110	Beehive oven
	2.8	1.95	2.270		78.881	9.393	.676		Wyoming
1	2.9	1.95	.120	.740	89.030	10.110	.690	.0120	Otto-Hoffman oven, Connellsville coal
1	2.9	1.69	.460	1.770	84.330	13.440	1.770	.0260	Choctaw Coke Co., beehive
1	2.6	1.81	1.000	1.200	87.310	9.400	1.090	.0160	McCreary Coke Co.
1	3.0	1.84	.130	1.220	87.750	10.900	.990	.0280	North Connellsville, beehive
1	3.0	1.80	.200	1.350	89.220	9.230	1.430	.0180	Beehive oven, Pittsburg coal
1	3.0	1.94	.140	2.140	90.370	7.420	.960	.0300	Talladega Furnace Co.
1	2.9	1.81	.910	1.620	87.150	10.320	.970	.0140	Cumberland plateau, beehive
1	2.5	1.75	.072	.798	94.657	3.775	.698	.0030	
1	2.8	1.78	2.480	.270	87.409	9.073	.768	.0080	Upper Freeport coal, beehive
1	2.9	1.74	.860	.914	88.679	9.815	.506	.0070	No. 3
1	3.0	1.80	.142	1.033	92.744	5.630	.451	.0030	No. 4
1	2.7	1.75	.126	.979	92.423	5.925	.547	.0030	No. 5
1	3.0	1.79		.003	91.690	8.410	.972	.0021	Gas coal seams
1	3.0	1.75		.250	92.480	7.270	.850	.0010	Screenings from whole coal bed—gas

Carlsson, F. S. Hyde, J. D. Pennock, O. O. Laudig, and E. H. Williams.

proportion as it approached, in size, the worthless condition of breeze. The destructive action of the use of small coke in the Sydney blast furnaces is a cautionary example in this respect.

COMPARISON OF BEEHIVE AND BY-PRODUCT COKING

The following physical and chemical determinations made in a series of experimental tests in coking Connellsville coal in the Otto-Hoffman oven, and in testing Connellsville and Tuscarawas coals in the Hüssner ovens in Germany, as shown in Table VII, will exhibit the properties of the cokes made in these ovens. The Connellsville standard beehive coke is given for comparison.

The analyses of the coals used in these coking tests are as follows (Hugo Carlsson, chemist):

	Connellsville, Pa. Per Cent.	Tuscarawas, Ohio Per Cent.
Moisture, 212° F.	.840	2.530
Volatile combustible matter	31.600	44.110
Fixed carbon	59.860	46.280
Ash	7.700	7.080
Sulphur	.820	3.490
Phosphorus	.008	.004
Theoretic coke	68.060	55.450

The analyses of the cokes made from the above coals follow:

	Connellsville, Pa. Per Cent.	Tuscarawas, Ohio Per Cent.
Moisture, 212° F.	.030	.130
Volatile combustible matter	.510	2.750
Fixed carbon	86.380	84.210
Ash	13.080	12.910
Sulphur	.630	3.710
Phosphorus	.015	.015

The product of marketable coke from the Connellsville coal is given at 70.10 per cent.; the coke from the Tuscarawas coal is stated at 61.47 per cent. The percentage of breeze and ashes is not given separately, but these have no value in blast-furnace work.

As the Connellsville coal, in retort ovens, affords 70.10 per cent. of useful coke, it will require 1.426 tons of coal to make 1 ton of coke. The theoretic product of coke from this coal, 68.06 per cent., would require 1.469 tons of coal to make 1 ton of coke, showing a gain from deposited carbon in coking of 2.9 per cent.

The Tuscarawas coal gives 55.45 per cent. of theoretic coke, requiring 1.80 tons of coal to make 1 ton of coke. As the oven yield is 61.47 per cent., the deposited carbon is 9.79 per cent., exhibiting this large accretion of carbon from the tar of this rich bituminous coal. It will be readily seen that, in the process of coking the Connellsville coal in the Hüssner oven, 45 per cent. of

TABLE VII

Locality	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Lb. Per Cubic Inch, ‡ Ultimate Strength	Ft. Height of Furnace Charge, Supported Without Crushing	Order in Cellular Space	Hardness Per Cent.	Specific Gravity	Chemical Analysis Per Cent.						Remarks
	Dry	Wet	Dry	Wet	Coke	Cells						Fixed Carbon	Moisture	Ash	Sulphur	Phosphorus	Volatile Matter	
Connellsville-Standard	12.51	21.62	47.69	82.20	43.93	56.07	272	108	1.00	3.0	1.74	86.88	.79	11.54	.695	.005	1.31	Beehive oven[1]
Connellsville-Hüssner	14.09	23.09	53.68	87.97	45.08	54.92	400	160										
Connellsville-Hüssner	16.00	24.02	60.96	91.52	51.09	48.91	410	164										
Connellsville-Hüssner	15.34	23.61	58.45	89.95	49.57	50.43	325	130										
Connellsville-Hüssner	14.55	23.19	55.44	88.35	47.22	52.78	413	165										
Connellsville-Hüssner, average	14.99	23.73	57.13	89.45	48.24	51.76	387	155	1.00	3.1	1.89	86.38	.03	13.08	.630	.015	.51	Hüssner oven[2]
Tuscarawas-Hüssner	10.96	21.13	41.76	80.51	37.94	62.06	164	66										
Tuscarawas-Hüssner	11.78	17.25	44.88	82.45	39.88	60.12	163	65										
Tuscarawas-Hüssner	11.09	21.86	42.25	83.29	40.41	59.59	172	69										
Tuscarawas-Hüssner	10.72	21.05	40.84	80.20	37.00	63.00	124	50										
Tuscarawas-Hüssner, average	11.14	20.32	42.43	61.61	38.81	61.19	156	62	1.00	2.5	1.75	84.21	.13	12.91	3.710	.015	2.75	Hüssner oven[3]
Connellsville-Otto-Hoffman, side of oven	14.64	21.02	55.79	80.07	61.13	38.87	465	186										
Connellsville-Otto-Hoffman, bottom of oven	20.49	24.23	78.07	92.30	77.22	22.78	940	376										
Connellsville-Otto-Hoffman, average	17.57	22.62	66.93	86.18	69.17	30.83	702	281	1.25	3.3	1.90	85.60	.12	12.26	.520	.006	2.02	Otto-Hoffman oven[4]

[1] Chemist, T. T. Morrell

[2] Chemist, Hugo Carlsson

[3] Chemist, Hugo Carlsson

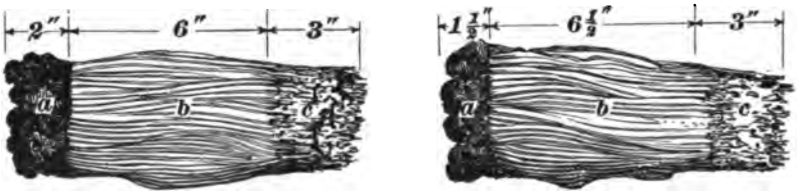
[4] Chemist, Dr. J. J. Fronheiser

the sulphur has been volatilized. In coking the Tuscarawas coal, 46 per cent. of the sulphur has been eliminated. The Tuscarawas coke is too high in sulphur for use in the manufacture of pig iron. The largest volume of the sulphur in the Tuscarawas coal is found as bisulphide of iron, FeS_2. In the process of coking, one equivalent of sulphur is volatilized, leaving the monosulphide, FeS, in the coke. Disintegrating and washing this quality of Ohio coals would reduce the sulphur.

In furnace operations, about 4 per cent. of the sulphur goes over to the pig iron. As the Connellsville coke contains .63 per cent. of sulphur, it would contribute to the pig iron .0252 per cent. of this element, which would be slightly increased from the sulphur in the ore and flux, but these are usually small. The sulphur limit in the best Bessemer pig is .04 to .05 per cent.

In examining the physical structure of these cokes, the effects of the Hüssner oven in exerting a certain pressure to the charge in coking are quite evident in both these cokes.

There are three sections of different densities in the structure of these cokes, as shown in Fig. 1. Beginning on the sides of the oven, section *a* contains 1 to 2 inches of the most dense portion. Section *b*, 6 to 6½ inches long, contains fairly well developed cellular structure. Section *c*, next to the middle division of the coal in coking, is greatly inflated in its cells, extending about 3 inches from its central end.



(*a*) *Connellsville* (*b*) *Tuscarawas*

FIG. 1. COKE FROM HÜSSNER OVEN

In making the determinations shown in Table VII, Connellsville coke made in beehive ovens was tested by three samples each of 48- and 72-hour coke. The table, therefore, affords a general average of the physical properties of this standard coke.

In the Connellsville and Tuscarawas cokes, made in Germany, in the Hüssner retort oven, four samples of each quality of coke were used. The table gives these determinations in full, with the general averages of each kind for comparison.

The tests of the coke from Mr. Frick's Connellsville coal, made in Germany, in the Otto-Hoffman oven, consisted of two average samples from the top and bottom of the oven.

The determinations of the physical properties of the Hüssner-Connellsville coke show considerable variation in density, the general averages exhibiting an increased density of structure from the beehive-Connellsville of 7.7 per cent. The coke is lumpy. It shatters easily into finger pieces, on planes nearly at right angles to the side walls of the oven. It does not inherit the silvery coating that gives the beehive-Connellsville coke such a desirable appearance.

The Hüssner-Connellsville coke is somewhat harder-bodied than the beehive-Connellsville coke. It is probable that the increased hardness of body of the former will compensate for the carbon glaze of the latter. Both hardness of body and carbon coating protect coke in its passage down a blast furnace from the dissolving agency of hot carbon dioxide.

The Hüssner-Tuscarawas coke is lumpy and dark-colored, shattering quite easily under slight shocks into slender pieces, on similar planes as the Hüssner-Connellsville coke.

The Otto-Hoffman-Connellsville coke is the hardest-bodied fuel, exhibiting good work in the oven. But its largely increased density reduces its value as a vigorous blast-furnace fuel. It is, on a general average, 45 per cent. denser than the standard beehive-Connellsville coke, and 40.4 per cent. denser than the Hüssner-Connellsville product. It approximates in its most dense sections to anthracite. It may be submitted, however, that the samples furnished by Dr. F. Schniewind were very select as to completeness in coking and density of structure.

It has been determined, by actual furnace work, that, for the attainment of the maximum efficiency of coke fuel in metallurgical operations, two prime elements are absolutely necessary: hardness of body and fully developed cell structure.

The following table will show the work of fuels, accurately determined, for calorific energy and economy in American blast furnaces:

TABLE VIII

Kind of Fuel	Size of Furnace Feet	Output Per Month Gross Tons	Location	Average Per Cent. Iron Ore	Pounds Fuel to 1 Ton Pig Iron	Year	Remarks
Charcoal	12 by 60	3,379	Wisconsin	55	1,815	1891	Bay Furnace
Anthracite	17 by 65	2,698	New Jersey	55	2,244	1890	Secaucus Furnace
Anthracite and coke	15½ by 55½	2,565	Pennsylvania	58	2,200	1885	
Coke	22 by 90	12,000	Pennsylvania	59	1,800	1892	Edgar Thompson Connellsville coke

From the foregoing results in blast-furnace practice, it will appear that in the physical condition of the fuels two conditions

TABLE IX

RELATIVE COST, IN HOURS, PER TON, OF COKE AT GLASSPORT, CAMBRIA, AND HOLLAND NO. 3, GERMANY*

	Number of Men Per Day			Total Hours Per Month			Hours Per Ton of Coke		
	Glassport	Cambria	Holland No. 3	Glassport	Cambria	Holland No. 3	Glassport	Cambria	Holland No. 3
Coal handling	15.95	7.67		4,785.0	2,379		.37	.39	
Coke ovens	86.38	45.49	36	32,696.8	16,922	12,960	2.54	2 78	2.68
Condensing house at ovens	17.04	3.90		6,134.4	1,458		.48	.24	
Condensing house proper	5.70	.92	3	2,052 0	341	1,080	.16	.06	.23
Ammonia house	10.37	3.93	4	3,733.2	1,464	1,440	.29	.24	.30
General labor, superintendence and labor	20.07	22.32	12	7,225.2	8,302	4,320	.56	1.36	.89
Total	155.51	84.23	55	56,626.6	30,866	19,800	4.40	5.07	4 10
Coal handling, which is not shown in German pay roll	15.95	7.67		4,785.0	2,379		.37	.39	
Total	139.56	76.56	55	51,841.6	28,487	19,800	4.03	4.68	4.10

* The average production, per hour, of these mines was as follows: Glassport, 12.86 tons; Cambria, 6.08 ton; Holland No. 4, 3,.826 tons

TABLE X

COMPARISON OF LABOR AT GLASSPORT AND JOHNSTOWN COKE OVENS. MAY AT GLASSPORT; JUNE AT JOHNSTOWN

Departments	Occupations	Number of Hours		Amount of Wages		Hours Per Ton		Cost Per Ton	
		Glassport	Johnstown	Glassport	Johnstown	Glassport	Johnstown	Glassport	Johnstown
Coal Handling	Foreman	310	222	$ 60.00	$ 35.52				
	Engineers	670	249	92.25	33.63				
	Chutemen	830		114.25					
	Shovelers	3,030	919	382.88	91.90				
	Labor at washer		298		37.90				
		4,840	1,688	649.38	198.95	376	362	$ 5.050	$ 4.271
Ovens, Regular Operations	Foremen	744	720	135.00	121.70				
	Engineers	756	720	137.25	97.22				
	Larry and winchmen	4,173	2,376	521.62	237.60				
	Door tenders	3,411	1,467	426.37	146.70				
	Levelers	2,715	720	339.37	72.00				
	Quenchers and hookers	2,682	1,354	323.98	135.40				
	Coke loaders	11,055		1,396.87					
	Motorman on loader		720		90.02				
	Car and track cleaners	1,587		198.37					
	Mud mixers	1,203	1,135	149.62	114.10				
	Screeners, extra loaders	2,950		362.81					
		31,276	9,212	3,991.26	1,014.74	2,432	1,978	31.036	21.785
Condensing House at Ovens	Oven inspectors	372		50.00					
	Gas tenders	1,431	555	178.87	55.50				
	Tar chasers	1,500	720	187.50	72.00				
	Stand-pipe cleaners	1,548	733	193.50	72.30				
	Pencilers	1,623	720	203.25	72.00				
		6,474	2,728	813.12	272.80	503	586	6.323	5.856

Con-densing House	Engineers	744	709	124.00	95.73				
	1st helpers	711	679	88.42	67.90				
	2d helpers	666		69.37					
		2.121	1,388	281.79	163 63	165	298	2.191	3.513
Ammonia House	Foremen	744		108.50					
	Stillmen		667		90.06				
	Centrifugal men	1,428	559	178.50	65.70				
	Lime men	831		86.55					
	General labor	861	60	89.92	6.84				
		3,864	1,286	463.47	162.60	301	276	3.604	3.491
General	Superintending	1,116	720	285.00	159.30				
	Laboratory chemist	648		130.00					
	Laboratory assistant	324		20.25					
	Office bookkeeper	324		75.00					
	Office timekeeper	372	260	35.00	45.00				
	Office boy	324	266	20.25	15.96				
	Yardmaster	372		50.00					
	Storekeeper	372		38.75					
	Engineer pumping station		185		24.98				
	Firemen at boilers	1,488	1,413	223.20	166.52				
	Pipe fitters	468		82 87					
	Blacksmith	256	115	48.00	15.53				
	Blacksmith's helper	591		69.62					
	Machinist		720		162.01				
	Carpenter	54	297	18.00	33.42				
	Teamsters	24		4.00					
	Watchmen	744		89.90					
		7,477	3,976	1,189.84	622.72	581	854	9.252	13.369
	Totals	56,052	20,278	$7,388.86	$2,435.44	4.36	4.35	$57.456	$52.285
	Tons coke	12,860	4,658						

NOTE.—Glassport is running on bituminous coals on the Youghiogheny and Monongahela rivers. Cambria uses the dry semibituminous coals of the Alleghany Mountain region.

have been established, with their relative consumption of fuel and pig iron produced. The first is the work of the Connellsville standard coke in the Edgar Thompson blast furnaces, where the smelting of 1 ton of Bessemer pig iron has been accomplished with 1,800 pounds of coke. In the other, 2,200 pounds of anthracite was required to perform similar work.

The monthly outputs of the coke and anthracite fuels indicate their relative calorific energies. As this great difference in fuel energy has not its source in their chemical composition, it follows that it must be found in their physical structure.

In this structure there are two terms of relative density: in the anthracite 100 per cent. and in the standard Connellsville coke 44 per cent. It is self-evident that any increase in the density of the coke toward that of anthracite is just so much of an approach to this slow-acting fuel, and hence its value in furnace work is depreciated in direct proportion; perhaps more so in the coke than in the anthracite, as the latter decrepitates in the presence of furnace heat and thus presents enlarged surfaces to the combining gases in combustion, while the coke does not break up under heat, and is therefore directly less energetic.

It was evidently for such reasons that Sir I. Lowthian Bell, in comparing the work performed in his blast furnaces by coke made from Bears Creek coal in beehive and Simon-Carvés retort coke ovens, remarks as follows:

"(1) Mixtures from collieries usually supplying Clarence works and made in beehive ovens, 100 per cent.; (2) Bears Creek coke made in beehive ovens, 101.11 per cent.; (3) Bears Creek coke made in Simon-Carvés retort ovens, 111.11 per cent.

"In comparing the two kinds of Bears Creek coke, 1 and 2, if No. 2 is taken as a 100 per cent., then No. 3 will stand as 109.89 per cent., exhibiting an inferiority of nearly 10 per cent. in efficiency in smelting 1 ton of No. 3 iron. The average consumption of the three fuels was 2,520 pounds, 2,548 pounds, and 2,800 pounds, respectively."

Comparative Yield of Coke in Different Ovens.—On the other side, with careful work in coking, the percentages of large coke made in beehive Hüssner, and Otto-Hoffman ovens are as follows:

	PER CENT.
Beehive oven	65
Hüssner oven	70–72
Otto-Hoffman	70–72

The yield in the retort ovens is, therefore, nearly 9.02 per cent. above the yield afforded by the beehive oven. This increased yield in the retort-oven coke will compensate in part for its increased density, requiring increased quantity to perform equal work with the beehive product. In the investigation of the comparative merits of these two coke fuels, the vital inquiry is, Will 65 units of beehive coke perform as much work in the blast furnace as 72 units of the denser retort fuel?

It may be noted here that the increased product of coke from the retort ovens over that of the beehive is more apparent than real, as has been determined in blast-furnace and cupola practice. The Buffalo blast-furnace tests, with Semet-Solvay and Connellsville-beehive cokes, illustrated this in a very interesting manner. Both cokes were made from Connellsville coal. Their chemical composition was as follows:

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.
Semet-Solvay	1.25	1.61	86.66	10.48	.77
Beehive	.19	1.17	89.02	9.62	.90

The general average of the coke to smelt 1 pound of Bessemer metal was: Semet-Solvay, 1.028 pounds; Connellsville-beehive, .956 pounds; showing 7 per cent. of excess in retort-oven coke. The beehive coke inherited 11.06 per cent. of cells more than the retort product. In a further test of Connellsville coal in Otto-Hoffman retort coke ovens, at the Glassport plant, the yield of coke was 71 per cent.

The composition of the Otto-Hoffman and Frick cokes is as follows:

	Moisture Per Cent.	Volatile Matter Per Cent.	Fixed Carbon Per Cent.	Ash Per Cent.	Sulphur Per Cent.	Phosphorus Per Cent.
Otto-Hoffman	.12	.74	88.97	10.10	.70	.012
Frick-beehive	.52	.098	89.55	8.95	.84	.022

Melting Power.—The following is a comparison of results obtained from these tests at the steel works of the Lorain Steel Company, September, 1898:

With the use of by-product coke, 9.71 pounds of iron was melted per pound of coke; with the Frick coke, 10.64 pounds. This shows 8.83 per cent. more iron melted with the Frick beehive coke than the Otto-Hoffman product. The speed in melting was decidedly on the side of the former coke, but it must be submitted that there are economies in the retort-coke-oven work. Taking the relative percentages of useful coke produced by these two systems at 71 per cent. and 65 per cent., respectively, it is evident that the retort coke will only require 1.41 tons of coal to make

1 ton of coke, and the beehive 1.54 tons, showing 8.45 per cent. of economy in the coal used in the retort oven. This nearly balances the loss in the retort coke in the blast furnace. Some economy in the labor of making the retort coke, as well as in the saving of the by-products of gas, tar, and ammoniacal liquor, less the increased cost of the retort oven over the beehive, will reduce the net margin of saving to about 30 cents per ton of coke produced.

It has been found quite difficult to procure an accurate statement of the work and cost of making coke in the retort coke ovens, especially the cost of repairs. The tabulated statements, Tables IX, X, XI, XII, and XIII, will throw some light on these matters:

TABLE XI

COST AND PRODUCTION OF OTTO-HOFFMAN COKE OVENS AT JOHNSTOWN, PENNSYLVANIA, FISCAL YEAR 1898–1899

	AMOUNT	TOTALS	COST PER TON
Superintendents, assistants, clerks, chemist, pumping station	$ 6,914.40		
Labor on coal	7,826.78		
Labor, washing and mixing coal, and team service	2,808.91		
Labor at ovens	39,845.14	$57,395.23	$ .425
Repairs to ovens	3,464.55		
Repairs to tracks, pumping station, and general repairs	2,100.67		
Coal-mixing machinery	4,550.70	10,115.92	.075
Oil, waste, packing, tools, etc	2,998.84		
Transportation	6,005.25		
Loam and clay	343.80		
Office expenses and incidentals	4,653.72		
Coal for steam and heating ovens	7,425.04	21,426.65	.158
General expenses		2,319.91	.017
Taxes		1,222.00	.009
Cost of coking		92,481.71	.684
213,761.64 net tons coal at .89		190,372.68	1.409
Gross cost of coke		282,854.39	2.094
Credit for by-products		23,371.85	.173
Net cost 135,083.40 net tons coke		259,482.54	1.921
Firing new ovens		4,955.14	.039
Mud-dam		371.92	
29,089 ovens		$264,809.60	$1.960

BY-PRODUCTS

CREDIT	AMOUNT	TOTALS
56,100,000 cubic feet of gas at 5 cents per thousand	$ 2,805.00	
3,433.90 net tons of tar at $5.06	17,366.83	
263.37 net tons sulphate of ammonia at $50.47	13,291.65	
275.37 net tons concentrated liquor at $22.87	6,297.89	$39,761.37
DEBIT		
Labor at by-product plant	10,958.92	
Repairs at by-product plant	1,518.49	
Lime and sulphuric acid	3,547.97	
General expenses	364.14	16,389.52
Net credit for by-products		$23,371.85

PRACTICE	PER CENT.
213,761.64 tons coal used for coke	
135,083.40 tons scale weight coke produced	63.19
3,433.90 tons tar produced	1.61
263.37 tons sulphate produced	.12
275.37 tons concentrated ammonia liquor produced	.13
	CUBIC FEET
Gas	262

TABLE XII

COST AND PRODUCTION OF OTTO-HOFFMAN COKE WORKS, FISCAL YEAR 1895–1896

	AMOUNT	TOTALS	COST PER TON
Superintendents, assistants, clerks, chemists, pumping station	$ 6,489.14		
Labor on coal	3,302.09		
Labor at ovens	24,612.96	$34,404.19	$ .653
Repairs to ovens	14,298.20		
Repairs to tracks, pumping station, and general repairs	2,370.04	16,668.24	.317
Oil, waste, packing, tools, etc	3,326.78		
Transportation	2,722.75		
Loam and clay	311.17		
Office expenses and incidentals	1,311.77		
Coal for steam and heating ovens	7,843.60	15.516.07	.295
General expenses	1,937.37		
Taxes	80.00	2,017.37	.038
Cost of coking		68,605.87	1.303
66,965.62 net tons coal at $.98		65,681.63	1.274
Gross cost of coke		134,287.50	2 550
Credit for by-products		5,281.64	.100
Net cost 52,666.43 net tons coke		$129,005.86	$2.450

BY-PRODUCTS

Credit	Amount	Totals
Cubic feet gas at		
1,635.75 net tons tar, at $5.95	$ 9,713.71	
302.62 net tons sulphate of ammonia, at $39.99	12,100.69	$21,814.40
Debit		
Labor at by-product plant	11,387.26	
Repairs at by-product plant	902.20	
Lime and sulphuric acid	4,243.30	16,532.76
Net credits for by-products		$5,281.64

Practice	Per Cent.
66,965.62 tons coal used for coke	
52,666.43 tons scale weight coke produced	
52,666.43 tons coke credited	78.65
1,636.75 tons tar produced	78.65
302.62 tons sulphate produced	2.44
	Cubic Feet
Gas	45

TABLE XIII

COST OF MAKING COKE IN BEEHIVE OVENS

	Cents
Drawing coke	.1800
Leveling	.0200
Yard boss, $75 per month	.0050
1 locomotive engineer, $12.25 1 charger, $1.68 per day	.0090
1 track cleaner, 1 car trimmer, $1.35 per day	.0040
1 car shifter, $1.75 per day	.0030
1 track man, $1.50 per day	.0020
3 cart horses	.0040
Water	.0100
Half superintendent's salary, $175 per month	.0050
Repairs	.0300
Interest on investments	.0030
Taxes, insurance, etc	.0250
Coke working extra	.0250
	3520
1.5 tons of coal at 89 cents per ton	$1.3350
Repairs per ton of coke	.0135
Total	$1.7005

Johnstown, Pa., April 1, 1899.

Table IX exhibits the time required to make 1 ton of coke in Otto-Hoffman coke ovens at Glassport and Johnstown, Pennsylvania, with the time used at Holland No. 3, Germany.

Table X affords in full details the several departments of labor in making coke and saving by-products, with the aggregate cost of each department, as the relative cost per ton for labor, in Glassport and Johnstown.

Table XI affords the cost of the several elements of labor and materials required in making 1 ton of coke and saving by-products. It also affords the ultimate aggregate cost of coke, charging the cost of coal at 89 cents per net ton, and crediting the manufacture of the coke with the value of the saved by-products, making the net cost of 1 ton of coke' $1.92, including ordinary repairs of ovens, but excluding extraordinary expenses.

Table XII gives cost and production of Otto-Hoffman coke ovens at Johnstown during the fiscal year, 1895-1896. Evidently these costs include new construction, and the large cost per net ton of coke has not been used in calculations. The moderate cost of $1.92 has been taken for comparison. The cost of maintenance of these Otto-Hoffman coke ovens is only incidentally afforded in the foregoing tabulated statements. These do not cover a sufficient length of time to give reliable data in this important element of cost. Taking what is given in these statements of the minimum average cost of repairs per net ton of coke produced, with the saving of the by-products and avoiding unusual expenses, it is 8 cents. This is included in the net cost of $1.92 per ton of coke made. This plant of coke ovens is comparatively new; as it ages, the cost of repairs will increase largely.

In this connection it may be interesting to compare the cost of making coke in the Connellsville-beehive coke oven, as shown in Table XIII. It is estimated that the life of a beehive coke oven is 16 years. To maintain it during this time will cost: for bottoms, $34.50; tunnel heads, $32; and fronts, $76; making in all $142.50; say, $1.50 per oven during the 16 years. Taking the average annual product of an oven at 700 tons, the cost of repairs will be $.0133 per ton of coke. Adding this to the cost of making coke, will give the total net cost of producing coke in a beehive coke oven at $1.7005 per net ton, showing an economy on the side of the beehive of $.2195, as compared with the work of the retort ovens at Johnstown.

It is not assumed that the cost of production of coke at the Johnstown retort coke ovens is a minimum quantity, but it indicates that the claims of large profits in this type of coke oven over the ancient beehive oven are not assured in the foregoing instances. When the great difference in the cost of these ovens is considered, with the relative interest on investment in plants, the economies will still be increased on the side of the round oven. But it must be considered that there is an additional credit due the retort oven. Taking the relative product of coke from Connellsville coal at 65 per cent. for the beehive and 72 per cent. for the Otto-Hoffman, respectively, it is evident that the former will require 1.538 tons of coal to make 1 ton of coke, and the latter 1.39 tons to 1 ton of coke, exhibiting an economy in the use of coal in the retort oven of 296 pounds. This, at 89 cents per ton, gives $.132 of credit to the retort oven. The relative costs of producing coke, per net ton, in the two cases under consideration are as follows: beehive, $1.7005; Otto-Hoffman, $1.788, thus showing substantially equal cost in the production of coke by these types of coke ovens.

If a further investigation of the interest in investment on the plants of ovens and by-product saving is considered, with the additional fact that 72 per cent. of retort coke is only equal to 65 per cent. of beehive coke in blast-furnace operations, the value of the retort coke ovens, considered in this comparison, dissipates much of the claims for economy. But their essential usefulness must be recognized in their capacity to produce coke from the dry coals that could not be made into good coke in the beehive ovens. This element of their usefulness will increase as the coal suitable for the open-oven manufacture becomes partially exhausted.

EFFECTS OF THE SEVERAL TYPES OF COKE OVENS ON THE PHYSICAL PROPERTIES OF THEIR COKE PRODUCTS

With the manufacturers of coke for metallurgical uses, the fact is well established that coke ovens dominate, in a large degree, the physical properties of their products. It is, therefore, now proposed to consider the relative effects of the typical coke ovens on the physical condition of the coke produced in each kind. It is well known that in the great variety of coke ovens there are only three root types: the beehive, or round, oven; the Knab, or retort, oven; and the Appolt, or upright, oven.

In the beehive and other horizontal types of coke ovens, it will be readily understood that the governing element in their operations is similar; a broad charge of coal, 24 to 26 inches deep, affording the greatest liberty to the charge of coal in fusing to develop the fullest cellular structure and to glaze the upper portion of the coke with deposited carbon, giving it a sheen that, in addition to its appearance, contributes to its resistance to the dissolving agency of hot carbon-dioxide gas in blast-furnace and cupola operations.

The moderate heat of these ovens, in the initial operations of coking, prevents a too inflated or frothy physical structure in the coke. The physical properties of the coke from this type of coke oven are most excellent. With the use of the best qualities of coking coals in the manufacture of coke, the product is always the best possible for blast-furnace use.

This family of coke ovens yields 63 to 66 per cent. of marketable coke with 2 to 3 per cent. of small coke and ash. The percentage of coke obtained depends on the skill and economies applied in the coking operations, as well as in the quality of the coal used.

The Knab coke oven, with its numerous offspring of these narrow vertical ovens, has chambers 18 to 24 inches in width and 25 to 35 feet in length. The Simon-Carvés, Semet-Solvay, Hüssner, Seibel, and Otto-Hoffman are examples of this type of oven. With narrow chambers and charges of coal 5 to 6 feet deep, a certain amount of pressure is exerted in the process of coking, producing coke of increased density of structure as compared with the product of the round or the horizontal ovens. This density of coke is readily seen near the side walls of the coking chamber, and especially at the bottom section of the oven. As the coking begins at the sides and bottom of the oven, a minimum quantity of carbon is deposited from the gases evolved in coking. From the great heat maintained in these ovens by the combustion of gases in the bottom and side flues, the operation of coking begins quickly and is usually accomplished in a thorough manner, avoiding much of the black ends that occasionally appear on coke from the horizontal ovens.

The vertical posture of the chamber of the Appolt oven confers on its coke the densest physical structure. It is probable that this oven could be used in the manufacture of coke from coals very rich in fusing matter, as it would tend to repress a too inflated structure in the coke. These retort coke ovens produce from 70 to 73 per cent. of marketable coke.

Table XIV will show the relative influence of these coke ovens on the physical properties of their coke.

In this table, reference letter (*a*) gives the average physical properties of the standard Connellsville coke made in the beehive coke oven. This general average embraces samplings taken in the coke from the top, middle, and bottom of the charge. It is therefore a fair average of the best quality of this coke. (*b*) gives the results of a coking test made in a Hüssner retort coke oven in Germany, from a shipment of Connellsville coal, during the early movement to introduce these narrow coke ovens into the United States of America. Samplings of this coke were secured from the side, middle, and bottom of the coke made in this oven; the average result is given in the table. (*c*) exhibits the physical properties of coke made in the experimental coking plant of the Semet-Solvay Company at the Solvay Chemical Works, Syracuse, New York. It was made from a shipment of coal from the Connellsville field in 1895. This average determination of the physical properties of this coke embraces samplings from top, middle, and bottom of the charges. (*d*) exhibits the work of the Otto-Hoffman retort coke oven, from a shipment of Connellsville coal sent to Germany for the purpose of a general test. The average of two samplings from top and bottom is given in the table. (*e*) gives the physical properties of coke made from Morris Run coal, Tioga County, Pennsylvania, in a beehive coke oven. (*f*) exhibits the physical properties of coke made in a Semet-Solvay coke oven from the Morris Run coal. The design was to determine the influence exerted by this type of retort coke oven in repressing cellular structure in the coke, as compared with the

TABLE XIV

FULTON'S TABLE EXHIBITING THE PHYSICAL AND CHEMICAL PROPERTIES OF COKE

REVISED SERIES

Locality	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Lb. Per Cubic Inch ‡ Ultimate Strength	Height of Furnace Charge, Feet, Supported Without Crushing	Order in Cellular Space	Hardness Per Cent.	Specific Gravity	Chemical Analysis Per Cent.						Remarks
	Dry	Wet	Dry	Wet	Coke	Cells						Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur	Phosphorus	
(*a*) Connellsville—Standard Coke...	**12.51**	**21.62**	**47.69**	**82.20**	**43.93**	**56.07**	**290**	**115**	**1**	**3.0**	**1.80**	**.79**	**1.310**	**86.880**	**11.540**	**.695**	**.0050**	Average Standard beehive oven, av. of 3 tests.
(*b*) Hüssner, German tests..........	14.99	23.73	57.13	89.45	48.24	51.76	387	155	1	3.1	1.89	.030	.510	86.380	13.080	.680	.0150	Connellsville coal, av. of 4 tests
(*c*) Semet-Solvay. Syracuse, N. Y...	15.43	24.18	58.12	91.92	49.49	50.51	370	147	1	3.0	1.90	1.250	1.610	86.660	10.480	.770	.0180	Connellsville coal, av. of 3 tests
(*d*) Otto-Hoffman, German tests....	17.57	22.63	66.93	86.18	69.17	30.83	702	281	1¼	3.3	1.90	.120	.120	85.600	12.260	.520	.0060	Connellsville coal, av. of 2 tests
(*e*) Morris Run, Tioga Co., Pa.....	13.02	22.41	49.03	85.37	41.82	58.18	246	97	1	2.3	1.90	.360	1.290	89.360	8.990	.760	.0110	Beehive oven
(*f*) Semet-Solvay, Syracuse, N. Y...	15.02	23.41	57.20	89.20	47.68	52.32	340	136	1	3.5	1.91	.230	.920	86.040	12.810	.560	.0050	Morris Run coal, Semet-Solvay
(*g*) Reynoldsville, Pa..............	12.44	22.17	47.39	84.48	40.63	59.37	181	73	1	3.0	1.87		1.120	87.110	11.770	1.800	.0110	Beehive oven
(*h*) Gallitzin, Pa..................	11.91	21.99	45.37	83.79	38.49	61.51	213	85	1	2.5	1.89		1.200	89.250	9.550	1.460	.0160	Beehive oven, B coal
(*i*) Monongah, W. Va.............	12.63	22.05	48.11	84.02	42.33	57.67	306	122	1	3.2	1.82	.230	.800	89.770	9.800	.970	.0290	Beehive oven, Pittsburg coal
(*k*) Pineville, Ky..................	14.10	22.24	53.73	84.73	50.37	49.63	227	91	1¼	2.6	1.71	1.140	.410	94.660	3.780	.590	.0070	Beehive oven
(*l*) Pocahontas, Va................	15.67	23.53	59.68	89.64	52.07	47.93	236	94	1	2.5	1.83	.345	.341	92.694	5.882	.738	.0063	Beehive oven
(*m*) Anthracite coal, natural coke...					100.00					2.8	1.75	2.270	8.830	78.831	9.393	.676		Lykens Valley

product of the beehive coke oven, with its horizontal posture and freedom of action in coking. (*g*), (*h*), (*i*), (*k*), and (*l*) afford examples of the physical properties of cokes made from different qualities of coals in beehive coke ovens. (*m*) gives the anthracite or natural coke. It has no cell structure and is the most dense fuel used in blast-furnace operations. It will be interesting to compare the relative percentage, by volume, of coke to cells in the foregoing tests, as shown in Table XV.

TABLE XV

	Coke Per Cent.	Cells Per Cent.
(*a*) Connellsville beehive standard coke	43.93	56.07
(*b*) Hüssner, Connellsville coal	48.24	51.76
(*c*) Semet-Solvay, Connellsville coal	49.49	50.51
(*d*) Otto-Hoffman, Connellsville coal, German test	69.17	30.83
(*e*) Morris Run coal, beehive oven	41.82	58.18
(*f*) Semet-Solvay, Morris Run coal	47.68	52.32
(*g*), (*h*), (*i*), (*k*), and (*l*) beehive, various coals, general average	44.78	55.22
(*m*) Anthracite, general average	100.00	

TABLE XVI

	Per Cent.
Anthracite	100.00
Connellsville standard beehive coke	43.93
Hüssner, Connellsville coal, Germany	48.24
Otto-Hoffman, Connellsville coal, Germany	69.17
Otto-Hoffman, Connellsville coal, Glassport, Pennsylvania	53.73
Semet-Solvay, Connellsville coal, Syracuse, New York	50.12
Morris Run coke, beehive oven	41.82
Morris Run coke, Semet-Solvay ovens	47.68
Average of all retort-oven coke, Connellsville coal	55.72
Average of all beehive ovens on various coals	42.88

The above statements will exhibit in a brief manner the effects of the different types of coke ovens in repressing the physical structure of the coke, as compared with anthracite at 100 per cent. Direct comparisons can thus be made of the coke products of the beehive and retort types of coke ovens.

Taking the volume of the body of the beehive-Connellsville coke at 43.93 per cent., and the Hüssner coke from Connellsville coal at 48.24 per cent., the latter retort oven has compressed its coke 8.94 per cent. The Semet-Solvay oven, using Connellsville coal, compresses its product 11.23 per cent. The Otto-Hoffman, using Connellsville coal, compresses its product 24.49 per cent. The general average of the retort coke ovens represses their product 21.03 per cent.

But we have a very interesting test of the effects of the beehive and Semet-Solvay ovens, using Morris Run coal, on their coke product. The beehive oven gives the coke a cellular structure of 58.18 per cent., while the Semet-Solvay retort oven gives only 52.32 per cent. of cells in its coke, a difference of 11.02 per cent. in favor of the beehive structure; or, in other words, the retort oven densifies its coke 11.02 per cent. over that of the round or beehive oven.

It follows, therefore, that, as the calorific energy of any fuel is in proportion to the extent of its surface exposed to the oxidation agencies in a blast furnace, then the greater this surface, within certain limits, the more energetic the combustion As anthracite, or natural coke, is the most dense of fuels and the least energetic in its combustion, it follows that, in the preparation of artificial fuel in coke ovens, every approach in the density of the coke to that of anthracite reduces its calorific energy and therefore its value for blast-furnace operations.

Of course in this conclusion, the economy of the work in producing coke in the retort ovens, with the additional revenue derived from the by-products, must be considered as an offset of credit against the density of the coke. But if the prime effort is to produce the most energetic fuel for blast-furnace work, then the repression of the cells and the densification of the coke in the narrow ovens cannot be defended.

CHAPTER VIII

THE LABORATORY METHODS OF DETERMINING THE RELATIVE CALORIFIC VALUES OF METALLURGICAL FUELS

There can be little difference of opinion in deciding that the test in blast-furnace use of the three principal fuels is the most reliable method of determining their relative calorific values, provided the conditions of the work are equalized justly.

This assumes that such tests shall have been made in blast furnaces whose dimensions have been proportioned to assure the best possible results in the fuel used; not only this, but that the pressure and heat of blast have been in harmony with the requirements of the fuels, in order to accomplish their complete combustion and economical application.

It is further assumed that in these practical determinations of the calorific values of these fuels in blast-furnace work, three chief considerations shall have been accurately noted: (1) The weight of fuel to smelt 1 ton of pig iron; (2) the time required in smelting; and (3) the purity of the fuel. The first shows the economy in fuel; the second, economy in the cost of superintendence; and the third, exemptness from dangerous impurities in the pig metal produced.

The table on page 354 exhibits, approximately, the work of the three chief fuels in blast-furnace operations.

Equating the results shown in the table to approximately equal practical conditions, the relative calorific efficiency of these three fuels will stand as follows: Coke, 100 per cent.; charcoal, 90 per cent.; anthracite, 78 per cent.

It is submitted that the statements in the table of blast-furnace work are practical general averages. They are greatly exceeded by recent work, as will be seen in the following statement:

"Furnace No. 1 of the Carnegie Steel Company, at Duquesne, Pennsylvania, has just made a record for long blast on one lining and for output that will probably stand for some time. This furnace was blown in on June 8, 1896, and was in continuous blast until October 21, 1903, a period of 7 years, 4 months, and 13 days. During its blast, the furnace turned out 1,287,400 gross tons of Bessemer pig iron. The best day's record was on October 26, 1898, when the furnace made 748 tons and 350 pounds. The best week's work was for the week ending October 29, 1898, when the furnace made 4,990 tons and 209 pounds. The best month's work was October, 1898, when the product was 18,672 gross tons of Bessemer iron. The average coke consumption per ton of pig iron was 2,020 pounds. This furnace is 100 feet by 22 feet in size. It will be repaired and relined."

COMPARATIVE WORK OF FUELS IN BLAST FURNACES

Kind of Fuel	Size of Furnace	Output Per Month Gross Tons	Location	Iron Ore, Average Per Cent. Metallic Iron	Pounds of Fuel to 1 Ton of Pig Iron	General Remarks
Charcoal........	10′ 5″×45′	1,488	Michigan	59.00	1,844	Spring Lake Furnace, Lake ore
Charcoal........	10′×48′	2,615	Michigan	60.00	2,060	Bay Furnace, Lake ore
Charcoal........	12′×60′	3,379	Wisconsin	55.00	1,815	Hincle Furnace, Ashland
Averages........		2,494		58.00	1,907	
Anthracite......	17′×65′	2,698	New Jersey	55.00	2,244	Secaucus, Hudson Company
Anthracite......	16′ 6″×65′	2,376	New Jersey	55.21	2,347	No. 9 Furnace, 75 per cent. coal, 25 per cent coke
Averages........		2,537	New Jersey	55.10	2,295	
Coke...........	22′×90′	10,536	Pennsylvania	59.00	1,737	Edgar Thompson, Connellsville coke
Coke...........	22′×90′	12,000	Pennsylvania	59.00	1,800	Edgar Thompson, Connellsville coke
Coke...........	22′×100′	17,700	Pennsylvania	59.00	1,850	Duquesne Furnace, Carnegie Steel Co.
Averages........		13,412	Pennsylvania	59.00	1,796	

It is further submitted that the above practical results, in actual furnace work, afford sure standards for laboratory determinations of the value of fuels for metallurgical purposes. It has been shown that the two chief essential physical requirements in fuel for blast-furnace use are hardness of body and well-developed cell structure.

The first essential physical requirement of hardness of body is important in protecting the fuel in its downward passage in a blast furnace from loss in dissolution by carbon dioxide. Sir I. Lowthian Bell long ago pointed out, first, "that the carbon, as it exists in different qualities of coke, is not influenced in the same degree by this solvent power of CO_2; second, that the soft description, known as black ends, is more easily attacked than the hard, silvery-looking kind."

In two tests, with hard- and soft-bodied coke, Mr. Bell proves that the hard coke, pulverized to the size of mustard seed, exposed at a temperature of melting zinc for ¾ of an hour to a current of CO_2 gave a mere trace of CO. The soft coke, similarly treated, in 1½ hours gave 92 cubic centimeters of CO. This indicates the loss that the soft variety of coke suffers by dissolution in the blast furnace is nearly 8 per cent.

In the second requirement, the valuable results from full development of cells in coke are readily understood, as these cell spaces afford free entry to the ascending hot gases, which thus permeate the coke thoroughly and impart to it a high temperature, which aids materially in its rapid combustion. In addition to this, the large area of the cell spaces affords ample surface for the hot oxygen of the blast to act on, securing rapid combustion with high temperature and calorific energy, resulting in the rapid working of the furnace.

Now anthracite is not lacking in hardness of body; in this physical property it is equal to the average cokes. We have seen, however, that it requires 2,347 pounds of anthracite to do the work of 1,796 pounds of coke in a blast furnace. It is evident, therefore, that the property of hardness of body alone will not afford the best results in smelting pig iron. The great density in this fuel confers on it the slowest combustion in a blast furnace. Only for the decrepitation, which takes place near the tuyères, its rate of combustion would be further retarded.

On the other hand, coke possesses an average hardness equal to the anthracite; but any slight difference of hardness of body cannot be urged to account, in any important degree, for the great difference in the calorific energy of coke over anthracite in blast-furnace operations.

As the difference in the calorific efficiency of these fuels has not its exclusive genesis in the physical property of hardness of body alone, it is evident that it must be looked for elsewhere. This has been discovered to be in the cellular structure of the coke, other conditions being equal.

In the best varieties of coke the aggregate volume of the cell spaces to the body of the coke is as 44 to 56 nearly. In some cokes, this cell structure is too inflated, conferring on it brittleness in furnace work, with lack of energy at the tuyères.

From these conditions, in the anthracite and coke fuels, it is evident that in the best varieties of each we have, from actual work in the furnace, two different results: in the anthracite, a dense, languid fuel, and in the coke a cellular, vigorous fuel. The ratio of the former to the latter in calorific energy or speed is as about 1 to 3, assuming that they have about the same or equivalent chemical composition.

LABORATORY TESTS

From these tests of the physical properties of these two important metallurgical fuels, the following methods of determining the values of all qualities of coke for blast furnace or for similar uses have been established:

Cell Structure.—An average sample of the coke is carefully and accurately cut into inch cubes. One or more of these cubes, depending on the accuracy required in the determinations, is thoroughly dried, and, when cooled, carefully weighed. This gives the weight of the body of the coke in its dry condition. The cubes are then immersed in a vessel of distilled water and put under the receiver of an air pump, the air pumped out of and the water forced into the cells. The cube or cubes are again weighed; the difference in weight, equated to the specific gravity of the coke, gives the aggregate cell space in the cube of coke.

An easier method is suggested by the late Doctor Sterry Hunt, in the "Report of the Geological Survey of Canada," 1863-6, pages 281-3.

His method is to select suitable specimens of any size or shape, usually pieces from 20 to 40 grams in weight; these are to be dried and weighed; then fill their cells with water and weigh in water; the pieces are then taken out of water, the excess of water on their surfaces carefully removed, and weighed again in air. These operations furnish all necessary data for calculating the following properties:

1. The apparent specific gravity, or the relationship between the whole mass of material and an equal volume of water.
2. The true specific gravity or the specific gravity of the body of the coke or other matter.
3. The aggregate of cell space in one hundred volumes of material, or percentage of cells by volume.
4. The volume of cells in a given weight of material, as cubic centimeters in 100 grams.

The loss in weight of the material saturated with water, being equal to the volume of water displaced by the mass, enables us to determine the specific gravity of the latter; while this loss in weight, less the weight of the water absorbed by the mass, gives the true volume of water displaced by its body, and hence the means of determining its specific gravity.

The division of the amount of water absorbed by the amount of water displaced gives the amount of volume of the cells in a unit of the material, and the division of the weight of the water absorbed by the weight of the dry mass gives the aggregate volume of cells in a unit of the mineral.

Let $a =$ weight of dry material;
$b =$ weight of water that it can absorb;
$c =$ loss in weight, in water, of saturated material.

Then, $c : a = 1{,}000 : x =$ apparent specific gravity, or the specific gravity of the mass.

$c - b : a = 1{,}000 : x =$ true specific gravity, or specific gravity of the body of the mineral, water being 1,000.

$c : b = 100 : x =$ percentage by volume of the cells in the mineral.

$a : b = 100 : x$ = volume of cells in 100 parts by weight of the mineral; say, cubic centimeters in 100 grams.

In coke determinations, Messrs. Mills and Rowan, in "Chemical Technology," Philadelphia, 1889, submit the necessity of some changes in the foregoing methods, as follows:

"Suitable specimens from 20 to 40 grams in weight were selected to represent the average physical condition of the coke. They were thoroughly brushed to remove any loosely adhering particles that might fall off during the experiments and thus vitiate the results, and were weighed just as received; they were dried at a temperature of 100° centigrade for 1 hour, cooled under the desiccator, and weighed, the loss in weight representing the amount of moisture found in the specimen as received.

"Great difficulty was experienced in thoroughly filling the cells with water, on account of the small adhesion between the surface of the coke and the water, but, after considerable experimenting, the following general plan was adopted.

"In filling porous substances generally with water, two methods are in use; one to soak the specimens in water for a time and then to place them in water under the receiver of an air pump, and exhaust until no more air is given off; and the other to keep them suspended in boiling water until the pores (cells) are filled with water, as is shown by their ceasing to gain in weight on taking them out, cooling, and weighing. In this case it was found more expedient to use a combination of these two methods.

"In the determination of the specific gravity, there are two sources of variation, one inherent in all specific gravity determinations, and unavoidable, the other accidental and in a measure disappearing in the averages. The first error is due to the possible presence of water-tight pores, or cells, causing a minus error in the determinations. The other error is due to the possible presence in a piece of coke of a small piece of slate, causing a plus error."

Tests for Strength.—The cubes of coke used in determining the cellular structure are dried, or others that have not been wet are then used to determine the capacity of the coke for bearing furnace burdens without crushing, in a machine for testing the compressive strength of materials.

The hardness of the body of the coke is determined by the usual methods; but when great care is required, the resistance of a cube of coke to abrasion, under specific pressure and speed on an emery wheel is used to ascertain this important property of hardness of body.

With the data obtained under these methods, it is demonstrated that an accurate estimate can be made of the calorific value of the coke for blast-furnace purposes, as the following estimate, followed by a blast-furnace test, will show:

In October, 1891, Mr. J. H. Allen, vice-president and general manager of the Cumberland Valley Colliery Company, Pineville,

FULTON'S TABLE EXHIBITING THE PHYSICAL AND CHEMICAL PROPERTIES OF COKE

REVISED SERIES

Locality	Grams in 1 Cubic Inch		Pounds in 1 Cubic Foot		Percentage by Volume		Compressive Strength Per Cubic Inch, ½ Ultimate Strength	Height of Furnace Charge Supported Without Crushing	Order in Cellular Space	Hardness	Specific Gravity	Chemical Analysis Per Cent.						Remarks
	Dry	Wet	Dry	Wet	Coke	Cells	Lb.	Feet				Fixed Carbon	Moisture	Ash	Sulphur	Phosphorus	Volatile Matter	
Connellsville, Standard	15.47	23.67	58.98	87.34	49.96	50.04	301	120	1	2.5	1.89	87.46	.49	11.32	.69	.029	.011	Beehive oven coke.
Pineville, Kentucky. . .	14.10	22.24	53.73	84.73	50.37	49.63	227	91	1	2.1	1.71	94.66	1.14	3.78	.59	.007	.410	Beehive oven coke.

Kentucky, sent a sample of his coke for examination and estimate of its value as a metallurgical fuel. The accompanying table and report were returned to Mr. Allen.

Dear Sir:—In compliance with your request of September 17, I have examined the sample of your coke that you forwarded for this purpose. Assuming that this sample of your coke, submitted for chemical and physical examination, is a fair average of its quality, I have had seven physical tests made, giving the average of the seven in the accompanying table. In this table, the Connellsville coke is included for purposes of comparison between this and other cokes. On general principles, coke for metallurgical uses should possess hardness of body with well-developed cell structure so as to insure exemption from combustion in the upper regions of a blast furnace, and to afford the utmost calorific energy in the lower region of the furnace. Hardness of body in coke prevents its dissolution by the furnace gases, in a section of the furnace where it is not only a waste of fuel, but where it disturbs the orderly working of the furnace. The large cell development in coke assures its calorific energy in combustion.

The coke you have submitted from your Pineville works shows that it has been carefully and intelligently treated in the coke ovens. There are no indications to show where an improvement could be suggested in this respect. The coke has the usual slender columnar structure somewhat peculiar to Kentucky cokes. It will be seen in the table that the cellular structure of this coke is somewhat below the standard Connellsville.

This slight physical defect is compensated, in a great measure, for blast-furnace use by the slender finger structure of the coke as it comes from the coke ovens. Its burden-bearing qualities are equal to the highest blast furnaces now in use or likely to be attempted in time to come. The hardness of this coke is so near that of the Connellsville standard that it is not necessary to draw any special distinction. The chemical analysis shows that it is a much purer fuel than that of the Connellsville standard. The ash is remarkably low, only one-third of the volume found in the Connellsville. As a clean fuel, it has few if any superiors. It will also be noted that the exceptionally low percentage of the element phosphorus in this coke gives it special adaptability for smelting Bessemer pig iron. The sulphur is low, under that of the standard. It will be found a very superior fuel for blast-furnace purposes, for smelting iron in cupolas, and for all metallurgical purposes in which coke is used as a fuel.

John Fulton, E. M.

Immediately following this report, a shipment of this coke was forwarded to the Nashville Furnace Company for an actual test of its value in this furnace. The following letter shows the result of this test.

Nashville, Tennessee, October 31, 1889.

Messrs. J. D. Anderson & Co.

Gentlemen:—In reply to your favor of this date, we have to say that on the 23d, 24th, and 26th inst., we made a test at our furnaces of the Cumberland Valley Colliery Company's Pineville coke. As the coke was new to us, we, as a matter of prudence, charged light in the beginning, using 4,000 pounds of ore, 2,100 pounds of lime, and 2,800 pounds of coke. The furnace being too hot on the 23d, we increased the ore to 4,800 pounds. The furnace still being too hot on the 24th inst., we increased to 5,300 pounds, being the same burden we had carried with Pocahontas coke, with as good results. When we came to understand the nature of the Pineville coke, we produced as much iron and a higher grade of iron than we had previously done with other cokes.

Yours, etc.,
H. W. Buttorff,
President and General Manager.
J. H. Hanley,
Superintendent and Furnace Manager.

Test for Resistance to Solution by CO_2.—An additional test has recently been introduced, in determining the resistance of coke to the dissolving agency of hot carbonic-acid gas, which proves the relative hardness of body in anthracite and coke fuels.

Average samples of each kind of fuel are powdered and thoroughly dried. About 800 cubic centimeters are placed in a test tube. Hot carbonic-acid gas is passed over the powdered coke during a fixed time. The coke is carefully weighed as it is placed in the tube, and after it is taken out the difference in weight shows the loss by dissolution and the relative hardness of body in resisting dissolution by this test.

TABLE SHOWING RESISTANCE TO SOLUTION BY CO_2

Kind of Fuel	Left After Treatment With CO_2 Per Cent.	Loss as CO Per Cent.	Hardness	Remarks
Anthracite	96.0	4.0	2.5	
Connellsville coke	94.5	5.5	3.7	Coked in Otto-Hoffman ovens
Connellsville coke	91.9	9.0	3.0	Coked in beehive ovens
Morris Run	88.8	11.2	2.6	Coked in Semet-Solvay ovens
Bennington	86.1	13.9	2.4	Coked in beehive ovens

The preceding table exhibits some tests made in this way, by the late Doctor James J. Fronheiser.

The percentages in the CO column indicate, approximately, the probable loss in these fuels from softness of body.

The following statement shows the ultimate average compressive strength of the above fuels, per cubic inch, without crushing:

	Pounds	
Anthracite	3,000	
Connellsville coke	2,260,	coked in Otto-Hoffman ovens
Connellsville coke	1,204,	coked in beehive ovens
Morris Run coke	1,360,	coked in Semet-Solvay ovens
Bennington coke	848,	coked in beehive ovens

From the foregoing data, it will readily appear, that laboratory determinations of the properties of these fuels will afford very accurate results in estimating their several calorific values in metallurgical operations.

It may be noted here that in selecting the several portions of the coke for cutting into cubes for physical tests, that the outside, inside, top, middle, and bottom pieces have been carefully selected, so as to secure the true general average.

The Buffalo blast-furnace tests of Connellsville, beehive coke, and Semet-Solvay coke, made from Connellsville coal, is interesting as exhibiting the relative calorific energies of these fuels. The work of 2 days was selected, during which the furnace was considered to be in equally favorable conditions for testing these fuels, 1 day to each kind.

The following results were obtained: 1895, May 14, 2,193 pounds of Connellsville coke to 1 ton Bessemer metal; 1895, May 20, 2,400 pounds of retort coke to 1 ton Bessemer metal. Exhibiting an increased heat value of 8.21 per cent. of the former above that of the latter product.

Taking the cellular spaces of these fuels, at a general average of 56 per cent. in the beehive to 50 per cent. in the retort, the increased volume of the former over the latter is 10.7 per cent., exhibiting a slight increase in theoretic heat value over the blast-furnace tests.

CHAPTER IX

THE LOCATING OF PLANTS FOR THE MANUFACTURE OF COKE

Preliminary Considerations.—In former chapters, the methods of preparing coal for making coke with the ovens adapted for producing the best metallurgical fuels have been considered. It is evident that the first important effort that should elicit the full attention of the manufacturer of coke is to produce it of a uniform first-class quality. This will assure his product a ready market, and secure his men continuous work at the ovens in the usual times of uninterrupted business. The second effort relates to a consideration of how, in the economies of location of a coking plant, full profit can be secured to the manufacturer.

It is assumed that wise coke makers do not enter this branch of industry alone in the interest of science, but reasonably expect moderate compensation for capital invested, time devoted to the industry, and compensation for the exhausting coal.

In order to secure this second condition, as far as it can be controlled by the location of the coking plant, it will readily appear that this element, in affording economy in the coking operations, requires careful consideration. Without in the least undervaluing the good practical judgment of the coke manufacturer, it may be submitted that it will conduce to economy to secure the professional service of an expert engineer in the work of locating the coke-oven plant. Sometimes a few dollars are saved by not employing a competent engineer, with the result that in the end a great many are wasted.

In common with modern progress in the economical location of industrial plants, the arrangements of the coking plant and its source of coal supply should receive the benefits of recent improvements in these respects. The principles that evidently should govern the location of a coking plant consist in affording full facilities in the performance of all the work in the manufacture of coke with its resultant economizing in this labor. The location, however, is governed, in part, by the topography of the locality in which it is designed to establish the work. The general plan will require to conform to these conditions.

It may be noted that the site for the coke ovens is generally determined by the location of the coal mine opened for the supply of coal to the ovens. A little preliminary careful attention in the location of the coal mine with a view of affording the best possible ground for the ovens would conduce to economies in both.

In the location of plants of coke ovens of one or more banks, the gradients of the larry tracks on the ovens, as well as the tracks of the railroad sidings, should afford descending grades of at least 1 per cent., so as to secure the movements of the larries and railroad cars by gravity, thus avoiding mainly the use of locomotives or horse power in these operations.

FIG. 1. ELECTRIC COKE LARRY

It may be noted here that electrical power in moving the coal-charging larries along banks of coke ovens is rapidly superseding horse or mule power. At this writing many of the large plants of beehive or retort coke ovens have this power in full operation, securing rapid movement of the larries and quick charging of the coke ovens with coal after the coke has been drawn out, increasing the time of coking in the oven and securing a more complete product of coke.

Fig. 1 shows an electrically operated larry. The sheet-steel box hopper *a* is about 8 feet 6 inches square and 2 feet 6 inches deep. The bottom of the hopper tapers on all four sides as shown. The larry shown has but one discharge chute *b* and is used for bank ovens that are charged from one side of the larry. If the larry track is situated between two blocks of ovens, there are two discharge chutes, one on each side of the larry. The outer part of the chute *c* is hinged to the fixed part *b* so that it may be drawn up by means of the chain *d* and wheel *e* and thus stop the coal from running down the chute. The larry hopper and chutes are supported by a metal framework that rests upon four wheels, each pair of wheels being provided with springs in connection with the journal-boxes. The larry shown is electrically operated by a motor *f* that transmits the motion to the axle *g* by means of the gearing *h*, *i*. The current is taken from overhead wire through the trolley pole *j*.

The equipment of many larries consists of a standard railway motor of the enclosed type mounted on one of the axles. The motor, controller, and trolley may be applied to larries at present drawn by animal power, it being unnecessary to design a special larry adapted for the electrical equipment. The control is so perfect that when about to discharge its load into the ovens, the larry may be moved in either direction literally "an inch at a time," and a much higher speed is possible than with horses or mules. The result is a surprising saving in time in hauling from and returning to the tipple, and in discharging the coal at the ovens. The trolley or third-rail system, preferably the latter, may be used to convey the power to the motor, and the approaches to the ovens may be much more cheaply constructed, as it is unnecessary to provide a path for the horses or mules.

One electrically equipped larry with its operator will easily do the work of two mule larries with their drivers, and when the conditions permit, the electric larry may supply the motive power for other larries, which, operated as trailers, may be dropped at the proper places, having been loaded at the tipple, and picked up on the return, in the meantime having discharged their loads into the ovens. The increased adoption of electric mining locomotives and electric motors for driving pumps, hoists, car conveyers, blowers, etc. should be considered in connection with the installation of a dynamo for the operation of coke larries, but even if the conditions are such as to debar other applications of electricity, the investment will show a very good return. At many mines, generating plants are already installed, in which cases the additional investment would be very small indeed, and the saving in cost of operation would soon pay for the electrical equipment of the larry.

Attention should also be given to facilitating the disposal of the waste products of ashes and coke dust, as these elements accumulate largely, even in a plant of moderate size. The water supply should be pure and the quantity ample at all seasons of the year, with a medium pressure to afford a full supply of water and prevent wear to the hose or injury to the brickwork of the ovens by an overpressure in the water discharge. In retort coke ovens, where the coke is cooled on the outside of the oven, the regulation of pressure in the water supply would only refer to the wear on the connecting hose.

The following plans of the location of beehive and retort-coke-oven plants are given to illustrate the salient elements to be secured in laying out new works. They are not designed to convey the idea of perfectness, put to indicate the means of doing the best with the topography of the locality in which the ovens are to be built.

The **Morrell plant** in the Connellsville region illustrates the methods of locating a group of four banks of coke ovens, each bank containing 100 beehive ovens. This plant was constructed in 1880 by the Cambria Iron Company, of Johnstown, Pennsylvania. Fig. 2 shows the general location of ovens, tipples, bins, and railroad sidings. In locating at this place, it was found necessary to open the mine by a slope *a* driven down the coal seam, which is 8 feet thick and has an inclination or dip of 5½° to the northwest. The coal is raised by extending the plane of the slope until it attains an elevation of about 40 feet above the level of the tops of the coke ovens.

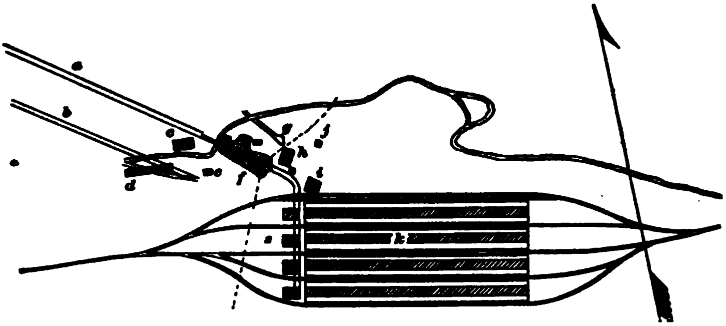


FIG. 2. MORRELL COKE WORKS, CAMBRIA IRON CO.

a, Morrell slope; *b*, manway; *c*, car shop; *d*, stable; *e*, office; *f*, coal pile; *g*, air-shaft; *h*, boiler house; *i*, engine house; *j*, blacksmith shop; *k*, 400 coke ovens; *s*, railroad sidings.

The beehive coke ovens *k* are located in four parallel banks, each of which is 700 feet long. Each bank of ovens has its flanking wharves. These wharves afford ample space for drawing the coke from the ovens and loading it on railroad cars. The wharves are 25 feet wide and 7 feet high.

The ground on which these ovens have been located has a gentle inclination eastwards, with sufficient descent to enable railroad cars and charging larries to be moved down grade by gravity. The railroad tracks have been arranged so as to afford ample room for receiving empty coke cars at the upper or west end of ovens, and to permit the shifting of the loaded cars below the ovens.

No locomotive power is used at this plant. A man shifts the railroad cars from the upper sidings and places them at points along the wharves for loading with coke. When loaded they are shifted down to the sidings below the lower end of the coke ovens.

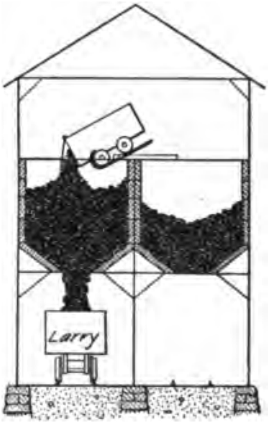


Fig. 3. Coal-Storage Bin

The coal bins, Fig. 3, are constructed of heavy framed timbers, with white-oak plank lining. Each bin holds from 300 to 400 tons of coal. There is one bin, with a double line of hoppers, to each bank of 100 ovens. These coal-storage bins afford ample supplies, so that the ovens can be charged promptly after the coke has been drawn out.

The coal is brought from the mine to the platform along the front of these bins, and is there dumped into any of the compartments in the usual manner. Horses or mules are used in the movements of the mine cars from the head of the slope plane to these bins. This arrangement has been found to work with economy. A device consisting of an endless wire rope, with grip, might be used with economy for this work of delivering loaded cars and returning the empty ones to head of plane; or, better still, electrical power might be employed.

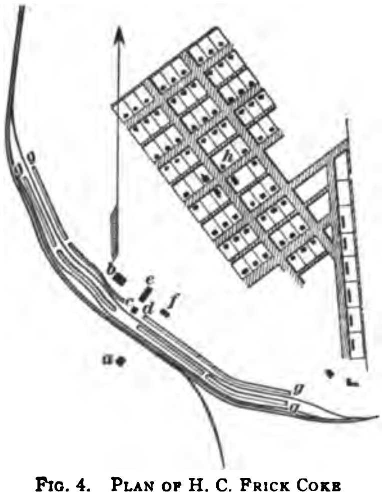


Fig. 4. Plan of H. C. Frick Coke Company's No. 3 Coke Plant

a, Fan and air-shaft; b, shops; c, coal bins; d, shaft; e, engine; f, boilers; g, coke ovens; h, village.

The water supply comes from the Youghiogheny River. It is pumped to an elevation affording sufficient head to supply the ovens and the tenement houses at this and the Wheeler plants.

No. 3 Plant, H. C. Frick Coke Company.—Fig. 4 will convey a correct conception of the general plan of location of the large coking plant constructed by the Leisenring interests under the name of the Connellsville Coke and Coal Company. It is now owned and operated by the H. C. Frick Coke Company.

It will be seen by Fig. 4 that these ovens *g*, *g* were located in two curved wings on either side of the coal bins *c* and shaft *d*, up the gentle valley threaded by the Pennsylvania railroad and the sidings for this large plant of coke ovens. The ovens are charged in the usual way, a small locomotive being used in handling the coal larries to the several banks of ovens. This secures commendable despatch in this department of the work. The larry tracks are between the double rows of ovens. The side chutes to these charging larries can be seen in Fig. 5.

The wharves are ample, and the whole arrangement, for each division of labor, very complete.

The elevation, Fig. 5, showing details of head-house and bins affords very complete details of these constructions for a central supply of coal for charging the ovens.

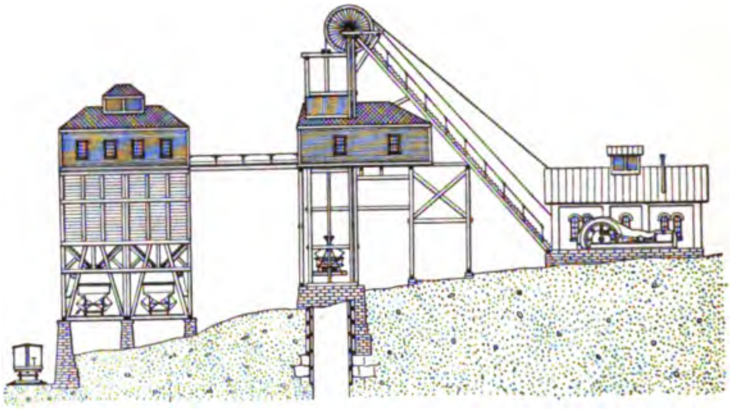


Fig. 5. Head-House and Bins, H. C. Frick Coal Company's No. 3 Coke Plant

The only suggestion that occurs on the line of security against fire at this plant is that the head-house over the deep shaft would be safer from the danger of fire if constructed mainly of iron.

The burning of a head-house causes immediate stoppage of the coke works, with interruption to coke shipments and serious financial loss.

Oliver Plant.—Messrs. Wilkins and Davison, Engineers, Pittsburg, Pennsylvania, have kindly furnished plans, Fig. 6, of the two very complete coking plants of the Messrs. Oliver, of Pittsburg, located near Uniontown, in the Connellsville coke region.

The whole arrangement of these plants with their coal mines and bin storage supplies affords excellent examples of wise harmonies in securing economical and safe conditions to both the mines and coke ovens.

The following able paper by Mr. Fred C. Keighley, general superintendent of the Oliver Coke Works, will afford much valuable matter on the location, size of plant, with an outlook as to the requirements of the works to supply special markets and other

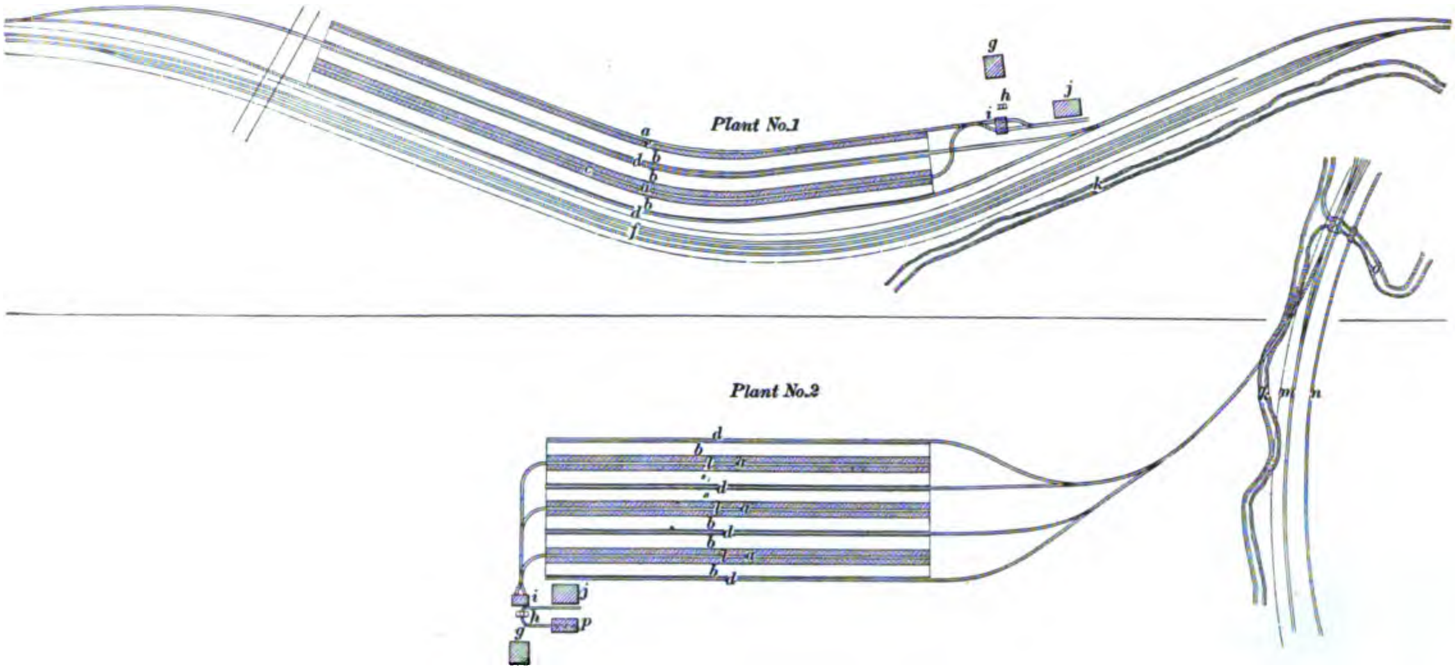


FIG. 6. PLANS OF OLIVER COKE & FURNACE COMPANY'S COKE PLANTS, NOS. 1 AND 2
a, coke ovens; *b*, coal yards; *c*, block ovens; *d*, railroad tracks; *e*, bank ovens; *f*, P. V. & C. R. R.; *g*, engine house; *h*, shaft; *i*, coal bin; *j*, boiler house; *k*, creek; *l*, block ovens; *m*, S. W. Penna. R. R.; *n*, B. & O. R. R.; *o*, creek; *p*, blacksmith shop.

related conditions. It also affords many practical suggestions on these elementary requirements in the order of economy and facility of operations.

Plant No. 1 consists of 300 beehive ovens, in two slightly curved lines, to conform to the topography of the ground, securing desirable gradients for railroad sidings and larry tracks. One of these banks of coke ovens is located in a line of single ovens 1,400 feet long, containing 100 ovens. The second line, of about the same length, consists of a bank of a double row of ovens, containing 200 ovens.

The railroad tracks and sidings are ample and well located to afford the necessary facilities for handling the output of coke.

Fig. 7. Coke Oven Plant (300 Ovens). Plant No. 1, Oliver Coke Works, Redstone Junction, Pennsylvania

The ovens and railroad tracks are on gradients of 1 foot per 100 feet, descending with the tonnage. The ovens are 12 feet 3 inches in diameter. This plant was completed early in 1892; since that time it has been increased to 1,208 ovens.

The locations of the shaft, engine house, and coal bin can be seen on the plan. They were located to secure the utmost economy in the manufacture of coke. Fig. 7 shows some of the ovens in process of building.

Plant No. 2 has been located in three double banks of coke ovens. Each bank is 825 feet long and contains 120 coke ovens, making in all at this plant 360 ovens. The compact location of these ovens, with the close relations of shaft and coal bins to the ovens evidence careful work in the plans.

The railroad sidings are well located for convenience. The railroad cars require some extra handling at this plant, as the railroad connections are confined to one end of the ovens.

At these works, the shafts to the coal are about 415 feet deep.

Danger from fire has been guarded against at these works by constructing the head-frames of shafts of steel covered with corrugated iron, Figs. 8 and 10. The coal-storage bins have been constructed with similar materials and the engine houses of brick with iron roofs. It is claimed that these fireproof structures are the first of their kind introduced into the Connellsville coke region. This introduction, in the lines of safety to life and true economy in assuring continuous work, is very commendable. The water supply is secured from the Youghiogheny River, 10 miles distant.

COKE MAKING FOR PROFIT*

A plant of more than 300 coke ovens becomes unwieldy; and when the ovens are less in number than 300, the fixed charges are apt to be high. A man can manage two 300-oven plants, if not too far apart, with more ease than one 600-oven plant, and it takes as many officials to operate a 600-oven plant as to operate two 300-oven plants. So, if a large number of ovens is desired, the best plan is to divide them, as nearly as practicable, into 300-oven plants. This is not only my view of the matter, but the view of the more experienced coke men of the Connellsville

FIG. 8. HEAD-FRAME AND ENGINE HOUSE, PLANT NO. 1, OLIVER COKE WORKS, REDSTONE JUNCTION, PENNSYLVANIA

---

*Fred C. Keighley, in American Manufacturer.

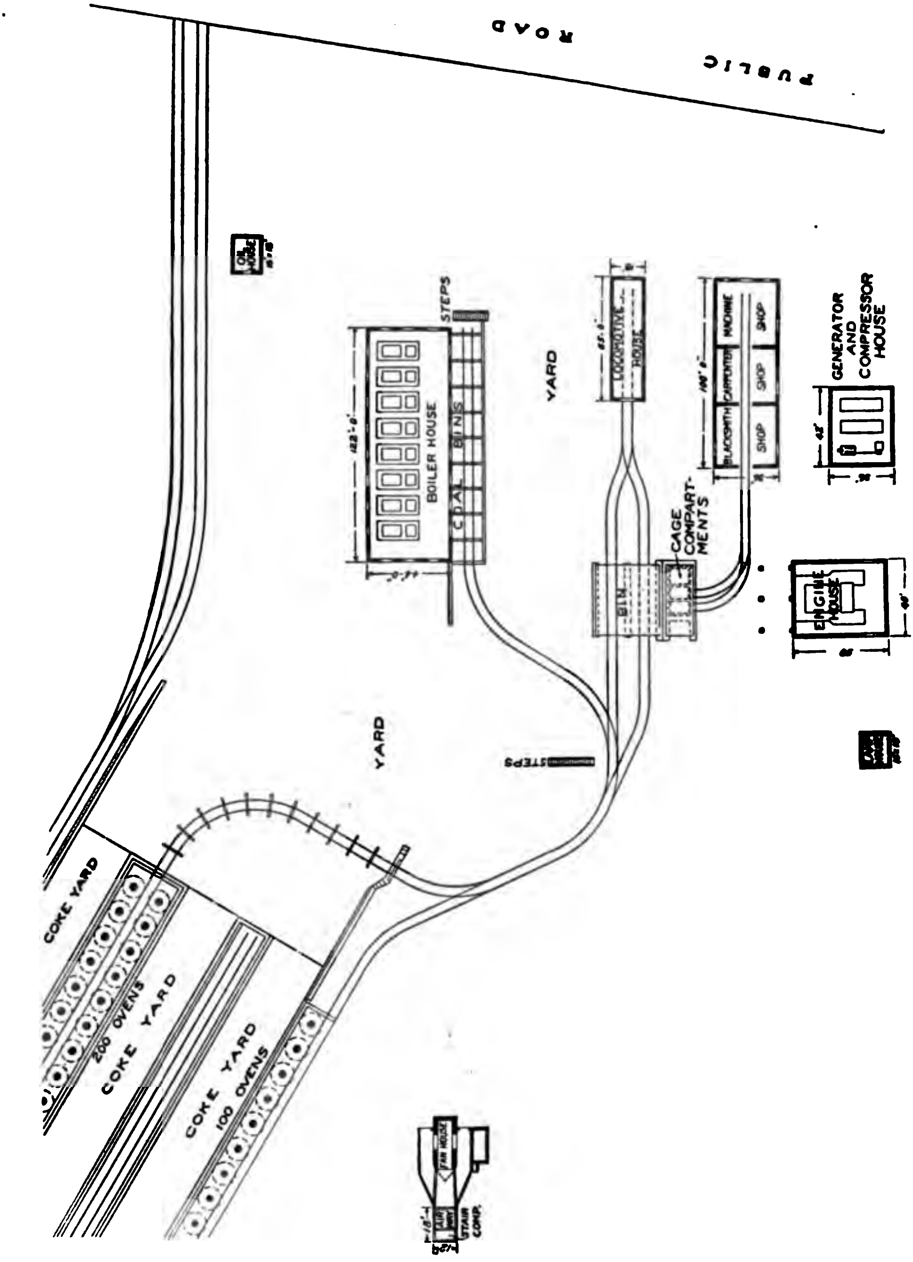


FIG. 9. PLAN OF SURFACE EQUIPMENT AT OLIVER NO. 3 PLANT

coke region. So, in what I write hereafter, I shall make my observations and suggestions mainly with reference to a plant of that magnitude. However, there are many people who will not, or cannot, build a plant of 300 ovens, and they will naturally ask how they are to determine how many ovens to build. This is a somewhat difficult matter to decide, as there are many things to consider; yet there are certain conditions that in a degree indicate what is to be done. For instance, if the manufacture of coke for the blast-furnace trade is contemplated, then the extent of that kind of trade to be had will fix the number of ovens to be built.

Modern blast furnaces consume all the way from 300 to 600 tons of coke per day, and as many furnace men object to the use of mixed coke, owing to its interfering with regular or uniform work, to build less than sufficient ovens to run one furnace would certainly be fatal to the success of the venture. Generally speaking, 12-foot beehive coke ovens will yield 2 tons of coke per oven per day; so that a blast furnace of 300 tons of coke per day capacity, will require 2,100 tons of coke per week of 7 days. A coke-oven week is but 6 days; therefore, the quantity required from the ovens will be 350 tons per day; this divided by 2 will give us 175 coke ovens, the number required. A two 300-ton furnace capacity plant would require 350 ovens, and so on. If foundry trade were to be supplied, instead of furnace trade, the number of ovens required would be determined in an altogether different manner; and I know of no better or safer way of determining it than by the coal acreage owned or controlled by the prospective coke operators.

An 8-foot seam of Connellsville coal will yield fully 12,000 tons of coal per acre, if free from faults and skilfully mined, and this in turn, if properly manipulated, will yield 8,000 tons of coke. Taking 600 tons as the work of a 12-foot beehive oven for 1 year, an acre of coal will keep one coke oven running steadily for 13⅓ years—allowing for dull trade, strikes, car shortages, and repairs, we might safely put it 15 years.

If the coal to be operated is drift coal and comparatively cheap to develop and equip, 15 years will be a safe life for the plant; but should the coal be below water level, necessitating the instalment of costly machinery and pumps, and the sinking expenses be heavy, then 30 years will be none too great a period to allow to get out all there is in the equipment. For instance, a property of 150 acres of drift coal will require 150 coke ovens to make what I term a fairly well-proportioned plant; but a slope or shaft coal property of over 100 feet and up to 200 feet in perpendicular depth, to get the best attainable results, should be of such acreage as to sustain at least 200 coke ovens for 30 years. A 200-oven plant on such a basis will require at least 400 acres of coal. Deeper coal would require more coke ovens and a correspondingly greater acreage to make it a well-balanced venture. Take the following

FIG. 10. HEAD-FRAME AND COAL BIN AT OLIVER NO. 3 PLANT

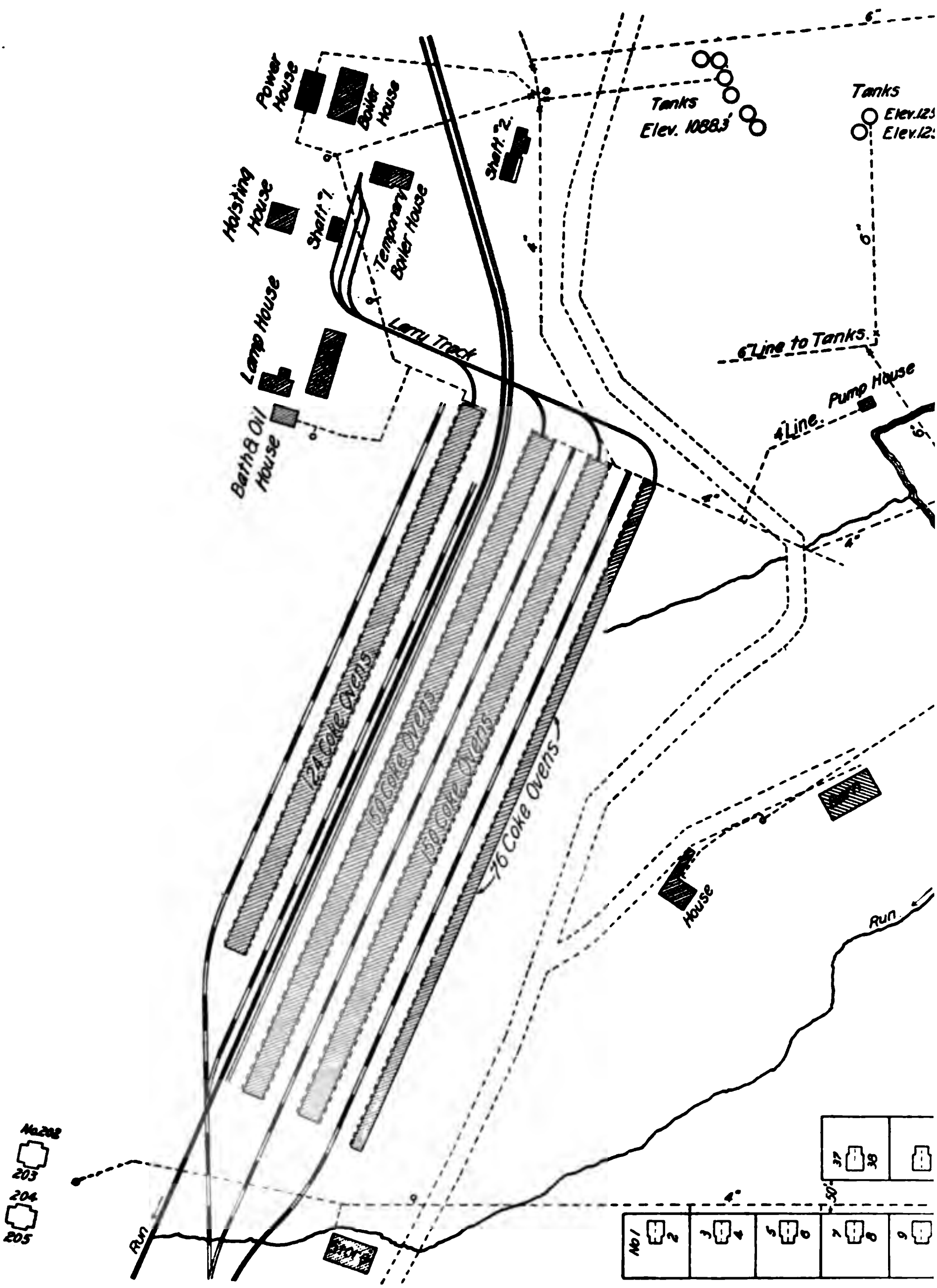
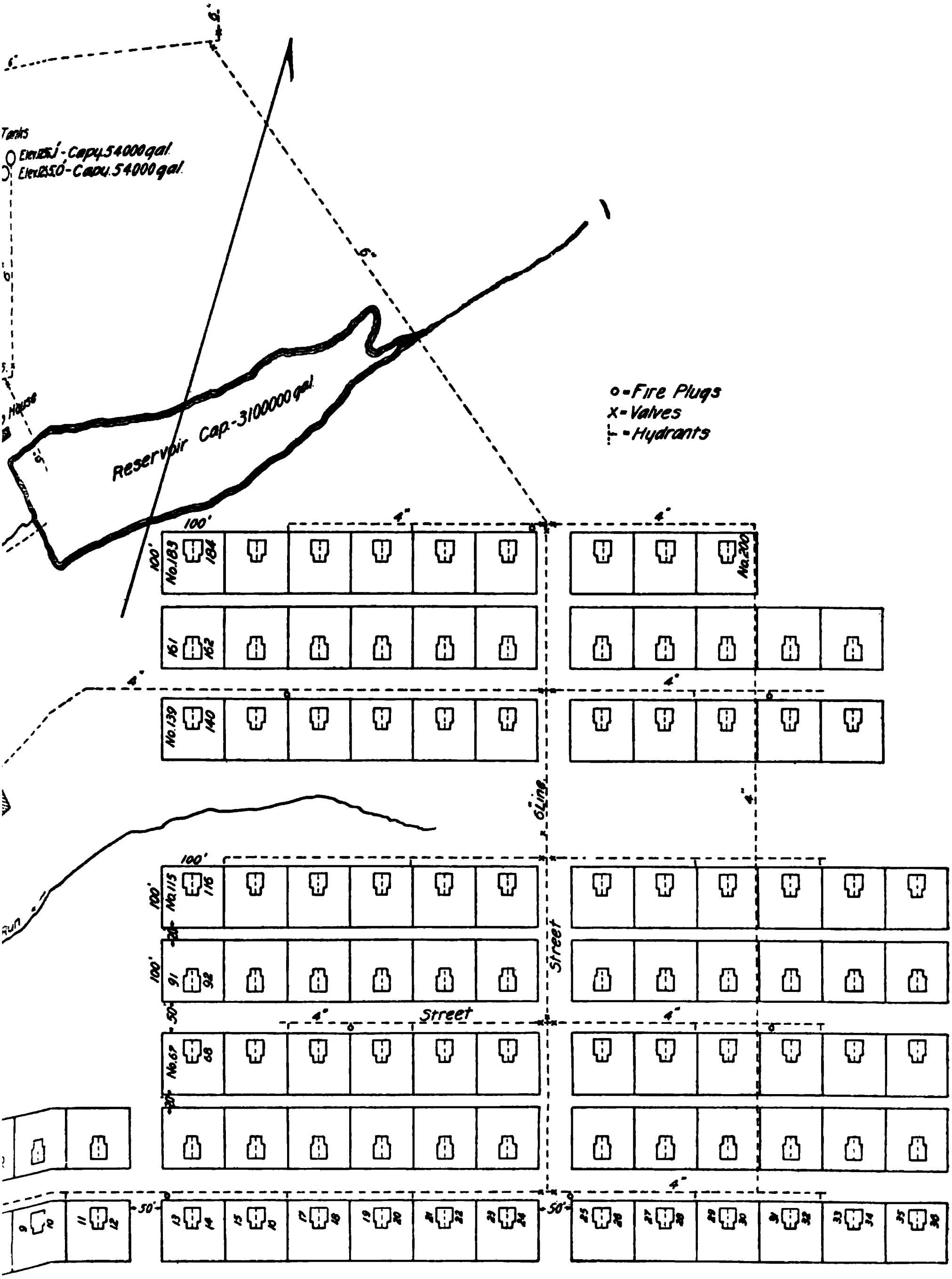


Fig. 11. Plan of American Coal and Coke



Coke Company's Plant at Edenborn, Pennsylvania

figures as factors: One coke oven yields 600 tons of coke per year. One acre of 8-foot Connellsville coal yields 12,000 tons of coal; 12,000 tons of coal makes 8,000 tons of coke. One acre of 8-foot coal will run one oven 15 years. Life of a drift plant is 15 years; life of a 100-foot sinking, 30 years. One acre of coal for each oven at a drift plant. Two acres of coal for each oven at a 100- to 200-foot depth. Twice as many coke ovens on a 200- to 400-foot depth as on a 100- to 200-foot depth, and a correspondingly increased acreage. In very large tracts of coal land, a correspondingly large number of ovens in plants of 300 ovens to each establishment.

With this data as a basis for calculation, any one of ordinary ability should be able to determine the number of ovens required on a given acreage, or the acreage required for a given number of ovens. Of course, the kind of trade expected must not be overlooked in making up the verdict.

Small coke plants are generally arranged on a single line of bank ovens, but the larger plants are made up of several rows of bank and block ovens, in order to secure compactness, etc. The arrangement of the ovens is generally governed by the location that is available. There are very few natural oven locations, and often, even when a good oven location is found, it cannot be used because it does not also afford a good coal mine site, or the grades are such that it cannot be reached by railroad with a profitable grade. It would be out of the question to lay down any rules as to the arrangement of the ovens; so what I have to say relative to the location of the ovens, etc., must be taken in a general way and with due consideration.

Beehive bank ovens when located parallel with or to moderately rising ground where the rock does not crop out above the floor or seat of the contemplated oven, and the soil is of the proper character and solidity and can be well drained, make the best and cheapest of all beehive-oven locations—best, because the oven can be located on naturally solid ground, affording a firm foundation at small cost, and the ground rising behind them affords not only a storage battery for heat, but also allows the oven to expand backwards instead of forwards, and thus relieves the oven and retaining walls from excessive strains. Another advantage with such a location is that all the ovens face the pure air, if all in one string, which is quite an advantage, as coke ovens that face the air always make more and, unless in stormy weather, brighter coke.

Bank ovens are the cheapest to build, for the reason that the side cut for the ovens also makes the filling for the coke yard, or wharf, while the dirt for filling around the ovens can be easily and cheaply obtained from the rising ground behind; however, I would not advise that the whole of the 300 ovens be located on a single line, for the following reasons, viz.: First, because it would not be the most economical way of charging the ovens, owing to the long distance to be traveled over; second, the long distance traveled

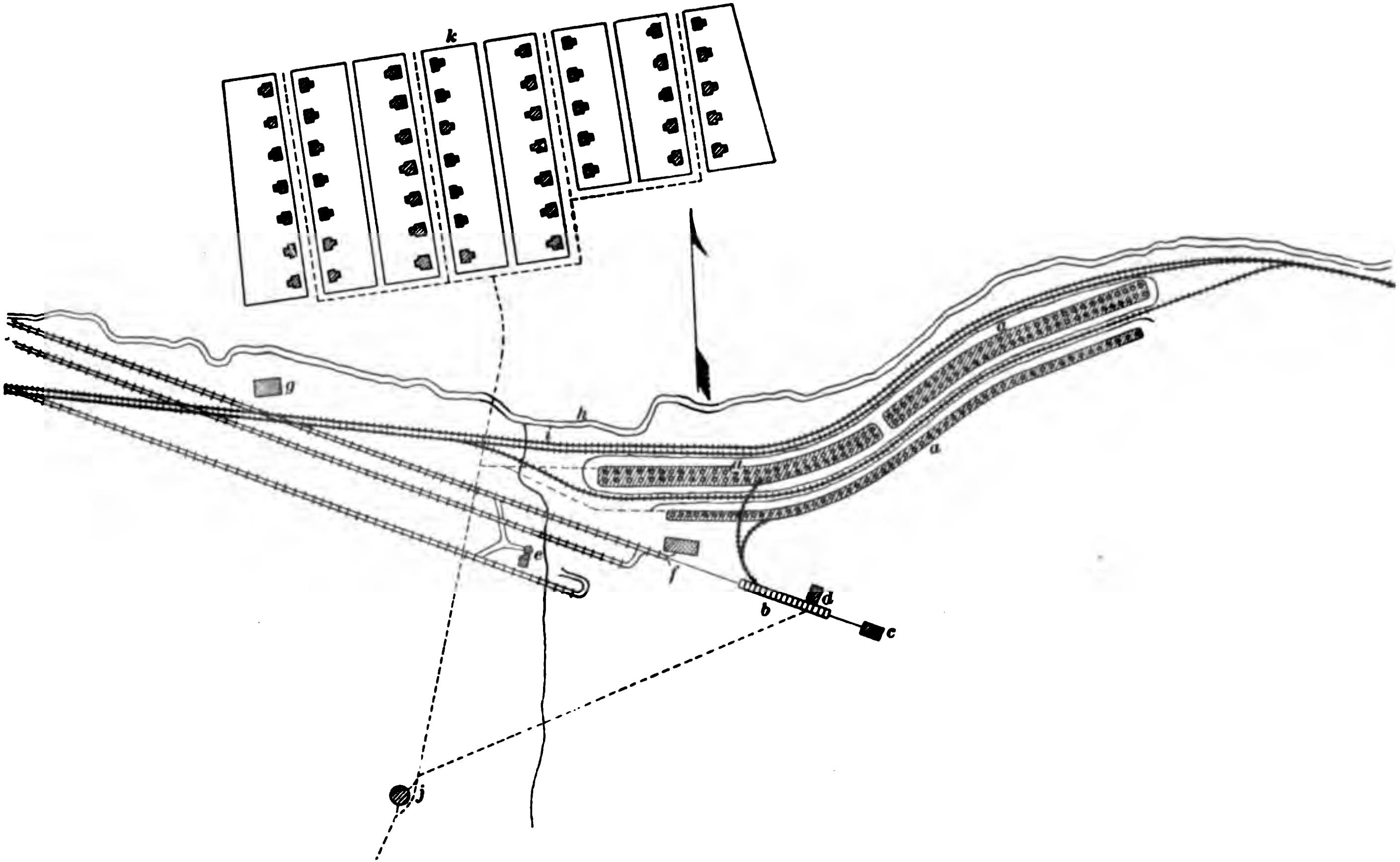


Fig. 12. Hostetter Coke Company, Lippincott Plant, Connellsville Region

a a a, 305 coke ovens; *b*, coal hoppers; *c*, hoisting engines; *d*, boiler; *e*, fan; *f*, slope; *g*, store and office; *h*, creek; *i*, railroad siding; *k*, workmen's houses.

over would necessitate an increase of speed for the charging equipment, which, in turn, would not only cause excessive vibration, which would shorten the life of the oven, but would also increase liability to accident, excessive strains to the larry tracks, and more wear and tear to the equipment; third, the wheel on the coke yard would be longer than desirable for the coke drawers; and fourth, the length of the larry tracks on the ovens, and the length of the sidings for the railroad cars would be very much greater than desirable, convenient, or economical, and would further necessitate many cuts or breaks in the ovens for ways for ash carts, etc. In view of the above important factors, the plant, if all bank ovens, should consist of two rows of ovens of 150 each, the said rows facing each other, with the railroad siding running down between the respective coke yards.

American Coke Company's Plant.—The coking plant of the American Coke Company, Fig. 11, is situated at the Edenborn mine in Fayette County, Pennsylvania, in the Connellsville region. It consists of a plant of 500 beehive coke ovens, arranged in four parallel banks or batteries, with wharves, railroad sidings, reservoir containing ample supplies of water, and all necessary appliances for the successful working of this plant.

The dwelling houses, as shown on this plan, have been neatly finished, affording comfortable homes to the miners, coke drawers, and other workmen. The whole arrangement of the several parts affords evidence of a carefully considered plan, securing harmony of its parts and economy in all its operations.

The **Hostetter Connellsville Coke Company's works** consist of two coke plants, the Whitney and Lippincott, located in the northern section of the Connellsville field, about ½ mile apart, on the Latrobe branch of the main line of the Pennsylvania Railroad.

Both these works have been located in little valleys on small streams, tributaries of Nine Mile and Loyalhanna creeks. They are very nearly alike in their plans of location and number of coke ovens. The method of location of the Lippincott plant, Fig. 12, will serve to illustrate the general plan of both these works. It has not been considered necessary to add the plan of the location of the Whitney works.

The Lippincott coke plant consists of 305 beehive coke ovens, which are 12 feet in diameter and 7 feet high to crown of the dome. The ovens have been located in two lines, along the south bank of the Nine Mile Run, conforming in their alinement with the contour of the ground at this place. The northern line of ovens is composed of a bank of a double row of ovens; the southern bank consists of a single line of ovens.

The plan, Fig. 12, exhibits the arrangement of the railroad tracks and sidings for the supply of coke cars for this trade. Ample room has been provided for storing empty coke cars at the upper, or west, end of the plant, with full space at the lower, or east, end for making up trains of loaded coke cars for transportation to market.

The coal cars are drawn up the slope from the mine by the winding engine and placed on the long coal bin, where they are unloaded rapidly into the hoppers underneath. The larries for charging the coke ovens are loaded under these hoppers.

The mine cars are not unhitched from the wire haulage cable, but are unloaded into this long bin by opening the bottom slides in these coal cars. A train of these loaded mine cars consists of ten cars, containing 45 bushels in each car, nearly 2 tons of coal. Immediately on their being unloaded, they are quickly lowered into the mine and unhitched from the cable, which is then hitched to a loaded train of cars.

The larries for charging the coke ovens are handled by a 7-ton locomotive operated on standard-gauge tracks. The gradients of railroad and larry tracks descend eastward, affording nearly balanced gravity lines for these operations.

The office and store is located at the west end of the works, where the incoming and outgoing cars pass.

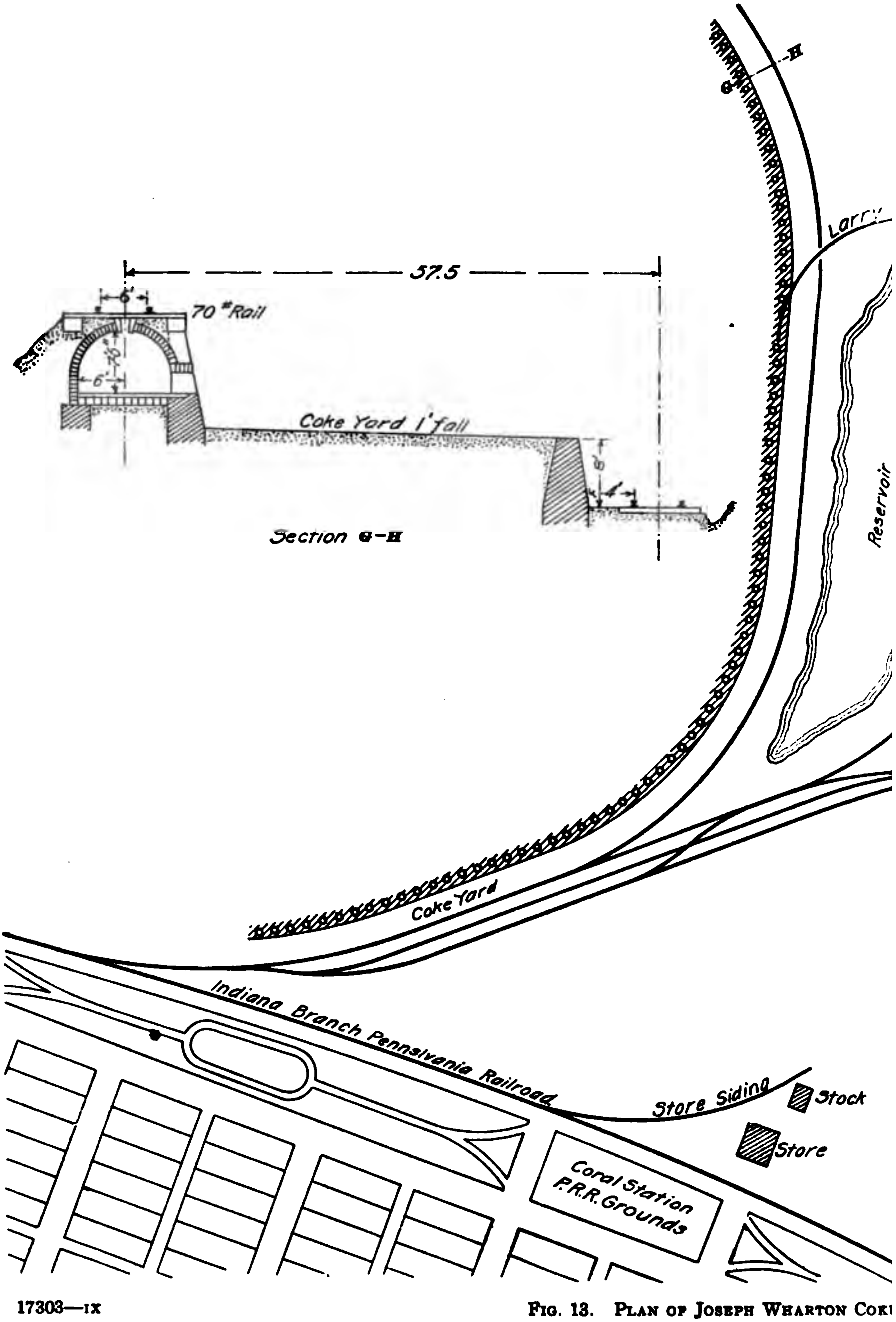
Arrangements have been made at both plants for shipping coal when found necessary to do so.

The slopes into the mines are 2,600 to 2,800 feet long. They have been driven in the large coal seam, which has here an inclination westwards of 6½ feet per 100 feet.

These works were constructed during the years 1889-90, under the plans and supervision of Mr. John McFayden, the general manager of the company.

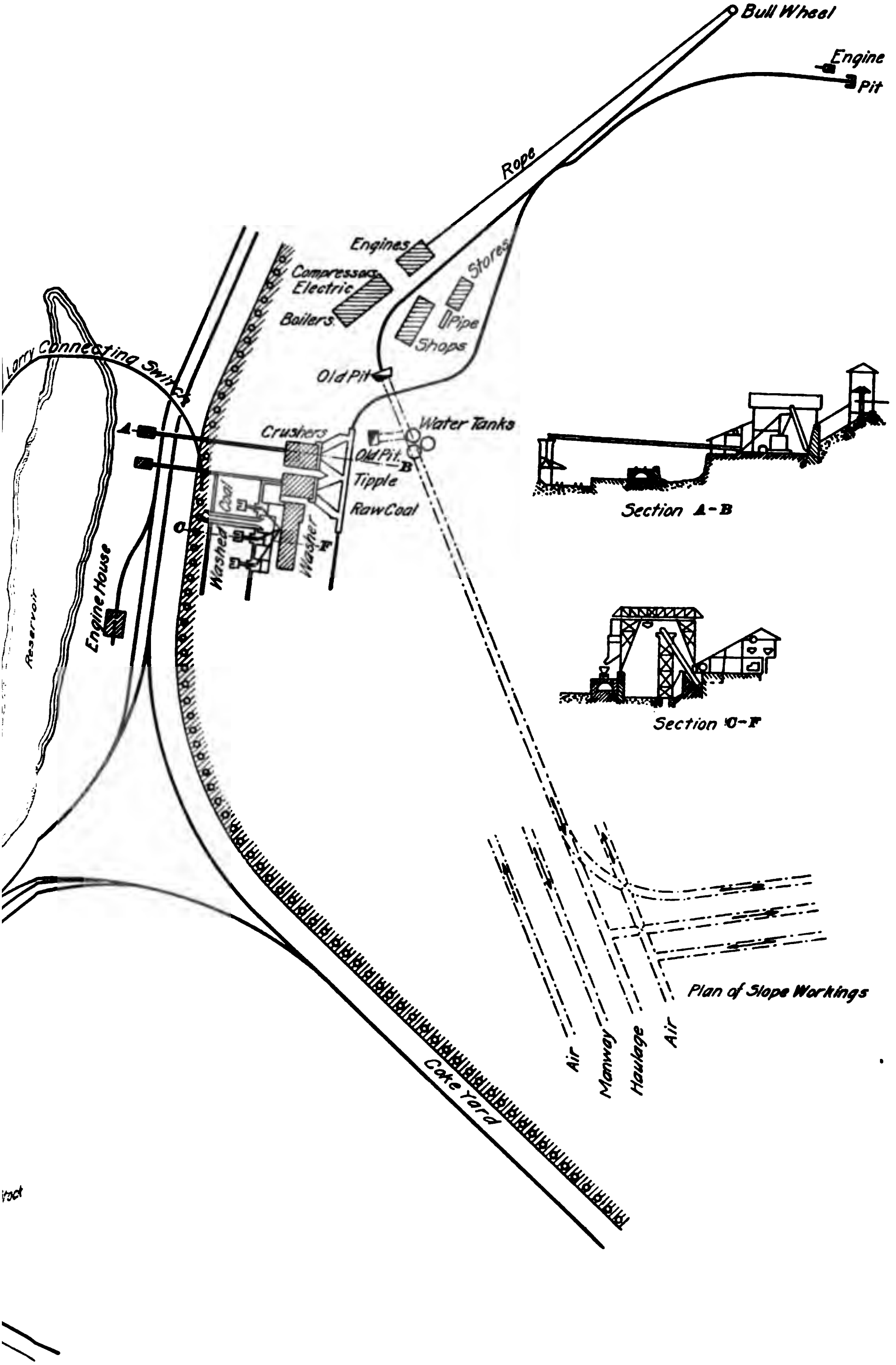
When in full operation, these works can produce about 1,200 tons of coke per day. The main effort in these locations was to reduce the cost of the labor of making coke to a minimum. It is evident that this has been secured as far as the plan of extended oven lines will permit. It is worthy of future consideration, in locating coke ovens, whether more compact lines, like those at Morrell and Oliver No. 2, will afford more labor economy in the section of the work in charging the ovens.

The **Joseph Wharton coke plant,** Fig. 13, illustrates the general plan of the Wharton Coke Works, situated at Coral Station on the Indiana branch of the Pennsylvania Railroad, in Indiana County, Pennsylvania. It consists of 300 modern beehive coke ovens, located in two curved sections on either slope of the valley of a little stream, a tributary to the large Two Lick Creek, securing advantageous gradients for the coke ovens, as well as for the railroad sidings and larry service. The water reservoir is located in the gentle valley of this small stream, and is of liberal dimensions to afford at all times an ample supply of water for all uses at their works. The water is mainly pumped from the nearby Two Lick Creek.



17303—IX

Fig. 13. Plan of Joseph Wharton Cok



Coke Plant at Coral, Indiana County, Pennsylvania

The mine from which the coal is obtained is shown on this plan, with its main workings, now being rapidly extended to meet the daily needs, which, when all the ovens are in blast, will be 1,100 to 1,200 tons per day. The coal lands of this plant consist of 3,000 to 4,000 acres, containing all the beds of the lower coal measures, in the aggregate about 19 feet of coal. The mine works are in the upper Freeport coal bed (E), here 5 feet 9 inches thick with a slate parting.

The coal is broken to small sizes and washed in preparation for coking. The coal washer is of the recent design of Stein and Boericke, of Primos, Delaware County, Pennsylvania, having ample capacity to meet the coke-oven supply. The broken coal is not classified, but is treated in three continuous washer pans, the tailings receiving an additional cleaning under conditions to meet its needs.

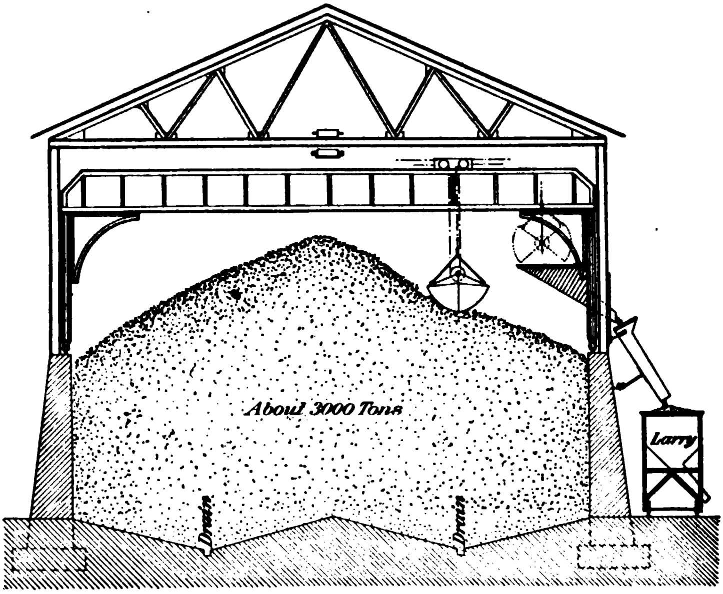


FIG. 14. COAL-STORAGE RECEIVER

The washed coal is elevated into a large coal-storage receiver, Fig. 14, where it is allowed sufficient time to part with its water. The receiver holds about 3,000 tons of washed coal for the ovens. As only about 1,100 tons per day are required for charging the ovens, it will be seen that the coal has over 60 hours in which to dry, prior to its being charged into the ovens.

Fig. 14 will exhibit the general arrangement of the coal-storage receiver, with the arrangements for lifting the coal and loading it into larries.

FIG. 15. JOSEPH WHARTON COKE PLANT AT CORAL, PENNSYLVANIA.

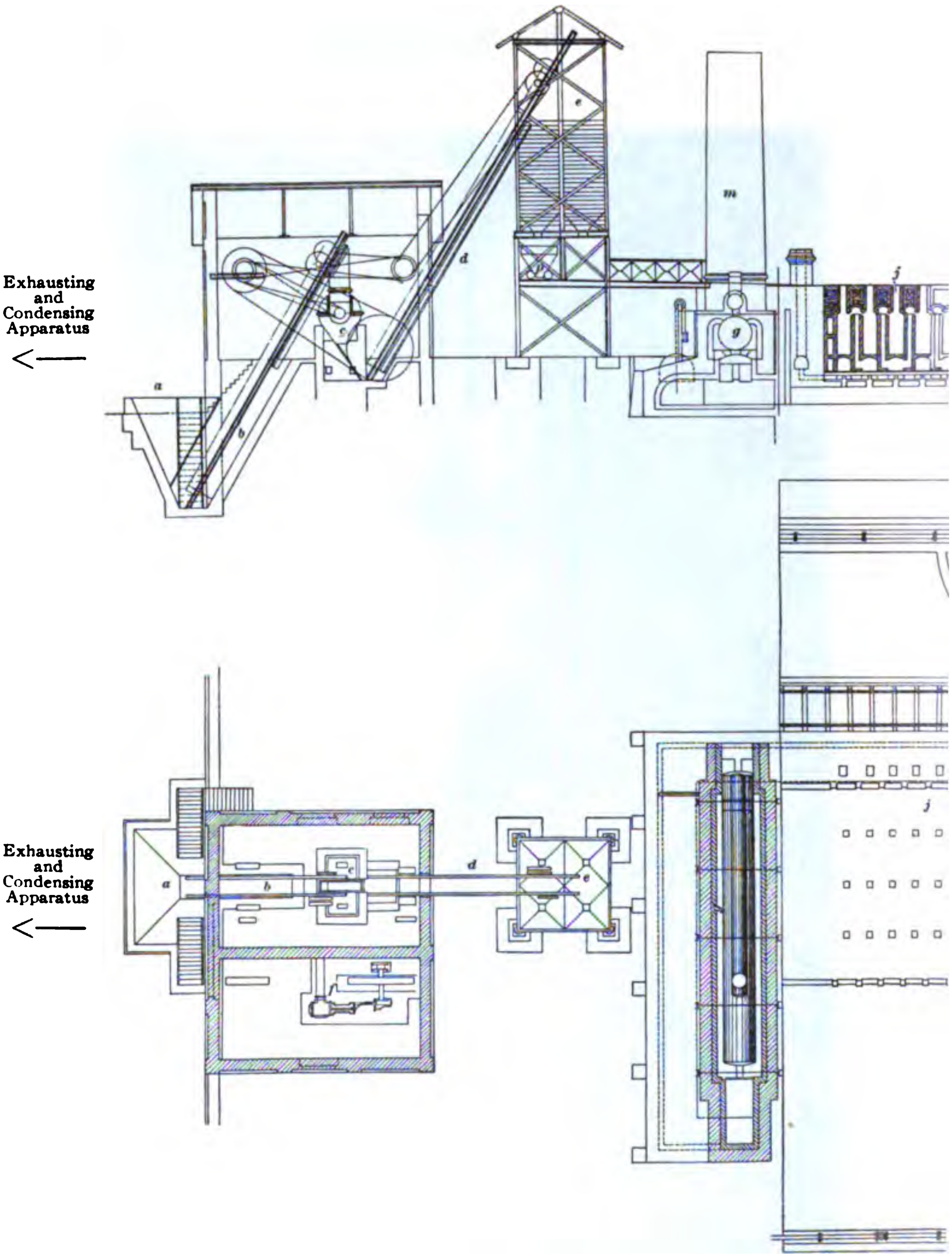
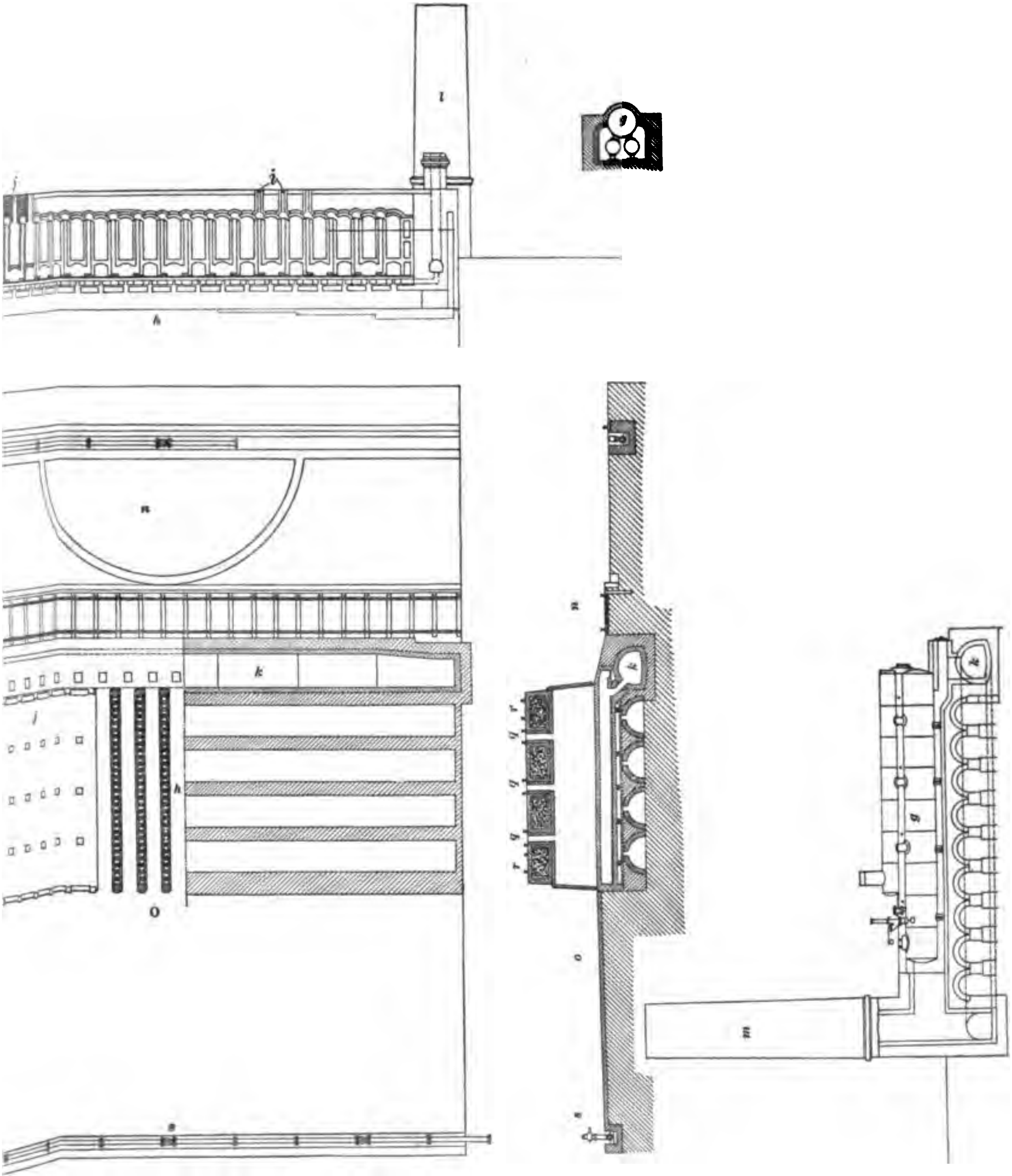


FIG. 16. ARRANGEMENT OF Co

a, Coal dump; *b*, elevator to feed *c*; *c*, disintegrator; *d*, elevator to storage tower; *e*, coal-sto
i, air inlet to ovens; *j*, charging holes for coal; *k*, gas flue; *l*, chimney to be used if gases are not
ram (pushing machine) travels parallel with ovens; *o*, coke discharge side; *q*, tracks for charging



NT OF COKE OVENS WITH CRUSHER. BERNARD'S SYSTEM

, coal-storage tower; *f*, engine; *g*, boiler heated by waste gases; *h*, twenty retort coke ovens without saving of by-products; s are not used for boiler heating; *m*, chimney to be used if gases are used for boiler heating; *n*, machine side of ovens where changing larries; *r*, tracks for windlass for raising doors of ovens; *s*, water supply.

The plan of the coke ovens is of the most modern design. Figs. 7 and 8, Chapter V, show the plan, section, and all details. In the front of this oven a double brick arch is seen above the shaped firebrick arch over the oven door. These ovens have been constructed of the best materials and in the most substantial manner, under the general superintendence of Mr. Harry McCreary, of Indiana, Pennsylvania.

The coke wharves to these ovens are very wide, so as to store coke during periods of a deficient supply of railroad cars. They are faced with permanent masonry retaining walls of increased height to meet the needs of modern steel coke cars.

The miners' hamlet is a model of neatness and excellent sanitary conditions. The whole plant is operated by steam and electric power, with the intelligent application of modern labor-saving machinery. A general view of the plant is shown in Fig. 15. This plant has been laid out under the general superintendence of Mr. Harry McCreary, ably assisted by Mr. R. M. Mullen, civil engineer.

Mr. Joseph Wharton, LL. D., of Philadelphia, has not been sparing of means in the construction of this excellent coking plant. It is most complete in all its parts, and should, under intelligent management, afford satisfactory results in both the quantity and quality of its product.

Mr. Wharton owns and operates a number of large blast furnaces at Wharton, New Jersey. The coke from this and another coke plant in the Connellsville region goes to these blast furnaces.

RETORT-OVEN PLANTS

The plan and elevation, Fig. 16, show the general requirements in locating retort coke ovens. It will be seen that the requirements in their location differ materially from the location of the beehive ovens, in the wider spaces demanded for the steam ram or pushing engine for discharging the coke from the retort ovens. In the above instance, a width of 45 feet is required for steam connections and pushing engine. In the beehive ovens, the coke is usually drawn out by manual labor, requiring only 30 feet of wharf room, while in the retort ovens 40 feet width in wharves is required on both sides of the ovens.

The plan shows the method of locating a bank of 20 Bernard coke ovens, with coal dump or hopper for receiving the coking coal from the mine or railroad cars, with elevators, disintegrator, and storage tower; all in close relations to the bank of coke ovens. The coal-storage tower has double hoppers below, through which the coal is loaded into the charging larry.

The steam boilers are placed at the end of the bank of ovens, and are usually fired by the gases from the coke ovens;

but in case of failure of an adequate supply of gas, the deficiency can readily be obtained in coal from the adjoining coal-storage tower.

The space on the wharf required for discharged coke is, in this instance, 40 feet wide to receive the charge of coke from the ovens, which are 30 feet long.

The bank of ovens can be extended to embrace a line of 60 coke ovens. When a greater number is required, parallel banks can be readily located. If the by-products are to be saved, the necessary exhausting and condensing apparatus can be placed immediately behind the coal-storáge tower, in a building set apart for these uses.

In locating large plants of retort coke ovens in parallel banks, the exhausting and condensing appliances can be proportioned to supply two banks of 60 ovens each. A similar application can be made of the apparatus for treatment of coal, when it may be found necessary, that is, one apparatus to supply two banks of coke ovens.

In most cases it is considered prudent to establish duplicate condensing apparatuses, as any interruption to this part of the work would produce general disorder.

Steam rams or pushing engines have been constructed under different plans. Some of these engines carry with them a steam boiler, while others receive their steam through ingenious arrangements of movable steam pipes from stationary boilers.

The gradients of railroad sidings and charging larry tracks should be governed by the same principles that are found necessary to economy of work in beehive ovens. In some cases the retort ovens are located in the immediate neighborhood of the blast furnaces, and the coke is handled from the former to the latter in the usual coke barrows. Even in this location, gradients descending with the tonnage will conduce to facility and economy of this work.

In the foregoing considerations of the location of plants of coke ovens, the sites have been contemplated at or quite near the coal mines. The usual quantity of coal to make 1 ton of coke is 1.5 to 1.7 tons. The economy of locating coke works at the coal mines is based on the less freight charge on 1 ton of coke, against the charge on 1.4 or 1.6 tons of coal.

It is quite evident that in most cases this method of locating the coke ovens at the coal mines is the true policy. It has, however, some drawbacks. There is usually a loss of 2 or 3 per cent. in the loading of coke at the ovens and unloading it at the furnaces or steel works. In the wet and winter seasons it occasionally receives 2 to 3 per cent. of moisture in the transit. But the loss in both of these would not compensate for the increased freight on coal to make coke at the furnaces or steel works, provided that the freight charges per ton are equal.

PRODUCTION OF ILLUMINATING GAS FROM COKE OVENS*

The object of this paper is to describe the progress that has been made in the United States and Canada in recovering illuminating gas from by-product coke ovens. A clear account of this cannot be given without repeating some of the previous statements published.†

Before entering upon the subject, I cannot resist the temptation of discussing its bearing upon the vexed smoke problem of large cities.

The Fuel Supply of Large Cities.—The question of the fuel supply of large cities is of the greatest importance. Nothwithstanding this fact, its study has been neglected in a distressing manner. We still see the large manufacturing cities in Great Britain, as well as in the United States and other countries, darkened and begrimed with clouds of smoke and soot resulting from the use of bituminous coal. The annual expenditure for the maintenance of buildings, etc. is increased, not to mention the deleterious effect on the health of the people.

The subject has been discussed by George Beilby in his presidential address before the Society of Chemical Industry.‡ He gives the following table:

CONSUMPTION OF COAL IN THE UNITED KINGDOM IN 1898

Coal for the generation of power in industries:		Long Tons
Railways	10,000,000 to 12,000,000	
Coasting steamers	6,000,000 to 8,000,000	
Mines	10,000,000 to 11,000,000	
Factories	38,000,000 to 40,000,000	
Total		71,000,000

---

*Paper read before the gas section of the Engineering Congress at Glasgow by F. Schniewind, Ph. D.

† (*a*) Professor Hoffmann's extract from Dr. F. Schniewind's test report on Dominion coal at Glassport, Pennsylvania, "The Production of Illuminating Gas in By-Product Coke Ovens" Engineering and Mining Journal, October 8 and 15, 1898; Progressive Age, 1898, page 575. (*b*) "The Everett Coke-Oven Gas Plant," Progressive Age, August 15, and September 1, 1899; January 1, 1900; Journal of Gas Lighting, Vol. LXXIV, pages 1,114, 1,176; Vol. LXXV, page 274; Vol. LXXVII, pages 616, 679, 749, 820. (*c*) "Otto-Hoffman Coke-Oven Practice." American Gas Light Journal, Vol. LXXVII, page 444. (*d*) "By-Product Coke in the United States." Iron Age, Vol. LXXVIII, page 14.

‡Journal of the Society of Chemical Industry, Vol. XVIII, page 643; Journal of Gas Lighting, Vol. LXXIV, page 175.

Coal for the generation of heat in industries:		Long Tons
Blast furnaces	16,000,000 to 18,000,000	
Steel and malleable-iron works	10,000,000 to 12,000,000	
Other metallurgical works	1,000,000 to 2,000,000	
Chemical works, potteries, and glass works	4,000,000 to 6,000,000	
Gasworks	13,000,000	
Total		51,000,000
Coal for domestic purposes		35,000,000
Coal for the generation of power in industries, as tabulated on page 381		71,000,000
Total consumption		157,000,000

Of this amount of bituminous coal, only a very small percentage is subjected to dry distillation, which converts it into smokeless coke (see following table); the remainder is almost entirely burned directly, under conditions that are favorable to the production of smoke.

COAL SUBJECTED TO DRY DISTILLATION IN THE UNITED KINGDOM IN 1898

	Long Tons
Gasworks	13,000,000
Blast furnaces	2,000,000
By-product coke ovens	1,250,000
Total	16,250,000

This figure does not include the coal coked in beehive ovens without the recovery of by-products, which amount is approximately 12,500,000 long tons.

Mr. Beilby suggests two solutions of the smoke problem: (1) the use of improved appliances for the combustion of the raw coal, and (2) the transformation of the raw coal into smokeless fuel by carbonization or gasification.

We are of the opinion that the first method offers only a partial relief, and, furthermore, that it is a wasteful one, because valuable products can be recovered from bituminous coal by dry distillation that are wasted in the direct combustion of raw coal. The second method, i. e., that of the conversion of the raw coal into a smokeless fuel by carbonization, seems to us the most rational and economical solution of the problem. This method has, in the meantime, developed to a very considerable extent in the United States. The United Coke and Gas Company, of New York, has introduced into the United States by-product coke-oven systems exploited by Dr. C. Otto & Co., of Germany, chiefly the Otto-Hoffman coke ovens. A large number of these plants have been erected. In Germany, these plants are operated almost entirely for the production of metallurgical coke, while the surplus gas is burned under boilers. A number of the American plants operate in the same way, but several of the later plants are designed for the exclusive manufacture of domestic and railroad coke and illuminating gas.

A very large proportion of the coal, as given in Mr. Beilby's table, is consumed in or near large cities, and we believe this coal should be subjected to a carbonizing process before use. This would supply to the city at once a cheap smokeless fuel suitable for practically all purposes. We will show further on that the use of coke instead of coal would not be coupled with a great expense to the fuel consumer. By the erection of large carbonizing works near or in large cities, the smoke problem would find its ready solution; and at the same time, a great saving, from a national economic point of view, would result from the recovery of the valuable by-products and gas.

How urgent the demand for smokeless fuels has become is plainly shown by the fuel statistics of some of the larger American cities. In the United States, anthracite is found in a small district in Pennsylvania, while bituminous coal is scattered over almost all the states east of the Mississippi. Notwithstanding the close proximity of the bituminous coal fields to some of the larger cities, enormous quantities of anthracite are brought to them from a great distance, and consequently at great expense.

The following table demonstrates how enormous the demand for smokeless fuel has become, and furthermore, that a great premium is paid for the smokeless character of the fuel. The prospects are, therefore, encouraging for the erection of carbonizing plants near large cities.

FUEL STATISTICS OF SOME AMERICAN CITIES FOR 1900

	Bituminous Coal		Anthracite	
	Quantity Used Net Tons	Price Per Net Ton Dollars	Quantity Used Net Tons	Price Per Net Ton Dollars
New York..........		2.50 to 3.50		3.50 to 4.00
Philadelphia.........	1,700,000	2.00 to 3.00	3,300,000	4.00 to 4.50
Boston..............	2,050,000	2.50 to 3.50	1,950,000	4.00 to 5.00
Chicago.............	7,000,000	2.00 to 3.00	1,600,000	5.00 to 6.00

NOTE.—The total amount of bituminous coal and anthracite for domestic consumption and the supply of steamers in New York and adjacent cities belonging to the port of New York is estimated at 15,000,000 net tons.

In order to facilitate an understanding of the more detailed account of the process, a general description of the combined coke-oven and gas process is first given, comparing it at the same time with ordinary gas-retort practice.

The coke ovens have a charging capacity of 16,000 pounds of coal, which is all carbonized in 24 hours and less. Ordinary gas retorts have a charging capacity of only 300 to 400 pounds, which is carbonized in about 4 hours.

On account of the increased charge, all the operations around the coke ovens are performed by machinery, which results in a saving of labor per ton carbonized, as compared with the present coal-gas system.

On account of the larger charges and the peculiar construction of the coke ovens, a far better coke is produced, as compared with that obtained in ordinary small gas retorts. The coke oven yields, if required, a coke that satisfactorily sustains the burden of a modern large-sized blast furnace. It is consequently of much higher value than gasworks coke. The coke oven may also produce domestic coke far superior to gasworks coke.

The coke oven, like the ordinary gas retort, saves tar and ammonia, and eventually several additional by-products. The coke oven yields, however, a higher percentage and a better quality of these products than the gas retort.

The ordinary gas retort produces the heat necessary for carbonizing the coal by burning a part of the resulting coke under the benches. In the coke-oven process, all the coke is saved, while a part of the resulting gas is burned under the ovens.

THE EVERETT COKE-OVEN GAS PLANT*

The property consists of about 288 acres of land in Everett and Chelsea, Massachusetts. This is largely tidal marsh land, but a ridge of gravel extends from Beacham Street, Fig. 17, to the point between Mystic and Island End rivers. This gave excellent material for filling and also for making concrete. The character of the ground necessitated a great deal of piling. There was driven a total of about 35,000 piles, and immediately upon these piles a cap of concrete was put.

The present plant of 400 ovens occupies but a small part of the property. The design of the plant permits of an increase to 1,200 ovens, the erection of which number is ultimately contemplated. The next set of 400 ovens will be located between the present plant and the wharf, and the third between the present plant and the purifying house.

Coal-Handling Plant.—The coal employed is washed Cape Breton slack coal received from the Dominion Coal Company. The coal-handling plant was designed by L. J. Hirt, the chief engineer of the New England Gas and Coke Company, and is on the rope-haulage principle.

---

*By Dr. F. Schniewind, in Progressive Age for August 15, 1899.

The steamers land the coal on the company's wharf, Fig. 17. On top of the 6,000-ton coal bin *A*, three hoisting towers are provided with so-called "clam-shell" grab buckets of 1.5 tons capacity. The speed of unloading is about 150 to 200 tons per tower per hour from the full cargo. During the "trimming" of the coal the capacity is of course reduced.

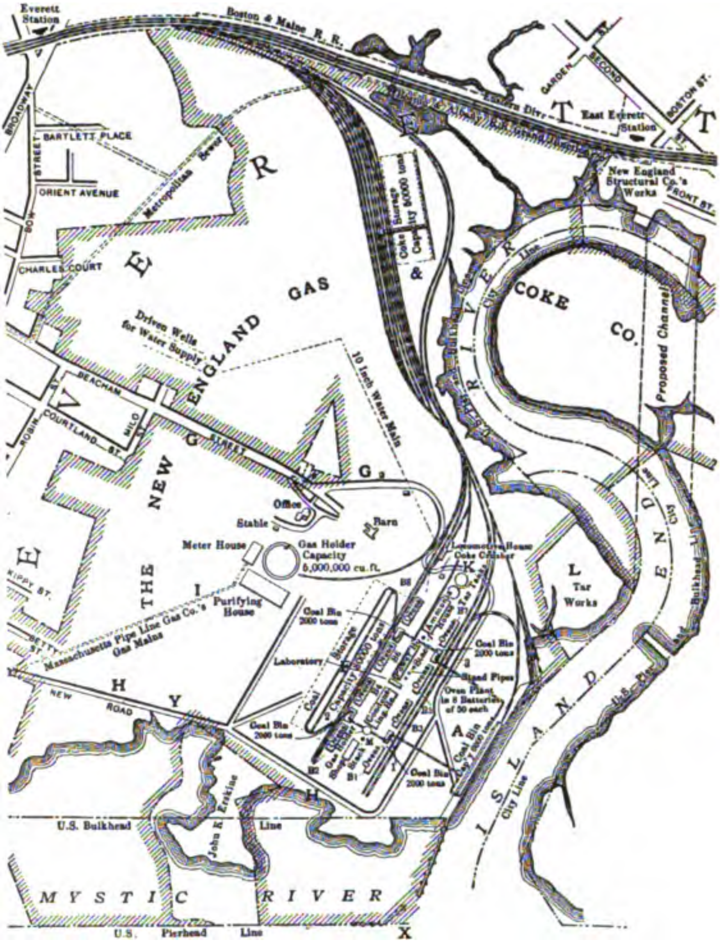


Fig. 17. Plan of Works, New England Gas and Coke Company

Underneath the bin are three tracks provided for coal larries, or cars holding about 2.5 tons each. There are thirty of these larries. The loaded larries run by gravity to the north end of bin *A*, where they are connected with the cable, which carries

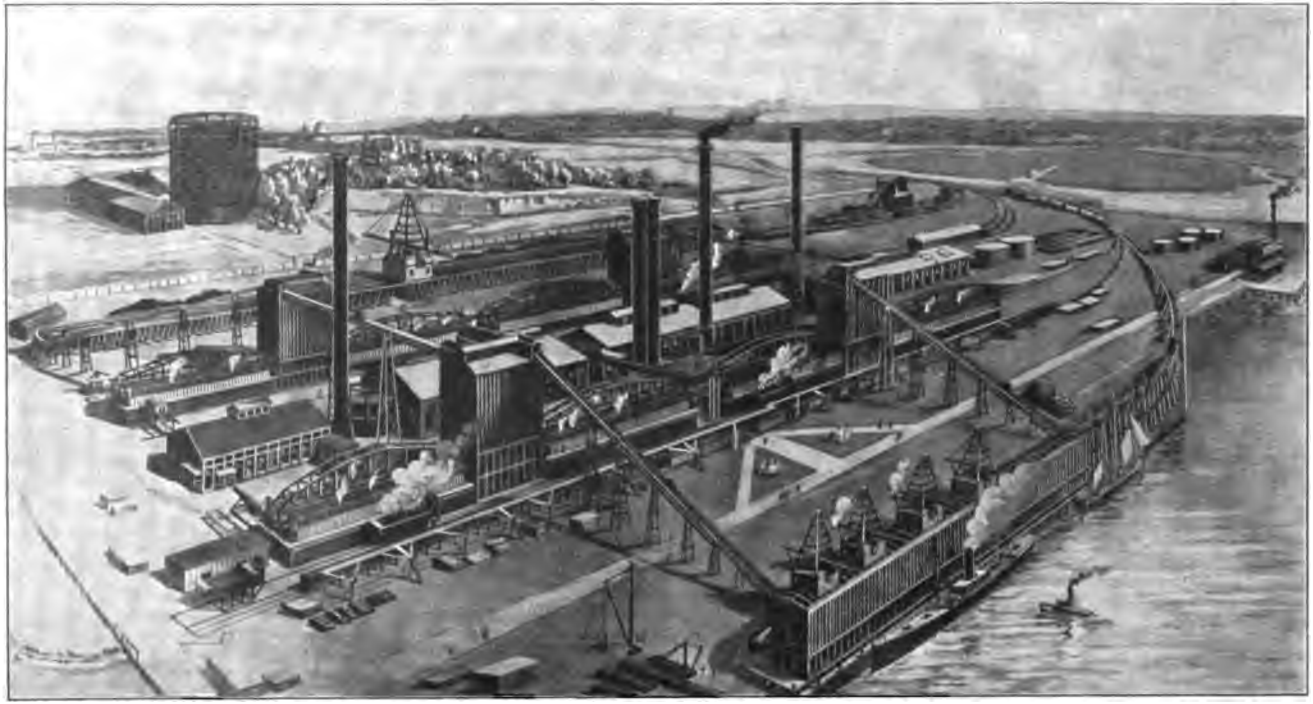


Fig. 18. Bird's-Eye View of Plant, New England Gas and Coke Company, Everett, Massachusetts

them to the four coal bins *3*, *4*, *2*, *1* (of a capacity of 2,000 tons each) at the ovens, and into the large storage yard *F*. The latter provides for the storage of 80,000 tons of coal and consists of a wooden trestle from which the coal can be dumped upon the ground. From this pile, a movable double tower can pick up the coal on either side of the trestle and transfer it back to the coal larries, which then convey it to the oven bins.

It is during a short period in March or April only that the Cape Breton harbors (Louisburg and Sidney), from which the coal is shipped, are icebound, and consequently with the beginning of winter sufficient coal will be accumulated to tide the works over this period.

At present, the motive power for the coal towers on top of the storage bin *A*, as also for the cable-driving machinery, is steam, but it is the intention to operate these by electricity. All the bins are of steel with wooden lining.

The **coke ovens** are arranged in eight groups, or batteries, of 50 each, *B1–B8*, Fig. 17. Two of these groups, 100 ovens, form one working unit and are supplied with coal from one bin. Batteries *B1*, *B2*, *B3*, *B4* are connected with stack *M*, and *B5*, *B6*, *B7*, *B8* with stack *N*. The batteries are erected on high foundations for two reasons, viz.: first, to bring the bottom of all flues above extreme high water, and second, to admit of dumping the coke into the highest railroad cars without another lifting.

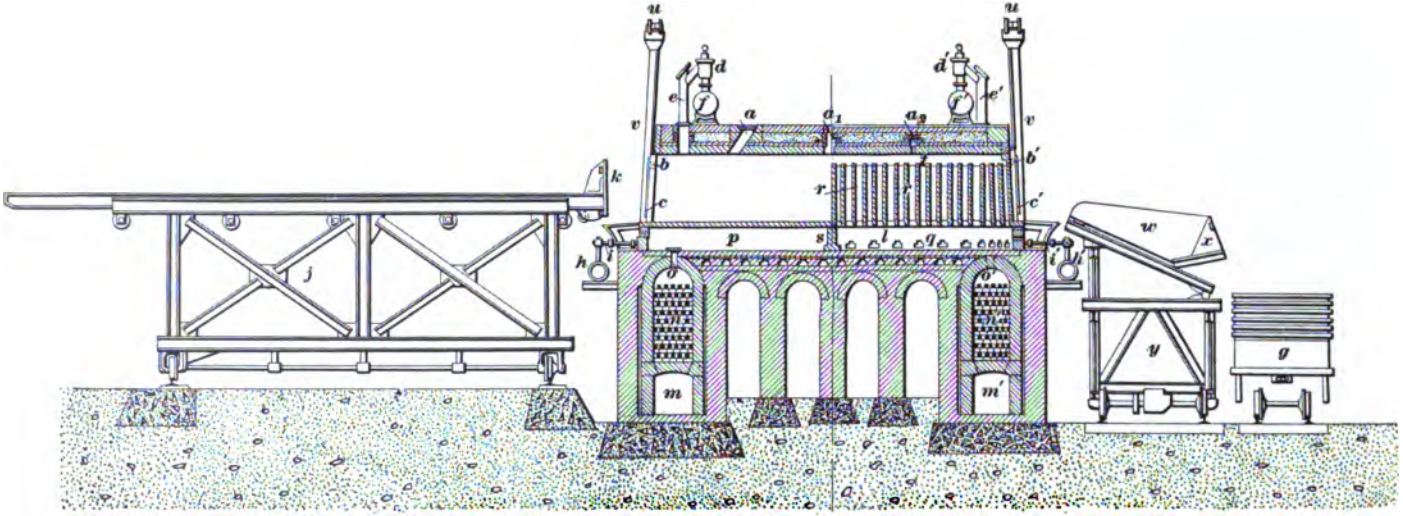
At present, batteries *B1* and *B3* are in operation, and battery *B2* is being heated by means of some surplus gas from batteries *B1* and *B3*.

Capacity.—The retorts are 33 feet long, nearly 6 feet high, and 18 inches average width, and have a capacity of 6 net tons coal per charge. They are of the Otto-Hoffman type with several modifications to adapt them to the present requirements.

Firebrick.—Unusual care has been taken in truing the brick used for erecting the walls, and so successful have been these efforts that no allowance had to be made for joints. The importance of obtaining gas-tight walls is manifest. As in these works the gas is of more importance than usual with coke ovens; this care was wise.

It has been found that the average American firebrick is far more refractory than the European coke-oven brick, but nevertheless even the best brands are generally not suitable for retort coke ovens. The reason is the considerable shrinkage of these American brick when exposed to high heat.

The strains on coke-oven brick are very severe, as the walls in the bottom flues are subjected to very high, continuous temperatures from all sides, while again in another part (the retort proper) the brick are subject to sudden cooling by the cold and sometimes wet coal charges and to the mechanical abrasion of the coke charge when pushed out.



(a) Section Through Retort Section Through Side Wall (b)

FIG. 19. SECTION THROUGH OTTO-HOFFMAN OVEN WITH PUSHER, COKE LOADER, AND CAR

The first Otto-Hoffman plants, when built in this country, viz., at Cambria Steel Company, Johnstown, and the Pittsburg Gas and Coke Company, Glassport, Pennsylvania, experienced considerable trouble on this account. But the problem had to be solved, as the introduction of the retort oven into the United States depended on the securing of suitable domestic firebrick; and it may be said that by properly using various refractory materials the problem has been solved so successfully that 60 ovens at Johnstown, now in continuous operation for 2 years, do not show the slightest cracks or deviations from their original dimensions.

Charging.—The coal charge is brought from the bin to the ovens by means of an electric charging machine (not shown in the illustrations) and filled into the retort through three charging holes in the roof, a, a_1, a_2, Fig. 19. The coal is then leveled by introducing scrapers through small holes b and b' in the two doors, c and c'. When this charge is level, holes b and b' are closed and luted, and the same is done with the three charging holes, a, a_1, a_2.

Removal of Gases.—The evolution of gases and vapors has at once commenced with the charging of the coal. By raising the drop valve d, the products of distillation are permitted to escape through standpipe e into the gas-collecting main f. It should be mentioned that this is a dry main and not a hydraulic main. The mains are kept free of pitch by a tar flushing system.

The Coking Time.—The charge of coal, 6 net tons, is carbonized in from 24 to 30 hours. This time varies from several causes, among which is an important one—the character of the coke that it is intended to produce. If we wait until the last traces of volatile matter are expelled, then we will produce a very hard coke, but will require a long coking time. If, on the other hand, we push the oven before the last traces of volatile matter are driven off, then the coke is softer and better suited for domestic and boiler-firing purposes and the coking time is materially reduced.

In the beginning, 60 ovens were pushed per day out of the 100 in operation. With the growing demand for coke, this number was increased to 80 ovens. This corresponds to a coking time of 30 hours. But with this modus operandi a considerable number, from 20 to 30 ovens, are always "around," i. e., ready to be pushed. Thus, the coking could easily be reduced to 24 hours, and will be shortly with the constantly increasing orders for coke.

Discharging of the Coke.—When the oven has ceased to give off gas, which can be ascertained through small holes in the doors, the valve d', Fig. 19, is closed and thus the oven is disconnected from the poor gas main f'. The charging-hole covers a, a_1, a_2 are then opened and the oven is ready for the coke pusher.

In order to distribute the fresh charges over the entire battery, a regular rotation of pushing the ovens has been established. Beginning, for instance, with oven No. 1 at one end of the battery, the next ovens are 11, 21, 31, and 41; after this, ovens Nos. 6, 16, 26, 36, and 46 are pushed. This is followed throughout the entire 100 ovens. It is apparent that such an arrangement makes it impossible to charge two adjoining ovens in short succession.

The electric coke pusher *j*, Fig. 19, is then brought opposite the oven ready to be pushed. The doors at both ends, *c* and *c'*, are hoisted by means of electric contrivances, situated at the end of each battery. Rollers *u* are provided over each door, on which a long bar is resting, which connects with the electric door hoist. Whenever a chain is attached to the door and to this bar and the bar moved sidewise, the door will be raised.

The electric coke pusher *j* consists of a long rack and pinion that forces through the oven a shield *k* bearing against the coke charge. Thus, the entire charge of coke is forced out toward the coke side. In order to facilitate the moving of the charge, the oven is a little wider at the discharge end than at the pusher side. The hot coke then falls into the electric coke-loading machine *y*. A jet of water is thrown upon the coke immediately upon its leaving the oven.

The coke loader consists of a long, inclined pan *w* capable of holding the entire charge of about 4.5 net tons of coke. In order to obtain a good distribution of the coke in this pan, the entire machine is moved sidewise while the coke is coming out. As soon as the charge is on the pan, this travels with its hot charge to one side, and a second loading machine finishes the operations at the oven. Thus, the men are not exposed to the high heat from the glowing coke. The hot charge then receives another quenching. When the coke is fully cooled, partly by water and partly by the air, the pan is tilted and the gates *x* are opened, which allows the entire coke charge to slide into the railroad cars *g*.

Immediately after the coke has been pushed out, the pusher bar is withdrawn and the doors *c* and *c'* are lowered. The doors are forced close against the brickwork of the oven by means of bars, held in buckstaves *v* between the ovens, and wedges. After this the doors are sealed hermetically by throwing loam around the same, and the oven is ready for another charge. The entire operation of discharging the oven and recharging the same is completed in about 10 to 12 minutes.

Disposal of the Coke.—All the coke coming from the ovens is first loaded into railroad cars. The New England Gas and Coke Company owns 150 cars, which are of improved open top-rack type. The capacity of these cars is about 22 to 25 tons. Provisions are also made to load the coke into box cars. The coke coming from the ovens consists chiefly of columnar pieces about 9 inches long. With these pieces is mixed a small percentage of smaller pieces. This coke is called "run-of-oven coke," and is shipped directly for use under boilers, locomotives, for metallurgical purposes, etc.

If the coke is to be used for domestic purposes, the railroad cars are switched to a coke crusher by which it is broken into different sizes and screened. The different sizes are collected in separate bins, from which they are drawn into railroad cars for shipment. The railroad cars can be shifted directly on to lighters that transfer the coke to any of the large coal yards, etc. in Boston. Provisions are also being made to load the coke in bulk into steamers and sailboats. There is, furthermore, in construction a large storage yard capable of holding about 50,000 tons of coke for the winter trade, and a movable crane is being erected, which has a span of 200 feet and travels a distance of 600 feet, thus covering a total area of 120,000 square feet. This crane will either load the coke from the cars on to the storage pile, without breaking it by a high drop, or will load it back from the pile into the cars.

CHAPTER X

GENERAL CONCLUSIONS ON THE WORK, COST, AND PRODUCTS OF THE SEVERAL TYPES OF COKE OVENS

Adaptability of Different Ovens in the Several Coal Fields.—In the eastern and middle coal fields of the United States, the areas of the sections of the coal measures whose beds are adapted for the manufacture of coke, in greater and less degrees, have been generally well defined. Much has yet to be done in the great far West in the further development of its coal fields, and in determining the special localities affording coal suitable for making coke.

So far as our present knowledge extends, there are at present four well-known groups or sections of coking coals. These areas of coking coals are found in meridional strips, conforming in their general southwestward courses to the crest-line trends of the Appalachian mountain chains. They are found in the following order from west to east:

Section 1. The several types of coals very rich in bituminous matter, affording a light coke with a highly inflated physical structure, and not regarded as a desirable fuel for metallurgical purposes. This class of coals contains from 35 to 40 per cent. of volatile matter.

Some efforts have been made to coke these coals; evidently the progress thus far has not been quite satisfactory. Treatment in the horizontal types of ovens appears to have produced the best results; but the coke is usually spongy, inheriting an inflated physical structure and lacking the hardness of body so essential to a good metallurgical fuel. It is coming to be understood that this class of rich bituminous coals requires a moderate oven heat to secure the best possible coke.

A serious difficulty has embarrassed the efforts hitherto made to produce clean metallurgical coke from these coals, from the rather large percentage of sulphur inherited by most of them. This sulphur is found generally interleaved in the bedding planes of the coal, as well as scattered through it in thin scales. The attenuated condition of this sulphur admixture constitutes the chief difficulty in efforts to reduce or remove it by the ordinary processes of disintegration and washing. A practical plan for reducing this thinly mingled sulphur from these western coals would enable a coke to be made from them that could be used in whole or in part of blast-furnace operations.

A broad horizontal oven, with flues under its floor, heated with returned gas evolved in coking, and without side flues, would probably be the best method of reducing the injurious action of the surplus fusing matter in these coals. This would be a somewhat different application of the meiler or mound principle of coking coal. It is probable that a mixture of the class of dry coking coals with these rich bituminous coals would produce a firm coke. This, however, would involve the additional expense of freight, with extra care and labor in mixing the coals.

It is important to note that the area of this section of rich bituminous coal is by far the largest, in fact larger than all the others together. It follows, therefore, that it presents an inviting field for further experiment in determining the best type of coke oven for the successful production of useful coke in this large area of bituminous coal.

The type of coke oven to produce the best possible coke, with the saving of by-products, would evidently follow promptly the success of cleaning the coal for the manufacture of coke.

Section 2. This small section embraces the best qualities of coals for the manufacture of coke. They contain 25 to 35 per cent. of volatile matter. The strip is narrow, averaging 3 to 5 miles wide in Southwestern Pennsylvania, located parallel to and west of the Chestnut Ridge. It constitutes the celebrated Connellsville coke region. It extends through West Virginia, inheriting in that state a slightly increased volume of bituminous matter. The cokes made from these coals are firmly established as regards purity and calorific energy in all metallurgical operations.

Section 3. This section, consisting of the dryer qualities of coking coals, is next in magnitude to Section 1 and only secondary in quality to Section 2. These coals, under careful oven treatment, afford good coke; they contain 20 to 25 per cent. of volatile combustible matter.

This strip is located in Pennsylvania, Maryland, and the Virginias. It is situated along the eastern border of the Appalachian field. Its coal can be coked in horizontal ovens with fairly good results; but, with some exceptions, it does not usually inherit the hardness of body and calorific energy of the cokes from the coals of Section 2.

It is quite evident that the vertical types of coke ovens are best adapted for the production of the best quality of coke from this family of coals, as they confer on it the essential physical property, hardness of body, which assures its value as a blast-furnace fuel. They would also afford an increased percentage of coke from these rather dry coals as compared with the horizontal type of coke ovens.

It is also evident that in using the vertical or retort coke oven, in making coke from these coals, the plant should be provided with the necessary apparatus for saving the by-products of tar and ammonia sulphate, as the profits from these will be found helpful on the credit side of earnings.

As it is now becoming evident that the comparatively limited areas of the best coking coals are being rapidly exhausted, the question of securing the best means of manufacturing coke from the secondary or dry coals is a pressing one, deserving the earnest attention of the coke manufacturers who may be required to use this class of coals.

As the regions of the first-class coking coals become more reduced in area on the one side, with the expansion of the use of coke on the other, it follows that the increase of coke demanded by the iron and steel manufacturers must be supplied mainly from the coals of Section 3. Some investigations and tests have been made in the use of retort coke ovens in coking these coals, which so far have afforded assurance of the best results in coke from these secondary coking coals. The chief element retarding the introduction of these vertical coke ovens consists in the large capital required in establishing a plant of these ovens, with or without by-product-saving auxiliary. There would also be an added expense in mining the coal in the thin beds of this section, with the added cost of disintegrating and washing the coal preparatory to charging it into the ovens. Some compensation is afforded in this locality in the reduced railroad freight eastwards.

Section 4. The coals embraced in this section are very dry, holding only 15 to 20 per cent. of volatile combustible matter, and requiring special oven treatment. It is situated mainly along the eastern border of the Appalachian field, from Northern Pennsylvania to Southern Virginia. It has several outlying and detached fields, such as the Blossburg, Lycoming, Broad Top, Cumberland, etc.

There are some notable additions to the outer edge dry coals. One of these is found at Johnstown, Pennsylvania, where the coals contain only 16 to 19 per cent. of volatile matter, and although located in the third section of medium coking coals they really belong to the fourth section of dry coals. From its geographical position westwards, its coal should inherit at least 25 per cent. of volatile matter, but it is a remarkable fact that a broad belt of this exceptional dry coal is found in this inner section of the Appalachian field. Its extremities northeast and southwest have not been defined.

For the proper treatment of this section of extremely dry coals the narrow vertical oven must be used. The coal will also, in most instances, require preparation by disintegration, in separating slates and pyrites, and in many cases by washing.

In this connection, a very marked example of the effects of coking Blossburg coal in beehive and Semet-Solvay ovens has come to notice. In the round oven this dry coal affords 61 per cent of marketable coke. In the Semet-Solvay oven it yields 78 per cent. of large coke. Samples of each were tested in the laboratory for resistance to hot carbon dioxide. A few grains of each were placed in a test tube, and submitted to the action of a stream of hot carbonic-acid gas, for equal periods of time, with the following results:

	Left After Treatment With CO_2	Loss as CO
Semet-Solvay	88.8	11.2
Blossburg	65.4	34.6

These tests indicate the very wide difference in the hardness of the body of the coke and its property of resisting the dissolving agency of carbon dioxide, such as would be encountered in a blast furnace. The CO column shows more than three times the probable loss in the horizontal-oven coke above the Semet-Solvay oven coke.

The difference in product in these ovens is quite large, the vertical oven affording an increase of seventeen units of coke, or 22 per cent. increase in product over the beehive oven. This increase contributes to the reduction of the volume of impurities to the sum total of the coke.

It may therefore be accepted as a general principle in the treatment of these dry coals that the quick and superior heat in the retort ovens produces the hardest-bodied coke with an increased quantity of it.

The Connellsville coke made in beehive and Otto-Hoffman ovens gave, from a similar test, the following results:

	Left After Treatment With CO_2	Loss as CO
Beehive Connellsville coke	91.0	9.0
Otto-Hoffman	94.5	5.5

As a standard for comparison, anthracite, which is a natural coke, gave the following result:

	Left After Treatment With CO_2	Loss as CO
Anthracite	96.0	4.0

The Connellsville coke made in beehive ovens, as well as the portion made in Otto-Hoffman ovens, is best qualified by hardness of body to resist destructive dissolution in blast-furnace operations. This assures the economy of fuel per ton of pig iron made, and the further advantage of increased output.

In the West, the newer coal deposits afford occasional areas of good coking coals. The states of Colorado and Wyoming have shown considerable progress in the production of good qualities of metallurgical cokes. The gradual debituminization of the coals eastwards has been noticed very fully in Chapter I.

An examination of the geological map will show the general contour of the eastern edge of the great Appalachian coal field. It will be noted that this eastern contour line maintains a certain parallelism with the old-time Atlantic shore line of this portion of the North American Continent. The intense dynamic thrust westwards in the states of Kentucky, Tennessee, and Alabama, with the subsequent erosion along their eastern border, has removed the region of the dry coals, and conferred on their remaining coals a medium quality between the bituminous coals of the west and the dry coals on the eastern borders.

With these well-defined areas of coals that can be coked, the coke manufacturer can decide three important conditions in selecting a location for his plant: (1) In which of these sections will he establish his coking plant? (2) What type of coke oven will be best adapted to producing the best possible metallurgical coke? (3) Will it be profitable in making coke to save the by-products: the tar, and ammonia sulphate?

It may be helpful in determining the location of the coke plant, with the type of oven to be used, to submit the following considerations:

If possible, the manufacturer of coke should locate his plant in the best coking-coal belt. This assures the best product of coke, and removes any suspicions as to its quality; to be liable to be called on to defend the character of coke made in localities not well known, or not having the quality of its coke assured, adds considerable worry to the duties of the manufacturer.

It will be found, on careful consideration, that the difference in the price per acre is not a vital element of discouragement in shaping a decision. For instance, the best coking coal land costs now $600 to $1,000 per acre. An acre of this coal bed, 7½ feet thick, will afford an output, with careful mining, of 12,000 net tons of coal. The mining of this coal, under existing conditions in the Connellsville field, costs about 25 cents per net ton. The coal requires no disintegration or washing.

	Per Net Ton
The royalty on coal, at $1,000 per acre, is	$ .0833
Mining coal	.3000
Total	$ .3833

Second-class coking coal can be purchased for $50 per acre for the coal bed alone. Assuming the thickness to be the same, 7½ feet, affording 12,000 net tons of coal per acre, the cost will be as follows:

	Per Net Ton
Royalty on coal	$ .00416
Mining	.50000
Total	$ .50416

The difference is $0.121 per net ton or $1,452 per acre in favor of the first quality. But the difference in cost is $950, against the best coal, having still in its favor $502 per acre, to cover interest on the increased investment.

Again, supposing that the second quality of coking coal requires disintegrating and washing, this will add 5 to 8 cents per ton usually, or at least $600 per acre, making the ultimate difference, in this case, equal to $1,102 in favor of best quality of coking coal. It is therefore evident that the best qualities of coking coals, commanding the higher price, are, under full consideration, the cheapest in the end.

In the thin beds of the third section of coals the difference in ultimate cost would be still greater, as the increased cost of mining and mine ways would have to be considered.

COMPARISON OF DIFFERENT TYPES OF OVENS

In the selection of coke ovens for coking the several qualities of coals, the table on page 398, which gives, approximately, the cost and output of each type of oven, will be found helpful. This table is believed to be approximately correct, but with the varying cost of materials and labor, as well as local conditions, no fixed estimate of the cost of plants of coke ovens should be submitted. The sure method of learning the cost is by direct application to the companies or individuals engaged in the construction of coke-oven plants.

It may also be submitted, in explanation of this table, that the comparative standard of annual production, in marketable coke, has been fixed at 118,800 net tons. This is about the yearly product of two banks of Otto-Hoffman coke ovens of 60 ovens each.

Column (*a*) gives the estimated costs of these coke ovens. Column (*b*) shows the cost, per oven, of the exhaust, condensing, and scrubbing plant. Column (*c*) gives the total cost per oven, including, where used, the by-products-saving plant. Column (*d*) gives the average daily product of marketable coke from each type of coke oven. Column (*e*) gives the number of each kind of oven to produce 118,800 net tons of coke per year. Column (*f*) gives the total cost of each coking plant. Column (*g*) shows the amount of labor and materials to maintain the works in good condition, estimated at 5 per cent. on investment. This charge is designed to afford a fund to make the necessary repairs during the 20 years' life of the plant. Column (*h*) distributes this interest sum over each ton of coke made. Column (*i*) exhibits the proportion of the cost of sinking the whole plant in 20 years. It is estimated that, during this period, 2,376,000 net tons of coke shall have been made. Column (*k*) gives the cost of labor in

TABLE EXHIBITING THE RELATIVE ULTIMATE ECONOMY OF PLANTS OF TYPICAL COKE OVENS, SINKING INVESTMENT IN TWENTY YEARS

Name of Oven	Cost of Oven Dollars	Cost of By-Product Plant Per Oven	Total Cost Per Oven Dollars	Daily Output Per Oven	Number of Ovens to Make 118,800 Net Tons Per Year	Total Cost of Plant Dollars	Maintenance, 5 Per Cent. on the Investment Dollars	Maintenance Per Ton of Coke Dollars	Sinking Plant, 20 Years—Per Ton Coke Dollars	Cost of Making Coke and Saving By-Products Dollars	Total Cost Per Net Ton Dollars	Per Cent. Coke Made	Value of By-Products Per Ton of Coke Dollars	Economy in Saving Coal Dollars	Ultimate Cost of Coke Per Net Ton Dollars	Remarks
	(*a*)	(*b*)	(*c*)	(*d*)	(*e*)	(*f*)	(*g*)	(*h*)	(*i*)	(*k*)	(*l*)	(*m*)	(*n*)	(*o*)	(*p*)	
Beehive	300		300	2.0	198	59,400	2,970	.025	.025	.45	.500	65			.500	Cost of coal not included
Thomas	900		900	3.9	102	91,800	4,590	.039	.039	.45	.528	65			.523	Cost of coal not included
Simon-Carvés .	1,400	1,000	2,400	3.0	132	316,800	15,840	.133	.133	.40	.666	72	.15	.050	.384	Cost of coal not included, saving by-products
Semet-Solvay .	1,800	1,500	3,300	4.0	99	326,700	16,355	.130	.130	.40	.660	72	.20	.132	.388	Cost of coal not included, saving by-products
Semet-Solvay .	2,500	2,000	4,500	5.0	79	355,500	17,775	.150	.150	.38	.680	72	.22	.132	.368	3 high ovens, 30 feet long. 3 high ovens, 30 feet long, saving by-product 4 high ovens, 30 feet long, saving by-products
Semet-Solvay .	3,000	2,000	5,000	6.0	66	330,000	16,500	.140	.140	.38	.660	72	.22	.132	.368	4 high ovens, 35 feet long, saving by-products
Semet-Solvay .	3,300	2,500	5,800	8.0	44	255,200	12,760	.110	.110	.38	.600	72	.22	.132	.368	5 high ovens, 35 feet long, saving by-products
Otto-Hoffman	3,000	2,500	5,500	6.0	66	363,000	18,150	.110	.110	.40	.620	72	.22	.132	.368	Oven 43 feet 6 inches long, saving by-products Work of this oven estimated.—Ed.

NOTE.—In the above table the cost of coke, including the coal to make it, can be determined by adding the cost of coal to the ultimate cost of making coke and saving coal and by-products, as given in column (*p*).

making coke and saving the by-products. Column (*l*) shows the total cost per net ton of coke made; it embraces the costs in columns (*h*), (*i*), and (*k*). Column (*m*) gives the percentage of coke which each type of oven produces. Column (*n*) gives the value of the by-products of tar, ammoniacal liquor or sulphate of ammonia, and gas per ton of coke. This value is considerably under the usual sums estimated for these products. But it is submitted that the value of by-products at the works and in a more or less distant market differs materially. It may also be noted that these products have, in common with all others, their variations in market value. Column (*o*) shows the saving of coal by increased percentage of product. Column (*p*) gives the ultimate cost per net ton of coke produced.

In all the calculations it has been assumed that the best coking coals have been used. No charges have been made for the preparation of coals that require crushing and washing. No patent-right charges have been embraced in these columns. In making the foregoing comparisons, no credit has been given the retort ovens for heat supplied for making steam, or for surplus gas for lighting purposes.

The entire cost of coke made in these ovens can readily be ascertained by taking the percentage of marketable coke produced by each type of oven, as given in column (*m*). For instance, the beehive oven yields 65 per cent. of coke; it will, therefore, require $\frac{100}{65} = 1.538$ tons of coal to make 1 ton of coke. The cost of the coal, delivered at the coke ovens, can readily be learned for any locality. The ultimate cost in column (*p*) added to the cost of the amount of coal to make 1 ton of coke will give the absolute net cost of 1 net ton of coke.

The table on page 400 has been furnished by the United Coke and Gas Company, of New York City.

In the areas of the best coking coals, the horizontal types of coke ovens will probably retain their places of usefulness. The principles involved in the manufacture of metallurgical coke in these ovens are undoubtedly the true ones, concentrating the greatest heat at the crown of the oven and graduating it downwards toward the bottom of the oven. This secures, under the moderate pressure of the charge of coal, the liberty or freedom of the mass to develop cell structure, and secures the deposit of a maximum quantity of carbon from the gases evolved in coking as they pass upwards through the incandescent portion of the charge, glazing it with this deposit of pure carbon.

The manual labor in drawing the round ovens should be removed, as it is exhausting to the workmen and expensive to the manufacturer.

In the determination of the quality of coal for the manufacture of coke, the sure method is to have a sufficient quantity of it coked carefully in one or more selected types of coke ovens. The

BY-PRODUCT COKE OVENS IN THE UNITED STATES AND CANADA IN 1903

Company	Location	Number of Ovens	Use of Coke	Use of Gas
OTTO-HOFFMAN OVENS				
Cambria Steel Co.[1]	Johnstown, Pa.	100	Blast furnace	Fuel
Cambria Steel Co.	Johnstown, Pa.	160	Blast furnace	Fuel
Pittsburg Gas & Coke Co.	Glassport, Pa.	120	Blast furnace and domestic	Illuminating and fuel
New England Gas & Coke Co.	Everett, Mass.	400	Domestic and locomotive	Illuminating
Dominion Iron & Steel Co., Ltd.	Sydney, Cape Breton	400	Blast furnace	Fuel
Hamilton Otto Coke Co.	Hamilton, Ohio	50	Foundry and domestic	Illuminating
Lackawanna Steel Co.	Lebanon, Pa.	232	Blast furnace	Fuel
Lackawanna Steel Co.[2]	Buffalo, N. Y.	564	Blast furnace	Fuel
South Jersey, Gas, Electric & Traction Co.	Camden, N. J.	100	Foundry and domestic	Illuminating
Maryland Steel Co.	Sparrow's Point, Md.	200	Blast furnace	Illuminating and fuel
Michigan Alkali Co.	Wyandotte, Mich.	15	Burning lime	Fuel
Sharon Coke Co.[1]	Sharon, Pa.	212	Blast furnace	Fuel
Zenith Furnace Co.	Duluth, Minn.	50	Blast furnace and foundry	Illuminating
SEMET-SOLVAY OVENS				
Solvay Process Co.	Syracuse, N. Y.	40	Lime kilns	Fuel
Semet-Solvay Co.	Dunbar, Pa.	110	Blast furnace	Fuel
Semet-Solvay Co.	Sharon, Pa.	25	Blast furnace	Fuel
Semet-Solvay Co.	Ensley, Ala.	240	Blast furnace	Fuel
National Tube Co.	Benwood, W. Va.	120	Blast furnace	Fuel
Peoples Heat and Light Co.	Halifax, Nova Scotia	10	Domestic	Illuminating and fuel
Solvay Process Co.	Delray, Mich.	120	Lime kilns	Fuel
Philadelphia Suburban Gas Co.[1]	Chester, Pa.	40	Blast furnace	Illuminating
Central Iron & Steel Co.[1]	Tuscaloosa, Ala.	80	Blast furnace	Fuel
Pennsylvania Steel Co.[1]	Lebanon, Pa.	90	Blast furnace	Fuel
Milwaukee Coal & Gas Co.[1]	Milwaukee, Wis.	80	Blast furnace and foundry	Illuminating
Empire Coke Co.[1]	Geneva, N. Y.	30	Foundry and domestic	Illuminating
NEWTON-CHAMBERS OVENS				
Retort Coke Oven Co.	Pocahontas, Va.	60	Blast furnace	
Cleveland Furnace Co.[1]	Cleveland, Ohio	66	Blast furnace	Illuminating and fuel
Total		3,714		

---

[1] In course of construction.

[2] There has been a dispute as to the type of oven to be installed at this plant. Doctor Rothberg, metallurgical engineer of the Lackawanna Company, and inventor of the Rothberg oven, writes under date of April 19, 1904: "We have here 188 Otto-Hoffman ovens and 282 of my type practically finished, and are starting 470 more of my type. The whole plant will have 940 ovens. The first 470 will be started in about a month."

physical properties of the coke, as well as its calorific value for blast-furnace use, can be accurately ascertained by laboratory tests.

In selecting the type of oven for coking any of the several qualities of coal, it will be well-directed economy to have this work performed under the care of an expert in the manufacture of coke, as not only the type of oven is to be selected as best adapted for coking the coal, but the proper dimensions of the several parts of the oven chosen are to be determined.

Attention is invited to the ingenious plant of Doctor Otto for obtaining the by-products from the beehive type of horizontal ovens. Doctor Terne, in his paper, calls earnest attention to the large waste in the United States of this valuable manure in the manufacture of coke. With the 42,000 of these ovens now in operation, a large field is invitingly opened to inventors to devise a practical plan for saving these by-products and augmenting the oven heat by the returned gas.

The products of Doctor Otto's round oven are shown to be equal to any of the retort ovens, 75 per cent. coke, 1 per cent. ammonia sulphate, and 2½ to 3 per cent. of tar. The cost of this oven has not been given. From its plain construction this cost would be small, as compared with the vertical ovens.

Advisability of Saving By-Products.—An important supplementary consideration for the coke manufacturer is presented in the question, in connection with the use of retort coke ovens, whether it will be profitable to invest the large additional sum required in the conduits and condensing plant for the saving of the by-products of tar and sulphate of ammonia. The approximate cost of the auxiliary plant for saving these by-products is given in the table on page 398.

In approaching this inquiry, it may be submitted that hitherto considerable prejudice has been manifested against the quality of coke made in retort coke ovens, in which the by-products were saved. Sufficient evidence has not been developed in this country to settle this matter by accurate tests in blast-furnace use, but on the continent of Europe it is alleged that at present no discrimination is made by metallurgists against this quality of the retort oven coke, provided that it is made in a careful manner.

There does not appear any evident reason why the exhausting of the gases in coking should deteriorate, in a marked degree, the quality of the coke, but it should on the other side, by increasing its hardness, more than compensate for any loss in the exhaustion of the gases.

Market for Tar and Ammonium Sulphate.—Mr. Wagner, of Darmstadt, has recently shown that ammonium sulphate is superior to Chili saltpeter or guano as a fertilizer in agricultural uses. In the United States, there are approximately 300 millions of acres of land under cultivation. Perhaps one-third of these retain much of the normal richness and will not at present require concentrated manures. It is further assumed that one-third will be manured in the usual way with barnyard and compost manures, and that 50 millions of acres will be manured by native and imported guano, phosphates, nitrates, and ammonium sulphate, leaving 50 millions of acres to be supplied mainly by native ammonium sulphate. This will require 160 pounds of this salt or its equivalent to fertilize 1 acre in an ample manner. For the 50 millions of acres, 4 millions of tons of this manure will be required, but it is not probable that this will be used by the agriculturists for some time to come.

Reducing the probable quantity of this concentrated manure that may be required to 2 millions of tons per year, it will readily appear that the product of ammonium sulphate, during the year 1893, did not greatly exceed 60,000 tons, leaving 1,940,000 tons to be provided for. Should the coke ovens of the United States be changed to save this by-product, from the 10 millions of tons of coke, it would afford 1 million of tons of ammonium sulphate, leaving a deficit of 940,000 tons. The outlook for a market for ammonium sulphate is well assured. It may be noted, however, that in competition with other manures its price will be held at a maximum not greatly exceeding 3 cents per pound.

The chemical works and tar distilleries at Philadelphia, Buffalo, Cleveland, and Chicago are prepared to purchase tar and ammoniacal liquor. These companies usually own and furnish iron tank cars for freighting these liquid products from the coke works to the chemical plants. Some of the companies are prepared to receive the tar during all the months of the year; others require the coke manufacturer to store the tar in great tanks during the winter months.

It becomes an important consideration, in this connection, how far the coke manufacturer should advance these distillates in order to secure the maximum profit from their sale in market. It is evident that tar, as it is condensed from the gases at the coke ovens, can be shipped with the most economy in its crude state, provided that it can be marketed continuously throughout the year. Boiling it to pitch involves extended chemical operations, in securing the utmost economy.

A companion investigation relates as to whether the coke manufacturer will dispose of the ammoniacal liquor, at the strength usually required, 2°, 2.5°, and 2.8° Twaddell, or advance it to ammonium sulphate, either as an agricultural manure or for chemical uses. The latter involves an ammonia-factory addition to the condensing plant, with expert chemical supervision.

If the market or chemical works is not at a great distance from the coke works, it would in most cases conduce to economy to ship the ammoniacal liquor in the moderate strength usually required by the chemical companies. If the market is quite

TABULAR STATEMENT EXHIBITING THE ESTIMATED COST OF THE MANUFACTURE OF AMMONIUM SULPHATE FROM AMMONIACAL LIQUOR

Number	Making 1 Ton of Ammonium Sulphate													Remarks
	Gas Liquor Dollars	Sulphuric Acid, 1 Ton Dollars	Lime Dollars	Coal Dollars	Labor Dollars	Casks and Packing Dollars	Sundry Repairs Dollars	Wear of Plant Dollars	Interest on Plant Dollars	Strength of Liquor	Total Amount Dollars	Value Per Ton Dollars	Profit Per Ton Dollars	
I. . .	12.00	12.50	.90	1.000	3.250	1.253	1.503	.83	.506	4° T.	33.736	55.00	21.273	American
II. . . .	12.00	12.50	.95	1.000	3.500	2.003	1.503	.70	.456	4° T.	34.606	55.00	20.403	American
III	12.00	12.50	.25	1.250	4.740	.813	1.123	.75	.456	6° T.	33.876	55.00	21.133	American
Average	12.00	12.50	.70	1.083	3.823	1.353	1.373	.76	.466	4⅓° T.	34.066	55.00	20.933	American

distant, it becomes a question of the cost of transportation in shipping the liquor or advancing it to the ammonium sulphate. In this latter case it is evident that the manufacture of ammonium sulphate at the coke ovens would be the true economy, as the freight charges on the ammoniacal liquor would be quite large.

It may be noted in this inquiry that it requires 3,520 gallons of 2° Twaddell of the liquor to make 1 net ton of the sulphate of ammonium, composed as follows:

59.410	per cent. SO_3 (sulphuric acid)
25.060	per cent. NH_3 (ammonia)
.018	per cent. Fe_2O_3 (ferric oxide)
15.512	per cent. H_2O (water)
100.000	

About 8 per cent. of ammonia is lost in the manufacture of ammonium sulphate.

It may be noted here that the cost of gas liquor will change with the size of the plant and the quality of the coal used in making coke. Coals with large volumes of volatile matter will usually produce the largest amounts of liquor and gas, which can be sold at reasonable profits, reducing the cost of the coke. The selling price of the salt, ammonium sulphate, fluctuates from $50 to $65 per ton in the city markets.

In the larger coke works, producing by-products, this inquiry broadens in its general aspect, involving two important considerations; first, whether it is more advantageous to supplement the condensing plant with an ammonia factory and tar-boiling plants, or second, to invite some established chemical company to erect at the coke works a chemical plant to receive and treat the crude by-products, advancing them to tar and ammonium sulphate, with resultant distillates, thus economizing the freight expenses in handling these products.

There are some difficulties in establishing an equitable basis for regulating the prices of the crude products. This standard might be founded on the market value of the crude materials, or on their finished products, less the freights in either condition, to the nearest reliable markets.

On the whole, it would appear that a direct reference of the value of these by-products in the crude state, in the tanks at the works, would prove the more practical. The rates to be paid could be determined by their market values, deducting the freight thereto at such stated intervals as would be equitable to the producer and manufacturer.

An experiment has recently been made to utilize benzole in enriching illuminating gas. So far the results appear to be very encouraging. Should this new application prove successful, it would add materially to the revenue of the coke manufacturer, from the tar by-product. It has been found that in tar boiling, about 2 gallons of this distillate can be secured in the making of 1 ton of coke. The benzole is estimated to be worth 13 cents per gallon.

In some portions of the United States and Canada, briqueting coal waste and bog materials has been installed in a small way. Should these industries continue to expand, a large home market would be secured for the tar products of the retort coke ovens. Tar is also coming into a liberal use in the manufacture of roofing materials.

CHAPTER XI

THE FUEL BRIQUETING INDUSTRY

In Europe, during the past quarter of a century, the briqueting industry has been developed until at present it has impressed its importance among the world's industries. In this manufacture, the lower qualities of combustible fuels are utilized, placing them in compact forms for manufacturing, marine, railroad, and domestic uses. The expansion of this industry, with its increasing value in economizing waste products, has been brought into notice in the United States mainly through the agencies of the consular service. The combustible elements used in this manufacture consist of slack coal or screenings, anthracite culm or dust, coke breeze, lignite coal, charcoal dust, bog turf, carboniferous mud, and petroleum. The manufacture consists in pulverizing these elementary materials and then mixing them thoroughly with the necessary bonding matter, consisting chiefly of coal tar or pitch; the composition is then pressed into several shapes to meet the consumer's needs.

Evidently, this industry is in its most advanced condition in countries inheriting large areas of inferior qualities of coals, or with broad localities of peat bogs, and where fuel is high priced. It has also been largely developed in the countries in which retort coke ovens are in large use, producing coal tar as one of the chief by-products, which can be used in its crude state or boiled to pitch, thus contributing the important bonding material in the manufacture of briquets. It may be noted, in this connection, that in most of these countries producing briquets, the price of good coal, especially for domestic use, is nearly prohibitory, ranging from $3 to $20 per ton. To insure a market for the briquet products, the price must be considerably under that of good coal in the several countries in which briqueting has been established.

At this time Germany is the largest producer of briquets, and with the development of this industry there have been invented many varieties of briqueting machines. France, Belgium, Austria-Hungary, Netherlands, Norway, and Great Britain have also taken up this manufacture with much energy and have made hopeful progress. These examples of the economy of utilizing the less valuable fuels in briquets are extending the industry to other countries, especially to those having large deposits of the raw materials suitable for the manufacture of briquets. In 1882, 4,000,000 metric tons of briquets were produced; it is now estimated that nearly 25,000,000 tons are produced, or almost 3 per cent. of the total product of coal and lignite.

Fuel briqueting has for its aim the accomplishment of the following objects: (1) the utilization of the fine material unavoidably made in the mining and handling of coal; (2) the creation of a good hard fuel to burn practically without smoke or odor; (3) the concentration of the greatest number of heat units into the smallest space practicable, by cleaning and compressing material of inferior heating value.

In the mining of coal, a large proportion of the output of a mine is often necessarily dust, slack, or culm, of which a certain amount is wasted. In the case of coking coals, the slack is generally charged into ovens, but anthracite dust is usually wasted.

To appreciate the advantage of using fuels that burn without smoke or odor, one should contrast some American cities with those of Germany. The dense trailing clouds of smoke from mill and factory chimneys, which are so familiar a sight in Pittsburg and other cities in the United States extensively burning raw coals rich in bitumen, are said to be rarely seen in those sections of Germany in which briquets are largely used. In this latter country, the indiscriminate shoveling of raw bituminous coal into steam and other furnaces is considered an ignorant and wasteful proceeding.

The third object—that of obtaining concentrated fuel—is one not to be overlooked when fuel is to be transported long distances before it is used, and also when storage room is limited. Many coals require washing to remove impurities before coking, and a similar process is sometimes advantageously employed in briqueting processes to clean the material used.

The characteristics desirable in fuel briquets are enumerated in the following specifications issued by the French Navy and the Belgian State Railway: (1) the briquet must be hard, homogeneous in density and size, only very slightly hygroscopic, and should burn almost without smoke or odor; (2) the dust and breakage caused by handling and transportation should not exceed 5 per cent.; (3) the specific gravity should not be less than 1.19; (4) the briquet should ignite readily, burn with a cheerful flame, and retain its shape until completely burned; (5) the ash should not exceed 9 per cent. and the evaporation results should at least equal those of the best lump coal, from the screenings and dust of which the briquet was made.

Briquets are made in various sizes and shapes, some of which are shown in Fig. 1. The large briquets in the background are for factory, marine, and locomotive use, and are broken before being fired, while the others are used whole; the scale gives an idea of their dimensions. The Zeitz and the briquets between them are for factory, and the smaller ones in the foreground for domestic, use. They are made in sizes ranging from over 20 pounds each to a size that takes several to make a pound. Industrial briquets are usually of a square or oblong form, convenient to be closely packed or built up into a pile like bricks. They are generally loaded on cars for transportation, packed closely, and are similarly stored around works, particularly when intended to be kept for a time, or when large storage capacity is not available. In connection with the storage of briquets, it is of importance to note that there is practically no danger from spontaneous combustion, as is sometimes the case with run-of-mine bituminous and other coals when stored. Each briquet generally bears the initials or trade mark of the company by which it is produced, so that in case of any defect in quality the inferior briquet can be readily traced to its source of production. When burned whole, they usually are consumed slowly and give out a steady, moderate heat for a long time; when it is desired to quicken or intensify the flame, they are broken up, and in this condition are especially adapted to flue or tubular boilers, sugar evaporating, smelting and annealing furnaces, in glass manufacture, or in porcelain and cement factories—wherever, in fact, a fuel capable of producing a long, fierce flame is desirable.


MINES AND MINERALS.

FIG. 1. BRIQUETS OF DIFFERENT FORMS

Mr. Robert Schorr states, in a paper on Fuel and Mineral Briqueting, read before the American Institute of Mining Engineers, that "of the many shapes used, the prismatic shape with rounded edges is, as a rule, the most popular. Heavy blocks allow of a large output with a comparatively small investment, and they are very convenient for storage. However, they have the disadvantage of large, smooth surfaces, and unless broken up prior to being fed into a furnace they are apt to smother the fire and choke the draft, a circumstance that is nearly always the case with a poor grade of coal or one that has been too finely ground. To facilitate the breaking up of the large blocks, channels are pressed into the bricks, or they are perforated in one operation while being formed in the press. This construction offers the advantage of a better air circulation. The manufacture of tubular, or polygonal, briquets is very limited.

The French Navy estimates 820 kilograms of fuel blocks per cubic meter of bunker capacity (more than 51 pounds per cubic foot), i. e., 10 per cent. more as compared with the storage of lump coal. The losses in dust seldom exceed 4 per cent., while the best Welsh coal averages about 30 per cent., and in stormy weather nearly 50 per cent., dust, which reduces the stored heating capacity very considerably. Railroad transportation, even for long distances, causes generally not more than 3 per cent. of dust. Cylindrical, ball, and egg-shaped briquets give still less dust and breakage, but they are wasteful in space. Their shape insures a good air circulation and consequently a complete combustion.

The specific gravity of briquets varies with the material and pressure employed, and is usually as high as that of the fuel from which they have been made, i. e., from 1.1 to 1.4.

COMPOSITION OF BRIQUETS

Briquets may be made of any of the following materials: coal slack, screenings, or dust; anthracite screenings or culm; coke breeze or small coke; lignite coal; charcoal; peat or turf; carboniferous mud; petroleum.

Coal-Slack, Screenings, or Dust Briquets.—Among the principal carboniferous materials used in the manufacture of briquet fuels are coal slack, screenings, and dust. Mr. Schorr states that "the size and cleanness of the fuel are important items. The grains should not be larger than $\frac{1}{4}$ inch and not less than $\frac{3}{32}$ inch in size to make a good-burning briquet. If the coal is ground too fine it will make a very handsome-looking briquet, but it will not ignite as readily and it takes a strong draft to burn it successfully. The ash content should not exceed 6 per cent. If greater than this amount, the coal should be washed by water or treated in a pneumatic separator in order to remove the excess of ash. If presses with solid resistance are used, the raw material must be of a commercial dryness, but in open-mold presses a large amount of moisture may be present."

Slack from coals rich in bitumen will work into briquets with an addition of 2 or 3 per cent. of pitch, while leaner grades may require 6 to 8 or even 10 per cent.; the last proportion is sufficient at times, when the cost of pitch is high, to render such coal unprofitable for briquet purposes. Briquets made from bituminous slack, although not smokeless, are more nearly so than ordinary bituminous coal. When burned in locomotives or any well-constructed boiler or other furnace with a good draft, they create only a thin translucent mist that contains relatively little soot, and is very different from the inky clouds that roll up from many factory chimneys where soft coal is shoveled indiscriminately into the furnaces. The one notable defect of such briquets is that the mineral pitch, which is used as a binder, contains more or less creosote; this renders dust and fumes from such fuel acrid and sometimes irritating to the skin when confined in a close, hot boiler room.

In the manufacture of briquets from coal slack, screenings, or dust, the material is reduced by a disintegrator to fine particles when necessary. The binder is then added, and when pitch is used as a bonding material the mixture is ready for the heater. The most common way of mixing is the dry method, by which the pitch is ground up and added to the coal in a dry state. The combined mass of coal and pitch is then placed in a heater in which the pitch is melted; in some instances, the heater is a drying apparatus as well, removing any water that may be in the coal. After treatment in this machine the hot mass passes to the presses, where it is rapidly pressed into the form of briquets.

Anthracite-Screenings, or Culm, Briquets.—Anthracite screenings, or culm, has been used in the manufacture of briquets. In some cases, a slight mixture of bituminous slack coal is added to reenforce the bonding pitch. Owing to the cost of the binder and the comparative cheapness of the coal, anthracite briquets have never been a commercial success to any great extent. At such points as Chicago, where anthracite is transferred from boats to railroad cars, or at seaboard towns where large amounts are handled and much fine coal made, this fine material is sometimes briqueted for local use.

Coke-Breeze, or Small-Coke, Briquets.—In the manufacture of coke in beehive coke ovens, about 2 to 3 per cent. of small coke or breeze is produced. This is reduced to very small sizes or dust and mixed with pitch or tar in the usual way. Necessarily this coke breeze must be washed to be freed from the ash or slate associated with it, which often amounts to 20 or 30 per cent. The manufacture of these coke briquets is very trying to the machinery, as the powder is very sharp, wearing away the metal of the grinding and mixing machinery very rapidly. In all countries in which the coke-making industry is large, an inviting opening is presented for the utilization of this coke waste in the manufacture of coke briquets. The briquets made from coke dust are especially desirable for domestic uses, as they are almost smokeless.

Lignite Briquets.—Lignite, or brown coal, is a very important element in the manufacture of briquets. It varies in its value and adaptability for briqueting purposes according to its geologic age, hardness, and the percentage of water that it contains. A lignite with less than 30 per cent. of water is very difficult to work by the usual processes. The amount of moisture in lignite fuel forms the key to the whole economic briqueting process. The crude brown coal is brought from the mine, crushed and pulverized, and then dried and heated with the proper temperature to develop the latent bitumen in the lignite and make the powdered mass plastic and easy to mold, under heavy pressure between heated iron jaws, into a hard, clean briquet, with a glistening surface and sufficient firmness of structure to stand weather, transportation, and other contingencies. To do this perfectly and economically, the natural lignite should contain, as it comes from the mine, approximately enough moisture so that heating to the proper temperature for pressing will evaporate out just sufficient water to leave it at the proper degree of moisture. The ideal proportion is about 45 per cent. of water. Considerable interest attaches to lignite as a briqueting proposition in the different countries, as it is an inferior fuel direct from the mine, on account of its tendency to rapidly disintegrate on exposure to the air.

Charcoal Briquets.—In the countries in which much charcoal is produced, the dust made in its manufacture and handling affords a most excellent and pure material for the manufacture of briquets. The usual mode of preparation is quite economical, and the binding material is mixed with the charcoal dust in the usual way. These charcoal briquets afford the purest quality of fuel and are especially adapted for supplying heat in the manufacture of iron and steel.

Peat, or Turf, Briquets.—The bogs in which peat is contained cover extensive areas in the northern temperate latitudes, both in Europe and America. In Germany, they cover nearly 11,583 square miles, and in Ireland, according to Snell, they cover the tenth part of the country. The depth is very variable, but is, on an average, 5.4 to 7.6 yards; in Ireland, bogs are found with a depth as great as 16.3 yards. It may be estimated that 1 square mile (2.59 square kilometers) 5.4 yards deep will give about 1,813,000 metric tons of dried peat; hence, it will be seen that the amount of fuel in those bogs is enormous. Peat is organic matter formed from mosses and other minor plants that have been submerged in water and are thus preserved in the bogs.

As a material for fuel, peat ranks next in the natural order below lignite, in that it is of similar, but much more recent, geological order, contains more water, is but slightly carbonized, and has a correspondingly lower thermal value than lignite, or brown coal. The task of converting peat into serviceable fuel consists of cleaning the material of roots and rubbish, reducing the water to a smaller percentage, and condensing the peat in volume so that its thermal value shall be raised to practical efficiency. This is done by various methods, which may be grouped under three heads, according to the form that the ultimate product is to assume: first, compressed peat, with or without the admixture of coal dust or of inflammable matter; second, peat coke; and third, briquets made by compression, with or without heat, of the material prepared by the first process.

Peat cut from the bog has been used for centuries and in the ordinary process of drying the material is cut into cubes and laid in the air, where most of the water held between the fibers soon leaches out by gravity or evaporation. Machine peat, which is the compacter and better article, has come into use within recent times. Two principal systems are distinguished in making machine peat, depending on the treatment of the raw material immediately upon raising it from the bog. One plan is to digest the peat with the addition of water into a liquid mud, which is then poured into molds in the open air and, after losing some of its water, divided into blocks and allowed to dry. The other and more commonly employed process consists of grinding or mincing the peat as it comes from the bog into a soft, plastic mass, which is then made into bricks and dried. This grinding of the peat is to better prepare the fibers to give up their liquid contents.

One of the important improvements of recent years has been attained by mixing the peat pulp as it passes through the grinding machine, with other inflammable materials; such as, bituminous coal dust, or slack, up to 30 per cent.; anthracite culm, to 40 per cent.; or dry sawdust, to 15 per cent. These dry pulverized materials, when mingled with the wet peat, not only greatly enhance its subsequent value as fuel, but facilitate the drying process and render it tough, dense, elastic, and capable of being pressed cold into briquets of high quality. But by far the most modern, scientific, and rational method of utilizing peat appears to be that of converting it into coke by carbonization in retort ovens, with recovery of the gas, tar, and other by-products of distillation. One method of coking peat consists in carbonizing the peat in closed ovens heated by burning the gases generated by the coking process itself. Another method makes use of the electric current to carbonize the peat. Comparatively recently, several processes by which artificial coal or briquets have been made successfully from peat by the application of machinery have been patented, but have not yet been fully established on an industrial basis.

Carboniferous-Mud Briquets.—Carboniferous mud is a lower vegetable deposit than peat or turf. In some instances, it is derived from the refuse of the turf industry; at other localities, along the estuaries of lakes and rivers, these black-mud accumulations are found. They are composed mainly of vegetable matter, rotted principally under water and mixed with various percentages of earthy matters. The black mud requires very little preparation for its manufacture into briquets; the most important consists in drying the briquets after leaving the press. The manufacture of fuel on a large scale from the black mud of grass meadows is an important industry in several countries of Europe, notably in Holland and Russia; mud briquets are also reported as being made on a commercial scale in the United States.

Petroleum Briquets.—Petroleum briquets have been manufactured in various ways in different countries, notably in Russia, France, and the United States, as a fuel for steamships and certain industries where rapid production of heat is desirable. The advantages of such a substitute for coal are readily apparent—less storage room, complete combustion, etc. It is somewhat surprising that petroleum has not been more generally utilized in this form. The objections were that the briquets were said to injure the boilers after a short time, by reason of some chemical action produced in combustion; further, the blocks did not keep their form under the action of the heat, but fell through the firebox in a liquid state; and the price is stated to be two-thirds more than that of coal. A company is said to have been formed for the manufacture of petroleum briquets, which claims to have obviated all the objections except that in regard to price. Petroleum briquets can be used for any kind of domestic or industrial work without changing the furnaces.

Binders.—Bonding material is used to cement the small particles of fuel employed in making briquets except such as contain the necessary bituminous matter, such as lignite, peat, carboniferous mud, and petroleum. The greater the amount of bituminous matter, the smaller is the quantity of binder employed. The most common binder used is pitch in its various forms, the pitch being a by-product in gas and coke making, and to a limited extent from furnace gases in ironworks that use raw coal as a fuel. Hard pitch is of foremost importance in this connection, and when of a good quality should contain 75 to 80 per cent. of carbon and only .25 to .5 per cent. of ash. The addition of from 5 to 10 per cent. of pitch as a binder improves the heating value of fuel from 2 to 4 per cent., depending on the number of heat units possessed by the raw material. Tar and soft-pitch binders have many disadvantages that do not apply, to the same extent, to hard pitch. The presence of the light and heavy volatile hydrocarbons in the former creates smoke and smell when this binder is used in briquets; also, the point of distillation of soft pitch is about 400° F., while that of hard pitch approximates

800° F. Thus briquets made with soft pitch have to be kept cool or they will soften and, by sticking together, form large lumps. It has been stated that the briqueting of slack and fine coal in Germany is practically limited by the amount of pitch obtainable from the by-product coke ovens.

Among the other organic binders, the most important are starch paste and sugar molasses; but these, and a few others of this class, have not as yet attained more than local importance.

The use of inorganic binders is to be avoided wherever organic binders may be had at reasonable cost. The most important inorganic binder is magnesia cement, which is both cheap and abundant. The use of 5 per cent. of this material is said to produce a stronger briquet than that made by any other binder; when 5 per cent. of this binder is used, the quantity of ash added amounts to but 2.5 per cent. Mr. Schorr says "the process of using magnesia cement is very cheap, as no drying is required and the only fuel expended is that for power. The briquets harden gradually at the ordinary temperature, and after from 6 to 10 hours are strong enough to be stored or handled; in a few days they are capable of standing a pressure of from 7,000 to 22,000 pounds per square inch. Wherever good hard-pitch briquets are in the market, it will be difficult for a magnesia-cement briquet to compete with it on account of the higher ash content of the latter.

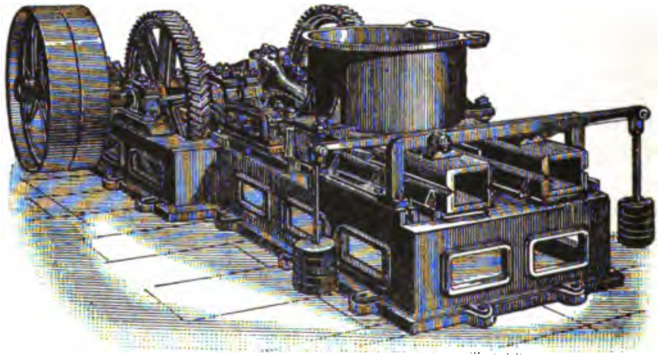


Fig. 2. Open-Mold Press

One hears and reads from time to time of a new matrix or binder that will cheapen the cost of coal briquets, facilitate their manufacture, and improve their quality; but these accounts usually are founded rather on the claims of inventors and promoters than on demonstrated industrial results.

Presses.—To obtain a solid briquet, it should be of uniform density, which can only be effected by using a high pressure and by keeping a proper ratio of the cross-sectional area of the briquet to its height. If the pressing is done against a solid resistance, and from one side only, a comparatively higher pressure must be exerted; and even then the density in various layers will differ. The larger the briquet, the higher should be the pressure per square inch. The depth of the briquet has an important bearing on the character of the briquet produced; even the largest and heaviest fuel blocks should not exceed 5 inches in depth.

There are two general types of presses in use: the press with open mold and the press with closed mold. The open-mold press, Fig. 2, is extensively used for lignite and peat; it works well with washed coals containing up to 20 per cent. of water and gives a big production. Its construction is simple and solid, and it is easy to work. It has for its elements a pipe or tube whose cross-section is, in shape and size, that of the face of the briquet, and a piston that fits one end of the pipe or mold, the other end being open. When a sufficient amount of "paste," or briqueting material, falls into the mold, the piston moves forward and forms a briquet; when the piston recedes, new material drops from a hopper into the space between the piston and the previous briquet pressed; then the piston moves forward again, pressing a new briquet and at the same time forcing a finished briquet from the open end of the mold, thus forming a continuously moving column. The pressure exerted by the piston in this type of press need not be very great, being dependent on the friction of the completed briquets

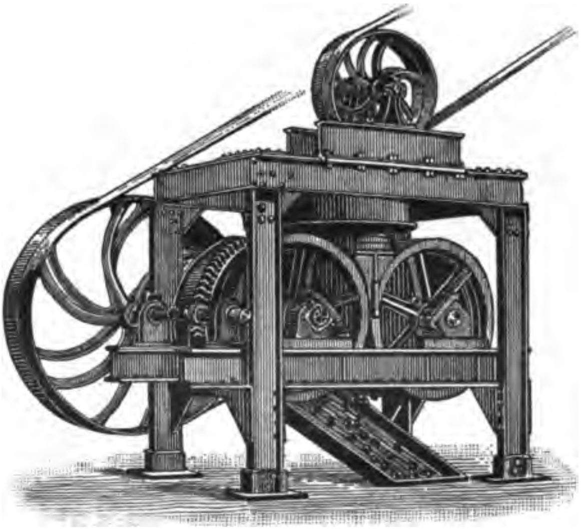


FIG. 3. CLOSED-MOLD PRESS

against the walls of the mold and the length of the mold. To increase the pressure, the mold is sometimes tapered from the piston to the open end. Notwithstanding the difficulty of securing a desirable pressure in this type of mold, it is the one most in use, having the counterbalancing advantage of rapid production of briquets, which the closed-mold method lacks. It is very wasteful in the consumption of power. Open-mold machines are generally fitted up in pairs on the Bourriez continual-motion system.

The closed-mold, or solid-resistance, presses, Figs. 3 and 4, are divided into two classes; tangential presses and plunger presses. The tangential type comprises a mechanism that consists of wheels working against each other, and carrying molds, or molds and corresponding teeth, on their peripheries. The action of this press is continuous and permits a large number of small briquets to be made in a short time. However, the briquets are apt to be poorly and unevenly pressed, and the waste of material and the wear upon the machine is very high, while from 9 to 10 per cent. of binder is required. This press makes the familiar egg-shaped briquets suitable for domestic use, but generally too expensive for industrial purposes.

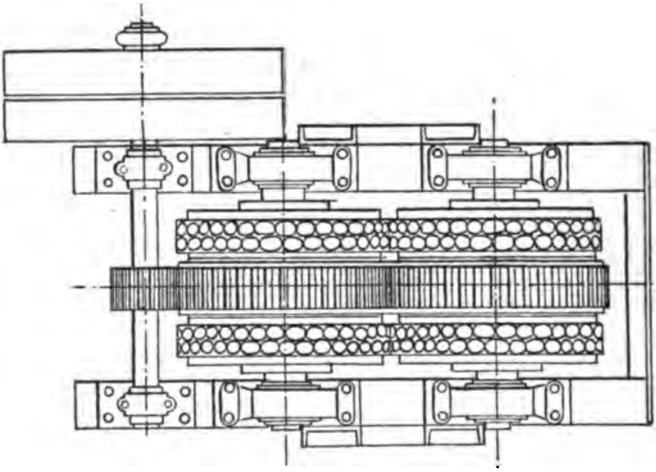


FIG. 4. PLAN OF CLOSED-MOLD PRESS

The more important class of the closed-mold type is the plunger press. In this machine, molds filled with the paste, or briqueting material, by a distributor, pass under an arrangement that exerts pressure on one or both sides of the briquet, which is afterwards ejected automatically. A large number of these presses are in operation making briquets of all sizes.

METHODS AND COSTS OF MANUFACTURING BRIQUETS

Having considered the general character and the various kinds of briquets, we will now take up the methods and costs of manufacturing briquets in the principal countries manufacturing this form of fuel. Much of the information relative to the briquet industry on the continent of Europe and in England is taken from the reports of the United States Consuls stationed in these countries.

Briqueting in Austria-Hungary.—While the manufacture of the briqueted fuel in Austria-Hungary is of comparatively recent origin, it has had so rapid a growth that it bids fair soon to be classed among the important industries of the country. Its remarkable development is attributed to two causes, viz., the comparatively high price of fuel in some parts of the monarchy and the great abundance of waste or inferior coal in others.

Until quite recently, briquets have constituted only a comparatively insignificant item in the household economy of the inhabitants of Vienna. During 1902, however, various enterprising firms, chiefly German, took energetic steps to popularize the article, and their efforts have, to a certain extent, been successful. Trieste has one briquet factory that turns out about 5,000 tons of fuel annually.

The principal ingredient of the briqueted fuels manufactured in Austria-Hungary is coal dust or screenings. In Bohemia, coal is mined in large quantities, and briquets are chiefly made of the refuse of the coal. In the greater portion of Hungary, bituminous coal is employed in the manufacturing plants, while in Styria and Bosnia, lignite is utilized. In Croatia-Slavonia, as well as in Carinthia and some other parts where large quantities of charcoal are produced, charcoal dust has of late also been used in the manufacture of "patent fuel."

The cost of manufacturing varies greatly, according to the location of the plant and the kind of material used. Bituminous screenings are, of course, cheaper than anthracite, and the price of crude labor varies in the different portions of the monarchy from 30 cents to $1 and even more a day. The briquets made in Trieste are of the charcoal variety and are produced at a cost of about $10 per ton. The cost of manufacture of lignite briquets in the province of Styria is said not to exceed $4 per ton. The selling price of lignite and bituminous briquets ranges from $4.50 to $6.50 per ton, while the charcoal briquets manufactured at Trieste sell at $12 per ton. The prices of other fuel for domestic use are as follows: beech wood, $2 per cubic meter, or about $7 per cord; bituminous coal, from $3 to $6 per ton, according to quality; gas coke, $10 per ton; charcoal, $12 per ton. Nearly all the methods of manufacture are of German origin, and Germany still supplies many of the machines used.

The charcoal briquets manufactured in Trieste are made in the following manner: The charcoal screenings are first ground fine, after which coal tar is added, and the mixture stirred until it has the proper consistency for pressing. The latter is then molded into egg-shaped pieces weighing, in a dry condition, from 2 to 3 ounces. These pieces are dried in kilns and in the open air.

Substantially the same process is employed in the manufacture of lignite and bituminous briquets. Lignite, however, owing to its low heating power, is seldom used without the addition of from 20 to 30 per cent. of anthracite or bituminous coal. This mixture of coal is likewise ground fine, and about 10 per cent. of pitch added. The composition, after having been thoroughly blended and partially dried in a kiln having a temperature of from 158° to 176° F., is pressed into bricks weighing about 10 pounds each. The product is then ready for the market.

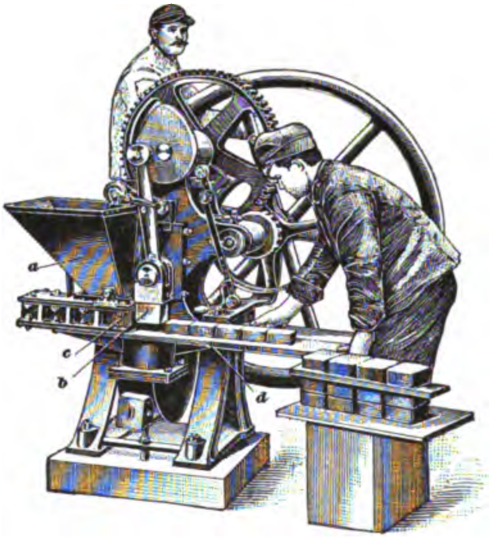


Fig. 5. The Weisner Briquet Machine

Formerly, pitch was universally used as a bonding material, but its present high price has led many manufacturers to substitute for it a composition of milk of lime, tar, and "Weisner's patent bonding material" (a solution of sulphuret of lime with free sulphurous acid, resinous substances, and lignite).

The average daily capacity of the Trieste plant, which employs from twenty to thirty men, is from 20 to 30 tons.

Edward Weisner and brother, of Vienna, manufacture a hand-power machine, Fig. 5. It works as follows: The funnel or hopper *a* is filled with the composition to be pressed into briquets.

A turn of the flywheel causes the plunger *b* to rise. The sliding apparatus *c*, which in the meantime has been filled from the hopper, then passes over the mold and pours its contents into it. Another turn of the wheel brings the sliding apparatus back under the funnel to be again filled. In the meantime the plunger enters into the mold and sufficiently compresses the contents to form the briquet. The plunger and the bottom of the mold then rise simultaneously until the latter is in line with the base of the sliding apparatus and the pallet placed on the discharging table *d*. While the plunger continues to rise, the sliding apparatus, filled with material, moves over the mold, thereby pushing the finished briquet on the pallet and at the same time discharging its contents into the mold, whose moving bottom has in the meantime again dropped down.

The heating value of the various kinds of coal briquets manufactured in Austria is stated to be as given in the following table:

Kind	Calories
Anthracite	5,000 to 6,000
Bituminous	3,500 to 4,000
Lignite	3,000
Charcoal	7,000 to 8,000

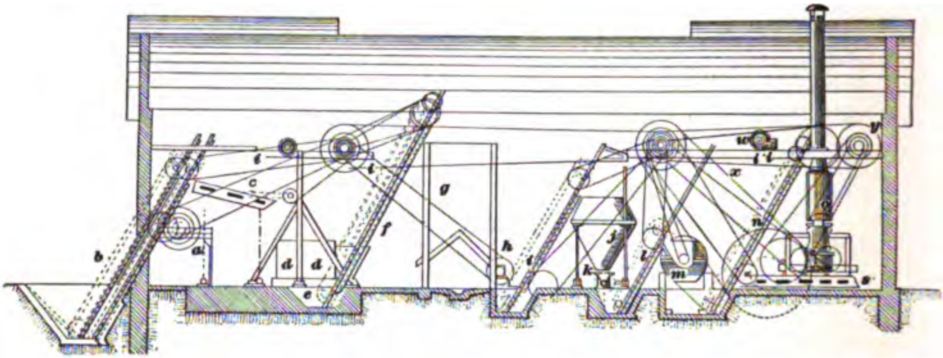
Briqueting in Belgium.—The latest available official statistics concerning briqueted fuel in Belgium cover the year 1901. They show that there were at that time thirty plants engaged in the manufacture of various kinds of briquets, distributed as follows: Twenty-seven plants in the province of Hainaut, with a total of sixty presses and employing 1,237 workmen, and three plants in the province of Namur, with ten presses and employing 83 workmen.

The amount of coal consumed in the province of Hainaut was 1,130,460 tons, from which was produced 1,236,450 tons of briquets, valued at $4,608,068, or $3.726 (19.31 francs per ton). The following tabulated statement shows the annual production and the average price per ton of briquets in the province of Hainaut during the last 5 years.

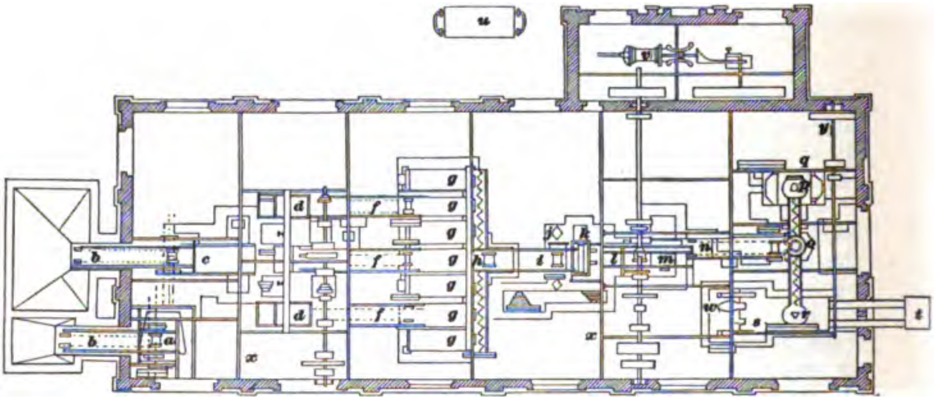
Year	Production Tons	Average Price Per Ton
1897	1,030,330	$2.413
1898	1,119,180	2.586
1899	1,023,290	3.128
1900	1,091,150	4.599
1901	1,236,450	3.726

The three plants in the province of Namur make coal and pitch briquets, and during the year 1901 consumed 94,790 tons of coal in the production of 105,870 tons of briquets, valued at $383,915.25 or $3.626 per ton.

Materials from which briquets are made in Belgium vary according to the use for which the fuel is destined. When manufactured for railroad consumption, generators, power plants, etc., about 90 per cent. of bituminous coal is used, to which is added mineral pitch or coal tar. The mixture varies according to the nature af the coal employed, whether ruddy, close, or half free-burning



(*a*) Elevation



(*b*) Plan

Fig. 6. Machine for Sorting, Washing, and Making Briquetted Fuel

a, separating drum; *b*, endless-chain bucket; *c*, oscillating table; *d*, coal-washing tubs; *e*, tank (or absorbing well); *f*, bucket chains; *g*, drain pipes; *h*, forcing screw; *i*, bucket chain; *j*, recipient; *k*, proportional distributor of pitch and coal; *l*, bucket chain; *m*, Carr grinder; *n*, bucket chain; *o*, pug mill and distributor; *p*, *r*, distributors; *q*, *s*, briquet presses; *t*, cutting table; *u*, steam heater; *v*, steam engine; *w*, ventilator; *x*, beams and columns; *y*, general transmission.

coal. The paste contains from 13 to 14 per cent. of water. When intended for domestic use, about 30 per cent. of clay or marl is added. Briquets of an inferior quality are made from a mixture of sawdust, tannery and brewery residue, peat, turf, and lignite.

A plant for separating, washing, and making coal briquets is illustrated in Fig. 6. This plant can work up 500 tons of coal into briquets in 10 hours, and costs 8,000 francs ($1,544). The work is divided as follows: (1) to sort 300 tons of coal; (2) to wash 150 tons; (3) to make 120 to 150 tons of briquets weighing 11 pounds each, and 50 tons of ovoid balls weighing 5.289 ounces each.

The coal first passes through the separating drum *a*, which separates it into three classes, 70–40 millimeters, 40–25 millimeters, and 25–0 millimeters. The 70–40 and 40–25 sizes are put aside for sale. The 25–0 size is passed into the tank by means of the endless-chain buckets *b*, from which it passes into the shaking screen *c*, which separates it again into three classes. The first two classes are carried to the washing tank *d*; after washing, they are carried to tank *e*, by the endless-chain buckets *f*, which then hoists them to the draining tower *g*. The third class is also elevated by a movable bucket to a storing tower. A screen conveyer *h*, working at the foot of the towers, removes the washed coal, when sufficiently drained, from either tower and permits the reclassing of the three kinds of coal. It is evident that the arrangement permits the manufacture, according to the requirements of the purchaser, of three sorts, unwashed, mixed, or thoroughly washed. The coal is then carried into the tank of the endless-chain buckets *i* that hoist it into the tank. Under this tank is the proportional distributor of pitch and coal *k* in which the exact division of pitch and coal is made. The mixture is then carried to the Carr pug mill *m* by an endless-chain bucket *l*. The Carr pug mill is considered to be a perfect mixing machine and at the same time an excellent grinding machine. An endless-chain bucket *n* then hoists the material to the mixing machine *o*, where it is transformed, by the action ot steam, into a cohesive paste, which runs through two openings placed on the right and left side of the pug mill. Two screw conveyers specially disposed for cooling the paste take it to distributor *p* of the press *q* on one side and to distributor *r* of the briquet press *s* on the other. The briquets, as they issue from the molds, are taken to the cutting table *t* by means of two irons and separated by hand and then are stored or delivered.

The average capacity, per day, of plants depends entirely on the number of machines in use. In some plants, not more than 6,500 briquets are made per day of 10 hours; while in more elaborately equipped establishments, 30,000 briquets are turned out in the same number of hours.

The following table shows hands required and wages paid per day to work an ordinary briquet machine:

For Labor, Materials, Etc.	Cost
One foreman operating machine	$ .965
One stoker	.868
One overseer	.772
Two mixers, each 3.50 francs	1.351
Two carriers, each 3.50 francs	1.351
Three boys for loading briquets on wagons or cars, each 2 francs	1.158
One boy for washing and crushing resin	.386
Total	6.851
Oils, packings, etc.	1.061
Fuel, 900 kilos at 20 francs per ton	3.474
Total	4.535
Washed coal dust, 25.3 tons at 8.12 francs	39.647
Pitch resin (7 per cent.), 1,957 kilos at 75.75 francs	28.596
Tar (25 per cent.), 699 kilos at 60 francs	8.096
Total	76.339
Grand total	87.725

Plants are usually equipped as follows: steam generators; one motor machine; one coal crusher (in some cases useless) or drier; one resin crusher or boiler for melting resin; resin and coal measure for measuring mixture; heating and mixing machine; mixing machine; occasionally an endless cloth for cooling, transporting, and loading the briquets.

The estimated cost of manufacture, including raw material, labor, and interest on money invested, is about $3.281 (17 francs) per ton, divided as follows: coal, $1.64; tar, pitch, or resin, $1.25; labor and interest on money invested in plant, $.386. The average selling price for good quality briquets varies, according to conditions of contract and destination, from $3.474 (18 francs) to $3.86 (20 francs) per ton.

Briqueting in France.—Fuel briquets have been used in France for the past 50 years, and the briquet has acquired an importance in French markets from which it is unlikely to be dislodged so long as coal retains its supremacy as a generator of steam. The product of the French mines is friable and inferior to the high-grade British and American fuels, and until the briquet was perfected, a large percentage of the output of the mines represented a total loss. The manufactured fuel permits what was once largely refuse to be sold at prices running fairly even with the prices of the choicest coal taken out of the domestic mines. The French government requires the railways of the country to maintain a stock equal to their requirements for 3 months, and this reserve usually consists of briquets. On railroad locomotives and in marine service, briquets are preferred to coal, as their heat is more reliable, which enables closer calculations to be made as to the amount of steam that can be obtained from a given weight of fuel.

While the briquet is destined to continue an important factor in the French coal trade, the cost of manufacture is so great that of recent years every endeavor has been made by the railway companies and the manufacturers of boilers to devise some method of burning the low-grade fuel direct, and with a considerable degree of success. The Belgian railway companies were the first to adopt a definite scheme and, as far back as 1895, began to make use of coal dust, which did not cost over $1.15 (6 francs) per ton. In France, The Company of the East first took up the matter and is now burning washed small coal which is very pure, but which, nevertheless, may be bought at a far lower price than run-of-mine coal or briqueted fuel. The Paris, Lyons, and Mediterranean Railway Company, which has for years burned briqueted fuel exclusively, and owns three large factories for the treatment of the small coal mined along its system, has followed suit with considerable success. In the burning of fine coal direct, the fireman is obliged to exercise much greater care, and the grate bars must be closer together. Without changing the firebox and by using a combination fuel, the Paris, Lyons, and Mediterranean Company has succeeded in securing the same power per hour and per square yard of grate surface as was formerly obtained with high-grade fuel alone. In accomplishing this result, both of the French companies employ coal of rich quality that tends to conglomerate in the fire. These methods have been adopted by the Paris, Lyons, and Mediterranean Railway for the movement of freight, but not yet for the movement of fast passenger trains.

For general industrial purposes, two systems of burning extremely fine coal are now recognized as practicable. One of these involves the feeding of the coal from a hopper upon a moving grate. The second system requires the construction within the furnace, of a series of narrow shelves on which the coal rests, the grate bars being erected vertically. These great economies are not possible upon shipboard, and, granting their complete success, still leave the briquet supreme as a means of making the French fine coal available for navigation and for general domestic purposes. Being dearer than coal, briquets are, according to one authority, seldom used in manufacturing establishments. The amount of briqueted fuel consumed in France in 1902 was probably over 2,000,000 tons, and its use is increasing.

The principal binder used is pitch. The price of this pitch, most of which is imported from Great Britain, rises and falls in sympathy with that of coal. The highest quoted price since 1873 was $11.58 per ton in 1900, and it was as low as $1.79 in 1888.

All qualities of coal are susceptible of being conglomerated; but in France, the half-bituminous quality of fuel, of from 13 to 17 per cent. volatile matter, is particularly employed. The fine coal of this grade coheres with difficulty when employed directly and becomes much more valuable when manufactured. Certain coals in the Franco-Belgian basin, containing not more than 12 to 14 per cent. of volatile matter, also make good briquets if employed with from 9 to 10 per cent. of dry pitch. When the quality of the coal is so low as to contain not more than 10 per cent. of volatile matter, the resulting briquets burn slowly and with difficulty. The lignites are slow to conglomerate alone, but mixed with other combustibles yield a good product. At the factory near Marseilles, the half-rich anthracite of the Department of Gard, and Fuvean lignite are used.

While briquets are sold in a very large number of forms, the three notable types are: (1) the large square or cylindrical briquet, weighing about 20 pounds each; (2) the perforated rectangular briquet, weighing about 1½ pounds, and sold for general domestic and industrial purposes; (3) the round or egg-shaped briquet for domestic purposes. The standard recognized for these briquets by the French Admiralty is the Anzin briquet, a briquet yielding from 8,200 to 8,500 calories. The manufactured fuel for the navy is required to reach this standard, and the railway service is scarcely less exacting. The briquet for ordinary purposes, being in the majority of cases manufactured from coal of the poorest and smallest grade, averages not more than 6,600 calories. These commercial briquets are in large part manufactured from lignite (which is used with difficulty alone) in combination with forge coal and a relatively high percentage of pitch. Because of these requirements, it is almost invariably necessary to wash the small coal, at considerable expense, before the manufacture of briquets begins.

The manufacture of briquets in France includes coal-crushing, washing, and drying processes, the first two processes of which are entirely familiar. Generally the coal delivered to the pressing machines is damp; and when the moisture exceeds 4 to 5 per cent. it is necessary to remove the excess. The presses that apply a pressure lasting relatively for a considerable time, such as the Rivollier, Evrard, and Bourriez, relieve the paste of the excess water and give good results even though the paste as it enters contains as much as 10 per cent. of water. The Rivollier, however, is the only machine that absolutely guarantees this result. The presses operating instantaneously, like the Biétrix, which is manufactured by the house of Couffinhal et Ses Fils, at St. Étienne (Loire), France, give excellent results, but the product requires careful drying. It is recognized as necessary and useful to leave 1½ to 3 per cent. of water in the paste when ready for the press. This quantity contributes to the plasticity of the mass during the application of the pressure. In no event does the density of the briquet equal that of solid coal. There remain always certain spaces between the component particles, and if the paste is too dry these spaces contain compressed air, which diminishes the solidity of the mass.

In some cases, it is necessary to eliminate nearly all the water possible from the coal before the material passes to the presses; consequently, a drying operation is required, such as is carried on in the oven shown in Fig. 7. This oven is circular in shape, composed of a revolving platform of cast iron, and works continuously with the agglomerating machine. The platform is surrounded by masonry covered with sheet iron, on which rests a dome with a passage in the center for a cylinder of cast iron with a shaft furnished with flukes. A lateral firebox produces the temperature necessary to the heating of the coal and the elimination of any excess of water. The flames, after passing over the upper surface of the coal, heat the dome, pass under the revolving table, and

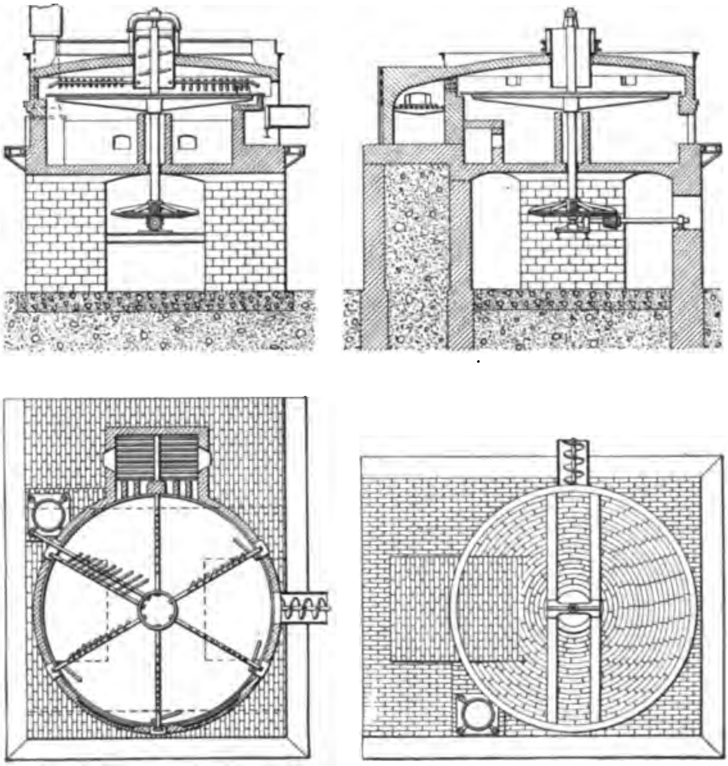


FIG. 7. OVEN WITH REVOLVING TABLE

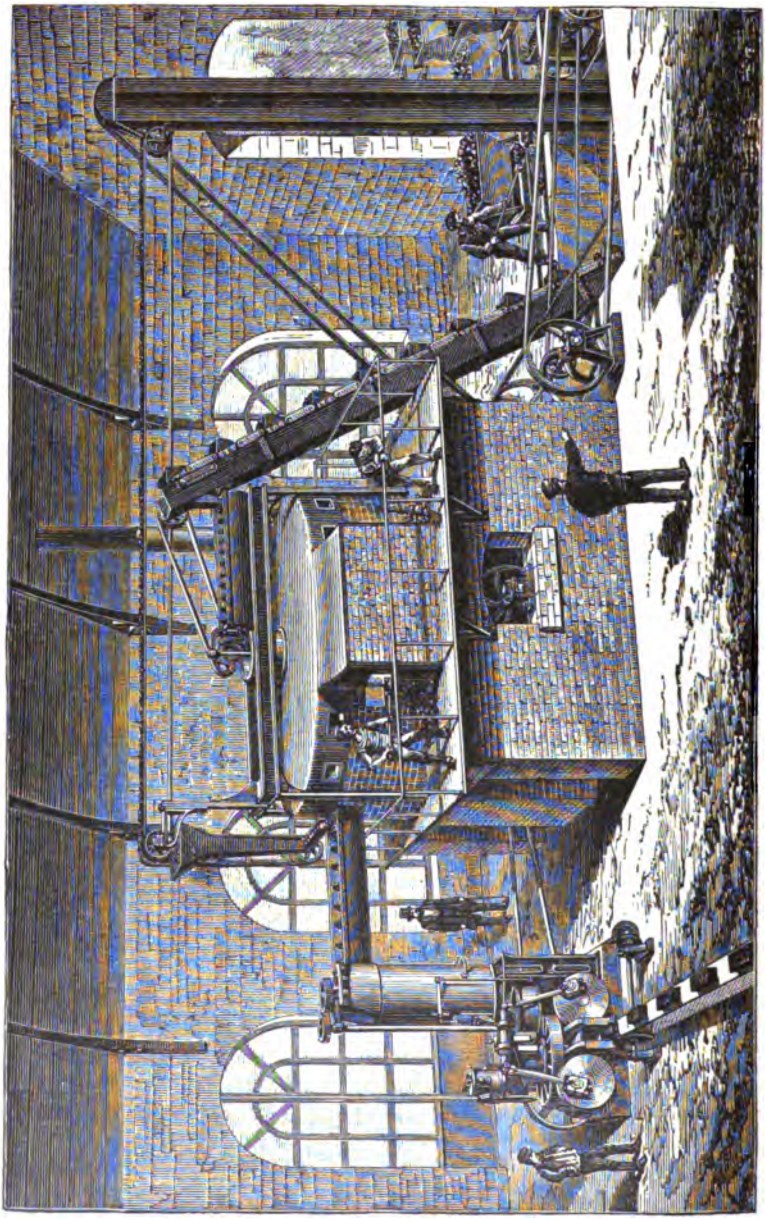


FIG. 8. DRYING OVEN AND BRIQUET PRESS

escape at the opposite end by a chimney. Around the covering of the oven are arranged six openings. The first four are used to introduce arms provided with spikes that turn the material, presenting all its parts to the heat of the flame. Opposite the fifth aperture are two bars that gradually bring the material from the center to the circumference. These bars also regulate the thickness of the layer of coal. By means of scrapers, the coal that is sufficiently dried is removed from the table, through the sixth opening, to a conveyer that carries it to the press, where it is made into briquets. Fig. 8 shows the method of operating such a drying oven in connection with a press.

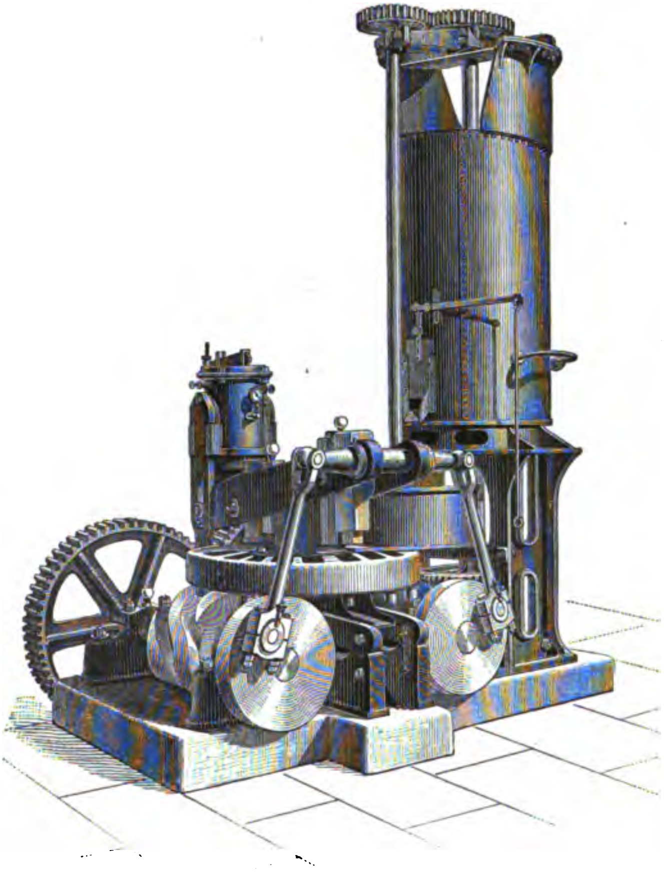
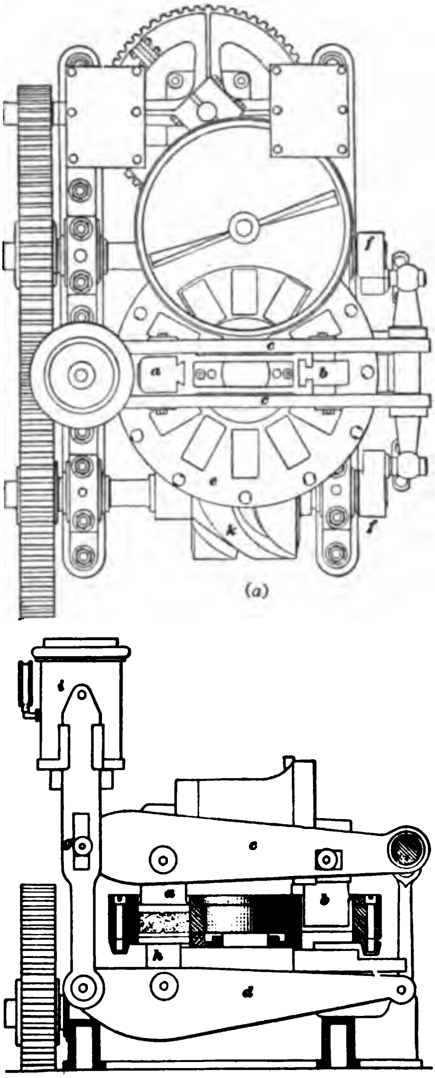


FIG. 9. BIÉTRIX BRIQUET PRESS

The pitch for the binder should be crushed as fine as possible and preferably should be melted before being mixed with the coal and brought to the temperature chosen for the fusion. It is melted in huge basins with bottoms slightly inclined toward the point of discharge, the load usually being 7 tons. Frequently the pulverized pitch is mixed dry with the coal, and the mixture is then brought to the proper temperature.



(a)

(b)

Fig. 10

The mixing mill consists of a vertical cylinder within which the shaft operates swiftly moving paddles upon the churn principle, by which the incoming pitch and coal are beaten and mixed as they move downwards toward the point of discharge. This cylinder is heated by steam, and requires as much as 110 pounds of steam per ton.

In 1903, the British presses were extensively used, though the Biétrix machine probably stands equally high. This latter machine presses the briquet simultaneously on its two faces upon the principle of a nut cracker, the various models producing 18, 50, 90, and 150 tons in 12 hours. The weight of the briquets is usually 13.2 pounds, but may be increased to 25 pounds. Its successful operation requires a paste containing 1½ to 3 per cent. of water and 6 to 9 per cent. of pitch, and the pressure varies from 1,300 to 2,300 pounds per square inch.

The Biétrix press is shown in perspective in Fig. 9, in plan in Fig. 10 (*a*), and elevation in Fig. 10 (*b*).

The double compression is effected by pistons *a* and *b*, Fig. 10, attached to upper beam *c* and lower beam *d*, respectively, working in molds on the revolvable disk *e* The beams *c* receive their motion through rods connecting them with cranks *f*. The operation of forming the briquet is as follows: The material in the mold is pressed down by the descending upper piston *a* until the upper layer of the briquet produces so strong friction on the walls of the mold that it will not yield any longer; at this stage the pivot *g* of the beam *c* shifts, the lower beam *d* is brought into action, and piston *h* then compresses the lower part of the briquet in such a way that the pressure on both parts is equal. The hydraulic cylinder *i* is so connected to the beams as to regulate the pressure on the briquet and it also acts as a safety apparatus. After the briquet is formed and the pistons *a*, *h*, and *b* have been removed from the molds, the mold disk *c* is turned by pins on its under side engaging a cam *k* on the crank-shaft. When the briquet in the mold comes under the piston *b*, it is ejected and, falling upon a conveyer, is loaded into a car.

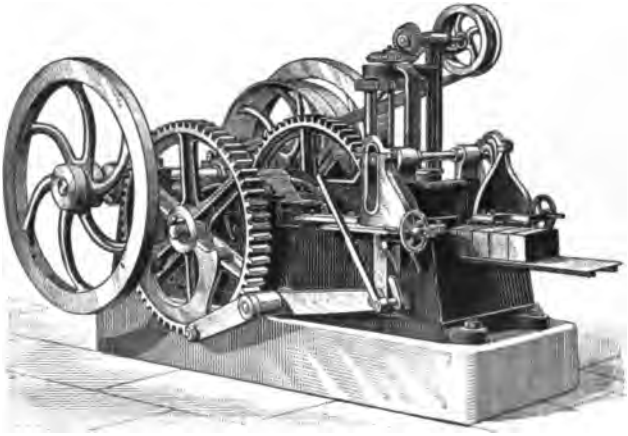


FIG. 11. THE DUPUY BRIQUET PRESS

Another excellent press, Fig. 11, is that of Th. Dupuy & Fils, Paris. This company guarantees to supply a plant, producing 100 tons of briquets per day, briquets weighing 13.2 pounds each, for $14,275, external shed included. The builders calculate 2 horsepower per ton of briquets produced per hour, to which must be added 2 horsepower per ton for the several necessary operations.

The presses for the manufacture of balls and egg-shaped fuel, Fig. 12, operate on a different principle from the others. While the briquets are sometimes piled directly into railroad cars, the rule seems to be to discharge them from the press upon a long conveyer, which permits them to cool and prevents a high percentage of breakage, which is certain to result if they are handled while still warm.

In 1882, the gas company at Lyons began the manufacture of briquets from coke, employing the Dupuy machine. The coke dust is mixed without further crushing with pitch and tar. The impurity of coke dust requires that it shall be washed and results in a loss of weight of 20 per cent. The washing process costs 29 cents per ton of weight before the washing, and the dust itself being quoted at 96 cents, the washed product costs $1.56 per ton. The complete installation of this plant cost the company about $8,685, not including the building. The production per day of 10 hours is 6,500 briquets, the gross weight being 28 tons. For this production there are required one foreman, one fireman, three laborers, four boys, costing $6.84. The general expenses per day amount to $4.52. The raw material cost is divided as follows: washed dust, 25.3 tons, $39.66; pitch, 4,305 pounds, $28.60; tar, 1,538 pounds, $8.10; total, $76.36. Adding thereto the cost of labor and the general expenses, the total daily expenses amount to $87.72. This makes the cost of the product $3.14 per ton. The market price of briquets follows the price of coal, the former being about 5 francs (96½ cents) per ton higher than the latter.

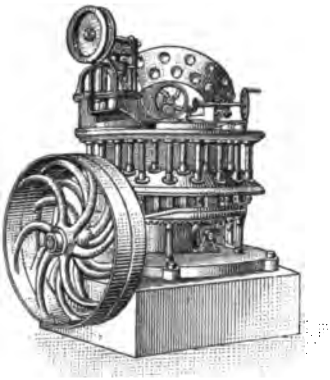


FIG. 12. PRESS FOR MAKING EGG-SHAPED BRIQUETS

There is a wide difference in the cost of manufacturing the briquets, attributable not only to the obsolete machinery employed in many cases, but to the conditions under which the coal is produced. The cost depends on the equipment of the mill and the rate of wages paid. It may be stated as a fair estimate that six workmen can turn out 100 tons per day. The equipment of such a plant costs about $20,000. The labor cost runs from 11 to 30 cents per ton, including the discharging of the coal and the loading of the briquets. The wear and tear of the machinery is seldom less than 5 cents per ton, and occasionally reaches from 19 to 39 cents per ton. The expense, per ton in detail, of manufacturing the briquets at one plant where two Biétrix presses were producing 250 tons per day and working 24 hours per day, is as follows: superintendent, $.007; manipulation of cars, $.005; discharge of pitch, $.009; discharge of coal, $.012; crushing material, $.032; manufacture, $.041; loading trucks, $.015; miscellaneous labor, $.012; firemen and engineers, $.019; total labor cost, $.152. Supplies: oil and grease, $.017; miscellaneous, $.014; wear and tear on machinery, $.019; fuel, at 6 francs per ton, $.010; total, $.11. In making up this total, labor is calculated at 60 to 77 cents per day. In another plant, composed of Rivollier presses, the total cost per ton amounts to 42 cents. This plant requires the services of forty-one men, who are paid at from 60 to 65 cents per day.

The most important item in the first cost of the coal briquets is the pitch, the price of which is twice as much in the interior as at the seaboard. Assuming as a minimum a consumption of 6 per cent. of pitch at a low price—that is, $5.79 per ton—the cost under this head will be 34.7 cents. Add to this the expense of labor and miscellaneous materials, estimated at 28.9 cents, and we have a total theoretical cost of 63.6 cents per ton. However, the seaboard factories usually work for the marine and employ at least 8 per cent. of pitch in order to secure a satisfactory cohesion. Under these circumstances the minimum cost of manufacture and materials will reach 75.2 cents. Mr. De Graffigny furnishes other figures, which lead him to say that a maximum of $1.698 per ton for labor and materials should never be exceeded by a well-organized plant.

The plant at Flers (Nord) is considered fairly representative, and is quoted for a production of 220 tons per 24 hours. It includes a washing apparatus for cleaning the coal, a double Bourriez press, Fig. 13, a 50-horsepower Corliss engine, and various other machines, tram lines, warehouses, stables, forge, ten houses, loading crane, one locomotive, four cars, and cost $135,100 in 1881, not including the land.

Mr. Robert P. Skinner, United States Consul-General, concludes that the manufacture of briquets is of the utmost importance in France, where the native fuel is poor in quality, and must be subjected in large part to artificial treatment; also, that the production of this fuel may be advantageously taken up in the United States. However, he believes that, as a rule, a more direct interest should be taken in studying methods of burning small coal as such, by means of inclined fireboxes and other devices. He states that certainly every coal company should utilize its refuse in generating its own operating power with greater economy than by converting it into briquets. The industries located in coal-mining regions could advantageously adopt the same methods. When there is a surplus of poor coal after these demands are satisfied, the conversion of the residue into briquets may be undertaken with assurance that if the work is scientifically carried on, the product will sell on a plane with large coal of the same grade and will give satisfaction.

In the spring of 1902, United States Consul Brunot, of St. Étienne, reported as follows: "Petroleum briquets have been manufactured in various ways in different countries, notably in Russia, France, and the United States, as a fuel for steamships and certain industries where rapid production of heat is desirable. A company has recently been formed at St. Étienne for the manufacture of petroleum briquets that claims to have obviated all objections except that in regard to price. The advantages of the product are set forth as follows:

"The briquet is composed of 97 per cent. of petroleum and 3 per cent. of hydrocarbon. The volume being equal, it weighs only half as much as coal and gives but from 2 to 3 per cent. of residue; it produces no slag, it does not 'run' when lighted, and keeps its form like coal; it burns without odor and without smoke; it may be wetted with impunity, losing none of its properties; it consumes without explosion or sparks and yet with a bright and long flame; it may be kept indefinitely without deterioration. By this process, a degree of saponification is obtained by which the briquets are rendered unchangeable, even to the extent that if a projectile should enter a ship's bunker filled with this fuel there would be no danger whatever of explosion, the effect being the same as in the case of ordinary coal. The average heating

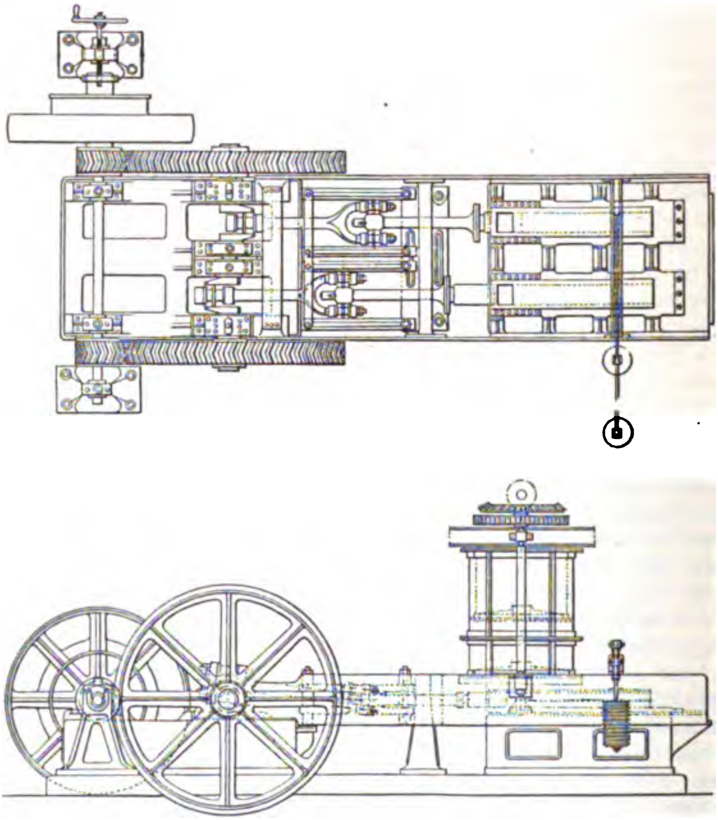


Fig. 13. Bourriez Briquet Press

power is from 12,000 to 14,000 calories, and the briquets can be employed in any firebox or in any grate for domestic purposes.

"The manufacture of these briquets is very simple. They are made without heat and no danger attends the operation. The petroleum is placed in one tank and the chemicals in another, and both are allowed to run into a mixing apparatus, when the chemical combination is formed immediately. The product is then passed to a press, where the desired form is given. The briquet is now ready for use, or it can be stored. The pressure used in molding the forms is about 300 pounds per square inch.

"As will be seen, the mode of procedure is very simple and the necessary plant inexpensive, requiring only tanks, mixer, and press, with small motor power for the latter two. Works erected at a cost of, say, $20,000 would turn out several hundred tons a day.

"The use of this chemical combination as a binder and enricher solves a difficulty frequently encountered in the making of coal-dust or saw-dust briquets.

"The same company manufactures what are called mixed briquets—half coal and half petroleum; but if these are cheaper than the former, they present less advantages, from the fact that the density is greater and the heating power is only 9,000 calories. A steamer carrying 8,000 tons of coal would require 3,500 tons of mixed briquets and only 2,500 of the pure petroleum briquets."

Briqueting in Germany.—United States Consul-General Frank H. Mason, of Berlin, Germany, has reported upon the briqueting industry in that country as follows:

Among the several branches of German industry that deserve attention by reason of their economy, the recovery or utilization of some raw material that exists unused in Germany, or because they involve the most intelligent application of scientific knowledge to technical processes, may be reckoned the manufacture of briquets from brown coal, peat, and the dust and waste of coal mines. By reason of long, careful, scientific experience, briqueting in Germany has long passed the experimental stage and become a standard commercial industry. Briquets form the principal domestic fuel of Berlin and other cities and districts in Germany. They are used in locomotives and other steam fires, and are employed for heating in various processes of manufacture. Like most other important German industries, the briquet manufacture is controlled by a syndicate, which includes among its members thirty-one firms and companies, and which regulates the output and prices for each year. The official report of this syndicate for 1901 gave the total output of briquets for that year as 1,566,385 tons, and in this connection it is interesting to note the distribution of this output: 749,208 tons were taken by German railways; 124,380 tons were sold to retailers; 497,136 tons were sold to factories and works of various kinds; and 149,089 tons were used by German merchant steamers and the navy, or exported to German colonies or neighboring European districts.

United States Consul Walter Schumann reported that during the year 1900 the production and home consumption of briqueted fuel, in Germany, were as follows:

	Production Long Tons	Home Consumption Long Tons
Bituminous briqueted fuel	1,970,316	1,849,916
Lignite briqueted fuel	1,025,000	878,910

Consul-General Mason continues as follows: The following tabulated statement shows the production, the sales of the syndicate, and the mean price per ton from 1891 to 1901, inclusive:

Year	Production Tons	Sales of Syndicate Tons	Price Per Ton
1891	482,495	202,780	$3.02
1892	533,075	516,508	2.49
1893	694,025	645,144	2.16
1894	745,414	719,258	2.10
1895	796,363	780,185	2.16
1896	830,985	817,300	2.22
1897	943,732	934,221	2.38
1898	1,078,113	1,245,269	2.43
1899	1,530,816	1,485,130	2.34
1900	1,563,928	1,519,811	2.92
1901	1,566,385	1,560,230	3.17

German briquet factories are divided, in respect to crude material employed, into two general groups: those that make household briquets from brown coal (lignite) or carbonized peat, and those that produce the so-called "Industrie briquets," using as basic material coal dust or slack, the waste of bituminous coal mines.

Household briquets, as made in Germany from brown coal, peat, and to a small extent from anthracite dust, are used in grates, heating stoves, cooking stoves, and ranges, and constitute the principal household fuel of Berlin and other German cities. They are cheaper in Berlin, ton for ton, than anthracite or good bituminous coal. The standard household briquet is about 8 inches in length by 4 inches in width and 2 inches thick, and is retailed and delivered in Berlin at about $2 per thousand in summer and $2.50 in winter. They are made largely from brown coal at factories located mainly in Silesia, Saxony, and in the Rhine provinces. There are in Germany 439 brown-coal mines, which, in 1901, produced 44,211,902 tons of lignite. Of this whole number of mines, 181 have each from one to six briquet factories, in each of which from one to ten presses are employed. The whole brown-coal briquet industry of Germany includes 286 factories, with a total of 691 presses.

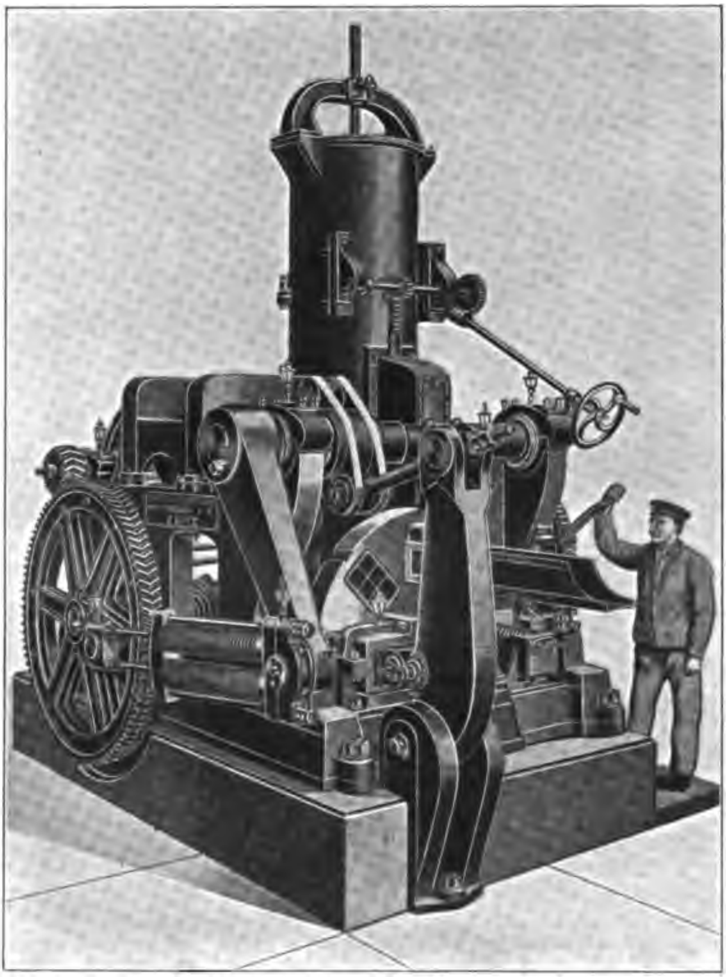


FIG. 14. ZEITZ BRIQUET PRESS

Industrial briquets are used in Germany for firing locomotives and other steam boilers, for smelting and reverberatory furnaces, and for many other kinds of industrial use. They are made of bituminous coal dust, held together by a matrix of mineral pitch. Pitch of this quality costs in Germany from $10 to $12 per metric ton.

Anthracite is so sparingly produced in Germany that the use of hard-coal dust for briquet purposes is relatively unimportant. Experts have agreed that, with a mixture of from 4 to 8 per cent. of matrix, the manufacture of anthracite briquets that will bear transportation by sea or land in any climate presents no technical difficulty. While Germany is preeminent in the scientific utilization of lignite and peat as material for prepared fuel, it is not apparent that this technical superiority is so absolute in the treatment of coal dust. It is true that the coal-briquet manufacture is fully organized and developed in Germany, that there are several German builders of coal-briquetting machinery, who are masters of that branch of construction, but the same is true of France and Belgium.

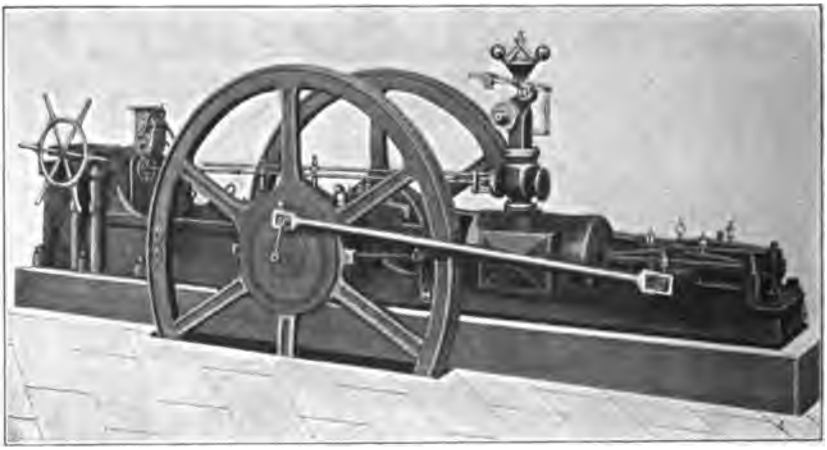


Fig. 15. Briquet Press Used in Saxony

Lignite varies in its value or adaptability for briqueting purposes according to its geologic age, hardness, and the percentage of water contained. It is for this reason that Austria-Hungary, which has comparatively a very old and hard brown coal that contains from 26 to 28 per cent. of moisture, has practically no supply of briquets from that source. The German lignite, on the other hand, is of much more recent formation; it contains from 46 to 52 per cent. of water, and is usually so soft that it can be cut with a spade. The ideal proportion is about 45 per cent. of water, so that German lignite contains rather too much, while Austrian contains most too little, though this latter difficulty has been practically overcome by steaming.

Fig. 14 shows a Zeitz briquet press that is very largely used in Germany. Pressure is exerted from both sides at the same time and the mold can be exchanged without removing the mold disk. Fig. 15 shows another form of briquet press adapted for all of the usual forms of briquets and made by the Königen Marienhütte Actien-Gesellschaft, of Cairnsdorf, in Saxony. Fig. 16 shows the pressroom of a briquet factory containing three presses with a daily capacity of 3 tons.

A typical example of a German briquet factory is shown in Figs. 17 and 18. This factory is located at Lauchhammer, about 80 miles south of Berlin, on the direct line to Dresden, and is of the latest and most approved construction. It has eight presses, with the necessary pulverizing, heating, and drying plant, run by electric motors with current generated by steam generated with wood from the mines. The whole is under handsome and substantial buildings of brick, stone, and iron, that cost—with tracks, switches, and full equipment for handling raw material and loading the briquets into cars—$371,000, of which $178,500 was paid for machinery. Each press weighs 32 metric tons and stamps out 100 to 120 briquets per minute, or 70 tons in a double-turn day's work of 20 hours. The heating and drying apparatus for each press weighs 18 tons. The power required for each press and drier is 125 horsepower, and both the drier and jaws of the

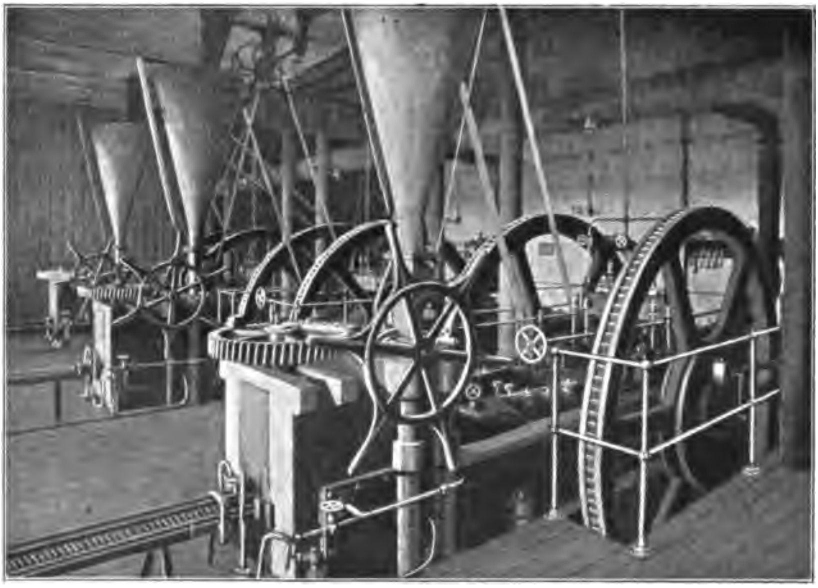


Fig. 16. Pressroom of Briquet Factory

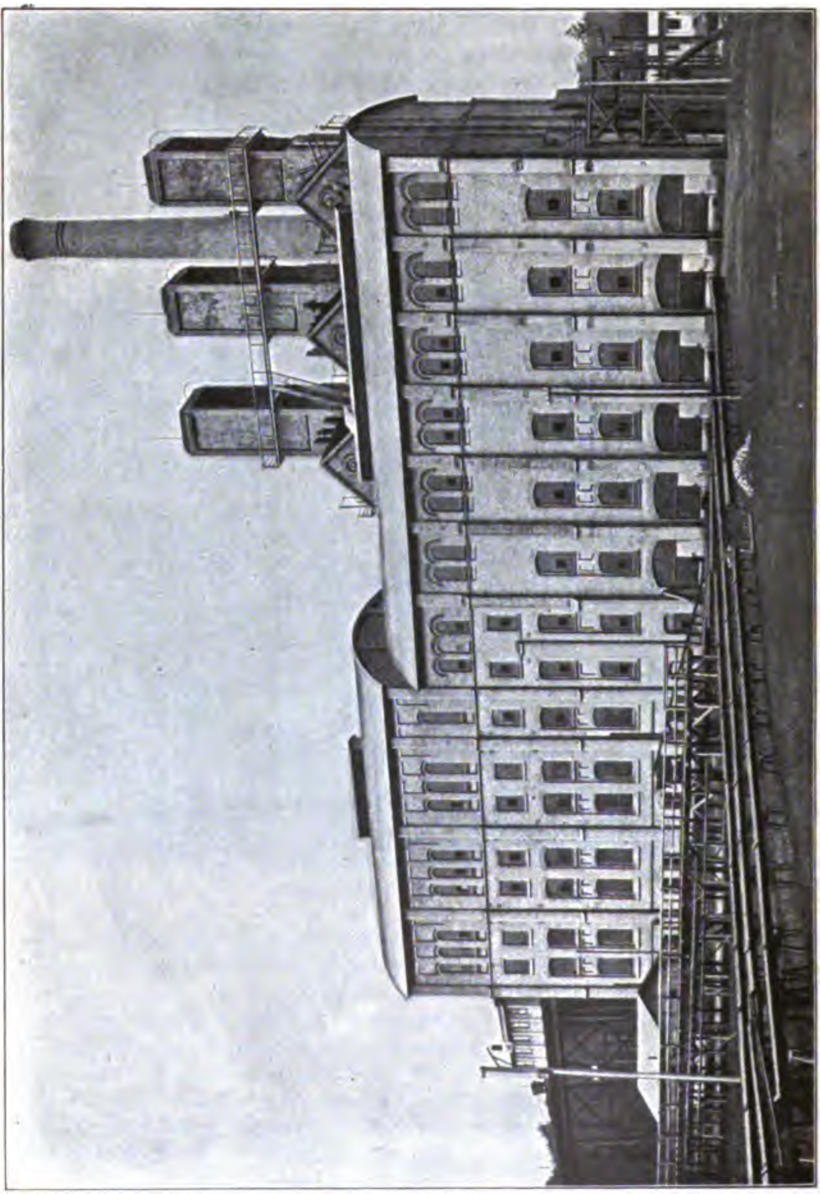


FIG. 17. GERMAN BRIQUET FACTORY

press, between which the briquets are squeezed at enormous pressure, are heated by exhaust steam from the Corliss engine in the power house, the whole supply for the eight machines being equivalent to about 150 horsepower. Thus equipped, the plant at Lauchhammer turns out from 500 to 600 tons of briquets per day, which sell on cars at the factory for from $1.66 to $2.14 (7 to 9 marks), according to season and market, with an average of $1.90 per 1,000 kilograms, or metric ton of 2,204 pounds.

The cost of manufacture per ton of briquets in Magdeburg in 1903, depending on the material and the percentage of water contained, was stated by Consul Walter Schumann to be approximately as follows:

Materials	Cost
From lignite taken from the open working under good conditions, with water content of about 46 per cent.:	
In large briquet factories	$1.14 to $1.29
In small briquet factories	1.19 to 1.33
From lignite taken from open working, with water content of more than 46 per cent. in large briquet factories	1.33 to 1.62
From lignite taken from the deep working, with water content up to 46 per cent.:	
In large briquet factories	1.31 to 1.62
In small briquet factories	1.62 to 1.74
From lignite taken from the deep working, with water content of more than 46 per cent., in large briquet factories	1.66 to 1.86
From heavy air-dried peat, with 30 to 40 per cent. water, reckoning the peat at 66 to 71 cents (2.8 to 3 marks) a ton:	
In briquet factories with one press	1.66 to 1.95
In briquet factories with two presses	1.66 to 1.86
From a lighter air-dried peat, with 30 to 40 per cent. water, reckoning the peat at 71 cents (3 marks) a ton.	2.14 to 2.38
From sawdust of soft wood, with 30 to 35 per cent. water, reckoning 1 ton of this material at 47 cents (2 marks) in briquet factories with one press	1.62 to 1.71
From sawdust of hardwood, with 30 to 35 per cent. water, reckoning 1 ton of this material at 47 cents (2 marks) in briquet factories with one press	1.48 to 1.62

In the case of materials containing from 15 to 18 per cent. water, for which a drying process is not necessary, the cost of manufacture is considerably lower.

Peat as a material for fuel ranks in natural order below lignite, in that it is of similar, but much more recent, geologic origin, contains more water, is but slightly carbonized, and has a correspondingly lower thermal value than brown coal.

A pioneer in the invention of machinery and processes for making compressed peat in Northern Europe appears to have

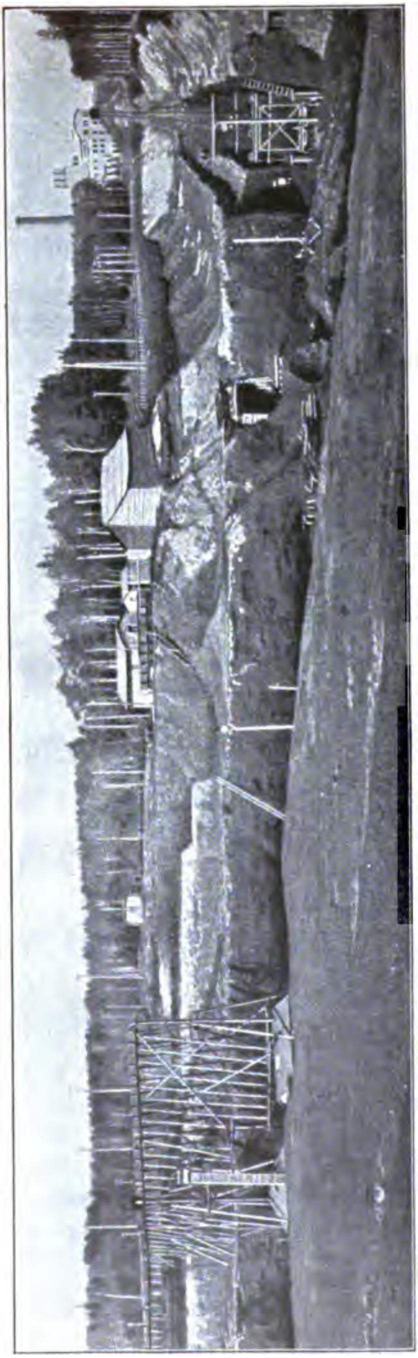


FIG. 18. PEAT EXCAVATIONS AND PLANT IN GERMANY

been Mr. C. Schlickeysen, of Rixdorf, near Berlin. His first two machines were of vertical construction, and were built in 1859 for a steam peat-compressing plant at Zintenhof, near Riga, Russia, where they worked successfully for many years, turning out daily about 80,000 pieces of wet compressed peat, which, after drying, were used as smokeless fuel in a large cloth factory at that place. During the ensuing 40 years, he has built peat-compressing plants in Holland, Hungary, Switzerland, and at various places in Germany, constantly improving his equipment and processes with a view of perfecting the product, cheapening its cost, and substituting more and more automatic machinery for manual labor, until the system so evolved may be accepted as standard in this country.

Raw peat, as it comes from the bog, contains about 85 per cent. water, 13 per cent. combustible material, and 2 per cent. inorganic matter. To obtain the 13 per cent. of combustible elements in the cheapest, most direct manner, the peat is cut with spades and shoveled into the trough of a long, sloping belt-and-bucket elevator, Fig. 19, which carries it up and drops it into a machine, Figs. 20 and 21, which cuts, tears, kneads, and mixes it to uniform consistency, in which state it is forced out by a horizontal screw into long, plastic skeins about 3 in. × 4 in. in transverse section. These are delivered at the tail of the machine on boards 3 feet long, which are lifted off by hand when filled, laid on tram cars, and run out to a clear space, where they are laid in rows on the ground; the skeins are then cut with a knife into bricks or sections 10 inches long, which, being left to dry, lose by exposure in ordinary weather one-half their water content in a period of 2 weeks. The peat loses by this machine process one-third of its bulk, so that a machine that works 742 cubic feet

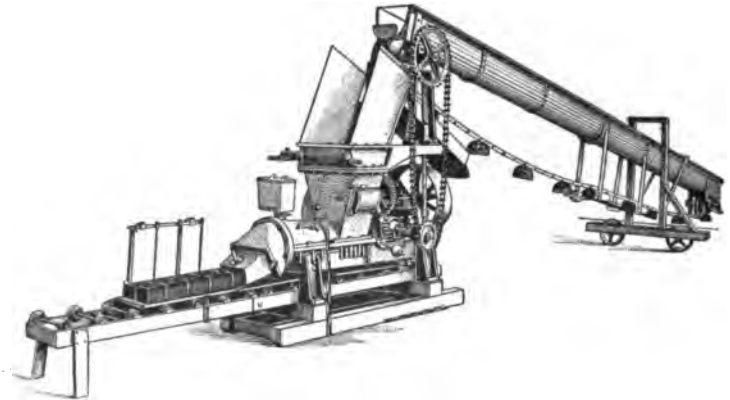


Fig. 19

(21 cubic meters) of raw turf per hour delivers 495 cubic feet of clean peat or 7,000 wet bricks of the size indicated, which contain from 3 to 4 tons of dry compressed peat in a condition to be used as fuel. Fig. 20 shows the inside of a press having double cutting and mixing knives in the long horizontal cylinder. Fig. 21 shows a similar machine with a double breaker superposed. A plant of this kind includes, besides the elevator and grinding press, a 10-horsepower portable engine, which is fired with peat refuse, and cars and tracks for handling the material. The whole plant is movable, is taken bodily to the bog, set up at the farther edge of the moor to be worked, and moved backwards as the peat bed is excavated and exhausted. An important recent improvement by Mr. Schlickeysen is an excavating machine, which, in moors reasonably free from logs and stones, digs and elevates peat with great rapidity, thus saving the hard, wet, unhealthy work of several men. The cost of such a plant, complete with engine, tracks, cars, etc., ready to operate, is $4,431 (18,620 marks), and its operation, when used without machine digger, employs 17 men besides engineer and fireman, a total cost for labor in North Germany of $28.56 per day.

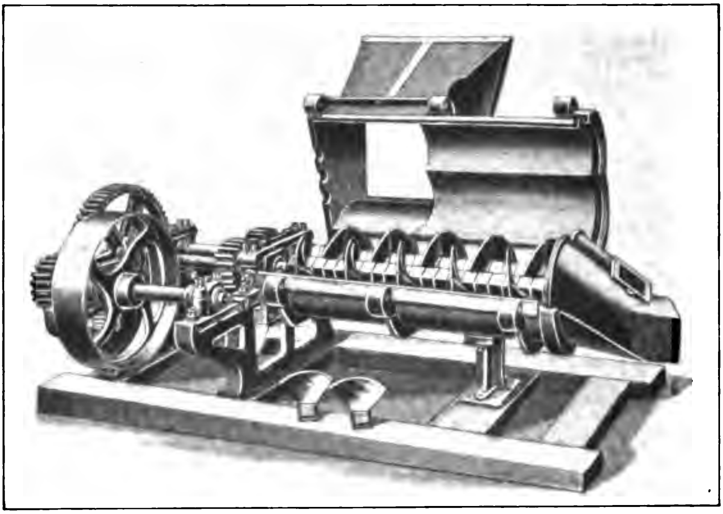


FIG. 20

A matter that has been the subject of many serious studies and experiments in Germany is that of peat coke and secondary products. The best results by this method are stated to be embodied in a system perfected and patented by Martin Ziegler, which gives to the manufacture of peat coke the dignity of a perfected industrial process. The Ziegler method consists of carbonizing peat in closed ovens heated by burning under them the gases generated by the coking process itself. Such a plant is therefore self-sustaining, the only fuel required being coal or wood sufficient to heat the oven for the first charge, when the gases generated by the coking process become available. Not only this, but the heat from the retort furnaces passes on and heats the drying chambers in which the raw, wet peat is prepared for the ovens by drying to the point of economical carbonization.

The peat coke produced as the primary product of this process is jet black, resonant, firm, and columnar in structure, pure as charcoal from phosphorus or sulphur, and having a thermal value of from 6,776 to 7,042 calories; it is so highly prized as a fuel for smelting foundry iron, copper refining, and other metallurgical purposes that it readily commands from $9.52 to $11.90 (40 to 50 marks) per ton. It is also a high-class fuel for smelting iron ores, but as the process is comparatively new and the output limited, it is yet too scarce and expensive for blast-furnace purposes. Crushed and graded to chestnut size, it forms an excellent substitute for anthracite in base-burning stoves. In larger lumps, as it comes from the oven, it fulfils substantially all the various uses of wood charcoal as a clean, smokeless fuel. The cost of a four-oven plant, with all apparatus for cutting and drying the

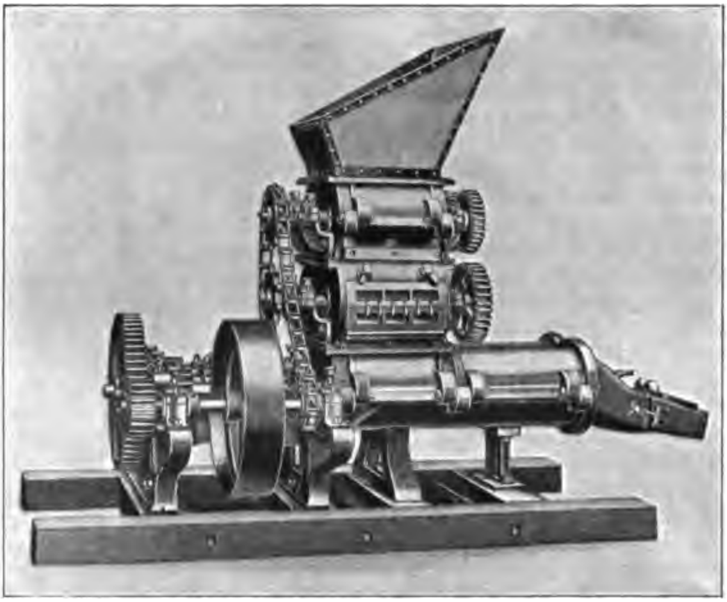


Fig. 21

peat, distilling the gas liquor, and extracting paraffin from the tar, is given at $95,200. Such a plant has a capacity of 15,000 tons of peat per year, the various products of which would sell, at present wholesale market prices, for $117,596. A plant of twelve ovens, with all appurtenances complete, would cost $261,800 in Germany, and should produce annually products worth $350,000, from which, deducting the carefully estimated cost of peat, labor, depreciation of property, and other expenses—$179,200—there would remain a profit on the year's operation of $170,800. Consul-General Mason further stated in March, 1903, that this process is in successful operation at Redkino, in Russia, and the German government has evinced its practical interest in the subject by placing at the disposal of the company a large tract of peat-moor lands, the property of the state, on which extensive works will be erected during the coming year.

There are several recently patented processes by which artificial coal, or briquets, have been more or less successfully produced from peat by the use of machinery, or methods, not yet fully established on an industrial basis. Among these methods is the Stauber, which was first brought into prominent notice in 1901, when the Imperial testing station at Charlottenburg announced, as the result of experiments made with peat briquets manufactured by the Stauber system, that they contained 45.14 per cent. of fixed carbon, 4.54 per cent. hydrogen, 29.34 per cent. oxygen, and 9.09 per cent. ash, and had a thermal value of 3,806 calories. The Stauber system as thus applied includes a process of rapidly drying moist peat, by means of heated and compressed air in a closed chamber or channel, communicating with conduit pipes in such a manner that heated air can be forced through the drying channel and cold air through the outlet pipe; the effect being that the cold air rapidly absorbs the hot saturated air of the drying chamber and condenses it in the conduit pipes, thus greatly stimulating the process of evaporation by which the peat is dried. It is claimed for the Stauber method that it reduces the moisture to 18 or 20 per cent. quickly, effectively, and, what is most important, without changing the chemical composition of the peat. The drying machine is in the boiler form, and of a size to conveniently produce 5 tons of dried peat per day. In a large plant this unit would be simply repeated, as a number of machines can be worked with air-currents generated by the same engine. A large plant for working the process was stated to be in course of erection near Königsberg, on the Baltic sea, and another was already in operation at Ostrach, in Wurtemburg, in 1903. The peat coal can be used for locomotives or other fuel raw, or it can be coked, the coke being wholly free from sulphur, and is therefore as valuable as charcoal for certain industrial purposes.

Estimates furnished by the company give the cost of a plant capable of turning out 50 tons of briquets per day as follows:

Buildings, $14,280; machinery, $17,850; steam engine and fixtures, $3,570; means of transporting material and product, $3,570; total, $39,270.

A second process is that invented by Mr. Schülke, of Bach Strasse, Hamburg, the salient feature of which is that the turf or peat used is cleaned of roots, stones, etc., then liquefied by water and pumped through a pipe line several miles to the works, where, as claimed by the inventor, it is leached and converted by heat and pressure into briquets at a net cost of $2 per ton, or into artificial coal, having a thermal value of 6,250 calories, at a cost of $2.50 per ton. It is understood that a large plant is in progress of erection on the northern coast of Germany for the utilization of this method, but as to the actual condition of the enterprise or the practical value of the process on an industrial scale no exact information is at hand.

Briqueting in Norway and Sweden.—Coal has not as yet been discovered in paying quantities in any part of Norway, but peat of the best quality is found in abundance, and in some places is the only fuel used for domestic purposes. It is generally obtained in the old-fashioned way, i. e., cut with a spade by hand.

A society, counting many prominent Norwegians as members, has been formed for the specific purpose of utilizing the peat bogs, which cover an area of about 3,861 square miles. The quantity and quality of the peat varies much, of course, in the different bogs, but some of the deposits are of the best quality and exceed 12 feet in thickness.

Peat briquets are made and burned in several factories located where peat is easily obtained. The machinery used is built principally on the Anreps system; some is imported and some made at the machine shops at Aadals and Hasle Brug. Of the latter, illustrations and descriptions follow.

The product of these machines is known as "pressed peat," and the process is quite similar to that of brickmaking. The peat is dug from the bog and put into the machine, where it is ground and then forced through a square spout out upon a moving platform, where it is cut into convenient lengths. Thereafter it is dried, either in the open air or artificially, until its volume of moisture is reduced 20 to 25 per cent. It is estimated that 1.8 tons of pressed peat equals 1 ton of soft coal, for heating purposes, while a ton of peat made in the old way, by hand, equals only about one-third of a ton. The total cost of cutting, drying, and storing the peat will not, under ordinary conditions, exceed $1.60 per ton.

Fig. 22 shows a 4-horsepower, steam peat-briquet machine, requiring a crew of six men, eight women, and two boys. It delivers 20,000 briquets per day and costs $107. Fig. 23 shows a similar machine to be operated by two horses.

Attempts have also been made to manufacture coke from peat, and a plant for that purpose was built at Stangfjord, in the neighborhood of Bergen.

The partially dried peat briquets are carbonized in hermetically closed retorts by electrical heat. The process allows the peat blocks to be carbonized within a short time and with great uniformity, while the peat charcoal produced consists of a dense black mass, showing the structure of the peat. The peat is first submitted to a drying and pressing operation, which is performed in a 5-horsepower press that can turn out about 2,500 blocks of peat per hour, the weight of each block being 4.4 pounds. The partially dressed and dried peat briquets are next loaded on shelf wagons carrying 140 pounds each. When loaded, these wagons are pushed into the cooler end of the drying tunnel. The current of air passing through the tunnel is heated by the waste gases from the retorts and set in motion by means of electrically operated fans. At the top end of the tunnel, where the wagons emerge, the temperature of the air is 90° to 100° C., and at the lower end, where they enter, 40° to 50° C. The loads of dry peat are next taken direct into the retort house and emptied into the retorts. 102 wagons, two tunnels, three electric fans, and one hot-air stove compose the drying plant at Stangfjord, which is said to have been able to produce 1,000 air-dried peat blocks a day.

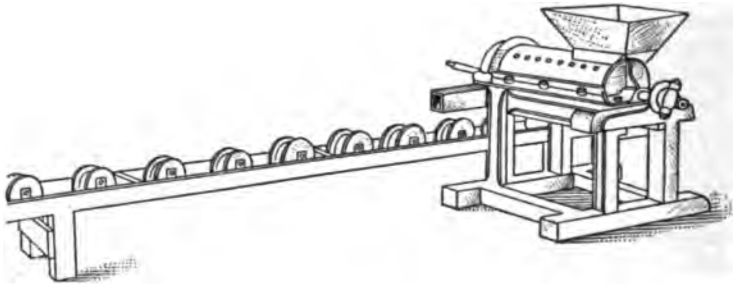


Fig. 22

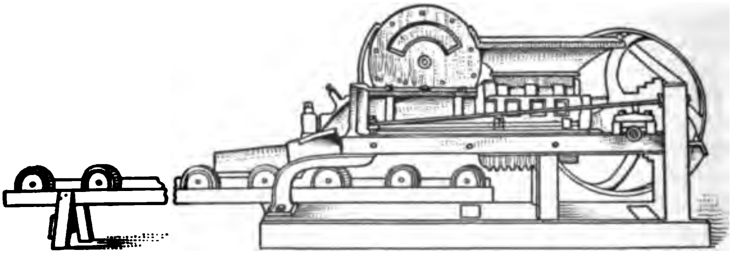


Fig. 23

The retorts consist of upright cylindrical vessels of iron about 6 feet 6 inches in height and 3 feet 6 inches in diameter, each retort being provided with a removable cover. The retorts have spiral resistance coils, so constructed that the peat blocks can be built up in contact with them until the mass of peat entirely fills the retort, the heating agent lying in the center. The top cover of the retort is then clamped down and the electric current turned on. Each retort is loaded with 882 to 1,102 pounds (400 to 500 kilograms) of dried machine-made peat and the coking requires 3 to 4 hours. The coke thus prepared burns with a bright flame. This process for carbonizing peat was invented by Herr P. Jebsen, of Dale, Norway, and it is said to be an advantageous one. It has been in operation during 3 years and the plant is now said to be closed on account of lack of sufficient capital.

United States Consul Victor E. Nelson reported on March 7, 1903, from Bergen, Sweden, as follows:

"It is known that Sweden possesses great wealth in her peat bogs, which are only awaiting development. The peat production of the world amounts at present to from 9,000,000 to 10,000,000 tons a year. Russia comes first with about 4,000,000 tons; peat is used there for locomotives as well as in the factories. One of the largest cotton works in the world is located in Russia, and it uses peat exclusively as fuel. Most of the peat fuel of Sweden is used in the homes, but some is employed for industrial purposes. There are, for instance, in the province of Skane, two factories using peat exclusively as fuel. The quality of the Swedish peat is excellent, yielding an inconsiderable percentage of ashes. Moreover, the moors of Sweden are high and easy to drain. No other European country, excepting Russia, possesses such an abundance of good peat.

"The important question is the cost of manufacture. According to one calculation (in 1901) this is on an average of 81 cents (3 kronor) per ton for unsheltered peat, to which must be added 27 cents (1 krone) per ton for transportation and shelter. This would make the cost of the peat at the place of consumption $1.07 per ton, which is equivalent to coal at $2.14 per ton. For machine-made briquets, the rate (free on cart from the moor) was $1.34 to $1.61 per ton.

"Compared with the present prices for wood and coal, peat is unquestionably the cheapest fuel. One cord of pine wood must not cost more than $1.07 if it would compete with peat at the above-mentioned rate. If 1 ton of hard coal is equal in fuel value to 1.8 tons of peat (the trial results vary between 1.6 and 1.8), the calculated peat price would be equal to a coal price of $2.89 per ton—a price at which coal cannot be bought in Sweden. The government railways, which are the largest consumers of coal in this country, and consequently are able to buy cheap, have, during many years, paid on an average $3.75 per ton at the port of landing

"The government and parliament manifest comprehension of the great importance of the peat industry. The trials of firing with peat on the Swedish government railways, have, according to the official report, shown that peat is about as expensive as English coal, when the rate is $2.50 for the former and $4.29 for the latter, exclusive of freight charges and the cost of loading on the tenders of the locomotives."

Engineer Alf Larsson, at a meeting of the Association of National Economy, at Stockholm, in a lecture on "The Use of Our Peat Bogs," is reported to have stated as follows:

"Russia yearly produces 4,000,000 tons of peat, and the Russian Government receives $938,000 per annum for leasing peat bogs; Germany produces 2,000,000 and Holland 1,000,000 tons; Austria, Denmark, Iceland, and other European countries also utilize their deposits of this cheap fuel; here in Sweden the production of peat for fuel is about 1,000,000 tons a year.

"Peat can be recommended as a very good fuel and its preparation gives employment to many persons in this country. Near Falkoping, for instance, about 1,000 persons are each summer employed in the industry. Peat can also be utilized as fuel by the paper mills, glass works, ironworks, brick kilns, and especially in the households. The government engineer for the peat industry estimates the supply of peat in Sweden to be 4,000,000,000 tons. The peat question is at present the most important problem in Sweden. The government has done some experimenting in the matter, with good results, but very much remains to be accomplished."

Briqueting in Great Britain.—Coal briquets for household use were first made in 1877. For many years the industry has been chiefly carried on in Wales, where the coal screenings are better adapted to this use than any other quality of coal produced in the United Kingdom. Fuel briquets are made to a limited extent in England and Scotland. The immense peat bogs in Ireland, stated to comprise one-tenth of the whole country in area, should warrant attention being given to the mechanical preparation of this fuel in the near future.

Reports from consuls show a moderate condition of the manufacture of briquets in England. Liverpool manufactures 2,000 to 3,000 tons annually at a cost of $4.87 (20 shillings) per ton, from bituminous coal dust. In Manchester, the few briquets used are made by the Whitefield Colliery Company, of Staffordshire. They are about the size of an ordinary brick, and their chief component is coal dust (slack), with a little tar added. The price at this place delivered was $2.43 (10 shillings) for 300 briquets, in December, 1902. At Sunderland, the Wear Fuel Works Company, Limited, at one time made briquets. The annual output was in number from 50,000 to 100,000. The materials used were bituminous-coal dust and pitch, the latter for combining purposes. The briquet presses were mainly constructed by the company itself, and two kinds were used—trough and table. One of the briquets that was manufactured by this company evaporated 14.4 pounds of water at 212° F., while the best North Country steam coal averages 14 pounds of water to 1 pound of coal. The selling price of this fuel was generally equivalent to that received for the best coal. There are a few other places in England in which briquets are produced in a small way; evidently, this manufacture has not yet attracted the attention of coal operators.

In the latter part of 1902, briqueted fuel was only produced in the Edinburgh district at the gasworks completed by the Edinburgh and Leith Corporations Gas Commissioners, at Granton, a suburb of Edinburgh. At these works, briquet machinery was utilized for the purpose of working up the coke siftings into fuel. This residuum of gas production heretofore was wasted. This briquet plant was erected at a total cost of $5,000, the price of the machine being $2,250. The press used is known as the Johnson type, Fig. 24, manufactured by Wm. Johnson & Sons, Leeds, England. It had a capacity of 5 tons per hour. The coke siftings were mixed with pitch and fed to the press, the briquets being pressed on both sides simultaneously, the pressure applied equaling about 2 tons per square inch. The plant worked satisfactorily, barring the tendency to clog when the material was a little too wet. The briquets weighed 4 pounds each, and were ready for immediate use as fuel, although it improved them somewhat to lie a week or 10 days in the open air. It was the original intention to use these briquets in the furnaces of the gasworks, but it was found to be better economy to place this fuel on the market for household purposes at $2.50 per ton, which price yielded a good profit. The Johnson press is said to be adapted, also, to lignite, bituminous coal and anthracite, charcoal, and peat.

Ever since they were introduced, briquets have been on the market in East Scotland. During the last 10 years, however, the consumption has gradually fallen off. Colliery owners in districts where the coal is all bituminous, who installed briquet plants, stopped the manufacture some years ago, as the local demand was not sufficient to warrant its continuance, especially in competition with large producers in West Scotland and North England.

Briqueting in Wales.—Consul Daniel T. Phillips writes from Cardiff, Wales, December 24, 1898, as follows:

"The manufacture of coal briquets known as patent fuel is conducted on an extensive scale in this consular district and elsewhere on the seaboard of the South Wales coal field, and, along with the general coal trade, is making headway every year. The first shipment at Cardiff was in the year 1859, when 4,700 tons was exported; and last year the total reached nearly 400,000 tons, to which must be added shipments from Newport and Swansea, augmenting the quantity named about 50 per cent. In fact, all the fine coal not used in the manufacture of coke—for which, by the way, the harder fine coals are not suitable—is utilized in making patent fuel, most of which is manufactured in this district.

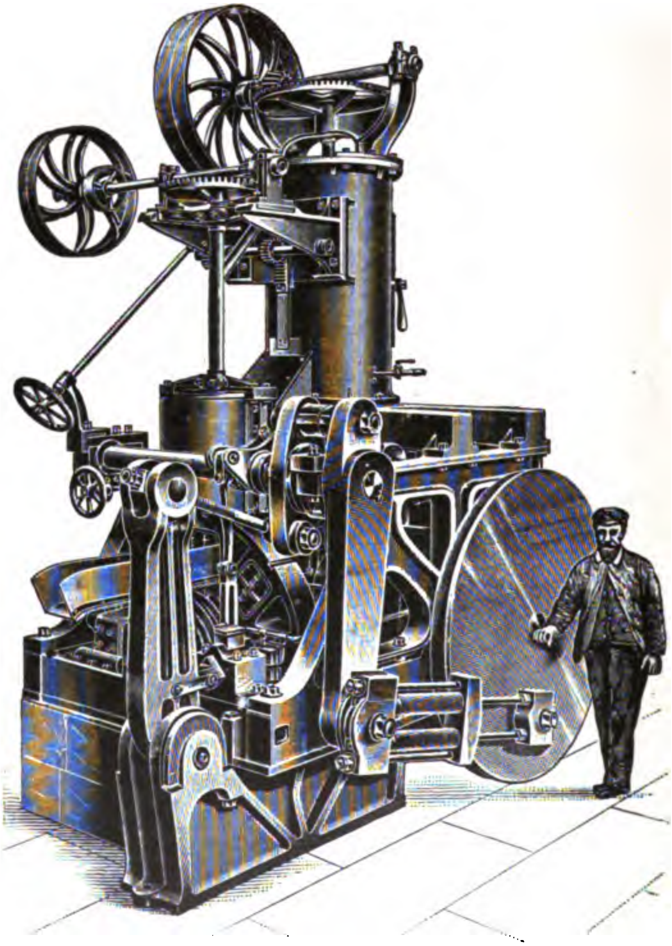


Fig. 24. Johnson Briquet Press

The exports are chiefly to European ports, at certain of which briquets are also made on the spot from the imported coal.

"A local manufacturer, Mr. T. E. Heath, says that thirty odd years ago the 'Coulliard' or ordinary French process was introduced into Cardiff, and, being found mechanically much more perfect than the old process—which was both slow and costly—soon became general. The great majority of fuel works here and abroad are merely modifications of the Coulliard. When the fuel is wanted for immediate use, it would be difficult to get a better; but a great objection arises from the steam being injected into the pug mill instead of having the mixture dried and heated by hot, dry gases. The steam condenses in the mixture of coal and pitch, and the blocks, when pressed, contain, therefore, not only the original moisture, very much increased in wet weather, but also the condensed steam that has been used to heat the mixture. As the blocks come from the press, and for hours afterwards, they are visibly giving off vapor, and this goes on in dry weather until the briquets become more or less porous; consequently, if it rains, as is usually the case, and they are afterwards exposed to frost, they fall to pieces. Such fuel cannot be stocked without disintegration and considerable loss of calorific value; whereas, fuel made by a dry-heat process, which drives out the original moisture instead of adding to it, will remain for an indefinite period as sound as on the day it was manufactured. In fact, the fuel is thus superior to the best Cardiff steam coal, which loses, by exposure, more or less of its evaporative efficiency, as the pitch in the dry-heat fuel prevents the ingress of moisture and the egress of gases.

"In this district, not so much attention is paid to the mechanical preparation of the coal used in briquet manufacture as in the various districts on the continent of Europe, where the coals are of a much poorer quality than those mined in South Wales. Once the due proportion of pitch for any class of coal has been found, the question of mixing becomes simple. A briquet is a compressed mixture of fine coal and pitch. The quantity of the latter varies according to the bituminous matter in the coal; the greater the amount of bitumen present, the less pitch is needed. The former, being adhesive, performs to some extent the same function as the latter; but the average proportion of pitch used is from 7 to 9 per cent. The preparation of the coal is limited to screening at the colliery and afterwards reducing it to as fine a condition as possible in a disintegrator, from which it is conveyed to the mixer. Here it meets the pitch, and is then taken to the heater. In each process, the coal and pitch are intimately intermixed. In what is termed the melted-pitch process, the pitch is melted (sometimes with additions of common tar) prior to being added to the coal. In the dry method, which finds more favor, the pitch is ground up with the coal in a dry state, both being heated as nearly as possible to the firing point of the pitch, in an externally heated chamber, until each particle of coal is covered with a film of melted pitch and so rendered fit, for compression into blocks. The mixture of paste is said to contain from 3 to 5 per cent. of moisture, in order to facilitate the sliding of the particles of coal on each other during compression; but, manifestly, the heat causes such moisture to be thrown off quickly. After having been thoroughly mixed, the whole passes out of the chamber into a bin, whence it is conveyed in buckets of suitable size by means of an endless chain or belt to the press.

"The compressing machines used may be roughly divided into three classes, irrespective of the nature of the power employed. These classes are: First, the single-compression machines, under which head should be placed the 'Mazeline,' 'Stevens,' and 'Dupuy' presses; second, machines compressing on both sides of the briquet, such as the 'Middleton,' 'Biétrix,' and 'Veillon'; third, machines acting by the tangential pressure of rolls, like that of 'Fouquemberg,' and those of the sausage-machine type, such as the 'Bourriez' press.

"As far as this district is concerned, the single machines appear to be common and the shape of the briquet is rectangular. The best-looking kind that I have seen is the 'sausage,' being about 5 inches in diameter and to all appearance a solid piece of bright carbon. The rectangular blocks chiefly exported weigh from 20 to 25 pounds; and, as some markets demand smaller sizes, a division plate is inserted in the mold employed for the larger size, thus reducing it by one-half. For obvious reasons, the 'ovoid' form of briquet is common, because there are no corners to chip off in the handling.

"Hot from the press, the briquets have little cohesion, and must therefore be treated with care in stocking and in loading. The endless belt saves a deal of labor both at the factory and at the ship's side, the donkey engine in the latter case being utilized in working an endless 'hopper' at the side of the vessel, so that while one laborer is putting briquets on at the bottom, another laborer is employed in taking them off at the top and handing them to the loaders on the vessel.

"Inquiries as to the cost of labor, fuel, supplies, and maintenance of a briquet factory show an average of half a dollar per ton, exclusive of the cost of materials.

"It should be noted that almost any resinous or tarry matter may be used. For instance, seaweed boiled in water for some hours produces a glutinous mass, and acts as a good binding material if mixed with the coal dust in the pan. Again, fine sawdust, in the proportion of 7½ per cent., mixed with the coal dust before going into the pan, improves the quality of the briquet. Of course, the quantity of each binding material can be best ascertained by experiment. Locally, 'soft medium' pitch is used. Pitch, being a waste product, is subject to fluctuation, both in quantity and in price; and at times a pitch famine, as in the year 1895, sends the price so high as to make the manufacture of patent fuel unprofitable. The inventive American has here an opportunity to make a fortune by providing a satisfactory substitute for pitch.

Such substitutes as have been tried are said to have added 1 or 2 per cent. of ash, and, besides, the fuel made by them goes to pieces in the first shower of rain.

"In many parts of our coal-producing states, immense dumping grounds of unused fine coal might be utilized; and the one reason given by coal operators for not turning their attention to artificial fuel is the scarcity of pitch. This would not apply generally, and where pitch is obtainable at a moderate cost, it is to be hoped that immediate attention will be paid to this manufacture, and that elsewhere serious efforts will be made to invent a substitute which can be produced in unlimited quantities at a comparatively small cost.

"It is claimed for patent fuel that it is about twice as hard as coal and, in some works, the minimum cohesion allowed is 83 per cent. of lumps to 17 per cent. of dust, the test being made in a revolving apparatus in which square chunks of fuel are picked up and let fall upon an iron bar screen. According to Mr. Heath, large coal in similar chunks, tested in the same machine, gives only 40 per cent. of lumps and 60 per cent. of dust; and he tells of a cargo of fuel, the cohesion of which was 83.10 per cent., shipped for a long voyage to a hot climate, which had a breakage of only 2.13 per cent. and a wastage of .88 per cent., although the shipment was made in very wet weather.

"With regard to calorific qualities, local experiments cited by a Mr. Colquohoun show, in three tests, 8.41 pounds, 8.77 pounds, and 8.99 pounds, respectively, as the weight of water evaporated from 1 pound of fuel at 212° F., the average evaporative power of several of the best Welsh steam coals being 9.33 pounds; so that the artificial fuel is almost equal in this respect, besides occupying less space.

"In order to compete with Cardiff in the South American trade, advantage should be taken of local experience in briquet manufacture. Those who intend to enter the patent-fuel trade will find several firms in South Wales prepared to accept orders for complete plants. One well-known firm is the Uskside Engineering Company, the managing director of which is a Mr. A. J. Stevens, who has had considerable experience in this line, the postal address being Newport, Monmouthshire.

"As to the cost of the fuel here, I can only say that the market price is determined by that of coal itself, the normal figure being slightly under $2.50 per ton, or about 50 cents below the present figures. In conclusion, I desire to emphasize the desirability of establishing the manufacture of patent fuel in the United States, as I foresee that it will be developed into a most important industry."

Briqueting in Canada.—A number of conditions have encouraged fuel briqueting in Canada, particularly in the Province of Ontario where there are practically no deposits of coal, and, on the other hand, where there are peat bogs of greater or less size widely distributed. What Ontario lacks in coal beds is made up by her wealth of peat bogs, which, in extent and wideness of distribution, are probably not exceeded by those of any other country of equal area. There is practically no fuel briqueting in other parts of Canada. In addition to the abundance of peat in bogs, the briqueting industry has been stimulated by a scarcity of anthracite and bituminous fuel, on the occasion of strikes in coal fields supplying Ontario with these forms of fuel. Also, the splendid hardwood forests of Southern Ontario have been almost destroyed, making it necessary to depend on other sources than wood for fuel. Among those who have been particularly instrumental in placing the peat manufacture on its present high level in Ontario, are Mr. Alexander Dobson, of Beaverton, and Mr. J. M. Shuttleworth, of Brantford; also, Mr. A. A. Dickson, of Toronto.

It is stated that the European practice, although successful under special circumstances, notably cheap manual labor, cannot be profitably followed on this side of the Atlantic. Only bogs of an average depth of 4 feet and upwards and of considerable area (at least 100 acres), should be selected, on account of the expense of the briqueting plant. Two principal systems are defined in making machine peat, depending on the treatment of the raw material immediately on raising it from the bog. One plan is to digest the peat, with the addition of water, into a liquid mud, which is then poured into molds in the open air, and after losing some of its water, divided into blocks and allowed to dry. This product is sometimes called "knead" peat. The other, and more commonly employed process, consists of grinding or mincing the peat, as it comes from the bog, into a soft, plastic mass, which is then cut into bricks and dried.

Among the prominent peat bogs in Ontario are the Welland and the Beaverton bogs. The Welland bog is about 6 miles from the town of Welland on the Welland Canal, and is owned by the Peat Industries, Limited, of Brantford. It covers an estimated area of 4,000 acres, and varies in depth from 3 to 7 feet, averaging probably 5 feet. The Beaverton bogs cover an area of about 100 acres near the town of Beaverton, and are owned by Mr. Alexander Dobson, of that place. The factories at these two bogs are characteristic of peat manufacturing plants in Ontario, and a brief description will be given of the methods in use at them.

The three divisions in which may be grouped the various operations comprising the making of fuel peat by what we may call the Canadian process are: (1) excavating; (2) drying; (3) compressing. Various methods are adopted for carrying on all these operations according to the nature of the bog and other controlling circumstances; but it cannot be too strongly stated that the crux of the manufacture lies in drying the raw material.

The difficulty consists not merely in getting rid of the water, but getting rid of it at reasonable cost. It is at this point that numberless promising processes have broken down, and it is this essential feature of manufacturing that requires unceasing vigilance on the part of the peat maker if his product is to be satisfactory.

Peat bogs are of two classes, wet and dry. In a permanently wet bog, the peat is submerged in water that does not admit of being drained away. A dredge floating on the bog excavates the peat in trenches, and then follows into the paths thus cut for itself; scows accompany the dredge, each carrying a number of boxes in which to load the peat. The scows are towed to a point from which the boxes are conveyed to the works where the peat is to be treated.

For dry bogs, different methods are required. The word "dry" as applied to a peat bog does not mean the absence of water, but rather that the bog is not submerged and is capable of being drained. The first thing to be done is to get rid of the surplus water, for which purpose drains or ditches must be dug.

At the Welland bog, the following system has been adopted: Two or more parallel drainage ditches are run through the length of the bog 660 feet apart and 10 feet wide. They are sunk through the peat into the clay underlying the bog, and conduct the water to the county ditch with which they connect. A series of cross-ditches is now run at right angles to the first, intersecting them at intervals of 50 feet until a plot of working area 660 feet square, or 10 acres in extent, has been ditched and drained.

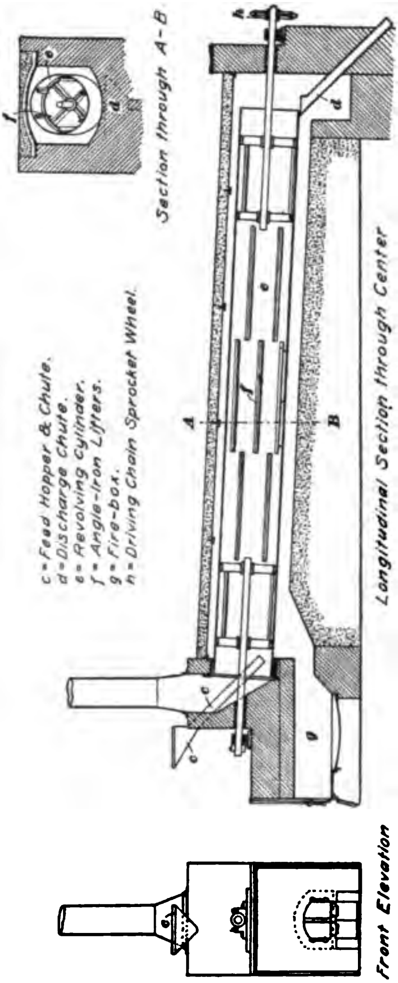


Fig. 25. Dobson's Peat-Drying Machine

At nearly all of the other bogs in the province where peat-fuel manufacture has been attempted, drainage has been necessary, the expense per acre varying with the depth and size of the drains. After draining, the light, growing, or undecomposed moss is removed, together with protruding stumps and roots of trees, and a level surface is prepared for the digging or excavating process, which comes next in order. The laying of light tramways on which to haul the peat into the factory is the next preliminary.

Usually the first step in the actual harvesting or gathering of the peat is to run an ordinary farm harrow over the surface and expose a thin covering of peat to the action of the wind and sun. This plan is employed where stumps and roots are numerous, as on the Welland bog. When dried down to a water content of about 45 per cent. the peat is scraped by hand over to the tramways and loaded into cars to be transported to the factory.

At the Beaverton works, the peat is conveyed from bin or stock pile or deposited directly from the tram-car. The air-dried peat passes into the hopper of the "breaker" or disintegrating machine, where it is subjected to a manipulation that breaks up the peat fibers, thus permitting the remaining moisture to be more readily liberated in the drier. Dobson's drying machine, Fig. 25, consists of a circular sheet-iron box, incasing a horizontal shaft from which project radial cast-iron arms about 1 foot in length. The Dobson drier is the distinguishing feature of the Beaverton works. The principles it embodies are: Applying the greatest heat to the exterior of the upper end of the cylinder where the damp peat enters; causing the flames and hot gases to pass along and about the outside of the revolving cylinder, to the lower or rear end before entering, and then to pass back through the interior of the cylinder, traversing the showering peat; arranging an internal system of lifters so that this showering of the peat will be continuous and uniform from side to side of the cylinder; slightly pitching the

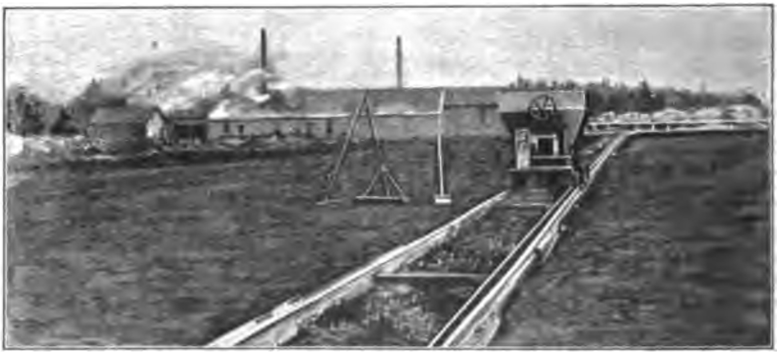


FIG. 26. PEAT DIGGER

cylinder so that, as it revolves, the peat will travel slowly toward the discharge end; and so adjusting the firing in accordance with the proportion of water present in the peat that a product uniform in moisture content will be the result. One test of this drier for a day of 10 hours gave the following results: Weight of air-dried peat charged into drier, 29,300 pounds, containing 34.21 per cent. water; weight of peat discharged from drier, 23,000 pounds, containing 16.61 per cent. water. The weight of water evaporated was 6,300 pounds.

The Beaverton method of excavation is entirely different. After the bog is drained and leveled, a mechanical and electrically driven digger, Fig. 26, is set at work, which travels slowly up and down one or both sides of the area under removal, the excavating device working in the side or wall of the ditch.

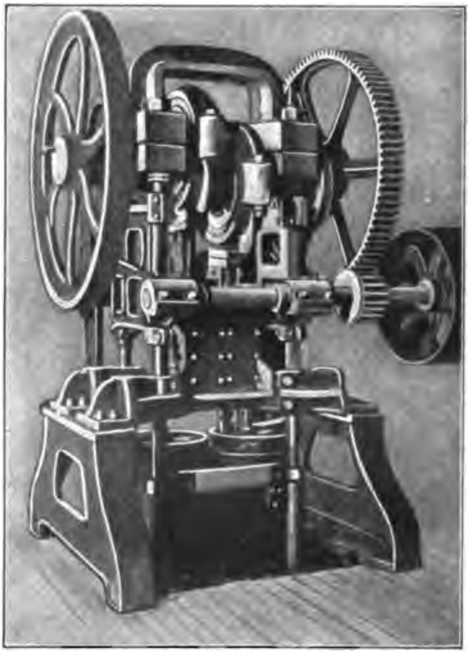


FIG. 27. DICKSON BRIQUET PRESS

At Beaverton, this excavator, or harvester, digs, pulverizes, and spreads the peat at one operation, only one man attending to a 15-horsepower motor, which handles from 100 to 150 tons in 10 hours. The harvester consists of an endless chain with special buckets and cutters, which cut the peat the entire depth of the bog and elevate it to a point about 8 feet above the bottom of the bog. The machine is so arranged that it can cut any depth down to 4 feet, the depth being easily controlled by the raising or lowering of the lower end of the case containing the endless chain with the cutters. The spreading of the peat on the dry top of the bog is the most important part of the work, as tests show that the moisture can be reduced to about 36 per cent. after several hours' exposure on a good drying day. The whole machine, the harvester and spreader combined, is driven by a 6-horsepower electrical motor. The rate of travel is from 3 feet to 3 feet 6 inches per minute, and the width of the cut is 12 inches. Loading the air-dried peat and tramming it into the factory complete the field operations as practiced at Beaverton.

The final step, in the Canadian methods of peat-fuel manufacture, is compressing the dried and powdered peat into blocks or bricks. It has been found that a cylindrical briquet, about 2 inches long and about the same in diameter, best answers requirements, and this shape is also a convenient form for manufacturing.

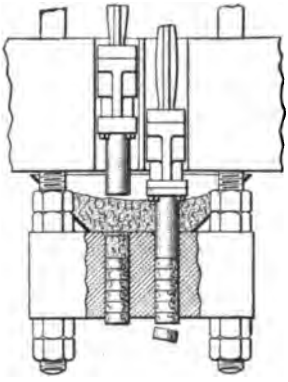


FIG. 28

The original briqueting apparatus employed in Ontario was of the open-tube type patented by Mr. A. A. Dickson, and known by his name, Figs. 27 and 28. It was first set up at Welland about 12 years ago, and since then the many modifications and improvements made by the inventor from time to time have been tested there. The principle of this press lies in the fact that if a tube of indefinite length be fed with any material, the resistance due to the friction between the material and the tube will gradually rise until no more can be forced in. Peat is of such a nature that, when once caused to pack in the tube, continued pressure on the material generates a rapid and great increase in the frictional resistance.

At the Beaverton works, the discharge pipe from the drier empties into the shoe of an elevator, which carries the dried peat into the large galvanized hopper or bin interposed between the drier and the briqueting press. This reservoir serves several important purposes, and is practically indispensable. It permits of a reserve supply in case of accident to the drier; allows the dried peat to cool; and enables the press attendant, by drawing from various parts of the bin containing material differing in degree of dryness, to send to the press a supply of peat practically uniform in water content.

The resistance block press in use at Beaverton is the result of 4 years' experiments carried on by Mr. Dobson. The press embodying Mr. Dobson's own idea on the plan of the Dickson press, is in use at the Beaverton plant. In the Dobson press, Figs. 29 and 30, friction is almost entirely eliminated, each die, previous to being recharged, being oiled to prevent friction of the peat against the die wall in the subsequent expulsion of the briquet. A number of dies are employed in this press, allowing the briquet to remain in each die during one cycle; it is then subjected to pressure and expelled. The following is a description of the machine: There are two punches in each machine and to each punch a die block containing eight snugly fitting dies. The down thrust of the punches is imparted by two heavy eccentrics faced with roller bearings, and with each stroke of the punch the die block is turned through one-eighth of a revolution. Working in the next die to the compressing punch is the release punch, which expels the finished briquet, while the third receives an oil swab that coats the inside of the die with a film of crude petroleum, to lessen the friction and facilitate the expulsion of the briquet.

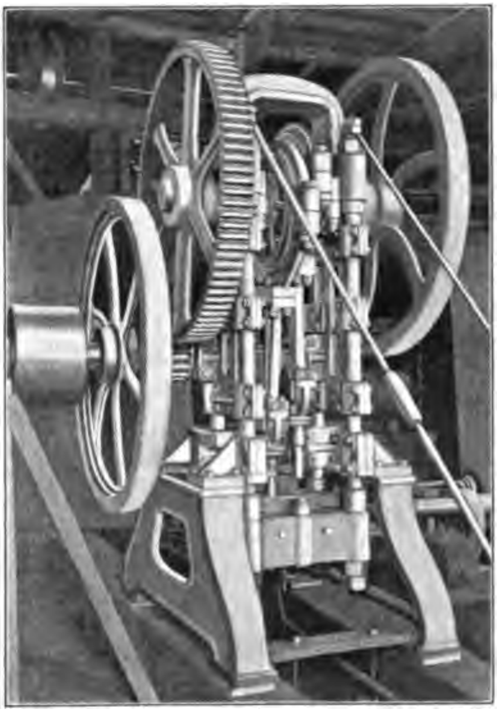
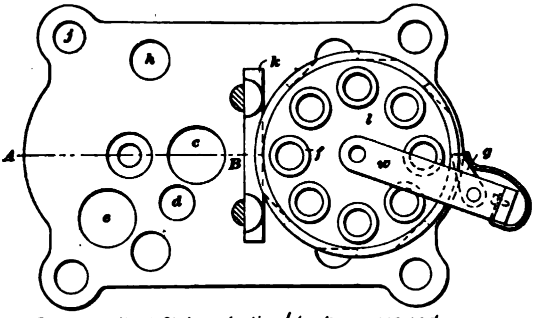


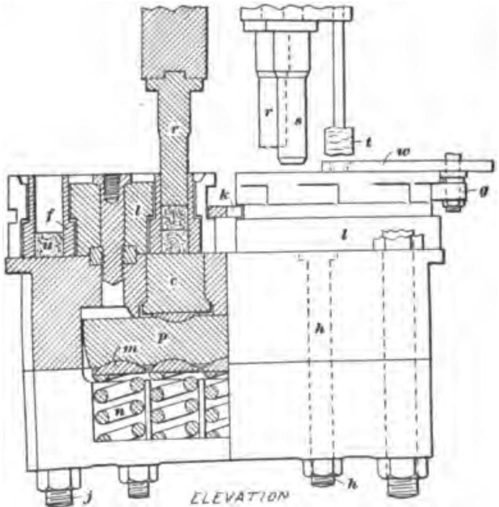
FIG. 29. DOBSON BRIQUET PRESS

The two punch systems of the press act reciprocally, a stroke being delivered at every half revolution of the eccentric shaft. With each down stroke, the compressing punch forms a briquet on the top of one previously made in the same die, the discharging punch expels from the next die the bottom or completed briquet and the third die receives the coating of oil from the oil swab. It makes 50 or 51 revolutions per minute, producing 100 or 102 briquets per minute. Twenty-five briquets weigh about 10 pounds, and consequently the output of the press in 10 hours is about 12½ tons finished fuel.

We now take up the cost of manufacturing the briquets, both at Welland and Beaverton. At Welland the workable depth of the bog is 3 feet as against 2½ feet at Beaverton, which gives an advantage to the former in price per ton of fuel; also, at Welland the capacity of the two briqueting presses is considerably greater than that of the one at Beaverton, while at each the expenditure for labor is about the same.



PLAN, with left-hand die block removed



Left half, with die block in place in vertical section through A-B

FIG. 30

At Welland, 17½ tons of briquets per day cost as given in the following table:

COST AT WELLAND

	Per Ton
Field operations	$.3771
Attendance on drier	.1650
Attendance on presses	.2171
Power	.2113
Total	$.9705

Wages have gone up since the Welland tests were made, and laborers now get at least $1.40 per day. This advance will add proportionately to the cost of manufacture.

At Beaverton, 12½ tons of briquets per day cost as shown herewith:

COST AT BEAVERTON

	Per Ton
Field operations	$.3911
Drying	.3673
Briqueting	.2512
Total	$1.0096

In neither case do the above figures cover more than actual operating costs, nothing being allowed for interest on capital invested, wear and tear of machinery, royalty charges, or profits.

COST OF PLANT

Machinery, Etc.	Cost
Briquet press	$2,500
Drier	1,350
Breaker	400
Excavator, including motor	600
Generator, tram car, motor, and tracks	1,200
Engine and boiler, 50 horsepower	2,000
Shafting, belts, and conveyers	700
Buildings (brick)	1,500
Sundries	200
Total	$10,450

The above is the cost of the plant according to the Beaverton plan, with a capacity of 3,000 tons of briquets per year, working 10 hours per day, or 6,000 to 7,000 tons when run continuously 24 hours per day.

In the following figures an attempt is made to include all items of cost such as those for depreciation, interest, etc., which can only be approximate.

TOTAL COST OF BRIQUETS

	Per Ton
Manufacturing	$1.0006
Cost of bog	.0180
Depreciation of plant	.3483
Interest on capital	.1741
Royalty	.2500
Total	$1.8000

The price at which this Beaverton product sold at the factory in 1901 and part of 1902 was $3 per ton.

It is necessary at these plants, for the continuous operation of the works the year round, to harvest, semidry, and stack during the summer a sufficient supply of peat for the months when harvesting is impossible. Another fact in connection with peat-fuel briquets is that the manufactured product must at all times be kept dry. Contact with water renders the peat practically valueless as fuel; hence, the care in preparing and housing it is of the utmost importance.

Briqueting in the United States.—The United States of North America has been so amply endowed by the Creator with excellent mineral fuels, covering areas aggregating 344,450 square miles, that thus far very little attention has been given to the utilization of coal waste, screenings, bog carboniferous mud, and other combustible matters, in their manufacture into briquets. With this great abundance of good mineral coal so widely distributed, it may be submitted, as a general principle, that from its moderate cost, ranging from $1.50 to $6 per ton, it is evident that, except in special localities, the manufacture of combustible matters into briquets could not be made with profit in competition with the coal.

Efforts have been made in Canada to briquet bog material, as already described, but at the low rate of manufacture there attained, on account of the reduced heating power of peat briquets as compared with coal, the latter would command the preference in the United States.

Some efforts have been made to manufacture briquets from coal screenings and coal dust, but these so far have not been distinguished as successful enterprises. Even with coal screenings at 50 to 60 cents per ton, using 6 to 10 per cent. of pitch for bonding matter at $12 to $13 per ton, with the necessary labor in preparation and manufacture, the cost of briquets would probably reach $2.25 to $2.75 per ton.

At the Hazleton meeting of the American Institute of Mining Engineers, in October, 1874, a Mr. Loseau exhibited some egg-shaped briquets made from anthracite culm or waste screenings, but this exhibit failed to impress its value at that time. Undoubtedly, thousands of tons of this culm have been wasted. This material affords when washed the best substance for the manufacture of briquets, especially for domestic uses. Even now it offers a practicable field for this industry. The culm produced from the usual annual output of 50,000,000 tons of anthracite affords an ample supply of this material for several briqueting plants.

About the year 1890, the Lehigh and Wilkes-Barre Coal Company, at Audenreid, Pennsylvania, installed a large briqueting plant to make briquets from anthracite culm. The culm was received in a large storage bin, from which it was elevated to an automatic mixer, into which 5 to 10 per cent. of pitch was thoroughly blended with the culm. From the mixer this compost was conveyed to a cylindrical drier and thence to the briqueting press which made briquets 4 in. × 4 in. × 9 in. When thoroughly dried, these were tested in the small locomotives at the mines, but did not prove successful. It was concluded that the briquets were too large and smaller sizes were made, but these, also, on trial, were not considered a success. The plant was therefore abandoned. After being out of use a year or more, Mr. Thomas A. Edison came to Audenreid and looked over the plant and purchased it. He removed it to his magnetic iron-ore plant in New Jersey, where it was used in making briquets from the magnetic iron-ore dust, until the whole plant was abandoned.

Next to the anthracite culm waste, the waste of breeze at the several coke works offers very desirable material for the manufacture of briquets. About 2 to 3 per cent. of breeze is made in the manufacture of coke. As the United States produced, in the year 1902, 23,090,342 net tons of coke, the amount of breeze at the low estimate of 2 per cent. would be 461,806 net tons of clean coke dust for briqueting. All or nearly all of this is at present wasted. It is quite probable that this coke breeze could be secured for the removing of it from the coke works, or at most at a mere nominal price. Briquets could therefore be made at a moderate cost. Briquets made from anthracite culm and coke breeze would be very nearly smokeless, the only smoke-producing substance being the pitch used in bonding these materials.

Much of the great lignite deposits of the United States could be manufactured into briquets with a minimum percentage of the binding materials. This would compact this fuel and render its handling and use quite acceptable.

In connection with fuel briqueting in the United States, Consul-General Frank H. Mason, of Berlin, Germany, under date of November 20, 1902, reported as follows: "The correspondence received during the past month from nearly every state and territory of the Union, making inquiry concerning the machinery and processes employed in Germany for making fuel briquets from lignite, peat, and coal dust, indicates that public interest in the whole subject of utilizing the hitherto wasted or neglected fuel materials, so abundant in America, has been thoroughly aroused.

"There are in New England, Western New York, Michigan, Illinois, Wisconsin, Oregon, Washington, the two Dakotas, and the Gulf States, large deposits of lignite and material midway in character between lignite and peat, and there are in all the coal-mining states enormous quantities of bituminous dust and anthracite culm, all of which may, by the employment of modern machinery and processes, be added to the fuel supply of the United States." This is an industry in which the first tentative efforts made in the United States have generally failed, but which has been developed in European countries into an important and successful system of production.

Samples of lignite from near Bismark, North Dakota, and from Troy, Alabama, have been received at the German Consulate, turned over to a German briqueting syndicate, and molded experimentally into briquets with entire success. The Dakota lignite is old and hard, containing 38 per cent. of water, but crushes and pulverizes easily and forms, without binder, briquets of firm structure that burn readily, are practically smokeless, and leave only 4 per cent. of ash, while the best German brown-coal briquets yield from 9 to 12 per cent. of inorganic residue. The percentage of water contained is rather low, but by adapting the heating and drying process to that proportion of moisture, this obstacle, such as it is, can be easily met, and the reduced task of evaporation will be an economy in the general process. The Alabama lignite, on the other hand, is an ideal material, and from the one sample submitted, it is conceded in Germany to be even superior to the standard brown coals of Germany. It contains the direct percentage of moisture, crushes easily, and molds readily into firm, shining, black briquets. The importance of these simple demonstrations will be inferred from the fact that, according to a recent State geological report, there are 55,000 square miles of lignite beds in the Dakotas and Montana, all near the surface of the ground, and ranging in depth from 20 to 80 feet. The extent of the lignite deposits in the Gulf States is perhaps less exactly known, but they certainly cover a large area.

When, some 10 years ago, the attention of American iron makers was called to the German system of making blast-furnace coke in retort ovens, which save the valuable volatile elements of the coal, it was thought worth while by certain of them to bring over two carloads of Connellsville coal to be coked as a test by the German process. The complete success of that experiment decided the introduction of the standard German type of coking ovens in the United States.

Something similar, it would seem, might profitably be done with the materials that Americans have not yet succeeded in converting into satisfactory briquets. There are experienced engineers and a dozen manufacturers of briquet-making machinery who would gladly cooperate in these tests and would furnish machinery adapted to working the material thus technically defined. Upon a basis of such tests, plans and estimates could be obtained for the erection of plants in the United States with specified daily capacity.

As a result of the present widespread interest in this subject and the many inquiries that have been received from mine owners and operators for technical information as to processes, cost and capacity of machinery, etc., a combination has been formed between three of the foremost machine builders in Germany, whose products collectively include all the necessary apparatus for making briquets from coal dust, brown coal, and peat. The purpose of this syndicate is to meet promptly and efficiently the American demand for machinery and working methods, which represent the best results obtained by scientific study and mature experience in Germany. The combination is entitled "The Export Syndicate of Briquet Machinery Manufacturers," with central office at No. 59 Friedrich Strasse, Berlin, and includes as members the Zeiter Eisengiesserei, at Zeitz, Saxony, the Maschinenfabrik Buckau, at Magdeburg, and the Maschinenfabrik, at Ehrenfeld, Cologne.

An opportunity will be thus offered for American mine owners and operators to ascertain definitely in advance the theoretical value of their materials for briquet making and the cost of a plant of a given daily capacity.

Meanwhile the same results can be reached with important saving of time if owners of coal mines or lignite beds will send to the above address, directly or through the Berlin consulate, 10-pound samples of their material in the exact condition in which it will be available in large quantities for practical use. The percentage of water in any briquet material is an important factor in determining how it best can be worked.

If the material is dry—as, for instance, slack from a well-drained bituminous coal mine—the sample may be sent in an ordinary box or package. If, on the other hand, the slack or culm is obtained wet from a washing process, or if the material is lignite or peat from a bog, the sample should be sent in a tight tin case, which will preserve the exact percentage of moisture that will be encountered when it is mined for use on an industrial scale.

The postal-package treaty between the United States and Germany provides for the transmission, by post, reciprocally, of packages not exceeding 5 kilograms (about 11 pounds avoirdupois) in weight at a uniform rate of 12 cents per pound. Allowing for the weight of the necessary covering, this will enable interested persons in America to forward to Berlin samples of their material sufficient in quantity to be analyzed, submitted to various tests, and even made experimentally into briquets, so that its adaptability to briquet manufacture, the percentage of binder required, the calorific value of the product, and methods and machinery best adapted to working it can be ascertained and reported on in advance by responsible experts, who are prepared to follow up their estimates by practical operations. In this way the technical experience and scientific knowledge that have made the briquet industry successful and important in Germany will be made directly available by American operators, who desire to begin at the point of economic efficiency that has been attained by the best practice in Europe.

In addition to the utilization of coal and coke wastes and lignite for the manufacture of briquets, there are, in the United States, large areas of bogs in the West, North, and Northeast that could be used in the production of briquets. Some of these bogs are accumulating at this time, especially in the North, where frequent rains occur. The whole operation of the growth of these bogs can be witnessed in Newfoundland, where the vegetable matter receives frequent drizzling rains, rotting the thick surface of the mosses and converting them into the black matter called peat.

Consul-General Mason reported the following in regard to peat in the latter part of 1903:

"There are in New England and in the Middle and Western States vast beds of peat that have been heretofore left neglected as waste material in the economy of nature. In Alaska and on the islands that lie along its shores—where the limited supply of coal brought from British Columbia sells for $20 per ton and men perish from cold for want of fuel—there is a practically unlimited supply of peat of the best quality, all of which would be available as fuel if carbonized and converted into coal or briquets. No process that includes air drying or works the peat at ordinary temperatures would be practicable there for more than a small part of each year—the brief arctic summer of that northern clime. If those vast deposits of fuel material are ever successfully utilized, it must be by some process similar to those herein described, whereby the peat is quickly machine-dried by means independent of the sun or wind and then carbonized by heat that can defy even the cold of an arctic winter. The electrical method will be first tried on an industrial scale in Ireland, an island which, with a total area of 32,393 square miles, has 2,830,000 acres of peat."

Dr. Edward Atkinson, president of the Boston Manufacturers' Insurance Company, has issued a pamphlet bearing on the briqueting of bog materials, and dated March, 1903. He says: "Consul-General Mason's reports give minute accounts with diagrams and descriptions of the machinery used. I observe, however, that the mechanism described is almost identical with the mechanism that I invented in 1867 for converting peat into briquets at the Indian Orchard Mills. The price of coal in that paper-money era being very high, we successfully worked a peat bog for many months in a boiler plant of mills of about 30,000 spindles, giving it up when coal went back to normal prices. But what we call peat, which is very full of hollow fibers of the grasses that grow on the top of the moss preserved in the peat, is very much more difficult to compress, and takes much longer to dry than this slimy, nearly homogeneous black mud from the Taunton River. Professor Norton is now having a machine made on my original plan for the conversion of this mud into briquets.

"The only claim that I make is to having called attention to what seems to me a great fact, namely, that the mud in the fresh and salt water meadows, as well as the peat in the peat bogs, may be regarded as a vast source of energy, requiring for its conversion into heat mechanical appliances rather than any other, so as to bring these materials into a semisolid shape, in which they may be converted into heat and power."

The Peat Fuel Company of America bought out a small establishment in New Haven, Connecticut, where coke was made for several years from salt-marsh mud taken from the sides of a tidal creek. This product has been made in a small way and sold in New Haven at full prices. The promoters have now moved the apparatus to a grass meadow and are opening bogs in Brookfield, Massachusetts, where the mud appears to be composed almost wholly of decayed grasses. The areas in this section are very large. This Brookfield bog, it is stated, has been sounded to a depth of 47 feet without reaching bottom. Fourteen hundred pounds, net weight, as taken from the bottom of a trial pit, yielded 800 pounds of fuel, bone dry. It is expected that this deposit will yield 500 tons of coke, or 1,000 tons of fuel briquets per acre, for each foot in depth below the sod. This mud is to be artificially dried, molded into hollow cylinders, and made in coke of first quality.

It is said that great deposits of mud are known to exist all over the United States: in the northern section, in the hollows of the glacial drift; in the West, in the swamp lands and in the sloughs or hollows of the prairies; in the South, in the hollows left by the great lagoons that covered an immense area when the waters of the Gulf of Mexico receded, and the lowlands or prairies of Texas, Louisiana, and all the other states up to the Ohio River, were slowly lifted above the sea level; and in the savannas and swamps of the eastern coast.

Messrs. Chisholm, Boyd, & Co., of Chicago, have given briqueting machinery considerable practical attention; but so far mainly in the interest of blast-furnace work in briqueting the iron-ore dust from the down-comer pipe. The bonding material in this operation is lime. The iron-ore dust with 1 to 2 per cent. of slacked lime (cream of lime) is thoroughly mixed and wetted into a pasty condition in a large cylinder mixer annex *a*, Fig. 31, to the briqueting machine. This prepared paste is passed into a large pan in which are heavy traversing rollers *b* immediately over a circular steel disk *c* perforated around its outward perimeter; the heavy rollers press the prepared material into these perforations in the circular movement of the disk. An arm *d* with two punchers removes the briquets from the large disk and delivers them on a conveyer *e* that carries them to any desired point, where they can be dried for use. It may be noted here that this briqueting machine is not confined to the treatment of iron-ore dust, but can be used in briqueting any materials that can be prepared for this purpose.

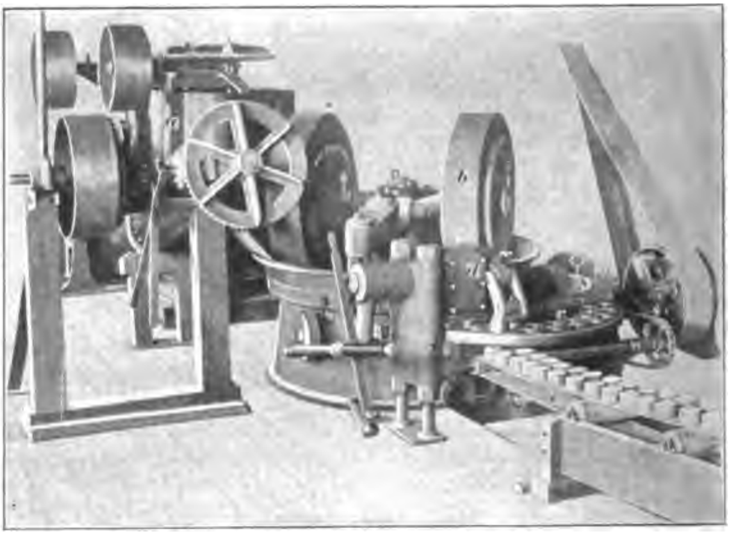


FIG. 31

The Henry S. Mould Company, of Pittsburg, Pennsylvania, is now making and testing briqueting machinery. The following description, with Fig. 32, shows the general plan of the White coal briqueting press and apparatus in which melted pitch is used as a binder. The process is shown commencing with fine coal in condition for briqueting. Where it is necessary to crush or screen the coal to bring it down to the proper size, this operation is done first and requires the proper crushing and screening apparatus.

The fine coal is automatically fed to the heater. This heater is built in several styles, some using steam, others using direct or indirect heat as best adapted to the coal to be operated upon.

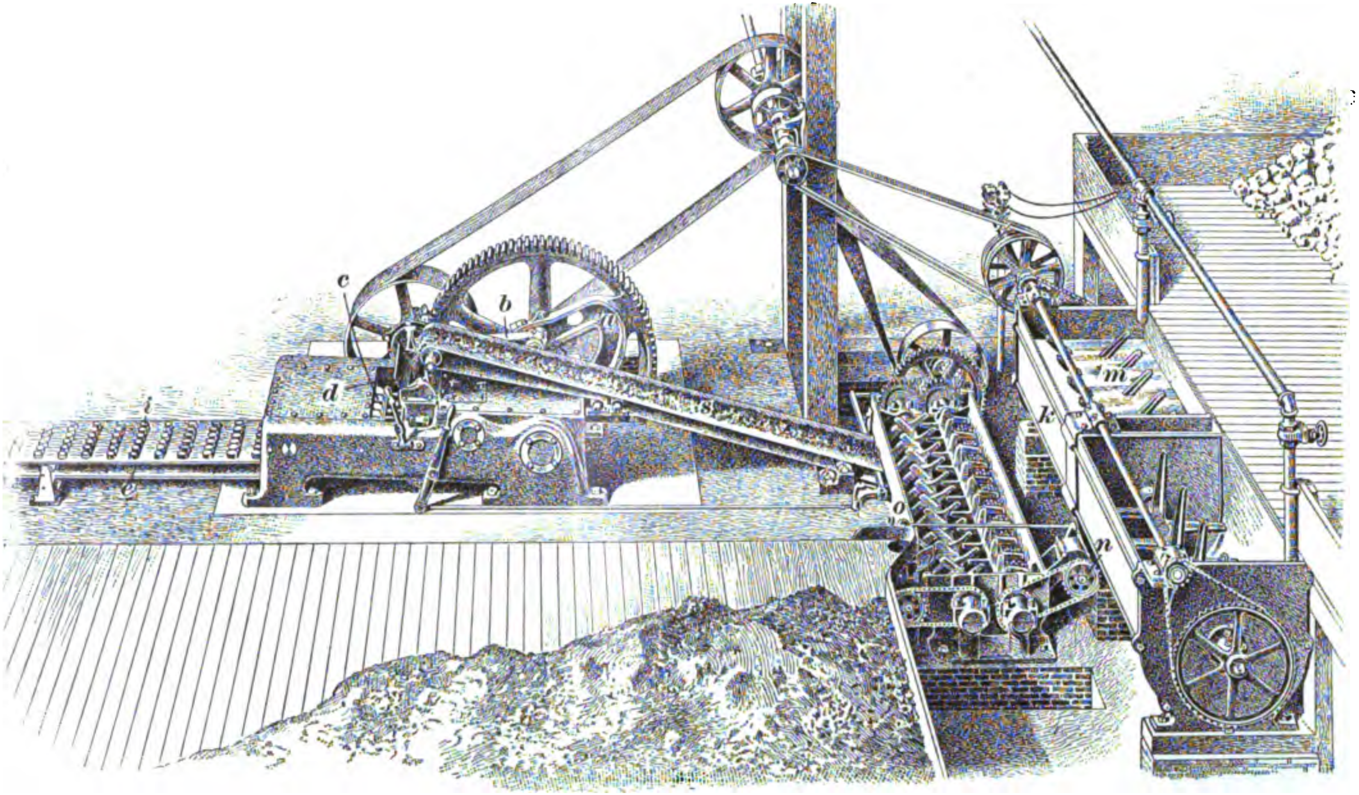


FIG. 32

The object of the heater is to eliminate all moisture and bring the temperature of the coal up to about 300° F. It is desirable to have the material at this temperature so that it will not chill and thicken the pitch when introduced into the coal, but become a plastic mass when properly mixed. From the heater, the fine coal is deposited at the end of the conveying mixer *o*. On a floor slightly elevated are two pitch tanks *m*, having steam pipes on the sides and bottom, the first one to melt the solid pitch and the second to keep the pitch in a melted condition for use. An automatic measuring device distributes the pitch in the proper proportion to the coal in the mixer. The mass is thoroughly mixed and conveyed from the mixer to hopper *d* of the press by feed-belt *s*. The briquets *i* are ejected on a carrier belt *e*, and with slight cooling are ready for storage bins or cars.

The pressing mechanism is very simple. A rotating crank *a* and pitman *b* move the compression plungers forwards and backwards with a movement exactly the same as that of the piston rod of an engine. The press box *c* has an independent motion, as it is operated by the cam-track in the gear through the cam-arm, rocker-arm, and links. The press box remains stationary at its rearward position, while the compression plungers pass across its interior space, pushing the material ahead of them and forcing it into the molds. This motion continues until the plungers have entered the mold a sufficient distance to compact the material into solid briquets under great pressure. The continued motion of the crank will now start the compression plungers forwards. At the same instant, the cam in the main gear causes the press box to move forwards at first with a motion exactly coinciding with that of the compression plungers, then with an increasing speed forwards, thus gaining on the receding compression plungers until their ends project slightly through the back ends of the molds. This motion ejects the briquets; and should they stick to the plungers, they are displaced by the knocking-off device and fall upon the delivery belt. The cam-track now returns the press box quickly to its normal, or rearward, position. The compression plungers at this time being at their forward position, new material falls into the press box ready for another compression. The motion of the press box in relation to the hopper above is such that it crowds the material downwards when moving rearwards. Hanging bars also swing through the material, breaking down any arch that may have formed over the plungers. An adjustment is provided whereby the compression plungers may enter any desired distance into the molds.

The entire operation is controlled by the press operator, one lever controlling the friction clutch pulley on the mixer, this latter lever also controlling the heater and pitch feed. For a single-press plant, besides the press operator, two men are required to take care of the pitch tanks and heater, and this is all the labor required from the point at which the fine coal is fed to the heater to the finished briquet on the carrier belt. In the double-press plant, the presses are built right- and left-handed, so that one operator can take care of both presses. The pitch tanks are enlarged so as to have capacity for both presses, and, where desired, a single heater of sufficient capacity will supply both presses. An additional man is required for the two-press plant. The pressure on the White briqueting press is adjustable, and from a light pressure to 20,000 pounds per square inch can be put upon the briquets. It is said that by means of heavy pressure it is possible to successfully briquet bituminous coals with from 4 to 5 per cent. of pitch, whereas from 7 to 12 per cent. is the best done in foreign practice.

The capacity of the press and size of the heater depend on the size of the briquets made. Four shapes of briquets can be made on the White press; and these presses vary in capacity from 50 to 120 tons per day of 10 hours.

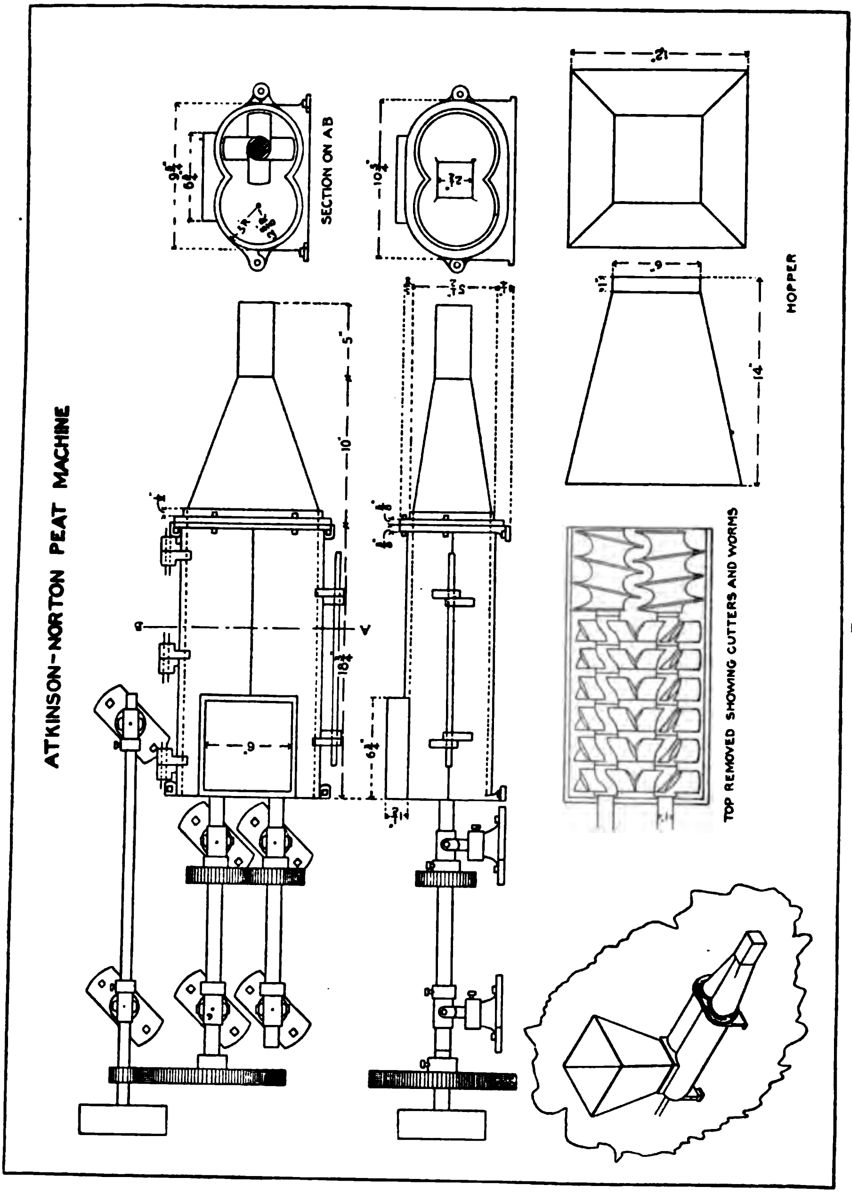
Another method of operation, known as the dry process, is where the pitch is broken up fine and mixed with the coal, the mass put through a disintegrator, then through a heater, and finally to the briqueting press.

The price of the No. 1 White briqueting press complete is $6,000, but it is difficult to give anything like accurate figures on a complete plant without knowing the binder or process to be used. The necessary apparatus outside of power and buildings, etc., for a plant to produce 12 tons per hour, would be from $35,000 to $40,000.

There are a number of binders that can be used in the production of coke briquets, some of which are secret mixtures and some patented. These binders vary in their effectiveness and also in their cost, ranging from 40 cents to $1 per ton of briquets. In a good-sized plant, the total operating cost should not exceed 10 to 12½ cents per ton of briquets.

During a recent visit to portions of Europe, Asia, and Africa, I noticed great heaps of briqueted fuel stored along the lines of railroads in these countries. It is used in Palestine on the railroad from the seaport of Jaffa to the city of Jerusalem, and in Egypt on the railway from Alexandria to Cario. In Continental Europe, it is freely used on most of the railroads, especially in Germany, Belgium, and France. It is also coming into use, in a moderate way, in the British Isles. The use of the briqueted fuel in generating steam in the locomotives appeared to afford ample power in the passenger-train service, but these, as a general condition, were quite short and light as compared with the long and heavy passenger trains in the United States.

In Ulster, Ireland, I was favored with briquet fuel in a small grate in my room. At this hotel, it was mixed with a small portion of coal. The heat derived from the briquets did not impress



ATKINSON-NORTON PEAT MACHINE

FIG. 33

me with a feeling of great warmth; just the opposite, and the smoke from the pitchy bonding material emitted fumes that were not at all pleasant. At this place, semi-bituminous coal for domestic uses cost $6 per ton, so that the utilization of the slack coal into briquets was a matter of economic necessity.

In conclusion, the following extract is given from a report on the production of coal in 1902, by Mr. E. W. Parker:

Prior to 1902, about 400 patents had been issued in the United States on artificial fuels, but up to the close of 1901 none had proved a commercial success. Mr. Parker gives a list of United States patents granted since January 1, 1902. It remains to be seen whether any of them will be successfully developed. The list includes 37 patents, but contains no mention of fuels made from petroleum or petroleum residue unless used in connection with coal, lignite, or peat. Neither does it include any compounds that have for their object the increase of fuel efficiency unless they are used in the manufacture of the fuel itself. Three patents were issued on briqueting machinery.

The steady advance in the price of coal—no less than 40 per cent.—which has taken place since 1898 has stimulated experiments looking to the invention of artificial fuels. Results obtained in foreign countries from the use of lignite and peat in briqueted form should encourage producers in the United States to try similar methods of manufacture. Small sizes of anthracite formerly wasted are indeed recovered now by washeries from the old culm banks and utilized. A large amount of coal lost in the form of dust or finely pulverized material might also be put into convenient shape for domestic consumption, and slack now wasted at many of the bituminous mines in the United States might be used to advantage if compressed into briquets. There are many indications that the time is not far distant when these neglected fuel resources will be utilized.

THIRD REPORT OF PROF. CHARLES L. NORTON UPON BOG FUEL

Since making the earlier report on the bog fuel, several new phases of the matter have developed. We have perfected our Atkinson-Norton machine and have manufactured or, as they say abroad, "machined" a great amount of peat in large and small lots. The details of the machine are shown in Fig. 33.

With the examination of the fuels brought to us to run through this machine we have found a number of interesting developments.

1. All the bog fuel appears to be capable of treating by maceration in this machine so as to develop a binder that causes the blocks of soft mud-like material to become, in drying, of about the density and hardness of hard wood.

2. The by-products appear to be much like the by-products of the European bog matter.

3. No satisfactory coke can be made without macerating and drying before coking, and even then the coke resembles charcoal, unless coked under pressure.

4. Many bog samples have been found that contain too great an amount of ash to be of commercial value.

5. Some of the best samples contain as large a percentage of volatile matter as 65 to 70 per cent., making them apparently of great value as producers of gas.

The machine, as will be seen from the drawings, Fig. 33, is much like the Swedish and German machines, and consists of a set of revolving blades and cutters incased in a closely fitting cylinder, together with a pair of Archimedean screws to force the bog matter on to the cutters and out through a conical nozzle. The whole arrangement is not unlike the ordinary sausage machine. There appears to be a certain ratio of cutting to grinding and squeezing, which gives the most dense and best drying blocks, and the success of any machine must depend in large part on its adaptability to the particular bog matter with which it is used. Those machines that are best suited to a peat full of roots and sticks are less suited for use with some of the softer and less fibrous masses. By varying the number of cutters and the relative positions of the forcing screws, the Atkinson-Norton machine is adaptable to a wide variety of peats and hence is useful in examining samples from different sources.

The machine is simple in operation, the fuel being dumped into the hopper, rammed down from time to time, and the finished product coming out in a continuous stream from the nozzle, is cut into blocks and dried on boards. In actual commercial practice, both the cutting and removing from the nozzle can be done mechanically. Until the machine is set up and run on the bog for some time, there is no way of estimating its output very closely, but it is probable that from 5 to 10 tons a day, dry fuel, can be got from the machine with a 2-horsepower motor.

The bog fuel, on coming from the machine, may be air-dried under ordinary conditions in from 2 to 6 weeks, and by supplying artificial heat in a much shorter time. The danger of cracking in drying may be diminished by regrinding through the machine from time to time a few bits of already dried peat along with the fresh charge of wet material. After thorough drying, the blocks are sensibly waterproof and they may be left outdoors without injury.

The bog matter that makes the densest blocks of the highest calorific power is usually of a brown color rather than a black, and it may or may not be fibrous. As has been predicted by several writers, the material highest in ash comes from the lower parts of those bogs that are the settling basins for rivers and smaller streams on considerably higher land and occasionally overflowing into the bogs.

To be of maximum fuel value, a bog should yield a fuel of high calorific power, have a small percentage of ash, and should dry to a low percentage of water. Yet perhaps more important is it that the bog should be capable of being drained, and of such depth as to make it worth while to erect a plant of considerable size, since it is apparent that larger plants will be relatively more economical. The small bog can only pay as a supply of "machined" fuel for a local market fairly remote from the coal fields, but that they have a future in that direction is my firm belief.

The direction in which we must look for the greatest development of bog fuel is in the matter of gas production. While we do not yet know fully the exact nature of or amount of gas from a very large number of American bogs, it is clear that gas in approximately the same amounts and of much the same kind as that got from soft coal can be produced from some of the New England peats. The gas is nearly free from sulphur, has a fair amount of illuminants, and unless it proves to contain too much carbon-dioxide is of great value for heat, light, and power purposes. We shall very shortly have some further demonstrations of the use of peat gas in large gas engines.

The matter of by-products has been given a great deal of attention by us, but it is of such a delicate chemical nature that we are still far from having at hand a list of all the by-products in measured amounts obtained from the peat and bog fuels.

There is evidently a considerable difference in the by-products of material from different bogs, among the most common, beside coke and gas, being ammonia, acetic acid, anthracene, creosote, carbolic acid, toluene, phenol, and pitch. The by-products of the material taken from the Taunton bog were found to be as follows: (1) tar containing carbolic acid, toluene, phenol, benzol, creosote, and anthracene, together with a residue of black pitch; (2) tar water containing ammonium sulphate, alcohol, and acetic acid; (3) gas, whose volume was approximately 4 cubic feet per pound of peat, and whose calorific power was about 654 British thermal units per cubic foot. Coal would yield perhaps 5 cubic feet of gas of the same heating power. The peat gas is richer in illuminants.

We are preparing to make an exhaustive examination on large samples, to determine as nearly as may be the money value of the total by-products.

During the summer, an unusual number of distinguished European scientists and engineers have visited the Institute on their way to or from St. Louis, and many have called attention to the less fibrous or woody conditions of the bog fuel we are using as compared with that with which they were familiar abroad. It may be that there is a difference in the final condition of the decayed hydrocarbon masses that will account for the great amount of volatile gas-producing matter in some of our peats, that is, 65 to 70 per cent., as compared with 40 per cent. for many European peats, and 35 per cent. for coal. Of course, these gaseous bogs contain very little fixed carbon.

Respectfully submitted,
CHARLES L. NORTON.

MASSACHUSETTS INSTITUTE OF
TECHNOLOGY,
BOSTON, MASS., U. S. A.
December, 1904.

INDEX

A

Acetic acid, Effect of, in removing sulphur, 40.
Adelaide coke, 282.
Advantages of different coal fields for location of coke plants, 396.
Alabama coal and coke, Analyses of, 120.
  Stewart washery in, 114.
  Washery at Brookwood, 75.
Alaska coal, Analysis of, 29.
Alleghany Mountain coke, 162.
American Coke Company's plant, 375.
Ammonia plant, 323.
  Yield of, 257.
Ammonium sulphate, Costs of manufacture, 403.
  sulphate, Market for, 401.
Analyses and coking qualities of Rocky Mountain coals, 10, 17.
  of Alabama coal and coke, 120.
  of Alaska coal, 29.
  of anthracite, 7.
  of Appalachian bituminous coals, 8.
  of Appalachian coking coals, 25.
  of British Columbia and Vancouver coals, 17.
  of brown coals of Texas, 12.
  of Central Field coals, 9.
  of Coahuila Coal Company's coal and coke, 18.
  of coal before and after washing, Table of, 113.
  of coal, washed coal, coke, and refuse, 98.
  of Connellsville coal and coke, 147.
  of Connellsville coke from beehive and Semet-Solvay ovens, 280.
  of Davis coal and coke, 270.
  of different gases, Table of, 246.
  of fuels, Table of, 37.
  of German coking coals, Table of, 33.
  of Illinois coal and coke, 186.
  of Kanawha Valley coal and coke, 147.
  of Michigan coals, 9.
  of Morris Run coal, 266.
  of Nova Scotia and New Brunswick coal, 16.
  of Pacific coast coal, 16.
Analyses of Rocky Mountain and Great Plains coal field, 17.
  of the several varieties of coals in the Pacific Coast coal fields, 13.
  of Thomas coal and coke, 271.
  of Triassic coals and cokes, 7.
  of Tuscarawas coal and coke, 335.
  of Welsh coal, Table of, 34.
  of Western coals, 12.
  of Westphalian coking coal, 244.
  Relation of, to coking properties, 31.
Anthracite, 21.
  Analyses of, 7.
  Compressive strength of, 360.
  fields, 5.
  fields, Structure of, 8.
  in blast furnace, 326, 354.
  necessary to make one ton of pig iron, 338.
  Physical properties of, 326.
  screenings, Briquets from, 410.
Appalachian bituminous coals, Analyses of, 8.
  coal field, 7.
Appolt coke oven, 212.
  coke ovens at Blanzy, 215.
Ash, Analyses of, 98.
Atkinson-Norton briquet machine, 473.
Atlantic Coast Triassic coal fields, 7.
Austria-Hungary, Briqueting in, 417.
Axioms, 199.

B

Bauer by-product coke ovens, 302.
Baum washer, 123.
  washing plant at Gladbeck, Westphalia, 128.
Beaverton, Peat plant at, 456.
Beehive and by-product coke, Comparison of, 326.
  and Semet-Solvay coke plants, Relative costs and economies, 284.
  by-product oven, 311.
  coke oven, 148.
  coke oven, construction of, Specifications for, 153.
  coke oven, Cost of making coke in, 346.
  coke oven, Yield from, 163.
  coke, Structure of, 282.
Belgian coke oven, 206.

Belgium, Briqueting in, 419.
  Cost of briqueting in, 422.
  Price of briquets in, 419.
Belt Mountain coals, 29.
Bennington, Belgium coke ovens at, 208.
Benzol, 404.
  plant, 325.
Berard's coal-washing machine, 63.
Bernard coke oven, 294, 379.
Bessemer metal, Coke required to smelt, 343.
Biétrix briquet press, 427.
Binders for briquets, 413.
Bituminization of coal westward, 23.
Bituminous coal, 21.
  coals, Analyses of Appalachian, 8.
Blanzy, Appolt coke ovens at, 215.
Blast furnace charges in coke tests, 285.
  furnace experiments, Semet-Solvay coke, 277.
  furnace fuels, from 1854 to 1902, Table of, 326.
  furnaces, comparative work of fuels in, Table of, 354.
  furnace tests, Table of results, 287.
Bog fuel, Report of Prof. Chas. L. Norton, 473.
Bourriez briquet press, 432.
Bradford coal breaker, 47.
Briquet binders, 413.
  factory at Lauchhammer, 437.
  fuel in Ireland, 471.
  machine, Atkinson-Norton, 473.
  machine, Biétrix, 427.
  machine, Bourriez, 432.
  machine, Chisholm, Boyd & Co., 467.
  machine, Dickson, 458.
  machine, Dobson 459.
  machine, Dupuy, 429.
  machine, Henry S. Mould Company, 468.
  machine, Johnson, 449.
  machine, Wiesner, 418.
  machine, Zeitz, 437.
  machinery manufacturers, The German export syndicate of, 465.
  machines used in Saxony, 437.
  material, Samples for testing, 465.
  presses, 414.
  press for egg-shaped fuel, 429.
Briqueting, 406.
  cost of, in Belgium, 422.
  in Austria-Hungary, 417.
  in Belgium, 419.
  in Canada, 453.
  in France, 422.
  in Germany, 433.
  in Great Britain, 448.
  in Norway and Sweden, 445.
  in the United States, 462.
  in Wales, 449.
Briquets, Anthracite, 410.
  Carboniferous mud, 412.
Briquets, Characteristics of, 407.
  Charcoal, 411, 418.
  Coal-slack, 409.
  Coke-breeze, 410.
  coke, Cost of plant for, 430.
  Cost of, in Canada, 462
  Cost of, in Germany, 439.
  Heating value of, 419.
  Lignite, 411, 464.
  Loss in handling, 409.
  Methods and costs of manufacturing, 417.
  Mud, 467.
  Peat, 411.
  Petroleum, 413, 431.
  Production of, in Germany, 434.
  Sawdust, 439.
  Sizes and shapes of, 407.
  Standard sizes of, in France, 424.
  Weight per cubic foot of, 409.
  Welsh, Breakage in handling, 453.
British Columbia coal fields, 17.
  Columbia coals, Analyses of, 17.
Brookwood, Alabama, washery, 75.
Brown coals of Texas, Analyses of, 12.
Browney coke plant, 167.
Brunck coke ovens, 298.
By-product apparatus at Mines of Campagnac, 229.
  apparatus at Otto Station, 249.
  apparatus, Cost of, 243.
  apparatus for Otto-Hoffman ovens, 239.
  apparatus, Schniewind, 254.
  coke-making statistics, 134.
  coke ovens by States, 135.
  coke ovens in the United States and Canada in 1903, 400.
  ovens in the United States, Table of, 205.
By-products, Advisability of saving, 401.
  and coke, Yield of, 258.
  from Daube's coke oven, 177.
  from Siebel ovens, 224.
  of the coke industry, 256.
  Plant for saving, 320.
  Value of, 243.
  Value of, per ton of coke, Table, 398.
  Yield of, from Morris Run coal, 266, 269.

C

Calorific values of fuels, Laboratory methods of determining, 353.
Cambria, Cost of coke at, 339, 340.
Canada, Briqueting in, 452.
  Coal fields of, 16.
Capacity of jigs, 95.
  of revolving screens, 93.
Carboniferous mud briquets, 412.
Carbonization, Rate of, 192.
Carnap, Germany, Coal distillation plant at, 320.
Cell space in coke, 330, 351.

Cell structure, Laboratory tests, 356.
Cellulose, 21.
Central coal field, 9.
  Field coals, Analyses of, 9.
Charcoal briquets, 411, 418.
  briquets required to make one ton of pig iron, 338.
  in blast furnace, 326, 354.
  Physical properties of, 326.
Charging and coke-pushing machinery, 315.
Chemical properties of coal, 19.
Chisholm, Boyd & Co. briquet machine, 467.
Classification and areas of the coal fields of the United States, 1902, 14.
Coahuila Coal Company's coal and coke, Analyses of, 18.
  Washing plant at, 79.
Coal, Changes during formation of, 21.
  consumed in American cities in 1900, 383.
  consumed in United Kingdom for 1898, 381.
  crushing, 46.
  Debituminization of, eastward, Table of, 24.
  distillation plant at Matthias Stinnes mine, Germany, 320.
  field, Appalachian, 7.
  field, Central, 9.
  field, Eastern Rocky Mountain and Great Plains, 17.
  field, Michigan, 9.
  field, Northern, 9.
  field, Texas, 12.
  field, Western, 11.
  fields, Adaptability of different types of ovens, 392.
  fields, Anthracite, 5.
  fields, Atlantic Coast Triassic, 7.
  fields, Mexican, 17.
  fields of British Columbia and Vancouver Island, 17.
  fields of Canada, 16.
  fields of North America, 1.
  fields of Nova Scotia and New Brunswick, 16.
  fields of the United States, 5.
  fields of the United States for 1902, 14.
  fields of the world, 1902, Diagram of, 2.
  fields, Pacific Coast, 12.
  fields, Qualities of coal and coke from different, 392.
  fields, Rocky Mountain, 11.
  Formation and chemical properties of, 19.
  Importance of, 1.
  Impurities in, 38.
  periods, 4.
  Principal elements of, 22.
  ramming machine, 316.
  Relations of different varieties, Diagram of, 21.
  required to produce one ton of coke, 137, 141.
  Results of washing, Table of, 113.
Coal slack briquets, 409.
  used in manufacturing coke in the United States, 140.
  Varieties of, 22.
  washer, Robinson, 99.
  washing, 56.
  Weight per bushel of, 196.
  World's product of, 1901, 1902, Diagram of, 3.
Coals, Analyses and coking qualities of Rocky Mountain, 10.
  Analyses of British Columbia and Vancouver, 17.
  Analyses of Central Field, 9.
  Analyses of different varieties, Table of, 22.
  Analyses of Michigan, 9.
  Analyses of Nova Scotia and New Brunswick, 16.
  Analyses of Pacific Coast, 16.
  Analyses of the several varieties of, in the Pacific Coast coal fields, 13.
  Analyses of Western, 12.
  and cokes, Analyses of Triassic, 7.
  and impurities, Specific gravities of, 56
  Coking and non-coking, Table of, 26.
  Coking, Composition of, 24.
Coherence in handling coke, 334.
Coke, Amount of coal used in manufacture of, in the United States, 140.
  Analyses of Triassic coals and, 7.
  Average value of, in United States, 142.
  beehive, Structure of, 282.
  breeze briquets, 410.
  briquets, Cost of plant for, 430.
  by-products, Plant for saving, 320.
  cell space, 351.
  Coal required to produce one ton of, 137, 141.
  Coherence in handling, 334.
  Compressive strength of, 360.
  Cost of, at Glassport, Cambria, and Germany, Table of, 339.
  Cost of making, in beehive ovens, 346.
  Density of, 351.
  drawer, Hebb, 188.
  drawer, Smith, 187.
  drawer, Thomas, 166.
  Effect of type of ovens on physical properties of, 348.
  Effect on, produced by crushing the coal, 195.
  exported from the United States, 139.
  from compressed fuel, 312.
  handling machinery, 315.
  Hardness and cell space of, Table of, 330, 332.
  imported to the United States, 139.
  in blast furnaces, 326, 354.
  in blast furnaces, Tests of, 287.
  industry, History and development of, 131.

- Coke industry, Statistics of, 133.
  - Kentucky, Pineville, 358.
  - Laboratory tests of, 355.
  - larry, Electric, 362.
  - making for profit, 369.
  - making in by-product ovens, Statistics of, 134.
  - manufacture in the United States, Diagram showing growth of, 138.
  - Melting power of, 343.
  - oven, Appolt, 212.
  - oven, Bauer, 302.
  - oven, Beehive, 148.
  - oven, Belgian, 206.
  - oven, Bernard, 294.
  - oven, Brunck, 298.
  - oven, Continental, 150.
  - oven, Coppée, 208.
  - oven, Daube's, 177.
  - oven, Festner-Hoffman, 260.
  - oven, Hüssner, 292.
  - oven, Lowe, 306.
  - oven, Newcastle-upon-Tyne, 148.
  - oven, Old Welsh, 164.
  - oven, Oliver plant, 150.
  - oven, Otto beehive by-product, 311.
  - oven, Otto-Hoffman, 235.
  - oven, Ramsay, 173.
  - oven, Rothberg, 290.
  - oven, Schniewind, 252.
  - oven, Seibel's, 223,
  - oven, Semet-Solvay, 263.
  - oven, Simon-Carvés, 219.
  - oven, statement of Solvay Process Company for 1894, 268.
  - oven, Thomas, 164.
  - oven, Wharton, 152.
  - ovens, Adaptability of different types of, to the several coal fields, 392.
  - ovens at Browney Colliery, 167.
  - ovens, By-product, by states, 135.
  - ovens, By-product, in the United States and Canada in 1903, 400.
  - ovens, By-product, in the United States, Table of, 205.
  - ovens, Comparison of types of, 214.
  - ovens, Condition of coal charged in the United States, 141.
  - ovens, Costs of material for, 176.
  - ovens, Effects of types of, on physical properties of coke, 348.
  - ovens in the United States, 134.
  - ovens, Newton-Chambers, 186.
  - ovens, Number of, advisable in plant, 369.
  - ovens of different types, Relative economy of, 397.
  - ovens, Retort and by-product-saving, Introduction, 200.
  - Peat, 442.
- Coke, physical and chemical properties of, Table of, 334.
  - Physical properties of, 326, 329.
  - plant, Life of, 371.
  - plant, Locating, 361.
  - plant location, Comparison of advantages of different coal fields for, 396.
  - Preparation of coals for the manufacture of, 43.
  - produced in the United States, 139.
  - produced in the United States, Table of, 136.
  - pusher, 318.
  - pushing machinery, 315.
  - Semet-Solvay, Structure of, 282.
  - Tests of blast-furnace charges of, 285.
  - Tests of, with CO_2, 359.
  - to make one ton of pig iron, 338.
  - to smelt Bessemer metal, Beehive and Semet-Solvay, 343.
  - Weight of, 197.
  - What constitutes pure, 333.
  - yield of different ovens, 342.
  - yield, Percentage of, in beehive oven, 158.
- Coking and non-coking coals, Table of, 26.
  - charge, 48- and 72-hour, 158.
  - coals, Analyses of Appalachian, 25.
  - coals, Analyses of Durham, 25.
  - coals, German, Table of, 33.
  - coals, Influence of composition of, 27.
  - Connellsville and Tuscarawas coals in Germany, 335.
  - costs, 175.
  - experiments and results, 192.
  - Heminway process of, 178.
  - in heaps or mounds, 145.
  - in Ramsay and beehive ovens, Table of experiments, 174.
  - Percentage of sulphur volatilized in, Table of, 39.
  - process, The, 157.
  - properties and fusibility, 31.
  - properties of different portions of Connellsville seam, 198.
  - Rate of, 192.
  - tests, 160.
  - To determine loss of carbon in, 147.
- Comparative work of fuels in blast furnaces, 354.
- Comparison of beehive and by-product coke, 326.
  - of beehive and by-product coking, 335.
  - of different types of coke ovens, 397.
  - of oven types, 214.
- Composition of coking coal, 24.
- Compressed fuel, Manufacture of coke from, 312.
- Condensation plant at the Julienhütte, 239.
- Condensing plant, Schniewind, 254.
- Condition of coal charged into coke ovens, 141.

Conemaugh furnace, Coppée ovens at, 210.
Connellsville coal and coke, Analyses of, 147, 280.
  coal, By-products from, 246.
  coal, Coking, in Germany, 335.
  coal in Otto-Hoffman ovens, Test of, 245.
  coal seam, Coking properties of different portions of, 198.
  coke, Analysis of, 147.
  coke from Semet-Solvay ovens, Experiments in blast furnace, 277.
  seam, Localities of phosphorus in, Table, 41.
Continental Coke Company beehive oven, 150.
Coppée coke oven, 208.
Coral coke plant, 376.
Cost and production of Otto-Hoffman ovens, Johnstown, 344.
  of Bernard ovens, 298.
  of coke at Glassport, Cambria, and Germany, Table of, 339.
  of coke in various ovens, Table of, 398.
  of coke, Simon-Carvés oven, 222.
  of Festner-Hoffman ovens, 263.
  of making coke in beehive ovens, 175, 346.
  of making coke in Bernard ovens, 297.
  of Seibel ovens, 232.
  of Semet-Solvay plant, 265.
  of various ovens, Table of, 398.
  of washing coal at Coahuila, 97.
  of Wharton coke oven, 154.
Costs and economies of beehive and Semet-Solvay plants, 284.
  of manufacturing ammonium sulphate, 403.
  work, and products of several types of coke ovens, 392.
CO_2. Tests of coke with, 359.
Crushing coal, 46.
Culm briquets, 410.

D

Daube's economic down-draft coke oven, 177.
Debituminization of coals eastward, Table of, 24.
Density of coke, 351.
Diagram of coal fields of the world in 1902, 2.
  of world's product of coal in 1901 and 1902, 3.
Dickson briquet press, 458.
Diescher coal washer, 71.
Dobson's peat-drying machine, 455.
  briquet press, 459.
Dowlais, Results of washing at, 105.
Drying machine for peat, 444.
Dunbar, Semet-Solvay plant at, 273.
Dupuy briquet press, The, 429.
Durham coking coals, Analyses of, 25.

E

Eastern Rocky Mountain and Great Plains coal fields 17.
Economy of different types of coke ovens, 397.
Edenborn coke plant, 375.
Effects of types of coke ovens on physical properties of coke, 348.
Elliott trough washer, 59.
Ernst coke-handling machinery, 315.
Everett coke-oven gas plant, 384.
Exports of coke, 139.

F

Festner-Hoffman coke oven, 260.
Formation and chemical properties of coal, 19.
France, Briqueting in, 422.
  Seibel ovens in, 224.
  Standard size of briquets in, 424.
Frick Coke Company No. 3 Plant, 365.
Fuel briqueting industry, 406.
  statistics of American cities for 1900, 383.
Fuels, Analyses of, Table, 37.
  Blast-furnace, 1854-1902, Table of, 326.
  in blast furnaces, Comparative work of, Table, 354.
  Laboratory methods of determining calorific values of, 353.
Fusibility and coking properties of coals, 31.

G

Gases, Table of Analyses of, 246.
  Use of, for steaming at Pratt Mines, 169.
Gas, Illuminating, from coke ovens, 381.
  plant at Everett, 384.
  plant, Lowe, 308.
Gelsenkirchen Brunck ovens 301.
General conclusions on the several types of coke ovens, 392.
Geological section, 4.
German coking coals, Table of, 33.
Germany, Briqueting in, 432.
  Coal distillation plant at Matthias Stinnes in, 320.
  Coking Connellsville and Tuscarawas coals in, 335.
  Cost of coke in, 339.
  Production of briquets in, 434.
Gladbeck, Baum washery at, 128.
Glassport, Cost of coke at, 339.
Graphite, 21.
Great Britain, Briqueting in, 448.
Great Plains coal field, 17.
Greensburg, Stein & Boericke washery at, 122.

H

Hartz jig, 62.
Heating value of briquets, 419.
Hebb coke drawer, The, 188.
Heminway process of coking, 178.
History and development of the coke industry, 131.
Horsepower required in washery, 91.
Hostetter-Connellsville Coke Company, plant, 375

Hüssner coke oven, 292.
  coke oven, Coking tests in, 335.
Hydrogen to carbon in various coals, Proportion of, 35.

I

Illinois coal and coke, Analyses of, 186.
Illuminating gas from coke ovens, 381.
Importance of coal, 1.
Imports of coke, 139.
Improvement of coal effected by washing, 97.
Impurities in coal, 38.
  in coke, Effect of, on pig iron, 42.
Ireland, Briquet fuel in, 471.
Iron, Fuel required to make one ton of, 338.

J

Jamison Coal and Coke Company washery, 122.
Jigs, Capacity of, 95.
  Hartz, 62.
  Lührig, 62.
  Principle of, 51.
  Speed and stroke of, 95.
  Stein, 69.
Johnson briquet press, 449.
  Company, Blast-furnace experiments with Semet-Solvay coke by, 277.
Jones & Laughlin Steel Co., Lowe gas plant, 310.
Julienhütte, Plant at, 241.

K

Kanawha Valley coal and coke, Analyses of, 147.
Keighley, Fred C. (Paper), 369.

L

Laboratory methods of determining relative calorific values of fuel, 353.
  tests of coke, 355.
Lackawanna Iron and Steel Company's plant at Lebanon, 292, 315.
Larry, 362.
Latrobe coking plant, 186.
Lebanon, Lackawanna Iron and Steel Company's plant at, 292, 315.
Life of coke plant, 371.
Lignite briquets, 411.
  briquets, Cost of, 439.
  briquets in the United States, 464.
Lignites, 21.
Link-belt coal breaker, 54.
  belt crusher, 55.
Lippincott coke plant, 375.
Locating coke plants, 361.
Lorain, Blast-furnace experiments with Semet-Solvay coke at, 277.
Loss of carbon in process of coking, 147.
Lowe coke oven, 306.
Luhrig jig, 62.
Lührig washer at Dowlais, Wales, 101.
  washer at Nelsonville, Ohio, 108.
  washer at Punxsutawney, 110.

M

Manufacture of coke, 145.
  of coke from compressed fuel, 312.
  of sulphate of ammonia, 232.
Map of coal fields of the United States, 6.
Market for tar and ammonium sulphate, 401.
Melting power of coke, 343.
Methods and cost of manufacturing briquets, 417.
  of coking coal, 145.
Mexican coal fields, 17.
Mexico, Washing plant at Coahuila, 79.
Michigan coal field, 9.
Mines of Campagnac, By-product coke ovens at, 224.
Minister Stein pit, Brunck ovens, 301.
Montana coals, Coking, 29.
Morrell coke plant, 364.
Morris Run coal and coke, Analyses of, 266.
Mould Company, Henry S., briquet machine, 468.
Mud briquets, 467.

N

Nelsonville, Ohio, Lührig washer at, 108.
New Brunswick coal fields, 16.
  Brunswick coals, Analyses of, 16.
  Glasgow Iron, Coal, and Railway Company, Bernard ovens of, 294.
  Glasgow Iron, Coal, and Railway Company washery, 69.
Newton-Chambers system of coking, 186.
Northern coal field, 9.
Norway, Briqueting in, 445.
Nova Scotia, Bernard ovens in, 294.
  Scotia, coal, Analyses of, 16.
  Scotia coal fields, 16.
  Scotia, Washery of New Glasgow Iron, Coal, and Railway Company in, 69.
No. 3 Plant, H. C. Frick Coke Company, 365.

O

Old Welsh oven, 164.
Oliver coke plant, 366.
  plant, Beehive oven at, 150.
Otto beehive by-product oven, 311.
  Hoffman oven, 235.
  Hoffman oven, Coking tests in, 336.
  Hoffman oven, Cost of, 243.
  Hoffman oven, Temperatures in, 241.
  Hoffman ovens and by-product apparatus at Otto Station, 248.
  Hoffman ovens at Everett, Mass., 384.
  Hoffman ovens at Johnstown, Costs and production of, 344.

P

Pacific Coast coal, Analyses of, 16.
  coal fields, Analyses of the coals in, 13.
Peat, 21.
  briquets, By-products, 444.
  briquets, Cost in Canada, 462.
  briquets, Cost in Sweden, 447.
  briquets in Canada, 454.
  briquets in Germany, Cost of, 442.
  coke, 442.
  digger, 456.
  drying machine, 444.
  fuel, 439.
  harvesting in Canada, 455.
  manufacturing machine, Schlickeysen, 441.
  or turf briquets, 411.
  plant at Beaverton, 456.
  plant at Welland, 455.
Percentage of coke yield from beehive oven, 163.
Petroleum briquets, 413, 431.
Phosphorus in Connellsville seam, Table of, 41.
  Percentages of, in Pennsylvania coal and coke, Table, 41.
Physical and chemical properties of coke, Table, 334.
  properties of charcoal, anthracite, and coke, 326.
  properties of coke, Effect of type of ovens on, 348.
  properties of coke, Effects produced on, by crushing the coal, 195.
Pig iron, Effect of impurities in coke on, 42.
  iron, Fuel required to make one ton of, 338.
Pineville coke tests, 358.
Pittsburg Gas and Coke Company plant at Otto Station, 248.
Pratt Mines, Using waste gases under boilers at, 169.
Preparation of coals for the manufacture of coke, 43.
Presses, Closed-mold, 415.
  for briquets, 414.
  Open-mold, 414.
Prices of coke, 139, 142.
Production of coke, Rank of States and Territories in the, 143.
Properties of coke, 329.
Proportion of hydrogen to carbon in various coals, 35.
Punxsutawney, Lührig washer at, 110.
Purity of coke, 333.

R

Ramsay patent beehive coke oven, 173.
Rank of States and Territories in the production of coke, 143.
Rate of carbonization, 192.
Rate of coking, 159, 161.
Results with Stewart washery, Table of, 116, 120.
Retort and by-product-saving coke ovens, 200.
  oven plant, Location of, 379.
Robinson coal-washer plant, 99.
  washer, results, Table of, 100.
Rocky Mountain coal fields, 11.
  Mountain coals, Analyses and coking qualities of, 10, 17.
Rothberg by-product coke oven, The, 290.
  coke-handling machinery, 315.

S

Sampling briquet material, 465.
Sandcoulee coals, Coking, 29.
Sawdust briquets, Cost of, 439.
Scaife trough washer, 61.
Schniewind, F., Ph. D., 381.
  oven, 252.
Screens, Capacity of, 93.
Seibel oven, 223.
  oven, Dimensions of, 226.
  ovens, Cost of, 232.
  ovens, Work of, 233.
Semet-Solvay coke oven, 263.
  Solvay coke ovens, Improved, 273.
  Solvay coke, Structure of, 282.
  Solvay plant at Dunbar, 273.
  Solvay plant at Syracuse, 267.
  Solvay plant, Cost of, 265.
  Solvay plant, Cost of operating, 267.
  Solvay tests, Comparison of, 271.
Shawmut Mining Company's experiments in coking, Table of, 174.
Silica brick, 191.
Simon-Carvés oven, 219.
  Carvés ovens, Cost and yield of coke in, 222.
Smith coke drawer, 187.
Specific gravities of coal and impurities, 56.
Speed and stroke of jig, 95.
Speeding and gearing of machines in washery, Table of, 90.
Standard Coal Company's washery at Brookwood, Alabama, 75.
Statistics showing development of coke industry, 133.
Stedman coal breaker and disintegrator, 50, 52.
Stein & Boericke washery, 122.
  Walter M., Installation of Seibel ovens, 234.
  washers, 69.
Stewart coal washer, 113.
  washer, Table of results with, 116, 120.
Strength of anthracite and coke, 360.
  of coke, Laboratory tests, 357.
Structure of anthracite in the Appalachian coal fields, 8.
Stutz improved coal washer, 65.
Sulphate of ammonia, 232.
Sulphur, Conditions in which, is found, 45.
  Effect of acetic acid in removing, 40.
  volatilized in coking, Table, 39.

Sweden, Briqueting in, 445.
  Cost of briquets in, 447.

T

Tar, Market for, 401.
Temperatures in Otto-Hoffman oven, 241.
Texas, Analyses of brown coals of, 12.
  coal field, 12.
Thomas oven, 164.
Time required to make one ton of coke, 340.
Triassic coal fields, The Atlantic Coast, 7.
  coals and cokes, Analyses of, 7.
Trough washers, 57.
Tuscarawas coal, Coking, in Germany, 335.

U

United Kingdom, Consumption of coal in the, 381.
  States, Briqueting in the, 462.
  States, Coal fields of the, 5.
  States, Map of the coal fields of the, 6.
Utilization of the by-products of the coke industry by Dr. Bruno Terne, 256.

V

Vancouver coals, Analyses of, 17.
  Island coal fields, 17.
Varieties of coal, 20.

W

Wales, Briqueting in, 449.
  Lührig washer at Dowlais, 101.
Washer, Baum, 123.
  Berard's, 63.
  Diescher, 71.
  Elliott, 59.
  Scaife, 61.
  Stein, 69.
  Stewart, 113.
  Stutz, 65.
  Trough, 57.
Washery at Coahuila, Mexico, 79.
  Cost of, 97.
  of New Glasgow Iron, Coal, and Railway Company, 70.
  Speeding and gearing of machines in, Table, 90.
  Water and power required in, 91.
Washing coal, 56.
  coal at Brookwood, Alabama, Table of results, 79.
  coal at Dowlais, Results of, 105.
  coal, Cost of, 97.
  coal, Improvement by, 97.
Water required in washery, Table of, 91.
Welland, Peat plant at, 455.
Welsh coal, Table of analyses of, 34.
Western coal field, 11.
  coals, Analyses of, 12.
Westphalia, Analysis of coal, 244.
  Baum washing plant at Gladbeck, 128.
  Brunck coke ovens in, 298.
West Virginia coal and coke, 270.
  Virginia coals in Semet-Solvay ovens, 268.
Wharton coke oven, 152.
  coke oven, Cost of, 154.
  coke plant, 376.
Whitney coke plant, 375.
Wiesner briquet machine, 418.
Wood, Composition of, 21.
Work, costs, and products of several types of coke ovens, 392.
World's product of coal, from 1901 to 1902 (Diagram), 3.

Y

Yield of coke and by-products, Percentage, 258.
  of coke in different ovens, 342.

Z

Zeitz briquet press, The, 437.

17303-1-17-06-1200