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GAS PRODUCERS

AND

PRODUCER GAS POWER PLANTS

R. D. WOOD & CO.

PHILADELPHIA

INDUSTRIAL APPLICATION

OF

PRODUCER GAS

MOND GAS WITH BY-PRODUCT RECOVERY

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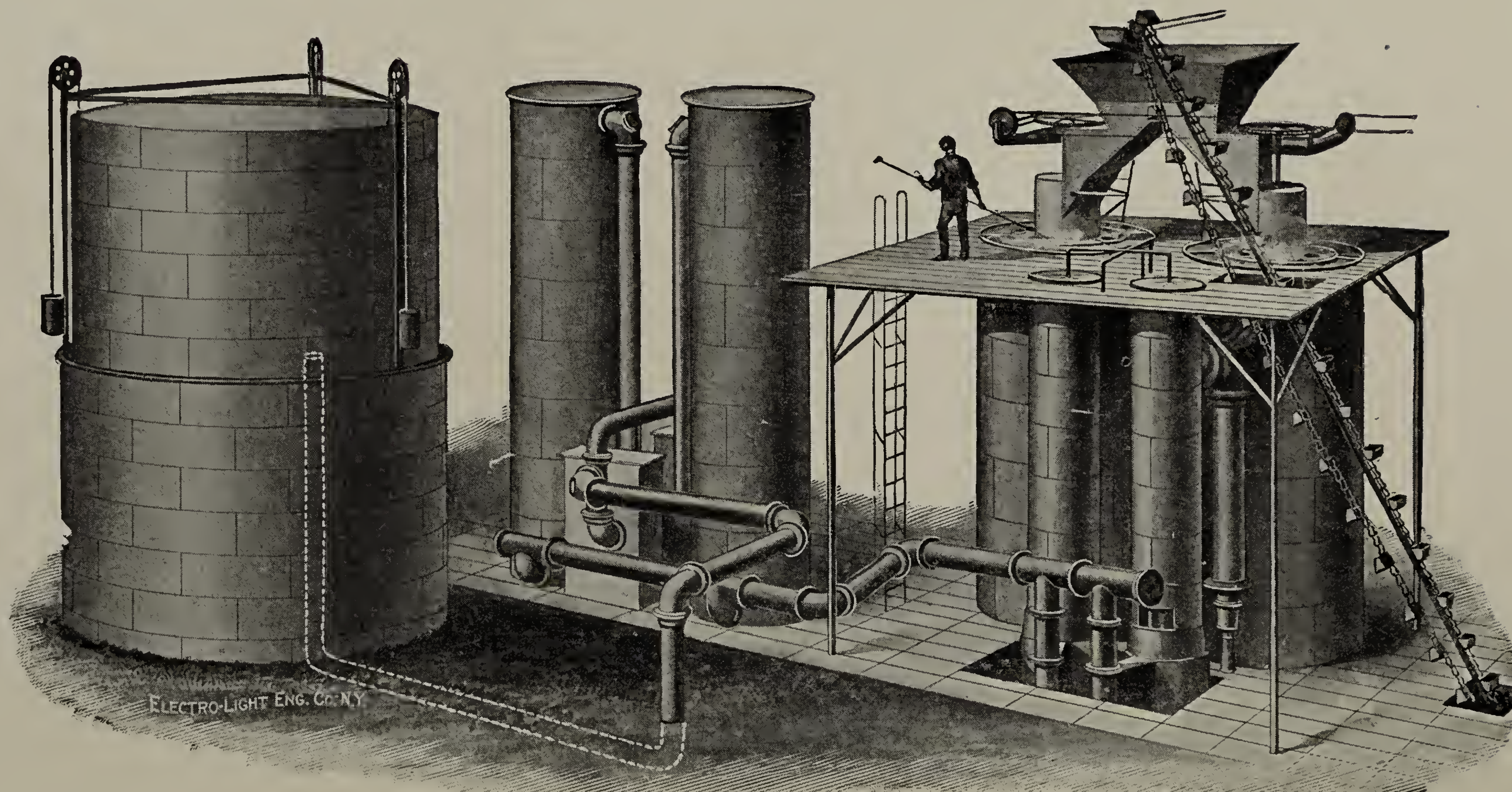

400 H. P. GAS PRODUCER POWER PLANT.

Gas Producers

AND

The Bildt Automatic Feed Device

PATENTED

SOLE MAKERS

R. D. WOOD & CO.

Engineers, Iron Founders, Machinists

PHILADELPHIA, PA.

Gas Fuel

AND THE

Application of Producer Gas

TO

Manufacturing Purposes

1903

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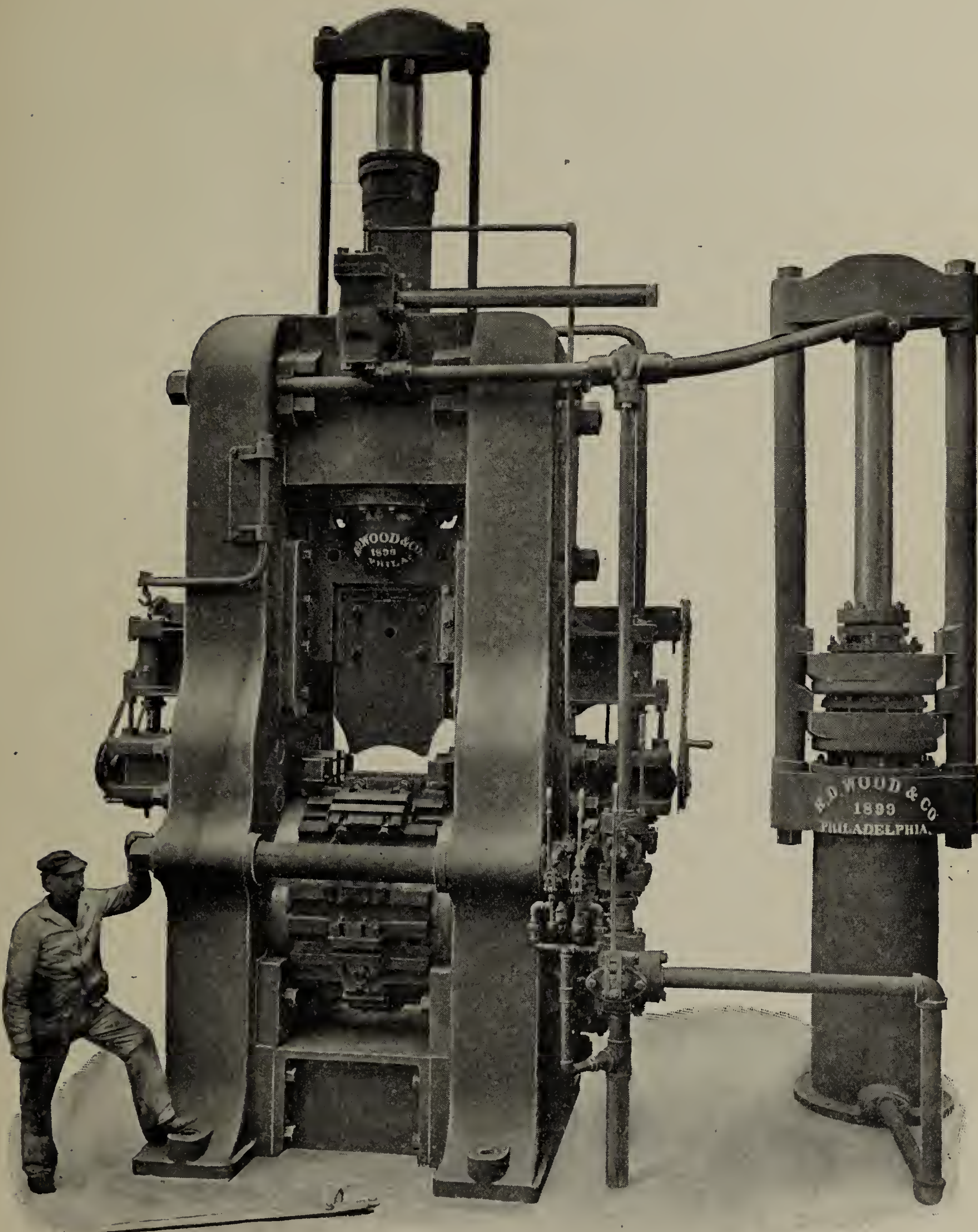

UNIVERSAL HYDRAULIC BEAM SHEAR—TURRET TYPE.

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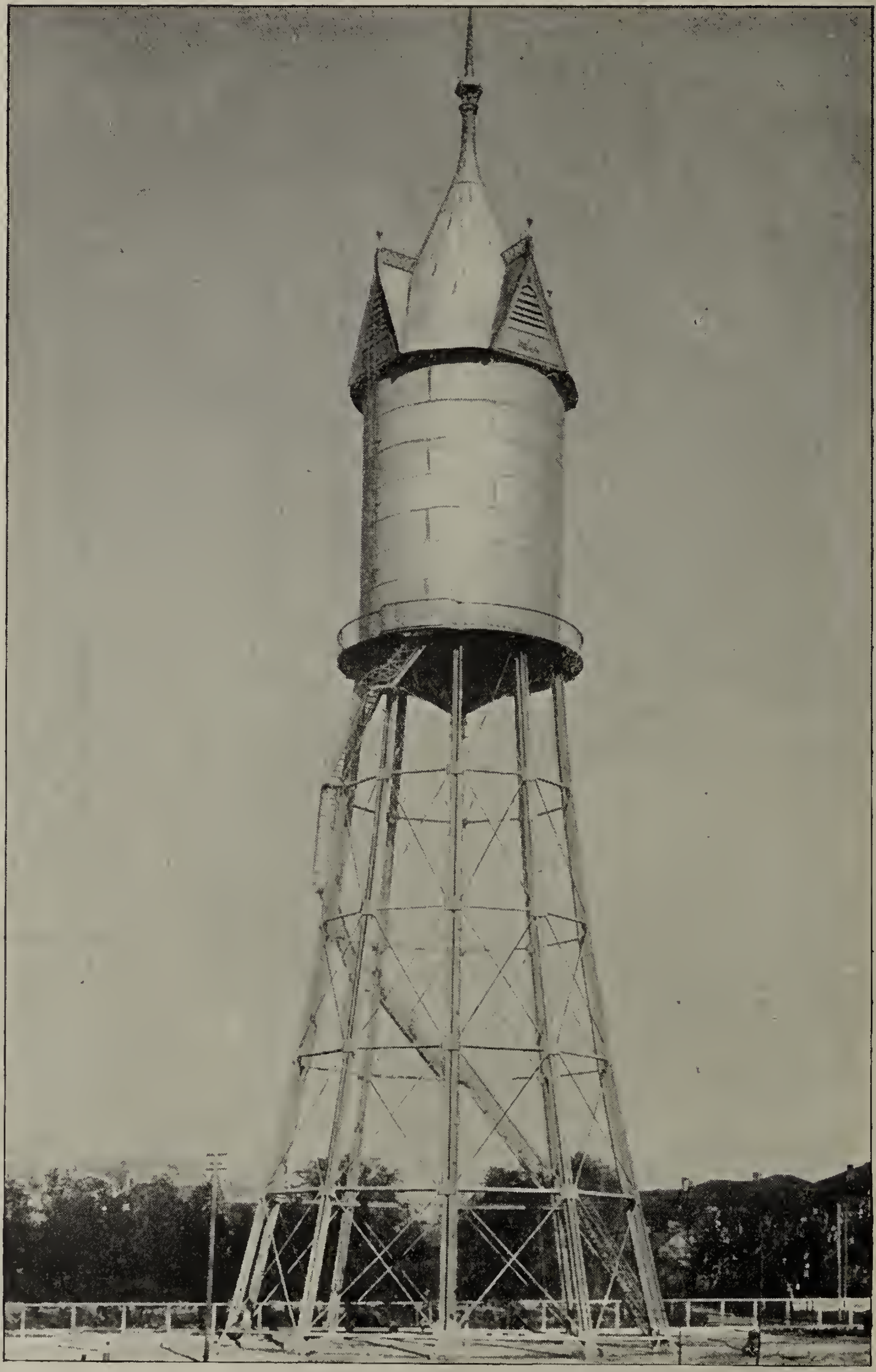

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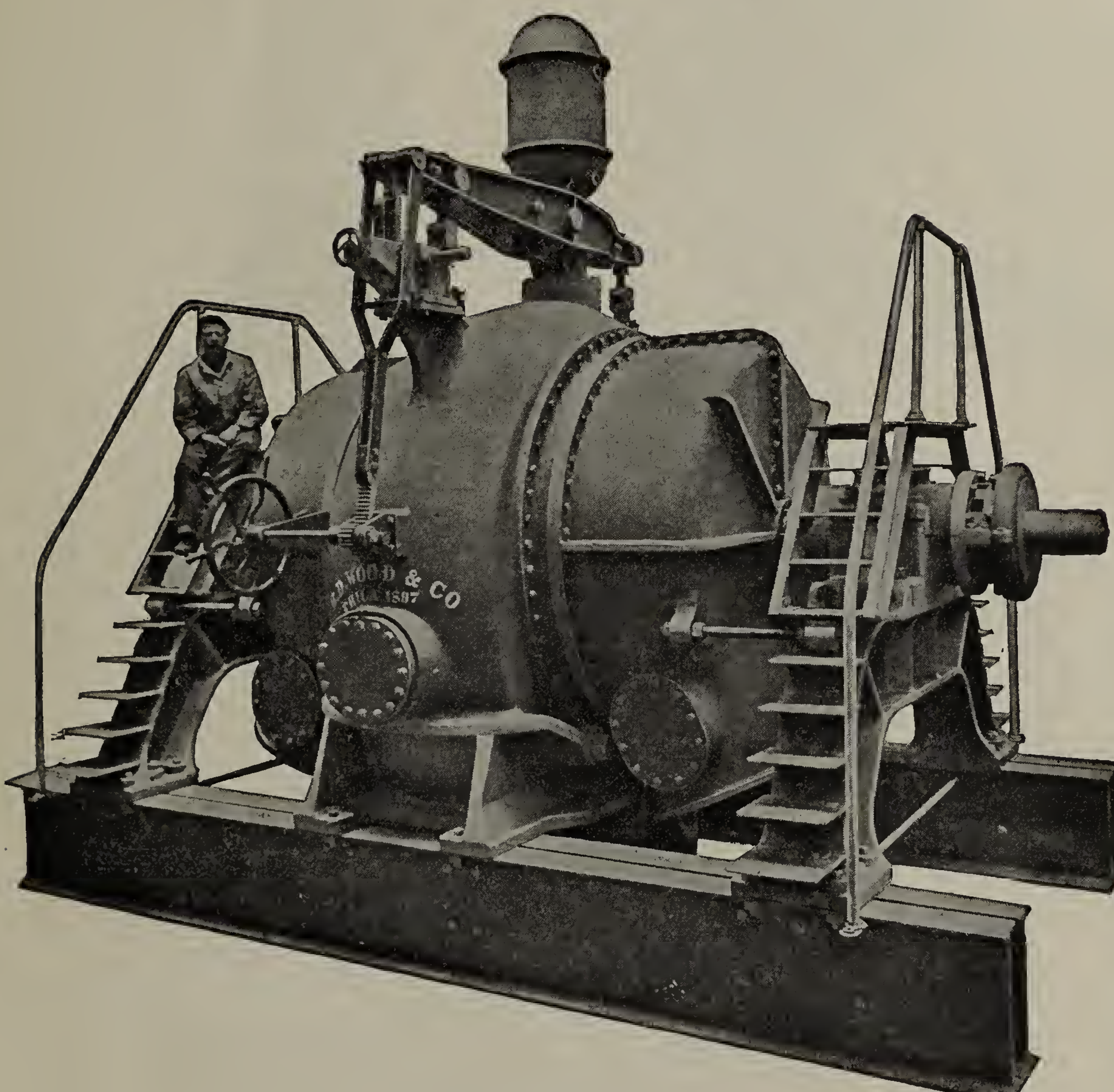

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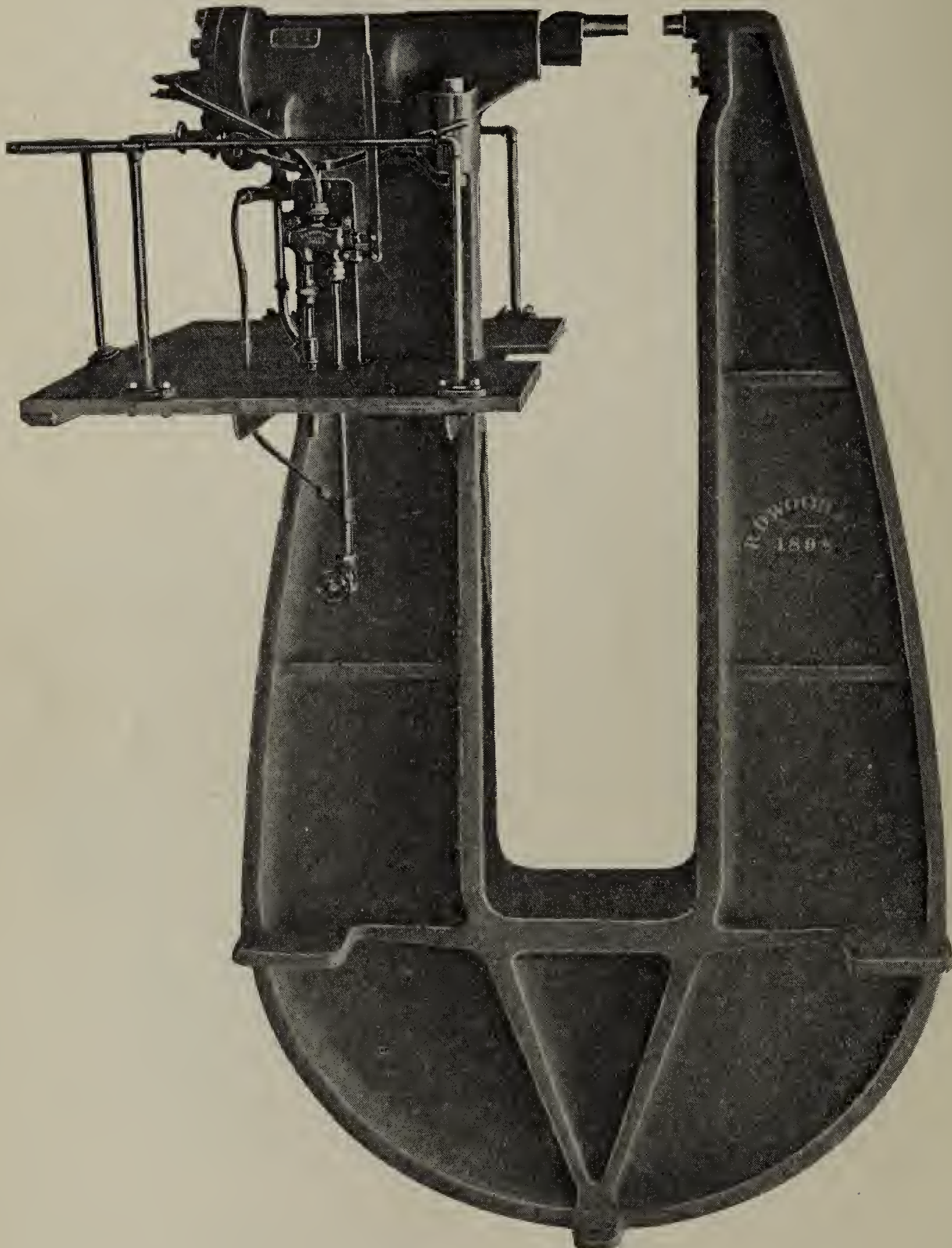
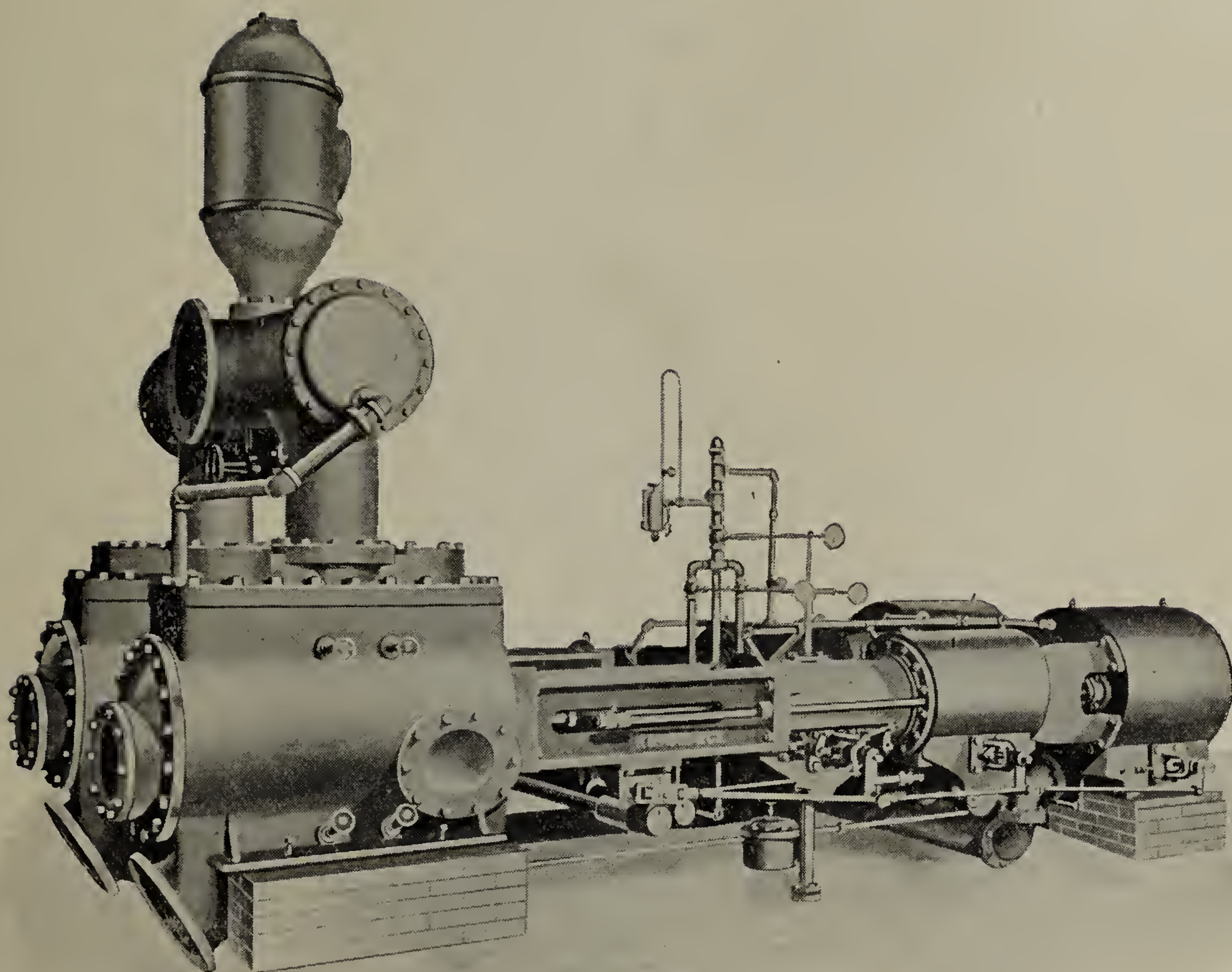


HYDRAULIC FIXED RIVETER.



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Made in units ranging in size from 1,000,000 gallons per 24 hours against 400 feet and upward, to 50,000,000 gallons against 30 feet and upward.

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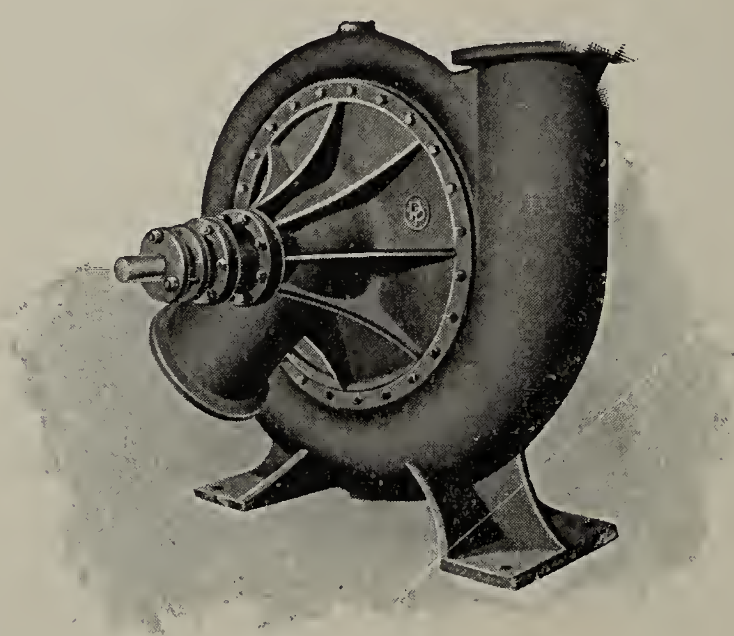

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WITH

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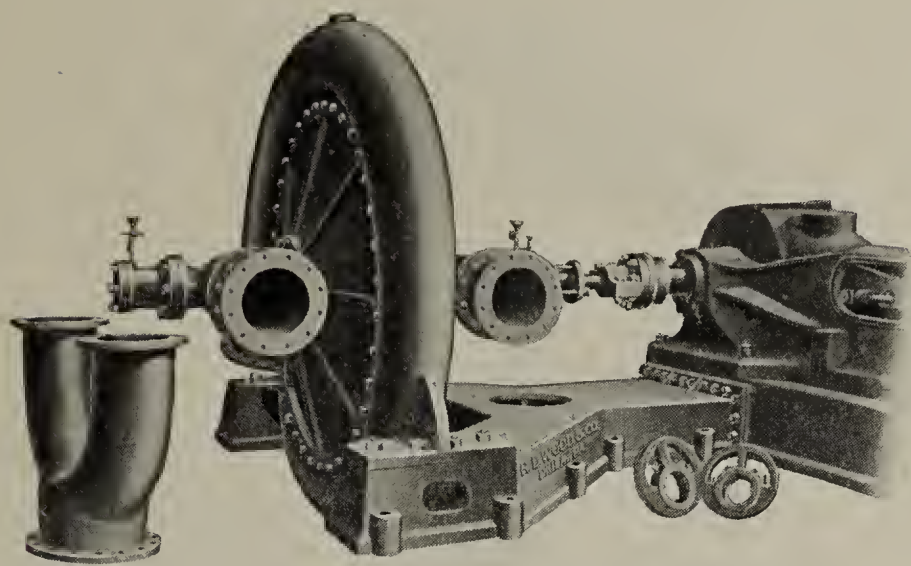

FOR

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SEWAGE, OILS, LIQUORS,
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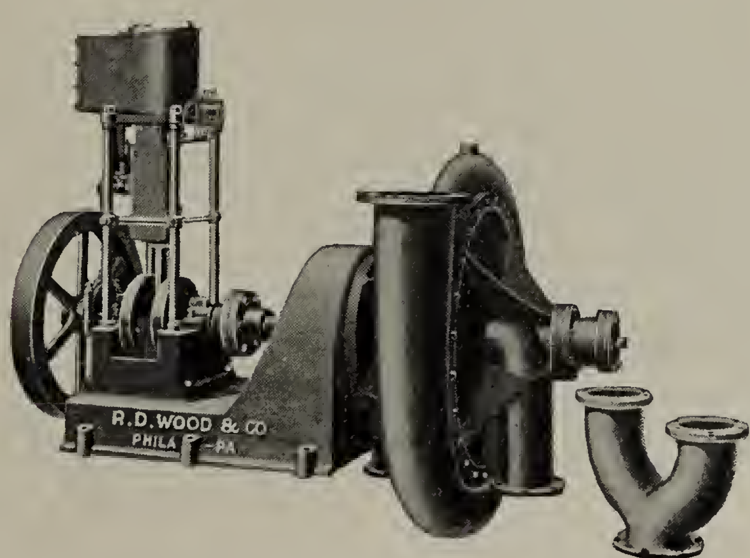

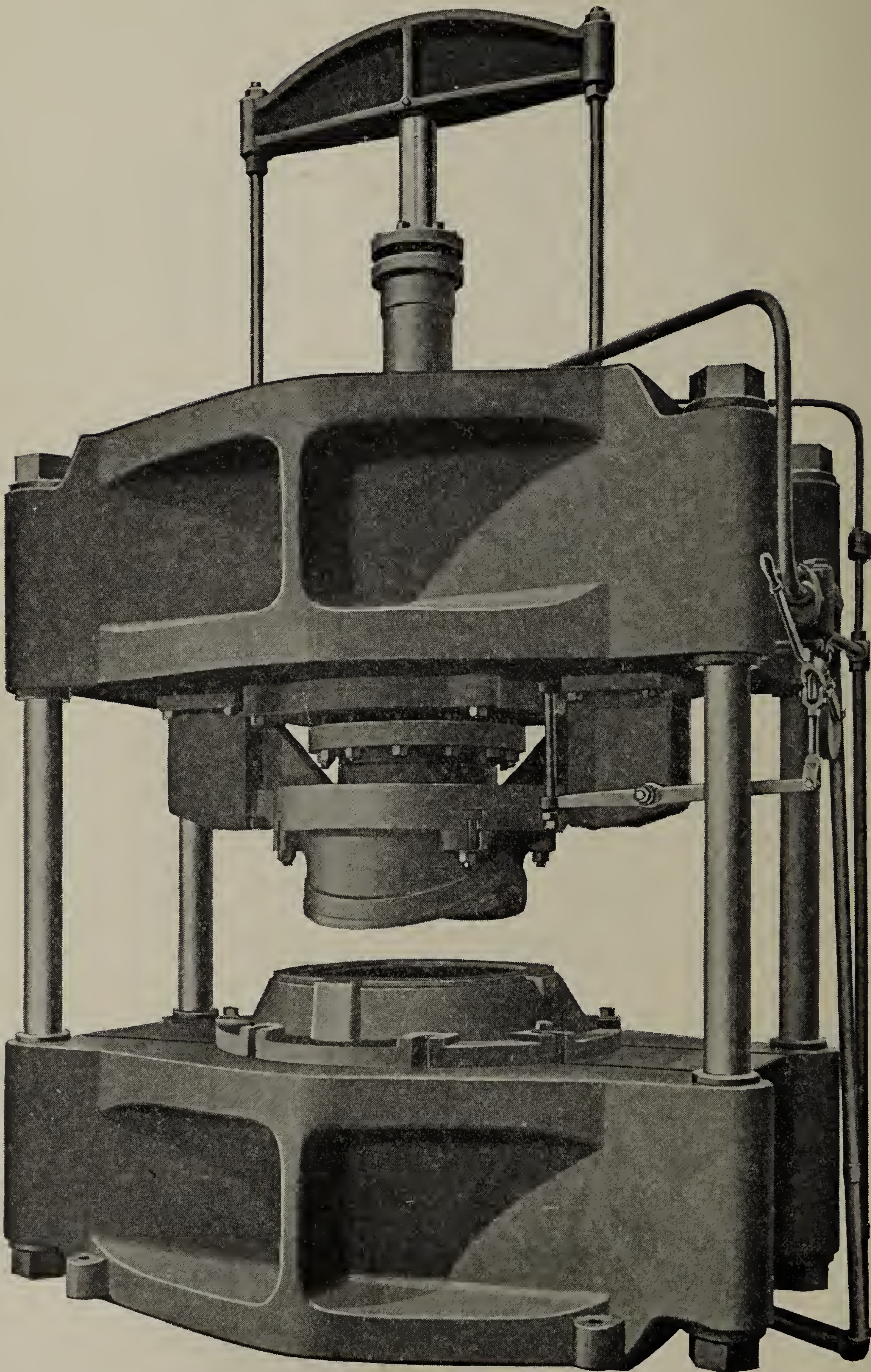

LIGHTENING-HOLE PUNCH.

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ILLUSTRATIONS:

CAUTION TO THE PUBLIC

AGAINST INFRINGEMENT OF THE
TAYLOR PATENTS FOR
GAS PRODUCERS.

THE public is hereby notified that the Taylor System of making gas is covered by a series of United States Patents, and among them is one No. 399,798, dated March 19th, 1889, which covers broadly, in the method of making gas, the placing and maintaining of a deep bed of ash under a bed of incandescent fuel and blasting through the ash and fuel. The said patent covers broadly the practical method of making producer gas on a deep bed of ash. All infringers of the said method patent for the making of producer gas will be rigorously prosecuted according to law, by the

TAYLOR GAS PRODUCER COMPANY,
Camden, N. J.

[Inserted by request of the Taylor Gas Producer Company.]

R. D. WOOD & CO.,
400 Chestnut Street,
Philadelphia, Pa.
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INTRODUCTION.

THE necessity for this fifth edition of the Gas Pamphlet is but an incident in the many evidences of the active and sustained interest of engineers and industrial management in the applications of producer gas. Its application to power generation or to metallurgical uses has demonstrated both its superior economy and supplementary advantages over other methods. Our recent introduction of the "MOND GAS" process with By-Product Recovery, using bituminous coals, has further broadened and strengthened its utility.

The construction of larger and reliable gas engine units is an important factor in this development and has brought it into strong and successful competition with the steam engine for both isolated and central power stations.

In these different applications much of the matter presented is based upon actual experience in the installation, starting and operating of Gas Producers under the varying conditions of an extensive service in the United States and foreign countries. The Bildt Continuous Automatic Feed has new and valuable features, while our recently patented Hollow Bosh Water Seal Producer will interest those desiring such type of seal.

Through the courtesy of Mr. W. J. Taylor, we continue to include the extract from his paper on "The Energy of Fuel; Solid, Liquid and Gaseous."

We are gratified by the many expressions of appreciation of this pamphlet from our correspondents, and trust that the value and helpful character they indicate may be increased by the additions made to it from time to time.

R. D. WOOD & CO.

Philadelphia, February, 1903.

THE essential requirements of a Gas Producer are that it shall insure—

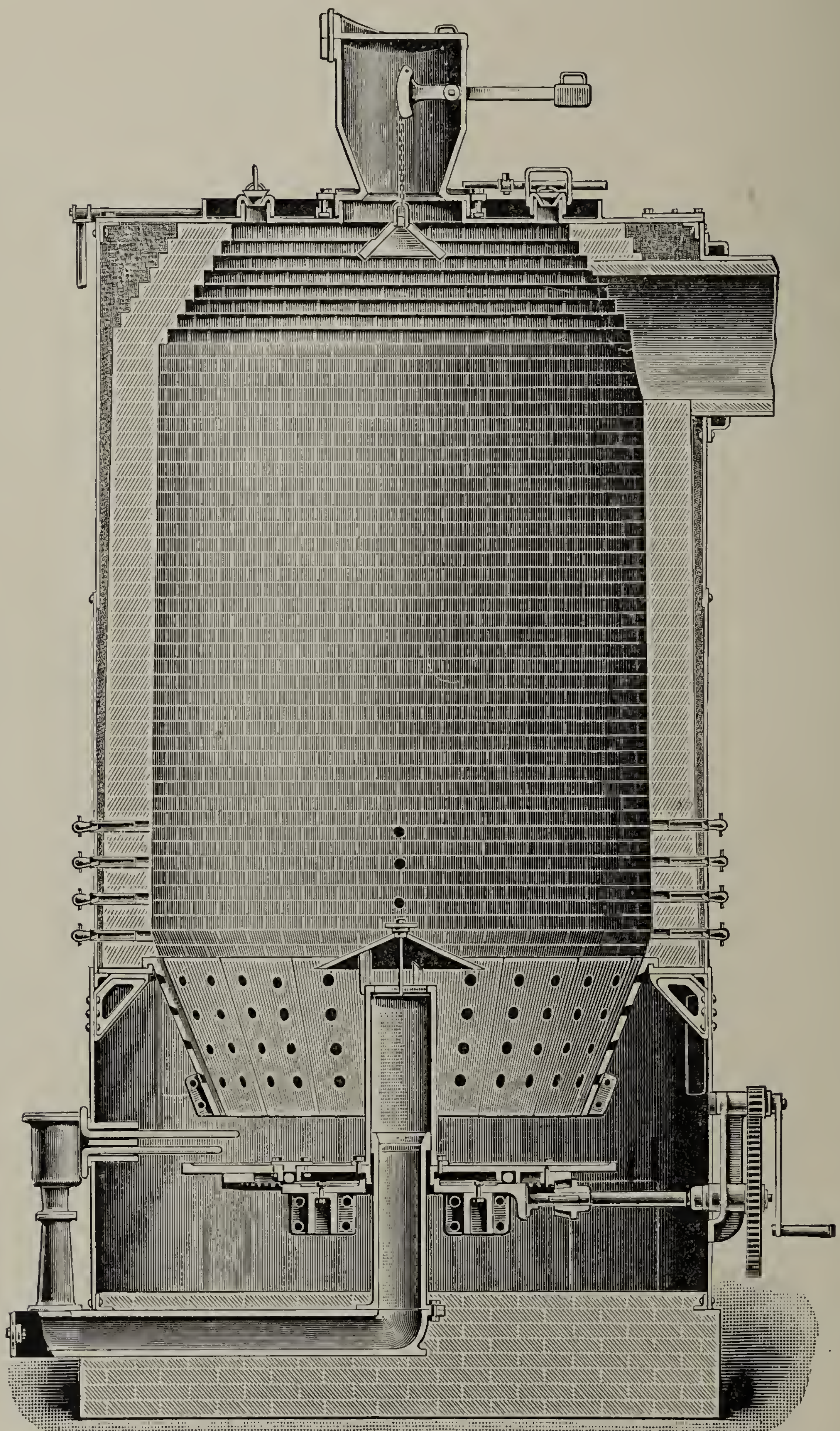
1st.—Complete Combustion of the Carbon.

2d.—Gas of Uniform Quality.

3d.—Ease in Operating.

4th.—Continuous Operation.

Note.—FOR EVERY ONE PER CENT. of economy in consumption of coal at $1.00 per ton, a manufacturer can afford to spend $250.00; at $2.00 per ton, $500.00, or, at $3.00 per ton, $750.00 PER PRODUCER, gasifying five tons per day.



GAS PRODUCER WITH REVOLVING BOTTOM, SHOWING OLD-STYLE HOPPER FEED.

GASEOUS FUEL.

Conversion into gas is the primary requisite for the utilization of other forms of fuel. Whether the gases of this conversion are combustible or not depends upon the nature of the fuel and the method of gasification.

The combustible elements of all ordinary fuels are chiefly Carbon (C) and Hydrogen (H) in great variety of chemical combination and physical characteristics. In all cases, however, the products of their **complete combustion** contain only Carbonic Acid (CO_2) and Water (H_2O), with the Nitrogen (N) and probably some Oxygen (O) of the air supply. With **incomplete combustion** they will contain in addition varying amounts of the gaseous Carbon Monoxide (CO), Hydrocarbons (C_xH_y), Hydrogen and possibly tar and smoke as products of distillation, all having a heat value.

In ordinary grate or "direct firing" the object is to effect complete combustion in proximity to the fuel bed. Within the same chamber the fuel elements are vaporized, distilled, gasified and completely burned. The first two processes absorb heat only and there are advantages in separating them from the point where combustion of the gases occurs and where high temperatures are developed by the heat evolved.

The gas producer or generator accomplishes this. Within it vaporization, distillation and gasification result in a combustible gas, which led away to a separate combustion chamber, is there burned under conditions favoring a fuller realization of the fuel value and the attainment of temperatures otherwise impossible.

The use of the gas producer does not produce a greater amount of heat than direct firing. Even with a close connection of producer to the furnace, and consequent utilization of the sensible heat of the gas, there is a loss of energy, but it should not exceed 15 to 20 per cent. of the calorific value of the fuel.

Notwithstanding this loss, experience has amply demonstrated that in the majority of applications producer gas accomplishes the same result with less fuel, and has made possible metallurgical operations which were impracticable with direct firing.

Reasons Why Gas Firing Excels Direct.—These are numerous and their thorough appreciation dependent upon a clear conception of the principles of combustion. In part they are:

First.—More complete combustion is secured.

Second.—Higher temperatures of combustion are possible.

Third.—There is less loss of heat through the waste products of combustion.

Fourth.—Greater efficiency in transfer of heat.

Fifth.—Heat may be recovered from hot waste gases and returned to the combustion chamber in preheated air.

Sixth.—Gas and air supply, and therefore combustion, are in easy and complete control.

Seventh.—Avoids loss through grates and transport of coal; concentrates and minimizes labor in handling coal and ash; eliminates deleterious effect of ash or extraneous matter on the substances subjected to heat, and the irregularities of charging in direct firing.

These advantages are largely mutually dependent and rest upon the same cause.

For combustion a theoretical amount of air is necessary and which in practice is exceeded. Direct firing requires at least double this theoretical amount and often much more to even approach complete combustion. This defect is further marked in the use of soft coals. As combustion progresses the bed becomes more compact, and as the time for a new charge approaches is less permeable. Obviously, with a given draught, the amount of air penetrating decreases with an increased depth and compactness of the fuel. A fresh charge of coal requires a greater amount of air to consume its volatile matters, and needs it at a time when its passage is most retarded and combustion further impaired by the reduction of temperature accompanying volatilization. With an air requirement therefore irregular, the grates must be arranged to admit this greater excess of air at all times less larger loss ensue from escape of unburnt gases.

In gas firing the air supply may closely approximate that theoretically necessary and is always under control. Combustion is more complete, therefore, because this less excess of air reduces the amount of the products of combustion. The heat evolved is concentrated in a smaller volume, thus raising the temperature of combustion, which in turn facilitates union of the oxygen of the air with the constituents of the gas. Moreover, the less air means less dilution of the gaseous mixture by inert nitrogen and vapors which retard combustion, while the possible intimate mixture of gas and air promotes their contact and combination.

The burnt gases being of higher temperature transfer their heat more readily, and because of reduced quantity carry less to the chimney. But on their way they may be intercepted and compelled to impart a large measure of their heat to the air going to the combustion chamber, an expedient which experience has shown of small value in direct firing. By this recuperation and return of heat to the system, there is an additional saving in fuel equivalent to the heat so returned, with the attendant advantage of still further promoting combustion, increase of temperatures and reduction of loss in waste gases.

Generation of Producer Gas.—This, as stated, is the product of an incomplete combustion in the generator.

The oxygen of the air entering the producer and coming in contact with the incandescent carbon of the fuel, forms a certain amount of gaseous incombustible carbonic acid (CO_2). The heat generated by this reaction is taken up by the CO_2 and the nitrogen of the air supplied. These ascending gases yield their heat to the fuel above, bringing it to incandescence. But in contact with this glowing carbon the CO_2 first formed takes up another portion of carbon, and is thus converted into combustible carbon monoxide (CO), chemically indicated thus:

$$CO_2 + C + \text{heat} = 2\,CO.$$

In absence of impurities in the fuel and with dry air, the gas contains all the nitrogen of the air and approximates

Carbon monoxide	(CO)	. . . 34.7 per cent.	by volume,
Nitrogen	(NO)	. . . 65.3 per cent.	

and has a heating value of about 118 British thermal units per cubic foot.

In practice, with carbonized fuel and an air blast, it contains always some CO_2 and a little H with the N of the air. The H arises either from the fuel or decomposition of the moisture in the air supplied upon its contact with the glowing carbon thus:

$$H_2O + C + \text{heat} = H_2 + CO.$$

With uncarbonized fuels, as soft coals, the products of distillation of the raw fuel in the upper zone are mixed with those of the gasification below. They consist chiefly of H, and the hydrocarbons Marsh Gas (CH_4) and Olefiant Gas (C_2H_4).

Conditions Affecting Quality of Gas.—Obviously, as large a proportion as possible of the CO_2 first formed should be converted into CO to raise the percentage of combustibles.

This is accomplished the more quickly and thoroughly the higher the temperature* of the producer, and the greater the surfaces of fuel exposed to contact of ascending gases. The formation of CO is promoted the more porous the fuel, the greater its depth and the finer divided, to a point where excessive resistance arises to passage of the air or gases. Large lump fuels which retain their form in combustion require, therefore, greater depth. A slower velocity (weaker draught or blast) of the gaseous current through the fuel bed acts similarly by prolonging contact.

Nevertheless, it is impossible to remove all the CO_2. Within the range of temperatures with which we are dealing, the reduction of CO_2 to CO proceeds to a certain ratio for the temperature, when, were other causes absent, action ceases by dilution.

The temperature of the producer has also an important bearing upon the volatile matters given to the gas when uncarbonized fuels are used. Higher temperature increases the percentage of combustible, especially CO, in the gas, and while less gas is produced per unit of carbon, it carries a greater per cent. of the heat energy of the coal. The amount of condensible products, as water and tar, is reduced, the tendency being more to the formation of soot or pitch. An analysis by Stöckman, illustrating hot and cold working on the same fuel, shows a decrease of 12 per cent. in volume of gases, with a gain of 20 per cent. in their heating value, which, of course, makes possible higher temperatures of combustion in the furnace.

Other things equal, the temperature of the producer will increase with the amount of fuel gasified in unit of time, and this is primarily dependent upon the air supply. But increased air supply means more rapid combustion, greater velocity of gaseous current through the bed, less duration of its contact

*Air over incandescent C gives minimum CO_2 at about 1900° F.

with the fuel and, therefore, indicates greater area (depth) of contact if quality of gas is to be maintained with CO_2 low.

Wet coals, by great loss of heat through high latent and specific heats of vaporization of water, retard hot working and, of course, for analogous reasons, carbonized work hotter than uncarbonized fuels.

Steam with Air Supply.—The jet blower is simple, compact and cheap, but it requires intelligent use. Its advantages are greater when the gas is much cooled before use; less with a close connection of producer and furnace, and with soft coals than with carbonized fuels. The use of steam (see also pp. 58 to 60) increases the combustibles by adding H to the gas, reduces the inert N, raises calorific power, lowers exit temperature of gases and retards clinkering. It does not produce more heat, simply transfers it from the generator to the furnace by the potential heat value of the H instead of the less efficient means of greater sensible heat in the gas.

Too much steam, however, reduces the combustible in the gas and lowers calorific power, reducing the amount of CO and increasing CO_2 and H. Jenkin reports analyses as follows:

Volume %.	Excess of Steam.	
	Moderate.	Great.
CO_2	5.30	8.90
CO	23.50	16.40
CH_4	3.30	2.55
H	13.14	18.60

In gasification of coke there is often strong tendency to clinker, and use of more steam may commend itself.

Sensible Heat of Producer Gas.—This is of importance because 12 to 18 per cent. of the heat value of the coal may exist in this form, the loss of which is only a question of cooling the gas. It is utilized only when gases reach the furnace hot, and the hotter the gases leave the producer, the greater may be this loss.

Hotter gases result from carbonized and dry fuels, rapid driving and dry-air blast than from uncarbonized and wet fuels or steam-air blast.

Temperatures of escaping gases, of course, vary considerably, depending upon character of fuel and rapidity of driving.

With coke, say between 900° and 1800° F.

Soft coals, say between 600° and 1600° F.

With anthracite and steam jet blower, 1100° F. is a frequent temperature.

Some Clues to Producer Operation.—The increased efficiency of this apparatus will repay a better supervision than it frequently receives.

Among the most common sources of trouble are irregular charging and neglect of attendant to close up the channels which form in the bed and permit air to ascend freely. The gases and air tend also to seek the walls, and the bed must be sufficiently solidified by stoking to retard this and close the openings in the bed. Too rapid driving or too thin fuel bed produce the same result as this neglect and air gets in too freely, burning the gas within the producer. The result is high CO_2, low CO and H, while the temperature of the gas is high and variable.

Excessive steam also increases CO_2 with decreased CO and higher H. See also p. 23.

Too little steam results in high temperature of gas and may cause trouble from clinkering if ash of fuel has that tendency, but it lowers CO_2 and H, with increase of CO.

Increase of blast pressure has sometimes a beneficial action.

Simple water gauges will often be a useful guide when registering the pressure at top and bottom of the producer or on the system; this especially to those whose inspection is irregular. In all cases frequent analyses of gas should be made, that the factors governing any particular practice may be determined and properly regulated.

Producer Fuel.—By previous gasification in a producer materials quite unsuited for heating operations are made available. Especially is this true of substances containing much moisture, turf or peat, wood, sawdust, tan bark, etc. The water may be readily removed from the gases, which can then be applied to operations requiring high temperature.

In general, of course, the composition and heating value of the gas vary with that of the fuel. The carbonized fuels, as coke and charcoal, work more favorably than those above cited or soft coals, but with them it is the more important to avoid cooling the gases before their consumption.

In gasification of fuels having a high percentage of water, high CO_2 and H may be found in the gas. This may be explained by the fact that at about 1100° F. water vapor oxidizes CO to CO_2 thus:

$$CO + H_2O = CO_2 + H_2.$$

Lignite.—Experiments made by ourselves in the application of Texas Lignite in Revolving Bottom Gas Producers, under the inspection of the State Geologist of Texas, resulted in demonstrating its great worth as a basis of gas production. The lignite tested resembles in composition much of this class of fuel abounding in Western States, and consists of

	Per Cent.
Moisture	21.86
Volatile matter	31.81
Fixed carbon	36.85
Ash	9.48

The gas is high in hydrocarbons, and, as a consequence, its flame produces an intense heat.

The following analysis of the coal and gas show the result of gasifying similar Peruvian coals:

COAL.		GAS.	
Water	18 per cent.	CO_2	6.4 per cent.
Volatile matter	40 " "	C_2H_4	.7 " "
Fixed carbon	31 " "	O	.8 " "
Ash	9 " "	CO	22.0 " "
Sulphur	3.5 " "	H	9.6 " "
		CH_4	1.6 " "
		N	58.9 (diff.)

Gas from the earthy and brown coals is very largely employed in Europe in many metallurgical works and manufactories requiring high temperature furnaces, as in iron and steel, potteries, glass works, etc. There is no apparent reason why the lignitic coals of the West should not be as satisfactorily used.*

Tan Bark.—Gasification of spent tan bark has also been successfully accomplished in our Producers.

The spent tan bark had the following composition:

	Per Cent.
Moisture	38.67
Ash	3.24

* Recent tests of lignite from Greece also gave good results, a gas engine running steadily on this gas for eight hours during the test.

The gas, obtained from the Producer plant of special character, after its cooling and washing analyzed as follows:

	1	2	3	
CO_2	10.8	18.8	15.0	per cent. by volume.
O	.6	.4	.4	
CO	17.6	10.2	14.2	
CH_4	2.4	4.8	5.6	
H	16.4	14.0	8.7	
N	52.2	51.8	56.0	

Calorific powers determined repeatedly by a Junker's calorimeter gave 125, 132, 141 B. T. U. per cubic foot.

Mixed with 25 per cent. of coke fines, an average of 145 B. T. U. was obtained.

The Yield of Gas from different fuels varies within wide limits, depending upon the composition and general character of the fuel and method of operation. More as an index to differences of yield than accepted data the following figures are given for the fuel free from ash, the dry gas and an air blast:

Material.	Yield per Pound.	
Coke or charcoal	104	Cubic feet.
Bituminous coal	75	
Brown coals	55	
Turf	45	
Wood	35	

Application of Producer Gas.—It has been applied with such marked economy for so many purposes that it is now considered essential to the prosecution of many lines of industry, notably Steel Works, Rolling Mills, Smelting Furnaces, Glass Works and Chemical Works. Its almost exclusive use in these and many new fields is only a question of time, for the reason, emphasized now by failing natural gas supply, that our only staple and reliable source of Heat on a large scale is coal and that the most satisfactory method of utilizing its heat is to first convert it into Gas and Ashes; this is the function of a Gas Producer.

However, in considering the use of producer gas in any new field it is well to bear in mind its relative weakness (it has only about one-fifth the energy of good illuminating gas per cubic foot), and that its most successful applications are in operations where a considerable body of the gas is burned rather than in very small work, where illuminating gas is suitable. **Yet it is by far the cheapest gas made per unit of heat, and contains more of the energy originally in the coal than any other.** These facts make it a very economical fuel when properly applied, and, in addition to the large high temperature furnaces where it has long been used, there are many cases where it can be applied with convenience and economy when low, even heats are needed, and the secondary economies are more important than the saving in the fuel consumed. But in this class of work as much depends on the proper application of the gas to the special purpose as on its production.

THE TAYLOR GAS PRODUCER.

A Gas Producer is perhaps the simplest of all metallurgical furnaces; in fact, almost any vessel capable of containing a deep bed of incandescent coal through which a current of air, or air and steam, can be forced or drawn is a good producer for a short time. But from the time they were first brought into use, thirty years or more ago, up to nearly the present, the removal of the ashes and clinkers has been always attended with a serious expenditure of time, labor and fuel. Various plans to overcome these difficulties have been tried, but now almost all producers are constructed with some sort of a grate, and differ principally in the kind used, or in some detail of construction.

The Taylor Producer was designed as a result of the troubles experienced by its inventor, Mr. W. J. Taylor, in the use of various types of producers for manufacturing producer gas in connection with his ore-roasting kilns at Chester Furnace, N. J., during a period of more than twelve years. The irregular quality and quantity of the gas, the frequent stoppages necessary for cleaning, the excessive labor and the great waste of coal in the ash in the best producers then attainable, conspired to turn his attention to the invention of an apparatus as free as possible from these defects.

After experimenting for years, Mr. Taylor designed a solid circular bottom or table to carry a deep bed of ashes, and arranged to revolve; the revolving of this bottom discharges the ash and clinker over its edge into a sealed ash pit beneath. This device has been well received by engineers and the manufacturing public.

What Constitutes a Good Gas Producer.—It is sometimes said that anything in the form of a closed box with a grate under it is good enough for a gas producer; and, in fact, several types of gas producer which are nothing more than such crude appliances have come into use owing to the general desire to obtain everything of the cheapest possible construction; the sole idea apparently being to make something to sell cheap, regardless of the **essential conditions for producing good gas continuously, with minimum labor and no waste of fuel.**

These conditions are briefly as follows:

1. A continuous automatic feeding device which shall spread the coal uniformly and continuously over the entire surface of the fire. This avoids the customary losses and annoyance from escaping gases at the dropping of a full charge at once, as in usual methods of feeding. Experience has shown that in some applications of producer gas the disturbing influence of intermittent charging seriously affects the heating operation. The beneficial effects of the continuous feed are felt in a uniform gas of better average quality and of regular flow, in reduced labor of attendance and advantage to workmen, while further promoting the cleanliness and order of the plant and the economy of its operation.

2. The incandescent bed of fuel must be carried on a bed of ashes several feet thick. This is necessary in order that the fuel shall gradually burn out and cool before being discharged. If this is not done, and the incandescent fuel is carried down close to a grate, it is impossible to prevent its passing through the grate in considerable quantities as coke; and even such as is fully burned out passes away hot instead of cool and moist.

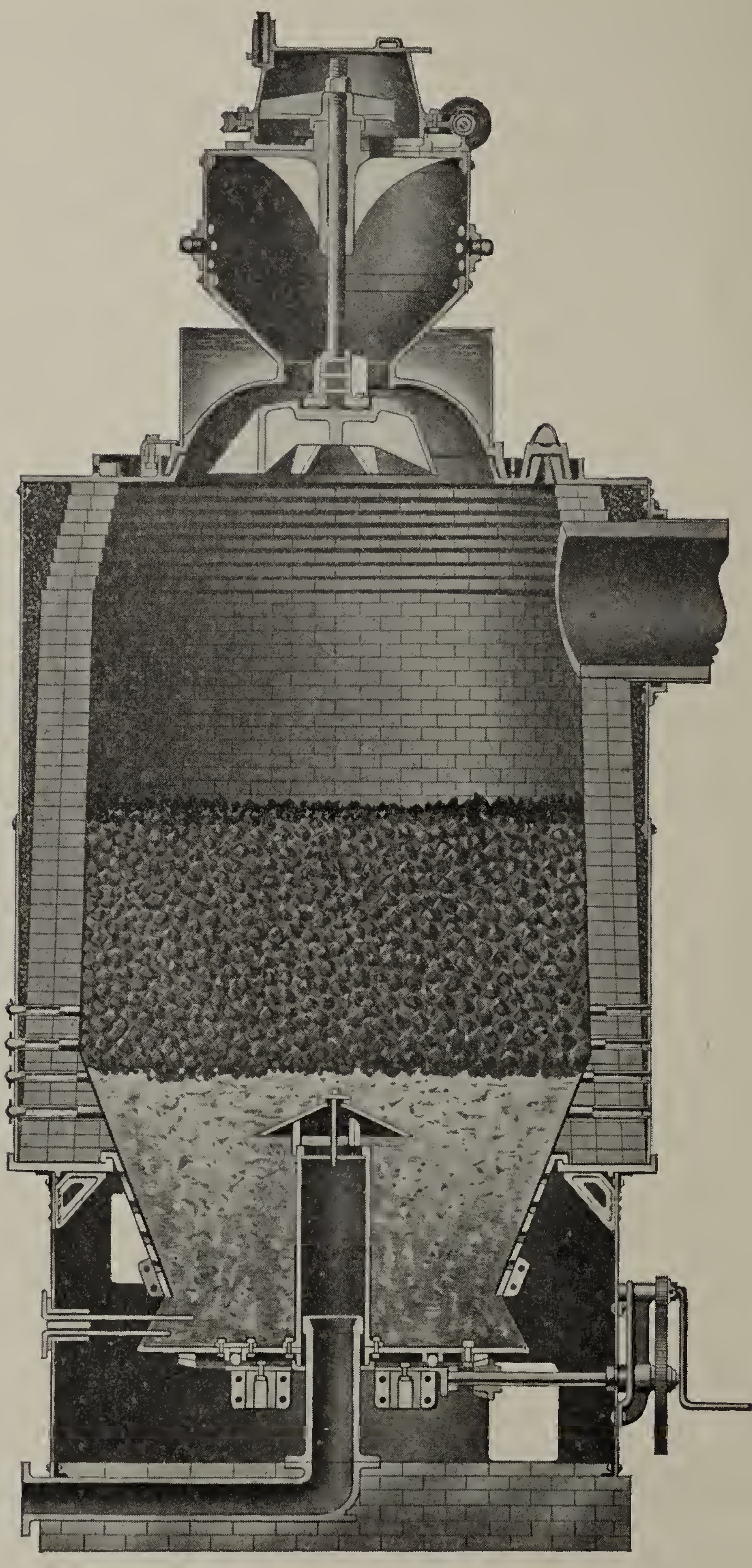
3. It is necessary to carry the blast up through this deep bed of ashes, by means of a conduit, to near the point where the fuel is incandescent, and thus avoid the necessity of blasting through the ashes. By this means the depth of ashes upon which the fire is carried can be made as great as is desired. This is not the case with producers whose blast is supplied underneath the grates; they, of necessity, have to carry a very shallow bed of ashes, with consequent loss of fuel in so doing.

4. The point where ashes are removed must be open and visible to the attendant while removing them, as it is absolutely necessary that he sees what he is doing. It must also be cool enough for him to work without great inconvenience. Producers which work with closed or water-sealed bottoms do not cover this important point; the attendants dig into the ashes which they cannot see, and therefore cannot control the fire intelligently; they have to **guess** what they are doing. In many such producers the ashes have to be forced through the grates by long bars from above, which involves a large amount of the hardest and most trying labor, and necessitates the carrying of a comparatively shallow bed of fuel, as otherwise the men cannot force their bars through it from above. This shallow fuel bed and excessive poking results in a poor gas, high in carbonic acid, for one of the essential conditions for making carbonic oxide and for decomposing the steam is a **deep bed of incandescent fuel.** The work with the bar of the attendant above should be merely to distribute the fuel properly over the surface after it has been dropped from the hopper, and not to poke holes through the fire. The ashes should be removable from a clear, open space below, and not through grates.

5. It is necessary that the support upon which the contents of the producer are carried should be level and horizontal. Any form of sloping grate, no matter how the slopes are arranged, will produce an uneven thickness of fire bed; the blast will have freer access through the fire at some points than at others, and there will always be a shallow place through which coke easily finds its way before being properly consumed. Any form of grate is undesirable, because it necessitates the passage of ashes through it; but a sloping grate is particularly objectionable. There is usually no access to the place where clinkers are formed, or, if such access is provided, it opens right into the gas-producing zone, which involves either shutting off the producer entirely or the possibility of suffocating the attendant by the escape of gas.

For a successful gas producer the conditions are summarized as follows:

1. A continuous and automatic feed; the former for regularity and uniformity of gas production with



A

REVOLVING BOTTOM GAS PRODUCER, WITH BILDT CONTINUOUS AUTOMATIC FEED.

improved quality, the latter for eliminating negligence of attendants.

2. A deep fuel bed carried on a deep bed of ashes; the first to make good gas, and the second to prevent waste of fuel.

3. Blast carried by conduit through the ashes to the incandescent fuel.

4. Visibility of the ashes, and accessibility of the apertures for their removal, arranged so that operator can see what he is doing.

5. Level, grateless support for the burden, insuring uniform depth of fuel at all points, and consequent uniformity in the production of gas.

The Bildt Patents broadly cover point No. 1. While many attempts have been made to accomplish this result, the Bildt Continuous Automatic Feed Device, manufactured by us, is the only practicable arrangement ever offered to the trade and kept successfully in operation. As to points Nos. 2 and 3 any construction which carries the blast up through a deep bed of ashes, the point of application of the blast to the fuel thus being at some height above the bottom of the ash bed, is an infringement.

The conditions Nos. 4 and 5 are also covered in a most excellent arrangement; and, while it may be varied in detail, it will be found that our design is a most practicable and thoroughly mechanical one, which cannot be surpassed for simplicity and effectiveness.

Referring to the preceding cut *A*, the No. 8 Producer is shown as charged with anthracite coal, the incandescent fuel being supported by the bed of ash, which is put upon the revolving bottom **before** firing; and this bed of ash is maintained as essential to the successful operation of the producer.

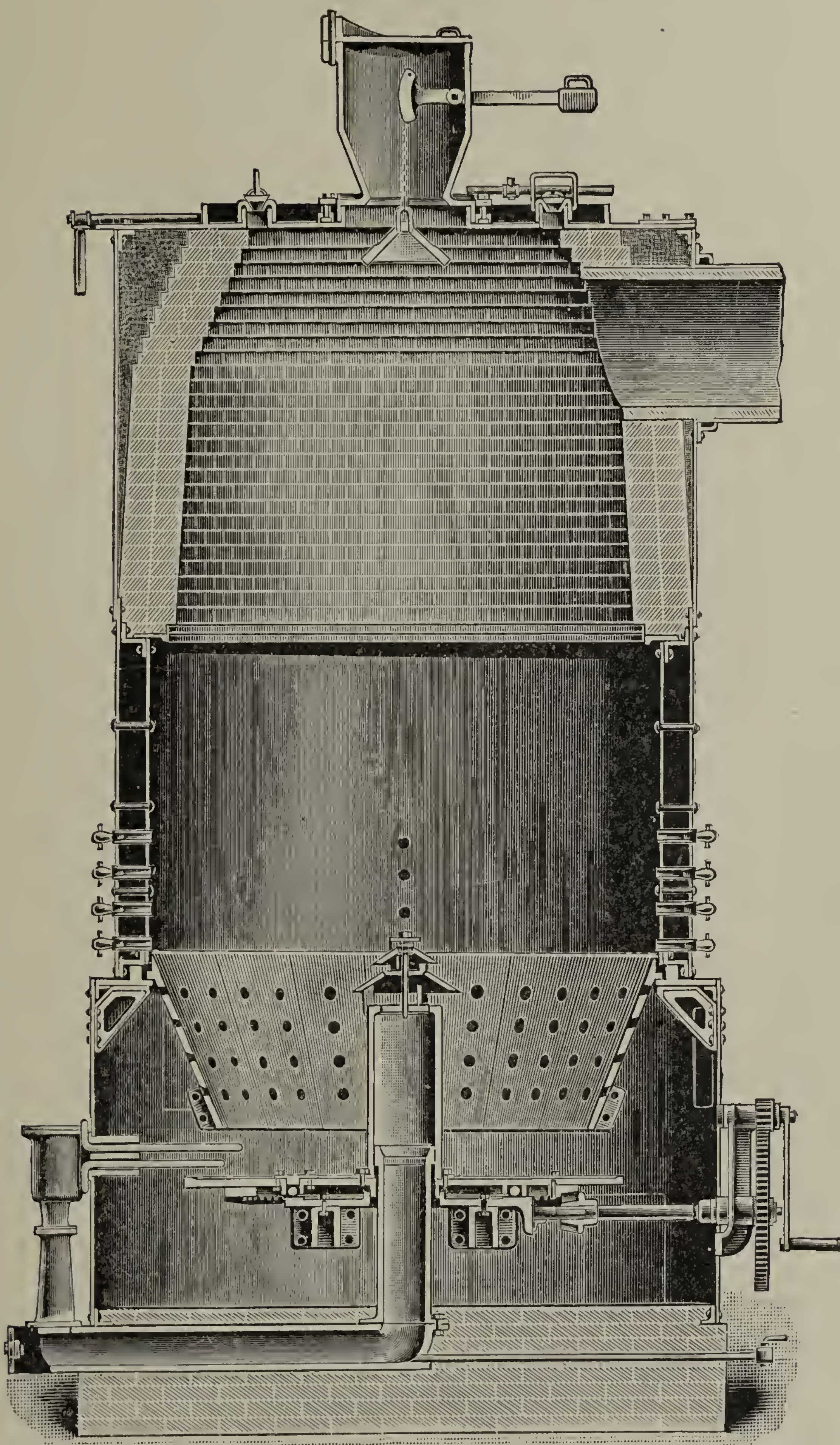
It will be noticed that the revolving bottom is of greater diameter than the bottom of the bosh, and is placed at such a distance therefrom that when it is revolved the ash, which forms its own slope at an angle of about 55°, is discharged uniformly by its own gravitation over the periphery and into the sealed ash pit below (which is under blast pressure), all without stopping the producer, and with little interference with the making of gas. In the regular operation of the producer the line between the ashes and fuel is kept about six inches above the cap on the central air pipe, thus permitting the fire to come into contact only with the brick lining; and all ironwork is kept away from the heat.

The grinding is done as fast as the ashes rise too far above the desired line; say every six to twenty-four hours, according to the rate of working. The bed of ash is kept about three and a half feet deep on the revolving bottom in the larger sizes, so that ample time is given for any coal which may pass the point of air admission without being consumed to burn entirely out; while in a producer with a grate it would have fallen into the ash pit and been wasted. **This is an important point and gives this producer a record for economy of fuel superior to that of any other,** tests of a week or more having been made when the loss of carbon in the ash averaged less than one-half of one per cent.

The turning of the revolving bottom causes a grinding action in the lower part of the fuel bed and closes up any channels that may have been formed by the blast, thus keeping the carbonic acid in the gas at a minimum. A few turns of the crank at frequent intervals will keep the fuel bed in a solid condition, reducing the necessity of frequent poking from above. The door of the ash pit is opened, say once a day, for taking out the ashes and clinkers; this requires but a short time, and interferes but little with the continuous working of the producer.

The blast is generally furnished to the producer by a steam jet blower. A fan blower may be used if more convenient, but then a small steam pipe must be run into the vertical air pipe to supply the steam necessary for softening the clinkers and keeping down the temperature of the producer. In general, it is desirable to use as large a proportion of steam as can be carried without lowering the temperature of the fuel bed below the point where all the steam will be dissociated, but any steam passing through the fuel bed into the gas will reduce its effectiveness.

The injected air and steam are introduced through a central pipe, and are discharged radially therefrom in order to prevent too



REVOLVING-BOTTOM GAS PRODUCER, HALF WATER-JACKET UPPER CASING.

much travel of the gas next the walls, which is the line of least resistance. This pipe is placed with its top at a point sufficiently high to carry the required bed of ashes, the top of which should never be brought as low as the top of this central air pipe. Sight or test holes are placed in the walls, so that the dividing line between the ashes and the incandescent coal can be ascertained at any time. Sometimes this dividing line becomes higher on one side than the other. To remedy this, four sets of agitating bars or scrapers are arranged just above the revolving table, any of which may be pulled out in case the ashes grind down too fast on one side; this retards the discharge on that side and levels up the ash bed. Gates are also provided, where anthracite coal is to be used, which may be arranged around the bottom of the ash bed to entirely cut off the discharge of ash on the low side when necessary. The boshes are perforated for the admission of punching bars, which are inserted through the observation doors in the lower casing, for the breaking up of occasional clinker which by inattention or bad coal, or both, has become too large to pass down and out without trouble.

The preceding illustration *B* shows a No. 7 Producer of the half water-jacketed type, and which is especially adapted to service in gasifying coals of inferior quality liable to clinker. The water-jacket rises from the top of the bosh about half-way upward so as to extend around the space occupied by the incandescent fuel, the producer being lined above the water-jacket with fire brick in the ordinary way. The clinker will not adhere so readily to the smooth sides of the water-jacket as to fire brick, and the former is not liable to injury when the poker-bars are used from above.

This design is modified in special instances by carrying the water-jacket all the way to the top; but water-jacketed producers are not recommended where the gas is used for heating purposes, as, compared with brick-lined producers, there results from the use of the water-jacket a loss of temperature, and consequently less dissociation of steam. Hence, unless the heat of the water can be utilized (see page 74) or the character of the coal necessitates the use of the water-jacket, the brick-lined producer is preferable.

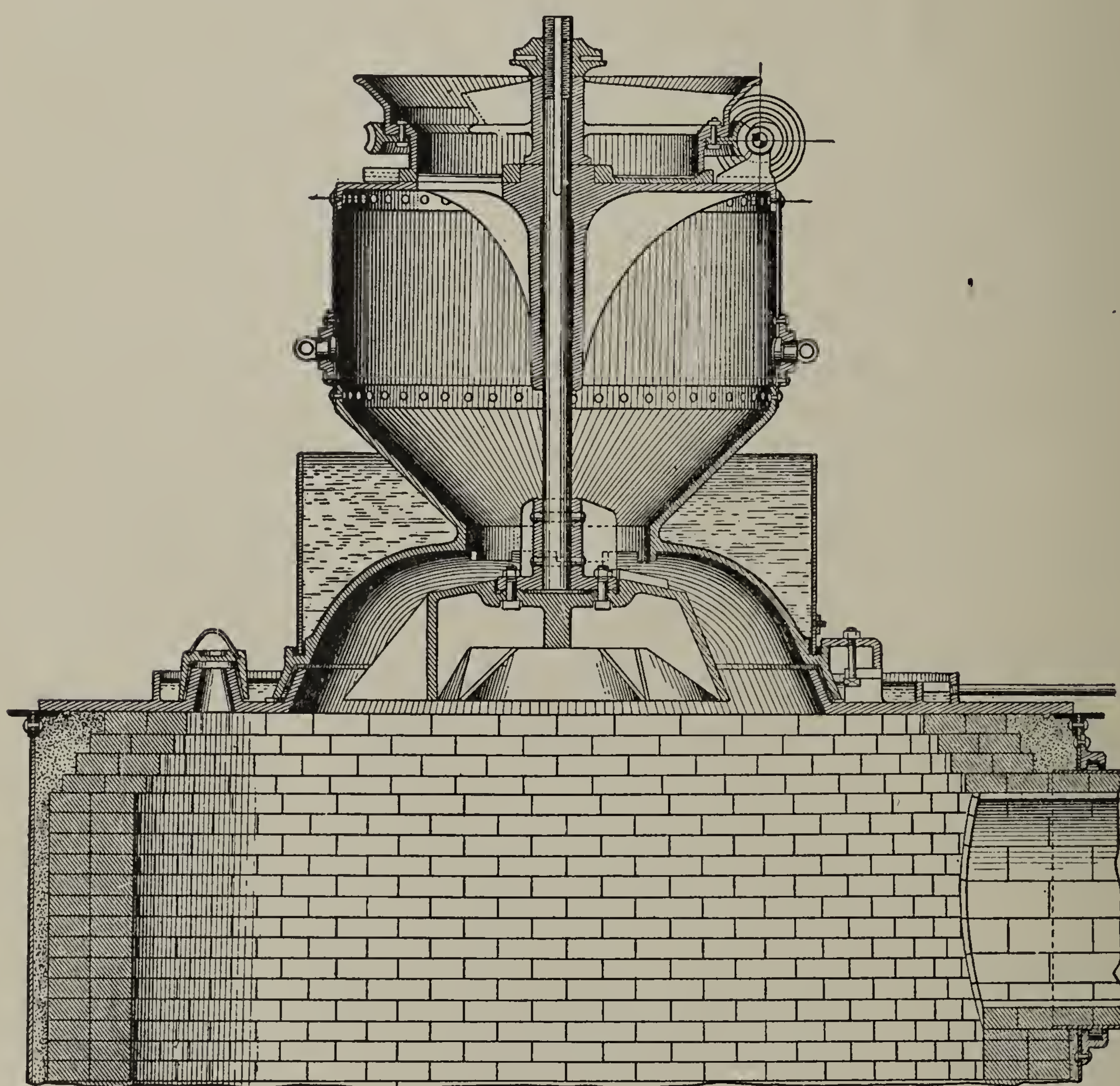
There are, however, many operations where a considerable quantity of hot water is required. In such cases, if the water has not to be retained against boiler pressure, the casings require less staying for requisite strength, and are therefore of simpler and cheaper construction.

The Bildt Continuous Automatic Feed Device.—It is generally recognized that the more uniform the freshly-charged layer of coal is kept in a gas producer, the better the results obtained by the more uniform combustion prevailing. Gas producers are ordinarily charged with coal by filling some form of hopper either by hand or from some overhead chute. By releasing the "bell," "cone damper," or equivalent device, the charge falls into the producer. The best of such devices have long been recognized as deficient by not evenly distributing the coal over the gas producing surface, a defect remedied, but still imperfectly, by the attendant using a spreading bar inserted through the poker holes of the producer top-plate. Because of this varying thickness in the fuel bed, the gases vary in composition at different portions of the bed, excess of carbonic acid and other inert gases arises with consequent waste of fuel. The bed will burn better in one place than another, forming local channels of higher heat and stronger tendency to clinkering. Moreover, the charging operation being repeated every ten to twenty minutes, a great volume of gas escapes at each dropping of a charge, a loss further increased by the subsequent opening of the poker holes for spreading the coal and breaking up incipient clinkers. The workman in such an atmosphere is soon enervated and frequently the producer is left to adapt itself as best it can to these irregularities of feeding, and, human-like, resents it later by serious internal difficulties.

The Bildt continuous automatic feed, as its name implies, continuously delivers the fuel in a steady shower of coal in controlled volume from the deflecting surfaces of a constantly rotating distributer. Being automatic, it eliminates any possible negligence on the part of the attendant in supplying fuel, and receiving its supply from a closed storage magazine above the producer, it avoids the serious loss of gas arising from other methods of charging. The storage magazine is of a capacity requiring to be filled at longer intervals than usual, and then, as stated, with trifling, if any, loss of gas. Thus a large saving in fuel and labor is effected, while the comfort and health of the attendant is promoted.

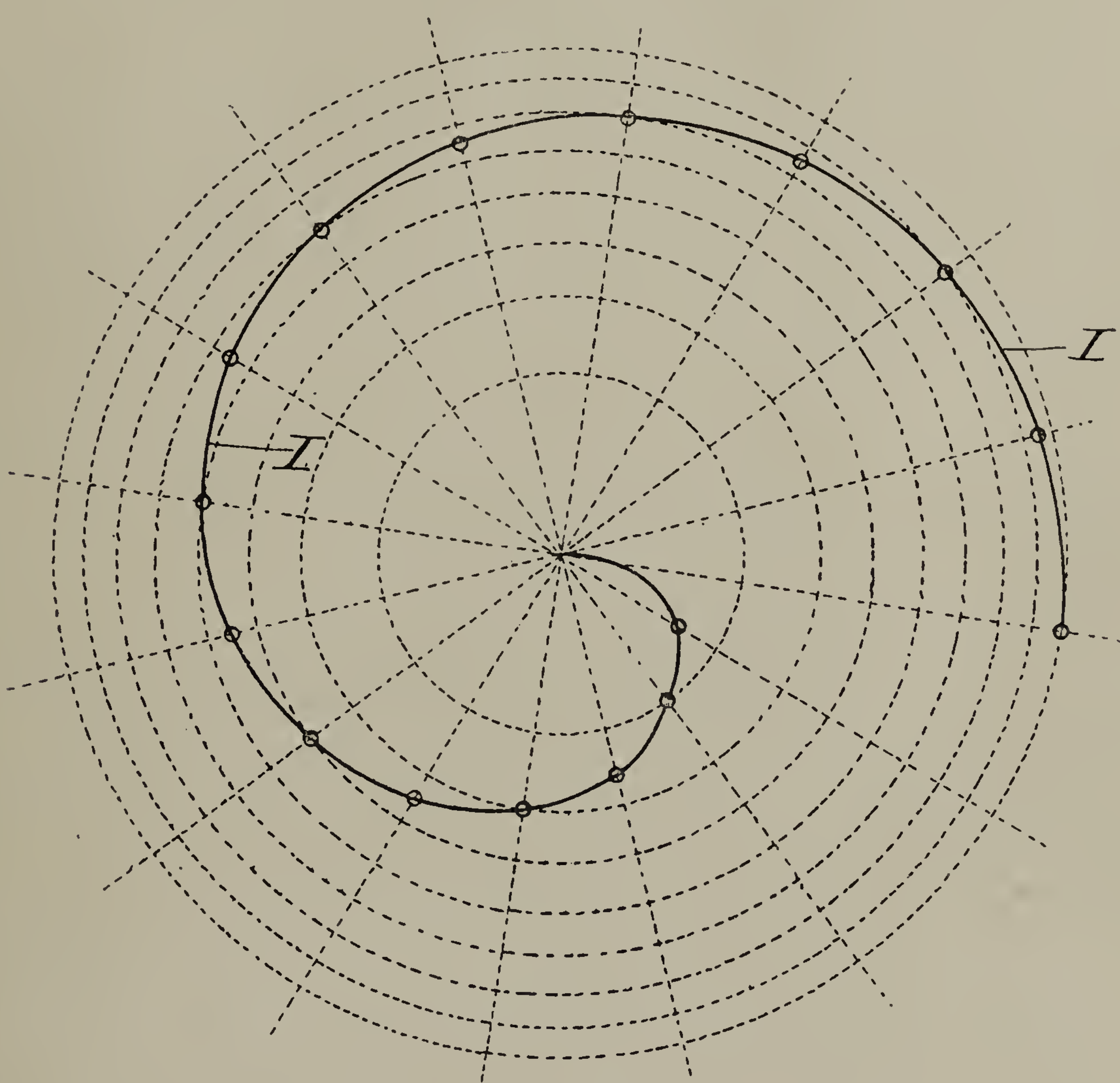
Where but one producer is in use, or, in any case where the fluctuations in the gaseous current are injurious, and they are sometimes seriously so, this form of feed will be of increased value. By its use also producers of greater area can be successfully operated where hand charging would fail, as the coal can be distributed equally as well over a large as over a small area.

The apparatus consists of a receiving hopper surmounting the main storage magazine, communication between the two being regulated by the horizontal rotating register or gate operated by a lever.



BILDT CONTINUOUS AUTOMATIC FEED.

Below the main magazine is suspended the distributer plate, its inclosing shield or hood, as well as the inverted conical base of the magazine, being water cooled. The influence of the cooling water and the location of the plate above the gaseous current facilitates the discharge with strongly caking coals. The distributer plate is supported by a steel shaft passing upward through the storage cylinder and suitably guided as shown. At the upper end of the shaft, above the supporting bracket, a worm-wheel and worm impart rotation to the receiving hopper which, through its radial arms and hub keyed to the shaft, revolves the distributer. The hand-wheel nut upon the threaded end of the axis gives means of adjusting the distance between the distributer plate and the coal reservoir. By such adjustment, and further by variable speed (one revolution in 1½ to 6 minutes) secured through step cone pulley, the rate of coal discharge is readily controlled. Instead of belting, the worm may be driven by fixing on the countershaft an eccentric the rod of which, extending to the axis of the worm, carries a pawl engaging a ratchet wheel on the worm shaft.



DEVELOPMENT OF CURVE REPRESENTING LINE OF DISTRIBUTION OF DISTRIBUTER PLATE.

In the sides of the magazine are holes for insertion of rod or inspection when necessary. The lower lip of the dome inclosing the distributer plate slips over the flange or rib rising from inner edge of the top plate, the joint thus formed being sealed by the water lute as shown. The apparatus, as a whole, may be readily lifted from the top plate, and, therefore, is easily accessible and facilitates entrance to the producer when desired.

The cut preceding is a geometrical development of the lower edge or line of distribution of the coal from the distributer and is a spiral.

Such line of distribution is secured on the distributer by having a dependent flange, the flare of which deviates to carry the distributing edge along the line of a spiral as far as experience has shown necessary. The cut clearly shows that by the revolution of such a construction every portion of the gas-producing surface is covered by some point of discharge of this plate.

In operating, while still sufficient coal remains in the main magazine to prevent escape of gas and with receiving hopper full, the register is opened, allowing the coal to enter the storage compartment. If desired, the gate may again be closed and the operation repeated, or, in first instance, the full capacity of magazine is drawn from overhead bin.

Worcester, Mass., U. S. A., February 11, 1898.

This is to Certify that a Gas Producer supplied with the Bildt Patented Automatic Feed Device in connection with a heating furnace has been in use continuously at the Washburn & Moen Works for the past seven months.

The distributing disk shows no material wear; the apparatus has required no repairs, and its general excellence can be highly commended. The coal is continuously and uniformly distributed over the charging area, and the gas is of uniform and excellent quality, and steadily supplied.

The consumption of coal is greatly reduced, as well as furnace waste, labor and repairs.

The analysis of the gas produced is as follows:

CO_2	4.9
O	None
CO	26.8
C_2H_4	0.4
CH_4	3.5
H	18.1
N	46.3
	100.00

WASHBURN & MOEN MFG. CO.
F. H. Daniels, *General Supt.*

Note.—See also text on Producer Gas Power Plants for further testimonials.

The preceding letter indicates the estimate of this apparatus held by those familiar with its use, and where the producers use soft coal.

Experience has amply demonstrated the durability of this distributing plate, exposed though it is to the hot gases and radiation from the fuel bed, while the simplicity and stability of construction of the whole avoids apprehension of frequent repairs.

Distributers which have been in use twenty months were still intact when last examined.

The apparatus is adapted to either anthracite or bituminous coals, and of the latter the following are analyses of coals with which it has been successfully operated and in "run of mine" grades:

Water	.80	10.00
Volatile matter	36.70	42.00
Ash	7.65	5.70
Sulphur	.61	2.20
Fixed carbon	54.85	42.00
Coke	62.50	47.70

With both coals it permits the use of the finer sizes and inferior, cheaper grades. Working results in our producers with this feed on such grades of anthracite is more fully detailed in the description of the Erie Railroad engine gas plant.

Regularity of flow and in the composition of the improved quality gas, economy in coal, maintenance of better fuel bed, reduction in labor, increased comfort of attendance, cleanliness of operation and elimination of neglect of feed are features of this device which must commend it to those at all familiar with gas producer practice.

Since the previous issue of this pamphlet a large number of these devices have been installed on both soft and hard coals, two of the largest steel works having equipped their producers with this feed. Whenever desired, for reasons of special practice, distributer plates of cast steel may be substituted for the usual cast iron.

It is made in sizes to suit the various diameters of producers. Prices quoted upon application.

Another arrangement of top plate, hopper and stoking of which we have supplied a number is the patented device of J. Wm. Gayner, of Salem, N. J. The device also includes a disposition of flues and scraping attachments which permits of clearing away accumulations without interruption to the process. The construction is an outgrowth of his experience in the operation of gas producers in the glass industry, and is designed as a simple expedient for lessening labor and promoting continuous operation by keeping clear the gas conduits where usually most obstructed by deposits of soot, etc.

By water-sealed hopper lid, gas tight lever fulcrum, suspended stoking bars, etc., there is secured a minimum of gas leakage and of effort in manipulating these producer attachments.

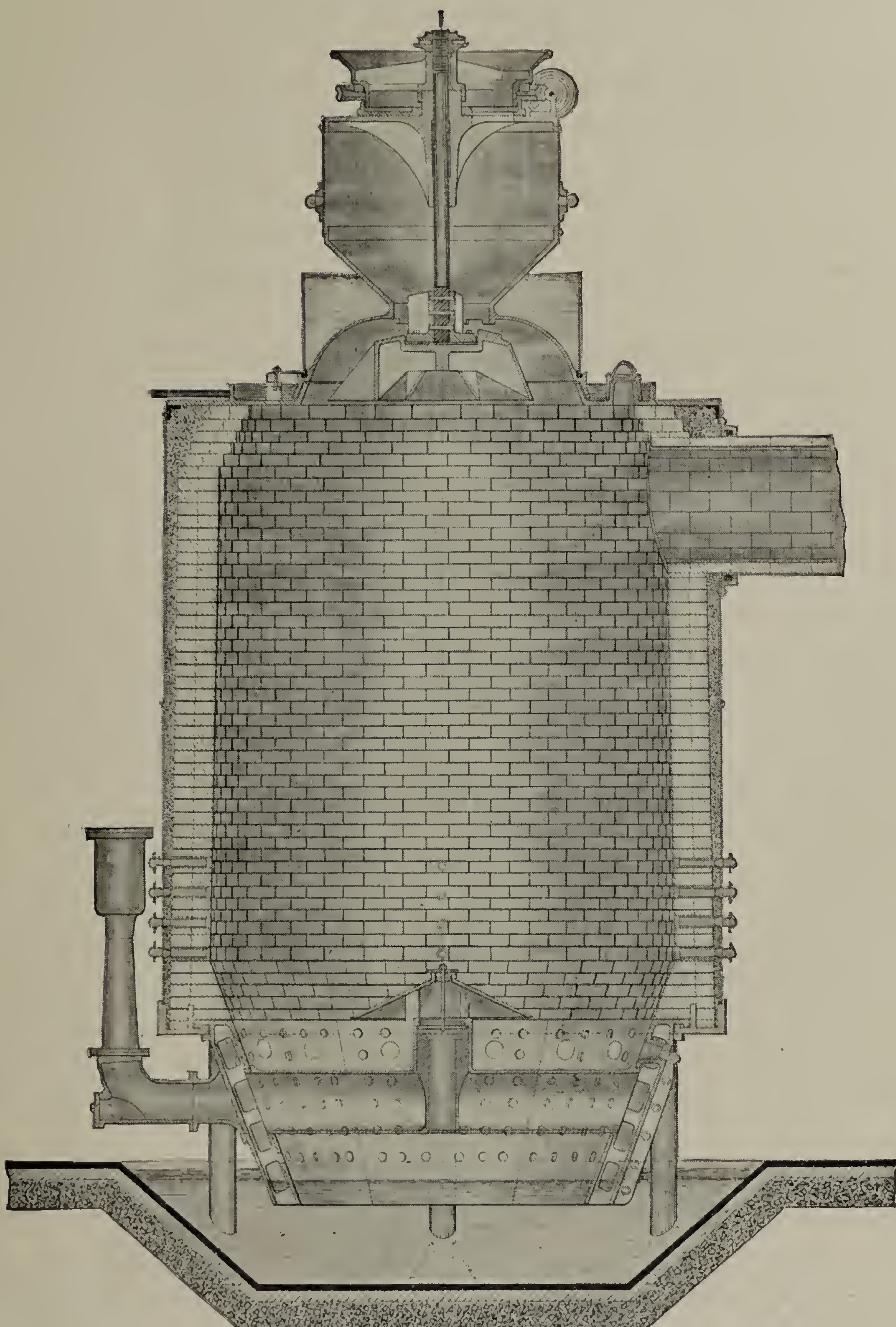
The arrangement has given good satisfaction, and we are prepared to furnish them or quote on application.

The Producer is regularly made in the seven sizes given on page 45, in which the design is altered to suit varying conditions incident to location, kind of coal to be gasified and other requirements.

The type illustrated in Design *A*, p. 30, with a revolving bottom and shell lined with fire brick, is that usually adopted for anthracite and a good quality of bituminous coal. For bituminous coals liable to clinker, the design is in some cases modified, as previously explained, by a water-jacket, which should be selected only when those conditions exist (p. 34).

In some rare instances, for very poor coal, the revolving gear has been eliminated, retaining the solid bottom only; but experience shows that even for such coal it can generally be used, during most of the day's run, to advantage; hence we recommend its retention, though it may often be necessary to work down the ash in the usual way. The half water-jacketed producer has been successfully adopted in gasifying low-grade coals in Montana, and also in Illinois. The latter, in addition to from twenty to forty per cent. of ash, carries a large quantity of pyrites, so that the clinkers are large and extremely hard, testing the capacity of the producers most severely.

In numerous instances this Producer has replaced the older type of grate-bar producers, the change resulting in a decided improvement in the quality and uniformity of the gas, and far



WATER-SEALED PRODUCER WITH BILDT FEED.

(Shem Patent.)

more perfect gasification, the loss of coal being practically *nil.* With producers of the half-jacketed type as used on inferior coals the water-seal may sometimes be adopted to advantage. With the Standard Producer, however, the water-seal is not necessary, nor is it recommended, in that it requires more space and is far from cleanly.

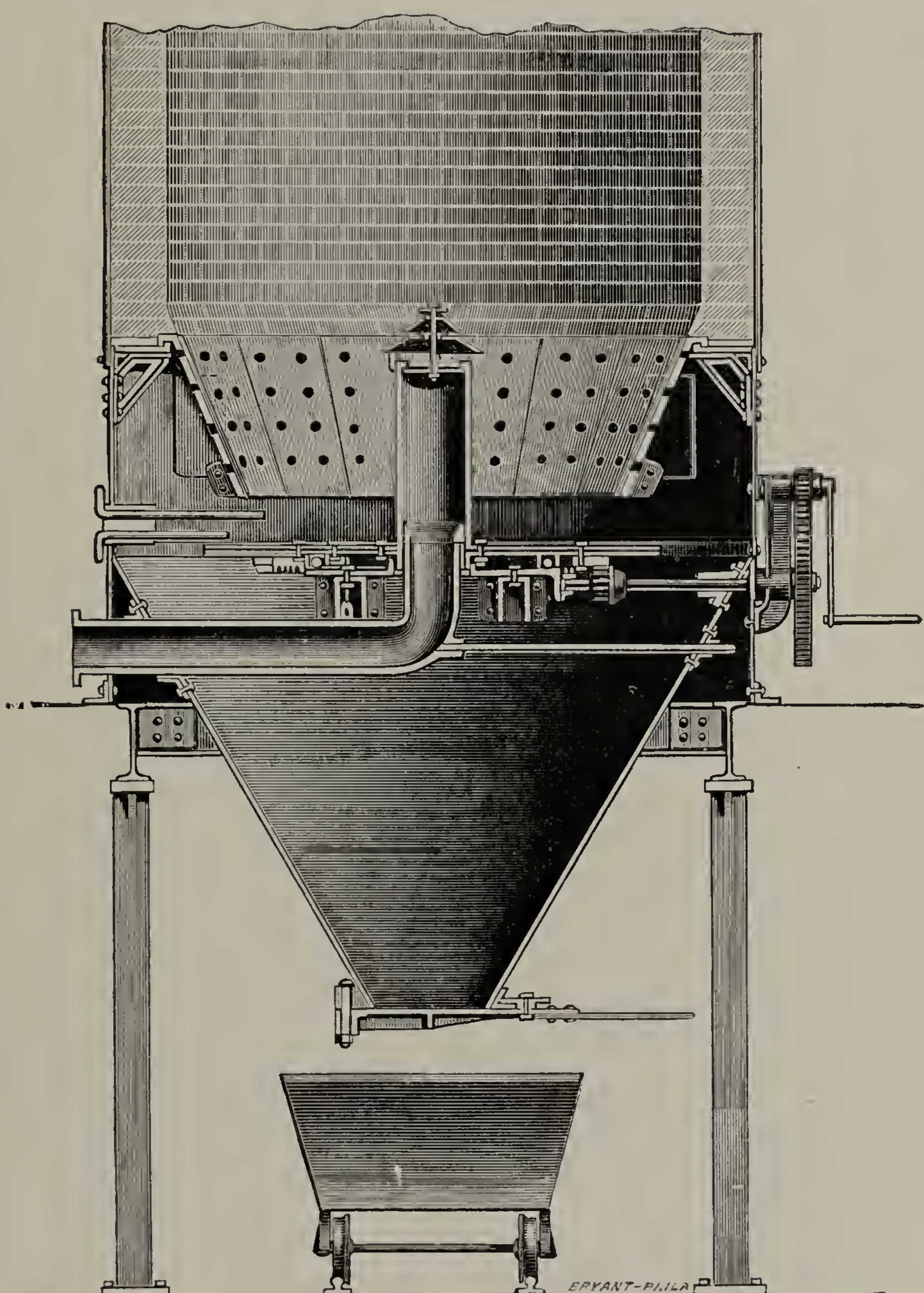
Water-Sealed Producer.—There are, however, special cases where a water-sealed bottom may be desirable, and to meet which we have designed the water-seal type illustrated on page 41. The special feature of this producer is the double bosh. The air entering the blast pipe, which protrudes through the bosh plate, passes to the vertical central air conduit and circulates also about the inner boshes. These are perforated, permitting the passage of the air into the ash bed, taking up its heat and insuring checking the escape of combustible matters in the ash. Any accidental obstruction in the blast pipe is readily accessible by removal of the blank flange at extremity of the blast pipe. Poker holes are suitably placed about the bosh for the insertion of a bar if desired. Such producers equipped with the Bildt automatic feed are giving most excellent service, some of them operating with the lignite coals in Western districts.

An extra heavy, plain cast iron top is sometimes substituted for the usual water-cooled top.

Producers are generally placed upon an ordinary foundation at ground level, but in large batteries are frequently elevated and provided with inverted cone bottoms, as illustrated on page 43, to receive the ash, which may then be discharged into conveyors or cars underneath them. Conveyors are also used in large installations for carrying the coal into bins placed above the producers, from which it may be drawn through chutes as required for charging. Such a plant we have recently installed where all coal and ash are chiefly handled by automatic feeds and conveyors, reducing labor to a minimum.

These modifications in our producer construction and practice are thus especially noted to emphasize the fact that almost every installation requires a special study of the surroundings, including the application of the gas, to insure the best results.

In the operation of Gas Producers the personal equation is an all-important factor. Intelligent direction and conscientious attention on the part of those in charge of producers will materially increase their efficiency. Not infrequently have instances been brought to our attention in which poor results obtained in one plant as compared with another were almost entirely due to carelessness. Again, it should be borne in mind that conditions often exist beyond the producers which materially alter the results. Especially should the mains have watchful care that dust accumulations do not obstruct pipes and valves. Cleaning attachments should be carefully located for the convenience and least labor of the attendant.



SECTIONAL VIEW OF THE LOWER PART OF A GAS PRODUCER, WITH CONED ASH-HOPPER ATTACHED BELOW THE REVOLVING BOTTOM, AS ERECTED IN BATTERIES.

Battery of 56 recently installed for Cambria Steel Works.

Special Advantages of the Producer:

1. **There is no grate to waste coal through,** and there is practically no waste in cleaning. The deep ash bed permits the coal to burn up clean, and in practice the carbon is frequently gasified so that less than **one-half of one per cent.** remains of the original carbon in the coal.

2. **Any clinkers that will pass through a six-inch space will be discharged from the producer in regular grinding without any manipulation or waste of fuel,** and this distance may be increased if desired.

3. Cleaning is done without stopping the producer for a moment, and the quality of the gas is only slightly injured for a short time; hence the producer is practically continuous, and at the same time it is just as perfect an apparatus when used intermittently.

4. By the use of the test or sight holes in the walls the attendant always knows when to grind down his ashes and when to stop.

5. In grinding down the ashes the settling of the fuel is active next to the walls, or it may be said the settling is more from the walls to the center, while the reverse is the case in all other producers. This is a feature that all experienced in producer practice will appreciate.

6. It is the most durable producer ever built. There is nothing to burn out, for the top of the ironwork is six inches below the fire, and the lower part of the producer is nearly cold.

There is nothing to wear out, for all the parts are heavy castings, and in ordinary working the table revolves only three or four times in a day. It will thus be seen that we have here all the conditions of a perfect gas producer for making gas from either anthracite or bituminous coal, even of inferior quality.

7. When provided with the continuous automatic feed it will operate upon qualities and sizes of coal which may be gasified otherwise, if at all, only with greatest difficulty, while in steadiness of gas production of uniform and improved quality it cannot be excelled.

Standard Sizes of Gas Producer.

DESIGN A.

Size No.	Inside Diam. of Brick Lining or Jacket.	Area of Fuel Bed.	Height to Top of Casing.	Approximate No. of Wedge Fire Brick Required.*
8	8 ft.	50.3 ft.	16 ft.	3200
7	7 ft.	38.5 ft.	15 ft.	2800
6	6 ft.	28.3 ft.	15 ft.	2300
5	5 ft.	19.6 ft.	15 ft.	2000
4	4 ft.	12.6 ft.	12 ft.	1300
3	3 ft.	7.0 ft.	10 ft.	950
2	2 ft.	3.1 ft.	10 ft.	680

* Based on fire brick of sizes regularly used by us. Fire brick sizes vary with different makers.

Larger sizes are made when necessary, the automatic feed being especially advantageous in larger producers.

Connections are made ¼ the diameter of Producer (see page 49), both inside brick lining.

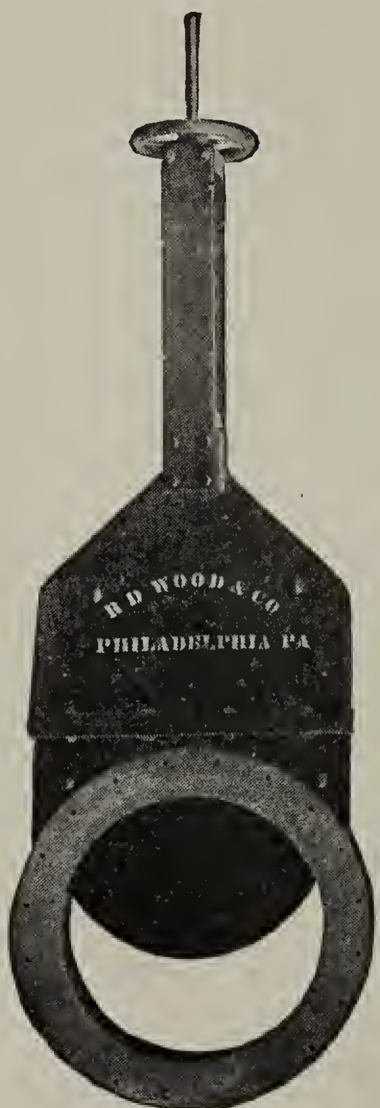
Prices on Application. Connections and fire brick for lining not included unless so specified.

Directions for starting and operating Producers, on page 93.

Competent men to erect and start up our Producers are furnished at moderate charges.

PART OF BATTERY OF FOURTEEN PRODUCERS.

List of Valves and Fittings for Gas Producers and Mains.

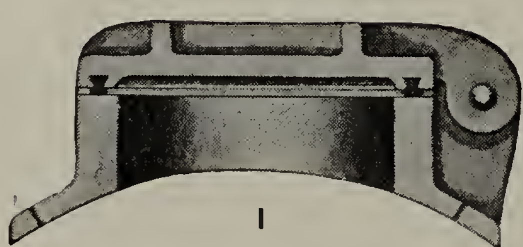


C

GATE VALVE WITH OUTSIDE SCREW STEM.

D

GATE VALVE WITH PLAIN STEM.



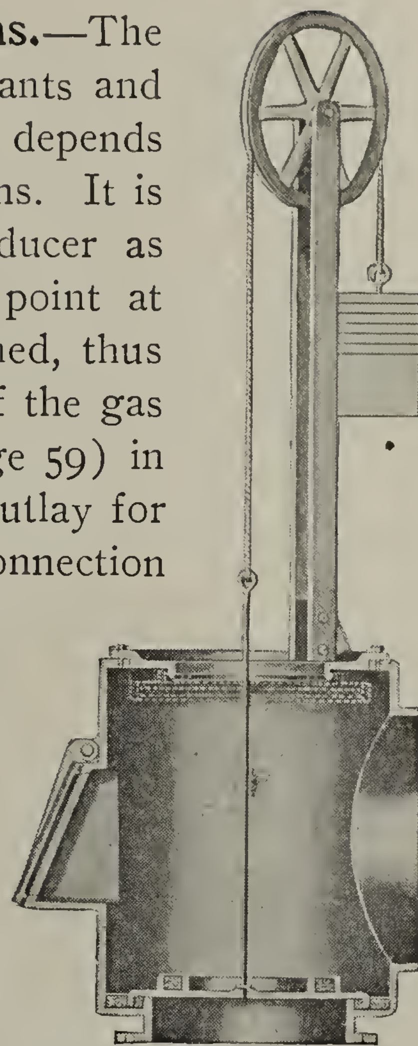
I

MANHOLE COVER.

C—Gate Valve with Outside Screw Stem in all sizes from 6″ to 6′.
D— " " " Plain Stem " " " 6″ to 6′.
E—Explosion and Cleaning Door for End of Main, 14″, 18″, 20″ (see page 47).
F—Cleaning Door. Several sizes to suit Mains (see page 49).
G—Sand Valve (with Explosion Door), 20″, 24″ (see page 47).
H—Solid Seat Valve (with Explosion Door), 10″, 12″, 15″, 18″, 21″ (see page 49).
I—Manhole Cover.

E

Explosion Door.

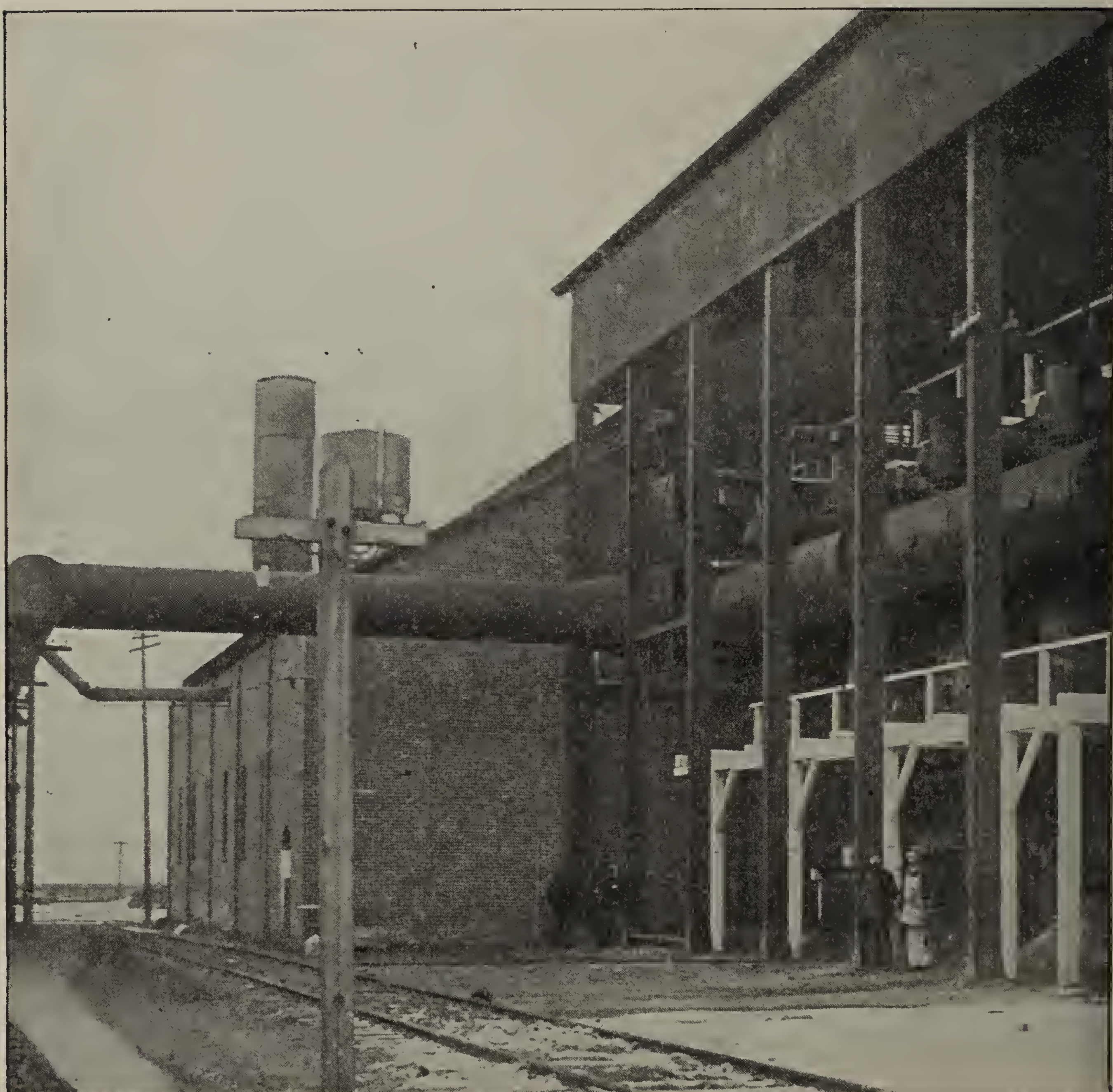


G

Sand Valve.

Producer Installations.—The arrangement of producer plants and their connections naturally depends very much on local conditions. It is desirable to locate the producer as near as practicable to the point at which the gas is to be burned, thus utilizing the sensible heat of the gas to a greater degree (see page 59) in burning at the higher temperature, while the outlay for connections is minimized. To this end, the connection should be properly lined, as far as may be, with fire brick or other non-conducting material. They should be laid out with a view to possible extensions, and provided with cleaning and safety or explosion doors. We make a specialty of gas-producer installations, including flues, valves and other details of approved design. We are also prepared to supply iron operating platforms; and, where so required, complete batteries of producers with coned ash bottoms, fuel bins, etc. An interesting instance of an installation of this kind is that of a battery of fourteen producers installed by us for the Guggenheim Smelting Company, parts of which are shown in the illustrations on pages 45, 48 and 51.

Piping Producer Gas.—Connections should be of such size and so designed and constructed as to convey the gas with as little loss of its initial temperature as possible, and should be provided with suitable valves, safety devices and sufficient hand and manholes. The loss in efficiency in piping long distances is greater in bituminous than in anthracite gas. In the former the loss is increased owing to the greater condensation and deposition of the unfixed heavy hydrocarbons, while in the latter (anthracite) practically no loss results except from cooling. Probably five hundred feet is the maximum distance to which bituminous producer gas should be carried; and in such instances it is essential to have the flues of ample diameter,—the greater the distance the larger the flue,—making allowance, of course, for the partial consumption of

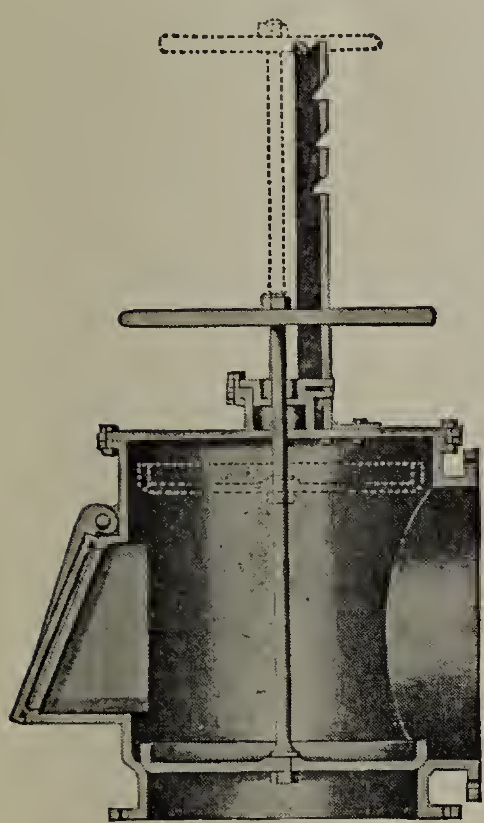


FROM PHOTOGRAPH SHOWING PART OF AN ILLUSTRATION OF CONE-BOTTOM GAS PRODUCERS, WITH CONNECTIONS.

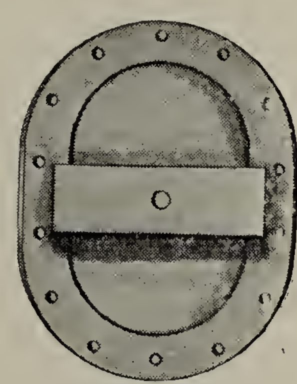
In this battery the Producers are supplied with coned ash-hopper bottoms from which the ash is taken by conveyors, which are also used to convey the coal to bins above the Producers.

the gas along the line. It is usually best to line the flues with fire brick or other non-conducting material for their entire length, though cast iron mains of small diameter, 18 inches or less, preferably protected with asbestos on the outside, are used for services which do not justify outlay for the larger lined mains.

The size of connection to each producer should be about one-quarter the diameter of the producer inside of the lining,—thus an 8-foot producer should have a 24-inch connection. The mains, when reasonably short, should have the same area as the sum of all producer connections feeding them.



H
SOLID SEAT VALVE.



F
CLEANING DOOR.

Gas per Ton of Coal.—As previously noted, the amount of gas produced from a ton of coal varies with the composition and general character of the coal and the method of operation, of which we may note especially the proportion of steam used in blowing the producer. But on the average it may be assumed that one ton of anthracite buckwheat coal produces about 170,000 feet of gas, containing 138,000 heat units per 1000 feet. Its composition will average as follows:

	Per Cent.		Per Cent.
CO, Carbon Monoxide	22.0	to	30.0
H, Hydrogen	15.0	to	7.0
CH_4, Methane, Marsh Gas	3.0	to	1.5
CO_2, Carbon Dioxide, "Carbonic Acid"	6.0	to	1.5
N, Nitrogen	54.0	to	60.0
	100.0		100.0

4

The analysis of gas from bituminous coal is nearly the same, except that CH_4 is a trifle higher and the H frequently above the maximum noted in table. But, as a matter of fact, an analysis of bituminous gas does not properly represent its energy, as most of the volatile combustible of the coal passes off as a **non-fixed gas and does not appear in the analysis** (being condensed in the tubes of the analytical apparatus), **yet it is utilized in the furnace.** (For explanation see under Gas Fuel and Producer Gas.)

Capacity of Producers.—The No. 8 Taylor Producer will easily gasify six and one-half tons of anthracite pea coal in twenty-four hours, and the smaller sizes somewhat more in proportion to their area. A deeper fuel bed is required when using bituminous coal than with anthracite, and the quantity gasified varies with the quality, usually more than anthracite. In ordinary service, on West Virginia or Pennsylvania bituminous coals, the No. 8 Producer will average eight tons in twenty-four hours, or 666 pounds per hour, and this coal is **all gasified** that is, converted entirely into gas and ashes; no coke whatever is found in the ash from the producer, a condition which does not exist in many other types, notably "water-sealed" of customary type, "sloping grate" and so-called "high capacity" producers, whose makers claim a capacity far beyond the possibility of making good gas or completely gasifying the coal so rapidly forced through them.

The fusibility of the ash in any coal determines its maximum rate of combustion in a producer. Probably, with a coal having the most infusible ash, about fifteen to sixteen pounds per hour is the maximum amount that can be gasified continuously per square foot of fuel bed. An exception to this rule is found, however, in the lignites of the Western States, some of which can be gasified at a much higher rate. But with a very fusible ash the rate of combustion must be much reduced to make good gas continuously without excessive labor or much waste.

Fuel.—In making gas from bituminous coal the best results are obtained from a good, clean coal, low in ash and moisture and high in volatile matter. A poorer quality does not make as good a gas, nor can the producer be driven as hard.

A PART OF A BATTERY OF FOURTEEN No. 7 CONE-BOTTOM GAS PRODUCERS.

In high temperature work a high percentage of volatile hydrocarbons in the coal is very desirable, and a smaller consumption of coal is then needed to do a given work. (See under Gas Fuel and Producer Gas.) Thus, where local coals are but inferior and cheap, it may be **cheaper** to bring from a distance higher-priced coals of good quality. This is done advantageously in numerous instances.

The size of coal is not so important, especially when the coal cakes, for it then fuses together into large masses, which on being broken with a bar make the fuel bed porous and open. The nut size is a very convenient one for use in the producer, although "run of mine" in which the lumps are small enough to pass through the hopper, or "slack," or a mixture of the two, are used very successfully. The clinkers which form from soft coal are rarely large, and are handled with little trouble, except when very lean coal is used.

Although the producer works to best advantage on coal of good quality, yet the superior facilities for cleaning and the perfect application of the steam and air make it possible to use successfully a very inferior coal; but the gasification must be slower than with good coal. We have one large plant using a slack containing over forty per cent. of ash, and, what is worse, a large amount of sulphide of iron; certainly a very difficult coal to deal with.

When anthracite is used the cheapest coal is a No. 1 buckwheat, with a low percentage of difficult fusible ash, low in moisture and high in volatile combustible. An important point in using anthracite is that too much fine dust is very objectionable, as it makes the interstices too small, or much smaller in some parts of the bed than others. This tends to "honeycomb" the fire bed unless much barring is done. Or, what is still worse, if the resistance in the fuel bed is too great the blast will seek the walls as the place of least resistance, and the gas will be worthless, becoming high in carbonic acid. Anthracite in the form of culm or poorly prepared buckwheat cannot be gasified to advantage in a producer. However, as might be expected, a continuous feed adjusted to just maintain the proper fire surface, and thus showering the coal regularly and as gasified, largely assists in using these coals inferior because of size or quality.

Because of the large percentage of ash in the smaller sizes of anthracite coal there is greater tendency to clinkering. Mixtures of coals from different mines may produce the same difficulty, the combined ash forming a more fusible residue than either coal alone.

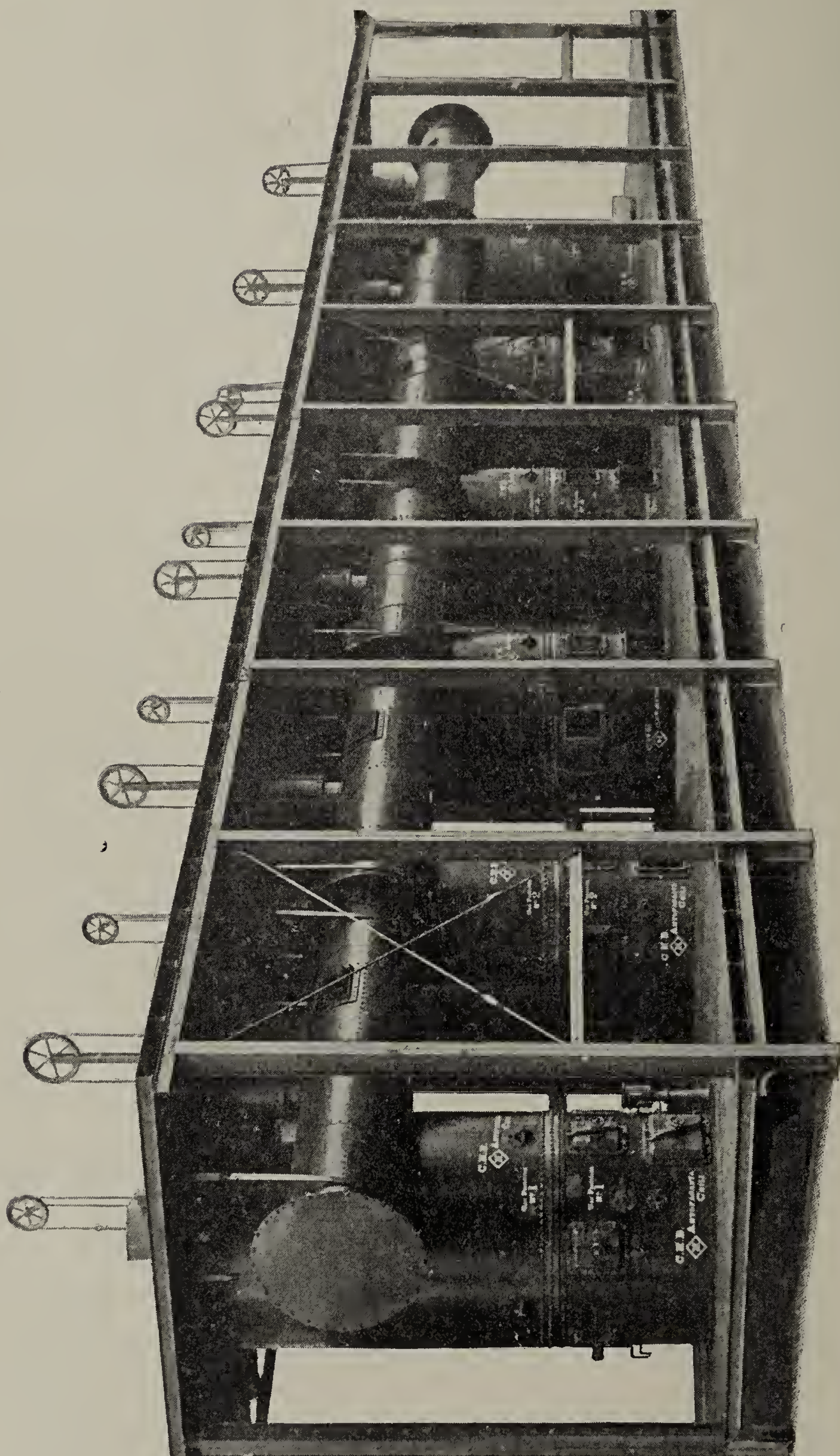
ANTHRACITE COAL SIZES.

SIZE AND NAME.	THROUGH A ROUND HOLE.	OVER A ROUND HOLE.
Chestnut	1½ inches diameter.	⅞ inches diameter.
Pea	⅞ " "	$\frac{9}{16}$ " "
No. 1, Buckwheat	$\frac{9}{16}$ " "	⅜ " "
" 2, " or Rice	⅜ " "	$\frac{7}{16}$ " "
" 3, " " Barley	$\frac{3}{16}$ " "	$\frac{3}{32}$ " "
Dust	$\frac{3}{32}$ " "	....

Comparative Value of Fuel—Containing Different Percentages of Ash and Carbon.—The following table shows the relative values of fuel used in furnace practice, either coal or coke, with different percentages of ash. Values are given in dollars and cents:

CARBON.*	PERCENTAGE OF ASH.												
	2%	3%	4%	5%	6%	7%	8%	9%	10%	11%	12%	13%	14%
75%	...	...	...	...	...	...	$2.83	$2.82	$2.80	$2.79	$2.77	$2.76	$2.74
76%	...	...	...	...	...	...	2.88	2.86	2.84	2.83	2.81	2.79	2.78
77%	...	...	...	...	...	$2.93	2.91	2.90	2.88	2.87	2.85	2.84	2.82
78%	...	...	...	...	...	2.97	2.95	2.93	2.90	2.88	2.86	2.84	...
79%	...	...	...	...	$3.01	2.99	2.97	2.96	2.94	2.92	2.90	2.88	...
80%	...	...	...	...	3.06	3.04	3.02	3.00	2.98	2.96	2.94	2.92	...
81%	...	...	...	...	3.10	3.08	3.06	3.04	3.02	3.00	2.98	...	...
82%	...	...	...	$3.17	3.15	3.13	3.10	3.08	3.06	3 04	3.02	...	...
83%	...	...	...	3.21	3.19	3.17	3.14	3.12	3.10	3.08	3.06	...	...
84%	...	...	...	3.25	3.23	3.21	3.18	3.16	3.14	3.12	...	...	...
85%	...	...	$3.33	3.31	3.29	3.26	3.23	3.20	3.18	...	...	...	...
86%	...	...	3.37	3.35	3.33	3.30	3.27	3.24	...	...	...	...	...
87%	...	...	3.41	3.39	3.37	3.34	3.32	3.29	...	...	...	...	...
88%	...	$3.46	3.44	3.42	3.39	3.36	3.33	...	...	...	...	...	...
89%	...	3.49	3.47	3.45	3.43	3.41	...	...	...	...	...	...	...
90%	$3.54	3.52	3.51	3.50	3.48	...	...	...	...	...	...	...	...
91%	3.58	3.57	3.56	3.54	3.52	...	...	...	...	...	...	...	...
92%	3.63	3.61	3.59	3.57	...	...	...	...	...	...	..	...	...
98%	3.68	3.66	3.64	3.61	...	...	...	...	...	...	...	...	...

*NOTE.—The carbon and hydrogen are counted as carbon. Sulphur generally runs about one-tenth of the ash, but fuel containing over one per cent. of sulphur must not be used for making iron economically. JOHN M. HARTMAN.



A BATTERY OF SIX GAS PRODUCERS, WITH OPERATING PLATFORMS AND MAIN FLUE, ERECTED AT WORKS PRIOR TO SHIPMENT.

Gas Fuel and Producer Gas.*—The utilization of fuel may perhaps be called the industrial question of the times. Fuel plays such an important part in our modern life, and its cost is often so large a part of the expense of conducting an industrial enterprise, that constant efforts are being made to improve our imperfect methods of fuel utilization and approach more nearly to the theoretical limit of efficiency.

Nature has furnished us with fuel in three forms, solid, liquid and gaseous; solid, the most common; liquid, containing the greatest energy; gaseous, the most convenient for use. The tendency of the day is to the conversion of solid and liquid fuel into the gaseous form. This is partly due to the wonderful developments of natural gas in various portions of the United States, and the intimate acquaintance with the advantages of gas as compared with other forms of fuel which its use has given to so many manufacturers. The gradual failure of supply in natural gas and the higher cost of oil-firing is giving increasing prominence and value to the gas producer converting solid gaseous fuel.

There is magic in the word "gas" to many who, through lack of knowledge, imagine that by mere conversion into gas an immense quantity of energy can be added to fuel of other forms, forgetful of the law of nature that the conversion of any substance from one form to another involves a loss of effective energy; and, therefore, that if, in certain cases, more duty can be obtained out of the gas resulting from a given amount of coal than the coal itself will supply when used direct, the cause lies solely in the more efficient utilization of the fuel in its gaseous state. Nevertheless, new processes for making gas are constantly crowded upon our notice with claims of far more energy for the product than is contained in the coal or oil from which it is made.

Advertisements not infrequently appear in our trade papers in which the promoters promise, by various mechanical manipulations, to deliver a gas which contains from one and a half to three times the energy originally in the fuel. These impossible schemes are constantly thrust on the investing public; in some cases doubtless without intention of fraud, but through the ignorance of the promoters themselves. Any new scheme for the utilization of fuel may safely be condemned without further investigation if it promises to deliver more heat than (or even as much as) the theoretical

* Mainly from paper by W. J. Taylor.

amount contained in the coal or oil consumed in the process of manufacture.

The cheapest artificial fuel gas per unit of heat is common producer gas, or "air gas," as it might be termed, since the oxygen for burning the carbon to carbon monoxide is derived mainly from air. The associated atmospheric nitrogen dilutes the carbon monoxide, making air gas the weakest of all useful gases—that is, the lowest in combustible, both in weight and by volume. Next in the order of heat-energy comes water gas, in which the oxygen for combining with carbon to form carbon monoxide is derived from water-vapor, and hydrogen is liberated. For equal volumes, this gas has more than double the calorific power of air gas. Third in the ascending scale stands coal gas, the ordinary illuminating gas distilled from bituminous coal, which carries more than double the heat-energy of water gas. Last and highest in the list comes the gas made in Nature's producer, which we cannot duplicate in practice by any known process. The calorific power of natural gas is about fifty per cent. greater than that of coal gas. The introduction of natural gas for metallurgical purposes has largely stimulated the production and use of artificial gas made from coal and from oil, if the vapors of the latter can be fairly considered a gas.

The tables given below will be found useful in heat calculations, and although not minutely accurate, are sufficiently so for practical work. The British thermal unit (B. T. U.) is used, and the heat-energies given are calculated upon the assumption of 62° F. as the initial temperature, and the reduction of the temperature of the products of combustion to the same point as the standard for the computation of all heat-energies:

Air by weight, contains 23 parts O, 77 parts N.

Air by volume, contains 21 parts O, 79 parts N.

Air consumed in combustion:

1 pound C burned to CO consumes 1.33 pounds O, with 4.46 N, making 5.79 Air.

1 pound C burned to CO_2 consumes 2.667 pounds O, with 8.927 N, making 11.594 Air.

Heat-units developed in burning.	For 1 pound of combustible B. T. U.	For 1 cubic foot of combustible. B. T. U.
C to CO	4,400	
C to CO_2	14,500	
CO to CO_2	4,325	319
H to H_2O	62,000	327
CH_4 to CO_2 and H_2O	23,500	1007
C_2H_4 to CO_2 and H_2O	21,400	1593

Of course hydrogen is usually only burned to steam, and the energy in this case at 62° initial and 212° final temperature, is 52,000 heat-units, or, making both temperatures 212°, about 53,000 heat-units. Many writers use this standard for hydrogen in their computations; but in all theoretical calculations hydrogen should be given credit for the energy developed when the products of combustion are reduced to the standard temperature, and the losses computed in its utilization from that standard.

Number of cubic feet in one pound of the following gases, at 62° F., and atmospheric pressure:—

Air	13.14	cubic feet	per pound.
N	13.50	"	"
O	11.88	"	"
H	189.70	"	"
CO	13.55	"	"
CO_2	8.60	"	"
CH_4	23.32	"	"
C_2H_4	13.46	"	"

Specific heat of hydrogen 3.4
" " all other gases may be taken at 0.25

The terms "**heat-unit,**" "**specific heat,**" and "**latent heat**" are not well understood by many people, but the following definitions by a well-known authority will make them clear:

'**Specific heat** is that quantity of heat required to raise one pound of any substance one degree compared with that required to raise the temperature of an equal weight of water one degree. In other words, in writing down the specific heat of any substance we do it in comparison with water. That is to say, water is the unit or standard. If it takes three and four-tenths times as much heat to raise one pound of hydrogen one degree as to raise one pound of water one degree, we say the specific heat of hydrogen is 3.4. Now the same quantity of heat that will raise a pound of water one degree will raise about ten pounds of iron one degree, so we say the specific heat of iron is .10, or, to be exact, .1098.

'**A British Thermal Heat-Unit** (B. T. U.) is that quantity of heat required to raise one pound of pure water one degree Fahrenheit at or about 39.1° F.

'Thus, when we say that a pound of carbon contains 14,500 heat units, we mean that if the pound of carbon were burned, enough heat would be generated to raise the temperature of 14.500 pounds of water one degree Fahrenheit.

'**Latent heat** is the quantity of heat that must be imparted to a substance to effect a change of state without changing its temperature, as when ice is converted into water or water into steam.

'Latent heat is therefore insensible heat, or heat not measurable with a thermometer. There is the latent heat of liquefaction, or the heat absorbed in or by a substance in passing from a solid to a liquid, and the latent heat of gasification, or the heat that is absorbed by a solid or a liquid in passing to a gaseous condition.

'Water in passing from the condition of ice, at a temperature of 32°F., to a liquid at 32°F., absorbs 142.4 units of heat per pound; hence the latent heat of water is 142.4.

'Water in passing from a liquid at 212°F. to steam at 212°F., absorbs 966 units of heat per pound, and therefore we say that the latent heat of steam is 966. We mean that the heat lost or absorbed by one pound of this substance in passing from a liquid to a vapor, and without its temperature being changed, equals the heat that would be required to raise 966 pounds of water from the temperature of 32°F. to that of 33°F.

'Though hardly necessary to define, **sensible heat** is that which gives rise to the sensation of heat and affects the thermometer.'

Fuel Energetics—(**Carbon Gas.**)—In considering any gas fuel, the first question is what percentage of the energy of the fuel converted is delivered with the gas? Producer gas, though the lowest in energy, can be produced more cheaply per unit of heat than any other. Yet in the old Siemens producer, practically all the heat of primary combustion—that is, the burning of solid carbon to carbon monoxide—was lost, as little or no steam was used in the producer, and nearly all the sensible heat of the gas was dissipated in its passage from the producer to the furnace, which was usually placed at a considerable distance.

Modern practice has improved on this early plan, by introducing steam with the air that is blown into the producer, and by utilizing the sensible heat of the gas in the combustion-furnace. One pound of carbon, burned to 2.33 pounds of carbon monoxide, CO, develops 4,400 heat-units, or about 30 per cent. of the total carbon energy; in the secondary combustion, 2.33 pounds of carbon monoxide burned to 3.66 pounds of carbon dioxide develop 10,100 heat-units, or 70 per cent. of the total energy; making in all 14,500 heat-units for the complete combustion of the original pound of carbon. Now, it is evident that if the heat of the primary combustion is not employed either to dissociate water or to impart a *useful* high temperature to the gas, 30 per cent. of the energy will be practically lost—*i.e.*, the gas will carry into the furnace only 70 per cent. of the total energy of the carbon. It is equally evident, that if all the heat of primary combustion could be applied to the dissociation of water, there would be little effective loss of energy in conversion; or if, instead of dissociating water, all the sensible heat of the gas (representing the heat of primary combustion) could be utilized, the loss would similarly be reduced to *nil.* But the complete realization of either alternative is impossible, for the loss by radiation from the producer is an important item, and the unrecovered energy expended in blowing the producer with air and steam amounts to from 3 to 5 per cent.

Good practice does, however, recover a considerable percentage of the heat of primary combustion by the use of both of these means —*i.e.*, by utilizing the sensible heat of the gas through close attachment of producer and furnace, and by introducing with the air blast as much steam as the producer will carry and still maintain good incandescence. In this way about 60 per cent. of the energy of primary combustion should be theoretically recovered, for it ought to be possible to oxidize one out of every four pounds of carbon with oxygen derived from water-vapor. The thermic reactions in this operation are as follows:—

		Heat-units.
4 pounds C burned to CO (3 pounds gasified with O of air and one pound with O of water) develop		17,600
1.5 pounds of water (which furnish 1.33 pounds of oxygen to combine with one pound of carbon) absorb by dissociation	10,333	
The gas consisting of 9.333 pounds CO, 0.167 pounds H., and 13.39 pounds N., heated 600°, absorbs	3,748	
Leaving for radiation and loss	3,519	
	17,600	

(It may be well to note here that the steam which is blown into a producer with the air is almost all condensed into finely divided water, before entering the fuel, and consequently is considered as water in these calculations.)

The 1.5 pounds of water liberates .167 pound of hydrogen, which is delivered to the gas, and yields in combustion the same heat that it absorbs in the producer by dissociation. According to this calculation, therefore, 60 per cent. of the heat of primary combustion is theoretically recovered by the dissociation of steam, and, even if all the sensible heat of the gas with radiation and other minor items be counted as loss, yet the gas must carry 4 × *14,500 — (3,748 + 3,519) = 50,733 heat-units, or 87 per cent. of the calorific energy of the carbon. This estimate shows a loss in conversion of 13 per cent., without crediting the gas with its sensible heat, or charging it with the heat required for generating the necessary steam, or taking into account the loss due to burning some of the carbon to carbon dioxide. In good producer-practice the proportion of carbon dioxide in the gas represents from 4 to 7 per cent. of the C burned to CO_2, but the extra heat of this combustion should be largely recovered in the dissociation of more water vapor, and, therefore, does not represent as much loss as it would indicate. As a conveyor of energy, this gas has the advantage of carrying 4.46 pounds less nitrogen than would be present if the fourth pound of coal was gasified with air; and in practical working the use of steam reduces the amount of clinkering in the producer.

Anthracite Gas.—In considering the gasification of anthracite coal, we find in it a volatile combustible, varying in quantity from 1.5 to over 7 per cent., and while its flame resembles that of hydrogen, the amount of marsh gas found in anthracite producer gas corresponds practically with the total volatile hydrocarbons in the coal. If this is correct, all the hydrogen in the gas is derived from the dissociation of water-vapor; but this, as previously shown, is in practice higher than the theoretical quantity. We generally find 1.5 per cent. or more of marsh gas in anthracite gas made from coal containing about 5 per cent. of volatile combustible, and this proportion is about what should be expected if all the volatile combustible in the coal is marsh gas. But if it is not, it is difficult to explain the presence of the marsh gas and the excess of hydrogen in the producer gas. If the percentage of carbon dioxide were high and the resulting excess of heat were expended in an increased dissociation of steam, that would account for the hydrogen; but with low carbon dioxide, and all the volatile combustible represented by marsh gas in the producer product, it is difficult to account for all the hydrogen in the face of our assumption that we cannot gasify with steam more than one-quarter of the carbon.

If we felt confident that solid carbon and marsh gas were the only combustibles to be considered in anthracite, it would be easy to

* Calorific power of carbon.

calculate from an analysis of producer gas the amount of energy derived from the coal, as is shown in the following theoretical gasification made of coal with assumed composition: Carbon, 85 per cent.; vol. hydrocarbons, 5 per cent.; ash, 10 per cent.; 80 pounds carbon assumed to be burned to carbon monoxide; 5 pounds carbon burned to carbon dioxide; three-fourths of the necessary oxygen derived from air, and one-fourth from water.

Process.	Products.		
	Pounds.	Cubic Feet.	Anal. by Vol.
80 lbs. C burned to..................CO	186.66	2529.24	33.4
5 lbs. C burned to..................CO_2	18.33	157.64	2.0
5 lbs. vol. HC (distilled)..............	5.00	116.60	1.6
120 lbs. Oxygen are required, of which 30 lbs. from H_2O liberate..................................H	3.75	712.50	9.4
90 lbs. from air are associated with..................................N	301.05	4064.17	53.6
	514.79	7580.15	100.0

Energy in the above gas obtained from 100 pounds anthracite:

186.66 pounds CO............................	807,304	heat-units.
5.00 " CH_4	117,500	"
3.75 " H	232,500	"
	1,157,304	"
Total energy in gas per pound...............	2,248	"
" " " " " cubic foot	152.7	"
" " " 100 pounds of coal..........	1,349,500	"
Efficiency of the conversion...........................	86 per cent.	

It will be noticed that 1.6 per cent. of marsh gas represents all the volatile combustible in the coal, and that 86 per cent. of the total energy is delivered in the gas; but the sum of carbon monoxide and hydrogen exceeds the results obtained in practice. The sensible heat of the gas will probably account for this discrepancy, and it is quite safe to assume the possibility of delivering at least 82 per cent. of the energy of anthracite.

To illustrate the loss caused by forming carbon dioxide in the producer, when none of the heat of primary combustion is used for dissociating water, the following theoretical gasifications of carbon are adduced, showing the resulting gases, in which 0, 5, 10, 15, 25, and 50 per cent. of carbon are successively burned to carbon dioxide, and giving the percentage of energy delivered in each case, without considering the increasing proportion of nitrogen as a factor in reducing the energy-ratio of the poorer gases.

100 Lbs. C, Gasified with Air.	Pounds of C Burned to CO_2.					
Products.	0	5	10	15	25	50
CO per cent.	34.4	31.5	29.5	26.6	22.7	12.9
CO_2 "	....	1.6	3.2	4.6	7.6	12.9
N "	65.6	66.9	67.3	68.8	69.7	74.2
Pounds of gas	679	708	737	766	824	969
Cubic feet of gas	9183	9468	9759	10,065	10,387	12,189
Per cent. of carbon energy in gas	70	66	63	59	52	35
Heat units per cubic foot of gas	109.7	100.5	94.1	85.8	72.04	41.1

But the formation of carbon dioxide in the producer is objectionable, not only when the heat of its combustion is lost, but even when a large portion of this heat is recovered by dissociating water. A theoretical gasification, in which 100 pounds of carbon are completely burned to carbon dioxide, and 70 per cent. of the resulting heat of combustion (1,450,000 heat-units), is assumed to be recovered by dissociating water, is illustrated in the following table:

Process.	Products.		
	Pounds.	Feet.	Per Cent. by Vol. (Approximate.)
100 lbs. C burned to .... CO_2	366.66	3153	25
70 per cent. of 1,450,000 heat-units is 1,015,000 units; which liberate from water .... H	16.34	3110	25
130.96 lbs. O, liberated from this water, combines with 49.2 lbs. C to form CO_2. This leaves 50.8 lbs. C to combine with 135.13 lbs. atmospheric O, which is associated with .... N	453	6115	50
	836	12,378	100

Here we have only 25 per cent. of combustible hydrogen, representing 70 per cent. of the carbon energy, in 836 pounds, or 12,378 cubic feet of gas; the latter is, therefore, of poor quality, and compares very unfavorably with the 70 per cent. conversion of the all-monoxide gas in the preceding table, where 34.4 per cent. of combustible (carbon monoxide) are found in 679 pounds, or 9,138 cubic feet of gas. It follows that whenever carbon dioxide is formed and its heat used for dissociating water, there is at best but a poor utilization of the energy. Probably all that can be recovered in this way does not exceed one-half of what may be obtained from carbon burned to carbon monoxide. But in special cases where practically all the sensible heat of the gas is utilized in a non-regenerative furnace or kiln, where mechanical difficulties effectually prevent good combustion, a very hot gas, containing 7 to 9 per cent. of carbon dioxide is found to be preferable to a cold gas low in carbon dioxide.

Bituminous Gas.—This gas differs from that made from anthracite, in containing a much larger percentage of hydrocarbons. It consequently has greater calorific energy and also much more luminosity. This latter quality gives it special value in high-temperature work, according to the latest theories of combustion. To utilize these hydrocarbons the gas must be kept at a temperature that will prevent their condensation. At the same time it must be borne in mind that a very high temperature will break down the hydrocarbons, and cause the deposition of soot.

In collecting a sample of gas for analysis, it is cooled to the temperature of the atmosphere, and the hydrocarbons are almost all condensed. This accounts for the fact that while the gas from bituminous coal may be doing 50 per cent. more work than the gas from the same amount of anthracite, yet their analysis will not differ materially, as shown in the following

TABLE OF AVERAGE GAS ANALYSIS, BY VOLUME.

Constituents.	European.	American.	
	Siemens Gas.	Anthracite Gas.	Soft Coal Gas.
CO	23.7	27.0	27.0
H	8.0	12.0	12.0
CH_4	2.2	1.2	2.5
CO_2	4.1	2.5	2.0
N	62.0	57.3	56.5
	100.0	100.0	100.0

When soft coal gas is passed through the cooling tube of the old Siemens producer, or through long unlined flues, the hydrocarbons are condensed, and the gas really has the composition as shown in the preceding analysis. A comparison of these analyses with the hypothetical one given below, in which none of the hydrocarbons are lost, shows the importance of preventing their condensation as far as possible.

To examine more closely into the conversion of bituminous coal, a theoretical gasification of 100 pounds of coal, containing 55 per cent. of carbon and 32 per cent. of volatile combustible (which is about the average of Pittsburg coal), is made in the following table. It is assumed that 50 pounds of carbon are burned to carbon monoxide and 5 pounds to carbon dioxide; one-fourth of the oxygen is derived from steam and three-fourths from air; volatile combustible is taken at 20,000 heat-units to the pound, probably a safe assumption, notwithstanding that a high authority puts it at 18,000. In computing volumetric proportions, all the volatile hydrocarbons, fixed as well as condensing, are classed as marsh gas, since it is only by some such tentative assumption that even an approximate idea of the volumetric composition can be formed. The energy, however, is calculated from weight, and is strictly correct:

GASIFICATION OF BITUMINOUS COAL.

Process.	Products.		
	Pounds.	Cubic Feet	Per Cent. by Vol.
50 lbs. C burned to....CO	116.66	1580.7	27.8
5 lbs. C burned to....CO_2	18.33	157.6	2.7
32 lbs. vol. HC (distilled)....	32.00	746.2	13.2
80 lbs. O are required, of which 20 lbs., derived from H_2O, liberate....H	2.5	475.0	8.3
60 lbs. O, derived from air, are associated with....N	200.70	2709.4	47.8
	370.19	5668.9	99.8

Energy in 116.56 lbs. CO	504,554	heat-units.
" 32.00 lbs. Vol. HC	640,000	"
" 2.50 lbs. H	155,000	"
	1,299,554	
Energy in coal	1,437,500	
Per cent. of energy delivered in gas		90.0
Heat-units in one pound of gas		3,484
" " cubic foot of gas		229.2

When these figures are compared with the theoretical gasification of anthracite, the vastly greater energy, both by weight and volume, in the bituminous gas, is seen at once. It is worth even more in practice than appearance indicates, since the high percentage of hydrocarbons is associated with lower nitrogen. All of the 32 per cent. of volatile combustible, except the tarry matter, must be volatilized and utilized in its full strength, whether it be fixed gas or simply distilled hydrocarbon. For this purpose it should not be suffered to cool below 300° before it enters the combustion-chambers or regenerators; the higher its temperature at the furnace the better.

The comparative value of the two gases in high-temperature work is illustrated by the fact that when anthracite gas is used in regenerative furnaces for heating iron, it is frequently necessary to gasify in the producers from two to three times more coal per ton of iron heated than when bituminous gas is used. It is also well known that the rate and effectiveness of heating rises with the percentage of volatile combustible. The results may prove that it can be used advantageously, especially when supplemented with a little oil, which could be introduced into the furnace about where the air and gas unite, and thus secure a luminous hydrocarbon flame. Such use of oil is said to be practiced to a limited extent in Europe, as a supplement to water gas. Broadly speaking, and for a wide field of work, the quality of the heating that has been done with anthracite gas is good. The comparison with bituminous gas is not always as unfavorable as the one we have considered. The energy of the bituminous gas described was 3,484 heat-units per pound, as against 2,246 heat-units for the anthracite; but most bituminous coals are lower in volatile combustible and higher in carbon than our specimen coal. Possibly a fair average would be 70 per cent. of fixed carbon and 20 per cent. of hydrocarbon with 10 per cent. of ash. A theoretical gasification of 100 pounds of such a coal, burning 5 pounds of carbon to carbon dioxide, and deriving one-fourth of the oxygen from water and three-fourths from air would show this result:

Process.	Products.		
	Pounds.	Cubic Feet.	Per Cent. by Vol.
65 lbs. C burned to .... CO	151.6	2054	30.8
5 lbs. C burned to .... CO_2	18.3	157	2.3
20 lbs. vol. HC (distilled)..................	20.0	466	7.0
25 lbs. O, from water liberate......... H	3.1	588	9.0
75 lbs. atmos. O mixed with............ N	251.2	3391	50.9
	444.2	6656	100.0

Calorific energy of the gas.................... 1,247,870 heat-units.
" " " per pound......... 2,809 "
" " " " cubic foot .... 187.4 "
" " " coal .... 1,415,000 "
Efficiency of the conversion.......................... 88 per cent.

Water Gas.—There is much more literature at our command on water gas than on producer gas. It is made, as is well known, in an intermittent process, by blowing up the fuel bed of the producer with air to a high state of incandescence (and in some cases utilizing the resulting gas, which is a lean producer gas), then shutting off the air and forcing steam through the fire, which dissociates the steam into its elements of oxygen and hydrogen, the former combining with the carbon of the coal, and the latter being liberated.

This gas can never play a very important part in the industrial field, owing to the large loss of energy entailed in its production; yet there are places and special purposes where it is desirable, even at a great excess in cost per unit of heat over producer gas; for instance, in small, high-temperature furnaces, where much regeneration is impracticable, or where the "blow-up" gas can be used for other purposes instead of being wasted. Some steel melting has been done in Europe with this gas, under the claim that much more work can be gotten out of a furnace in a given time, owing to the greater energy of the gas, so that the extra cost is more than balanced. The lack of luminosity (hydrocarbon flame) in water gas makes this doubtful, unless some oil is introduced into the furnace, as before described.

We will now consider the reactions and the energy required in the production of 1000 feet of water gas, which is composed, theoretically, of equal volumes of carbon monoxide and hydrogen.

	Pounds.
500 cubic feet of H weigh	2.635
500 cubic feet of CO weigh	36.89
Total weight of 1000 cubic feet	39.525

Now, as carbon monoxide is composed of 12 parts carbon to 16 of oxygen, the weight of carbon in 36.89 pounds of the gas is 15.81 pounds and of oxygen 21.08 pounds. When this oxygen is derived from water (steam) it liberates, as above, 2.635 pounds of hydrogen. The heat developed and absorbed in these reactions (disregarding the energy required to elevate the coal from the temperature of the atmosphere to say 1800°) is as follows:

	Heat-units.
2.635 pounds H absorb in dissociation from water 2.635 $\times$ 62,000	=163,370
15.81 pounds C burned to CO develop 15.81 $\times$ 4400	= 69,564
Excess of heat-absorption over heat-development	= 93,806

The loss due to this absorption must be made up in some way or other.

6.47 pounds of carbon burnt to carbon dioxide would supply this heat, theoretically, but in practice, owing to the imperfect and indirect combustion and radiation, more than double this amount is required. Besides this, it is not often that the sum of the carbon monoxide and hydrogen exceed 90 per cent., the remainder being carbon dioxide and nitrogen.

Fuel Oil.—The average yearly production of petroleum between 1880 and 1890 in this country was about 24,165,920 barrels, equal to 3,310,400 tons, against 150,000,000 tons of coal mined in 1889. Now, as the energy of oil is practically 50 per cent. more than that of coal, if all the oil taken from the ground for the year 1888 had been used for fuel, it would have displaced on this basis 4,965,600 tons of coal only; but assuming that oil could deliver in practice double the energy of coal, it could then displace only 6,620,800 tons, and we would still require 143,379,200 tons for heat. So that oil cannot play an important part in supplying our heat-requirements. The natural gas used in 1889, it is estimated, contained energy equivalent to from 12,000,000 to 15,000,000 tons of coal, or more than twice the energy of the oil-producing of the country for the same time. But, as before stated, oil contains so much more energy, particularly in proportion to its volume, than any other available fuel, that it is a valuable heating agent in some special and high-temperature furnaces.

Common crude petroleum is composed of about 84 parts carbon and 14 parts hydrogen; the balance (2 parts) being earthy matter. Hence the energy per pound is approximately:—

C to CO_2	$.84 \times 14{,}500 = 12{,}180$
H to H_2O	$.14 \times 62{,}000 = 8{,}680$
	20,860

or 44 per cent. more than that of a pound of good coal, which, owing to the hydrocarbons in it, usually carries the energy up to what it would be if it were pure carbon, and in some cases more. Oil can be burned with less relative waste than coal, but the best evaporation with oil in practice has never exceeded coal by more than about 50 per cent. The barrel of petroleum of commerce is 42 gallons, weighing 6½ pounds per gallon.

Fuel Utilization.—Gas Furnaces.—Producer gas being so low in caloric energy, cannot be used to advantage in high-temperature furnaces, without at least pre-heating the air for combustion. When both air and gas are properly pre-heated, as in the best regenerative furnaces, a very high economy can be obtained, and only a half or a third as much fuel is required to do a given amount of work as when the coal is burned direct.

The essentials for the economical heating of a high-temperature furnace are, a good quality of gas (preferably rich in hydrocarbons), properly mixed with just the right amount of air, both having been heated to as high a temperature as possible. The amount of air required is dependent upon the temperatures of gas and air. The proper mixing of the gas and air is very important. To obtain the best results, the mixture should be as rapid and intimate as possible, thus causing a high temperature in the shortest time after the air and gas come together. It is also important that the furnace should be of the proper shape and proportions, so as to utilize the heat generated to the best advantage.

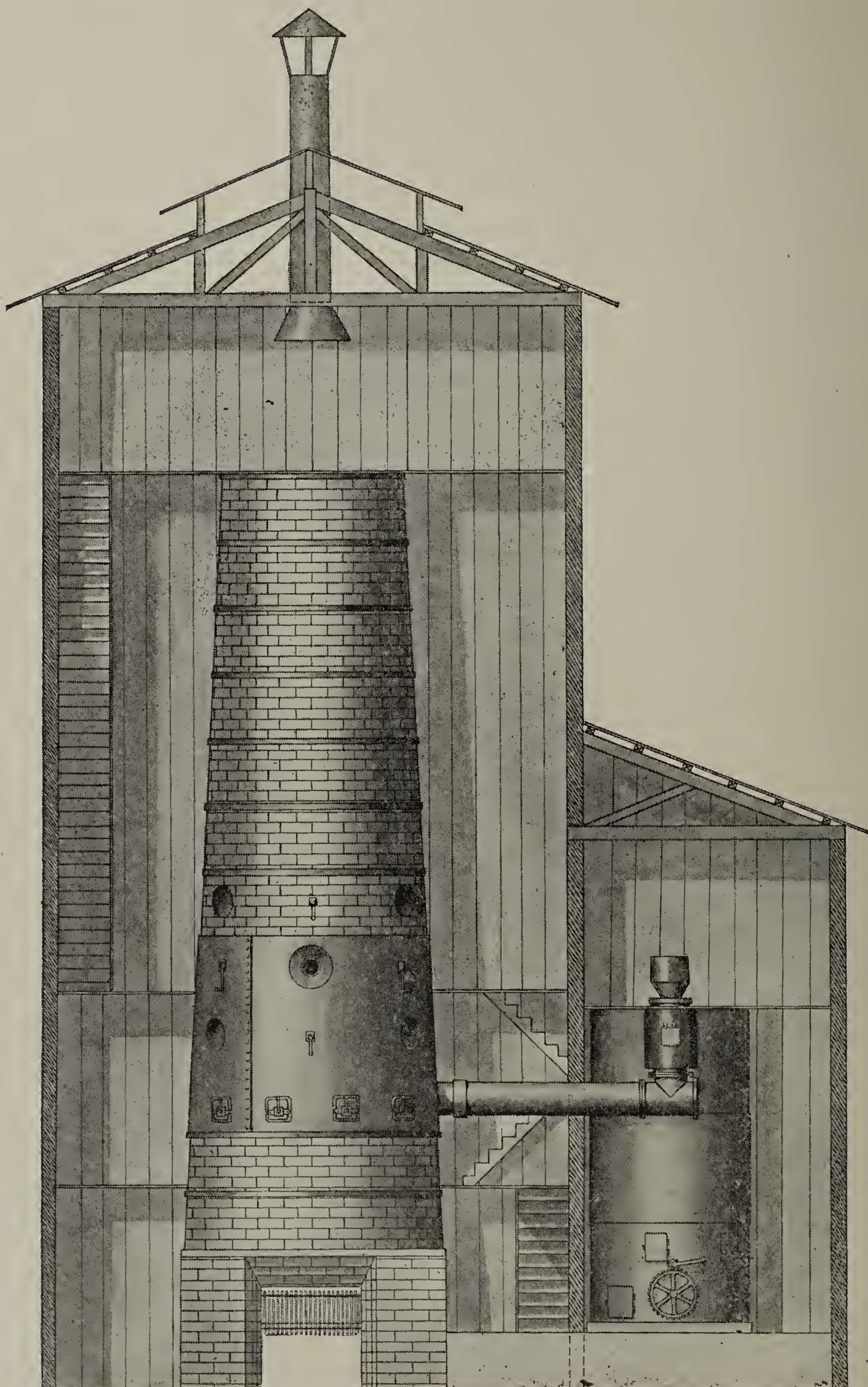
The modern practice of heating by radiation instead of by contact is undoubtedly right; hence the high roof of the so-called regenerative gas furnaces, and the large volume of luminous gas with its powerful radiating properties over the bed of iron or other material to be heated. It is certainly a fact that we require a very much greater volume of non-luminous gas than we do of luminous gas to do a given amount of heating at high temperatures.

In many works we find the waste heat from the furnace used in making steam, and this plan is advocated by some high authorities. But, if there were no other objections to it, the waste heat from the furnace heating iron for instance, would be very much more than is necessary for furnishing the power to roll the product. For this reason alone it is better to recover the waste heat and return it to the furnace, generating steam in a separate apparatus as required; for it will be impossible to arrange any works so as to utilize all the waste heat direct from furnaces.

Regenerative furnaces have been much improved of late years by making the roofs higher and working on the radiating principle. Maximum economies can only be obtained from these furnaces, however, by running them continuously, say for a week at a time, as it takes a large expenditure of energy to heat them up when they are once allowed to cool.

In many cases, where a very high temperature is not required, producer gas can be used with considerable economy over direct firing, by pre-heating the air only, up to a temperature of 500° or 600° in "continuous regenerators." These are usually composed of iron pipes, through which the air is blown or drawn, and which are heated from the outside by the waste gases from the furnace. While these do not give as great economy as the alternating brick regenerators, they are much less expensive and troublesome to operate. Of course they cannot be used when the temperature of the escaping gases is high enough to destroy iron pipes. Terra cotta pipes and fire brick flues have been used in place of iron pipes for continuous regenerators, but they do not conduct heat well, and are very liable to crack.

Although regeneration should always be employed when practicable, especially where the waste gases escape at a high temperature, in many kilns and furnaces, when the temperature required is not very high, producer gas may be used with marked economy without regeneration. This economy is principally due to the better



GAS-FIRED LIME KILN.

facilities for perfect combustion, the fact that less air is necessary, the saving of coal from the ashes, and especially where the producer is fed automatically and continuously the improved and uniform quality of the gas and consequent great regularity of the heat obtained. Besides these, the absence of dust, the smaller amount of labor required, and the substitution of a cheap for an expensive fuel, are often important points. But producer gas cannot be burned satisfactorily in very small quantities, where both gas and air are cold. The flame is very easily extinguished, and even a low red heat is reached with difficulty.

In Europe producer gas has been applied much more generally than in this country. We have become thoroughly familiar with its use, in the heating furnaces of our iron and steel mills, but it is fast working its way into other industries, such as glass furnaces, brick, pottery, and terra cotta kilns, lime and cement kilns, sugar house char-kilns, silver-chlorination and ore-roasting furnaces, for power purposes in gas engines, etc. The introduction of producer gas has conclusively shown that when made in a good producer and applied with a proper attention to the laws governing combustion, a considerable saving is effected over the former wasteful methods.

Lime Kiln, Producer-Gas Fired.—The preceding cut is a general elevation of a lime kiln, with a design of internal lines and detail which has operated very successfully with our type of gas producer.

Compared to the ordinary kiln, where the fuel and stone are charged in alternative layers, the gas-fired avoids contamination of the lime by the foreign matter of the ash.

With no ash, the clinkering and irregularities of operation resulting from its fusion with the lime are absent, and the labor of attendance is reduced with an improved quality of product.

In the ordinary kiln, if combustion should chance to be complete at the lower stratum of fuel the carbonic acid resulting is converted to combustible carbon monoxide in passing through the upper incandescent layers. Thus a large loss occurs by combustible escaping in the waste gases. To carry the fire nearly to the top of the kiln in an effort to reduce the amount of carbon monoxide escaping and save fuel is not an efficient remedy, for then the gases escape at such a high temperature that a large loss of fuel is represented in their sensible heat.

In a gas-fired kiln the intensely hot products of a complete combustion ascending freely, circulate through the mass of stone to which they impart their heat and escape at a much lower temperature. The descending stone returns this heat to the hearth, and that in the burnt stone may be utilized by preheating the air used for combustion, discharging the lime cold.

The operation of the producer and kiln is easy and regular to such an extent that the carbonic acid escaping in the gases may be maintained almost constant. The calcination is perfect and the lime pure. The kilns may be open top or arranged to collect the waste gases for recovery of the carbonic acid.

The fuel consumption is, of course, dependent on the kind of limestone treated, but an economy in fuel of 50 per cent. is frequently attained compared with current practice.

The regularity of operation and maintenance of uniform pressure by the facility of maintaining a uniform bed in the Taylor Producer, has shown this type to be especially adapted for this exacting service. Producer capacity should be ample, and the operation proceeds continuously with the drawing of lime at the base and proportionate feeding at the top.

While any kind of fuel may be employed, the use of charcoal, coke or anthracite will avoid the necessary burning out of flues where soft coal is employed.

Ore Roasting.—The use of ordinary producer gas for this operation has been of slow growth, for while the possible economies were inviting, it had the same element of risk which attaches to every new application. This is not a new experience, the history of metallurgy recording it in the inception of many attempts to establish methods which to-day are yielding large return.

The success of our Producers in this field was demonstrated several years ago, and recently there has been renewed interest in this direction.

It is gratifying to record, therefore, our recent installation of such a plant for a large reduction company, under whose management the plant is giving very satisfactory results. The gas is serving a series of roasters, including designs of the Ropp Straight

Line, Pearce and Holtoff-Wethey types. The producers are equipped with the Bildt automatic feed and are readily gasifying in twenty-four hours nine to ten tons each of a Colorado coal. Such installations pay 15 to 40 per cent. on the investment.

Forge Work.—Small furnaces for this industry have been operated for some time on fuel oil or gases more expensive than ordinary producer gas. Because of its lower heating value and consequent necessary large volume, difficulties exist in its application. The system is, however, in successful service wth large economy over oil or other methods of firing. The gas serves heating furnaces for bending, heading, bolt and rivet machines and a variety of miscellaneous work. The hearths of some of the furnaces are not more than 15 inches by 18 inches by 3 feet long, and furnish a continuous supply of material to the machines, economizing labor and increasing output. Soft coal is used and the system works satisfactorily with absence of the smoke and dirt of ordinary coal fires, and giving the highest temperatures required for work of this character.

We are also satisfied that by simple expedient the use of gas from anthracite coal or coke may be utilized with considerable fuel economy and the absence of the annoyances attending coal fires.

Cement Burning.—The process of burning in rotary kilns offers easy adaptability of gas firing to such furnaces. The application gives a well-burnt clinker, with economical use of fuel, centralizes coal and ash handling, gives an operation of easy and complete control, avoids the use of elaborate and expensive pulverizing plants, avoids the danger of spontaneous combustion, fire and disastrous explosion, and costs less to install and to operate in labor, repairs and power.

Boiler Firing.—There is no heating process where more of the energy is made available than in the evaporation of water in a good boiler. Fifteen pounds of water evaporated from and at 212° (to steam at atmospheric pressure) is the theoretical limit for one pound of good coal, equal to pure carbon.

To evaporate, in direct firing, 10 pounds of water from 1 pound of coal is not unusual in practice, and 11 or 12 pounds under exceptionally favorable circumstances is not entirely beyond our reach. Twelve pounds would be the utilization of 80 per cent., and 10 pounds, 66⅔ per cent. of the energy of the fuel. Compare this with the firing of an iron puddling-furnace, which in old-fashioned practice is estimated to utilize about 3 per cent. of the energy, and we have a fair comparison of the two extremes. In one case, the hot combustion-products are sent to a chimney at practically the same temperature as the furnace (which is high), and in the other they are discharged at a comparatively low temperature. That is, if the temperature of the combustion-chamber is 2000, and that of the smoke-stack 500, just 75 per cent. of the energy of the fuel has been utilized, provided the combustion is perfect without the introduction of any excess of air. This is impossible in practice as yet.

It is a great mistake to suppose that slow combustion under a boiler and a consequent low temperature is economical; for the greater the difference of temperature between the fire box and chimney, consistent with complete combustion, the greater, of course, is the utilization of heat. To further illustrate this, if the temperature of combustion could be increased from 2000° to 4000° without increasing the temperature of the chimney gases above 500°, only one-eighth of the energy would be lost, instead of one-quarter; and again, if the fire box were 1000° and the chimney 500°, the loss would be one-half. The three points to be striven after, then (for the best utilization of fuel-energy under boilers), are: First, perfect combustion; second, the use of the least possible excess of air; and third, to maintain the greatest possible difference in temperature between the fire box and chimney.

More or less experimenting has been done in Europe and in this country in firing boilers with gas made from bituminous coal, with quite satisfactory results; and even greater efficiency is hoped for from a more careful application of the gas and possibly by the use of water-jacketed producers, which serve as feed-water heaters. Good results have also been obtained in firing boilers with producer gas made from anthracite coal, but naturally the results are not as favorable as with bituminous coal.

Here, again, the problem is one which varies with the general conditions which surround each installation. Where the location will admit of it, and anthracite coal or a good quality of coke are available, the gas engine driven by producer gas affords by far the cheapest power. (See page 79.) This practically means the elimination of the boilers. On the other hand, large boiler plants of good design, using anthracite coal, and equipped with approved stoking devices, show as low fuel consumption as would be possible on the same boilers with anthracite producer gas, used for boiler firing only; though the duty thus secured through these boilers and a modern steam engine would be by far less than that attainable from a producer-gas-engine installation of the same horse power. This results in part from the fact that, in using the gas in the gas engine, there is one less conversion.

A considerable saving may be secured by firing efficient boilers with producer gas made from bituminous coal in a good producer when properly applied; and this economy may be further augmented where producer gas is also required for gas-fired furnaces and other purposes; and here producer gas from anthracite may sometimes be advantageously used.

Considered alone, the principal gain over direct firing with bituminous producer gas results from the more perfect combustion of the volatile hydrocarbons, with but little more than the theoretical amount of air. This prevents smoke, and saves the fuel otherwise used in heating a large amount of useless air. As the fire door is kept closed, the inrush of cold air incident to direct firing, which cools the gases as well, is avoided, and the life of the boilers prolonged, while the evenly maintained high temperature results in an increased steaming capacity; and there is a further saving of fuel ordinarily wasted through the grates. Where the gas is also required for firing furnaces, etc., it is possible to secure a further economy through the concentration and handling of the fuel and ash, etc. (see page 48), and resultant decreased attendance. The economy thus secured in producer gas-fired boilers is, of course, greater when compared with hand-fired than with stoker-equipped boilers. The latter, as in producer gas-firing, almost eliminate the variable factor of the fireman. Against the saving by gas-firing must be charged the loss by radiation from the producer, and the energy necessary for blowing it, amounting to 3 to 5 per cent. of the energy developed. In an article* on this subject, Mr. Blauvelt, the well-known fuel engineer, points out that while solid fuel has the advantage of the radiant heat from the fuel bed while in an in-

* "Producer Gas for Steam Raising," by W. H. Blauvelt, *Cassier's Magazine*, December, 1894.

candescent state, what this amounts to, or its comparative value, is not known; that while it is true more evaporation per square foot of surface can be obtained by a coal fire with a sufficiently strong draft than with gas, it is secured at a largely increased fuel consumption in proportion to the duty obtained; that notwithstanding this undetermined value of the radiant heat from the solid fuel, **numerous practical tests show the economy to be in favor of the gas,** which is a proof more satisfactory to the steam user than elaborate thermal calculations.

It is therefore evident that under certain conditions an economy results from using producer gas in firing boilers, and that the gain is more or less according to the surroundings, size of the plant, character of the boilers, fuel, etc. **Under favorable conditions, producer gas-firing secures more duty per pound of coal, insures a higher average of good work, more regular steaming, and tends to prolong the life of the boilers, with a lessened cost of maintenance.**

It is obvious that a proper application of the gas to the boilers has much to do with the success of a plant. In the article referred tc above, Mr. Blauvelt refers to this application of the gas, and to the prevention of smoke in bituminous gas-firing, as follows:

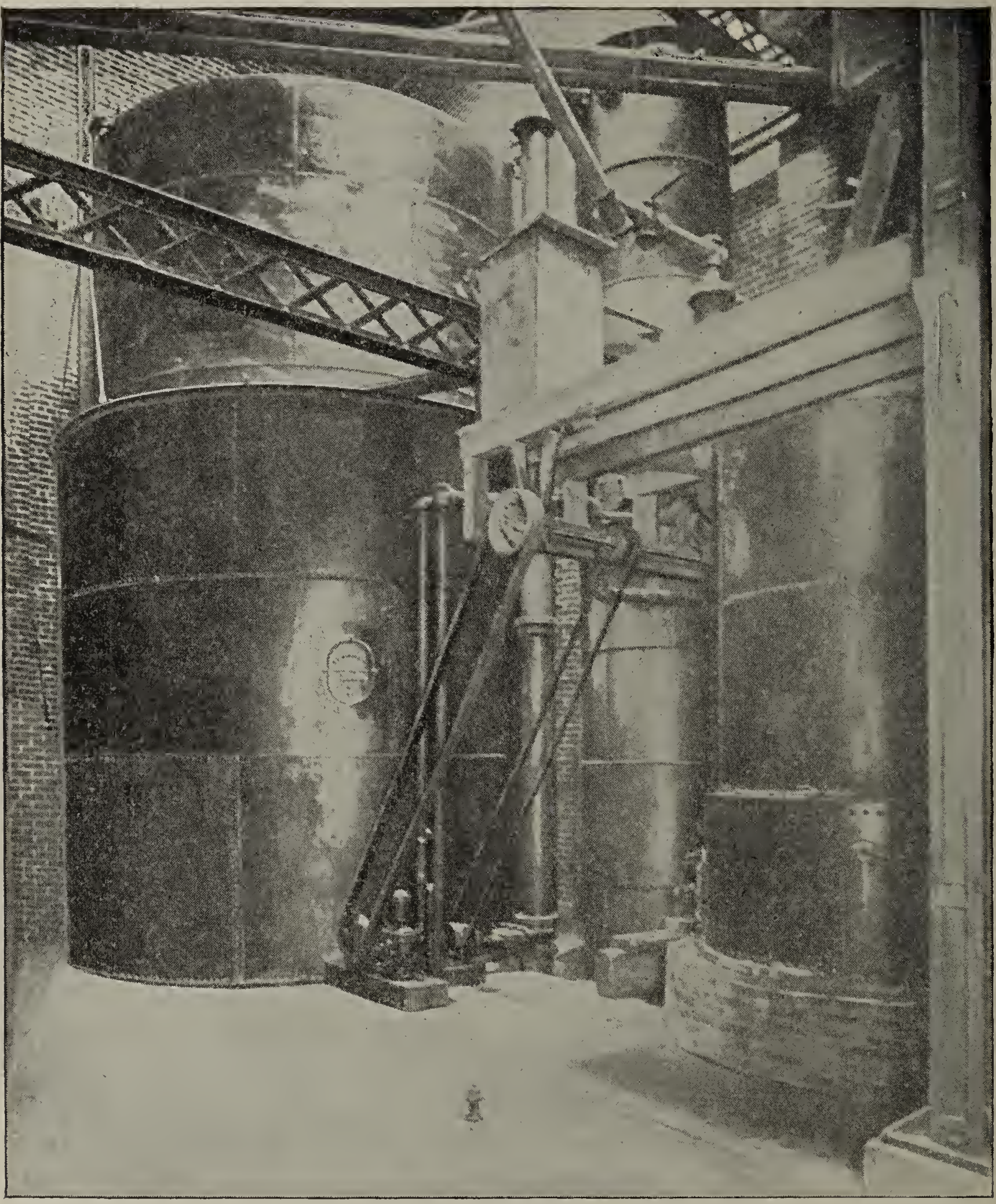
"In some applications of gas recently made to return tubular boilers by the writer, a careful use of the above principles in the light of previous less successful experience, resulted in the prevention of all smoke and in an increase of the evaporative capacity of the boilers of over 12 per cent. as compared with the results from the same coal burned on the grate. At the same time there was a saving of about 15 per cent. in the amount of coal used. The air for combustion was not pre-heated, and the temperature of the waste gases was 700° or more, as the boilers were too short for the most economical work. Had hot air been used, of course, this high stack temperature would not have been a source of serious loss. The mixture of the gas and air was made as promptly and as perfectly as possible, by a special arrangement of the ports, and inflammation was thoroughly developed in a brick chamber below the boilers. This was so arranged that but little more than the products of combustion reached the shell of the boiler, and at the same time the temperature at which combustion took place was kept high by the reflected and radiated heat from the walls of the chamber. For successful firing it is essential that the mixture of gas and air should take place as soon as possible after they enter the combustion chamber. Frequently they are introduced in parallel streams, but even if these streams are small, the gas and air often travel quite a distance with but little mingling of the currents. This is an important point.

"The arrangement referred to above provoked some criticism from onlookers, as the fire seemed too far from the boiler to those whose idea was that the conditions of a coal fire should be imitated as closely as possible. But the entire absence of smoke and the duty obtained from the coal, both as to economy and rate of evaporation, were sufficient arguments in proof of the correctness of the principle employed. One point noted during this test was that it was practically impossible for the firemen to make smoke except by the most gross inattention to the relative proportions of air and gas.

"I know of no other method of burning fuel which presents so practical and reliable a solution of the smoke problem, for it not only makes no smoke when carefully operated, but is equally free from that fault when the fireman's vigilance is relaxed, and it adds to this the advantage of economy over the methods in general use."

Average Volumetric Analyses.—For convenient reference, the following table is here inserted, showing what may be considered average volumetric analyses, and the weight and energy of 1000 cubic feet, of the four types of gases used for heating and illuminating purposes:

	Natural Gas.	Coal Gas.	Water Gas.	Producer Gas. Anthra.	Producer Gas. Bitu.
CO	0.50	6.0	45.0	27.0	27.0
H	2.18	46.0	45.0	12.0	12.0
CH_4	92.6	40.0	2.0	1.2	2.5
C_2H_4	0.31	4.0	......	......	0.4
CO_2	0.26	0.5	4.0	2.5	2.5
N	3.61	1.5	2.0	57.0	55.3
O	0.34	0.5	0.5	0.3	0.3
Vapor	......	1.5	1.5	......	......
Pounds in 1000 cubic ft.	45.6	32.0	45.6	65.6	65.9
H. U. in 1000 cubic ft.	1,100,000	735,000	322,000	137,455	156,917



APPARATUS OF EARLIER DESIGN FOR SUPPLYING PRODUCER GAS TO 100 HORSE POWER GAS ENGINE. SHOWS ROTARY INSTEAD OF STEAM BLOWER. ONLY SMALL FLOOR SPACE WAS AVAILABLE. ERECTED 1896. (From Photo.)

PRODUCER GAS POWER PLANTS.

One Horse Power—One Hour—One Pound of Coal.

"MOND GAS" WITH BY-PRODUCT RECOVERY.

No question of engineering has greater interest for the profession, is more worthy of attention or more likely to yield immediate and tangible results to industrial management than the economic generation of power.

While in America we have constructed the largest steam power plants, and have kept pace with England and the Continent in the use of the most approved method of fuel consumption on old lines, American engineers have not given as much attention to cheapening the production of power by using producer gas—a use which has grown so largely in England and Germany.

The investigations and patents of Dr. Ludwig Mond, of England, cover the most important advance that has been made in this direction, "Mond gas" for power or heating being generated from bituminous coals. (See p. 89.)

The Gas Engine.—The earliest types of internal combustion motors, it is true, fell short in regulation and smoothness of operation. Yet, established on an industrial basis less than twenty-five years ago, its present success and extended application can have been attained only by the development of a machine having inherent value with practical and substantial advantages.

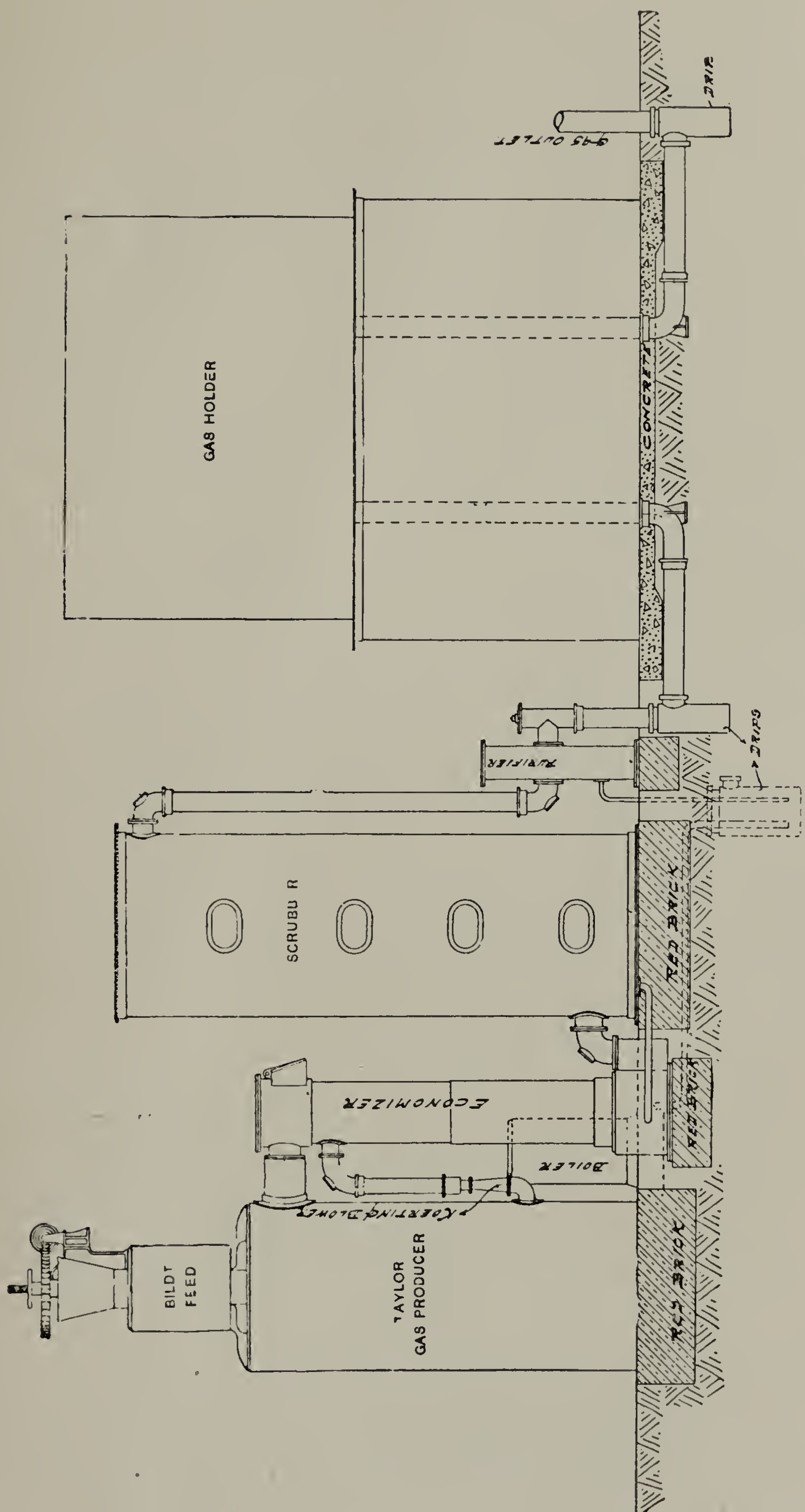
One reason for these advantages is in the much more direct conversion. In the steam engine the heat is first transferred from the coal to the water in the boiler, which, in the form of steam, is caused to expand its energy upon the piston of the engine; whereas, with the gas engine, the heat is transferred direct into the cylinder of the engine in the form of gas, without having first been converted into any other medium. This is not the whole difference, but is an important one.

Growth of Producer Gas Power Plants.—There are now over 60,000 horse power of gas engines in daily operation with producer gas, some forty of such plants with our type of gas producer in every variety of service. Indeed, this combination gas plant, either in single or several units of engine, from 50 to 1500 horse power, now successfully competes with steam. One brake horse power per hour on one pound of coal has been attained, and we may look forward confidently to such performance or better as that of daily practice.

Fuel Consumption and Efficiencies.—There are substantial reasons for this superiority of the gas producer-gas engine combination. The steam engine can be made an economical motor only when of enormous power. Between 100 and 500 horse power, and, under actual working conditions, the coal consumption per effective horse power per hour will range from 2.4 to 4 pounds. With smaller powers, current practice will require 5 or 6 pounds, while the average of an ordinary working district using a large number of small engines will be 10 or 12 pounds per effective horse power per hour.

Twelve per cent. of the heat value of the steam converted into mechanical work is about the performance of the best types in large units. The most approved form of boiler will not transfer to the steam over 80 per cent. of the energy of the coal; 50 per cent. may be a minimum and 65 per cent. a fair average.

The combined efficiency of the best engines and boilers is, therefore, not over 12 per cent. It is often much less, and with extensive steam lines or scattered distribution of units, as in large manufacturing establishments, it is very low. The modern gas engine, however, even in small powers, will give an efficiency considerably higher than the largest and most economical steam engine. If, however, these gas engines are supplied with illuminating gas as fuel, a large portion of this economy disappears, because of the **cost of the gas. Energy bought in the form of coal gas costs, at a dollar a thousand feet, about thirteen times as much as an equivalent amount of energy in the form of coal at three dollars per ton;** hence, in order to take full advantage of the gas engine, we must produce the gas economically where it is used; and such a plant, consisting of a gas producer with suitable cleansing and storage apparatus, working in connection with a good gas engine, gives us the most economical power of the present day. With a theoretical thermal efficiency of 80 per cent., a practical of 26 to 30 per cent., the gas engine will readily realize in actual working conditions 20 to 25 per cent. of the energy of the gas delivered to it. Indeed, as high as 31 per cent. has been attained when weak blast furnace gases served the motor.



STANDARD GAS PRODUCER POWER PLANT.

The gas producer of such an installation will readily transfer to the gas 80 per cent. of the energy of the coal. Thus, the **combined efficiency of the gas producer and gas engine with an inferior fuel is 20 per cent. as against the 12 per cent. of a steam plant using the best of steaming coal.**

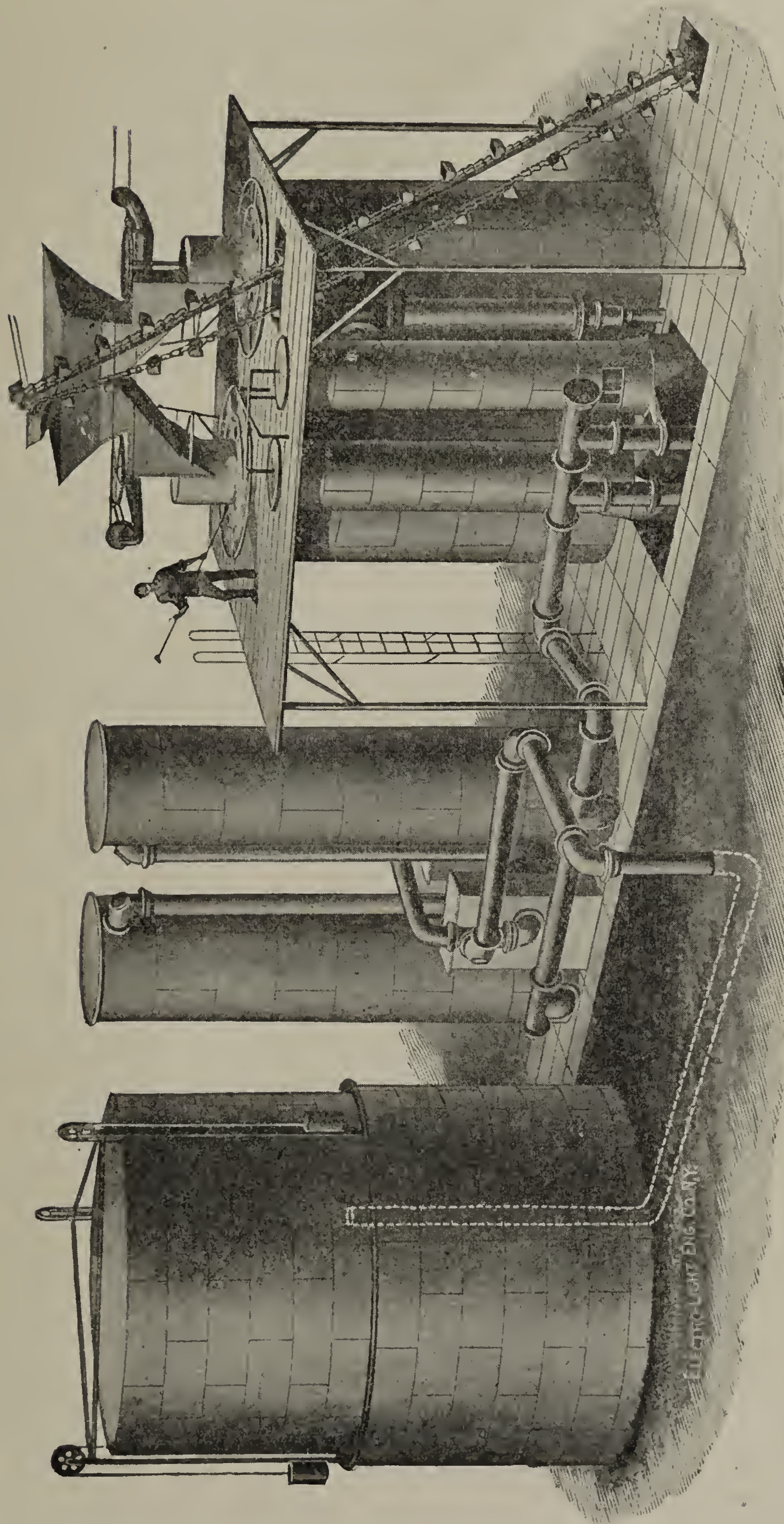
With an average coal, therefore, a steam plant of the highest efficiency and large power would require 67 per cent. more fuel than a gas engine on producer gas, appearing relatively with increasing disadvantage as the horse power of the installation decreased. With such a coal and 90 per cent. efficiency of the dynamos, there would be a consumption with gas of 1.13 pounds, with steam 1.88 pounds of fuel per electric horse power per hour; an economy of 40 per cent. with the gas installation or a ratio of efficiencies of 18 to 10.8 per cent.

One indicated horse power per hour for less than 1¼ pounds of coal can be easily obtained with as small as 100 horse power. In practice it will be at least not more than one-fourth of a good steam engine of the same power.

A Gas Producer Power Plant of our standard design for supplying producer gas to gas engines is shown by the illustration on page 81. It consists of a small steam boiler, a Gas Producer with Bildt Continuous Feed, an economizer with super-heater and wash box, a scrubber, purifier and gas holder in steel tank and guide framing, with suitable drips and connections. The details are modified to suit varying conditions: the boiler, for instance, may be omitted where steam can be secured from another source, and in some cases no separate steam generator is used at all.

This equipment is made in sizes proportioned for operating 50, 75, 100, 150, 200, 250, 300, 400 and 500 horse power, each size being capable of running about 25 per cent. over its rated capacity for a short time. Larger equipments with two or more producers are varied in general design and arrangement.

While for the smallest plants a coal elevator and storage bin above the feed magazine is not necessary, yet it is sometimes added, and for the larger sizes of producer is recommended. When in batteries it is customary to provide an elevator and conveyor with chutes from the conveyor to each feed device.



400 H. P. GAS PRODUCER POWER PLANT DESIGNED AND CONSTRUCTED FOR THE ERIE RAILROAD AT JERSEY CITY, N. J.

BOTTOM, AS ERECTED IN BATTERIES.

One plant of this character has been most thoroughly investigated by Professor H. W. Spangler. In his report (see Journal of the Franklin Institute for May, 1893,) he describes the testing of a one-hundred-horse power gas engine and producer plant at the Otto Gas Engine Works, Philadelphia, in which the results may be summarized as follows:

Coal used per indicated horse power per hour......	.95	pounds.
" " " brake " " " "	1.3	"
Combustible per indicated " " " "	.83	"
" " brake " " " "	1.15	"

The engine used in the above case was a new one, and had, consequently, as shown by the figures, a very large internal friction, the brake horse power only being 72 per cent. of the indicated horse power. It is reasonable to suppose that had this engine been working with the ordinary efficiency of 85 per cent., the coal per brake horse power would have been only about 1.1 pounds; that is, a higher efficiency than has ever been obtained in any marine engine or large pumping plant in the world.

Since the date of the above test experience has developed improved design and construction in both the producer and accessory parts. This is exemplified in the installation designed and constructed by us early in 1899 for the Erie Railroad, at Jersey City, N. J.

We call special attention to this **400-Horse Power Engine Gas Plant,** which was built under a guarantee of delivering in the gas 10,000 B. T. U., or 80 cubic feet of gas of 125 B. T. U. per cubic foot, per pound of coal gasified in the producer, with a further guarantee on the engines of 1¼ pounds of coal per horse power per hour; the coal to be a fair quality anthracite, buckwheat or pea size.

While these guarantees, no doubt, were influences largely prompting the adoption of the gas installation, yet it is especially noteworthy that it was selected only after a careful review of the economies possible with a high-class boiler and steam engine plant in which the high-priced lump coal was to be replaced by the cheaper and finer sizes of anthracite. The economy in change of kind of coal was in itself large, with but little difference in the costs of the two installations.

The illustration, p. 83, shows the arrangement of the gas plant, essentially as erected. It comprised two No. 7 Revolving Bottom

Gas Producers of capacity sufficient for 400 indicated horse power in Otto gas engines. A link-belt elevator carries the coal from the elevator boot near the base of the producers, to which point gravity takes it from the coal bins, and delivers it upon chutes conveying it to the receiving hoppers of the Bildt automatic and continuous feed devices. The automatic feed distributes the coal continuously and uniformly over the entire surface of the fuel bed, the arrangement almost entirely eliminating labor in the transfer of the fuel from storage bins to its withdrawal as ashes from the bottom of the producer.

The gases leaving the producer enter the superheater and economizer, through which latter attachment the air blast of the producer travels in the reverse direction to the Korting blower. Passing through the wash-box, the gas largely deposits its extraneous matter. Here also is arranged a seal against the gases stored in the holder and present in the rest of the apparatus. Entering the scrubbers, whose compartments are filled with coke and showered by water sprays, it is still further purified of any tarry matter, sulphur or ammonia, which operation is sufficiently completed in the purifier, the next and last element of the plant, before reaching the holder. In the holder is stored a sufficient supply to start and for several minutes' run, but it serves mainly as a regulator of pressures and cares for variations in consumption and mixture of gases. Drip pots and drainage pipes, minor but very essential parts, are placed suitably, while the hot water from the producer tops is carried to the holder tank.

There are two 90-horse power and several 45-horse power Otto gas engines, a 130 two thousand candle power arc light machine, a 450 light incandescent machine, a belt driven Ingersoll-Sergeant duplex air compressor, while gas is piped to about 1200 feet distant, and used in gas engines at the coal chutes and ash handling plant.

One man attends to the producers and fires the boilers installed for steam heating when they are in use, though in summer only a small boiler is fired to serve the producers. Another man and helper look after the engines and electric apparatus.

The following testimonial, unsolicited, was received after the plant had been in operation for some time:

JERSEY CITY, N. J., August 15, 1899.

R. D. WOOD & Co., Philadelphia, Pa.

Gentlemen:—The Gas Producing Plant you installed at Jersey City is very satisfactory. The test you made indicates that you are doing better than you guaranteed: to furnish gas of such quantity and quality as to equal 10,000 heat units from one pound of coal—and this from rice anthracite, while your guarantee was to get these results from the more expensive grade of buckwheat anthracite. We believe this is a very efficient plant.

Yours truly,

H. F. BALDWIN.

Examination of the gases showed a gratifying regularity of composition and calorific power, two of the analyses taken on different days showing:

	1	2
Carbon dioxide, CO_2	8.6	8.2
Oxygen, O	.4	.8
Carbon monoxide, CO	17.2	19.4
Hydrogen, H	18.3	16.6
Marsh gas, CH_4	2.4	2.8
Nitrogen, by difference, N	53.1	52.2

The calorific powers ranged from 136 to 143 B. T. U. per cubic foot and 84.7 cubic feet of gas per pound of coal. Thus, while the guarantee called for 80 cubic feet of gas of 125 B. T. U. per cubic foot, or 10,000 heat units per pound of coal, approximately 12,100 B. T. U. per pound were obtained. The engines gave an indicated horse power on 1.03 pounds of coal against the 1¼ pounds guaranteed, with the producer plant also showing a capacity of 471 horse power against a guarantee of 400. These results were the more valuable because they were obtained from the gasification of rice anthracite, in the use of which the producers showed unusual facility of operation.

Of our later installations may be mentioned those of United States Radiator Co., Dunkirk, N. Y., 250 horse power; Marinette Iron Works Mfg. Co., Marinette, Wis., 200 horse power; Union Traction Co., Philadelphia, 700 horse power; Agar, Cross & Co., N. Y., 200 horse power; Easton Power Co., Easton, Pa., 1000 horse power; Camden Iron Works, Camden, N. J., 400 horse power.

The general results in fuel economy, gas analyses, etc., closely approximate those of the Erie Railroad described above.

Space Required.—Although varying with the power, with single producers an area of 15 feet by 35 feet or less will comprise several hundred horse power exclusive of the holder. The size of the latter may be modified to suit special conditions, but with ample producer capacity less storage is required, and its need further reduced by the automatic regulation of gas production by movement of the holder. The holders are 1000 cubic feet capacity or upwards.

First Cost and Labor Charge of such installations are about equal to that of first-class steam engines and boilers, but the resultant economies would justify a largely increased expenditure and cover it in a brief period. One man may serve up to 500 or even 1000 horse power, depending upon the number of producers and detail of the plant; the labor may be taken as from 50 to 75 per cent. of that of steam.

Repairs and Maintenance are also less than that of a steam plant of the same power. After eighteen months' service of one of our largest plants the repairs were almost nominal. Producer linings have stood as long as ten years, and in any case should stand several years. However, fifteen to twenty cents per horse power per year may be taken as an approximate estimate for medium sized plants.

Economy in Transmission of power by producer gas is one of its important advantages. The average pressure on the line is about two inches, and there is an absence of the great losses by condensation and leakage as with steam. Indeed, being a fixed gas, its additional cooling is an advantage, for its energy per unit volume is proportionately increased. The gas may, therefore, be piped in exposed pipes long distances to isolated engines, and in large works attain thus great saving in shafting, belting and their attendant power losses. Expensive stacks are avoided also.

Water Consumption.—In the combined gas plant more water will be required than with steam, the water jackets of the engine using the major portion. It may, however, be largely recovered by the use of tanks for cooling, settling and storage.

Readiness for Operation and Fuel Economy During Hours of Idleness are marked features of a gas plant. Stopping and starting gas generation is simply a matter of manipulating the small valve at the steam jet air blast. The producer will retain fire for two weeks with comparatively trivial fuel consumption, and over night without the least attention. A consumption or waste of four pounds of coal per hour in medium-sized plants may be assumed as an average, a result far surpassing steam. The engine may always be started by the gas in the holder and the producers are soon in full operation.

Illumination by Producer Gas may be secured by a simple expedient about the plant using such a power installation.

Guarantee.—The gas plants are guaranteed to deliver in their gas 10,000 British thermal units per pound of coal gasified in the producer. This is based on approximately 125 B. T. U. per cubic foot and 80 cubic feet of gas per pound of coal, whereas the heating value more nearly averages 145 B. T. U. per cubic foot. The fuel is either a fair quality anthracite buckwheat or pea coal. Upon such gas, engine builders usually guarantee from 1 to 1½ pounds of coal per B. H. P. per hour, depending upon the size of engine and detail of installation.

Kind of Fuel Available.—In the above type of plant the most satisfactory fuel is either anthracite coal or coke. The coke, however, must be in small pieces approximating, say, one-inch cubes; large size coke will give a weak gas as ordinarily gasified. About one-third more by weight should be taken as fuel consumption when coke instead of anthracite is used. By automatic and simple apparatus the gas may be enriched to 250 to 300 heat units per cubic foot.

It may be noted, however, that while in this form of installation there may be preferences in fuel, with a modified plant, such materials as peat, tan bark, wood, sawdust, etc., may be advantageously gasified for use in gas engines.

"MOND GAS"

WITH OR WITHOUT BY-PRODUCT RECOVERY.

The use of bituminous coal in the production of power or heating gas finds most satisfactory solution in this process.

Dr. Ludwig Mond has skillfully developed it on scientific lines, his plant generating a clean, cheap gas admirably adapted to gas engines and a large range of heating operations.

With by-product recovery the nitrogen of the coal is converted into ammonia, with subsequent absorption in dilute sulphuric acid, forming ammonium sulphate. By evaporation, this solution yields crystals of the commercial "Sulphate of Ammonia" finding an extensive and ready market.

A ton of coal produces 140,000 to 160,000 cubic feet of gas and, gasified on a sufficiently large scale and under favorable conditions, ammonia equivalent to 90 pounds of "Sulphate of Ammonia."

The gas averages 145 British thermal units per cubic foot, is free from tar, soot or dust, and contains less sulphur than ordinary producer gas, while the thorough system of heat recuperation returns in the gas 84 to 86 per cent. of the heat value of the coal gasified.

In the by-product recovery an excess of steam is delivered to the producer with the air blast. A part of the major portion of this steam is decomposed in the producer, largely increasing the hydrogen contents of the gas, while the balance is recovered at a later stage and again returned to the producer with the air blast.

The hot gas and undecomposed steam pass from the producer to tubular regenerators, wherein their sensible heat is largely utilized in superheating the mixed air and steam blast which passes in the reverse direction to the base of the producer. Thence entering the washer, the hot gas and vapor are brought into intimate contact with water, vaporizing it, thus cooling and saturating the gas while converting the sensible into latent heat.

The acid tower next abstracts the ammonia, and the gas then entering the gas-cooling tower meets a shower of cold water over tiling, itself is cooled, its associated steam condensed with a net result of a cold, clean gas ready for use and hot water. This hot water, entering the top of the air-heating tower, showers down over tiling, saturating and preheating the air blast passing in the reverse direction on its way to the base of the producer through the tubular regenerator referred to above.

Where the quantity of fuel to be gasified is less than 30 tons per day, and the necessary exhaust steam or vapor beyond that obtained in the gas-cooling tower is not available, the sulphate recovery is better dispensed with and the first cost of the plant is materially reduced.

When the ammonia is not recovered, about the same quantity of steam is required as is used in ordinary producers.

The Mond producer gives a uniform gas under a wide range of one-third to full load, responds at once to increased demand for gas, while its methods of charging and ash removal in no manner interfere with its continuous steady operation.

Engines working on this gas have run continuously at full loads for six months and are now operating in sizes up to 650 I. H. P., gas engines working at varying load consuming one pound of fuel per I. H. P. per hour.

The most notable plants now erected are those at the Chemical Works of Messrs. Brunner, Mond & Co., of England, and the Solvay Process Co., in America, by which the ammonia and tar products are secured from the coal with the most satisfactory results in economy and efficiency.

Below are given the results secured at the works of Messrs. Brunner, Mond & Co., England, for twelve months' operation, which yield a credit from the by-products of $1.78 per ton of coal gasified after all costs of production of gas are considered.

With the well-established fact that gas engines are producing power with less than 1¼ pounds per horse power per hour, there is a saving of fully 50 per cent. over the ordinary steam engine. If in addition to this there is a further economy of $1.78 per ton to be gained from securing by-products (as is accomplished in the Mond producer), those considering the generation of power in large units have before them an opportunity for reducing the cost of power to an extent which has heretofore not received the attention that the subject demands.

The large engine plants of this country are ready to furnish generators driven by gas engines and capable of delivering 2000 H. P., and, as we have secured Dr. Mond's patents for this country, it is our desire to call the above facts to the attention of parties contemplating the erection or enlargement of power plants to the use of Mond gas for the production of power.

As an Illustration :

In the use of gas engines over steam engines there is an economy of about 50 per cent.

If a by-product plant is added to the gas producers, say, in a 2000 H. P. Station, which would consume 8035 tons of coal per year (300 working days, 24 hours each) there would be an annual saving through by-products—on a basis of $1.78 per ton of coal gasified—of $14,300, or over $7 per H. P. This saving is from by-products alone and is in addition to the saving from the use of gas engines over and above steam engines.

The Mond Producer Gas Process is peculiarly adaptable for use in steel, glass, chemical or other works where a large amount of fuel is consumed, and it will be remembered that by the removal of the by-products the heat units are not reduced.

Statement showing the average cost of production of sulphate of ammonia at the works of Brunner, Mond & Co., Ltd. (Northwich, England, for twelve months, ending March, 1899:

Average Monthly Yield of Ammonium Sulphate	180.2 tons.
Average Monthly Amount of Coal Gasified	4650.0 "

Items in Cost of Production.	Average Cost per Ton of Ammonium Sulphate for Twelve Months, Ending March, 1899.			
	£.	s.	d.	American Equivalent.
Working Producer and Sulphate Plant, gasifying an average of 4650 tons of fuel per month	1	8	5.53	$6.930
Materials Account—Manufacturing	...	3	8.38	.900
Repairs—Materials and Labor	1	1	8.64	5.289
Acid used at 24 shillings per ton	1	3	6.18	5.726
Total Cost of Producing One Ton of Ammonium Sulphate, the necessary steam being provided without charge from exhaust of steam or gas engines	3	17	4.73	18.845

Average Market Value of Ammonium Sulphate in America during the last three years	$64.960
Average Cost of Producing One Ton of Ammonium Sulphate	18.845
Profit in Producing One Ton of Ammonium Sulphate	$46.115

Note.—Where the gas is used in gas engines the heat of the exhaust gases from these engines will suffice to provide this steam at atmospheric pressure.

In steel works, chemical works, etc., there is usually waste steam available in abundance: where neither exhaust from steam nor gas engines is available, it has to be raised in special boilers.

MOND GAS ANALYSIS.	At Full Load.	At ⅓ Load.
Hydrogen	24.00	21.60
Carbon monoxide	16.00	16.40
Marsh gas	2.20	2.40
Oxygen	0.00	0.00
Carbon dioxide	12.40	12.40
Nitrogen	45.40	47.20
B. T. U.—per cubic foot	145.90	144.50

Results obtained in the year 1898 on working a Gas Engine using Mond Gas and coupled direct to a Siemens Dynamo, at Messrs. Brunner, Mond & Co.'s Works, England:

HOURS RUNNING.

Total number of hours in year	8,760
Number of hours gas engine ran on load	8,356.5
Hours running as per cent. of total	95.4

GAS USED AND UNITS OF ELECTRICITY GENERATED.

Number of units of electricity (1000 Watt hours) generated by the gas engine, dynamo and measured at the switchboard during 1898	558,726

CUBIC FEET OF GAS.

Cubic feet of Mond gas supplied to the gas engine during the year, measured by meter	64,281,240

COAL PER UNIT OF ELECTRICITY GENERATED.

Cubic feet of gas measured at atmospheric temperature per kilowatt-hour	115.05
Equivalent to slack used per electric unit generated—in pounds	1.79
Average amperes (at 100 volts) during year	668.50
Average electrical horse power (at switchboard)	89.60
On the assumption that the electrical efficiency of the dynamo is 91 per cent., and the mechanical efficiency of engine 85 per cent., the combined efficiency becomes—in per cent	77.35
Average I. H. P. for the year is	115.80

GAS PER I. H. P.

Mond gas used per I. H. P. hour (average)—in cubic feet	66.40

SLACK PER I. H. P.

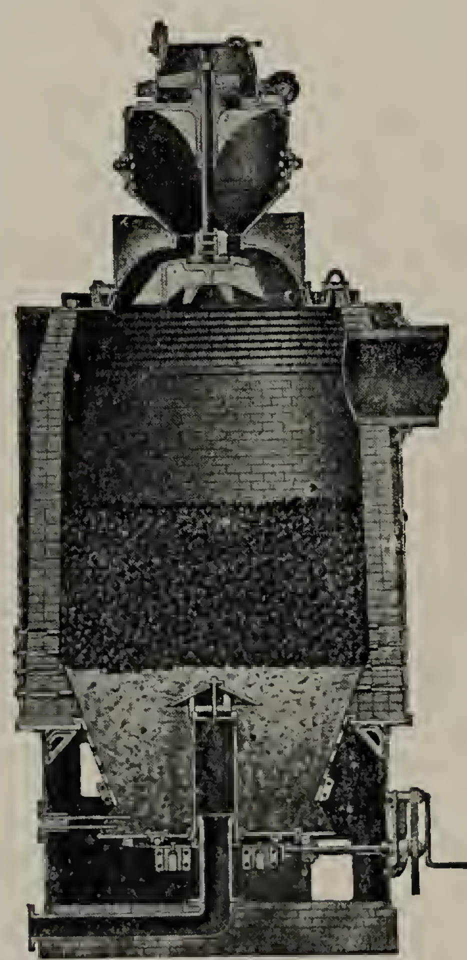
Equivalent of slack fed into producer—in pounds	1.03

EFFICIENCY.

Thermal efficiency, calculated from the I. H. P.—in per cent	25.40

The greatly increased familiarity with gaseous fuel during the last few years has resulted in a more general knowledge of its nature. Whatever of prejudice existed against fuel in this form has been shown to be groundless on the part of those whose faith rested in the coal mass and shovel as a more tangible form of energy. Experience has amply demonstrated it is safe in use and storage; that it is readily controlled and has a range of adaptability possessed by no other fuel. Applied to the gas engine, the economies attained with producer gas are in daily evidence, whether in general power, pumping, electric light or traction. These economies are such as to warrant inquiry into its substitution for steam in established plants, and certainly no new construction or increase of power in manufacturing or central power stations should be undertaken without such investigation.

Directions for Starting and Operating the Gas Producer.—Before putting the center piece with bell and hopper in place, put in ashes, which should be as free from coal as possible, until the top of the center dome (cover to air pipe) is covered say 3″, and still higher next to the walls by say 4″ or 5″. Ashes containing much coal are liable to catch fire and make the bottom of the producer very hot. Coarse sand or fine gravel is better than ashes full of coal. The top center of the ash bed should be coarse,—that is, the fine ashes sifted out so that the air will have an easy passage through it. This ash should be put in as loosely as possible around and above the dome. It can be dumped in up to this point, and, if tight, a little grinding before firing will loosen it up. After the ashes are up to the lowest opening in the dome, better lower the rest in buckets and have a man down in the producer to empty them. He should stand on a plank to prevent packing of the ashes. If the top ashes are thrown in they become very much



packed, and the pressure is high at the start. Just before putting in the wood, put full pressure of steam on the blower and note what pressure is obtained on the gauge. If over ½ of an inch to ¾ of an inch of water, the crank should be turned a few times to loosen the ashes.

To fire up, put in a lot of small dry wood about 8 inches or 10 inches thick, as on a grate, and fire it with oily waste or hot coal. Blow or let it burn by natural draft until well fired and partly burned to live coals. Then put on coal and as fast as it brightens on top bring up the fuel burden as fast as it can be done, the same as in any other producer. Put bell and hopper in place soon after coal firing is commenced. When soft coal is used, it is more convenient to use a few bushels of coke in starting up.

For anthracite, a fuel bed or burden of about 2½ feet to 3 feet is ample, and less will do unless the producer is pushed hard. When running on soft coal a depth of fuel about 3½ feet to 4½ feet should be carried. The producer should take the air necessary for this, at a pressure not exceeding 3 inches to 4 inches of water.

If the producer burns too fast on the walls, the coal is too fine or the blast too strong, and one or the other must be changed accordingly. A certain amount of barring is necessary to prevent honeycombing of the fuel bed, to keep it solid and the CO_2 low. If hydrogen in the gas is not objectionable, use as much steam as the producer will carry. Grind down the accumulated ash as often as it rises say 12 inches above top of center dome; but never grind below 6 inches above the top of dome; that is, below the level of the first sight hole above the bottom one. Poke the fuel bed well from the top after grinding, to get it solid, and particularly next to the walls to keep them clear of clinker. In grinding it is sometimes better to make say one revolution of the table then shake or jar it a little backward and forward with the crank, and reverse, turning the crank the other way for say one revolution of the ash table; shake again and so on until the ash is brought down to the proper height, which can always be ascertained by pricking the little sight holes with a rod. In this way the attendant can readily ascertain the dividing line between the ash bed and incandescent fuel, and also whether it is higher on one side than on another. If so, before grinding, push the agitating bars well in on the high side and draw them out on the low side, or, in an extreme case, put in the gates on the low side also. In this way, with a little experience and care, the ash bed can always be kept level and the producer in normal condition. If the ash bed is fairly level, keep all the doors or agitating bars pushed in when grinding. This accelerates the discharge of the ash and clinker all around alike. If the coal is very bad and makes large clinkers that will not pass out of the 9-inch space between the bottom of the bosh and the table, an "observation door" must be opened and the clinkers broken with a sharp bar introduced through the holes in the bosh.

In working anthracite, if the fuel bed gets pasty and the blast pressure high, say 5 inches to 7 inches, it is owing to the ash of the fuel fusing at a low temperature. The blast will then go to the walls, making the gas lean. In this case, try the use of a larger proportion of steam, obtained by partially covering the top of the blower with a piece of board or sheet iron, and turning on a little more steam. If this does not prevent the pasty condition, the producer must be driven much slower, but coal that gets so pasty that barring will do no good, should not be used, nor should coal containing too much dust be used, as this clogs the interstices too much and sends the blast to the walls, greatly to the injury of the gas. The producer, unless using our Automatic Continuous Feed, will not work well on anything smaller than No. 1 buckwheat on this account. A mixture of bituminous with anthracite buckwheat can be used and works well, but in that case the fuel should be higher, and when using all soft coal still higher. In charging soft coal a second charge should not be put on before the first has coked and been broken up with a bar. Holes in the fuel bed should also be kept closed, but beyond this very little poking is needed except after grinding.

Always keep the top of the producer under a slight pressure so that the gas will come out when the poker hole covers are removed or the bell lowered, instead of air going in, thus preventing any tendency to explosions.

In stopping the producer, it is important to have good incandescence on top of the fuel instead of fresh coal. Before stopping, slacken the blast and then remove the poker-hole covers before entirely taking off blast. With the lessened blast, a gentle current of gas will issue from the poker holes, and, if hot enough, will ignite. If it does not do so, ignite it. Then, in entirely cutting off the blast, the air will follow the receding flame into the producer, and the gas will burn quietly without explosive puff.

A good drain pipe or drip cock must be arranged in bottom of blast pipe to carry off the water from the condensed steam.

The air pressure gauge pipe should be tapped in on top of horizontal air pipe near where it enters the foundation. The pipe should be ¼ inch gas pipe about four feet long. The gauge is an ordinary manometer, conveniently made of glass tubing inch inside diameter, bent into the form of a U about 10 inches high, and half filled with water. This is fastened on a board and attached to the ¼ inch pipe by a piece of rubber tubing.

Sufficient water should be kept running on the top plate to prevent the formation of much steam, and the same directions apply to the jacket water of a water-cooled producer.

The gas is of the best quality when the top of the fuel bed is almost black to a dull or medium red.—When very hot, the CO_2 is always too high.

Use the sight holes in the casing to maintain fire line at proper point.

We are prepared to send out competent men to superintend erection, start up the producers, and instruct those who will have immediate charge of operating them.

Comparison of Producer and Illuminating Gas.—First-class carburetted water gas, made with 4½ gallons of Lima oil per 1000 feet of gas, C.P. 26½; contains 730 H.U. per cubic foot.

One pound of anthracite coal (C 85 per cent., HC 5 per cent., Ash 10 per cent.) will make about 90 cubic feet of gas of following composition:

CO 27 per cent., H 12 per cent., CH_4 1.2 per cent., CO_2 2.5 per cent., N 57 per cent.

This gas contains about 137 H.U. per cubic foot.

Therefore 17 cubic feet of carburetted water gas are equal in heat-units to gas from one pound of anthracite.

1000 feet C.W. gas equals gas from 59 + pounds anthracite.

WEIGHT PER CUBIC FOOT OF COAL AND COKE.

	Lbs. per Cu. Ft.	Storage for Long Ton.
Anthracite coal, market sizes, loose	52-56	40-43 cu. ft.
Anthracite coal, market sizes, moderately shaken	56-60	
Anthracite coal, market size, heaped bushel, loose	77-83	
Bituminous coal, broken, loose	47-52	43-48 "
Bituminous coal, moderately shaken	51-56	
Bituminous coal, heaped bushel	70-78	
Dry coke	23-32	80-97 "
Dry coke, heaped bushel (average 38)	35-42	

Standard bushel American Gas Light Association: 18½″ diam. and 8″ deep = 2150.42 cu. in. A heaped bushel is the same plus a cone 19½″ diam. and 6″ high, or a total of 2747.7 cu. in. An *ordinary* heaped bushel = 1¼ struck bushel = 2688 cu. in. = 10 gallons dry measure.

Crude petroleum = 7.3 lbs. per gallon.

TEMPERATURES.

Degrees Fahrenheit = $\frac{9}{5}$ Degrees Centigrade + 32, or F.° = 1.8 C.° + 32.

Degrees Centigrade = $\frac{5}{9}$ (Degrees Fahrenheit — 32).

Degrees Absolute Temperature, T. = C.° + 273.

Degrees Absolute Temperature, T. = F.° + 459.

Absolute Zero = { — 273° on Centigrade Scale. / — 459° on Fahrenheit Scale.

Mercury remains liquid to — 39° C. and thermometers with compressed N. above the column of mercury may be used for as high temperatures as 400° to 500° C.

Temperatures in some industrial operations:

	Degrees. Centigrade.	Degrees. Fahrenheit.
*Gold—Standard alloy pouring into molds	1180	2156
Annealing blanks for coinage, furnace chamber,	890	1634
Silver—Standard alloy, pouring into molds	980	1796
†Steel—Bessemer Process, Six-ton Converter:		
Bath of Slag	1580	2876
Metal in ladle	1640	2984
" " ingot mold	1580	2876
Ingot in reheating furnace	1200	2192
" under hammer	1080	1976
Siemen's Open Hearth Furnace:		
Producer gas near gas generator	720	1328
" " entering recuperator chamber	400	752
" " leaving " "	1200	2192
Air issuing from " "	1000	1832
Products of combustion approaching chimney,	300	590
End of melting pig charge	1420	2588
Completion of conversion	1500	2732
Pouring steel into ladle { beginning	1580	2876
Pouring steel into ladle { ending	1490	2714
In the molds	1520	2768
Siemen's Crucible Furnace:		
Temperature of hearth between crucibles	1600	2912

* W. C. Roberts-Austen.
† Prof. Le Chatelier.

	Degrees. Centigrade.	Fahrenheit.
Blast Furnace on gray Bessemer:		
Opening in front of tuyere	1930	3506
Molten metal — beginning to tap	1400	2552
Molten metal — end of tap	1570	2858
Siemen's Glass Melting Furnace:		
Temperature of furnace	1400	2552
Melted glass	1310	2390
Annealing bottles	585	1085
Furnace for hard porcelain, end of "baking"	1370	2498
Hoffman red brick kiln, burning temperature	1100	2012

MELTING POINTS.

	C.°	F.°		C.°	F.°
Sulphur	115	239	Copper	1054	1929
Tin	230	446	Cast iron, white	1135	2075
Lead	326	618	" gray	1220	2228
Zinc	415	779	Steel, hard	1410	2570
Aluminum	625	1157	" mild	1475	2687
Silver	945	1733	Palladium	1500	2732
Gold	1045	1913	Platinum	1775	3227

HEAT UNITS.

(See pp. 57 and 58.)

A French Calorie = 1 Kilogram of H_2O heated 1° C. at or near 4° C.

A British Thermal Unit (B. T. U.) = 1 lb. of H_2O heated 1° F. at or near 39° F.

A Pound-Calorie Unit = 1 lb. of H_2O heated 1° C. at or near 4° C.

1 French Calorie = 3.968 B. T. U. = 2.2046 Pound Calories.

1 British Thermal Unit = .252 French Calories = .555 Pound Calories.

1 Pound Calorie = 1.8 B. T. U. = .45 French Calories.

1 B. T. U. = 778 ft. lbs. = Joule's mechanical equivalent of heat.

1 H. P. = 33,000 ft. lbs. per minute.

$= \frac{33000}{778} = 42.42$ B. T. Us. per minute.

$= 42.42 \times 60 = 2545$ B. T. Us. per hour.

The British Board of Trade unit is not a unit of heat, but of electrical measurement and

= 1 kilowatt hour.

$= 1000$ watts $= \frac{1000}{746} = 1.34$ H. P. per hour.

CHEMICAL NOMENCLATURE.

The following gives the characters used by chemists to briefly designate various substances:

CO_2 [44]† = Carbon Dioxide, "Carbonic Acid," Choke or Black Damp.

CH_4 [16]† = Methane, Marsh Gas, Pit Gas or Fire Damp.

H [1]* = Hydrogen.	O [16]* = Oxygen.
N [14]* = Nitrogen.	H_2O [18]† = Water.
CO [28]† = Carbon Monoxide.	C_2H_6 [30]† = Ethane.
C_2H_4 [28]† = Ethylene or Olefiant Gas.	C_2H_2 [26]† = Acetylene.

*Atomic weight. †Molecular weight.

CHEMICAL EQUATIONS FOR COMBUSTION IN OXYGEN.

HYDROGEN, H.

$$2H_2 + O_2 = 2H_2O.$$

Relation by volume — (2 vols.) + (1 vol.) = (2 vols.).
" " weight — 1 + 8 = 9

CARBON MONOXIDE, CO.

$$2CO + O_2 = 2CO_2.$$

Relation by volume — (2 vols.) + (1 vol.) = 2 vols.
" " weight — 7 + 4 = 11

OLEFIANT GAS, C_2H_4.

$$C_2H_4 + 3O_2 = 2CO_2 + 2H_2O.$$

Relation by volume — (1 vol.) + (3 vols.) = (2 vols.) + (2 vols.).
" " weight — 7 + 24 = 22 + 9

MARSH GAS, CH_4.

$$CH_4 + 2O_2 = CO_2 + 2H_2O.$$

Relation by volume — (1 vol.) + (2 vols.) = (1 vol.) + (2 vols.).
" " weight — 4 + 16 = 11 + 9

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1 cu. ft. of Hydrogen at 32° F. and 14.7 lb. per □″ =.00599 lb. To find the weight of any other gas per cubic foot, multiply half its molecular weight by .00599.

CALORIFIC POWERS OF FUELS CALCULATED FROM ULTIMATE ANALYSIS.

Dulong's formula:

Heating value in B. T. Us. $= \frac{1}{100}\left[14{,}600\ C + 62{,}000\left(H - \frac{O}{8}\right) + 4050\ S\right]$.

Heating value in Calories $= \frac{1}{100}\left[8140\ C + 34{,}400\left(H - \frac{O}{8}\right) + 2250\ S\right]$.

Mahler's formula:

Heating value, Calories $= \frac{1}{100}\left[8140\ C + 34{,}500\ H - 3000\ (O + N)\right]$.

In the above C = Carbon, H = Hydrogen, O = Oxygen, N = Nitrogen, S = Sulphur.

Heats of Combustion of Various Substances in Oxygen.

(Favre & Silberman.)

One Part by Weight of	Burning to	Evolves. Kilo-Calories.	Evolves. B. T. U.
Hydrogen	H_2O at 0° C.	34462	62032
Hydrogen	H_2O at 100° C.	28732	51717
Carbon (wood charcoal)	CO_2	8080	14544
Carbon	CO	2473	4451
Carbon Monoxide	CO_2	2403	4325
Marsh Gas	CO_2 and H_2O	13063	23513
Olefiant Gas	CO_2 and H_2O	11858	21344

Heats of Combustion of Gases in Oxygen.

(By Julius Thompsen.)

Name.	Symbol.	Products of Combustion at 18° C. (64.4° F.), Water Liquid.	Heat Units Evolved.		Kilo-Calories per Cubic Meter.	B. T. Us. per Cubic Foot.
			Calories per Kilogram of Gas.	B. T. Us. per Pound of Gas.		
Acetylene	C_2H_2	$2\,CO_2 + H_2O$	11,917	21,421	13,881	1,554
Benzine	C_6H_6	$6\,CO_2 + 2\,H_2O$	10,102	18,183	35,300	3,954
Carbonic Oxide	CO	CO_2	2,436	4,385	3,055	342
Ethane	C_2H_6	$2\,CO_2 + 3\,H_2O$	12,420	22,356	16,692	1,870
Ethylene (Olefiant Gas)	C_2H_4	$2\,CO_2 + 2\,H_2O$	11,931	21,476	14,967	1,677
Hydrogen	H_2	H_2O	34,180	61,524	3,062	344
Methane (Marsh Gas)	CH_4	$CO_2 + 2\,H_2O$	13,320	23,976	9,548	1,070

Weight and Volume of Gases and Air Required in Combustion.

Name.	Weight per Cubic Foot in Pounds at 32° F. and 14.7 Pounds per Square Inch.	Volume in Cubic Feet of 1 Pound of Gas at 14.7 Pounds per Square Inch.		Cubic Feet Required to Burn 1 Cubic Foot of Gas.		Pounds Required to Burn 1 Pound of the Gas.		Cubic Feet Formed of	
		32° F.	62° F.	Oxygen.	Air.	Oxygen.	Air.	Steam.	CO_2.
Air	.08073	12.39	13.12	.....	.....	.....	.....	...	...
Carbon Dioxide	.12300	8.12	8.60	.....	.....	.....	.....	...	...
Carbon Monoxide	.07830	12.77	13.55	.5	2.39	.57	2.4B	0	1
Hydrogen	.00599	178.80	189.80	.5	2.39	8.00	34.8	1	0
Marsh Gas	.04470	22.37	23.73	2.0	9.60	4.00	17.4	2	1
Nitrogen	.07830	12.77	13.55	.....	.....	.....	.....	...	...
Olefiant Gas	.07830	12.77	13.55	3.0	14.4	3.43	14.9	2	2
Oxygen	.08940	11.20	11.88	.....	.....	.....	.....	...	...

Air = 20.92 per cent. of Oxygen.

1 lb. Carbon burning to CO_2 requires 11.6 lbs. of air.
1 " " " " CO " 5.8 " " "
Liquid Hydrocarbons approximate 20,000 B. T. U. per lb.
Good coal approximates 14,000 B. T. U. per lb.
2½ lbs. of dry wood = 1 lb. of coal or .4 lb. coal = 1 lb. wood.

SPECIFIC HEATS OF SUBSTANCES.

SOLIDS AND LIQUIDS.

Glass	.1937	Coal	.20 to .24	Copper	.0951
Cast iron	.1298	Coke	.203	Charcoal	.2410
Wrought iron	.1138	Brickwork / Masonry	.20	Mercury	.0333
Steel, soft	.1165	Wood	.46 to .65	Water	1.0000

AT CONSTANT PRESSURE.

GASES.

Air	.2375
Oxygen	.2175
Hydrogen	3.4090
Nitrogen	.2438
Carbon Dioxide, CO_2	.2170
Carbon Monoxide, CO	.2479
Olefiant Gas (ethylene) C_2H_4	.4040
Marsh Gas (methane), CH_4	.5929
Blast Furnace Gas	.2280
Chimney Gases from Boilers	.2400
Steam, superheated	.4805

"VOLUMETRIC" SPECIFIC HEATS.

Air, Oxygen, Carbon Monoxide, Hydrogen and Nitrogen = .019.
Carbon Dioxide and Marsh Gas = .027.
Producer Gas = .019.

Volumetric specific heat is the quantity of heat required to raise the temperature of 1 cubic foot 1 degree from 32° to 33° F.

SPECIFIC GRAVITIES.

(Approximate.)

Coal Gas, .400. Water Gas, .570. Producer Gas, .970. Air = 1.00.

FORMULA FOR CALCULATING DIAMETERS OF PIPE.

Q = Discharge per hour; S = specific gravity of gas; h = pressure in inches of water; l = length of pipe in yds. D = Diameter of pipe. Then

$$D = \sqrt[5]{\frac{Q^2 S l}{(1350)^2 h}}$$

Ample margin should be allowed in calculations based upon this formula.

As far as the effect of heat is concerned, the volume of a gas varies as its absolute temperature. Its absolute temperature is the ordinary temperature + 273° on the Centigrade or + 460° on the Fahrenheit scale. Each degree rise Centigrade increases the volume $\frac{1}{273}$ of its volume at 0°C., or $\frac{1}{460}$ of its volume at 32° F., approximately.

HEATING VALUE OF SOME FUELS.

Peat, Irish, perfectly dried, ash 4 per cent	10,200	B. T. U.
Peat, air-dried, 25 per cent. moisture, ash 4 per cent	7,400	"
Wood, perfectly dry, ash 2 per cent	7,800	"
Wood, 25 per cent. moisture	5,800	"
Tan bark, perfectly dry, 15 per cent. ash	6,100	"
Tan bark, 30 per cent. moisture	4,300	"
Straw, 10 per cent. moisture, ash 4 per cent	5,450	"
Straw, dry, ash 4 per cent	6,300	"
Lignites	11,200	"

The above are approximate figures, for on such materials qualities are very variable.

WEIGHT PER CORD AND COAL VALUE OF THOROUGHLY AIR-DRIED WOODS.

S. P. Sharpless.

Hickory or hard maple	4,500 lbs.	= 1,800	lbs. coal
White oak	3,850 "	= 1,540	"
Beech, red and black oak	3,250 "	= 1,300	"
Poplar, chestnut and elm	2,350 "	= 940	"
Average pine	2,000 "	= 800	"

NATURAL GAS AND COAL.

Equivalent values for natural gas and coal vary considerably, no doubt from variations in quality of gas and coal and differences in practice. Approximately—

35,000 cubic feet of natural gas = in heating value 1 ton of coal.

FUEL OILS.

American crude petroleum carries more of the lighter oils than the European or Peruvian. These latter leave when distilled a residuum or "fuel oil" consisting largely of the heavy oils. Steam atomizers give better results with them than the air spray. In some Russian tests the steam required to atomize was 4 per cent. of the water evaporated.

"Astatki," "Mazoot," petroleum refuse, reduced oil, etc., are terms used to designate fuel oil.

Approximately 1 lb. oil = 1.45 lbs. coal.

Test at Minneapolis Water Works showed that for same duty 224 gallons of oil weighing 6.875 lbs. per gal. = 1 ton (2,240) Youghiogheny coal. Urquhart gives value of oil and coal in weight as 10 : 7 = 1.43.

Applications of Producer Gas to Metallurgical Operations:

OPEN HEARTH AND CRUCIBLE FURNACES,

SOAKING PITS AND REHEATING FURNACES,

PLATE BENDING AND ANNEALING FURNACES,

RETORT ZINC FURNACES AND THE ROASTING PROCESSES OF ORE TREATMENT.

Manufacture of Chemicals:

OXIDIZING AND REDUCING FURNACES,

PHOSPHORUS, SODA AND SULPHATE FURNACES,

ACID CONCENTRATION, WOOD DISTILLATION,

PIGMENT FURNACES.

Manufactures in Glass:

TANK AND CRUCIBLE FURNACES,

SHEET, GLASS AND BOTTLE WORK.

Manufactures in Earthenware:

KILNS AND MUFFLE FURNACES FOR PORCELAI AND CROCKERY WARE,

ORNAMENTAL AND ROOFING TILES,

BRICKS AND REFRACTORY MATERIALS AND CEMENT, LIME AND ENAMELING KILNS.

A SHIPMENT OF 48″ PIPE LEAVING WORKS.

CAST IRON PIPE and SPECIAL CASTINGS.

60″x 60″x 60″ Y. WEIGHT 57,000 LBS.

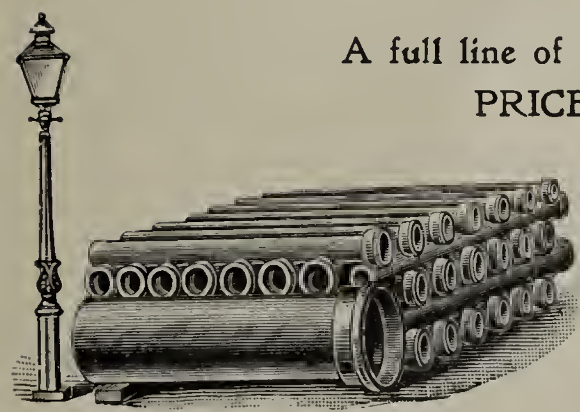
Constructors of

GAS AND WATER WORKS.

Manufacturers of all kinds and sizes of

CAST IRON PIPE

FOR WATER AND GAS MAINS, SEWERAGE, CULVERTS, etc.



A full line of all Regular sizes usually in stock.
PRICES ON APPLICATION.

Inquiries should state size, kind, approximate quantity and weight of pipes—or pressure under which they will be used; and, if possible, the intended service, delivery desired, etc.

FLEXIBLE JOINT PIPE.

STANDARD FLANGE PIPE.

SPECIAL CASTINGS.

Send for Circular.

Chemical and Sugar-House Work.

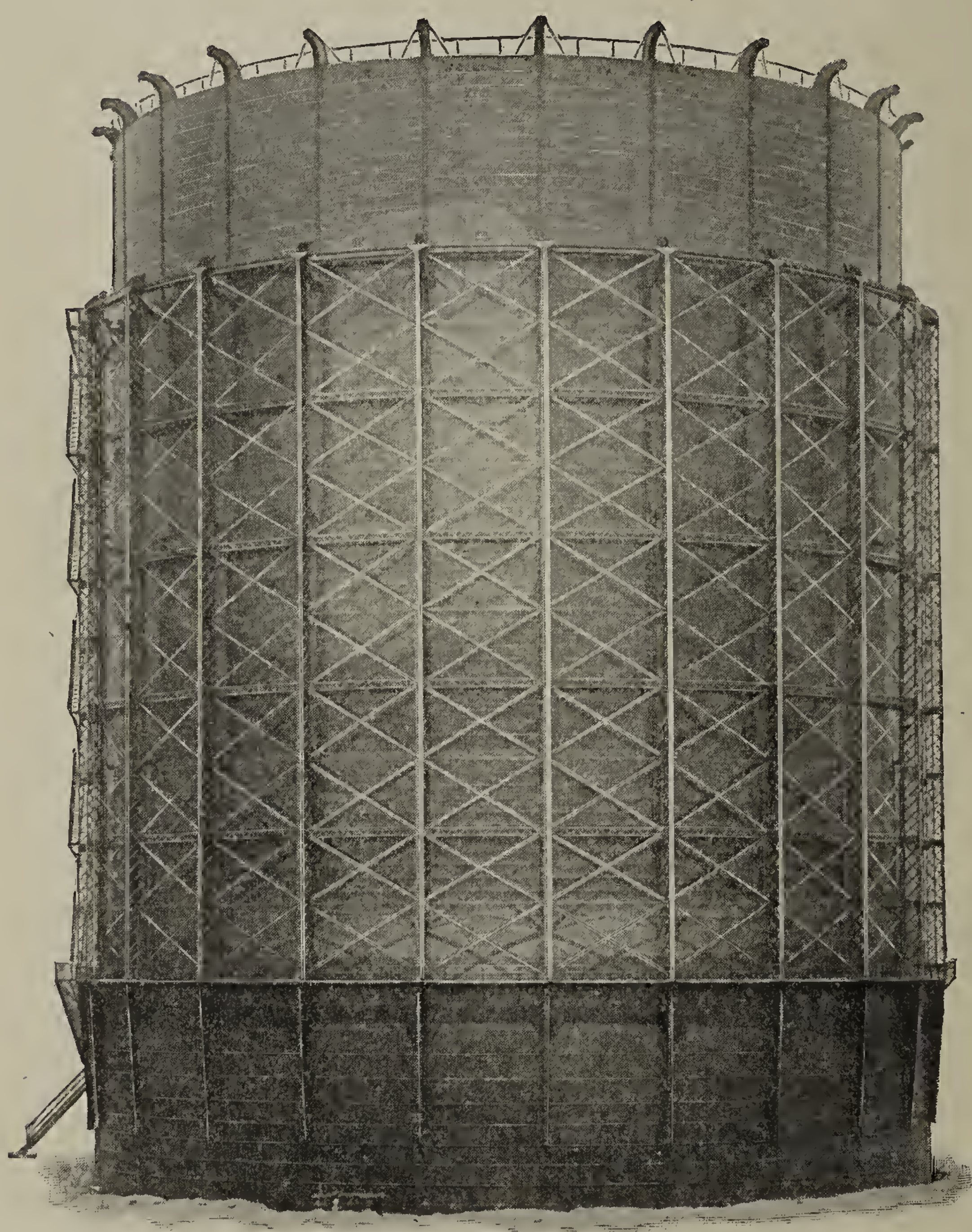
HEAVY SPECIAL MACHINERY

TO PURCHASERS' DRAWINGS.

GENERAL CASTINGS.

Designing and Constructing Engineers of

GAS WORKS APPLIANCES.



SINGLE OR MULTIPLE LIFT GAS HOLDERS

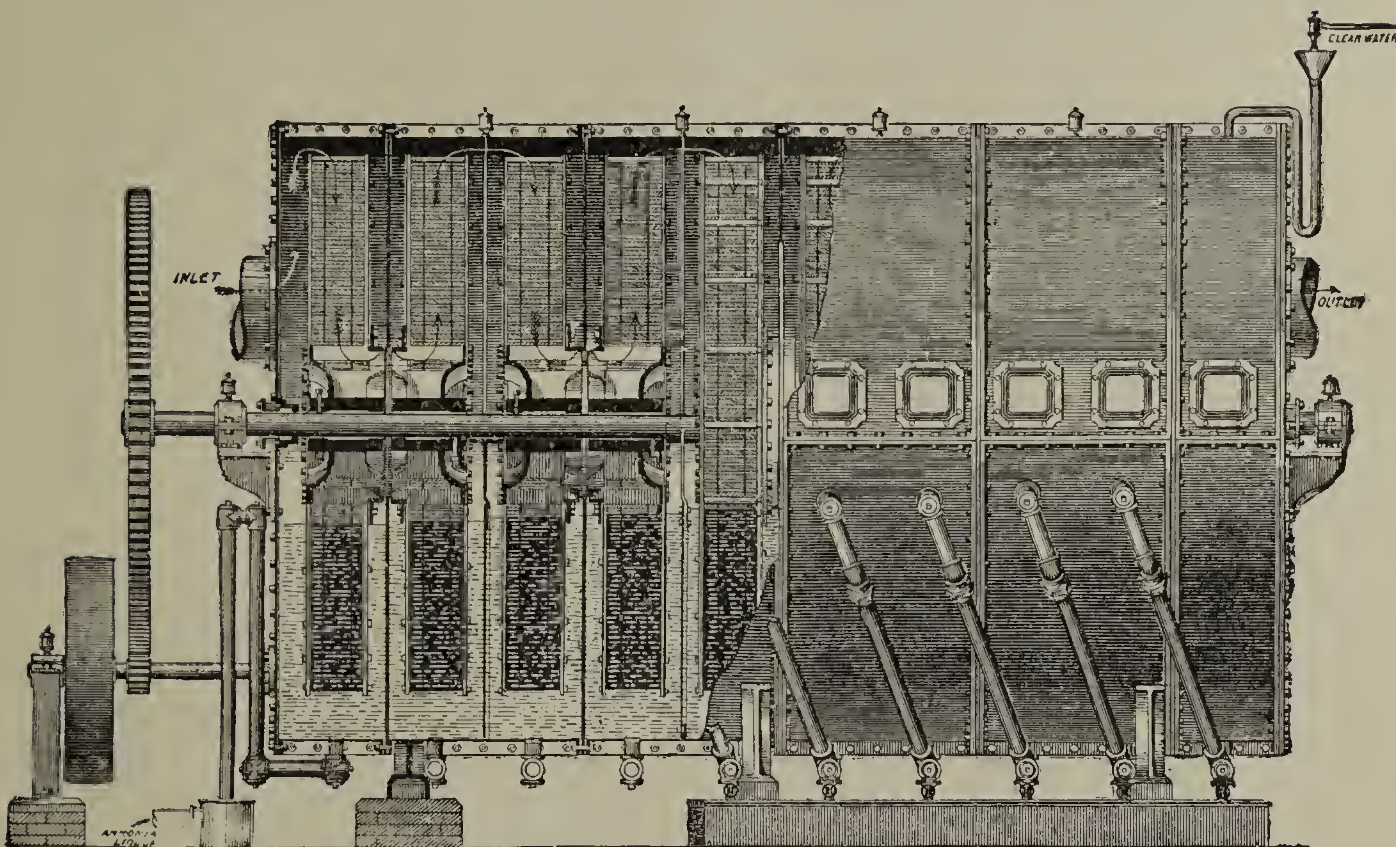
WITH OR WITHOUT STEEL TANKS.

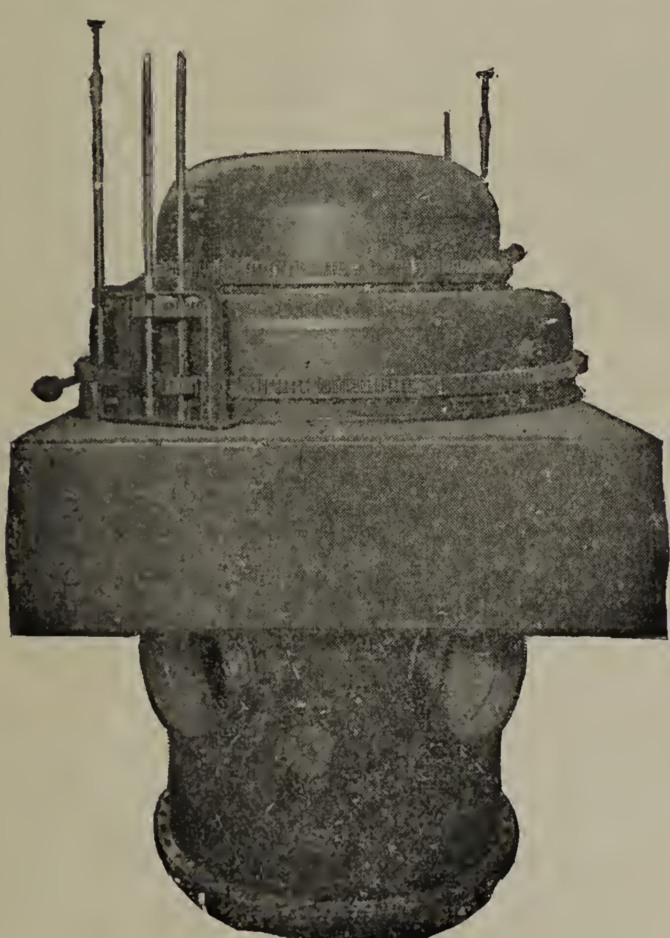
MITCHELL SCRUBBER.

Matton & Mitchell Self-Sealing Mouth-Pieces, Purifiers, Condensers, Scrubbers, Bench Work, Center Seals, Gas Valves, Lamp Posts, etc.

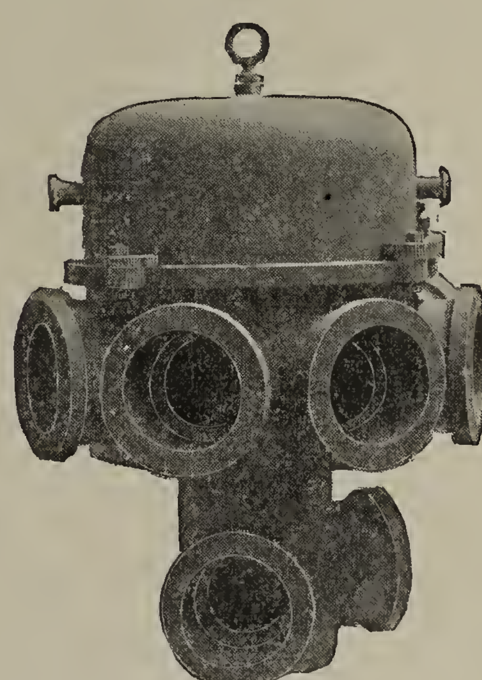
Manufacturers of the

MITCHELL SCRUBBER.



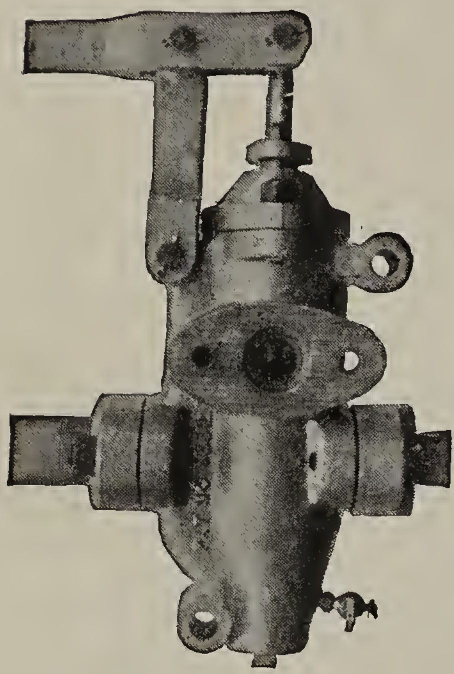


MITCHELL CENTER SEAL.



ORDINARY
CENTER SEAL.

Hydraulic Valves.

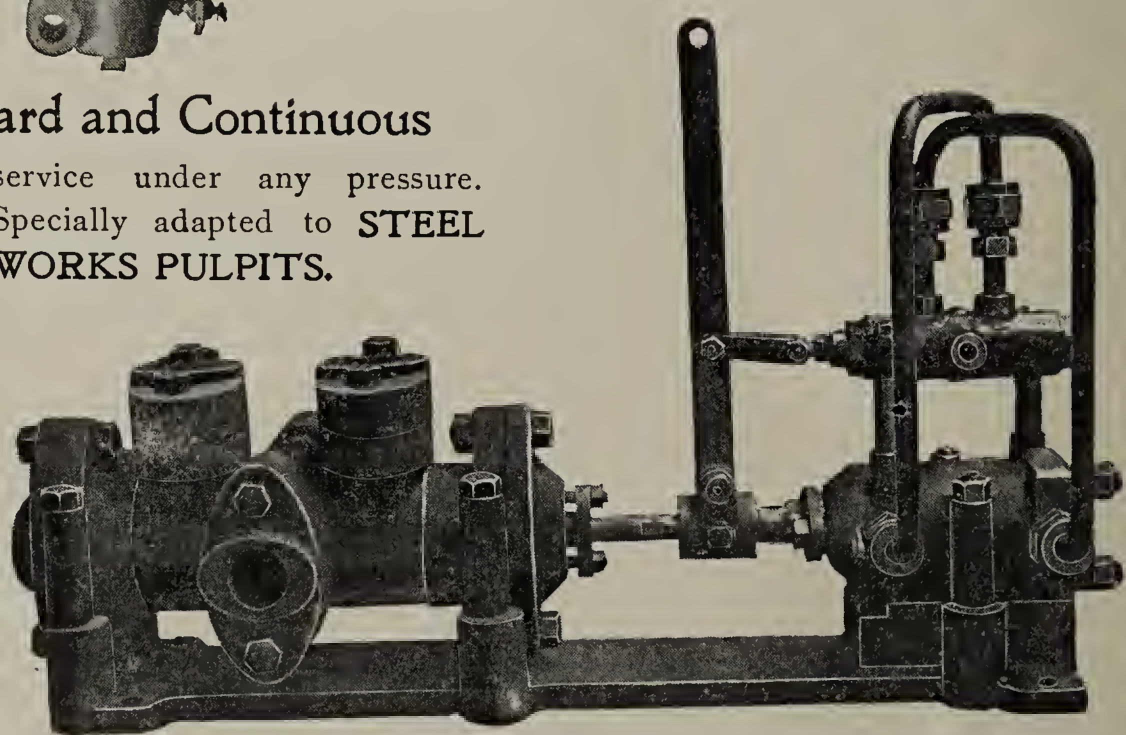


Every Valve has Clear Passage

throughout equal to the area indicated by its size. The ½″ and ¾″ sizes are in Solid Bronze Shells and have screw-pipe connections. The 1″ and larger are in Cast Iron Shells, Bronze-lined, with flange connections. Price includes companion flanges.

For Hard and Continuous

service under any pressure. Specially adapted to STEEL WORKS PULPITS.



LARGE VALVE WITH PILOT VALVE AND FLOATING LEVER.

3-Way or 4-Way

each have only one spindle, giving the 4-Way valve but one-half the cup packings required in other modern valves.

Perfectly Balanced and the Easiest Working

valve yet introduced. The arrangement of leather cups gives the utmost durability; will usually have six times the life of cups in Critchlow or other similar types. A worn cup is easily renewed in five minutes.

Built with the Greatest Care

under rigid inspection, and only the finest grade of material used throughout.

Builders of

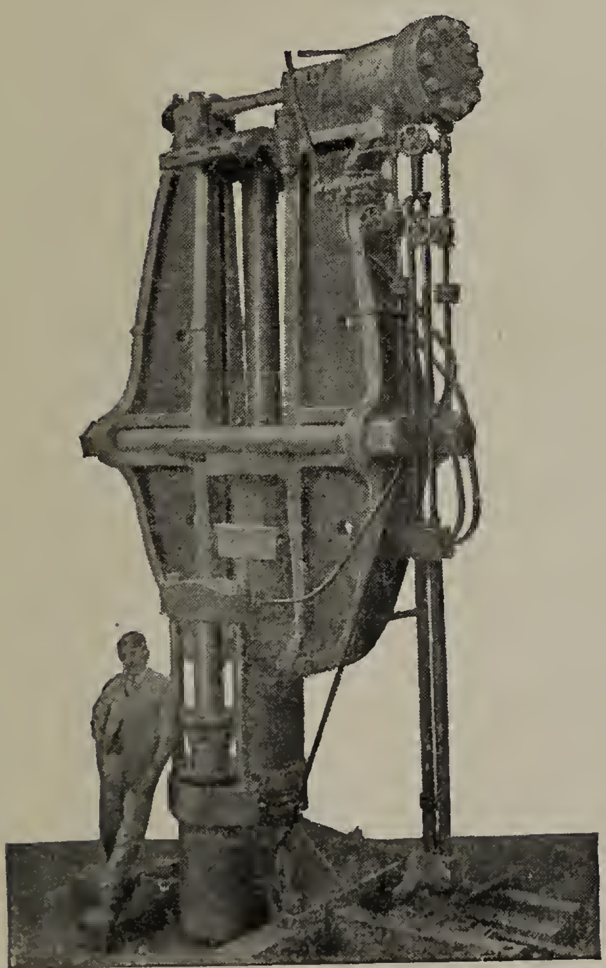
Hydraulic
Fixed and Portable Riveters,
Punches and Shears,

ESPECIALLY DESIGNED

For Service in the shops of Boiler Makers, Bridge and Ship Builders.


Portable Hydraulic Riveter and Hydraulic Lift.

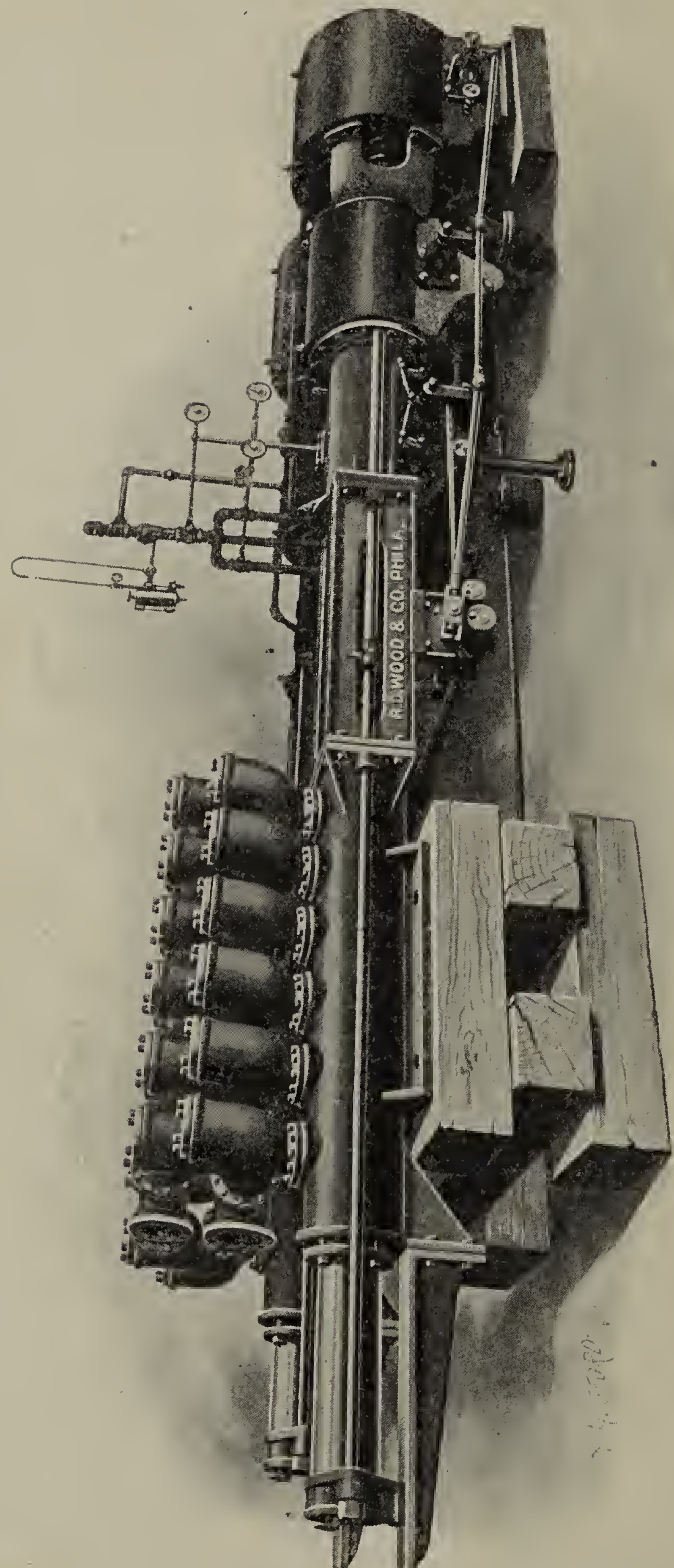
HYDRAULIC I-BEAM AND SLAB SHEARS, and HYDRAULIC PLATE SHEARS.


Patent Hydraulic Lifting Riveter, for Girder Work, etc.

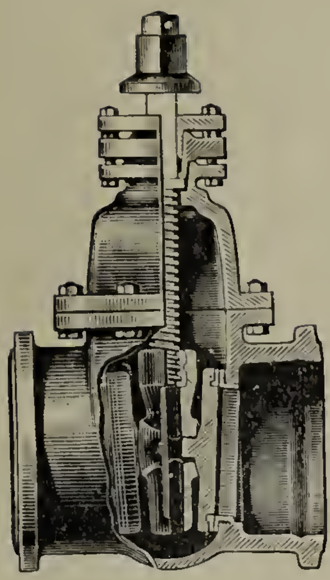
HYDRAULIC FORGING AND BENDING MACHINERY.

HEAVY SPECIAL
HYDRAULIC MACHINERY
PRESSES,
CUPOLA and MILL HOISTS.

HYDRAULIC CRANES,
ACCUMULATORS
and
INTENSIFIERS.



TRIPLE EXPANSION PRESSURE PUMPING ENGINES FOR ANY SERVICE.



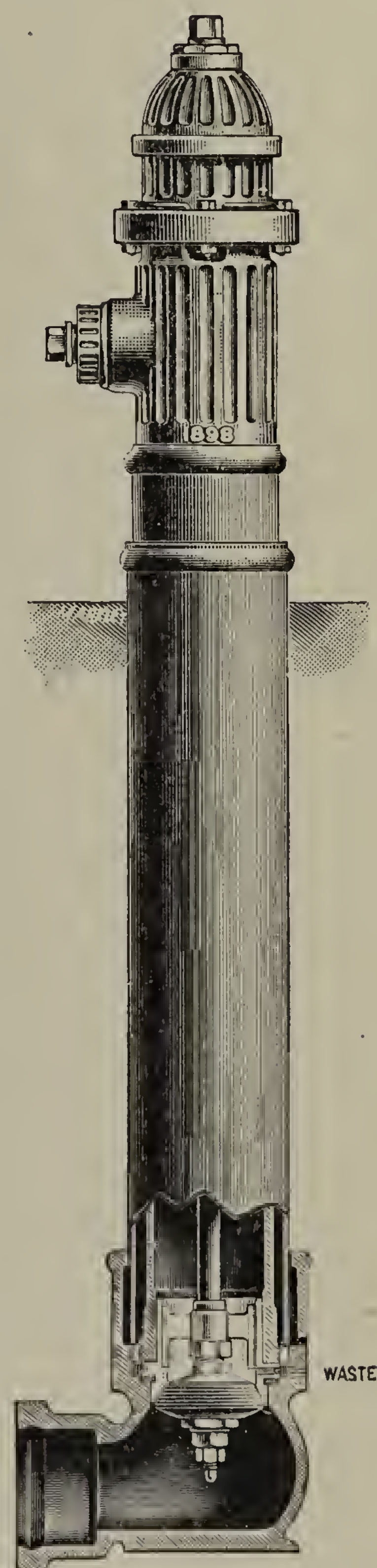
Manufacturers of

"Gate" Valves,

HUB, SCREW
and FLANGE,

for Water, Gas and Steam,
and all purposes.

Send for circular.



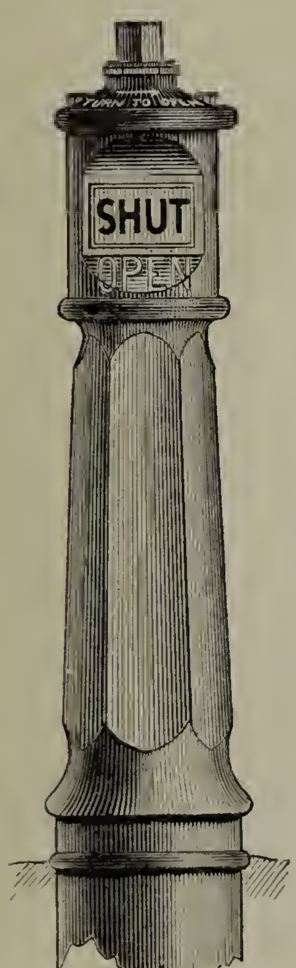
Indicator Valve Post.

(PATENTED.)

Designed especially for use with Water Valves connected with Fire Service, in Mill and Factory Yards, etc.

R. D. WOOD & CO., PHILADELPHIA,
SOLE MAKERS.

This Post shows plainly, to every passer-by, whether valve is open or shut. It avoids the delay of hunting for a flush gate-box hidden under snow or dirt, or the delay of opening a frozen gate-box cover.



Mathews' Patent

Fire Hydrants.

Single or Double Valve,

with or without the

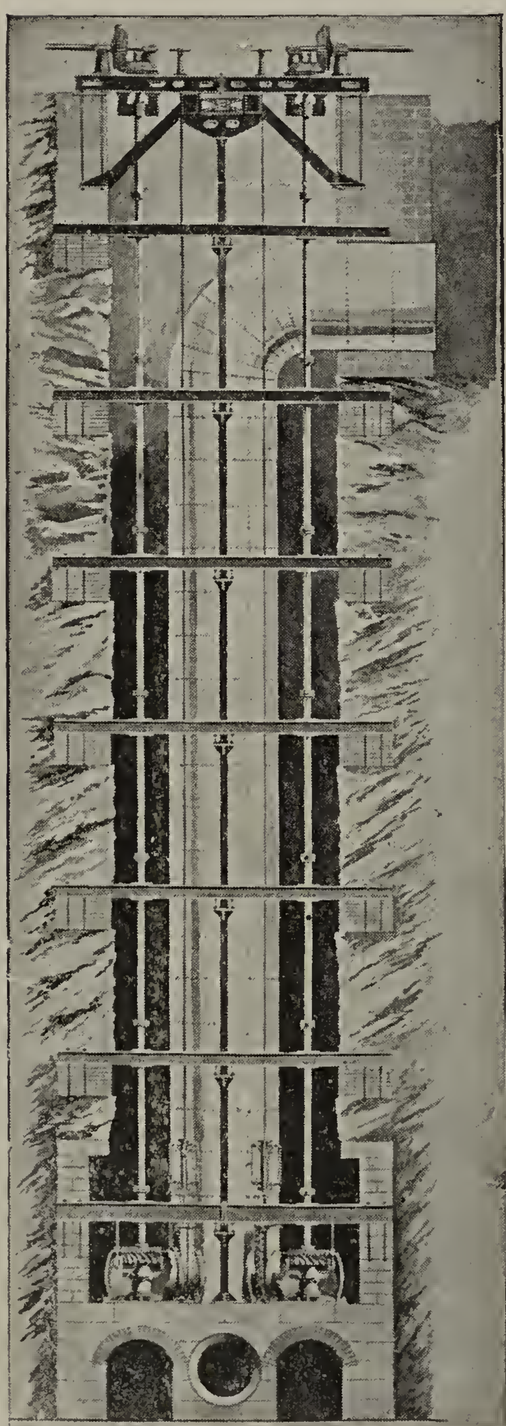
Patent Independent Cut-off.

Send for descriptive circular of Mathews' Hydrants.

Builders of

Geyelin-Jonval Turbines

FOR



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Power Plants,
Electric Light Plants,
Pumping Stations,
etc.

LARGE PLANTS
A SPECIALTY.

Water Power Pumps
and Turbines
for
Pumping Stations.

CORRESPONDENCE SOLICITED.