STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

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STATE GEOLOGICAL SURVEY

FRANK W. DE WOLF, Chief

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# WATER-GAS MANUFACTURE WITH CENTRAL DISTRICT BITUMINOUS COALS AS GENERATOR FUEL


BY

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and

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ILLINOIS MINING INVESTIGATIONS

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FRANK W. DEWOLF, *Chief*

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Fig. 1.—Bituminous coal zone C, established by the U. S. Fuel and the U. S. Railroad Administrations, April 1, 1918, and corrected to October 1, 1918. Includes low-sulphur coal areas in southern Illinois.

At the time this map was made, producing districts in Illinois were restricted in their shipments of coal during the winter to markets within and along the solid boundary line, and during the summer to markets within and along the heavy dashed boundary line and its solid continuation south from Albia, Iowa, and Milwaukee, Wisconsin. Under date September 26, 1918, this order was modified as follows:

The Lower Peninsula of Michigan is to be included for the winter in Zone C. Those parts of Wisconsin and Minnesota lying between the solid and dashed lines in the figure may receive coal the entire year from Illinois.

The period during which shipments may be made into South Dakota is extended to November 1.

# WATER-GAS MANUFACTURE WITH CENTRAL DISTRICT BITUMINOUS COALS AS GENERATOR FUEL

**By W. W. Odell, U. S. Bureau of Mines, and**
**W. A. Dunkley, State Geological Survey Division**

## INTRODUCTION

This circular presents data on present water-gas manufacture, as gathered by the writers during an inspection of twenty water-gas plants in Illinois and surrounding states, in which bituminous coal from the central mining district of Illinois, Indiana, and western Kentucky is being used in place of coke as a generator fuel. The term "central district bituminous coals" as used in this paper refers to those originating in this district.

The generator fuel formerly used in these plants was either retort-house coke made usually from an eastern coal, or else oven coke transported from a distance. Eastern coal produces a better coke in the gas retort than western coal, and therefore a coke that can be used to greater advantage in the water-gas set. This coke and the coke hauled direct from the east will give a greater production of gas from a water-gas set in a given time than will uncoked bituminous coal from either the east or the central district. However, the well-known conditions prevailing at the present time in the coal and railroad industries make it desirable and perhaps necessary to haul as little coal or coke as possible from the eastern points of production to the central west. The use of central district bituminous coals as generator fuel will not

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During the entire year producing districts of Vermilion County, Illinois, along the Wabash Railway may in addition ship coal to points of delivery along the Wabash Railway within Indiana. Similarly, producing districts of Sangamon County may ship to stations along the Cincinnati, Indianapolis, and Western Railroad, as far east as Indianapolis, and including points of delivery within switching limits on connecting lines. Neither of these counties produces low-sulphur coal, however.

A modification affecting the distribution of Jackson and Randolph county coals is as follows: All producers located along the Mobile and Ohio Railroad and short-line connections in Illinois may ship coal to points of delivery on the Mobile and Ohio Railroad within Tennessee and Mississippi, as far south as Meridian, Mississippi, including stations within switching limits on connecting railway lines. Jackson County is a producer of low-sulphur coal from seam No. 2.

Consult the District Representative of the Fuel Administration, 2017 Fisher Building, Chicago, to learn decisions on suggested changes still pending. Of these changes, the one affecting particularly the coal-gas industry relates to the addition of a part of Iowa to the territory of Zone C.

only reduce freight traffic but will release for other necessary uses coke now used as water-gas fuel. Furthermore, such successful practice with these coals may be developed that a new permanent market for them will be established. For these reasons, it is desirable that central district coals be substituted for eastern coal and coke wherever possible.

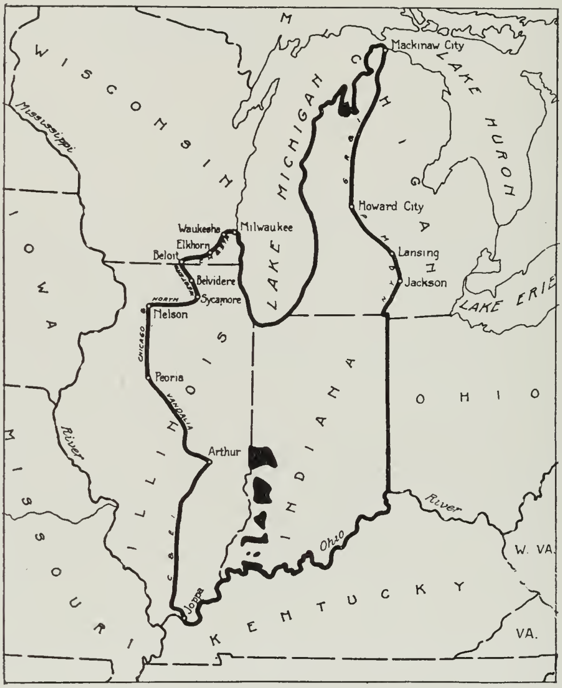


Fig. 2.—Bituminous coal zone D, established by the U. S. Fuel and the U. S. Railroad Administrations, April 1, 1918, and corrected to October 1, 1918. Includes low-sulphur coal in western Indiana.

As the zoning was originally established, all producing districts of Indiana were restricted in their shipments of coal to markets within and along the heavy boundary line. Under date September 26, this order was modified so as to include all of the Lower Peninsula of Michigan in the territory of Zone D.

Last winter the shortage of coke fuel at many water-gas plants led to some independent experimentation with bituminous coal of various sizes from districts in Illinois and Indiana where low-sulphur coal is mined. As a rule the results have been encouraging. The plants have been kept going, and under certain conditions central district coal as generator fuel has proven more economical than coke.

This report outlines the difficulties which were anticipated, and those actually met and overcome in connection with the change of fuel; and presents operating data from several plants at which central district coal is used successfully. Actual operating costs listed reveal no increase due to the use of bituminous coal; in fact an actual saving is indicated where the capacity of the plant is ample.

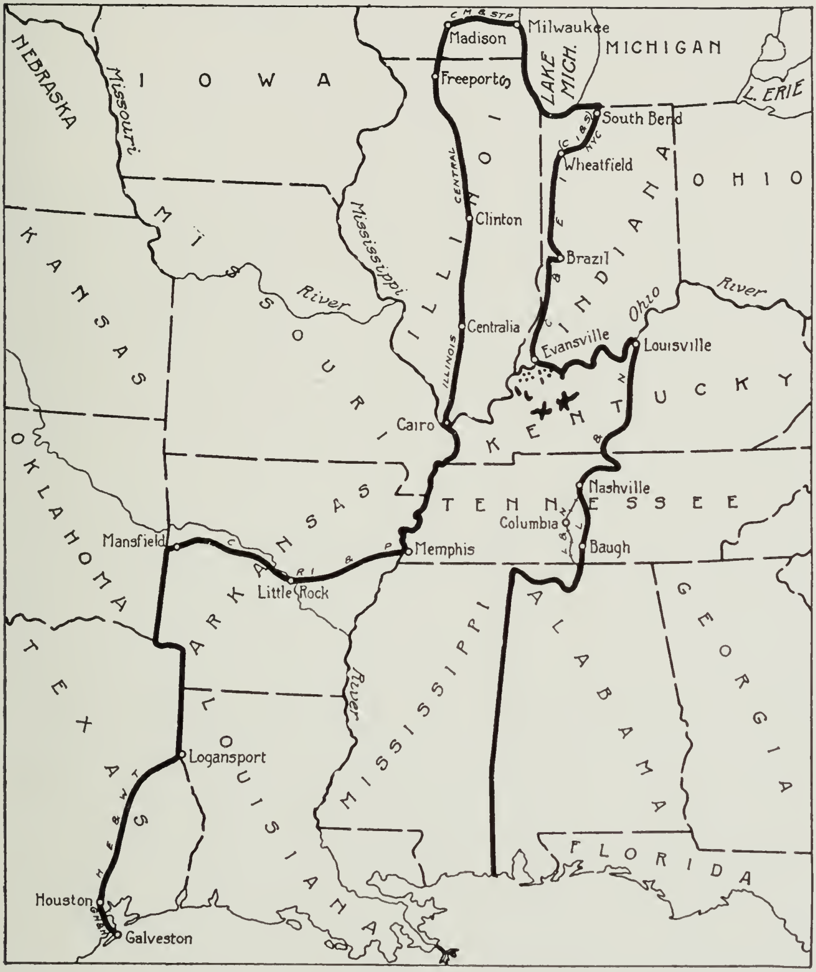


Fig. 3.—Bituminous coal zone E, established by the U. S. Fuel and the U. S. Railroad Administrations, April 1, 1918, and corrected to July 1, 1918. Includes low-sulphur coal in western Kentucky.

Producing districts in western Kentucky, shown in black, are restricted in their shipments of coal to markets within or along the heavy boundary line.

Modifications of the original zoning made prior to July 1, 1918, have been incorporated in the map. Later modifications affecting the gas-coal markets are as follows:

Producers in the western Kentucky districts may in addition distribute their coal (1) along the Louisville, Cincinnati and Lexington Division of the Louisville and Nashville Railway between Louisville and Newport, Kentucky, inclusive, and (2) in Cincinnati, Ohio, and points of delivery located within the Cincinnati switching district.

Producers of this district may not ship coal without permit into those parts of Illinois, Wisconsin, and Indiana, included originally in zone E as shown by the heavy boundary line. A provision is made, however, which should be noted by the coal-gas manufacturer: Any western Kentucky producer may ship coal of special quality for special uses to points of delivery within the prohibited territory under permit which may be obtained from the Fuel Administration on application of the consumer.

The inspection reveals that there are still many operating problems to be solved; and that a further study of these will be of benefit to the gas industry. Consequently, this circular is only preliminary to the publication of the results of further investigations which are being undertaken by the cooperating agencies.

## OBJECTIONS OFFERED TO THE USE OF BITUMINOUS COAL AS GENERATOR FUEL

At some plants operators have been deterred from using bituminous coal as generator fuel because of difficulties expected on the basis of their experience with coke fuel. It is usually anticipated that the coking or matting together of the fresh coal in the generator will obstruct the passage of blast and steam through the fire, thereby leading to the formation of flues through the fuel bed with consequent decreased capacity and efficiency of the generating set. The large amount of volatile matter which is released when fresh coal is charged into the generator is another anticipated cause of difficulty. Not only is the fear of creating a smoke nuisance a deterrent with some operators whose plants are located where complaints would likely arise, but the ill effect of this large amount of volatile matter upon the operation of the plant is feared. It is often anticipated that if an effort is made to burn all of this volatile matter in the machine or at the stack, these parts of the apparatus will be seriously overheated, resulting not only in upsetting the operating balance but also, perhaps, in injury to the machine itself. Some operators also anticipate that the operation of the hot valves will be impeded by the tar present in the gases given off by the generator and that the checker bricks in the carburetor and superheater will be fouled rapidly; also that the purifying equipment of the plant will be overloaded by excessive sulphur in the gas. On account of the relatively low melting point of the ash from most central district coals, as shown when cokes from these coals are used as generator fuel, the formation of excessive and troublesome clinker has also been expected from the use of these coals.

In general, these difficulties have been met and overcome. It is true that the average figures at the twenty plants visited showed a decreased capacity of the set of about 25 per cent when using coal in place of coke, and an increase of about 30 per cent in the amount of fuel needed for making 1,000 cubic feet of gas. However, the cost of coal being less than coke, and the amount of oil necessary being decreased about 10 per cent, the actual cost of gas per 1,000 cubic feet decreased when coal was used.

## METHODS OF OVERCOMING OBJECTIONS

When the central district coals are charged into a water-gas generator in the same volume as coke would be charged, a rather dense firm mat of coke is formed on blasting. The mat arches over the top and does not drop without being poked from the charging door. This property of matting when heavy charges are used, naturally increases the tendency to form flues or chimneys in the fuel, and reduces the capacity and operating efficiency of the machine. To overcome this caking difficulty, coal must be charged into the generator in much smaller quantities by volume than coke, since coal is heavier per unit of volume. Some operators, particularly those handling the larger sets, carry a deeper fuel bed than they would otherwise consider possible, by making "split" steam runs; that is, they reverse the direction of flow of steam through the fire while the run is in progress.

At a few plants some trouble has been experienced from smoke, especially where the plant is located in a residence district. Any smoke in these districts results in immediate complaint. It is very difficult to avoid smoke or oil fumes at all times even with coke fuel. With coal the trouble is increased because it is especially difficult to completely burn the hydrocarbons given off from the incomplete combustion of coal in the machine during the early stages of the heating-up period when the checker bricks in the carburetor are not hot enough to ignite these gases. Where a set is operated to almost its full capacity, these bricks will not usually cool off so much during lay-over periods that any great difficulty will be experienced in quickly igniting the generator gases, but in a plant operating but a few hours a day the problem is greater. One ingenious operator has hastened the ignition by means of an automobile spark plug screwed into a short length of pipe extending above the carburetor. With this device he is able to ignite the gases passing into the carburetor long before the bricks would become hot enough to ignite them. At the same time the heating up of the carburetor and superheater is hastened. In order to reduce the smoke formed after coaling the machine, some operators blast before coaling and make a steam run before blasting again.

The prevention of the overheating of carburetor and superheater during the blasting period lies in the proper timing of this operation. It is generally accepted that on blasting coal containing a high percentage of volatile matter a gas will be produced containing some of the hydrocarbons of the volatile matter of the coal. Such blast gases are higher in heating value than the blast gases from coke, and when burned in the machine they produce more heat in the carburetor and superheater. Therefore, a long blast on such a fuel as central district bituminous coal will result in the production of more heat than is required for cracking and fixing the carburetting oil. This means that the gas in excess of the amount required for the proper heating of the checker brick has to be burned at the stack. Not only is this a wasteful process, but it so heats the stack that there is danger of melting it. Therefore prolonged blasting such as is sometimes practiced with coke, is undesirable when bituminous coal is used as a generator fuel.

More tar is formed with coal as generator fuel than with coke, the average increase noted being 25 per cent. Under some conditions it causes the valves, and particularly the hot valve, to stick or work less freely. While this excess of tar need not cause any serious trouble, most operators take precautionary measures. Sometimes distillate or paraffin oil is poured down the stem of the hot valve after completing the day's run to soften the tar. The tar trouble may also be diminished by tapping a hole in the valve bonnet and pouring a little lubricating oil into the valve through this opening once a day.

Actual practice indicates that the coals from southern Illinois and from Indiana containing less than 1½ per cent of sulphur have not caused any sulphur trouble when used in the manufacture of water-gas. One gas company reports that the unpurified gas from these coals contains only 5 per cent more sulphur than the water-gas manufactured from coke, using the same kind of oil in both cases. Some operators state that the gas manufactured with bituminous coal purifies more easily than that produced when using coke fuel. Serious sulphur trouble has not been noticed in any of the gas plants visited.

From the experience of various operators with central district coals, it seems that the fear of an excessive deposit of carbon in the checker bricks resulting from the use of coal, is largely groundless. At only one of the plants visited was any abnormal deposition of carbon reported. In this case a loose deposit of carbon in the shape of an inverted cone was said to form in the interstices of the superheater checker bricks, the apex of the cone being near the bottom of the checker work and the base of the cone near the top, where it extended to within a foot of the wall. The set was 8 feet 6 inches in diameter and was operated 24 hours a day. A sample of the carbon analyzed carried over 98 per cent combustible matter, showing that it was deposited carbon and not coal dust. In operating this machine some of the blast gas was burned outside the machine at the stack. The operating cycle consisted of a three-minute blast and a four-minute steam run; the blast pressure was 16 inches. The steam used was

40 to 45 pounds per minute, and alternate up and down runs were made.

In those Illinois gas plants where good results with coal are being obtained without the formation of carbon, the method of operation is to employ a greater blast pressure, a shorter time of blast, and a greater amount of steam per minute during the runs than is used when coke is the generator fuel. By using what appears to be an excessive amount of steam, the temperatures of the carburetor and superheater are reduced to such an extent that the gas produced in the subsequent blast can be burned entirely within the machine without overheating it. With this practice no carbon troubles are experienced in the superheater.

The fusing point of the ash of central-west coal is lower than that from eastern coke; therefore, to avoid clinker, which is simply ash fused or melted together, it is necessary to avoid unduly high temperatures. For this reason, if the fuel bed is not blasted too long and the air pressure is not too high, little clinker trouble need result. As will be noted in a later section of this circular, there is a tendency among operators to use relatively more steam with coal than with coke, which practice together with the blasting method employed usually results in a clinker which is more easily broken up than the clinker from coke.

## WATER-GAS MANUFACTURE AT PLANTS USING BITUMINOUS COAL FUEL

As a result of the inspection of water-gas plants using bituminous coal, it is possible to discuss the principal points in operating practice which seem essential to success. The advantages and disadvantages of any particular method of operation or the detailed chemical reactions of the water-gas process will not be discussed in this circular.

The following variables seem to be most important:

1. Kind and size of fuel.
2. Depth of fuel bed and its relation to blast and steam cycle.
3. Quality and quantity of oil used.
4. Distribution of oil in the carburetor.
5. Temperature maintained in the carburetor and in the superheater.
6. Purging the machine with air.

Each of these variables has so important a bearing upon the operating results, and all are so inter-related that a change in one condition almost invariably necessitates a change in others if the heat balance in the machine, necessary to good operation, is to be maintained. It is not possible to predict exactly what combination of conditions will be necessary in each case. In the following, the tendencies of present practice, rather than absolute results obtained when changing from coke to coal, will be discussed.

### Kind and Size of Fuel

The coal now used is either low-sulphur coal from seam No. 6 in southern Illinois or from seam No. 4 in western Indiana. Other bituminous coals from the central ditsrict, if low in sulphur, could probably be used successfully. The smaller plants use lump coal about 5 inches in diameter. Lumps larger than these are broken up with a sledge while the charging buggy is being filled, and fine coal is removed by forking. In the larger plants it is the practice to use egg-size coal or lumps between 2 and 6 inches in diameter, which is charged into the generator without preliminary breaking.

### Depth of Fuel Bed and Its Relation to Blast and Steam Cycle

The depth of the fuel bed maintained in the generator and the blast and steam pressure carried during operation are so closely interrelated that they may well be discussed together. The effect of a thin fuel bed in reducing the tendency of the fuel to mat together has already been discussed. Most operators find that the fuel can best be maintained at the desired depth by coaling the generator more frequently and with a smaller weight of charge than when using coke. Several operators state that the weight of the coal charge should be about 80 per cent of the weight of the coke charge, and that one or two fewer runs should elapse between charging times.

A decreased depth of fuel bed permits the passage of more air or steam through the fire in a given time at a given pressure. Since the amount of air required to bring the fuel bed to the proper condition varies roughly with the amount of fuel, a shallow fire requires less blast than a deep fire. With bituminous coal most operators not only blast at about 2 to 3 inches water pressure less than when using coke, but also decrease the length of the blasting period.

With a shallower bed of incandescent fuel for the steam to act upon, it might be expected that the duration of the steam run and the amount of steam used per minute should be decreased in order to maintain the heat balance in the set. However, in the majority of plants visited the steam was not decreased in the same proportion as was the air blast, and the length of run was usually the same as with coke. A very common cycle was a 2-minute blast followed by a 4-minute steam run. A 3-minute blast followed by a 5-minute run was also frequently observed.

In the matter of proportioning the "up" and "down" runs there was a great difference of opinion. Some operators alternated the up and down runs after the set had been brought to normal running conditions. Others made more down runs than up runs, while still others favored more up runs. A few preferred to "split" every run as heretofore discussed. It was quite common practice in the plants inspected to use about 10 pounds more of steam per minute on the down runs than on the up runs.

The operating conditions observed suggest that much benefit can be derived from the study of the composition of the generator gases produced under various conditions of operation and the determination of the amount of steam passing through the fire undecomposed.

The conditions actually maintained in some plants were impossible to ascertain. The poor condition or lack of steam and air gauges and meters in several cases made experimental work with a view to bettering operating conditions almost impossible. In a few cases, carelessness or ignorance of those actually handling the machine was the principal handicap to good results.

## Quality and Quantity of Oil Used

The quality of oil used in a given plant will of course affect the operation and have a part in determining the proper cycle. The concensus of opinion seems to be that oils from different fields require different heat treatment, and so it is impossible to prescribe operating conditions without taking the kind of oil into account. However, assuming that a change is made from coke to coal fuel, there are certain differences to be observed in operation.

The so-called "blue gas" produced from bituminous coal fuel is higher in heating value than the "blue gas" from coke since it contains a considerable percentage of hydrocarbons. Consequently less oil is required per 1,000 cubic feet of gas to enrich to the required standard. The reduction in the amount of oil required may be as much as 0.5 gallon per thousand cubic feet of gas made. Since the amount of gas made per run is usually less with coal than with coke, the amount of oil required per run is of course less. To fix the oil the same temperatures are usually maintained in the carburetor and superheater as when using coke fuel. These temperatures range from 1250° F. to 1350°F.

### Distribution of Oil in the Carburetor

In changing to coal fuel, the oil spray in the carburetor is often left as it was when coke was used. The result is that with a decreasing oil requirement per run, it is necessary to reduce the rate of oil flow through the nozzle and frequently this reduction results in poor distribution. Instead of spraying uniformly over the surface of the bricks in the top of the carburetor, much of the oil may pass down through the center of the carburetor, resulting in incomplete vaporization and low oil efficiency. As a consequence a large portion of the oil is wasted. Furthermore the concentration of oil in the center of the carburetor may cause the formation of an excessive deposit of carbon which fouls the checker bricks and soon necessitates recheckering. This matter should have the immediate attention of any operator making the change.

### Purging the Machine with Air

In some plants it is the practice to purge the machine with air after completing the steam run and before raising the stack valve. There is evidently a gain by doing this, although oftentimes it is carried so far that the dilution of the gas by the lean-air gas thus manufactured makes necessary the use of an excessive amount of oil to bring the gas to the required B. t. u. standard. By watching the quality of the gas the operator can estimate how far he can carry this purging process. One advantage in purging not usually considered is that during this purging carbon is being burned in the generator, thus causing a rise of temperature in the fuel bed; and at the same time the carburetor and superheater are being heated less than during the regular blast period when blast gas is being burned in these chambers. Since the usual tendency in operation is to allow the superheater to become too hot, this process of purging may give the operator greater control over the temperature. As a precautionary measure, before opening the air blast to purge, the operator should make sure that the blower is up to speed, so that there will be sufficient pressure in the air lines to prevent back firing in the blast line.

## OPERATING DATA FROM TYPICAL PLANTS WHERE COAL IS USED AS GENERATOR FUEL

At several plants where both water-gas and coal-gas are manufactured they are not metered separately. In these cases it is usual to estimate the yield of coal-gas from the amount of coal carbonized and to estimate the amount of water-gas as the difference between the combined yield and the estimated coal-gas yield. Operating data from these plants can not be used for accurate comparison.

It was possible, however, to obtain data from several plants where water-gas only was manufactured and at others where the water-gas was metered separately. It should be remembered that results obtained at any particular plant depend not only on the operating methods, but on the quality and kind of fuel and oil and on the general equipment and its physical condition.

As bituminous coals from only a few mines in the central district have been used in water-gas manufacture, no comparison of different coals is possible at this time. Also since the use of bituminous coal is new, the operating conditions have not been fully standardized, and each operator is using individual operating methods.

Although the data furnished by the operators was given as average practice, yet the desire to report the best results should be taken into consideration. At some plants the facilities for weighing the fuel were poor and therefore the figures given for fuel consumption may be approximate only. The operating data selected from four typical plants are given in the table following:

TABLE 1.—*Practice at four water-gas plants*

| Details of practice | EQUIPMENT | | | | |
|---|---|---|---|---|---|
| | 2-6 ft. U. G. I. sets Generator 4 feet internal diameter | | 1-8 ft. Western Gas Construction Co. set Generator 6 ft. internal diameter[a] | 2-8 ft. 6 in. U. G. I. Generator 6 ft. 6 in. internal diameter[a] | 1-8 ft. 6 in. Gas Machinery Co. set Generator 6 ft. 6 in. internal diameter[a] |
| | PLANT A | | PLANT B | PLANT C | PLANT D |
| Kind of fuel | Indianapolis egg size oven coke | Franklin Co., Ill., lump coal | No. 4 seam Indiana lump coal | Franklin Co., Ill., egg coal | Jackson Co., Ill., lump coal |
| Generator fuel per charge *lbs.* | 500 | 750 | 1000-1100 | 1100 | 1600-1800 |
| Frequency of charging generator | 30 min. | 35 min. | Every 5 runs | Every 5-6 runs | Every 8-9 runs |
| Air per minute *cu. ft.* | 1800 | 1027 | 3200(?) | No meter | No record |
| Steam per minute (up run) *lbs.* | 22 | 28 | 55 | 40 | 60 |
| Steam per minute (down run) *lbs.* | 27 | 33 | .... | .... | 45 |
| Running time *hrs. per day* | 14.6 | 18.3 | 14.4 | 22.0 | 18-20 |
| Cycle { Blow *min.* | 3 | 3 | 2 | 3 | 2 |
| Cycle { Steam run *min.* | 5 | 5 | 3 | 4 | 3 |
| Split runs *min.* | 2 up 2 down 1 up | 2 up 2 down 1 up | ½ min. up 2½ min. down | No split runs | No split runs |
| Kind of gas-oil used | 32°-36° Baumé | 32°-36° Baumé | .... | 28°-30° Baumé | 28°-30° Baumé |
| Gas made per run *cu. ft.* | 3633 | 2900 | 3800 | 4550 | 4400 |
| Gas made per hour *cu. ft.* | 27245 | 21750 | 41800 | 38700 | 52800 |
| Generator fuel per M cu. ft. of gas *lbs.* | 32.75 | 44.5 | 42.5 | 40 | 42 |
| Oil per M cu. ft. gas *gals.* | 3.54 | 3.13 | 2.68 | 3.2 | 3.0 |
| Heating value of gas *B. t. u.* | 600 | 600 | 575 | 565 | 588 |
| Temperature at bottom of superheater *Degrees F.* | 1300-1400 | 1300-1400 | 1240-1280 | 1300 | 1300-1400 |
| Cleaning time | 2 hrs. per day | 2 hrs. per day | 1 hr. for 2 cleans | 2 hrs. per day | 2-2½ hrs. per day |
| Gas per minute per sq. ft. of grate area *cu. ft.* | 58 | 46 | 45 | 40 | 44.4 |
| Steam per M cu. ft. gas *lbs.* | 33.7 | 52.6 | 43 | 30.2 | 36 |
| Air per M cu. ft. gas *cu. ft.* | 1480 | 1060 | 1680? | No meter | .... |
| Blast pressure *ins. of water* | 18-20 | ? | 16 | 16-18 | 20-22 |

[a]Data on practice with coke fuel not available for publication.

## Discussion of Table

At plant A it was possible to secure figures covering operating data when coke as well as coal had been used as a fuel. Thus that part of the table under A gives a direct comparison at the same plant between coke and southern Illinois lump coal. At this plant more steam is required per thousand cubic feet of gas manufactured with coal as fuel than with coke. Less air is used with coal than with coke fuel. The capacity per hour of the machine is approximately 20 per cent less with coal. Moreover, with coal the generator fuel per 1,000 cubic feet of gas is increased 11.8 pounds, or about 27 per cent, but the oil used is decreased 0.41 gallon per 1,000 cubic feet of gas manufactured, or 11.5 per cent.

At plant B, decidedly less steam and somewhat more air are used per 1,000 cubic feet of gas made than at plant A, operating with coal fuel. Although the generator fuel and oil used per unit of gas is somewhat less in plant B than in plant A, yet the larger size of the generating set at plant B and lower quality of gas made would account for these results. In general the results for plants A and B are in agreement.

At plant C, when starting a fresh fire in the generator each morning, the first charge is coke, although all succeeding charges are coal. With this difference taken into consideration, the amount of fuel used at plant C checks closely with that used at plants A and B.

At plant C it was found necessary to burn an appreciable amount of the combustible blast gas at the stack while the generator was being heated to the required temperature, in order to prevent the carburetor and superheater from becoming too hot.

In general, as compared with plants A and B, less blast pressure and shorter steam runs were used at plant C, but the steam consumption per unit of gas made was about the same, while the oil used per unit of gas made was considerably greater.

This was the only plant visited where the blast gases were partly burned at the stack instead of being entirely consumed in the machine. Another exceptional feature was that carbon was deposited in the superheater to such a degree that the checker brickwork had to be laid in flues instead of in the usual staggered fashion. It is possible that the grade or composition of the oil influenced the formation of the carbon deposit.

At plant D, on starting the generator in the morning, an extra number of down runs are made, and hard carbon-free clinker forms on the grate. It is considered there that better results are obtained when running the generator with this bed of clinkers. It requires three men two hours each day to clinker the machine. The results obtained at plant D agree very closely with those obtained at the other plants.

In spite of the considerable variation in operating methods in the four plants, a study of the results reported shows that there is fairly close agreement. Different local conditions demand different treatment and it is not possible to say that any particular set of operating conditions is best for all cases. This is apparent when it is considered that differences in oils, coals, and gas-quality standards, together with differences in operating equipment, make it necessary for each operator to select methods fitting his own particular requirements.

## THE ECONOMICAL ADVANTAGE OF CENTRAL DISTRICT COAL AS WATER-GAS GENERATOR FUEL

Many water-gas plants in Illinois and neighboring states are now operating successfully with central district bituminous coals as generator fuel in place of coke. The use of coal was first resorted to because of the shortage of coke. Probably little or no profit from its use was anticipated. Many plants, however, are now realizing a substantial saving in the cost of gas manufacture with coal fuel, and other plants operating under favorable conditions would doubtless find its use profitable.

To determine what if any saving can be realized in a given case, local conditions must be considered, and certain assumptions based upon the results which have been obtained by others must be made. It is the purpose of this paper to apply the average operating results reported by several plants to a case in which certain fuel, labor, and operating costs are assumed and to point out how the various conditions affect the cost of manufacture. The costs assumed do not represent the conditions existing in any particular plant, but are taken merely for illustration. It is believed that any operator can use his own figures and arrive at a conclusion as to whether the use of coal would pay in his own case.

In changing from coke to coal, several factors are to be considered in determining the effect of the change on the final cost of manufacture. These factors include for each fuel the following items:

1. Cost of the amounts of materials required to produce a given volume (say 1,000 cubic feet) of gas of the required quality.
2. Cost of operating labor per 1,000 cubic feet of gas.
3. Cost of repairs per 1,000 cubic feet of gas.

4. Overhead and miscellaneous expense.
5. Income realized from the sale of residuals.

It is very difficult except after long operating experience with each fuel, to assign definite values to all of these items, and in some cases the difference would be so slight as to have little weight in the comparison. In assuming values for the different items, the unit costs selected do not apply to the operating conditions in any particular plant. The amounts of materials used per 1,000 cubic feet of gas, however, are fairly representative of the present practice in several plants.

## Cost of Materials

In the following comparison, it is assumed that central district bituminous coal can be delivered at the gas plant for $4.00 per ton and that coke costs $9.00 per ton. In a mixed gas plant the unit price adopted for coke as generator fuel may be somewhat lower than the price at which the coke could be bought. In this comparison, however, it is assumed that the water-gas plant operates as an independent unit. From results obtained by several plants, 35 pounds of coke or 45 pounds of coal seem to be typical figures for generator fuel per 1,000 cubic feet of gas. The generator fuel cost on this basis would be $0.15 per M for coke and $0.09 per M for coal.

Most operators are able to effect a substantial saving in gas oil when using coal. For making a 575 B. t. u. gas, typical amounts are 3.25 gallons of oil with coke fuel and 2.90 gallons with coal fuel per 1,000 cubic feet of gas. At 7 cents per gallon for oil in each case, this gives $0.227 with coke and $0.203 with coal.

The cost of steam in each case is more difficult to estimate. Both fuel and labor enter into this item, and the percentage capacity at which the steam equipment is operating in each case will largely determine the total cost. It is assumed here that the cost per 1,000 cubic feet of gas is proportional to the time of operating. Most operators can produce in a given time about 70 per cent as much gas with coal as with coke. If therefore $0.05 is assumed as the cost of steam with coke fuel, the cost when using coal will be $0.071.

Several miscellaneous materials beside those mentioned, such as waste, lubricating oils, electric current or gas for lighting, cooling water, paints, purifying material, etc., enter into the manufacturing cost. Of these none except the purifying material cost would probably be enough changed to affect the comparison. The amount of sulphur to be removed from the gas in either case depends largely upon the amount which was present in the fuel, if the same oil is used in both cases.

The cost of purification with coke fuel would probably not exceed $0.008 per 1,000 cubic feet of gas. An assumed increase of 10 per cent, which is larger than some operators report, would give about $0.009 for coal fuel. In this case on account of the smallness of the item, both labor and material are included.

## Cost of Operating Labor

The increase in operating labor due to a decrease in capacity of about 30 per cent will depend greatly upon the percentage capacity at which the water-gas machinery was operating with coke fuel. If, for example, a plant is normally operating 8 hours per day with coke and the operating force is on a 12-hour basis, a change to coal will perhaps permit the force to be more fully employed with little or no increase in cost. On the other hand, if the plant is already working a full shift, a change to coal would necessitate putting on another shift, working overtime, or starting an additional generating set. For the purpose of this paper it is assumed that the operating labor cost is proportional to the time of operating. If the generator-house labor, including the cost of bringing fuel from stock pile to generator is taken as $0.012 with coke, then with coal $0.017 per 1,000 feet of gas would seem reasonable, since about 28.6 per cent more coal would be handled, and the apparatus would be operated about 40 per cent longer to make the required amount of gas. The miscellaneous operating labor and works superintendence would also increase somewhat perhaps, but it is not believed that these two items, especially the latter, would actually increase in proportion to the increase of operating time. They will not be considered in this estimate.

## Cost of Repairs

The experiences of operators with coal fuel do not indicate that the wear and tear on the apparatus is any more severe with coal than with coke. While the apparatus is working more hours per day, the usual opinion expressed is that there is less trouble from the formation of hard clinkers and that the wear on the generator lining caused by breaking off the clinkers is less. It will be assumed in this estimate that the cost of repairs per 1,000 cubic feet of gas made is the same for both fuels.

## Overhead and Miscellaneous Expense

No reason is apparent why these expenses should be materially affected by the kind of generator fuel used, and they will not therefore be considered.

## Income from Sale of Residuals

The only residuals obtained from water-gas manufacture are tar, and, in the case of some of the larger plants, a certain amount of light oils. The effect of coal as generator fuel upon light-oil production has not been studied. As to tar production there is some difference of opinion. It is difficult to measure the production of water-gas tar except where it has accumulated over a considerable period of time. Some operators estimate that the production of tar increases 50 per cent when coal is used as generator fuel. To be conservative, half this increase is assumed here. The yields taken are 0.5 gallon of tar with coke fuel and 0.62 gallon with coal. A price of 1.5 cents per gallon is assumed which would give a gross income of $0.007 with coke and $0.009 with coal.

## Summary

Using the values assumed in the foregoing, the following comparisons may be tabulated:

Table 2.—*A comparison of the approximate manufacturing costs of water-gas with coke and with coal as the generator fuel*

| | Coke fuel *Cost per M cu. ft. of gas made* | Coal fuel *Cost per M cu. ft. of gas made* |
|---|---|---|
| Generator fuel | $0.150 | $0.090 |
| Oil | .227 | .203 |
| Steam (fuel and labor, etc.) | .050 | .071 |
| Gas-making labor (including fuel handling) | .012 | .017 |
| Purification expense | .008 | .009 |
| Total | $0.447 | $0.390 |
| Credit from sale of tar | .007 | .009 |
| Net | $0.440 | $0.381 |

Saving by the use of coal as generator fuel, $0.059 per M cu. ft. of gas made.

This table does not take into account all of the elements of cost but only those which would seem to be affected by the kind of generator fuel used, it being assumed that the same amount of gas is produced pay day in each case. Therefore these figures *are not presented to show the actual cost of gas to the holder* but merely to indicate the approximate saving in manufacturing cost which might be effected under the conditions assumed. The actual saving will vary. Some plants report considerably higher savings while others are not doing so well.

## CONCLUSIONS

Inspection of these plants leads to the following conclusions regarding the use of central district coal as compared with coke for generator fuel:

1. Central district coals are successfully used in the manufacture of water gas.

2. Under present operating conditions a decrease in producing capacity of from 20 to 35 per cent may be anticipated from the use of coal as compared with good coke.

3. Clinker troubles are not usually as serious as with coke fuel.

4. There are no serious sulphur troubles if selected low-sulphur coals are used.

5. Gas made with central district coal as generator fuel costs less per 1,000 cubic feet under present conditions than does gas with coke generator fuel. Though more fuel is used per 1,000 cubic feet of gas, this is offset by the lower price of the fuel, the decrease in the amount of oil required, and the increase in amount of tar for sale.

## SUGGESTED PROBLEMS FOR FURTHER STUDY

As a result of this preliminary work, a number of problems in the manufacture of water-gas have been suggested for experimental study as follows:

Determining the best operating cycle under the varying conditions.

Increasing the capacity of the water-gas machine.

Reducing the required amount of generator fuel and of oil.

Eliminating the smoke trouble.

Reducing the quantity of carbon in the ash and clinker.

Results obtainable with various kinds and sizes of central district coal.

The gas section of the Cooperative Mining Investigations is engaged in experimental work on certain of these problems and hopes to distribute further reports and recommendations.