THE USE OF CENTRAL DISTRICT COALS IN WATER-GAS MANUFACTURE

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An extensive investigation of coal and coal mining has been in progress since 1911 under a cooperative agreement between the U. S. Bureau of Mines, the Illinois State Geological Survey, and the Engineering Experiment Station of the University of Illinois. The particular phase of this investigation which will be discussed in this paper is the use of coals of the central district, including Illinois, Indiana, and Western Kentucky, in the manufacture of carburetted water-gas. In discussing this topic it is not the intention to go as extensively into the details of operation as would be done in a paper addressed primarily to the gas operator, but rather to treat the subject in a more general manner and point out its bearing upon the development of the coal resources of this region and upon the gas industry.

The production of manufactured gas in the State of Illinois alone amounts to approximately thirty billion cubic feet per year. Of this amount about one-third is coal gas made by the distillation of coal in retorts or coke ovens, and about two-thirds is carburetted water-gas. To make this amount of gas the amount of fuel required is roughly about one million tons of gas coal, 350,000 tons of coke or its equivalent, and 65 million gallons of gas oil, in addition to the fuel required to operate the steam power plant which is a necessary adjunct to every gas plant. It will be seen, therefore, that the gas industry is a fairly large user of fuel, and it may also be stated that it is a particular user. To be suitable for gas manufacture, whether coal-gas or water-gas, the fuel must comply with certain standards which are fairly well defined, and which narrow the selection very greatly. While in the present case we are chiefly concerned in the water-gas process, it may be said that coke produced as a by-product in retort and oven coal-gas manufacture has been heretofore the chief generator fuel used in water-gas manufacture, and therefore the requirements of the water-gas process have had an important bearing on the selection of coal for coal-gas manufacture.

To be suitable for use in water-gas making, a fuel, whether coke or coal, must have fairly good physical strength, so that it will stand transportation and will not break up too much in the generator. It must be low in sulphur, since usually at least one-fourth of the sulphur is transmitted to the gas made. When burned in the water-gas generator, it must not produce a clinker which is too difficult to handle or which obstructs the passage of air too much within a reasonable operating time, nor should the amount of clinker be excessive; therefore the ash content of the fuel should be as low as possible.

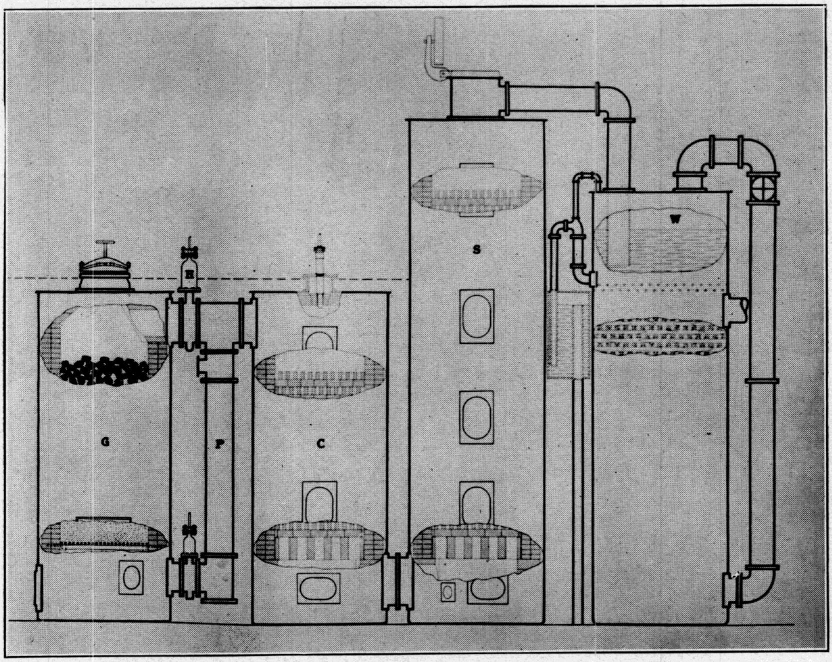
These specifications as to fuel quality, both for coal-gas and water-gas manufacture, have heretofore narrowed the production of coal for these purposes to certain rather limited areas. Among these the most notable ones in the eastern part of the United States are the Pittsburgh district and certain areas in West Virginia and eastern Kentucky. The enormous growth of the steel industry which uses roughly one ton of coke for every ton of pig iron produced, and the steady growth of the gas industry, even in the face of electrical competition have drawn heavily upon the resources of the best coking coals, and already the necessity is felt for using coals from other regions which even if somewhat inferior to those from the localities just named are at least usable without too radical changes in the gas-making methods and equipment now in use.

The State of Illinois has enormous bituminous coal resources, estimated at about 200 billion tons. This is one-third more than West Virginia, nearly twice as much as Pennsylvania, and more than twice as much as Ohio. Of this enormous amount of coal, very little if any fulfills completely the rigid requirements of the gas and cooking industry.

In general, it may be said that most of the central district coals, under present operating methods, produce a softer, more fragile coke, and about 20 per cent less gas per ton than the best eastern gas coals and while the by-product yield is good, most of the central district coals contain considerably more than 1 per cent of sulphur, which was formerly regarded as the upper limit for gas coals. As water-gas generator fuel, the coke from central district coals does not usually produce as large a volume of gas in a given time as some eastern cokes and the ash frequently fuses to a clinker which is very obstinate to handle. With present methods, therefore, only a few restricted areas produce coal which is considered usable. Nevertheless, even these restricted areas are capable of producing much more than sufficient tonnage of coal to meet the gas-making needs of this region.

The production of central district coal for gas making was greatly stimulated by the war. Transportation difficulties and the zoning system of the Fuel Administration made fuel supply conditions very critical for the gas industry of this region. Many gas companies found it not only impossible to obtain eastern coal for coal-gas manufacture, but were even unable to obtain any kind of coke at all for water-gas making. Their only resort was to turn to raw bituminous coal, a fuel which though it had been tried by some enterprising water-gas makers at various times, had never been used with any marked success, on account of many difficulties attending its use. With necessity as a spur, however, many gas operators accomplished wonders. They not only kept their plants in operation but were able to realize economies which made the use of bituminous fuel financially attractive under prevailing price conditions, even when other fuels became obtainable again. It is the purpose of this paper to discuss some of the problems encountered and their solutions.

For the benefit of those who may not be familiar with the water-gas process, a brief description may not be out of place. The accompanying diagram illustrates the usual arrangement of parts of the apparatus, though there are some machines which are different in design though similar in principle. The machine consists of three principal chambers, the generator, carburetor, and superheater, marked G. C. and S., respectively. In general these chambers consist of cylindrical shells of heavy steel plate lined with refractory blocks. The generator is the heart of the gas machine. In it is a deep bed of fuel resting on a grate and filling the generator nearly to the take-off connection.


H
G
P
C
S
W

Below the grate is a connection by which air is admitted from a high-speed blower during the blasting portion of the operation. The air soon brings the fuel bed to a high state of incandescence. During this blowing period the air gas formed, which contains a considerable percentage of carbon monoxide, is burned by a secondary air blast in the carburetor and superheater, and some of the heat is stored in the piles of staggered brick checkerwork with which these chambers are filled. The combustion products pass through the open stack valve into the air. When the fuel bed and the checkerwork have attained the proper temperature, the blowing is discontinued, the stack valve is closed, and steam is then blown through the incandescent fuel bed.

The steam reacts with the carbon of the fuel, forming carbon dioxide, carbon monoxide, and hydrogen. The carbon dioxide content of the gases leaving the generator is at first low, but increases as the fuel bed cools. Since this constituent is of course undesirable, the steaming process is interrupted so soon as it becomes unduly prominent, and the fire is again blasted with air. The gas produced during the steaming, or run period as it is called, usually has a heating value of about 300 B. t. u. per cubic foot. Since most states require a heating value in the finished gas of at least 565 B. t. u., as in Illinois, it is necessary to enrich this "blue" gas, as it is designated, by gas men. This is accomplished by spraying oil onto the hot bricks in the carburetor. The oil is broken up into vapor which mixes with the "blue" water-gas, and this vapor by further contact with the hot bricks in the superheater, becomes largely fixed as a permanent gas which will not condense back into oil when cooled. The carburetted gas passes through the water seal of the wash box, W, and thence through further apparatus where it is cooled, cleaned, and purified before being distributed to the consumers.

It is not to be assumed that the operation is so simple in practice as just described. The blowing and steaming periods have to be regulated with great care, not only as to duration, but also in respect to the amount of air, steam, and oil admitted. A small fraction of a minute added to or subtracted from one of these periods has marked effects on the temperature balance of the machine and nearly all modern gas sets are equipped with steam, air, and oil meters and with pyrometers to show temperatures in the fixing chambers, and the gas maker times the operation with a clock equipped with a second hand. The steaming and blowing periods are different in different plants. While an infinitesimally short blow, followed by an infinitesimally short run would probably be the ideal arrangement or cycle, the time required to operate valves makes extremely short periods impracticable. In practice we find blow periods from 2 to 4 minutes and run periods from 3 to 6 minutes or possibly even longer in some cases. During the blast period the air always passes upward through the fire, but in modern practice a portion of the steam runs are made down through the fuel, the gas passing to the carburetor through the refractory lined pipe, P. This reversal not only protects the hot valve, H, from becoming overheated, but also puts the fire in better condition for gas making. The lid on the top of the generator is opened at intervals of perhaps five or six runs to introduce a fresh charge of fuel. At intervals of perhaps 8 to 10 hours, depending upon the fuel, operation has to be discontinued and the accumulated ashes and clinkers removed through the lower doors. This procedure, which may require anywhere from a few minutes to four or five hours, of course shortens the actual operating time and may cause the rejection of a particular fuel, which otherwise might be considered suitable, and frequently much experimenting is done to find a set of operating conditions which will make practical the use of a particular fuel which, though otherwise good, gives an obstinate clinker. It is remarkable what can sometimes be accomplished by slightly modifying the amount or duration of the blowing or steaming, or by changing the percentage of up and down steam runs.

Coke or anthracite coal, since they contain very little volatile matter, could, except for the complications sometimes introduced by the nature of the ash formed, be considered as pure carbon. With bituminous coals, however, the gas maker is confronted by new problems. The coals of the central district usually contain from 35 to 45 per cent of volatile matter, and exhibit the property of caking when heated. The volatile matter of the coal consists not only of water vapor and permanent gases, but also of heavy condensible vapors which upon cooling form tar.

The volatile matter and the caking property are the chief factors which make the use of bituminous coal for this purpose, a problem of many difficulties. To follow exactly the same methods as employed with coke or anthracite would be to court failure from the start. Among the difficulties usually encountered may be mentioned, the production of great volumes of smoke, a marked decrease in gas production capacity, and the rapid plugging of the brick checkerwork with pitch and soot. To overcome these difficulties a vast amount of experimenting has been done by various gas operators. While there has been some exchange of views among the operators, it was found on an inspection tour made last summer, by Mr. W. W. Odell, gas engineer of the U. S. Bureau of Mines, and the writer, that many operators were beset by so many difficulties connected with securing labor and materials and maintaining their plants that they had little time to devote to the solution of actual machine operating difficulties. As a result of the inspection, the Geological Survey published its Cooperative Mining Investigations Bulletin No. 22, describing the observed practice in operating with bituminous coals up to that time and it was decided to make an investigation on a practical scale to learn more facts if possible for dissemination to the gas industry. The Public Service Company of Northern Illinois very generously offered the facilities of the Streator plant for the experiments. Mr. Odell and the writer spent several weeks in that plant, experimenting with various coals under different conditions. While there are still some difficulties to be overcome, it is felt that the results obtained there and the application of the methods employed to some other plants have justified the time and money spent and have demonstrated that many of the difficulties formerly encountered can be entirely overcome or greatly diminished. In discussing the methods used at Streator, no attempt will be made to go into great detail. The main facts will be mainly outlined. It is not claimed that all the methods tried originated in the Streator tests. Some of them had been worked out by other operators and to them great credit is due for the pioneer work accomplished.

One of the first difficulties to be overcome in the use of bituminous coal was the obstruction to the passage of air blast and steam caused by the caking of the coal. With coke or anthracite it is often customary to make fuel charges of perhaps 700 or 800 pounds at a time in a 6 ft. set and after cleaning the fire it is often the practice to make double or even triple charges to build the fuel bed rapidly up to the proper operating depth. If this procedure is followed with bituminous coal, within an hour or so the caking of the coal has progressed to such an extent that an arch of partially caked fuel, almost impenetrable to the air blast, is formed. The result is that the rate of combustion is greatly slackened, the fuel bed becomes relatively cold, and the gas-making reactions of the steam run are also slackened. Under these conditions the rate of production falls far below that ordinarily obtainable with coke. The only remedy for this condition after it has taken place is to break up the caked fuel frequently, with heavy iron bars, a laborious time-consuming operation. The remedy applied at Streator and elsewhere was to avoid all double fuel charges and rather make the charges lighter and more frequent at the start until the fuel had been brought up to working depth. By this procedure barring the fire could be entirely avoided. While the rate of gas production was increased, it did not equal the production with coke, and a method developed at Streator for increasing production will be discussed a little later.

The smoke problem was also one which caused much concern to the gas operator, but especially to other establishments located in proximity to the gas plant. Water-gas sets do not usually have high stacks which dissipate smoke in the upper atmosphere. The combustion products are usually expelled just above roof level; consequently near neighbors get the full benefit when smoke is produced. The greatest difficulty was experienced after the machine had been idle for several hours and the fuel bed and checkerwork had cooled somewhat. If a charge of fresh coal were added to the fire and the blast commenced, the blast gas produced in the generator at first would not be rich enough to burn upon the addition of secondary air, or if it were the temperature of the checkerwork might be too low to ignite it. As a result, the tar vapors formed from incomplete combustion of the coal would pass through the carburetor and superheater unconsumed, and even the pilot light kept constantly burning at the stack would only partially ignite them if at all. The result was a dense cloud of yellow or brown smoke. After the fuel bed and checkerwork were well heated, little more trouble from this source would be encountered. A remedy which was developed at Streator worked out quite successfully, was to make a fresh charge of fuel just before shutting down the set and making only one or two runs from it. During the succeeding lay-over period this coal coked gradually and by the time the set was again put into operation it had become completely coked. Then upon blasting the machine could be brought rapidly up to temperature, and after one or two runs had been made, the addition of fresh fuel produced very little if any smoke, since the tarry vapors could be ignited and completely consumed.

As has been previously explained, the blow and run periods are so timed as to bring all three chambers to the proper operating temperatures at the same time. Since the caking property of the coal tends to make the fuel bed more resistant to the passage of air than coke fuel, it is evident that with a given air-blast pressure available, it will take a longer blowing time to get the coal fuel to the proper temperature. However, since there is considerable rich volatile matter given off from coal, this upon burning in the carburetor and superheater tends to overheat these chambers before the generator is hot enough. Since the temperature most favorable for properly fixing the gas oil is quite well defined, excess temperature tends to break up the oil too much with the formation of lamp-black which rapidly fouls the checkerwork and chokes the connections. If a great part of the combustible gas is burned outside the machine at the stack, the latter becomes overheated, and at any rate fuel is wasted. Several methods for remedying this condition have been tried, but practically all of them result in a great deal smaller production of gas in a given time than is possible with coke, the reduction amounting to as much as 30 per cent. A method was worked out at Streator which obviates this difficulty and at the same time increases capacity, and this method will be briefly described.

The gas produced during the blow period becomes momentarily greater in heating value as the blow proceeds, due to the increasing percentage of carbon monoxide. At the end of a three-minute blow, for example, it may have a heating value of perhaps 155 B. t. u. per cubic feet with coal fuel, due to the presence of carbon monoxide and hydrocarbons. It was concluded that a certain amount of this gas was worth saving and as the carburetor and superheater had usually attained a suitable temperature of 1350 to 1400 degrees F., by this time, the stack valve was closed and the blast continued for 15 to 30 seconds, no secondary air being admitted during this time. The term "blow-run" was coined for this part of the operation since it was a run with blast instead of steam. This additional blasting time improved the generator condition and since the gas was not burned in the carburetor and superheater, these chambers were not overheated by this additional blast. A volume of gas equal to 20 to 30 per cent of the usual volume was added to the production and while the amount of oil required to enrich this relatively poorer gas was somewhat greater, it did not equal that usually required with coke. The amount of generator fuel consumed per unit of gas volume materially decreased.

While this method is not claimed to be a panacea for all the troubles experienced in using bituminous coal in water-gas making, it worked successfully at Streator and has been applied with more or less success at other plants according to the extent to which the particular conditions are favorable to it. It is hoped that the investigation of its application may be continued farther.

The choice of a generator fuel for gas making is an economic matter depending upon the cost of the fuel and the efficiency with which it can be used. Assuming that a given fuel is usable and will produce the amount of gas required, the question which must always be answered is, what will be the relative cost of making 1000 cubic feet of gas with various fuels. Not only cost per ton and the actual amount of fuel consumed enter into the problem but also the effect on the amount of oil required to enrich the gas and the cost of other materials and of labor occasioned by its use. These costs will not be the same for a particular fuel in different plants, even if the actual cost of generator fuel is the same. To take a particular case and assume certain costs for materials and labor is always likely to lead to erroneous or misleading conclusions for there are always those who are sure to take assumed figures as statements of fact. In comparing coal and coke as water-gas generator fuels, it may be said, however, that with the difference in price in these fuels which has prevailed, many operators who were so equipped that they could maintain their gas production with coal have realized a very substantial saving from its use.

While during the earlier experimental stages a very large percentage of the heat in the coal was wasted in smoke and otherwise, some operators have now perfected their operation so that nearly if not quite as much of the heat in the coal is now utilized in the finished gas as when coke was used. The volatile matter of the coal also assists to a certain extent in enriching the gas. The gases leaving the generator when coal is used are richer than "blue" gas from coke, and consequently less oil is required to enrich the gas to a given quality. The saving in oil frequently amounts to a third of a gallon per 1,000 cubic feet of finished gas. The relative labor, repair, and purification costs with the two fuels depend upon the particular coal or coke used, the capacity obtained and the operating difficulties encountered. While these costs are in some cases slightly greater with coal than with coke, the difference is relatively unimportant. In general, it may be said that even with normal prices of materials and labor, coal as generator fuel shows a distinct economical advantage where it can be used, and its use can be greatly extended.

Aside from the gas operator point of view, this subject has a significance to the general public. Any saving effected by the gas companies in operation will in time be reflected in the quality of service rendered to the public. In some cases the use of coal in place of coke will either result in lower rates or will enable the gas companies to continue operation without increasing rates. Every ton of coal substituted for coke in this process releases a certain amount of coke for domestic use, and if coke were used more for domestic purposes in place of bituminous coal the atmosphere and surroundings would be distinctly brighter. Further a saving of a few tenths of a gallon of gas oil in the manufacture of a thousand cubic feet of gas would in the aggregate amount to several millions of gallons a year in this State alone, could such a saving be realized by all companies. The saving of long freight hauls of coke from eastern plants or of eastern coal to produce this amount of coke would be no small item of national economy. In addition to these factors, the use of central district coals for water-gas is one more step in the development of the great coal resources of this region, especially those of Illinois.