LOW-TEMPERATURE CARBONIZATION
OF COAL

BY

A. C. FIELDNER
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LOW-TEMPERATURE CARBONIZATION OF COAL

By A. C. Fieldner

INTRODUCTION

Low-temperature carbonization of coal is a subject of special interest at this time when some concern is being felt as to the future supply of petroleum. You no doubt are intensely interested in the technical and economic possibilities of recovering oils and motor fuels from the coal, lignite, and shale deposits of the Western States. I am including shale in my discussion because there is no sharp line of demarcation between carbonization processes for coal and for shale. In fact, there is much more difference in the types of apparatus required for coking and noncoking coals than there is between a plant for distilling oil shale and a plant for carbonizing lignite. Lignite, subbituminous, or other noncoking coal can be carbonized in a Scottish oil-shale retort, as oil shale can be distilled in most styles of retorts for low-temperature carbonization. Therefore, what I shall say about carbonization processes and principles is applicable in many respects to shale as well as to coal. In the restricted time at my disposal I must necessarily limit myself to fundamental principles and to brief descriptions of representative types of processes.

For further information you are referred to four recent textbooks on the subject and to innumerable papers in the technical press. One must, however, remember that most of these articles are written by incurable optimists. Some of them have processes to promote, others are simply editors or correspondents who do not have personal knowledge of the process but accept the inventors' and promoters' statements at face value.

1 Part of this paper was given in lectures at the Johns Hopkins University, Apr. 29, 1925, and at the Colorado School of Mines, Golden, Colo., Mar. 11, 1928, under the auspices of the American Gas Association.

WHAT IS LOW-TEMPERATURE CARBONIZATION?

Low-temperature carbonization of coal may be defined as the heat treatment of coal in the absence of air at temperatures of 450° to 700° C, as distinguished from the usual high-temperature carbonization at temperatures of 900° to 1,200° C. The aim is to keep the temperature low enough to prevent the decomposition of the primary tar, and thus obtain the maximum yield of liquid products and at the same time produce a solid smokeless fuel. At 450° to 500° C, the tar yield is two to three times that of the ordinary high-temperature process for making coke or gas.

AIMS OF LOW-TEMPERATURE CARBONIZATION

The reasons for the many attempts to devise low-temperature processes that would work on a commercial scale are as follows:

1. To obtain a larger yield of liquid fuels than can be obtained from high-temperature processes.

2. To provide a smokeless, easily ignitable solid fuel for domestic purposes.

3. To obtain a dry, easily pulverized, highly combustible, low-volatile material for pulverized-fuel furnaces, and at the same time to recover by-products.

4. To obtain a substitute for low-volatile semibituminous coal, for mixing with high-volatile swelling coals in order to make a suitable dense metallurgical coke.

Of these four objectives, the one common to all low-temperature processes is the increased yield of oil or tar. Liquid fuel, especially gasoline, seems essential for the continuation of our present highly developed system of automotive transportation. Our reserves of petroleum are much more limited than our reserves of coal and may become inadequate to meet demands within the present generation, hence the interest in methods for obtaining liquid fuel from our very much larger supply of solid fuel. European countries which have no oil fields within their boundaries take a particularly keen interest in this problem because of the need of a home source of petroleum substitutes in the event of a war shutting off foreign supplies. Great Britain felt this need during the last war to such an extent that the Government established a fuel research station which has for one of its important problems the development of a low-temperature process that is commercially feasible. Germany actually did install and operate a number of low-temperature carbonization plants during the latter years of the war.

There is in England a second objective almost as important as the first—namely, the manufacture of an easily ignitable smoke-
less fuel for open-grate fires. The Englishman must have his cheerful open grate, despite its low efficiency and the pall of smoke created by thousands of soft-coal fires. Abatement of this domestic source of smoke by providing a suitable smokeless fuel was the chief object of the early experiments in England.

In Germany and in France research on low-temperature carbonization is undertaken mainly for the production of gasoline and fuel-oil substitutes and for manufacturing a low-volatile semicoke for mixing with high-volatile gas coals to produce dense metallurgical coke. There is little interest at present in a smokeless domestic fuel. German engineers are investigating the possibilities of combining low-temperature carbonization with powdered-fuel firing or of burning the semicoke on chain-grate stokers in large central power plants.

Considerable attention has also been given to combining low-temperature distillation with complete gasification of the resulting semicoke in by-product gas producers.

**METHODS OF HEATING**

The fundamental difficulty in carbonizing coal at low temperatures is in transferring heat to the coal in a reasonably short time when a relatively low-temperature gradient is used. Coal is a poor conductor of heat. It takes much longer to transfer the necessary amount of heat through a given volume of coal when the retort walls are at a temperature of 500° C. than when they are at 1,200° C, as in the usual high-temperature process. As the cost of the operation depends in a large degree upon the installation charges per ton of coal carbonized it becomes necessary to accelerate the rate of carbonization, either by spreading the crushed coal in a thin layer on a heated surface or by agitating the coal, bringing fresh portions continually in contact with the heated walls, or by passing large volumes of hot producer gas, products of combustion, or superheated steam through the mass of broken coal.

Differentiated on the basis of method of heating the various processes fall into two classes, namely, (1) externally heated retorts in which the coal to be carbonized is supplied with heat through the walls of the retort and the products of distillation are not diluted with flue gases, and (2) internally heated retorts in which the coal to be carbonized is heated by direct contact with hot gases or superheated steam passed through the retort in intimate contact with the charge.

Carbonization processes may be intermittent, those in which the coal is charged into an empty retort and remains there until dis-
tillation is completed, when the entire mass of coke or residue is discharged at one time; or they may be continuous, those in which charging and discharging are continuous or in small increments.

Present high-temperature processes of by-product coke making are intermittent, because intermittent processes generally produce firm and lumpy coke. Continuous vertical retorts are coming into considerable use in the gas-making industry because continuous processes favor larger outputs and cheaper operation. The coke, however, has physical properties somewhat inferior to those of coke produced by intermittently charged retorts.

As to the style of construction, retorts may be classified as follows: (1) Oven types, usually of rectangular shape, as the standard by-product oven; (2) vertical shaft types, as the vertical gas retorts or the Scottish oil-shale retort; and (3) rotating-cylinder types, vertical, horizontal, or inclined, similar to revolving driers or cement kilns; the cylinder type may also be stationary and have a revolving internal stirrer.

Table 1 gives a convenient classification for the many proposed processes.

**Table 1.—Classification of low-temperature carbonization systems**

A. Externally heated retorts—coal in thin layers, not stirred.
   1. Vertical layers of coal in narrow retorts.
   2. Horizontal thin layers of coal.
B. Externally heated retorts—coal stirred in contact with heated surfaces.
   1. Vertical retorts.
   2. Horizontal retorts.
      (a) Stationary retorts with internal stirrers.
      (b) Rotating cylinders.
   3. Retorts with coal stirred on a flat heated surface.
C. Internally heated retorts—coal in direct contact with hot gases or liquids.
   1. Hot gases generated by air or air and steam blown into the retort.
      (a) Coal charged in lumps or briquets.
      (b) Coal charged in pulverized form.
      (c) Complete gasification.
   2. Hot gases or vapors generated outside the retort.
      (a) Combustion products.
      (b) Producer gas.
      (c) Water gas.
      (d) Coal gas.
      (e) Superheated steam.
      (f) Combinations of the foregoing.
   3. Melted lead in contact with coal.
D. Two-stage carbonization to control the sticking properties of coal.

Only a few of the better-known processes of some of the various types can be described briefly in the time available.
EXTERNALLY HEATED RETORTS—COAL IN THIN LAYERS, NOT STIRRED

VERTICAL LAYERS OF COAL IN NARROW RETORTS

PARKER PROCESS

The latest modification of the coalite process of the Low Temperature Carbonization (Ltd.), of England, is a return to the cast-iron vertical retort originally proposed by Parker in 1908. This retort is of small diameter and is intermittently charged. Each retort consists of a solid casting of 12 tubes in a double row of 6, each 4½ inches inside diameter at the top, tapering to 5½ inches inside diameter at the bottom, and 9 feet long; 32 of these retorts constitute a battery that has a capacity of 50 tons of coal per 24 hours. Figure 1 shows the two-battery experimental plant that has been in operation at Barugh, near Barnsley, in Yorkshire, England.

Tests of this plant by the fuel research station of England showed the following yields:

<table>
<thead>
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<th>Table 2.—Results of tests by fuel research station of Barnsley plant</th>
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<tr>
<td>Coke (6½ per cent volatile matter) per cent... per cent... 70</td>
</tr>
<tr>
<td>Gas (700 B. t. u. per cubic foot) cubic feet... 5,620</td>
</tr>
<tr>
<td>Crude tar (dry) U. S. gallons... 20</td>
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<tr>
<td>Ammonium sulphate pounds... 12.2</td>
</tr>
<tr>
<td>Crude light oil from gas gallons... 1.9</td>
</tr>
<tr>
<td>Refined motor spirit to 170° C. do... 1.5</td>
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<tr>
<td>Retort temperatures °C... 600 to 800</td>
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<tr>
<td>Volatile matter in coal per cent... 35</td>
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It will be observed that the temperatures were 100° to 300° C. above that of the usual low-temperature processes. This accounts for the volatile matter in the coke being 6 per cent instead of the normal figure of 10 to 15 per cent. The tar also suffered some cracking, and the result was a relatively high yield of light oil and gas, as judged by strictly low-temperature standards.

The Barnsley process was devised primarily to make a smokeless solid fuel for domestic purposes, and it accomplishes this purpose. The cylinders of coke as discharged from the retort fracture into triangular sections about 3 inches long. The coke is hard and compact; less than 5 per cent of it passes a ½-inch screen; it ignites readily and gives a cheerful glowing fire. In other words, it is an excellent smokeless fuel.


94639°—26—2
Figure 1.—Parker retort installation, Low-Temperature Carbonization (Ltd.) plant at Barnsley, England
I have referred to this process in some detail because it represents conditions that will produce suitable smokeless lump fuel, gas of high thermal value, and, as compared to the high-temperature process, an equal quantity of light oil and double the quantity of tar. The disadvantages are (1) high cost of operation in charging and discharging so many small test-tubelike retorts, and (2) doubtful life of the cast iron at the temperatures employed. Any warping of the metal will increase the difficulty of discharging the coke. Even if the process proves technically a success, there is doubt whether it will prove economical in competition with present high-temperature gas or coke-oven practice.

WALLACE PROCESS

In the United States Wallace proposed a vertical cast-iron cylinder of larger diameter than the Parker retort. In order to increase the rate of carbonization and avoid cracking the tar by the hot walls, Wallace fixed in the center of the retort a perforated tube, closed at the top, through which the gases and vapors are withdrawn, thus pulling them through the cold coal away from their usual course through the hot coke and up along the retort walls. This type of retort should give high yields of primary tar. As yet, no commercial plant has been constructed.

ROLLE RETORT

In Germany the same principle of withdrawing the gas to the unheated center has been used for years in distilling the rich brown coals for their wax and oil content. Figure 2 shows this retort, known as the Rolle oven. The brown coal is charged continuously at the top and descends in the 4-inch annular space between the cast-iron rings, arranged in Venetian-blind fashion, that form the inner cylinder and the heated fire brick that form the outer shaft. The distillation products are drawn into the interior space and out through the bottom of the oven. The brown-coal residue is a charcoal-like granular material about the size of rice. It is called "Grudekoks" and is sold as domestic fuel for use in specially constructed stoves and ranges. It is easily ignited and burns without flame with very little excess air. A heap of "Grudekoks" will burn slowly to the bottom with the air that diffuses into it. To minimize cracking of the oils the temperature in the retorts is not permitted to exceed 450° C. The output is low, only 4 tons per retort in 24 hours, and the first cost and the space occupied per ton of material carbonized are high. The use of the Rolle retort is limited to the
Figure 2.—Rolle retort for brown coal
soft, earthy, noncoking brown coals of Germany, and even there efforts are being made to develop retorts of much higher capacity which employ internal heating by hot gases.

HORIZONTAL THIN LAYERS OF COAL
PIRON-CARACRISTI PROCESS

The Piron-Caracristi process adopted by the Ford Motor Co. has attracted much attention. An oven with a capacity of 400 tons a day, about 50 feet long and 4 feet wide, was completed in 1924 at Walkerville, Ontario. This plant is adjacent to the power plant there, burning pulverized fuel in which the pulverized semicoke was to be burned. Figure 3 gives an outline sketch of the furnace. The process is as follows: 4

The crushed coal is charged into a series of shallow cast-iron pans 36 by 18 by 1 inch deep, which are part of a continuous chain belt. The coal layer is about five-eighths inch deep. During the carbonization period the coal particles do not move in relation to each other, but are free to swell, become pasty, and fuse into a sheet of coke, which detaches itself from the pan during the return of the belt.

Heat is applied to the coal through a bath of melted lead. The pans float on this bath and are dragged from one end of it to the other. The temperature of the bath is maintained by burning gas in cast-iron flues immersed in the lead, which is contained in a water-cooled tank made of clay refractories. As the temperature of the lead can be readily ascertained and controlled, the coal is subjected to a uniform definite temperature by the transfer of heat from the lead through the iron pan to the thin layers of coal in the pans.

The volatile matter evolved escapes to the condensers through ducts in the wall of the distillation chamber over the lead bath without being subject to higher temperatures than were intended.

Although the quantity of coal in each pan is small the time necessary to permit satisfactory carbonization of the thin layer of coal is so short (less than five minutes is the claim) that the furnace as a whole may have a large daily output.

Preliminary operation of this plant at Walkerville showed that all details of design had not been worked out satisfactorily. 5 It is a question if metallurgical science has yet developed a method of constructing, at reasonable cost, a chain mechanism suitable for operation over a long period at a temperature of 650° C. It is also difficult to design a charging and discharging mechanism that will never admit excessive quantities of air into a large retort space.

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Figure 3.—Piron-Caracristi lead-bath process
EXTERNALLY HEATED RETORTS

EXTERNALLY HEATED RETORTS—COAL STIRRED IN CONTACT WITH HEATED SURFACES

VERTICAL RETORTS

GREENE-LAUCKS PROCESS

Figure 4 is a diagrammatic view of the Greene-Laucks type of retort. It is described by Porter as follows:

The Greene-Laucks process, developed first at Denver, Colo., is now being tried out with Illinois coal screenings by a large coal-mining company in that State. This process propels the coal upward on a worm conveyor in a vertical retort in which heat is applied both on the outside and within the hollow conveyor shaft. As the object in this case is to make a good solid fuel with recovery of tar oils, little attention is paid to gas yield, and 15 to 17 per cent of volatile matter is left in the coke. The retorts now operating with this process have been producing good strong semicoke over long-continued periods at a rate of 24 tons of coal carbonized per retort per day. The fuel is readily ignited, burns smokelessly, and holds the fire well.

The movement of the charge is upward and the temperature of the heating flues is graded from higher at the top to lower at the bottom. The shaft of the worm may be utilized either as an auxiliary heating flue or as an offtake for the gas and by-products. With such method of movement of coal on a conveyor, there may be but little mechanical interference with the agglomeration of the caking mass, and, in fact, small-sized coal or screenings may build up into marketable sizes of lump coal or semicoke.

Figure 5 shows one of the experimental units.

HORIZONTAL RETORTS—STATIONARY RETORTS WITH INTERNAL STIRRERS

M'INTIRE RETORT

The most recent type of the externally heated, internally stirred horizontal type of retort is that designed by C. V. McIntire, and

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now operated on an experimental basis by the Consolidation Coal Products Co. at Fairmont, W. Va. This retort, shown in Figures 6 and 7, is a modification of the primary carbonization retort of the "Smith" or "carbocoal" process installed at Clinchfield, Va. The original carbocoal retort was not practical because the stirrer arms broke under the resistance of the pasty, fused mass of cok-

---

ing coal, and because other difficulties arose. The McIntire retort is reported to have solved this problem and to have successfully carbonized coal from the Pittsburgh bed, a coking coal, for considerable periods at the rate of 50 tons a day. The semicoke produced is not lumpy, but granular; it therefore requires briquetting to make it suitable for domestic fuel. Possibly, however, it could be pulverized for use in powdered-fuel furnaces.

The retort is 16\(\frac{1}{4}\) feet long and 8\(\frac{1}{2}\) feet in diameter. Its lower part consists of V-shaped sections of resistant iron that are heated by burning gas in the space below. The upper part of the cylinder is removable and is made of light boiler plate covered with sil-o-cel. The slack coal is fired continuously into one end of the retort and discharged at the other. The charge is agitated by a central oscillating shaft 30 inches in diameter, carrying arms with paddles. The gas leaves the retort at the coal-charging end.

With the coal heated to a maximum temperature of 450° C. the following yields were obtained:

Yields from McIntire retort, per ton of coal charged

<table>
<thead>
<tr>
<th>Product</th>
<th>Yield</th>
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<tbody>
<tr>
<td>Semicoke (12 to 14 per cent volatile matter)</td>
<td>75 per cent</td>
</tr>
<tr>
<td>Gas (875 B. t. u. per cubic foot)</td>
<td>3,000 cubic feet</td>
</tr>
<tr>
<td>Crude tar oils (1.080 specific gravity)</td>
<td>30 gallons</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>10 pounds</td>
</tr>
</tbody>
</table>

In this retort the moving metal parts operate at a much more favorable temperature (450° C.) than in the Piron-Caracristi retort,
yet it is a question whether the cost of maintaining this mechanism may not prove too high for profitable commercial use. Continued large-scale operation is required to answer this question.

**ROTATING CYLINDERS**

**GERMAN INVESTIGATIONS**

The total consumption of petroleum products (gasoline, kerosene, Diesel-engine oil, and lubricants) in Germany for the year 1922 was approximately 1,000,000 metric tons, but the total output of petroleum in Germany during the same year was only 45,000 tons. Germany is therefore intensely interested in the production of petroleum substitutes from coal. German engineers have calculated that the low-temperature distillation of 34,000,000 tons of coal will provide 1,700,000 tons of low-temperature tar, which in turn will yield 1,000,000 tons of petroleum substitutes, the present yearly need of Germany. Central electric power stations, large industrial power plants, and briquet works consume 63,000,000 tons of coal annually. It is therefore theoretically possible to provide from German coal fields the necessary quantity of petroleum substitutes for Germany’s needs by extracting the tar oils from this coal before it is consumed for generating power. I found German engineers keenly interested in this possibility, especially in connection with the burning of the low-temperature coke in pulverized form; indeed, this seems to me to be one of the logical fields for low-temperature distillation.

Franz Fischer, director of the Kaiser Wilhelm Institute for Coal Research at Mülheim-Ruhr, began intensive experimenting on low-temperature distillation and the investigation of low-temperature tars early in the war. He developed on a laboratory scale the small rotary retort which was subsequently built in full-size industrial units with various modifications by Thyssen, Fellner-Ziegler, Bamag-Meguin, and recently by the Mathias Stinnes Col-
liery at Essen. All of these retorts are externally heated. They produce gas of high calorific value and a friable, voluminous semicoke which can best be utilized by either briquetting with pitch or pulverizing for powdered fuel. These retorts have been operated in an experimental way, some of them over periods of months. None of them are in continuous commercial operation at present, partly because economic conditions are not now favorable for financial returns on tar oil, and partly because of technical difficulties not completely solved. As stated before, the utilization of the semicoke as pulverized fuel in such plants yet to be developed and the commercial utilization of the low-temperature tar are the present goals of research engineers in Germany.

THYSSEN RETORT

Through the courtesy of Doctor Fischer I had the opportunity of seeing a Thyssen rotary retort* at the August Thyssen works near Essen. It consists of a horizontally mounted steel cylinder 2.6 meters (8\(\frac{1}{2}\) feet) in diameter and 23 meters (75\(\frac{1}{2}\) feet) long (fig. 8). Spiral ribs on the inner surface carry the charge of coal through the retort, which is said to have a capacity of 100 tons per 24 hours. The maximum temperature inside the retort is 500° C. (932° F.), and the fuel consumption is 8 per cent of the coal carbonized. Judged from the samples of low-temperature coke displayed, the coals carbonized were noncaking. Fusing coals would stick on the walls of the retort, retard the transmission of heat, and cause eventual failure of the steel by overheating.

Because of the unusually high content of ethylene, propylene, propane, and other easily condensable gases in the gas from the retort, the Thyssen Co. has installed a Linde liquefaction apparatus for the separate recovery of these constituents and the light oils.

The average analysis of gas from a Ruhr noncoking coal is as follows:

<table>
<thead>
<tr>
<th></th>
<th>Per cent</th>
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<tbody>
<tr>
<td>Ethylene (C₂H₄), etc.</td>
<td>8</td>
</tr>
<tr>
<td>Ethane (C₂H₆), etc.</td>
<td>15</td>
</tr>
<tr>
<td>Methane CH₄</td>
<td>34</td>
</tr>
<tr>
<td>Carbon dioxide (CO₂) (+H₂S)</td>
<td>10</td>
</tr>
<tr>
<td>Carbon monoxide (CO)</td>
<td>6</td>
</tr>
<tr>
<td>Hydrogen (H₂)</td>
<td>12</td>
</tr>
<tr>
<td>Oxygen (O₂)</td>
<td>1</td>
</tr>
<tr>
<td>Nitrogen (N₂)</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>100</td>
</tr>
</tbody>
</table>

---

The gross calorific value is 8,000 to 9,000 calories per cubic meter, or 910 to 1,030 B. t. u. per cubic foot.

A noncoking screened lump coal (small lumps) passed through the retort gives a fair yield of lump material in the semicoke. A weakly coking coal comes through as a porous, spongy mass. Strongly coking coal can not be put through the retort.

One of the big drawbacks of retorts of the rotary type is the dust created by the tumbling coal. Special dust separators are required to throw down the dust from the hot gases before the tar begins to condense. Even with such dust-collecting equipment the tar is likely to contain from 1 to 2 per cent of dust. A high content of dust seriously impairs the market value of low-temperature pitch, especially if the pitch is used as a binder for briquets.
The retort was not in operation at the time of my visit, but it was said to have run continuously for a period of five months and seemed to be in good condition. I think the estimate of 100 tons throughput in 24 hours is very optimistic; 50 tons seems a more reasonable estimate.

The Fellner-Ziegler retort was the only low-temperature carbonization retort that I saw in actual operation in Germany. (See fig. 9.) At the time of my visit test runs were being made on sample shipments of noncoking gas coal from Upper Silesia. The screened lumps of egg and nut size charged into the retort came out in their original form, except that they had shrunk and were checked with
shrinkage cracks. The semicoke had an apparent density of about 0.7 and would serve as a smokeless fuel for stoves and house-heating furnaces. This particular retort at Gelsenkirchen was said to have been operated intermittently over a period of two and one-half years. It seemed to be in good condition. The retort, which is heated externally, is 2.5 meters (8 feet) in diameter and 20 meters (65 feet) long, mounted at an inclination of 5 per cent from the horizontal. A reciprocating scraper is provided to keep plastic coal from adhering to the retort surface. This scraper may function with weakly coking coal, but I doubt whether it can keep strongly coking coal from adhering to the shell.

The semicoke from weakly coking coal was soft and pulverulent, and should be ideal material for pulverized-fuel furnaces. The by-product recovery plant included a Linde three-stage compressor for separating the easily condensable gases by liquefaction.

The daily output of this plant when in full operation is given by Thau as follows:

\[ \begin{align*}
\text{Capacity and yield of FELLNER-ZIEGLER rotary retort} \\
\text{Throughput:} & \quad \text{tons of run-of-mine coal} \quad 54 \\
\text{Semicoke (9 to 10 per cent volatile matter):} & \quad \text{per cent} \quad 77.04 \\
\text{Gas:} & \quad \text{cubic feet per ton} \quad 3,883 \\
\text{Tar:} & \quad \text{per cent} \quad 6.46 \\
\text{Pitch:} & \quad \text{do} \quad 0.78 \\
\text{Gasoline:} & \quad \text{do} \quad 1.58 \\
\end{align*} \]

KOHLENSCHEIDUNGS-GESELLSCHAFT DOUBLE ROTARY RETORT

The double-cylinder inclined rotary retort recently installed at Karnap, near Essen, by the Mathias Stinnes Colliery (fig. 10) represents an attempt to increase the throughput of a rotary retort of a given size by utilizing the middle space of the big cylinder as a drier and preheater for the incoming charge of coal. The retort is externally heated with producer gas burned in a combustion chamber adjacent to the retort. Provision is made for diluting the hot combustion gases with flue gas to provide uniform and closely regulated temperatures around the retort.

The outer retort, approximately 3 meters (10 feet) in diameter and 25 meters (80 feet) long, is entirely supported on the inner retort, which carries the driving mechanism. This arrangement is said to be a decided structural advantage in that the large stresses and loads come on cold metal—the temperature of the inner retort never exceeds a maximum of 200° C. (392° F.). The steel shell of the outer retort may be heated to 600° C. (1,112° F.) without serious in-

\footnote{Thau, A., "Low-temperature carbonization in revolving retorts," Blast Furnace and Steel Plant, vol. 13, 1925, pp. 434–41.}
jury to the retort. It is claimed that the slow preheating of the coal in the inner cylinder so changes the nature of coking coals that weakly coking coals can be carbonized without sticking on the walls of the retort, especially if about 10 per cent of coke breeze is added to the charge.

I saw several hundred tons of a soft, friable semicoke on piles near the retort. It seemed of too low density and too friable for a high-grade smokeless fuel, although in a recent article Cantieny \(^{10}\), the manager of the company, says that this fuel is in good demand in Karnap for domestic purposes.

It is claimed that because of the double cylinders and the pumping off of evolved gases and vapors countercurrent to the flow of

![Figure 10: Vertical section of double rotary retort of Kohlenscheidungs-Gesellschaft](image)

the coal virtually no decomposition of the tars takes place, and that the yield of tar is 100 per cent of the laboratory yield in contrast to the yield of 60 per cent in rotary retorts in which the vapors are removed at the discharge end.

At the time of my visit the retort was shut down for changes in design after an experimental run of five months.

According to the engineers in charge, the chief unsolved problem was to increase the capacity of the unit from about 50 tons to 100 tons per 24 hours. It was hoped to solve the problem by passing superheated steam directly through the coal in the outer cylinder. Cantieny's recent report \(^{11}\) states that the problem has been solved


\(^{11}\) See footnote 10.
by introducing about 5 per cent of steam superheated to 400° to 500° C. at 0.5 atmosphere pressure into the coal in the outer retort. This steam is also said to keep the tar from decomposing and to prevent condensation on the relatively cool wall of the inner retort. The present capacity of the retort is said to be 60 to 80 tons of coal a day.

![Diagram of Kohlenscheidungs-Gesellschaft plant at Karnap](image)

Figure 11.—Schematic plan of Kohlenscheidungs-Gesellschaft plant at Karnap: a, Coal bunkers; b, aerial tram; c, coal bunker supplying retort; d, rotary retort; e, bucket elevator for semicoke; f, semicoke breaker; g, shaking conveyor; h, scales for weighing semicoke; i, semicoke bunker supplying gas producer; k, bunker for excess semicoke; l, disposal of excess semicoke; m, gas producer with steam generator; n, blower; o, blower supplying air for combustion; p, combustion chamber; q, distillation gases to condensing system; r, steam superheater; s, blower for circulating combustion products; t, chimney; u, circulating duct for products of combustion

A weakly coking coal in the form of fine slack, which contained 3 per cent water, 25 per cent volatile matter, 14.8 per cent ash, and 5.8 per cent oxygen, yielded per ton of dry coal:

Products from a weakly coking coal

<table>
<thead>
<tr>
<th>Product</th>
<th>Per cent</th>
<th>Cubic Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semicoke</td>
<td>82.0</td>
<td></td>
</tr>
<tr>
<td>Crude tar, water free</td>
<td>5.05</td>
<td></td>
</tr>
<tr>
<td>Light oil scrubbed from gas</td>
<td>0.43</td>
<td></td>
</tr>
<tr>
<td>Thick tar</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>2,500</td>
<td></td>
</tr>
</tbody>
</table>
Figure 11 is a schematic plan and Figure 12 is a view of the Kohlenscheidungs-Gesellschaft plant at the Mathias Stinnes Colliery I/II at Karnap, near Essen.

"FUSION" PROCESS

The "Fusion" rotary retort, which is operating on a small experimental scale at Middlewich, Cheshire, England, is similar to the Thyssen retort except that there are no spiral ribs and there is a
Figure 13.—“Fusion” rotary retort: a, Raw material hopper; b, air-tight automatic feed valve; c, breaker or pulverizer; f, rotating tube; g, ports with dampers for conveying the products of combustion to the heating chamber around the rotating tube; f, hopper with air-tight automatic valve for discharge of spent material; k, gas-feed conduit; l, gas inlet to combustion chamber; m, air inlet to combustion chamber; n, combustion chamber; p, flue to chimney; r, gland for making joint between rotating tube and end chamber; t, gear for rotating tube; e, rollers upon which the tube rotates.
star-shaped steel tumbler, as shown in Figure 13, within the retort to prevent plastic coal sticking on the sides. It is possible, therefore, to use a coking coal. The product contains a high proportion of fines which must be briquetted for domestic fuel or pulverized for powdered-fuel furnaces.

Wigginton\textsuperscript{12} reports that a plant of four “Fusion” rotary retorts, each 50 feet long and 4 feet in diameter, made by Vickers (Ltd.), is being installed at the Burghlee Colliery, Loanhedd, near Edinburgh, to treat waste coal.

\textbf{DOBBELSTEIN PROCESS}

A new German process has been described by Thau\textsuperscript{13} which is interesting in that it aims at making a dense coherent coke in a rotary retort. (Fig. 14.)

A dense hard coke is possible only when the coal is undisturbed during carbonization, and a low-temperature plant is most economical when its operation is continuous. These conditions are fulfilled in the Dobbelstein process, which has been developed on a semi-commercial scale at the Bottrop Collieries of the Rheinlsthil Arenstein Co. near Essen. The retort is a complex horizontal cylinder, the center of which consists of a double tube like the fire tube of a Cornish boiler. In the outer shell surrounding this are circular double-walled cells at short regular intervals. Heating gases pass from the inner tube into and through the cells between which are small chambers for the coal. The whole apparatus rotates once in three to five hours, in which time the coal is completely coked. Automatic equipment for charging and discharging is provided. Power consumption is small, as the only function of rotation is to facilitate charging and discharging. The tar is free from dust. The heating gases enter the cells at 550° C. and leave at 350° C. The coke resembles metallurgical coke but has smaller cells; it contains about 10 per cent volatile matter and is smokeless.

\textbf{INTERNALLY HEATED RETORTS—COAL IN DIRECT CONTACT WITH GASES OR LIQUIDS}

Internally heated retorts differ radically from the externally heated types already described. Processes using these retorts are usually continuous—the coal descends in a vertical shaft through which preheated gases or vapors ascend and impart their sensible heat directly to the pieces of coal. Products of combustion, producer


Figure 14.—Dobbelstein retort
gas, water gas, coal gas, superheated steam, or combinations of these gases have all been tried. Generally speaking, this type of retort contains no moving mechanism and is usually cheaper to build than externally heated retorts. It is not, however, adapted to strongly fusing coal which cakes and hangs in the retort. Likewise the gas can not circulate uniformly through the mass if the pieces melt together. Screened lumps of noncoking coal or briquetted fuel are best adapted for retorts of the internally heated type.

The chief disadvantage of introducing hot combustion gases into the charge is the dilution of the distillation products. The resultant large volume of gas of low calorific value must be used at the point of production, and the light oils have too low a partial pressure to be profitably recovered by passing the gas through oil scrubbers. Superheated steam has the advantage of a greater heat-car-

![Diagram](image.png)

**Figure 15.**—Maclaurin carbonizing plant

rying capacity than noncondensable gases, but it in turn involves the loss of the latent heat of the steam and the extra cost of a superheater, satisfactory designs of which are not yet available for the temperatures required. Nevertheless, the low first cost and the simplicity of internally heated retorts have led to many designs based on this principle, some of which are now in large-scale experimental operation.

**COAL IN SCREENED LUMPS OR BRIQUETS DIRECTLY HEATED BY HOT GASES GENERATED BY AIR BLOWN INTO THE RETORT**

**MACLAURIN LOW-TEMPERATURE CARBONIZATION PROCESS**

The Maclaurin retort (fig. 15) is essentially a large by-product recovery gas producer in which part of the semicoke is burned to pro-
ducer gas, the sensible heat of which carbonizes the descending charge of coal. The experimental producer near Glasgow, Scotland, is square in cross section, about 45 feet high, and 8 feet wide at the widest part. The air blast is introduced about 12 feet above the discharge doors through a large number of narrow ports in opposite side walls, and also by similar ports in a dividing wall which is carried across the center of the retort at the same level. The coke is cooled in the zone below the air ports by steam injected at the discharge doors; part of this steam ascends through the coke and becomes

heated and partly decomposed into water gas, then passes upward and mixes with the producer gas formed in the combustion zone. The raw coal is fed from an elevated hopper through a bell into the top of a cylindrical steel tank, 8 feet in diameter and 10 feet high, that rests on the brickwork at the top of the retort. The tank serves as a condenser for the oils and tars that drain down the side of an inner steel cylinder which dips into the well formed by a dished flange at the bottom of the tank. From the annular space between the tank and the cylinder the gases are led to tower coolers and scrubbers.

The capacity of the retort is about 20 tons of coal per 24 hours. The coal should not be strongly coking, otherwise the charge will
stick and not descend uniformly and the hot gases will not be distributed evenly throughout the charge. The retort can be used for complete gasification or for production of smokeless fuel; the adjustments necessary are in the regulation of the air blasts and the gas outlet valves. The operating temperatures are 750° C. at the air tuyères, 200° C. at the bottom of the steel tank on the top of the brickwork, and 60° to 80° C. in the gas oftake.

The semicoke produced (fig. 16) is but slightly fused and of low density; it is not a high-class domestic fuel—nevertheless, the Glasgow Gas Corporation has installed a battery of five producers at Dalmarnock aggregating 100 tons of coal per day at the gas plant for the purpose of supplying gas for heating vertical gas retorts and at the same time producing low-temperature coke for use as smokeless domestic fuel. The corporation expects a yield of 22,000 to 27,000 cubic feet of gas giving 240 B. t. u. per cubic foot, 12 to 17 gallons (U. S.) of dry tar oil, and 14 to 15 pounds of ammonium sulphate per short ton of coal.

Since this is a full-size commercial plant for which reliable figures of cost can be obtained, the results will be watched with great interest, especially the popularity of the smokeless fuel. It is a real question whether the public will be willing to pay a sufficiently high price for this fuel to cover the cost of manufacture. Figure 17 is a plan, and Figure 18 a general view of the new plant at Dalmarnock. ¹⁴

HOOD-ODELL LIGNITE-CARBONIZING PROCESS ¹⁵

The Hood-Odell oven for carbonizing lignite (see figs. 19 and 20) is similar in principle to the Macleurin retort, except that no by-products are recovered. The sole object is to convert brown lignite, which contains 35 to 40 per cent of moisture, into a stable, usable solid fuel. The oven is cheaply constructed from standard refractory materials. The first cost is low and the throughput per unit is high. About 50 to 60 per cent of the carbonized material can be screened out for direct use as domestic and industrial fuel; the remainder can be briquetted to form a high-grade domestic fuel.

The experimental oven was 6 feet long and carbonized 16 tons per 24 hours.

POWDERED COAL CARBONIZED BY HOT GASES

As the time of carbonizing a lump of coal by hot gases decreases with the size of the lump it follows that pulverized coal introduced into a stream of hot gases can be carbonized very rapidly.

M'EWEN-RUNGE PROCESS

Probably the most interesting event of the year from the standpoint of the power-plant engineer is the announcement that the International Combustion Engineering Corporation has contracted with the North American Co. to construct a 210-ton per day experimental plant for the low-temperature distillation of pulverized coal at the Lakeside plant of the Milwaukee Electric Railway & Power

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Co. by the McEwen-Runge process. This is a process\textsuperscript{17} for recovering by-products from pulverized coal by an internal heating method such that the carbonized residue can be used directly as pulverized fuel without repulverizing. The heating is so designed that the primary gaseous products can be recovered with minimum dilution

![Diagram of Hood-Odell lignite carbonizer](image)

**Figure 19.—Hood-Odell lignite carbonizer**

by inert heating gases, and these products are said to be rich enough for distribution as town gas.

Briefly, the process is two stage. It is carried out in two vertical cylindrical retorts (fig. 21), the first stage being superimposed on the second. The function of the first stage is drying and the removal

\textsuperscript{17} Mining Mag. (London), vol. 33, October, 1925, pp. 195–196.
Figure 20.—Carbonizing oven used in tests of North Dakota lignite. (See fig. 19 for sectional view.)
Figure 21.—Diagrammatic arrangement of McEwen-Runge process of low-temperature carbonization
of some water of constitution with CO₂. The heating is counter-current; hot combustion gases (700° F.) and air containing heat recovered from the carbonized residue are passed in at the base of the first retort, where they meet a descending stream of pulverized coal, giving up their heat to it. After passing through the retort these gases contain little combustible matter and are rejected. The hot coal falls into a bin, from which it is fed mechanically into the second stage retort. The descending coal is carbonized by (1) pre-heated distillation gases, (2) products of combustion introduced into the tower, or (3) products of combustion generated within the retort by the admission of a suitable quantity of hot air. The maximum temperature here is 1,500° F. Auxiliary apparatus includes the usual coolers and scrubbers for removal of the tar from the gas. The process is continuous—requiring six minutes for both stages—and the units proposed will have a capacity of 210 tons a day. The proposed process goes to the ultimate extreme in rapid transfer of heat to the coal and has possibilities of high throughput in equipment of relatively low cost; but the mechanical difficulties to be solved seem very great, especially the separation of the fine dust from the vapors.

Consumers of pulverized fuel evidently have faith in the pretreatment of pulverized coal and the recovery of by-products in connection with power generation at central plants. It will be recalled that the Caracristi-Piron process at the Ford Motor Co. was designed to pretreat coal for a power plant burning pulverized fuel. This process seemingly struck a snag when put into operation, as nothing has been heard about it during the last year.

**COMPLETE GASIFICATION**

In the report of the Giant Power Survey Board of Pennsylvania, issued in February, 1925, this statement appears on pages 381 and 382:

The outstanding commercial installation representative of by-product complete gasification processes is that of the Combustion Utilities Corporation, sometimes called the Doherty process. A plant was put into operation at the Hazel-Atlas glass factory at Washington, Pa., in the summer of 1924, following years of experimental plants in Denver, Colo., and Toledo, Ohio. (See fig. 22.)

The main problem of this type of process is to overcome the binding or sticking of the charge of coking coal within the retort, which has been the major source of trouble in all gas producers attempting large production with our eastern melting bituminous coals.

The retort may be classed as of the vertical stack, internally heated, continuous operation, semicombustion, gasification type, with recovery of tars

---

and ammonia, producing large volumes of low B. t. u. gas of about 160 to 210 B. t. u. As constructed, the stack is about 100 feet high and about 26 feet outside diameter at the base.

High-volatile bituminous coal, crushed and mixed with a proportion of coke sufficient to keep the mass from becoming too pasty at any stage of the process, is charged continuously. A controlled air blast enters a few feet above the bottom. Preheating the air blast increases the rate of formation and especially the heating value of the gas. A portion of the coked charge

accompanied with ash is withdrawn at frequent intervals at the bottom. The coke is screened and washed to separate it from the ash. The coke comes out in small pieces from nut size down to small granules. The coke is used to mix with raw coal to be charged again into the retort at the top.

The retort can be so operated that less but richer gas is obtained up to about 300 B. t. u. per cubic foot, and a large proportion of coke is withdrawn, so that some becomes available for sale or use as a power-plant fuel.

The plant described has been in operation more or less completely during the past two years. No definite operating data have yet been
published and it is not known whether a good quality of dust-free tar is obtained in regular operation. The plant includes Cottrell precipitators for cleaning the gas and Sharples supercentrifuges for dewatering the tar.

COAL HEATED BY HOT PRODUCTS OF COMBUSTION GENERATED OUTSIDE THE RETORT PROPER

SEIDENSCNUR-PAPE PROCESS

The Seidenschnur-Pape Process is of interest because it makes use of hot products of combustion, free from oxygen, for drying and distilling brown coal in two separate stages. I saw an experimental plant of 5 to 6 tons capacity per 24 hours at Freiberg, Saxony, in 1924. Figure 23 illustrates the principle of the process.

The raw brown coal containing 40 to 50 per cent moisture is charged into the drying chamber \( a \); thence it descends into the distillation chamber \( b \), where oxygen-free flue gases from the combustion chamber \( d \) enter at the bottom and leave at the top at a temperature of about 100° C., and then pass to the tar-recovery apparatus. From \( b \) part of the carbonized residue goes to the gas producer \( e \) for generating the necessary fuel gas for the process; the remainder is discharged through a cooling chamber. It is used as a domestic fuel in special stoves designed to burn it and is known as "Braunkohlenflammkoks."* The coke is in fine grains, is quite smokeless, and burns with a short flame. It is said to contain 20 to 30 per cent of tar-free volatile matter that is combustible.

The hot producer gas from \( e \) passes directly into the combustion chamber \( d \), where it is burned without excess of air; the necessary amount of air is supplied from the blower \( f \). The temperature

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of the hot gases entering the distillation chamber is further regulated by admixing a suitable amount of inert gases from the drying chamber through the blower. A suitable portion of the hot combustion gases from is constantly added to the drying-gas circuit in the mixing chamber.

Figure 24 illustrates one scheme of circulating the gases. The experimental plant that I saw was arranged for other combinations as well, including the use of superheated steam.

LURGI PROCESS

The Lurgi company at Frankfort, Germany, is also working on a similar scheme of circulating combustion products through a drying and a carbonizing zone (see fig. 24). As brown coals contain about 50 per cent moisture much more heat is required for
drying than for carbonizing the coal. The drying chamber temperature is approximately 250° C. and that of the carbonizing chamber about 500° C. The following results are reported on a 13-ton a day experimental unit: 20

Material: Earthy brown coal, of 45 per cent water, 7.5 per cent ash.

Net heating value, 3,000 calories; tar content according to Graefe method, 8.74 per cent.

Throughput per 24 hours, 13.75 tons (metric).

Additional brown coal used in gas producers for fuel gas, 13 per cent.

Yield of:

Semicoke .......................................................... per cent... 29.81
Tar ................................................................. do... 8.28
Light oil .......................................................... do... .66

Analysis of crude tar:

Specific gravity at 44° C.-----------------------------  .925
Setting point....................................................° C... 41.5
Insoluble in benzol............................................ per cent.. .12
Water content .................................................... do... .07
Paraffin content................................................ do... 11.0

Analysis of semicoke:

Net caloric value............................................calories... 6,200
Ash .............................................................. per cent... 22.5
Volatile matter ................................................ do... 15.0

Neither of these processes is yet in commercial operation.

COAL HEATED BY SENSIBLE HEAT OF HOT PRODUCER GAS GENERATED BY SEPARATE PRODUCER, OR BY REHEATING AND RECIRCULATING LOW-TEMPERATURE GAS

LAING-NIELSEN "SENSIBLE HEAT" PROCESS

Laing and Nielsen, of England, have designed a low-temperature carbonization process in which the coal is heated directly by hot producer gas, water gas, or reheated coal gas circulated through the interior of the retort.

The cylindrical steel retort is lined with fire brick and lagged on the outside with heat-insulating material. The coal is charged continuously into the upper end of the inclined cylinder and travels toward the lower end over a system of baffles designed to secure intimate contact with the hot gas that enters at the lower end of the retort. Figure 25 shows the plan of a plant to make 100 tons a day. An experimental plant 21 of approximately 15 tons a day has been erected at Barugh, near Barnsley, England.

The retort is about 45 feet long and 3 feet in outside diameter. The distilling medium can be (1) combustion products of producer

---

gas, (2) straight producer gas carrying the sensible heat of the gas reaction, (3) superheated water gas, and (4) a reheated circulating gas. The temperature of the distilling medium entering the retort is generally about 650° to 700° C., and it leaves the retort at a temperature not below 150° C. It has been found that the temperatures of the coal itself are 100° to 120° C. lower. Dust from the distillation gases is separated in cyclone dust catchers in which no tar is said to condense. The heavy tars and those of high boiling point are separated in two annular air-cooled condensers; but most of the oil passes into the water-tube condensers and the boosting fan, which also acts as an efficient oil separator. From there the gas passes through a "P. & A." separator, a final water-tube condenser, and two scrubbing towers through which wash oil can be circulated. The gas after being freed from its liquid products can be recirculated or led to wherever it is wanted.

**Figure 25.—"Sensible heat" (Nielsen) process. Producer-gas system.**
The accompanying figures are based on a series of tests made with Barnsley bed coking smalls:

**Analysis of coal:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>4.33</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>32.77</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>55.78</td>
</tr>
<tr>
<td>Ash</td>
<td>7.12</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

**Analysis of semicoke:**

<table>
<thead>
<tr>
<th>Component</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture</td>
<td>Nil</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>10.15</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>80.95</td>
</tr>
<tr>
<td>Ash</td>
<td>8.90</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100.00</strong></td>
</tr>
</tbody>
</table>

**Yields per short ton of raw coal:**

<table>
<thead>
<tr>
<th>Product</th>
<th>Per cent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semicoke</td>
<td>70.5</td>
</tr>
<tr>
<td>Oil (crude)</td>
<td>19.3</td>
</tr>
</tbody>
</table>

Gas, 3,000 cubic feet, 610 B. t. u. net per cubic foot at 60° F.
Oil from condensers, 92.6 per cent = 17.8 U. S. gallons.
Oil from gas scrubbing, 7.4 per cent = 1.43 U. S. gallons.

**Standard fractionation of condenser oil (Engler)**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Per cent by weight</th>
<th>Specific gravity</th>
<th>Fraction</th>
<th>Per cent by weight</th>
<th>Specific gravity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° to 170° C</td>
<td>0.3</td>
<td>0.860</td>
<td>360° to 400° C</td>
<td>18.5</td>
<td>1.026</td>
</tr>
<tr>
<td>170° to 230° C</td>
<td>13.1</td>
<td>0.945</td>
<td>Pitch coke</td>
<td>15.2</td>
<td></td>
</tr>
<tr>
<td>230° to 270° C</td>
<td>19.5</td>
<td>0.977</td>
<td>Oil from gas scrubbers</td>
<td>8.22</td>
<td></td>
</tr>
<tr>
<td>270° to 300° C</td>
<td>31.2</td>
<td>0.987</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Water in crude oil after 24 hours settling... per cent... 3.3 to 5.5
Tar acids in crude oil... do... 42
Sulphur in crude oil... do... 0.32
Flash point of Diesel fraction, 270° to 300°, 195° F.

**Thermal balance**

<table>
<thead>
<tr>
<th>Product</th>
<th>Therms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total heat in raw coal on dry basis</td>
<td>201</td>
</tr>
<tr>
<td>Total heat in raw coal as received</td>
<td>272</td>
</tr>
<tr>
<td>Recovered as semicoke</td>
<td>70.5 = 191.3</td>
</tr>
<tr>
<td>Recovered as oil</td>
<td>10.4 = 28.4</td>
</tr>
<tr>
<td>Recovered as gas</td>
<td>8.3 = 22.7</td>
</tr>
<tr>
<td><strong>Total recovered, gross</strong></td>
<td>89.2 = 242.4</td>
</tr>
</tbody>
</table>

Heat requirements in process:

<table>
<thead>
<tr>
<th>Component</th>
<th>Therms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture, 4.33 per cent—Heating, evaporation and superheating</td>
<td>1.175</td>
</tr>
<tr>
<td>Semicoke, 70.5 per cent—Leaving at 550° C</td>
<td>4.025</td>
</tr>
<tr>
<td>Oil, 10.4 per cent—Heat of formation, etc.</td>
<td>0.925</td>
</tr>
</tbody>
</table>
Distillation gas:
Useful heat per cubic foot between 650° C. and 150° C. = 15.85 B. t. u.
per cubic foot = 0.0001585 therm.
Total quantity of gas circulated = 44,000 cubic feet, leaving at 150° C. = 2.080
Radiation losses in retort, etc., and difference = 849

Total heat in 44,000 cubic feet of gas at 650° C. = 9.054.

This heat was provided by gasifying coke in a gas producer and
burning the producer gas with secondary air. The over-all efficiency
of the combustion is 50 per cent. Hence the therms required as
coke = 9.054 × 100 ÷ 50 = 18.1 therms = 6.64 per cent. The net heat re-
covery is, therefore, 242.4 − 18.1 therms = 224.3 therms, or 82.56 per
cent.

Figure 26 shows a proposed arrangement for recirculating stripped
and superheated coal gas. It is hoped by this scheme to obtain a
high B. t. u. gas approaching that of externally heated retorts and
yet retain the advantages of internal heating. Valuable experimental
data should be obtained in this plant.

USE OF SUPERHEATED STEAM

At first thought superheated steam may seem to be the best medium
of heat transfer for low-temperature carbonization. It has a rela-
tively high specific heat, it does not dilute the distillation gases, and
it permits the recovery of the light oils from the gases. Two strong
objections, however, have prevented the development of any promis-
ing process using steam alone. These are (1) the large heat losses in
the latent heat of vaporization, combined with a large and costly con-
densing system, and (2) the cost of superheating equipment that will
resist the strong corrosive action of steam superheated to the degree
necessary for carbonization.

The auxiliary use of a small quantity of steam in other processes
has been of some advantage in distributing heat through the charge
and in increasing ammonia yields, as, for example, in the Scottish oil-
slate process.

COAL HEATED BY DIRECT CONTACT WITH MOLTEN LEAD

Several patents have been issued for heating crushed coal in direct
contact with molten lead, whereby carbonization is completed in a
few minutes. The unavoidable loss of lead, however, makes these
processes too expensive for practical consideration.

\textbf{Figure 26. - "Sensible heat" (Nielsen) process. Superheated circulating gas system}
TWO-STAGE PROCESSES IN WHICH COAL IS PREHEATED BEFORE CARBONIZATION

Several processes for the low-temperature carbonization of coking coals have been proposed in which the coal is preheated to a temperature below the plastic temperature before it is charged into the carbonizing retort proper. Such pretreatment, especially when done in the presence of some oxygen, largely destroys the coking properties of the coal, so that it does not stick to the walls or clog the retort. Usually the first stage of heating is done in a rotary or stirred retort, but the preheating may also be done in an internally heated vertical shaft retort. According to A. R. Powell the advantages claimed for preheating are as follows:

1. The coal is dried before charging. Before the coal carbonizes in the retort it is necessarily dried by the oven heat, but the thermal efficiency and capacity of a drier where the coal may be kept in motion in a steel chamber before putting into the oven is much higher than the oven itself would be.

2. Sensible heat is introduced into the coal before charging. For the same reason as above the coal temperature is raised to just below the fusion point of the coal much more efficiently in a preheater than it would be in the oven.

3. The amounts of various coal components are said to be changed by the preheating so as to favor the production of good coke.

4. The preheating is said to produce conditions favoring autogenous carbonization by exothermic reactions.

The two best examples of two-stage processes are the Parr process and the Illingworth process. Powell describes these processes as follows:

PARR PROCESS

The process of low-temperature distillation devised by Parr and Layng in America has been one of gradual evolution. At the present time the retort used is a vertical cylinder externally heated, and has no novel mechanical features. The method claimed for heat transfer is different from those that have been described under the preceding headings. The claim is made that certain classes of coal, particularly Illinois or other high-oxygen coals, will give out heat during carbonization and this heat will be sufficient, provided the coal has been preheated to a certain degree, to carbonize the coal autogenously. In other words, the preheated coal is charged into the retort and then just sufficient temperature is kept at the outside of the retort to start the exothermic coking reaction in the outer layer. The claim is made that this exothermic reaction will then pass comparatively rapidly to the center of the retort and coking will be

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24 See footnote 23.
completed without a physical transfer of heat units from the outer wall to the interior.  

**ILLINGWORTH PROCESS**

The Illingworth process is essentially one of pretreatment in order to improve the coking quality of coal. The pretreatment consists in preheating the coal in an inert atmosphere so as to assure a selective decomposition of certain constituents which, if allowed to remain, have a bad effect on the quality of the coke produced.

**COMPARISON OF VARIOUS SYSTEMS**

From a consideration of the many different processes that have been and are being tried experimentally it is evident that no one process has yet proved an unqualified technical success. Each has its peculiar problems yet to be solved and a number have shown promise under certain favorable conditions. The processes that depend on internal heating are simpler and require less capital expenditure per ton of coal carbonized, but they are limited to non-coking coals, weakly coking coals, or briquetted or pretreated coals; also the gas is of low calorific value and the light oils can not be recovered from the diluted gas except when the heating agent is superheated steam. Such processes, however, are promising for future development in combination with large central power plants or industries using large quantities of gas of low heating value when diminishing supplies of petroleum shall create a demand for the oils obtainable by low-temperature carbonization.

The processes that show relatively higher costs and use externally heated retorts will probably find their most advantageous field in making relatively high-priced smokeless domestic fuel from a cheap noncoking or poorly coking coal and producing also a gas of high thermal value. These processes also yield several gallons of light oil that is not to be had from internally heated processes. Local economic conditions and the type of coal available are important factors governing the selection of the most suitable process.

**PRODUCTS OF LOW-TEMPERATURE CARBONIZATION**

The quantity and quality of the carbonization products depend on the type of coal used and the heat treatment the coal receives in the process. High-temperature processes yield hard cellular coke and crack the primary tars into fixed gases, aromatic light oils, and vis-

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ous tars containing phenols, cresols, anthracene, naphthalene, and other aromatic compounds. Low-temperature processes yield softer semicoke, which retains 7 to 15 per cent of volatile matter, and also yield uncracked and but slightly decomposed primary tars and oils containing paraffins, naphthalenes, cresols, xylenols, and higher phenols. The volume of the gas is only one-fourth to one-third that obtained in high-temperature coking, but the calorific value per cubic foot is almost twice as high. From both processes the quantity of light oil suitable for motor fuel is about the same, but the composition of the oil is quite different. The low-temperature process yields saturated and unsaturated paraffins, hydrocarbons, naphthalenes, and complex aromatic hydrocarbons; the high-temperature process yields benzol, toluol, and xylol.

The total yield of tar at low temperatures is about twice that obtained at high temperatures, but the ammonia yield is only one-third to one-half as much.

These comparisons apply to externally heated retorts. Internal heating dilutes the light oil vapors to a point where recovery is impracticable by present methods and produces large volumes of gas of low calorific value.

Table 3 gives approximate yields of high-temperature processes and the two main types of low-temperature processes—externally heated and internally heated retorts.

**Table 3.—Approximate comparative yields of high and low temperature carbonization processes**

<table>
<thead>
<tr>
<th></th>
<th>High-temperature carbonization</th>
<th>Low-temperature carbonization</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>by-product coke oven</td>
<td>Externally heated retort</td>
</tr>
<tr>
<td>Coke</td>
<td>60-70</td>
<td>70-80</td>
</tr>
<tr>
<td>Volatile matter in coke</td>
<td>1-2</td>
<td>7-15</td>
</tr>
<tr>
<td>Gas</td>
<td>11,000-12,000 cubic feet per ton</td>
<td>3,000-5,000 cubic feet per ton</td>
</tr>
<tr>
<td>Calorific value of gas</td>
<td>520-580</td>
<td>800-1,000</td>
</tr>
<tr>
<td>Tar</td>
<td>10-12</td>
<td>20-30</td>
</tr>
<tr>
<td>Specific gravity of tar</td>
<td>1.19</td>
<td>1.07-1.09</td>
</tr>
<tr>
<td>Light oil for motor fuel</td>
<td>2.5-3.0</td>
<td>2.5-3.0</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>25-30</td>
<td>10-12</td>
</tr>
</tbody>
</table>

An analysis of these yields shows that the only increased return is the 15 gallons more of tar oil per ton of coal carbonized over that now being recovered in standard by-product ovens. As the price of this tar is determined by the prevailing price of fuel oil (about 5 cents per gallon), the additional credit is only 75 cents per ton of coal. Against this credit must be charged less ammonia, about 35
cents per ton of coal, and a lower yield of gas. Obviously the by-products of low-temperature carbonization do not to-day afford a much greater financial return than those of existing methods of high-temperature carbonization.

IMMEDIATE FUTURE OF LOW-TEMPERATURE CARBONIZATION PROCESSES

Where then is the possibility of profit in the low-temperature carbonization of coal in America under present economic conditions? This is a hard question to answer. Most fuel technologists experienced in gas and coke manufacture are skeptical of any low-temperature process being commercially successful in the near future. They point out that the main product of the processes is semicoke. This product must find an adequate market at a price that will make the process profitable in competition with gas and by-product oven coke. It is not likely that any higher price can be had than the prevailing price of high-temperature coke sold for domestic purposes. Furthermore, this low-temperature coke from many of the proposed processes is too friable and porous to be used directly as a domestic fuel; it must first be briquetted, and this operation adds further cost.

In reply to these objections it is admitted that the commercial success of low-temperature carbonization of coal in the near future must depend mainly on the sale at an adequate price of the solid product—smokeless fuel—rather than on the liquid and gaseous by-products. The by-products are important contributing factors, but they can not carry the entire cost of processing the coal under the present competition of petroleum fuels. However, it does not follow that low-temperature carbonization can not be developed to make a high-priced fuel from low-priced noncoking coals. In the Central and Western States there is relatively little coking coal, and the noncoking coals are not suitable for by-product coke ovens. Because of the fairly large margin between the cost and the selling price of the processed fuel it seems possible to work out a low-temperature process that can compete with high-temperature processes which require more expensive raw material in supplying the smokeless fuel requirements of this region.

IDEAL FUTURE PROCESS OF COAL CARBONIZATION

In conclusion, I wish to emphasize the fact that the low-temperature carbonization of coal furnishes a yield of gasoline substitutes that is little if any larger than that obtainable from existing high-temperature processes. Low-temperature tar is essentially a fuel-oil substitute. Increased yields of gasoline require the hydrogenation
and cracking of these tars, or reduction of the phenols. A more promising method for producing fuels of low boiling point is by direct synthesis from carbon monoxide and hydrogen.

Some time in the near future, when petroleum becomes scarce, an ideal combination process of carbonization may be developed which will provide the necessary substitutes for oil and gasoline. In this ideal process the full yield of primary oils will be extracted from the coal by carbonizing at gradually increasing temperatures to remove all the volatile matter from the coke. Then the coke will be converted by way of the water-gas reaction to carbon monoxide and hydrogen which, when heated under high pressures (100 to 200 atmospheres) in steel autoclaves in the presence of suitable catalysts, may be converted into alcohols suitable for motor fuel. Doctor Fischer, of the Institute for Coal Research at Mülheim-Ruhr, has succeeded in making such a mixture of alcohols ranging from methanol to an alcohol containing 9 carbon atoms. This mixture, which he terms "synthol," was made at 150 atmospheres pressure and 400° C. by use of a catalyst composed of iron oxide impregnated with alkali. The fuel gave satisfactory service in a motor-cycle engine. Methanol is now made in Germany by a similar process in copper-lined autoclaves, with zinc oxide as catalyst, at a manufacturing cost of 18 cents a gallon.

The Bergius process recently developed in Germany for converting coal into oil also offers great possibilities for the treatment of western bituminous and subbituminous coal. In this process, as used at Mannheim, pulverized coal, mixed with oil or tar to form a thick paste, is heated at 400° to 450° C. in a steel autoclave under a pressure of 150 to 200 atmospheres of hydrogen. Under these conditions the coal is converted into a black, tarry liquid which, on distillation up to 300° C., yields oils and tar to the extent of 30 to 60 per cent of the weight of the coal. The by-products are ammonia and gas.

Bergius gives the following yields for 1 ton of a bituminous coal of 6 per cent ash:

<table>
<thead>
<tr>
<th>Products from 1 ton of coal by Bergius process</th>
<th>Gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor fuel</td>
<td>42</td>
</tr>
<tr>
<td>Diesel-engine oil</td>
<td>56</td>
</tr>
<tr>
<td>Lubricating oil</td>
<td>17</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>22</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>137</strong></td>
</tr>
</tbody>
</table>

Gas, 10,000 cubic feet.
Ammonia (NH₃), 10 pounds.
Coke residue, 500 pounds.

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This process can most certainly provide us in the future with ample quantities of substitutes for the products we now get from petroleum. Our reserves of coal are ample for many years. The time when such a process can be profitably worked will be determined by the exhaustion of our present abundant supply of petroleum. No one can predict the date. It may come before we expect it.