carbon dioxide (7 to 8 per cent in Texas lignites). It is this 32 to 40 per cent incombustible volatile matter which causes briquets made from raw lignite to explode in the fire. Hence lignite must be retorted to render it fit for briquetting. The question arises: What is the most economic extent of retorting? For our experimental study of this question, the lignite used was obtained in the open market in Austin, but all of it was from the same mine. The lignite thus obtained was of rather mediocre quality. To our knowledge better lignite can be obtained even at this mine and certainly in other localities, but what we used is representative of much of the lignite now sold in Texas; hence, the figures presented below may be considered to be safe for all commercial lignites in Texas, but low for specially good lignites.

In our first set of experiments we retorted lots of 10 lbs. each in powdered form with constant stirring and fractionated the gas evolved as the temperature was raised. These experiments revealed:

- (1) The fact that the evolution of carbon dioxide ceases abruptly at about 525° C.
- (2) That the per cent by volume of carbon dioxide in the gas collected up to this temperature is from 23 to 33 per cent.
- (3) That the other constituents of the gas evolved up to 525° C. have high calorific powers, so that the mixture has a calorific power of 410 B. t. u.
- (4) That all the tar is evolved with this gas.

These results were obtained also with a different kind of a lignite from a totally different field. The gas fractions obtained at temperatures higher than 525° C. have heating powers of 410 B. t. u. per cu. ft. or less, and the total amount of gas obtainable by retorting a ton of this lignite is not more than 6500 cu. ft. (the lignite from another region gave 6900 cu. ft.), with an average heating power of the whole gas of 410 B. t. u. This result is in marked contrast with the 10,000 cu. ft. of 400 B. t. u. reported heretofore.

The coke left after complete retorting has an ash content of 25 to 28 or even 30 per cent and a heating power of 10,000 B. t. u. or below. The relatively poor quality of this coke and the fact that the gas obtained with it would have to be enriched to make it fit for "city use" led us to consider the feasibility of retorting the lignite with a maximum temperature of 525° C. It was evident that by removing as much as possible of the large per cent (about 30 per cent) of carbon dioxide from the gas obtained up to 525° C., its heating power could be raised substantially, and a simple trial showed that this could be done readily to such an extent as to make the gas directly fit for "city use."

To try out this whole procedure on a sufficiently large scale, we constructed an apparatus which retorted 1100 lbs. of lignite per 24 hrs. and purified all the gas. The retort was a 6-in. cast-iron pipe placed vertically and surrounded by a brick furnace 7 ft. high, with gas burners at the bottom. The low temperature required made it easy to operate in such a manner as not to injure the iron retort; its life is likely to be great. The amount of gas obtained was 2250 to 2500 cu. ft. per ton of raw lignite with a heating power of 525 to 540 B. t. u.; the yield of coke was 900 lbs. of 11,000 B. t. u. (or more!), and the yield of dry tar was 2 per cent. The carbon dioxide was removed down to 2 per cent by means of potassium and sodium carbonate solution.

Calculation shows that the amount of lignite needed as fuel for retorting is about 7.5 per cent of the lignite retorted. The coke comes out of the retort at a temperature just high enough for briquetting, and not so high as to take fire on exposure to air.

The advantages of this procedure are:

- (1) A coke of the highest heating power obtainable.
- (2) A gas immediately usable in city mains.
- (3) The maximum amount of tar obtainable.
- (4) A cheap retort with large capacity, operating under mild conditions, and yielding the coke at a temperature at which it can be easily and immediately handled for briquetting.

PROF. PARR: I would like to ask Mr. French if he expects sufficient binder for his briquet to come from the tars. One of his numerical factors especially interests us. He says 7 per cent of heat is lost in the final accounting for the heat. If he finds it possible to locate, with sufficient accuracy, those percentages of heat in the various constituents, and then say pretty accurately here is 7 per cent of heat unaccounted for, we would like to know about it. It is one method of getting at the exothermic quantity of heat. Seven per cent of 4000 cal. would be somewhere within the range where we think the measurement of quantity of exothermic heat resides. That factor, 7.6, is exceedingly interesting to our work.

MR. FRENCH: A remark of Prof. Schoch's reminds me I should mention some things myself. We found exactly the same things in the beginning of our work that he did. We never got 10,000 cu. ft. of gas or anything like it. I suggest that some of those high figures may be due to the method of carbonization, because I know of one case where a man was actually operating a carbonizer so designed that they fed moist coal to it. The moisture that was driven off passed through the hot charge and what you got was a gas producer on a small scale. This person may have got 12,000 or 20,000 cu. ft. of gas, but he was getting it at the expense of his residue. I judge from Prof. Schoch's remarks that he was primarily after gas. We were after residue, and it appears that with our own carbonizers we had just about enough to operate the carbonizers, and not much more.

Mr. Stansfield ran a series of experiments in the small retorts under pressure, vacuum, and with a steam atmosphere, but none of these seemed to show any advantage, and he went back to practically atmospheric pressure.

In answer to Prof. Parr's question on tars, we took the tar and distilled it at 325° C. On that basis, we got what we called "available binder," a quantity of pitch representing 2.5 to 3 per cent of the carbonized residue, and that is not sufficient. It is probably not a quarter of what is required. It takes a large quantity of binder to make residue briquets, because physically the residue more nearly resembles charcoal than it does coke. I imagine it will be similar to some coke which Prof. Parr has here.

Answering Dr. Porter, the water is the water of constitution. It is dry coal. It is dried at 105° C., and that is the water left after drying.

Returning to Prof. Parr, so far as loss of heat is concerned, I would prefer that Mr. Stansfield should answer that question himself, because I do not know very much about his calculations, except that I have a number of them, and I know the loss of heat always runs around the figures given.

THE COMMERCIAL REALIZATION OF THE LOW-TEMPERATURE CARBONIZATION OF COAL

By Harry A. Curtis

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The process herein described was developed for converting bituminous coal into a uniform, smokeless fuel resembling anthracite in properties. It was recognized at the outset that the problem was one in which small-scale tests alone would not yield the necessary data for plant design, and while much valuable information has been secured in small apparatus, the development of the process has been very largely through use of commercial-size units. For the past four and a half years large-scale experimental work has been carried on in parallel with laboratory tests. The experimental plant, as finally developed, has a capacity of about 100 tons of raw coal per day, but

GENERAL VIEW OF PLANT

since it was built only for experimental work, no attempt has been made to operate all units at capacity. In the course of experimental tests, the conversion of coal has, however, frequently reached 40 tons per day, and recently one of the commercial units was run continuously for 5.5 mo. without a shutdown. The experimental plant is fully equipped to handle all the by-products, and includes a tar distilling unit of 100,000 gal. per month capacity to work up the tar into the usual crude products.

During the World War construction of a commercial plant was begun, as a government war project. This plant was eventually completed and half of the retorts put into operation in June 1920. The usual minor difficulties of a new plant have been overcome without trouble and the balance of the retorts are now being put into operation.

DESCRIPTION OF PROCESS

The essential steps in the process are briefly as follows:

The raw coal is crushed and subjected to low-temperature distillation in horizontal retorts, the coal being continually stirred and advanced through the retort by paddles mounted on two heavy paddle-shafts running lengthwise through the retort. The retort is heated externally in a gas-fired furnace, and the by-products are collected essentially as in coke-oven practice.

During this low-temperature distillation, 850° to 950° F. in the gas phase, the volatile matter in the coal is reduced from, say, 35 per cent to about 10 per cent, the resulting semi-coke, being a soft, porous material considerably different from ordinary coke in structure. It can be used directly in a water-gas producer or as a boiler fuel, either hand-fired or with mechanical stokers. The material is not, however, in good shape for transportation and marketing away from the plant. The next step consists in grinding

the semi-coke, mixing it with hard pitch and briquetting. The resulting briquets are somewhat like the ordinary coal briquets on the market, except that they burn with but little smoke. The final step consists in charging these briquets into an inclined retort and carbonizing them at about 1800° F. for 6 hrs. During this carbonization the pitch is coked and the volatile matter in the briquet reduced to about 3 per cent. There is a shrinkage of approximately 30 per cent in the size of the briquet and the final product is a hard, uniform fuel, which burns with an entirely smokeless flame. Its structure is still markedly different from that of metallurgical coke, and the fuel burns more freely than coke.

COALS SUITABLE FOR THE PROCESS

At the experimental plant more than a hundred coals have been put through the process, and in no case has it been found impossible to make a satisfactory product. The procedure in briquetting has had to be varied considerably with different coals, but the hard, smokeless briquet has finally been produced in every case.

Since the ash in the coal is accumulated in the product, it is desirable, although not imperative, that the ash in the coal be low. Also, if a high yield of by-products is desired, a bituminous coal of high volatile content should be used. The process, however, can be applied to any coal.

It is, perhaps, of interest to mention that several lignites have been successfully treated, including those of Texas, Wyoming, Colorado, Saskatchewan, Japan, and Brazil.

BY-PRODUCT YIELDS

The yield of by-products in any carbonizing process will, of course, depend on the kind of coal used. In Table I is given the average yield of various by-products from twenty-nine different bituminous coals in which the volatile matter ran from 32 to 41 per cent, averaging

37 per cent. These results are from small-scale testing, charging about 33 lbs. of coal in the retort and making three to six charges to each test.

In comparing these results with those obtained by others working on the problem of low-temperature carbonization, it must be remembered that in the process under consideration both low- and high-temperature carbonization are used, and the yields obtained in the primary or low-temperature carbonization are augmented by those from the subsequent high-temperature carbonization of the briquets. It must also be borne in mind that the pitch, which is one of the usual by-products, is returned to the process, and yields, on carbonization, some by-products in addition to the pitch coke which remains in the briquet.

TABLE I—AVERAGE RESULTS FROM TWENTY-NINE COALS RUNNING OVER 32 PER CENT VOLATILE MATTER

Average Analysis of Coal (Dry)	
	Per cent
Volatile.....	36.9
Fixed carbon.....	56.0
Ash.....	7.1
TOTAL.....	100.0
Sulfur.....	1.1
B. t. u.....	13,783
Average Analysis of Finished Briquets	
	Per cent
Volatile.....	3.8
Fixed carbon.....	85.1
Ash.....	11.1
TOTAL.....	100.0
Sulfur.....	0.68
B. t. u.....	12,874
Yield, per cent.....	66.1
Yields of By-Products per Ton Dry Coal	
Dry tar, gal.....	34
Gas, cu. ft.....	8457
Ammonium sulfate, lbs.....	21
Light oil from gas, gal.....	1.87
Other tar oils, gal.....	19.3
Pitch, per cent of tar.....	43

The by-product yields from the commercial retorts are a little different from those obtained in the small apparatus, due in part, at least, to the fact that the primary distillation in the small apparatus is carried out in an iron retort, whereas the commercial retort is lined with carborundum, and in order to get capacity it is necessary to carry a higher shell temperature in the retort. This results in a little less primary tar and a little more primary gas than found in the small-scale tests.

COMPARISON WITH COKE-OVEN BY-PRODUCT YIELDS

Since coke-oven practice is established and well known, it is of interest to compare the by-product yields from this process with those from the ordinary coke oven. If the two processes be compared for a high volatile coal, say, 35 per cent, it must be assumed that the coke oven could handle such a coal, and the yields given in Table II will, therefore, appear a little unusual for a coke oven.

A further point must be considered in that while tar is a normal by-product of the coke oven, it is not, strictly speaking, a by-product of the other process, since the tar in the latter case is distilled and the pitch returned to the process. In order to compare the two processes, then, it must be assumed that in each case the tar is distilled, and the pitch in the Carbocool process charged against the process. In Table II this is done, the pitch being taken as 68 per cent of the coke-oven tar and 50 per cent of the other tar, these being representative figures in each case.

TABLE II—PRODUCTS FROM ONE TON OF DRY COAL (35 per cent volatile, 7 per cent ash)

	Coke Oven 66% (1% volatile)	Carbocool 68% (3% volatile)
Coke or Carbocool.....	10,000	9,000
Gas, cu. ft.....	3	2
Light oil from gas, gal.....	20	20
Ammonium sulfate, lbs.....	3.8	15
Tar oils, gal.....	8.2	None
Pitch, gal.....		

While there are a few coals of 35 per cent volatile which can be coked in an ordinary coke oven, such as, for example, the Illinois coal recently used in a test conducted by the Bureau of Standards at St. Paul, coke-oven practice in general calls for a much lower volatile coal. Instead of comparing the by-products from a high volatile coal, as is done above, it is probably far more significant, economically speaking, to compare the actual average by-product yields from coke ovens the country over, with the yields which the process secures, assuming logically that each process will use coals to which it is particularly well adapted. If we take the coke-oven data as the average of 7800 by-product coke ovens operating in the United States in 1917, the following figures obtain:

	Coke Oven	Carbocool
Coke or Carbocool, per cent....	71	68
Gas, cu. ft.....	11,000 (Estimated)	9,000
Light oil, gal.....	2.4	2
Ammonium sulfate, lbs.....	19	20
Tar oils, gal.....	2.3	15
Pitch, gal.....	4.8	None

In speaking of yields from the process, the particular coal in question must always be considered. In coke-

FEED MECHANISM, PRIMARY RETORTS

oven practice, the range of coals is rather narrowly limited and it is, therefore, permissible to refer to average yields, but in the other process, where the range of coals is not limited at all, no average or standard yields can be considered. It is, for example, quite possible to use a coal yielding 20 gal. of tar oils per ton, or one yielding 75 per cent of carbonized product. In the tables above a coal of 35 per cent volatile has been taken as one to which the process is particularly well adapted.

INDUSTRIAL PLANT

The industrial plant was put into operation in June 1920. It has a capacity of 500 tons of raw coal per

day and, besides the main plant, includes equipment for working up the by-products into the usual crude products for the market. The coal is mined but a few miles away, and is a good grade of high volatile bituminous coal. As the coal comes from the cars it is dumped into a track hopper and elevated to a crusher, where it is crushed to pass a three-eighths-inch screen. It is then delivered to six 80-ton bins in the primary retort building. There are 24 primary retorts, arranged in four batteries of six each. Each retort is about 7 ft. in diameter and 20 ft. long, with a capacity of a ton an hour. The crushed coal is fed into the retorts by self-sealing screw conveyors and is stirred and advanced slowly through the retorts by a paddle mechanism. The by-products are led off the discharge end of the retorts and handled as in coke-oven practice.

TOP VIEW OF SECONDARY RETORTS

The semi-coke which is discharged continuously from the primary retorts is carried by covered conveyors to storage bins in the briquet building. Here it is ground, fluxed with pitch, and briquetted. There are two of these roll presses having a combined capacity of about 24 tons of briquets per hour.

The raw briquets are carried slowly up a long cooling conveyor to the storage bins at the secondary retorts. From these bins they are drawn into larry cars and charged into the secondary retorts. The secondary retorts are built in two batteries of six and four, ten retorts in all. Each retort consists of six rectangular chambers, 21 ft. long and inclined at about 30°, with six charging and three discharging doors per retort, the capacity of the retort being approximately 15 tons of raw briquets.

The finished briquets are discharged into steel quench cars and carried to a quenching and loading station from which they are finally loaded into railroad cars.

The by-products from the secondary carbonization are combined with those from the primary, after a preliminary cooling. The usual by-product equipment is provided, including a light oil plant, and a tar-distilling plant.

DISCUSSION

PROF. PARR: Mr. Chairman, I would like to ask Dr. Curtis how nearly the pitch residue from the oil or tar in the process met the requirements of the binder for the briquets.

DR. CURTIS: It is about an even break on most high volatile coals. The point is not one which bothers us at all. Having a tar plant as a part of the equipment, we can if necessary bring in outside tar and distil it at a profit, giving the required additional pitch. In the case of one plant there is a small shortage and this is being done. The question of pitch yield depends, of course, on the coal which is being used in the process.

MR. SPERR: I should like to ask about the amount of gas produced. As I understand it, the comparison of the yields of this process with those obtained in by-product coke-oven practice was made on the basis of the entire gas production. That is evidently why the figure of 10,000 cu. ft. was given for coke-oven production. Have you any figures that we could use to compare the *surplus gas* produced by this process with that obtained from the by-product coke oven?

DR. CURTIS: The plant at Clinchfield has not been running long enough to give an accurate figure, but judging from results obtained at the Irvington plant it takes about 7000 cu. ft. of gas per ton of coal to run the process. At Clinchfield we do not consider gas as one of the salable products of the plant, but in case a plant were located near a city or industrial center, there would be a few thousand cubic feet of gas which could be disposed of. The gas yield depends, of course, on the coal used in the process, and with most high volatile coals is somewhat more than necessary for the retorts.

BY-PRODUCT COKING

By F. W. Sperr, Jr., and E. H. Bird

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For nearly two years the production of by-product coke in America has held the lead over that of beehive coke. By-product coke manufacture is now firmly established and continually growing, while beehive coke is certain to decline to a position of minor importance. Although the bulk of the coke and gas manufactured in by-product ovens is now consumed by iron and steel plants, there is an increasing tendency for the by-product coke industry to assume the position of an independent fuel industry, and its relations are broadening to such an extent that they must be considered in the study of almost every phase of fuel economy.

INCREASING SHORTAGE OF NATURAL FUELS

Among the underlying causes of the many-sided development of this comparatively new industry, there is, first of all, the increasing shortage of the important natural fuels—anthracite, natural gas, and petroleum. The difficulty of obtaining adequate supplies of anthracite and the inferior quality of the material have combined to favor the substitution of coke. Natural gas finds its most satisfactory supplement in coke-oven gas and has a further accessory in water gas made from by-product coke. Fuel oil is being replaced to an increasing extent with tar and tar oils, while benzene has been successfully introduced as a motor fuel distinctly superior to gasoline, although on account of the comparatively limited amount of the former available, there is no question of competition between the two. The high price and poor quality of the gas oils now available are having