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COKING OF ILLINOIS COAL IN KOPPERS TYPE OVEN

An Operating Test at the St. Paul Plant of Minnesota By-Product Coke Co. Conducted Jointly by National Bureau of Standards and Bureau of Mines

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PREFACE

The Bureau of Standards, having conducted tests of Illinois coal in a new type of coke oven, was requested by the Minnesota By-Product Coke Co. to make an operating test of its plant also, using Illinois coal. This work was done by the Bureau in cooperation with the Bureau of Mines under the direction of E. B. Rosa, chief physicist of the Bureau of Standards, and O. P. Hood, chief mechanical engineer of the Bureau of Mines.

The authors of this report, who were in charge of the field parties from the two Bureaus, take pleasure in acknowledging the assistance and cooperation of those associated with them in the work. Among this number were the following members of the Bureau of Standards' staff: C. E. Reinicker, associate gas engineer, who acted as assistant chief of the party; W. M. Berry, associate gas engineer, in charge of battery observations; E. A. Dieterle, consulting gas engineer, in charge of by-product sampling and laboratory tests; C. O. Fairchild, associate physicist, in charge of high temperature measurements; A. I. Phillips, gas expert, who was detailed to assist in the work by the Ordnance Department; B. D. Gordon, J. D. Mackenzie, H. F. Wakefield, and F. M. Washburn, assistant chemists; I. V. Brumbaugh, M. J. Frankel, G. A. Gray, and J. W. Lansley, assistant engineers; F. L. Mohler and J. S. Christie, assistant physicists; and J. H. Eiseman, aid. Members of the Bureau of Mines' staff assisting at the plant were: V. C. Allison, W. R. Ratliff, B. B. Wescott, C. E. Plummer, R. M. Winslow, Chas. Schramm, and W. R. Cunningham; sampling coal at the mine was Thomas Fraser; analyzing coal and coke samples were F. D. Osgood, G. H. Mengel, L. R. Eckman, O. C. Brown, and W. E. Surbled. Special mention is also due Mr. Brumbaugh for assistance in working up the data and in preparing this report.

The authors also take pleasure in acknowledging the cordial cooperation and assistance rendered throughout the test period by T. G. Janney, manager, K. G. Richards, superintendent, and the members of the operating force of the plant. Special acknowledgment is also due F. W. Sperr, jr., chief chemist of The Koppers Co., who with his assistants, was present throughout the test period and afforded especially valuable advice and assistance.

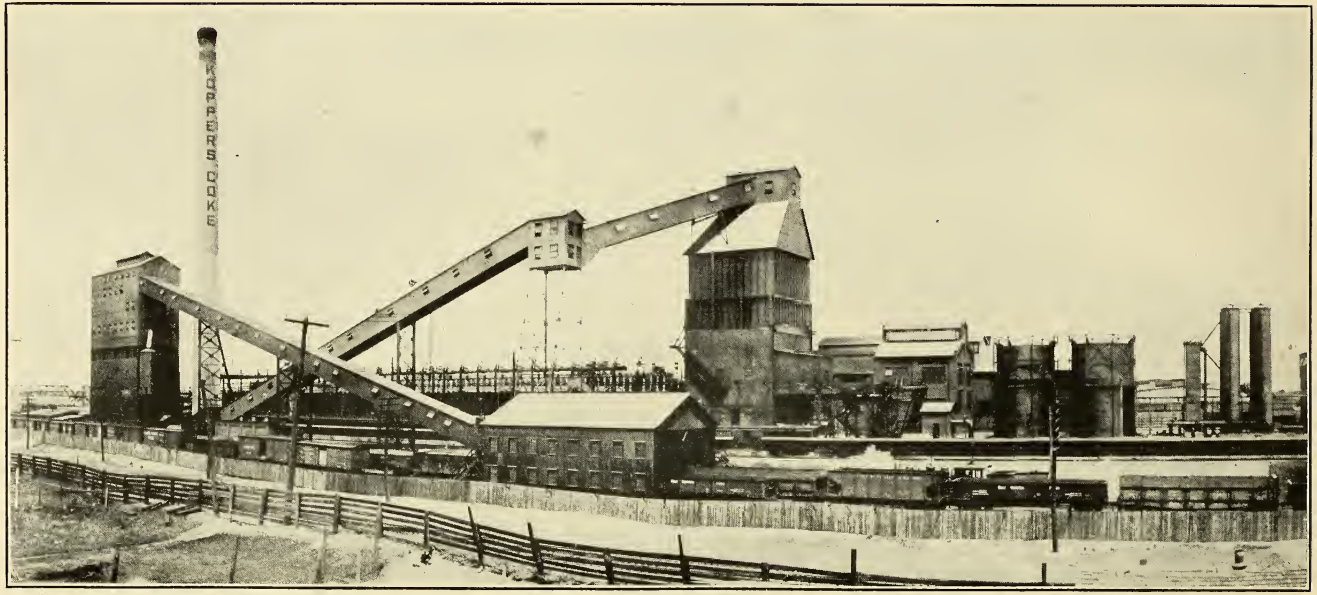

FIG. 1.—*General view of plant of Minnesota By-Product Coke Co., St. Paul, Minn.*

From the left are: The coal-crushing tower, stack, housing for inclined coal conveyor from coal-dumping building in center foreground to top of the coal-crushing tower, housing for inclined coal conveyor from bottom of coal-crushing tower to top of coal-storage bins at end of Battery B, from which bins the larry car is loaded with coal to be charged into the ovens. In the left-hand background are the two batteries, totaling 65 ovens. To right of battery storage bins in order are the by-product buildings, rich and lean gas holders, final gas coolers, and light-oil scrubbers

COKING OF ILLINOIS COAL IN KOPPERS TYPE OVEN

AN OPERATING TEST AT THE ST. PAUL PLANT OF MINNESOTA BY-PRODUCT COKE CO. CONDUCTED JOINTLY BY NATIONAL BUREAU OF STANDARDS AND BUREAU OF MINES

By R. S. McBride and W. A. Selvig

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PART I. INTRODUCTION

1. OCCASION FOR INVESTIGATION

The use of mid-continent coals, particularly those from Illinois, for production of metallurgical coke in by-product ovens has long been considered an important development, but this matter became particularly urgent during the period of the war as one possible means for reducing the demand upon our other coal resources which are particularly suited to these purposes. Numerous processes were proposed for the utilization of this coal, and among them a new coke-oven development was recommended to the Government for its consideration. The urgency of this matter led the President to instruct the Bureau of Standards to make an investigation of this process. In connection with this work, the Bureau was requested by representatives of The Koppers Co. to conduct a test of Illinois coal at the St. Paul plant, owned by one of its subsidiary companies, the Minnesota By-Product Coke Co. (See Figs. 1 and 2.) Appreciating this opportunity to secure valuable information that was urgently needed, the Bureau accepted this invitation and, with the cooperation of the Bureau of Mines, carried out an extensive operating test with about 7600 tons of Orient coal from Franklin County, Ill.

Although the results obtained are no longer of such urgent value as when the work was planned, yet they constitute an important contribution to the information available regarding the possibilities in the commercial use of the mid-continent coals. They are, therefore, presented for the general information of those who may be concerned with this important phase of our fuels work.

2. SCOPE OF INVESTIGATION

For this test, approximately 7600 tons of coal from the Orient mine of the Chicago, Wilmington & Franklin Coal Co., which operates in Franklin County, Ill., were obtained. This coal was handled in the plant of the Minnesota By-Product Coke Co. at St. Paul, Minn., which plant operated for the entire period of the test on this coal alone. All phases of coal handling, oven operation by-product recovery, and laboratory tests were under observation by a staff of Government representatives. Altogether 37 engineers and chemists were employed for this work, and in addition the Bureau of Standards and the Bureau of Mines had the benefit of advice and comment from a cosnsiderable number of expert engineers who are specialists in the field of coke-oven operation. The quantity of all products was carefully weighed or measured at regular intervals, samples of each of the products were taken, and complete analyses of the coal and these products have been made. Altogether, therefore, this report covers complete observations on all parts of the plant for the entire period from September 27 to October 5, 1918.

3. PERSONS PARTICIPATING

The Bureau of Standards was responsible for the general planning and supervision of the test work. Its representatives made all observations of battery operation, high-temperature measurements, by-product recovery, and chemical laboratory work on gas and by-products.

The Bureau of Mines was responsible for the sampling of the coal at the time it was loaded at the mines, and for the weighing, sampling, and analysis of the coal as used at the plant, and of all sizes of coke produced. Its representatives also made general observations on the character of the coke and the operation of the ovens.

Among the experts who were present to witness the test and advise regarding the work were the following: A. S. Knowles, representative of Consolidation Coal Co., St. Louis, Mo., who was

present as a consulting engineer of the Bureau of Mines; J. F. Blackie, superintendent of the Milwaukee Coke & Gas Co., Milwaukee, Wis.; G. C. Lowell, construction engineer, Peoples Gas Light & Coke Co., Chicago; W. A. Forbes, Steel Corporation, New York City; L. F. Burress, coke-oven superintendent, Gary plant, Illinois Steel Corporation; G. B. Evans, chief engineer, Laclede Gas Light Co., St. Louis, Mo.; R. C. Glazier, coke expert, United States Fuel Administration.

In addition to the regular staff of the Minnesota By-Product Coke Co., the following representatives of The Koppers Co. were present during the test: C. J. Ramsburg, vice president; Joseph Becker, consulting and operating engineer; F. W. Sperr, jr., chief chemist; H. L. Clarke, attorney.

PART II. DESCRIPTION OF PLANT AND TEST FACILITIES

1. HANDLING AND PREPARATION OF COAL

The coal for the test was sampled at the mine and loaded under the supervision of the Bureau of Mines' representative. The mine weights and car numbers were thus obtained as a basis of identification of the coal when received at the St. Paul plant.

The coal was received in hopper-bottom cars, was weighed on a Fairbanks track scale of the registering beam type and then dumped into the track hoppers from which it was elevated to the coal-crushing tower. A careful record was kept of cars as dumped. The track scale used had, previous to the test, been calibrated and accurately adjusted by the Bureau of Standards' track-scale experts so that the accuracy of the weights was assured.

The coal passed through a Bradford breaker with perforations of 1¼ inches in diameter. The material not broken up to this size was separated by the breaker and delivered into a waste bin from which it was removed at the end of the test and weighed in order to correct to the true weight of coal used. The coal passing through the breaker was delivered into storage bins from which it went to the hammer mill and was pulverized so that about two-thirds would pass through a 10-mesh sieve and over 90 per cent through a 4-mesh sieve.

This pulverized coal was then sampled on the elevating belt as it passed to the two-compartment, coal-storage bin over the battery. From this storage bin the coal was delivered into a four-hopper larry car, from which it was charged into the ovens. For uniformity the coal for each charge was carefully weighed in this

larry car, but these weights are not used as a basis for calculation of the test data, as the larry car was found to be inaccurate and it could not be repaired and adjusted in time for the test. All results are, therefore, calculated on the basis of the railroad track-scale weights.

Previous to and at the close of the test period all the coal-handling system and the coke-storage bins were cleared so that accurate measurements of the test supplies could be made. During the test no other type of coal or coke was handled in the plant.

2. COKE OVENS

The Minnesota By-Product Coke Co. plant consisted of 65 ovens; 60 of these in one battery "B" were standard-type Koppers ovens, and in the second battery "A" were 5 similar ovens, but with a special construction and arrangement of the heating flues. The ovens had a nominal capacity of 12½ tons each. They were 39½ feet long, 9½ feet high, 17 inches wide at the pusher side, and 19½ inches at the coke side, making a 2½-inch taper with an average width of 18¼ inches.

The plant is usually operated with a mixture of Pittsburgh, Elkhorn, and Pocahontas coal at normal coking times of about 16 and 17 hours. The normal capacity of the plant is approximately 1100 tons of coal per day. For the test period, since the coking time was slightly longer than normal, the capacity of the plant was reduced slightly below this figure.

The batteries are regularly operated with a separation of the rich and lean gas, the quantity of rich gas made being determined by the demand for this gas to supply the St. Paul Gas Light Co. Most of the lean gas is used for heating the batteries, but a small amount is available as boiler fuel. The batteries are constructed with a cross regenerator system, so designed that preheated producer gas may be used for heating, if desired. But no producers have as yet been installed at the plant, since there is ample surplus gas to supply the local demand.

During the test period it was desired to operate the batteries so that the best possible quality of coke would be produced from this coal, but certain limitations on the operation were imposed by the fact that it was necessary to maintain the quantity and quality of rich gas which was supplied to the St. Paul Gas Light Co. for its city service. This limitation made it impracticable to make the rate of coking slower than that used. All of the restuls obtained are, therefore, somewhat less favorable in quality of coke and yield

of certain by-products than the company would have obtained if they had been entirely free to adjust the plant operation as desired.

During the entire period of the test, including a few hours before the first coal was charged and a considerable period after the last of the test coal went into the ovens, all of the battery operations were under observation. From three to five Government representatives were present on the battery for each shift. These observers made a careful record of the time of charging and pushing the ovens. They noted the temperature and general condition of the ovens when empty and recorded any variations from the normal routine in either charging, pushing, cleaning of flues, and other battery work. The temperatures in the heating flues and coal mass of one of the ovens were recorded by an elaborate thermocouple outfit described later. From these observations, the coking time, general characteristics of the hot coke, uniformity of oven operation, and other characteristics of the battery operation could be computed or estimated.

3. COKE HANDLING AND SCREENING SYSTEM

The coke was pushed from the ovens into the usual type of hot-coke car and was quenched for about one-half minute in a typical quenching station located approximately 450 feet down the track from the battery. After draining for three to four minutes, the coke was delivered on the wharf, from which it was fed on to the belt conveyor by a typical gate and rotary feeder system. During the test, two different systems of screening were used as follows:

Screening System No. 1.—The coke was delivered by the conveyor over an inclined-bar grizzly screen in the first station. This screen was about 5½ feet long, 4 feet wide, and consisted of 1-½ inch bars spaced from 1¼ to 1½ inches. The oversize was delivered in the railroad cars and weighed as furnace coke. The undersize delivered on a second belt conveyor was carried to a second screening station, where it passed through an inclined, rotary, cylindrical screen, the first half of which consisted of ¾-inch square perforations, and the second half 1⅜-inch square perforations. The material passing through the ¾-inch perforations was rescreened on a ½-inch shaker screen to separate the breeze and pea sizes of coke. The material passing through the 1⅜-inch perforations was called nut coke, and that passing over the 1⅜-inch perforations was classified as stove coke. The breeze, pea, nut, and stove sizes were separately loaded in railroad cars and weighed before shipment or storage. Nut and stove sizes,

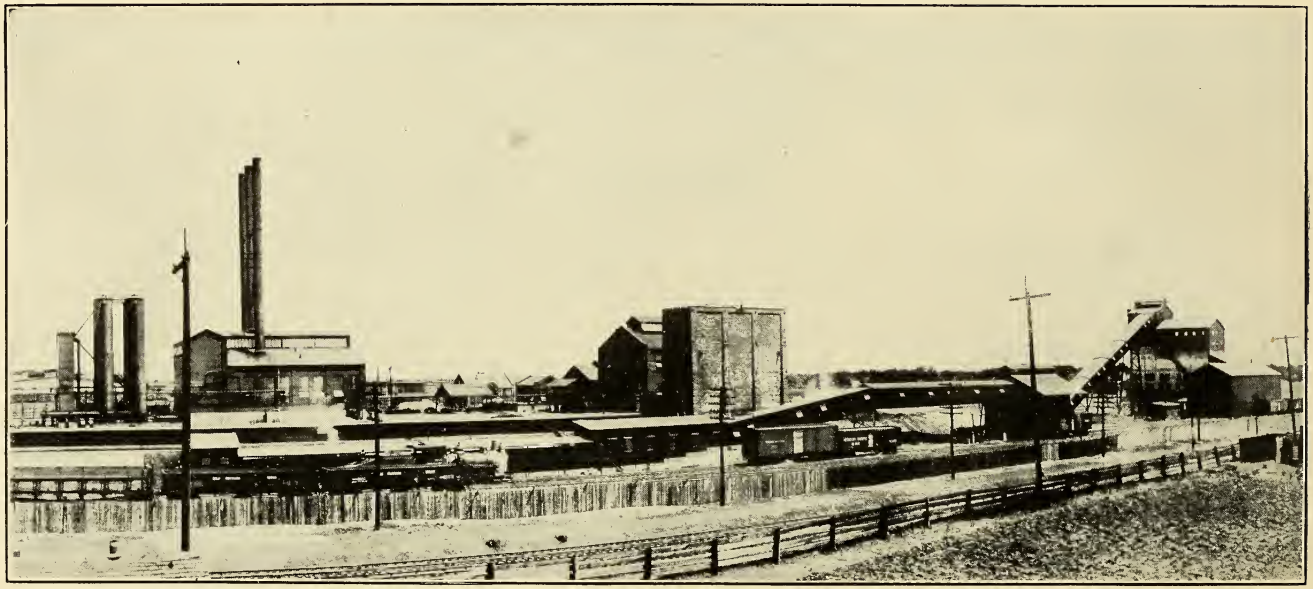

FIG. 2.—*General view of plant of Minnesota By-Product Coke Co., St. Paul, Minn.*—Continued

In the foreground from left to right are shown: Coke wharf, housings for the coke conveyors, the first screening station where large furnace coke is separated from run-of-oven coke, and the housing for the inclined coke conveyor to final screening station where the coke is further separated into small furnace and domestic sizes. In the background are the final gas coolers and light-oil scrubbers, shown also in Fig. 1, the power plant, laboratory, complete light-oil refining buildings, and coke-quenching station

as delivered from their respective bins, passed over shaker feeders before going into the railroad cars. The pea and breeze sizes were thus very completely eliminated from these two domestic sizes.

Since the separation of furnace coke by the inclined-bar grizzly in the first screening station was not considered satisfactory, because the screen was not large enough to handle the quantity of coke passing over it and make a good separation, a change was made after three days of the test to the second system which was as follows:

Screening System No. 2.—The inclined-bar grizzly in the first screening station was discarded and replaced by a 2½-inch rotary grizzly, the oversize of which was delivered directly into railroad cars as foundry or large furnace coke. The coke passing through the first rotary grizzly was carried to the second screening station where it passed over a second rotary grizzly set at 1⅞ inches. The oversize of this second grizzly was designated as small furnace coke. The material passing through the second grizzly was separated by the rotary cylindrical screen and sized exactly as in the first system. The furnace coke from the first system and both sizes of furnace coke from the second system, after being weighed, were stocked in a pile at the plant during the test period so that they were subsequently available for a blast-furnace test, as described later. The stove, nut, and pea sizes were sold for domestic fuel, as is customary from this plant. The breeze produced was used as boiler fuel at the plant, following the regular practice. The hot coke as pushed from the ovens was observed in order to know the termperature and general performance of each oven, and each lot was again observed after quenching and dumping on the wharf. By these observations a very complete idea of battery performance was obtained. These observations are summarized later in this report.

Each size of coke was carefully sampled for analysis and for determination of moisture content in order to correct to true weight at the time it was loaded in the railroad cars. Complete summaries of the methods of sampling, analysis, and the results obtained are given in the third part of this report.

4. GAS-HANDLING SYSTEM

The rich and lean gases, separated according to the system described above, were collected in separate mains and handled by separate systems throughout the remainder of the plant. Typical

flushing mains, bridge mains equipped with pressure regulators, tar sumps, etc., were arranged to convey the gas from the battery to the primary coolers which were of Koppers water-cooled tube type. The gas was drawn through the primary coolers by the exhausters, forced from this point through a typical P. and A. tar extractor, reheater, and saturator, which together make up the usual Koppers type by-product and direct sulphate-recovery apparatus. From the sulphate saturators, the gas passed through the final coolers to the light-oil scrubbers, and thence to the storage holders from which the rich gas was pumped to the city and the lean gas used either for heating the battery or, when there was surplus, as boiler fuel. As an indication of the general plant practice, the following typical temperatures of the gas at different stages of cooling and purification are of interest.

	Approximate temperature, °C
Inlet to primary coolers	80–85
Outlet of primary coolers	25–26
Outlet of tar extractors	37–38
Outlet of reheater	65
Outlet of final cooler	25

The volume of gas used for each purpose in the plant and the quantity sold to the St. Paul Gas Light Co. were measured and regular tests for heating value, specific gravity, chemical analysis, and other important characteristics were made. These results are presented in Part IV of this report.

5. TAR AND AMMONIA RECOVERY

In order to maintain proper operation, tar was continuously circulated in the collecting mains, and therefore the system at all times contained a considerable quantity of material. At the beginning and end of the test careful observation was made as to the quantity of tar and liquor in circulation in order to determine that exactly the same amount of these materials was present in each case.

The tar produced during the test was collected in the usual tar-circulating tank, from which it was pumped to a separator tank about 18 feet in diameter and 30 feet high. Here the liquor and tar were separated by the difference in gravity, the liquor flowing over the top of the tank into its storage tank, and the tar being siphoned from the bottom into two 200 000-gallon storage tanks. To supplement the practically complete separation thus accomplished, facilities were arranged for drawing off any liquor subsequently coming to the surface of the tar during storage and for pumping any tar settling to the bottom of the liquor-storage tank.

During the test daily inventory was taken of the quantity of the tar and liquor in stock, accurate weights and specific gravities of tar shipments were recorded, and other necessary arrangements made to permit accurate determination of the quantities of these materials produced.

It was the intention during the test to produce only ammonium sulphate and maintain the minimum practicable supply of ammonia liquor. However, a slight variation in the quantity of liquor at the beginning and end of the test inevitably resulted, and appropriate correction for this difference in inventory was made and appears in the record of results reported later. Samples of the tar liquor and sulphate were taken for analysis regularly, so that the quality, as well as the quantity of these materials would be a matter of record.

The sulphate delivered from the saturators into wheelbarrows was weighed as it was conveyed from the saturator room to the storage pile. Representatives of the test party either made or checked all of these weighings, and samples were taken from each centrifuge lot of sulphate made for determination of moisture, ammonia, and free acid. The scale upon which the sulphate was weighed had been examined and adjusted by the Bureau of Standards' scale experts in advance of the test.

6. LIGHT OIL RECOVERY

The light oil recovery equipment consisted of two pairs of standard Koppers hurdle-type scrubbing units. The benzolized wash oil produced in these scrubbers was handled by a complete modern Koppers type light oil plant, equipped for the production of pure products.

The quantity of light oil in the gas at the inlet of the scrubbers was determined daily, and the light oil from the gas at the outlet was also determined by the company's representatives. All of the light oil produced was collected for each 24-hour period in separate collecting tanks, and from these tanks accurarely measured into the storage tank.

Every precaution was taken to avoid complicating the operation, and the company during the period of the test did not handle any light oil except that produced from the test coal, although it is customary to handle light oil from outside sources as a part of their regular operation.

Samples were taken from each day's make of light oil and analyzed by approximate methods immediately, and later complete accurate tests were carried out both at the Bureau of Standards

and by The Koppers Co. laboratories. All of the methods of measurement, sampling, and analysis, together with results are given in Part IV of this report.

PART III. COAL USED AND COKE OBTAINED

1. COAL

The coal used in the test consisted of approximately 7600 tons from the Orient mine of the Chicago, Wilmington & Franklin Coal Co., located at Orient in the south central part of Franklin County, Ill. The coal was apparently clean and very well screened; the impurities consisted of a small amount of pyrite, mostly in the form of thin layers, calcite, mother of coal, and shale. The shipment comprised 159 cars of the following sizes:

50 cars "lump," over a 6-inch screen.
52 cars "furnace," through a 6-inch and over a 3-inch screen.
27 cars "small egg," through a 3-inch and over a 2-inch screen.
30 cars "stove," through a 2-inch and over a 1½-inch screen.

All but four of these cars were crushed and used in the quantitative test. One car of the stove size and three cars of furnace size were reserved for special tests of mixtures of Illinois with other coals.

Sampling Coal at Mine.—A sample of the coal was collected at the mine during loading by a representative of the Bureau of Mines. One gross sample representing the entire shipment was crushed and mixed according to the method described in the Bureau of Mines' Technical Paper 133,[1] and two sample cans were filled, sealed, and mailed to the Pittsburgh laboratories of the Bureau of Mines for analysis. The results of the analyses of this sample are given in Table 1.

TABLE 1.—Analysis of Mine Sample of Coal

		Coal as received	Calculated for moisture-free coal
Moisture	per cent	7.35	.....
Volatile matter	do	36.70	39.61
Fixed carbon	do	47.88	51.68
Ash	do	8.07	8.71
Sulphur	do	1.02	1.10
Hydrogen	do	5.35	4.89
Carbon	do	69.00	74.47
Nitrogen	do	1.57	1.69
Oxygen	do	14.99	9.14
Heating value:			
Calories		6758	7294
British thermal units		12 164	13 129

[1] Pope, G. S., Directions for Sampling Coal for Shipment or Delivery, Technical Paper 133, 15 pages, Bureau of Mines; 1917.

Size of Crushed Coal.—The coal was crushed at the plant as described in an earlier section. The intention was to get the coal as fine as was feasible with the apparatus available. The fineness of the coal as used is shown by the results of two sieving tests, presented in Table 2.

TABLE 2.—Sizes of Crushed Coal

[Results with Tyler sieves]

Mesh	Opening	Percentage through sieves (cumulative)		
		Sample No. 1—Date of crushing Sept. 29, 1918	Sample No. 2—Date of crushing Oct. 4, 1918	Average
	Inches			
4	0.185	96.4	94.5	95.5
10	.065	68.2	64.5	66.4
20	.0328	45.0	43.5	44.3
48	.0116	21.9	21.5	21.7
100	.0058	11.5	11.6	11.6
200	.0029	5.9	6.4	6.2

Sampling Coal at Plant.—A gross sample of about 1200 pounds of crushed coal was made up each day, taking equal portions of the material from the conveyor belt at stated intervals. This gross sample was reduced and prepared for the laboratory according to methods described in Bureau of Mines Technical Paper 133. The analyses of these daily samples of crushed coal are given in Table 3.

2. BATTERY OPERATION AND COKE HANDLING

Coal Charges.—The coal charged into each oven was weighed in the larry car, and these weights were corrected for scale error by comparison of the total with the total weight of coal shown by the track scale. Thus the amount of coal used each day was accurately known as a basis for calculating by-product yields. In Table 4 are given the test data for each of the nine days during which test coal was used. In this table the data for dry coal are calculated on the assumption that the average amount of water was present in the coal as charged. This is permissible since the percentage of moisture was very uniform throughout the whole test period, as shown by the data in Table 3.

TABLE 3.—Analyses of Coal Samples Collected at Plant

COAL AS CHARGED

	Daily sample number							Composite sample
	1	2	3	4	5	6	7	
Moisture.....per cent..	8.00	8.14	8.30	8.25	7.49	7.53	8.31	8.07
Volatile matter.....do....	34.47	34.83	34.66	34.34	35.62	35.39	35.04	34.66
Fixed carbon.....do....	48.77	47.78	48.07	48.26	48.51	48.11	47.46	48.38
Ash.....do....	8.76	9.25	8.97	9.15	8.38	8.97	9.19	8.89
Sulphur.....do....	1.14	1.04	1.03	1.12	1.10	1.01	1.02	1.04
Hydrogen.....do....	.....	.....	.....	.....	.....	.....	.....	5.32
Carbon.....do....	.....	.....	.....	.....	.....	.....	.....	67.51
Nitrogen.....do....	.....	.....	.....	.....	.....	.....	.....	1.49
Oxygen.....do....	.....	.....	.....	.....	.....	.....	.....	15.75
Sulphur in fixed carbon from volatile determination.....per cent..	.53	.55	.51	.52	.52	.44	.49	.51
Heating value:								
Calories.....	6702	6632	6643	6645	6781	6704	6638	6677
British thermal units.....	12 064	11 938	11 957	11 961	12 206	12 067	11 948	12 019

CALCULATED FOR MOISTURE-FREE COAL

Volatile matter.....per cent..	37.47	37.92	37.80	37.43	38.51	38.27	38.21	37.70
Fixed carbon.....do....	53.01	52.01	52.42	52.60	52.43	52.03	51.77	52.63
Ash.....do....	9.52	10.07	9.78	9.97	9.06	9.70	10.02	9.67
Sulphur.....do....	1.24	1.13	1.12	1.22	1.19	1.09	1.11	1.13
Hydrogen.....do....	.....	.....	.....	.....	.....	.....	.....	4.81
Carbon.....do....	.....	.....	.....	.....	.....	.....	.....	73.44
Nitrogen.....do....	.....	.....	.....	.....	.....	.....	.....	1.62
Oxygen.....do....	.....	.....	.....	.....	.....	.....	.....	9.33
Sulphur in fixed carbon from volatile determination.....per cent..	.58	.60	.56	.57	.56	.48	.53	.55
Heating value:								
Calories.....	7285	7220	7244	7242	7330	7250	7239	7263
British thermal units.....	13 113	12 996	13 039	13 036	13 194	13 050	13 030	13 073

Coking Time.—The time of a complete cycle of coking operations—i. e., from one charge to the next charge in the same oven—is called the "gross" coking time. A portion of this total period is, of course, used in opening, pushing, closing, and recharging the oven. The short time needed for these operations was taken for each oven as the interval between the pushing of one charge of coke to the closing of the lids on the succeeding charge of coal; this amounted to about 22 minutes on the average. Deducting the operating time from the gross coking time gave the time that the coal mass was actually in the oven, reported as "net" coking time. These data are given in Table 4.

Amperage to Push.—No consecutive record was maintained of the current necessary to push the oven charges. However, sufficient data were obtained to show that, in general, the charges pushed easily, though not as easily as with the usual coal mixture. With the pusher-ram motor operating on current at 240 volts, it generally required from 180 to 250 amperes to start the charge and from 120 to 180 amperes to keep it moving; in an occasional

oven the amperage required to start the charge amounted to from 300 to 350, with 200 to 300 amperes required to keep it moving. A very few of the charges stuck, so that it was impossible to push the charge out before the circuit breaker acted; as high as 550 amperes were noted in one or two of these cases. One charge in particular, oven No. 49, on September 29, gave a great deal of trouble; three attempts were made to push the charge before it was possible to clear the oven. However, in no case was it necessary to rake or dig the coke from the ovens.

Appearance of Hot Coke as Pushed from the Ovens.—Effort was made to observe the appearance of the coke as it was pushed from each oven, although it was not possible in every case to accomplish this. One factor which enters largely into interpreting the results noted is the question of individual judgment, for there is no standard with which the appearance can be compared and only a short space of time is available in which to form any definite conclusions. The following were the principal features noted after considering all of the notes made at the time the ovens were pushed:

TABLE 4.—Coal Charges and Coking Time

Day beginning at 8 a. m.	Ovens charged	Coal charged		Charge per oven		Coking time	
		As charged	Dry	As charged	Dry	Gross	Net
		Tons	Tons	Tons	Tons	h. m.	h. m.
Sept. 27	26	324.0	297.8	12.46	11.46	18 34	18 17
Sept. 28	85	1081.9	994.6	12 73	11.70	19 48	19 25
Sept. 29	78	996.6	916.2	12.78	11.75	19 44	19 23
Sept. 30	77	976.2	897.5	12.68	11.66	19 49	19 26
Oct. 1	82	1054.4	969.3	12.86	11.82	19 17	18 55
Oct. 2	80	1022.0	939.5	12.77	11.74	19 30	19 12
Oct. 3	79	1015.4	933.5	12.85	11.82	19 25	19 02
Oct. 4	81	1027.7	944.7	12.69	11.86	19 40	19 16
Oct. 5	15	187.5	172.4	12.50	11.49	19 34	19 12
Total or average	603	7685.6	7065.4	12.75	11.72	19 33	19 11

The top of the coke mass was, as usual, colder than the rest of the charge. In fact this condition was somewhat exaggerated during the test as it was impracticable to adjust the battery for the best use of the leaner gas from the Illinois coal when this was to be used for so short a period. From the level of the horizontal flue in the heating wall down to the bottom of the oven the coal was usually thoroughly coked; and in general the heats were uniform for the entire length of the charge. From a number of the charges some uncoked material remained in the center of the charge at the level of the horizontal flue.

From most of the charges a large amount of smoke and flame arose as the coke was pushed from the oven; this was especially noticeable in cases where uncoked material remained at the level of the horizontal flue. The overhang of the coke as it fell from the coke guide into the quenching car was irregular; on the coke side it ranged from 12 to 24 inches while on the pusher side the coke frequently showed signs of crumbling. Immediately ahead of the pusher ram the charge generally crumbled, thus causing a great deal of fine coke. A distinct line of cleavage was noted through the center of the charge in almost all cases.

Appearance of Coke on Wharf and in Cars.—The coke on the wharf was very irregular in size, but on the average the pieces were distinctly smaller than for the average by-product coke mixtures. There was no tendency to blockiness and very few pieces were as large as 6 inches in each dimension. The material was decidedly lighter than the average by-product oven coke, weighing only about 23 pounds per cubic foot. The color varied somewhat, but in general the furnace size was of a dark silver color.

The coke had a decided longitudinal fracture and many of the pieces before reaching the wharf were broken up into fingers. Even the larger pieces showed a tendency to fingering, and by completion of the decided longitudinal fracture generally these broke into several smaller pieces before reaching the cars. There was no apparent cross fracture, but the brittleness of the long fingers was such that these frequently broke into shorter pieces during handling.

In the railroad cars the furnace size from screening system No. 1, in which a 1½-inch inclined-bar grizzly screen was used, consisted mainly of small fingers from 1 by 2½ inches up to a maximum of about 2 by 6 inches. There were very few blocky pieces about 2½ by 3½ inches. The oversize of the 2½-inch rotary grizzly, used in screening system No. 2, in the cars was about half fingery and half blocky coke, averaging much larger than from screening system No. 1. The small furnace size from this second system, through the 2½ inch, but over the 1⅞-inch rotary grizzly, averaged about 2 by 2½ inches. The great difference in size between the coke on the wharf and after loading in the cars shows the decided tendency to breakage during handling.

The cells of the coke were small and regular and in general of a structure indicating suitable characteristics for furnace use. There was no sponge formed, but there was a decided tendency

to form a pebbly seam at a distance of 2 to 6 inches from and, in general, parallel to the oven wall. This seam appeared only in a part of the pieces in which it formed an incipient cross fracture. In general there were no pebbly seams in the coke at the bottom of the oven. The small amount of pebbly mass noted seemed to come from the top and center of the oven in the form of small, loosely cemented lumps of material which were readily crumbled in the hands. Although the coal contained considerable "mother of coal," there was very little evidence of foreign matter in the coke, probably because of the fineness to which the coal was crushed.

3. HIGH-TEMPERATURE MEASUREMENTS

High-temperature measurements were made continuously for several days during the test period in order to give an accurate idea of the operating conditions of the battery. Records were taken of the temperature in the oven walls, regenerators, waste-heat flues, in the coal mass, and in the vapor above the coal. Measurement of high temperatures in a by-product coke oven is attended with great difficulty because of the inaccessibility of certain points where temperature measurements are desirable and because of the limited variety and high cost of apparatus which can be used for these purposes. The results obtained from the measurements reported below are sufficient, however, to give an accurate idea of the range and average temperature maintained at the important points in the heating system.

Methods and Apparatus.—Pyrometers were installed in the heating walls and flues through observation openings on the top or side of the chamber in which the temperature measurements were to be made. The couples for measuring coal and vapor temperatures were introduced into the oven space through holes bored in the charging lids. Shortly before pushing the oven these couples were, of course, withdrawn.

Platinum-rhodium thermocouples were used where the temperatures were above 1000° C. These couples were made of wire 0.5 mm in diameter protected by glazed porcelain tubes made specially for this work. The lower temperatures in the waste-heat flues and the temperatures of the coal mass were measured with base metal thermocouples made of No. 8 gage wire, one element being chromel, the other alumel, two patented alloys. These couples were insulated with fire-clay tubes and protected by wrought-iron pipes closed at the lower end by welding.

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Since it had been determined in previous work that the mass of coal charged into an oven quickly reaches 100° C and remains at this temperature for many hours after charging, the couples for measuring the temperature of the coal mass were not introduced for several hours after the charge. This practice was entirely satisfactory and had the particular advantage that the thermocouples were much less contaminated, and therefore more accurate, when used for a shorter period. Even with this practice the protection tubes could be used only once, but the couples could be used for two charges before serious contamination occurred.

The temperatures indicated by the thermocouples were automatically recorded by potentiometer-type recorders made by the Leeds & Northrup Co. The couples were connected with

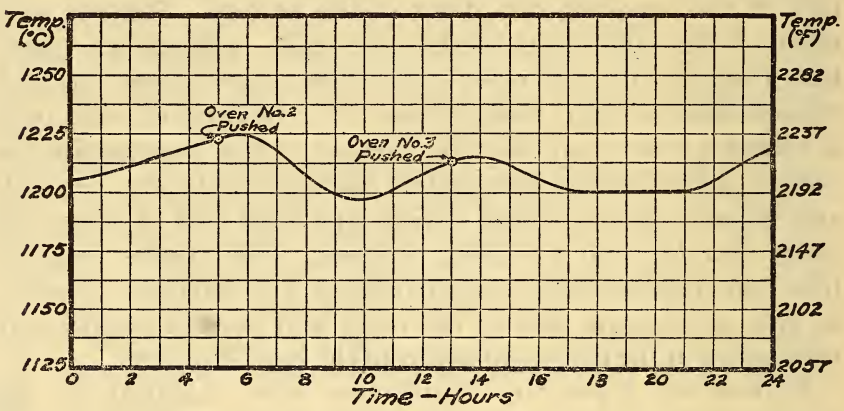

FIG. 3.—*Average temperature of heating wall, showing effect of charging and pushing*

Temperature recorded 7 feet below top of battery between ovens No. 2 and No. 3

compensating leads to a junction box and through a cold junction, which was buried in the ground to secure uniformity of temperature, to the recorders. The record made by the recorder was checked at appropriate intervals with a portable potentiometer. The couples were calibrated before use in the pyrometer laboratory of the Bureau of Standards and were again tested at the conclusion of the test for indications of any departure from their original calibration. Some of the base-metal couples used in the coal showed a slight variation, which may have introduced an error of 1 per cent in the original millivolt readings, but this would correspond to a discrepancy of only 10° C at the maximum. The probable error was much less than this, and therefore any discrepancy on this score can be regarded as wholly negligible.

A complete survey of temperature conditions through the entire battery was, of course, impossible, but representative points were chosen and the following results are typical of all operations. During the period of the test certain optical pyrometer measurements were made by the company engineers, which confirmed the fact that the locations chosen for our regular measurements were typical.

Heating-Wall Temperatures.—Two series of temperature measurements were taken in the heating wall between ovens Nos. 2 and 3 with rare-metal couples 7 feet long, one introduced in the

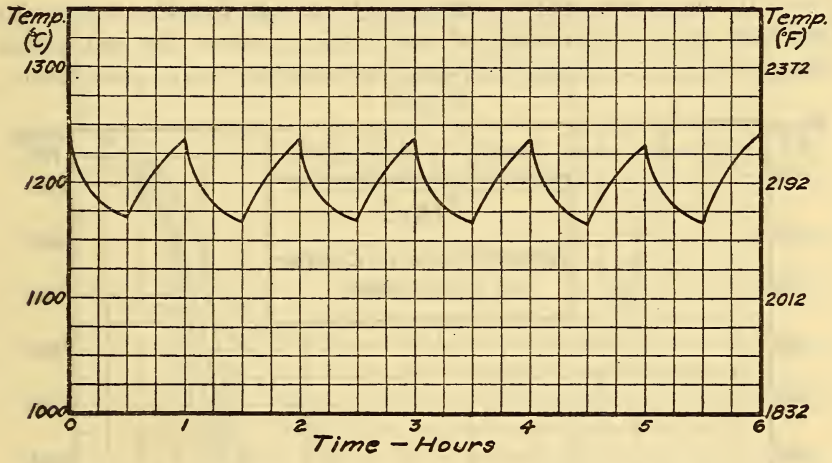

FIG. 4.—*Typical heating wall temperature, showing effect of reversals*

Temperature determined at point 7 feet below top of battery

seventh flue from the pusher end, the other in the fourteenth flue. The average temperatures for several days' observations at these points were as follows:

Date	Flue 7	Flue 14
	°C	°C
September 30	1172	1226
October 1	1175	1222
October 2	1192	1247
October 3	.....	1244
October 4	.....	1226
Average	1180	1233

The temperature was taken at one-minute intervals over a period of several hours on one of these couples in order to determine the magnitude of the temperature variation during reversal of direction of gas burning. The mean variation was found to be about 75° C. As an indication of the general trend of heating-wall

temperatures before, during, and after charging the adjoining oven the curve showing the general trend of temperature at this point is given in Fig. 3. These temperatures, of course, are not as high as prevail in certain parts of the wall refractory; for example, at the lower regulating brick near the air port, where the maximum temperature is reached.

To show the effect of gas and air reversal on the temperature in the heating wall, the curve of Fig. 4 is given. In this connection it is interesting to note that the gas was off about 55 seconds during each reversal, amounting to 3 per cent of the entire time. This interval gives ample opportunity for the heating system to be swept clear of products of combustion before the fuel gas is introduced, and thus the gas ignites at once and burns completely.

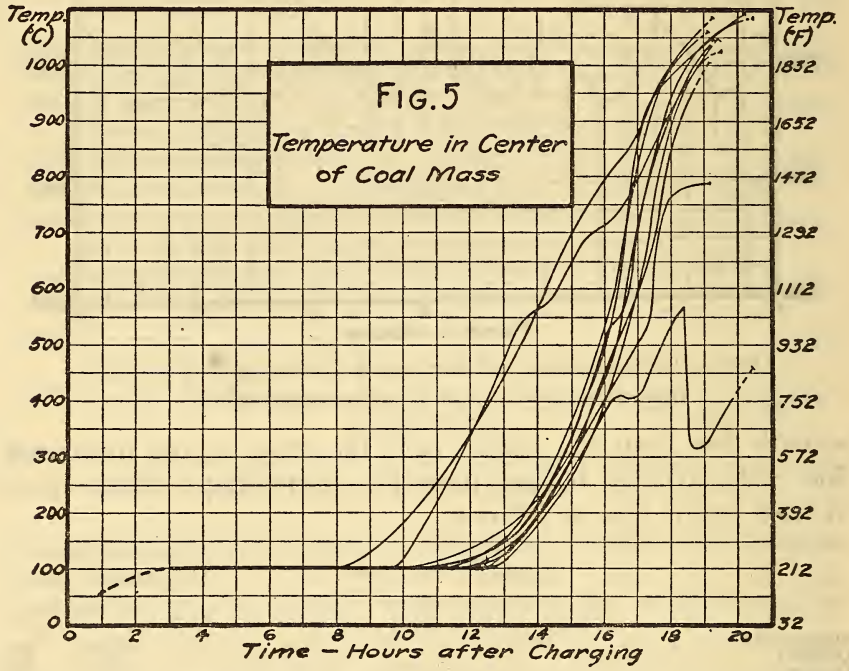

FIG. 5
Temperature in Center of Coal Mass

Regenerator Temperature.—Over the checker-brick in the right half of the regenerator under oven No. 3 at the coke end 54 inches in from the face of the regenerator wall a rare-metal couple gave the following temperature indications:

	°C
September 30	1134
October 1	1137
October 2	1146
October 3	1155
Average	1141

The variation in temperature during reversal of direction of gas burning was about 55° C at this point.

Temperature in Waste-Heat Flues.—Temperature measurements were taken 5 feet down below a manhole at the junction of the waste-heat tunnels from the two batteries. The results were as follows:

	°C
October 1	274
October 2	272
October 3	269
Average	272

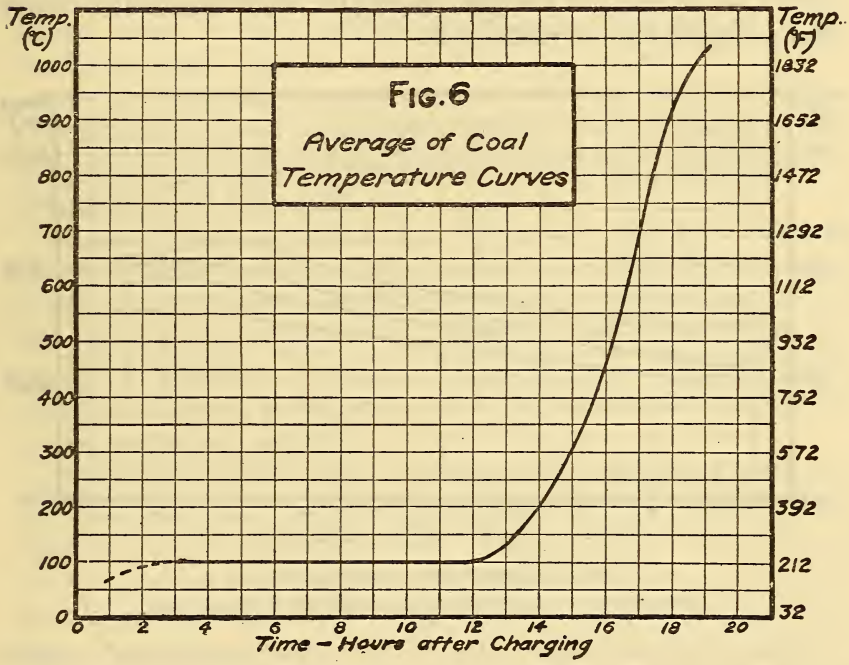

FIG. 6
Average of Coal Temperature Curves

Another pyrometer in this flue a short distance from the point of the observations indicated that the temperature of the products close to battery B was approximately 20° higher than the above indications.

Temperature in Coal Mass.—Temperature measurements were made in four consecutive charges of coal in oven No. 3, beginning with the charge introduced at 10 a. m., September 30. Readings were taken with couples 10 feet long introduced, as nearly as possible midway between the oven walls through charging lids 1, 2, and 3, counting from the pusher side of the battery. Since in most cases the curves were all very similar in shape they

are all plotted together in Fig. 5. The two curves which show an earlier rise of temperature probably represent an unavoidable placing of the thermocouple not at the center of the coal mass but at a point somewhat nearer one of the oven walls. The one curve showing very irregular temperature rise after the sixteenth hour is probably in error because of instrument difficulty. To show the typical temperature time curve for this location the mean of the similar curves is shown separately in Fig. 6. With so great opportunity for irregularity it is rather surprising to find that in 6 of the 10 curves the temperature was the same within 40 minutes of the time from the beginning of the charge that is shown for the mean of all.

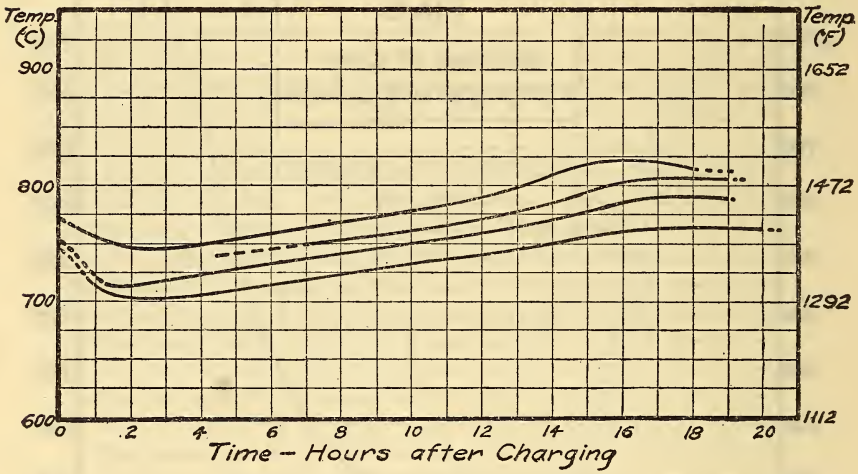

FIG. 7.—*Temperature of vapor above coal*

Temperature determined in gas space immediately above coal mass

Temperature in Vapor Above Coal.—Short base-metal couples were introduced 4 feet below the charging lid nearest the pushing end of oven No. 3. Four curves for four consecutive charges are shown in Fig. 7. These curves give an excellent idea of the temperature to which the gas leaving the coal mass is subjected just before it escapes from the oven, but of course these temperatures are not as high as those to which the vapors have been subjected while still within the coke mass.

4. COKE YIELDS AND ANALYSES

Sampling Furnace Coke.—The samples of furnace coke were taken from the belt conveyor as it was delivered into the railroad cars by diverting the entire stream from the belt at intervals.

A gross sample of about 125 pounds was collected from each car by making 5 collections of 25 pounds each, and a composite sample was prepared representing 5 cars by combining the individual car samples. This sample was quickly crushed to about 1½-inch size, mixed and worked down to about 100 pounds, in a manner similar to that employed for the coal sample, except it was not crushed smaller than 1½-inch pieces. From the 100-pound sample one quarter, or about 20 pounds, was taken as near as practicable at the time the cars were taken to the scales for weighing, and the total moisture determined at the plant by drying to constant weight at about 160° C. in a steam-coil drying oven by the method described in Bureau of Mines Technical Paper 148.[2]

On every alternate sample 20 pounds was taken and combined with similar samples for apparent specific gravity determination; three composite apparent specific gravity samples were made covering the period of the test.

All the discards obtained in working down the 5-car moisture sample were kept and combined with the discards representing a second 5-car moisture sample. This sample representing 10 cars was crushed and worked down according to the methods recommended by the Bureau of Mines' Technical Paper 133 for sampling coal for shipment or delivery. A 10-pound sample was sent to the laboratory for analysis.

Sampling Domestic Sizes of Coke.—The samples of pea, nut, and stove sizes were collected in a manner similar to that used in collecting samples of furnace coke. Collections of 125 pounds per car were taken, combined into one sample, and stored in barrels until a gross sample representing 12 hours' loading was obtained. The sample was worked down for a moisture sample, in a manner similar to that used for furnace coke, and the discards obtained in working down the moisture sample were kept and worked down, also in a manner similar to that used for furnace coke, for a 10-pound sample to be sent to the laboratory for analysis.

Sampling of Breeze.—A sample representing 12 hours' loading of breeze was taken and worked down in a manner similar to that used for the samples of domestic sizes, except crushing, which was not necessary. Total moisture was determined at the plant on a 20-pound sample and a 10-pound sample was sent to the laboratory for analysis.

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[2] Fieldner, A. C., and Selvig, W. A., The Determination of Moisture in Coke, Technical Paper 148, 14 pages, Bureau of Mines, 1917.

Inspection Sample.—One barrel of furnace coke, collected at intervals during the entire test in a manner similar to that used in collecting the furnace-coke sample, was shipped to the laboratory as an inspection sample.

Methods of Analysis.—The coal and coke samples were analyzed in the laboratory of the Bureau of Mines at Pittsburgh by the methods prescribed in the Bureau of Mines' Technical Papers 8 [3] and 76.[4]

TABLE 5.—Results of Proximate Analyses of Coke

Number of cars represented by sample	Coke as loaded in cars					Calculated for moisture-free coke			
	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	Volatile matter	Fixed carbon	Ash	Sulphur
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
FURNACE-SIZE COKE									
10	9.84	2.32	75.37	12.47	0.83	2.57	83.60	13.83	0.92
10	7.18	1.68	78.29	12.85	.84	1.81	84.35	13.84	.92
10	9.81	1.54	76.47	12.18	.72	1.71	84.79	13.50	.80
10	8.28	2.35	77.60	11.77	.82	2.56	84.61	12.83	.89
10	8.59	2.72	76.34	12.35	.83	2.98	83.51	13.51	.92
10	7.78	2.15	77.43	12.64	.82	2.33	83.96	13.71	.89
10	6.00	2.54	78.86	12.60	.86	2.70	83.90	13.40	.91
10	5.10	2.05	79.47	13.38	.89	2.16	83.74	14.10	.94
11	5.02	2.64	78.57	13.77	.85	2.78	82.72	14.50	.90
10	5.17	1.98	80.27	12.58	.83	2.09	84.64	13.27	.88
7	6.30	2.79	78.50	12.41	.86	2.98	83.78	13.24	.92
12[a]	6.8	.....	.....	.....	.....	.....	.....	.....	.....
Composite sample	7.15	2.18	77.93	12.74	.85	2.35	83.93	13.72	.92
DOMESTIC SIZES OF COKE									
7	16.00	2.98	69.52	11.50	0.74	3.55	82.76	13.69	0.88
5	15.70	2.33	70.29	11.68	.80	2.76	83.39	13.85	.95
7	11.20	2.25	74.62	11.93	.84	2.53	84.04	13.43	.95
5	8.50	2.87	75.96	12.67	.85	3.14	83.01	13.85	.93
11	10.80	2.36	74.48	12.36	.81	2.65	83.49	13.86	.91
6	9.10	2.27	74.90	13.73	.86	2.50	82.39	15.11	.95
9	10.50	2.86	73.68	12.96	.81	3.19	82.33	14.48	.90
7	10.45	2.36	74.67	12.52	.81	2.63	83.39	13.98	.90
10	12.00	2.67	73.52	11.81	.81	3.03	83.55	13.42	.92
5	11.70	1.80	74.88	11.62	.79	2.04	84.80	13.16	.89
14[b]	11.4	.....	.....	.....	.....	.....	.....	.....	.....
Composite sample	11.51	2.81	73.15	12.53	.82	3.18	82.66	14.16	.93
COKE BREEZE									
3	20.00	5.17	61.35	13.48	0.79	6.46	76.69	16.85	0.99
3	12.80	3.89	69.52	13.79	.92	4.46	79.73	15.81	1.05
3	16.55	3.92	65.06	14.47	.84	4.70	77.96	17.34	1.01
3	17.55	3.98	64.82	13.65	.85	4.83	78.61	16.56	1.03
1	14.05	3.67	67.20	15.08	.96	4.27	78.18	17.55	1.12
Composite sample	17.07	4.06	64.69	14.18	.87	4.90	78.00	17.10	1.05

[3] Stanton, F. M., and Fieldner, A. C., Methods of Analyzing Coal and Coke, Technical Paper 8, 42 pages, Bureau of Mines; 1913.

[4] Fieldner, A. C., Notes on Sampling and Analyses of Coal, Technical Paper 76, 61 pages, Bureau of Mines; 1914.

[a] Moisture only was determined on this sample, sample for analysis being accidentally mixed with some domestic-size coke.

[b] Moisture only determined on this sample, sample for analysis being accidentally mixed with some furnace coke.

True and apparent specific gravity determinations of the furnace coke were made by the methods described in Technical Paper 8. Composite samples representing the entire output of each size of coke were prepared at the laboratory and proximate and ultimate analyses of these were also made.

Results of Coke Analyses and Tests.—The results of proximate analyses and sulphur determinations on the coke samples are given in Table 5. Table 6 gives the results of the ultimate analyses and heating-value determinations on the composite samples of each size of coke.

TABLE 6.—Ultimate Analyses and Heating Value of Coke

	Furnace coke		Domestic coke		Coke breeze	
	As loaded	Dry	As loaded	Dry	As loaded	Dry
Carbon.....per cent..	77.81	83.80	73.47	83.03	65.68	79.20
Hydrogen .....do....	1.17	.41	1.67	.44	?	.77
Oxygen.....do....	6.55	.20	10.60	.41		.79
Nitrogen.....do....	.88	.95	.91	1.03		1.09
Sulphur.....do....	.85	.92	.82	.93		1.05
Phosphorus.....do....	.009	.010	.010	.011	.....	.....
Ash.....do....	12.74	13.72	12.53	14.16	14.18	17.10
Heating value:						
Calories.....	6385	6877	6049	6836	5453	6576
British thermal units.....	11 493	12 379	10 888	12 305	9815	11 837

The weight per cubic foot of furnace coke was determined on one car of large furnace coke, and also on one car of small furnace coke. This was done by leveling the cars and making the calculations from the net weights of coke and the rated cubic-foot capacity of the cars.

Apparent specific-gravity determinations were made on three composite samples of furnace-size coke collected as described under sampling methods, and an average of these is given as representing the entire lot. A single composite was made up for the entire lot and the true specific gravity determined. The porosity of the coke was calculated from these results for apparent and true specific gravity. These physical properties of the furnace coke may be summarized as follows:

Weight per cubic foot of dry coke:
- Furnace size from screening system No. 1.....pounds.. 23.4
- Large furnace size screening system No. 2.....do.... 22.8

Apparent specific gravity..... .88
True specific gravity..... 1.85
Porosity.....per cent.. 52.4

Coke Yields and Sizes.—The yield of each size of coke as separated by the two screening systems and for the entire test are given in Table 7.

TABLE 7.—Coke Yields and Sizes

[Total coal used 7065.4 tons]

	Screening system No. 1		Screening system No. 2		Entire test		
	Dry weight	Percentage of total coke	Dry weight	Percentage of total coke	Dry weight	Percentage of total coke	Percentage of coal
Furnace sizes:	Tons		Tons		Tons		
Large [a]	.....	.....	555.0	18.3	.....	.....	.....
Small [b]	.....	.....	666.7	22.0	.....	.....	.....
Total [c]	1482.7	82.7	1221.7	40.3	2704.4	56.0	38.3
Domestic sizes:							
Stove [d]	120.9	6.7	1057.2	34.8	1178.1	24.4	16.7
Nut [e]	93.0	5.2	456.5	15.0	549.5	11.4	7.7
Pea [f]	16.1	.9	73.8	2.4	89.9	1.8	1.3
Total	230.0	12.8	1587.5	52.2	1817.5	37.6	25.7
Breeze [g]	81.1	4.5	227.3	7.5	308.4	6.4	4.4
Total coke	1793.8	100.0	3036.5	100.0	4830.3	100.0	68.4

[a] Large furnace was over 2½-inch rotary grizzly.
[b] Small furnace was through 2½-inch rotary and over 1⅞-inch rotary grizzly.
[c] Total furnace coke was over bar grizzly in the first system and sum of large and small furnace for the second system.
[d] Stove was through the bar grizzly and over 1⅜-inch square mesh for the first screening system, and through 1⅞-inch rotary grizzly and over 1⅜-inch square mesh for the second system.
[e] Nut was through 1⅜-inch square mesh and over ¾-inch square mesh.
[f] Pea was through ¾-inch mesh and over ½-inch mesh.
[g] Breeze was through ½-inch mesh.

It is to be noted that 82.7 per cent of the dry coke produced in screening system No. 1 was classified as furnace coke, oversize of the 1¼ to 1½ inch inclined-bar grizzly. As explained under description of screening system No. 1, the separation of the furnace coke by the inclined-bar grizzly was not considered satisfactory, as the screen was not large enough to make a good separation; the very high percentage obtained for furnace size is, therefore, not representative. The total dry furnace coke was only 40.3 per cent of the total dry coke screened during that part of the test when screening system No. 2 was used. However, it should be noted that the yield of stove size is very large, 34.8 per cent of the total coke as screened; there is no doubt that a large amount of the stove size would have been included in the furnace size if it had been possible to install a 1½-inch inclined-bar grizzly screen large enough to handle the coke produced and make a good separation.

The small percentage of large-size coke obtained together with the large percentage of the smaller domestic sizes indicated that it would not stand handling and screening without breaking up into smaller pieces, due to the fingery and brittle characteristics of the coke.

5. SPECIAL OVEN TESTS

In order to study the effect of lower temperature and longer time of coking and to get some idea of the value of certain special coal mixtures, a few ovens were operated under different conditions than normal. The lower temperature trials were made in oven No. 1 during the period of the test by cutting down the quantity of gas burned in the heating walls of this oven. The special mixtures were made up at the end of the test period and tried out in one or more ovens.

Low-Temperature Coking of Orient Coal.—Oven No. 1 was changed from its regular operating period beginning October 1 and three charges of distinctly longer periods, 22¾, 23½, and 25¾ hours were pushed on October 3, 4, and 5, respectively. The temperature of this oven was from 50 to 100° C. lower than the temperature of the remaining ovens in the battery. The coke from these special tests was very similar to that obtained from the same coal coked for the usual 19-hour period in that the cell structure was not materially different and that there was the usual small amount of foreign matter and no sponge. However, the material as it lay on the wharf appeared decidedly larger and blockier and there was slightly less of the pebbly mass or pebbly seam. The blocks of coke were decidedly stronger, both judged by their action when handled and by the shatter test described below. The results of this special work at lower temperatures were very closely comparable with the results obtained at Dover, Ohio, when using the same coal in a narrower oven and coking at a corresponding rate, measured in inches of coke formed per hour. It is evident from these tests that stronger, larger coke will be obtained at the somewhat lower temperatures used in this work than at the temperature at which it was necessary to operate during the full test at St. Paul in order that the gas supply of the city would not be interrupted.

Mixture of Orient and Pittsburgh Coals.—In order to study the character of coke produced from a mixture of equal parts of Pittsburgh and Orient coals, a single oven was charged with this mixture. Oven No. 60 was charged 5.30 p. m., October 7, and pushed 11.30 a. m., October 8; the charge was 25 100 pounds. The coke from this 18-hour test was thoroughly coked, but the appearance on the wharf was not encouraging. There was decided longitudinal fracture, indicating the fingery tendency common to high-volatile coals, but the coke was fairly tough. The cell struc-

ture resembled that of Orient coal alone except in the upper central section of the oven, where considerable sponge was formed. There was no noticeable cross fracture, but the irregular shapes showed that the breakage of the material in regular handling would probably be rather high. The Pebbly seam so frequently noted in coke from 100 per cent Orient coal was not apparent in this single test, but the tendency of Pittsburgh coal to produce sponge was not counteracted by the mixture.

Mixture of Orient and Pocahontas Coals.—A mixture of 25 per cent Pocahontas and 75 per cent Orient coal was used in three ovens charged on October 7 and pushed after approximately 17 hours of coking. In each case the charge was about 25 200 pounds. The coke produced under these conditions was blocky and on the average of large size, but the pieces were very irregular. There was no tendency to finger, but a decided cross fracture was shown. The coke, although appearing soft, was unusually tough, as will be evident from the high percentage unbroken in the shatter test. The cell structure was irregular and the general appearance of the material on the wharf would have indicated undercoking, but the appearance while hot, as it was pushed from the oven, showed that this was not the fact. The very small percentage of fine material indicated that an unusually high percentage of furnace size would be available from this mixture.

Shatter Tests of Special Cokes.—In order to get a rough check on the relative strength of the different special cokes which were made, a shatter test was carried out on each of the samples. For this test a 50-pound sample of large pieces of coke taken from the belt, none of which pieces would begin to pass through a 2-inch, square-mesh screen, were dropped four times from a height of 6 feet onto an iron plate. The pieces of coke which following this test would not in any position pass through the 2-inch screen were weighed and their ratio to the weight of the original sample was taken as the "percentage unbroken" in results indicated below.

The usual foundry mixture consisting of 30 per cent Pocahontas, 35 per cent Pittsburgh, and 35 per cent Elkhorn coal was found to give a result of 68 per cent unbroken by this test. The straight Orient coal coked for 19 hours gave a coke of which only about 27 per cent remained unbroken by this test. The coke obtained from 22 to 26 hour coking periods was somewhat stronger, ranging from 27 to 38 per cent unbroken. The mixture of 50 per cent Orient and 50 per cent Pittsburgh showed about 53 per cent unbroken,

and the mixture of 25 per cent Pocahontas with 75 per cent Orient was the strongest of all, showing 74 per cent unbroken by this test.

The above results are merely an indication and must not be taken as any accurate measure of the strength, since only a limited number of tests were made. Large irregularities are always found in this kind of testing; and, moreover, this test is not strictly significant as to the strength of the material, since at the best it really gives an accurate measure only of the likelihood of breakage during handling.

6. BLAST-FURNACE TEST OF COKE

Purpose and Scope.—In order to test the behavior of the furnace-size coke produced from the Orient coal in the St. Paul plant arrangements were made to use some of this material in the blast-furnace plant of the Mississippi Valley Iron Co., St. Louis, Mo. The Bureau of Standards and the Bureau of Mines were each represented at the furnace test, but their representatives acted only as observers, having no part in the furnace operation. Also F. W. Sperr, jr., chief chemist, and C. R. Meissner, experimental engineer, of the Koppers Co., Pittsburgh, were present during considerable portion of the test period as observers.

It was first planned to make a one-week operating test, but after beginning the test additional coke was ordered and 1746 tons of coke were actually used in the furnace. This material was approximately equally divided between that shipped direct from the St. Paul test as loaded on the cars from the screening station and that reclaimed from the stock pile in which the coke during the first part of the test at St. Paul was stored. The coke shipped direct from the screening station was considerably larger than that reclaimed from the stock pile, as it had not been subjected to the unusually rough treatment of dumping into a concrete pit, recovery by crane for transfer to the stock pile, and a second handling by crane for reloading in freight cars. The larger coke was used during the first period of the test and the smaller during the latter portion. During the interval from 1 p. m. on October 19 to 4.30 a. m. on October 29 only this special coke was used in the furnace.

Blast-Furnace Plant.—The plant of the Mississippi Valley Iron Co. consists of one blast furnace with auxiliary equipment. A modern gas-cleaning system has been installed but is not yet in use. Four of the five hot-blast stoves are old, and because of their condition limit the furnace capacity. The furnace was relined in accordance with the most modern practice and blown in blast

on August 5, 1916, previous to which date it had been out of blast for about five years.

The furnace is 77 feet from hearth to top, 12 feet 8 inches hearth diameter, 15 feet 9 inches bosh diameter, 14 feet 6 inches bosh height, and built with a bosh angle of 83°, which is said to be the steepest in this country. Although the furnace is rated at 300 tons of iron per day, the limitations of the hot-blast stoves, blowing engines, etc., have always prevented operation at any such capacity. The output is generally materially less than 200 tons of pig iron per day. However, the height of the furnace is such that results on it correspond more nearly to those of a modern 500-ton furnace than would usually be the case for a plant of this capacity.

General Test Procedure.—The coke regularly used in the furnace is produced in the Koppers ovens of the Laclede Gas Light Co., St. Louis, from a coal mixture of Elkhorn 65 per cent, Illinois 20 per cent, and Pocahontas 15 per cent. The substitution of the Illinois coke for the regular coke was accomplished abruptly and continued without interruption throughout the test.

The ores used during the test were Beaver, Waukon, and Beaver manganese from the Minnesota ranges, and Pilot-Knob, a local Missouri ore. The first three of these ores are soft and rather earthy, but the Pilot-Knob is a very hard refractory lump ore. The limestone used throughout the test is known locally as McLoon.

At the beginning of the test the furnace was making malleable iron, but during the later stages the furnace was run to make basic iron, as it was believed that this would be a more severe test of furnace performance.

Operating Results and Observations.—Each day during the test the significant data were tabulated and operating notes recorded by the various observers present. These data sheets were submitted and approved by the furance operators as a record of the test.

During the test period a large number of operating irregularities occurred which subjected the coke to a great variety of conditions unfavorable to efficiency. The importance of these factors is made clear in the conclusions reached by the several observers as presented in the following section of this report. It was especially unfortunate that delay in securing the coke ordered for the latter part of the test made it impracticable to operate the furnace as rapidly as appeared possible. This fact should be taken into

account in interpretation of the results of the test. The results reported to the Bureau for the nine-day test period are summarized in Table 8. Similar data for August and September are given in Table 9 as a basis for comparison with the results of the coke from Orient coal with the regular coke used at this plant. In considering these data as to pig-iron output, it is interesting to note that the average daily output for several months during 1918, when using the regular coke supply, was no greater than the minimum day encountered during the period of use of the test coal. The minimum during the test period was 169 gross tons of pig, the maximum 250 gross tons, the average 198.

TABLE 8.—Results Reported to Bureau of Standards for Blast-Furnace Test of Coke

	First period of test	Second period of test	Total or average
Interval	Oct. 20–25	Oct. 25–29	Oct. 20–29
Size of coke	Large, direct from coke screens	Small, from stock pile	
Coke charged ... tons	902	742	1644
Pig iron produced ... do	1012	772	1784
Pig iron produced per day ... do	202	193	198
Iron yield ... actual percentage	58.1	52.9	55.8
Coke per ton of pig iron ... pounds	1774	1921	1843

TABLE 9.—Blast-Furnace Operating Results with Regular Coke

	August	September
Pig iron produced per day ... tons	174	182
Coke per ton of pig iron ... pounds	2364	2042
Iron yield ... actual percentage	55.4	55.0

Conclusions Drawn from the Test.—The conclusions reached by A. S. Knowles, the representative of the Bureau of Mines, as to the general performance of the furnace during the test period were as follows:

It may be noted that during the test practically all of the troubles which may be expected in ordinary furnace operation were encountered and very readily and quickly overcome. They may be listed as follows:

1. Sudden change from regular coke to an entirely different coke.
2. Chilling due to too rapid driving and short coke weight.
3. Chilling due to cleaning off of furnace walls.
4. Chilling due to damp, rainy weather giving wet blast, and also wet ore, stone, and coke.
5. Chilling due to too low hot-blast temperature.
6. Two and one-half hours' shutdown.
7. Operation for extended period on slack wind.
8. Irregular wind volume due to leaky stoves and mains.

In spite of all of these conditions within the limited space of nine days, the results show decidedly better practice than on regular coke and normal operation.

The principal feature of the Illinois coke is its rapid combustibility. This gives an intense heat right at the tuyeres and rapid, regular driving of the furnace. It must be borne in mind, of course, that the furnace lines aid most materially in this. The steep bosh is an ideal combination for small, fast-burning coke. The furnace is, of course, rather small and there is room for argument as to whether the results would be as good on the larger furnaces. However, the results for a short test are sufficiently encouraging to warrant the assumption that the coke would work very nicely in large furnaces, especially those having a steep bosh of 80° or over.

The conclusions reached by the blast-furnace operators are summarized in the following letter from Henry Carson, superintendent of the furnace, to the Bureau of Standards. The two blowers on duty at the furnace during the operating test have in writing expressed their agreement with these statements.

On October 19, at 1 p. m., we discontinued the use of Elkhorn-Laclede coke entirely and put on in its place the St. Paul coke. On the midnight cast of the 19th a change was noticed in the volume of gas—it being increased, and the furnace began to take an increased number of charges. The rapid working of the furnace dislodged large amounts of accretions and she began to scour on the 21st, dropping these accretions into the crucible, continuing to do so until about 9 p. m., the 22d. The results were to cool the iron, lower the silicon, and raise the sulphur. As the furnace had not scoured for two months, this action was about due. My impression is that it was probably hastened by the more rapid traveling of the furnace due to the faster working of the St. Paul coke. Our heats had continued to rise in the hot-blast stoves, due to the better gas, and notwithstanding the heavy scouring before mentioned, the cast following the offcast was down in sulphur, which was a recovery quicker than we have ever been able to make on the Elkhorn-Laclede coke.

On the morning of the 24th we developed a bad iron notch which necessitated taking the wind off the furnace entirely and let it stand while repairs were being made. In the meanwhile we had put on a burden of ore greater than we have heretofore carried.

On October 25 we were compelled, at 2 p. m., to take the wind off again on account of a charge-buggy getting caught in the bell and hopper. Our temperature in the stoves, however, continued very high.

Again on the 27th, in the morning, we had to stop operation in order to pack the hopper in the top of the furnace, which had been worked loose on account of the trouble we had had on the 25th with the accident caused by the buggy getting between the bell and hopper.

In the meanwhile, the larger size St. Paul coke being used up, we started on the stove size. It was so small our burden packed and had to put on 3 pounds' additional pressure of wind in order to get the wind through it. No appreciable change was noted between the larger size and the smaller size, except the additional wind pressure before mentioned and the slowing down of the number of charges.

This St. Paul coke seems to be a little harder than the Elkhorn-Laclede coke, and carried the burden quite as well. The most notable difference between the two cokes, I should say, is that the St. Paul coke works faster, gives a greater tonnage per day, yields a better gas for stoves and boilers, thereby giving a hotter blast temperature. It was noticeable that on 8 pounds of wind on St. Paul coke we got as good results as with 10 pounds of wind on Elkhorn-Laclede coke. I see no other difference in the coke, and had it been of full furnace we would have been able to charge about 60 charges per turn, or 120 per day, as compared with 85 charges, our average on Elkhorn-Laclede coke.

Edward F. Goltra, president of the Mississippi Valley Iron Co., has submitted to the Bureau the following comment on the furnace operation during this test:

1. Two sizes of coke were shipped us, the larger being above egg and below furnace size coke, the smaller being a little better than stove size.

2. We discontinued the use of Elkhorn-Laclede coke abruptly, substituting 100 per cent of the larger size St. Paul coke. This substitution resulted in an increased yield of gas for the hot-blast stoves and boilers. The temperature of the hot blast rising 200° and the steam rising in the boiler house. The furnace began to travel faster, increasing the charges from the customary 85, experienced on Elkhorn-Laclede coke, to a maximum of 110. Had we not experienced the stops on account of furnace top and other mechanical delays the yield per day would have been large.

3. After the larger size coke was consumed the stove size was used, resulting in a denser burden, and therefore requiring 3 pounds greater pressure of wind to drive it through.

4. It was patent that had the coal been coked in a narrower oven giving full-size furnace coke the furnace would have taken 60 charges a turn, or 120 charges a day, as it demonstrated itself to be a very much faster working fuel.

5. The peep-holes at the tuyeres disclosed that the coke held its size in its descent through the furnace, the combustion taking place fiercely at the tuyere line, giving a hot bottom and a cold top.

6. The furnace was more amenable to the will of the blower, as was demonstrated by its quick recovery in picking up heat.

7. It carried without difficulty the largest ore burden which was made up of the greatest percentage of our most refractory ore that we have as yet put on a burden. It carried our customary burdens as efficiently as the Elkhorn-Laclede coke we have been using.

8. After consumption of the St. Paul coke we abruptly discontinued its use, substituting 100 per cent Elkhorn-Laclede coke. We have experienced no furnace difficulties in making these abrupt changes. We notice the furnace is slowing down in taking charges.

In conclusion: The furnace operatives expressed themselves as having a preference for the St. Paul coke, instead of the Elkhorn-Laclede coke, as a result of the experience gained in the test; and in this I concur, having been present at the furnace night and day during the test.

Charles W. Markell, chief chemist of the company, has submitted the following observations as to the performance of the Orient coke:

I was present before and during the test of by-product coke made from Orient (Illinois) coal, and that to my certain knowledge the coke proved very satisfactory for use in our furnace.

We found that we could get more iron by using less wind pressure than with the coke furnished us by the Laclede ovens. The gas was better and produced better stove temperatures. The coke was slightly smaller in size, but harder, and seemed to come down to the tuyeres larger than the Laclede coke. The test was made under bad atmospheric conditions and at a time when we were compelled to use a great quantity of Pilot-Knob ore in order to get enough silica in burden. We had been using Workhouse stone regularly, but owing to the greater ash content of the Orient coke we obtained a lot of McLoon stone to make conditions about the same in regard to coke and limestone combined. In other words, it took practically the same amount of McLoon stone to flux ash from Orient coke as it took Workhouse stone to flux ash from Laclede coke.

The heating quality of the coke was very clearly shown on Sunday, October 27, when furnace at 9.30 a. m. cast showed iron analyzing Si—0.63, S—0.108. After a cast of high-sulphur iron it usually took 12 hours or more to come around, but the next cast at 12.55 p. m. showed Si—0.74, S—0.053. This quick recovery demonstrates that the coke undoubtedly has superior heating qualities, compared with the Laclede coke.

The following conclusions have been reached by F. W. Sperr, jr., chief chemist of The Koppers Co.:

The following points may be considered well demonstrated by the test, in respect to the Illinois coke used and the furnace on which the test was made:

1. The coke is a first-class blast-furnace fuel, which may be substituted directly for the regular coke without creating injurious irregularity of operation.
2. With Illinois coke of normal size, and with the usual wind pressure the rate of driving is much faster than usual.
3. With the smaller sized coke and with the same wind pressure, the rate of driving is still somewhat faster than usual.
4. With the Illinois coke of normal size, the wind pressure must be considerably reduced to bring the furnace to its normal rate of driving.
5. The normal-sized Illinois coke is about 12 per cent lighter than the regular coke, and this must be taken into account in comparing the charges.
6. The coke maintained its size well in passing through the blast furnace and presented a good appearance in front of the tuyeres.
7. The coke carries a normal basic burden well, with every indication that it would make any grade of foundry iron with the normal burden.
8. Using coke of this character, a blast furnace recovers more rapidly than usual from chilling.
9. The gas produced is of good quality, making it possible to maintain a satisfactory stove temperature without robbing the boilers.

It is indicated that with the Illinois coke the consumption of coke per ton pig iron is normal, or possibly even less than normal. This can not, however, be absolutely established in so short a test.

Commenting upon the conclusions above quoted, Mr. Sperr suggests the following:

In studying the results of this test, it is important to consider the lines of the St. Louis blast furnace. This furnace, although of small capacity, represents the most modern development in proportioning of bosh, stack, and hearth. The bosh is slightly steeper than that of any other furnace in America. Great caution should be used in applying the results of this test, in predicting what the Illinois coke might do if used on an older blast furnace of larger capacity, or with radically different lines. All that can be said is that the results are extremely encouraging for further tests on larger furnaces with similar lines. The height of the St. Louis blast furnace is only about 13 feet less than that of a modern 500-ton furnace, so that the actual difference is less than the relative capacity might indicate. It is impossible, however, to make any definite predictions as to the actual coke consumption and rate of production of pig iron on furnaces of different types, without actual tests, and such tests would be of the greatest practical importance.

It is important to bear in mind that the coal from which the coke used in this test was made represented the highest grade of Illinois coking coal, and the results should not be too broadly applied to Illinois coke in general. There are of course great differences in Illinois coals from different districts, with respect to ash, sulphur, phosphorus, and coking quality. Such conditions have, however, been considered to apply to the broader question of the economics of coking Illinois coal, which is being dealt with in another report.

7. EXPERIMENTAL-RETORT TESTS OF ORIENT COAL

In order to study the influence of the temperature of coking upon the quality of the coke produced and upon the quantity and quality of gas made from the coal the Bureau of Standards made a series of experimental-retort tests at different temperatures. Through the courtesy of the Bethlehem Steel Co., Sparrows Point, Md., the Bureau had access to the necessary apparatus and also received assistance and advice from experienced technical men of the company who have conducted a considerable number of tests.

The very large influence of temperature of coking upon the quantity and quality of coke and gas produced was evident. At the higher temperatures the results showed not only a more complete elimination of the volatile matter from the coal, but also a decomposition of the heavier volatile material into gaseous constituents, which also caused the average heating value of the gas to diminish. The volatile matter remaining in the coke increased as the temperature of coking decreased, and therefore the yield of coke was higher. The lower temperatures produced coke very much inferior to that of the higher temperatures.

The Bureau of Standards is publishing a full account of the experimental-retort tests in a separate technologic paper.

PART IV. BY-PRODUCTS AND GAS PRODUCED

The results obtained during six days from 8 a. m., September 29, to the same hour October 5, were used as the basis for by-product and gas results, since during this period only Orient coal was in use and the system contained only products from this coal. The methods of observation and the results obtained are reported in the following sections for tar, ammonia liquor and sulphate, light oil and its products, and gas.

1. TAR

The amount of tar produced during the six-day test period was determined by initial and final inventories, which were made with great care and corrected according to the shipments of tar taking place during the interval. Daily inventories of the stock were also made, but considerable irregularities due to the unavoidable inaccuracy in measuring the small quantities produced in a single day made these results of little value, and therefore only the total make is reported.

In inventorying the tar, changes in tank levels were used as a basis for computing the volume on hand. In the separating tank the level at which the tar and liquor were in contact might vary with changes in density of the two liquids, both those caused by change in temperature and those caused by change in composition of tar and liquor. Fortunately, however, taking into account the temperature and density on this tank at the beginning and end of the test, it was found that no significant change in relative densities of the two liquids had occurred. It was possible, therefore, to ignore this factor.

The yield and characteristics of the tar were as follows:

Tar produced, as measured	gallons	47 560
Tar produced, dry (computed)	do	46 100
Tar, as produced, per ton of coal as charged	do	7.81
Tar, dry, per ton of dry coal	do	8.23
Water in tar, by weight	per cent	2.6
Specific gravity, as produced		1.187
Specific gravity, dry basis (computed)		1.192

2. AMMONIA LIQUOR AND SULPHATE

During the test period it was planned to make only ammonium sulphate and not to accumulate any ammonia liquor. However, it was, of course, impracticable at all times to use up the liquor collected at just the rate produced. Most of the time the liquor was worked up, and at the end the system was in approximately the same condition as at the beginning of the test. The actual production reported represents, of course, the sum of the sulphate made and the liquor collected, computed as sulphate.

The ammonium sulphate was weighed as it was taken from the driers in wheelbarrows on a platform scale which had been recently calibrated by the Bureau of Standards. The records of the sulphate weights were kept by Bureau men who were stationed on all shifts to see that the scales were properly balanced and the tare weights carefully taken. Bureau men also took a sample from the wheelbarrows representing each lot of sulphate from the driers. These samples were preserved in tightly closed jars and daily an average sample made up for analysis.

The weight of sulphate produced daily varied largely in accordance with the amount of ammonia liquor accumulated or worked up into the sulphate during the day. The total weight of sulphate made throughout the test period was 155 506 pounds, equivalent to 151 102 pounds of pure $(NH_4)_2SO_4$ as calculated from the NH_3 present in the salt. The average daily analysis of the salt showed

25.06 NH_3, 0.12 free acid (calculated as H_2SO_4), and 2.51 per cent H_2O; equivalent to 97.18 per cent $(NH_4)_2SO_4$ in the salt and accounting for 99.81 per cent of the constituents.

The ammonia liquor on hand was inventoried daily, with special care given to the inventories at the beginning and end of the by-product test period. The inventory included the determination of the volume and composition of the stock in each of the tanks, including the liquor-storage tank, on top of the tar in the tar-storage tank, separating tank, circulating tanks, and still-supply tank. From the measurement of volume, the temperature, specific gravity, and per cent of NH_3 by weight, as determined in the laboratory test, the pounds of NH_3 and the equivalent weight of $(NH_4)_2SO_4$ were computed for the initial and final inventories. The change in stock represented 4841 pounds of NH_3, equivalent to 19 317 pounds of sulphate of the same purity as that produced on the average during the test, or equivalent to 18 777 pounds of pure $(NH_4)_2SO_4$.

The total production of sulphate and sulphate equivalent of liquor collected, divided by the tons of coal carbonized, gives the production results as 28.70 pounds of sulphate as weighed per ton of coal as charged, equivalent to 30.33 pounds of pure dry $(NH_4)_2SO_4$ per ton of dry coal. Equivalent figures for ammonia are 7.19 pounds of NH_3 actually recovered per ton of coal as charged, or 7.82 pounds NH_3 per ton of dry coal. Tables 10 and 11 summarize the yields and composition of the sulphate.

TABLE 10.—Ammoninm Sulphate—Production

Produced, scale weight	pounds	155 506
Produced, pure	do	151 102
Equivalent in liquor, start of test, pure	do	15 922
Equivalent in liquor, end of test, pure	do	34 699
Equivalent due to liquor increase, pure	do	18 777
Total production, pure	do	169 879
$(NH_4)_2SO_4$ per short ton of coal as charged	do	27.88
$(NH_4)_2SO_4$ per short ton of dry coal	do	30.33
NH_3 per ton of coal as charged	do	7.19
NH_3 per ton of dry coal	do	7.82
Average of NH_3 in ammonium sulphate produced	per cent	25.06

TABLE 11.—Ammonium Sulphate—Analysis

	Sept. 29	Sept. 30	Oct. 1	Oct. 2	Oct. 3	Oct. 4	Average
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
H_2O	2.05	2.65	2.52	2.55	2.68	2.60	2.51
NH_3	25.14	25.00	25.08	25.08	25.02	25.02	25.06
H_2SO_4	.15	.14	.14	.12	.08	.12	.12
$(NH_4)_2SO_4$	97.52	96.96	97.27	97.07	97.04	97.04	97.18
Total	99.72	99.75	99.93	99.94	99.80	99.76	99.81

In connection with the above figures it is interesting to note that the ammonia content of the liquor collected ranged from 0.63 per cent NH_3 by weight for the initial sample to 1.01 per cent NH_3 by weight for the final inventory sample.

In order to determine the efficiency of ammonia recovery in this plant, the amount of ammonia left in the gas was determined. It was found that the rich gas leaving the saturators carried 4.83 pounds NH_3 per million cubic feet and that the lean gas carried 7.83 pounds NH_3 per million cubic feet, as averaged from the daily 24-hour tests made by the plant chemists. Computing these losses to equivalent sulphate per ton of coal carbonized, it is found that 0.26 pound $(NH_4)_2SO_4$ per ton of coal as charged was escaping recovery. This represents nine-tenths of 1 per cent loss, or a recovery efficiency of 99.1 per cent. It should be understood, of course, that all these data in reference to composition and percentage recovery involve certain experimental uncertainties inherent in this type of laboratory testing.

3. LIGHT OIL

The rich and lean gas produced at this plant are separately scrubbed for light-oil recovery, but the light oil separated from the wash oil in the stripping stills is collected together. During the test period two sections of the light-oil "running tank" were used on alternate days in order to permit careful measurement of each day's light-oil production. It was planned to change over from one section of this tank to the other at exactly 8 o'clock each morning, and where this was not possible a slight correction to give the results for each 24-hour period was applied. The water collecting in the light oil produced each day was first blown off and then the light oil blown over into a storage tank, where it could be accurately measured. As is seen in Table 14, the production ranged from 3600 to 4000 gallons of light oil per day. In that table are also given other data from the approximate tests made each day by Bureau representatives in the laboratories of the plant as to composition of this light oil. More accurate results for the complete test period were available from work done subsequent to the test period on composite samples made up by taking a portion from each daily sample in quantity proportional to the make of light oil for that day.

The total light-oil production for the six-day by-product test period was 22 570 gallons, which equals 3.71 gallons per ton of coal as charged, or 4.03 gallons per ton of dry coal. This light

oil as collected showed on analysis 83.8 per cent boiling below 200° C. Applying this percentage to the volume collected, the so-called "true" light oil is found to be 3.11 gallons per ton of coal as charged, or 3.38 gallons per ton of dry coal. The analyses obtained by the Bureau of Standards and by The Koppers Co., using separate portions of the same composite sample for the entire test period, give results shown in Table 12. In both cases the Laclede still was used for the test. Two series of observations during distillation in a flask are shown in Table 13. The discrepancy in percentage of the various constituents is accounted for by the difference in rate of distillation caused by slight difference in still operation during analysis. It is unfortunate that so large a discrepancy as here indicated should be inherent in a method that is probably the best available procedure for determining the composition of these light oils.

TABLE 12.—Composition of Light Oil as Collected

[Results in each case with Laclede still on composite sample representing entire production during six-day test period]

	Bureau of Standards results	The Koppers Co. results
	Per cent	Per cent
Washing loss [a]	5.7	8.3
Benzene	56.8	56.1
Toluene [b]	13.4	14.3
Solvent naphtha	3.5	3.6
Residue [a]	20.6	17.7
Total	100.0	100.0

[a] Slightly different methods were used to obtain percentages of "washing loss" and "residue." However, the sum of washing loss and residue are substantially the same for the two analyses.
[b] Paraffins in toluene, none.

TABLE 13.—Light-Oil Distillation (Boiling Point) Test in Flasks

	Bureau of Standards test	The Koppers Co. test
First drop ... °C	80.4	76.3
Per cent over at—		
95° C ... per cent	53.1	62.0
100 ... do	62.1	67.6
120 ... do	72.2	75.6
150 ... do	77.8	80.8
180 ... do	81.4	83.8
200 ... do	84.4	86.7

Using the Bureau of Standards' results as the basis of calculation, the yields have been computed for the various constituents, as shown in Table 14:

TABLE 14.—Light-Oil Production and Analysis

	Sept. 29	Sept. 30	Oct. 1	Oct. 2	Oct. 3	Oct. 4	Total or average
Produced.....gallons..	3750	3980	3720	3920	3590	3610	22 570
Produced per ton of coal:							
As charged.....do....	3.76	4.08	3.53	3.83	3.54	3.51	3.71
Dry.....do....	4.09	4.43	3.84	4.17	3.84	3.82	4.03
Produced (per cent under 200° C).....	86.5	81.0	85.0	84.5	79.0	87.0	83.8
Produced per ton of coal (per cent under 200° C):							
As charged.....gallons..	3.25	3.30	3.00	3.24	2.80	3.05	3.11
Dry.....do....	3.54	3.58	3.26	3.52	3.03	3.33	3.38
Benzene (analysis) per ton of coal:							
As charged.....gallons..	2.132	2.315	2.005	2.175	2.010	1.994	2.105
Dry.....do....	2.323	2.515	2.180	2.368	2.180	2.170	2.289
Toluene (analysis) per ton of coal:							
As charged.....gallons..	.504	.546	.473	.514	.474	.470	.497
Dry.....do....	.549	.593	.515	.559	.515	512	.540
Solvent naphtha (analysis) per ton of coal:							
As charged.....gallons..	.132	.143	.124	.134	.124	.123	.130
Dry.....do....	.143	.155	.134	.146	.134	.134	.141

As a check on the light-oil recovery both The Koppers Co. and the Bureau of Standards' chemists made daily determinations of the light oil in both the rich and the lean gas entering the light-oil scrubbers. Unfortunately, however, the results were very irregular and no confidence can be placed in conclusions from them. As a matter of fact, the recovery was largely in excess of the apparent amount of light oil present. This fact is another striking illustration of the very unsatisfactory status of our knowledge of methods for determining light oil in gas.

4. GAS

The gas produced at the plant was separated at the ovens into rich and lean, the quantity of rich gas being so regulated as to just supply the requirements for the St. Paul Gas Light Co., to whom all of this gas is sold. The lean gas remaining was used for heating the battery and, if there was any excess, for firing the boilers.

Rich Gas.—All of the rich gas made during the test period was sold to the St. Paul Gas Light Co. as their city supply. This gas was measured at the coke plant through a Thomas meter; it was then pumped several miles through a high-pressure main to the gas company's holder station, where it was metered again by a Thomas meter and a third time by two wet-station meters operating in parallel. The record of these wet-station meters

is taken by the coke company and the gas company as a basis for payment, since these meters are considered to be more accurate than the Thomas meters. The Bureau representatives checked six times during each 24 hours the coke plant's Thomas-meter record and at the beginning and end of the by-product test period checked the readings of the gas company's station meters. The results of the gas company's measurements were reported daily to the coke company. A summary of these data, which were checked at the beginning and end of the period by the Bureau representatives and found to be correct, was used as the basis for computing the rich-gas yields. The Thomas meter at the coke plant, by comparison with these accepted results, was found about 5 per cent slow; the Thomas meter at the gas plant about 0.6 per cent fast; but neither of these two meters had been recently calibrated or adjusted accurately, so that it is not surprising to find these small discrepancies. It seems certain that the wet-meter readings were correct within 2 or 3 per cent, which is certainly sufficient for the present purposes.

In accepting the volume measurements shown by the gas company's wet meters, two sources of small discrepancies were ignored, namely, the slightly greater volume of the gas due to the reenrichment with benzol before it is sent from the coke plant, and the small decrease in volume caused by leakage and condensation in the pumping main between the coke plant and the city gas plant. These two errors were probably both less than 2 per cent and are of opposite effect upon the apparent volume. It can be properly assumed, therefore, that they just balance each other.

TABLE 15.—Rich Gas Produced

Day beginning 8 a. m.	Gas volume (M at 60° F and 30 inches)	Btu per cubic foot		Candle-power after reenrichment and pumping to city	Specific gravity before reenrichment (air=1)
		Before reenrichment	After reenrichment and pumping to city		
Sept. 29	4887	575	601	16.6	0.459
Sept. 30	5233	570	599	16.5	.460
Oct. 1	5416	568	595	15.2	.468
Oct. 2	5389	558	601	15.4	.501
Oct. 3	5552	578	597	14.8	.490
Oct. 4	5505	566	605	14.2	.480
Total or average	31 982	569	600	15.46	.476

The volume, heating value, candlepower, density, and analysis of the rich gas are shown in Tables 15 and 16. These data are more completely presented also in the summary, Table 18. These latter tables also show in detail the composition for each day and the average for the period, as well as the hydrogen-sulphide content, which on the average was 430 grains per 100 cubic feet of gas.

TABLE 16.—Gas Analysis

RICH GAS—BEFORE REENRICHMENT

	Sept. 29	Sept. 30	Oct. 1	Oct. 2	Oct. 3	Oct. 4	Average
CO_2 ..... per cent	4.5	4.5	4.5	4.5	4.6	4.5	4.5
Illuminants ..... do	3.9	4.7	4.3	4.9	4.4	4.3	4.4
O_2 ..... do	.5	.5	.5	1.0	.5	.3	.6
CO ..... do	11.5	11.0	11.0	10.4	11.1	10.8	11.0
CH_4 ..... do	34.0	33.4	30.3	31.7	30.8	29.2	31.5
H_2 ..... do	40.9	41.5	44.6	39.3	44.4	43.8	42.4
N_2 ..... do	4.7	4.4	4.8	8.2	4.2	7.1	5.6
Specific gravity	.459	.460	.468	.501	.490	.480	.476
H_2S[a]	.....	450	450	430	330	470	430

LEAN GAS

CO_2 ..... per cent	4.2	3.4	3.4	3.8	4.2	3.8	3.8
Illuminants ..... do	2.5	2.2	2.0	2.6	2.5	2.4	2.4
O_2 ..... do	.6	.3	.3	.4	.3	.6	.4
CO ..... do	12.6	12.8	12.5	11.3	12.8	12.3	12.4
CH_4 ..... do	29.7	25.4	25.6	22.5	23.2	24.2	25.1
H_2 ..... do	46.7	51.6	51.9	54.4	49.9	50.1	50.7
N_2 ..... do	3.7	4.3	4.3	5.0	7.1	6.6	5.2
Specific gravity	.451	.405	.419	.456	.458	.465	.437
H_2S[a]	.....	330	490	370	250	360	340

[a] Grains per 100 cubic feet of gas.

The above data show that 5.25 M of rich gas were produced per ton of coal as charged, equivalent to 5.71 M of rich gas per ton of dry coal. This is equivalent to 1490 Btu available in the rich gas per pound of coal as charged or 1625 Btu per pound of dry coal.

Gas to boilers.—The small amount of lean gas not needed to heat the battery was used under the boilers during the test period. During only three days was there gas thus available, amounting altogether to 1440 M, having a heating value of 490 Btu and the other characteristics described in the next section. This amounts to about 250 cubic feet of lean gas per ton of coal, equivalent to 55 Btu per pound of coal as charged or 65 Btu per pound of dry coal. This available heat should be added to the heat available in the rich gas in determining the total Btu available in surplus gas, which quantity was 1545 Btu per pound of coal as charged or 1690 Btu per pound of dry coal.

Lean gas.—The volume of lean gas used to heat the ovens was measured by two Venturi meters, one for each battery. These were new when installed in the plant less than a year before, and were apparently in very good order. To make sure that there was no large error introduced by them, they were calibrated by checking them for short periods against the small lean-gas storage holder, and it was found that they were substantially correct in each case. For practical purposes, therefore, no calibration correction was applied. The record of the integrating mechanism of the meters was used for this test.

The indication of these meters and the barometric pressure, temperature, and pressure of gas at the meter were observed six times each day and frequent determinations made of the specific gravity of the gas. Using these data as a basis, the volume of gas was corrected to 60° F, 30 inches mercury pressure, saturated with water vapor, and is thus reported. It was unnecessary to take any account of the changes in the quantity of lean gas in storage from day to day, as the holder capacity was negligible in comparison with the total volume of gas measured.

The results found for the gas to heat the two batteries and the small amount of surplus gas going to the boilers are summarized in Table 17, which table also gives the heating value and density of this gas as determined by the Bureau representatives. More details are given in Tables 16 and 18, including the results of analyses, hydrogen-sulphide determination, and other interesting observations.

TABLE 17.—Lean Gas Produced

Day beginning 8 a. m.	Volume (M cubic feet at 60° F, 30 inches			Heating value (Btu)	Specific gravity (air=1)
	Battery A	Battery B	To boilers		
September 29	426	4680	901	491	0.451
September 30	492	5091	353	491	.405
October 1	482	4957	186	487	.419
October 2	505	4761	.....	483	.456
October 3	489	4764	.....	495	.458
October 4	448	4762	.....	490	.465
Total or average	2842	29 015	1440	490	.437

From these tables it is seen that the total production of gas, rich and lean together, amounted to 2830 Btu per pound of coal as charged or 3080 Btu per pound of dry coal. Of this total 1280 Btu were used to heat the ovens for each pound of coal as charged. This represents 48.8 per cent of the volume of gas produced or 45.2 per cent of the Btu produced used to heat the ovens.

TABLE 18.—Gas Production

	Sept. 29	Sept. 30	Oct. 1	Oct. 2	Oct. 3	Oct. 4	Total	Average
Coal used:								
As charged.....tons..	996.6	976.2	1054.4	1022.0	1015.4	1027.7	6092.3	1015.4
Dry.....do....	916.2	897.5	969.3	939.5	933.5	944.7	5600.6	933.4
Volume of gas produced:								
Surplus—								
Rich to city....M cubic feet..	4887	5233	5416	5389	5552	5505	31 982	5330
Lean to boilers.....do....	901	353	186	.....	.....	.....	1440	240
Total surplus.....do....	5788	5586	5602	5389	5552	5505	33 422	5570
To ovens—								
Battery A.....do....	426	492	482	505	489	448	2842	476
Battery B.....do....	4680	5091	4957	4761	4764	4762	29 015	4834
Total to ovens.....do....	5106	5583	5439	5266	5253	5210	31 857	5310
Total gas made.....do....	10 894	11 169	11 041	10 655	10 805	10 715	65 279	10 880
Gas per ton as charged:								
Surplus.....cubic feet..	5810	5725	5310	5270	5470	5355	.....	5490
To ovens.....do....	5125	5720	5160	5150	5170	5070	.....	5230
Total.....do....	10 935	11 445	10 470	10 420	10 640	10 425	.....	10 720
Gas per ton of dry coal:								
Surplus.....do....	6315	6225	5780	5735	5950	5825	.....	5970
To ovens.....do....	5575	6220	5610	5605	5625	5515	.....	5690
Total.....do....	11 890	12 445	11 390	11 340	11 575	11 340	.....	11 660
Gas to ovens (per cent of total).....	46.9	50.0	49.4	49.4	48.6	48.6	.....	48.80
Heating value of gas:								
Rich.....Btu per cubic foot..	575	570	568	558	578	566	.....	569.2
Lean.....do....	491	491	487	483	495	490	.....	489.5
Heat in gas per pound of coal as charged:								
In surplus gas.....Btu..	1630	1615	1505	1470	1580	1515	.....	1550
In gas to ovens.....do....	1260	1405	1255	1245	1280	1240	.....	1280
Total.....do....	2890	3020	2760	2715	2860	2755	.....	2830
Heat in gas per pound of dry coal:								
In surplus gas.....Btu..	1775	1755	1640	1600	1720	1645	.....	1690
In gas to ovens.....do....	1370	1530	1365	1355	1390	1350	.....	1390
Total.....do....	3145	3285	3005	2955	3110	2995	.....	3080
Per cent of heat in gas used to coke coal.....	43.6	46.5	45.5	45.9	44.8	45.0	.....	45.2

PART V. SUMMARY AND CONCLUSIONS

The great importance during the war period of substituting mid-continent coal for coals from more distant sources, even in by-product coke-oven work, was well recognized. The Bureau of Standards was ordered to conduct an investigation of a new coke-oven process claimed to be especially suited to this purpose, and in connection with this the Bureau was requested to conduct a test of the St. Paul plant of the Minnesota By-Product Coke Co., which is owned by The Koppers Co., Pittsburgh. The Bureau of Standards, in cooperation with the Bureau of Mines, carried out this operating test, using about 7600 tons of coal from the Orient Mine, Franklin County, Ill. All phases of coal handling, by-

product recovery, and laboratory tests were under observation by the staff of 37 Government engineers and chemists employed on the work. In addition, those in charge had the benefit of advice and comment from a considerable number of experts who are specialists in the field of coke-oven operation.

The quantity of all coal used and of all by-products obtained was carefully weighed or measured at regular intervals and samples of each material were taken for analysis. The Bureau of Standards was responsible for the general planning and supervision of the test work. Its representatives made all observations of battery operation, high-temperature measurements, by-product recovery, and chemical laboratory work on gas and by-products. The Bureau of Mines was responsible for the sampling of the coal, both as it was loaded at the mine and as dumped at the plant. It supervised the weighing, coal-handling, coke-handling, and coke-sampling operations and made all analyses of coal and coke. Its representatives also made general observations on the character of the coke and operation of the ovens.

The Minnesota By-Product Coke Co. plant consisted of 65 ovens of 18¼ inches average width, operating during the test period with an average gross coking time of 19 hours and 33 minutes with coal finely pulverized, 12.75 tons per oven as charged. The temperature of the heating wall as determined by rare-metal thermocouples averaged about 1200° C during the test period. The coke was screened to produce large and small furnace sizes; stove, nut, and pea, domestic sizes, and breeze. The gas was separated into rich and lean at the battery. Separate test records were kept of each size of coke and of each quality of gas. Practically all of the ammonia produced was made up into sulphate immediately through the direct-recovery process. Although the plant operated for the production of pure light-oil products, only the total production of light oil was measured, but the yield of various constituents was determined by analysis.

The coke produced was very irregular in size, had a longitudinal fracture, was fingery, brittle, and shattered easily. The cell structure was very small and regular. The coke was lighter than the average by-product coke, weighing only 23 pounds per cubic foot. Table 19 summarizes the characteristics and yield of this coke further. The large percentage of domestic sizes obtained, and therefore the unusually small percentage of furnace size, demonstrates that the coke will not stand handling and screening without breaking up into many smaller sizes. This is due primarily to its fingery and brittle characteristics.

TABLE 19.—Coal and Coke Summary

Coal used:		
As charged	tons	7685.6
Dry	do	7065.4
Ovens charged		603
Coal per oven:		
As charged	tons	12.75
Dry	do	11.72
Coking time:		
Average gross	hrs:mins	19:33
Average net	do	19:11
Coke produced (dry):		
Furnace	tons	2704.4
Stove	do	1178.1
Nut	do	549.5
Pea	do	89.9
Breeze	do	308.4
Total	do	4830.3
Ratio of dry coke to dry coal:		
Furnace	per cent	38.3
Stove	do	16.7
Nut	do	7.7
Pea	do	1.3
Breeze	do	4.4
Total	do	68.4
Sizes of coke produced:		
Furnace	per cent	56.0
Stove	do	24.4
Nut	do	11.4
Pea	do	1.8
Breeze	do	6.4
Total	do	100.0

In order to test the behavior of the furnace-size coke produced from the Orient coal, arrangements were made to use about 1800 tons of this material in the blast-furnace plant of the Mississippi Valley Iron Co. The coke regularly used at that furnace is produced in Koppers ovens of the Laclede Gas Light Co., St. Louis, from a mixture of Elkhorn, Pocahontas (low volatile), and Illinois coals. The substitution of the Illinois coke for the regular supply was accomplished abruptly and continued without interruption throughout the 10-day period. Several experts were present during this test, and it was the unanimous opinion of these persons and of the blast-furnace operators that the Illinois coke had shown highly satisfactory results. However, it should be borne in mind that the furnace used for this test was of small capacity, and it

is not certain, therefore, that the results in this case would be duplicated on a large-size furnace.

The yields of gas and by-products are summarized in Table 20.

TABLE 20.—Gas and By-Product Yield—Summary

Product		Per ton of coal	
		As charged	Dry
Gas:			
Surplus	cubic feet	5490	5970
To ovens	do	5230	5690
Total	do	10 720	11 660
Tar:			
As produced	gallons	7.81	8.49
Dry (computed)	do	7.57	8.23
Ammonium sulphate, pure	pounds	27.88	30.33
Ammonia	do	7.19	7.82
Light oil:			
As produced	gallons	3.71	4.03
Under 200° C	do	3.11	3.38
Benzene	do	2.105	2.289
Toluene	do	0.497	0.540
Solvent naphtha	do	0.130	0.141

As a result of the test it is clearly demonstrated that some of the Illinois coals can be coked in the "chamber-type" oven without radical change in operating methods for the production of coke which can be successfully used in a blast furnace. However, it appears that the temperature at which Illinois coal should be handled for the production of the best coke is somewhat lower than the best operating temperatures for eastern coals, and moreover the speed of coking of the Illinois coal is somewhat less. The yield of gas and by-products from Illinois coal of the kind tested is excellent, both in quantity and quality. Of course the coal tested in this case represents one of the best Illinois coals for coking purposes, being lower in ash and sulphur and otherwise superior to many from this field.

In general, the comparison of eastern coking coals with those from the mid-continent field must be made upon an economic basis, since which source will be preferable depends altogether on local conditions which will affect the cost of the material and the relative expense of handling. These phases of the question have, however, not been discussed in this report.

WASHINGTON, March 20, 1919.

APPENDIX

SUMMARIZED REPORT OF TEST[5]

By F. W. Sperr, Jr., *Chief Chemist, The Koppers Co.*

In considering the use of the Minnesota By-Product Coke Co.'s plant for making a test on Illinois coal, with the primary object of making blast-furnace coke, we had to deal with the following three limitations:

1. The plant is arranged to supply the domestic coke market rather than to make maximum yields of metallurgical coke. The elaborate screening system, while it is well adapted to the separation of coke into the various sizes required by the trade, is not so satisfactory for preserving the bulk of the coke as blast-furnace coke. The matallurgical screening station is equipped simply with a 2½-inch rotating grizzly, which takes out the largest pieces of coke as foundry coke. The rest of the coke passes on to the domestic screening station where it is separated into the usual sizes. When there is a demand for blast-furnace coke a temporary bar screen with 1¼ inch openings is laid over the rotating grizzly in the metalurgical station. The coke passing over this temporary screen is loaded directly into cars as furnace coke. The position of the temporary screen is such that a considerable amount of hand labor is required to keep it clear and to keep the coke moving freely over it whenever it is used, and the furnace coke drops into the cars from a rather high elevation; both of which conditions cause it to be broken up somewhat more than would be the case if the screening station were designed primarily to produce blast-furnace coke. War conditions have, however, created so much demand for metallurgical coke that this temporary screening arrangement has been much used since the plant began operation. A great deal of coke has been shipped to various consumers, particularly to the Algoma Steel Co. There have been no complaints regarding its physical quality.

2. The average width of the oven chambers is 18¼ inches. There is no doubt that with coal of the character of Illinois coal a stronger coke is produced in narrower ovens. For example, we are now constructing at Terre Haute, Ind., ovens of 16 inches average width to coke a similar coal.

3. The requirements of the city of St. Paul for gas from this plant are such that the operation of the ovens at coking periods longer than about 19½ hours would produce a great deal of hardship. This situation was fully discussed by F. L. Cross, general manager of the St. Paul Gas Light Co., in his letter of September 18, 1918, to T. G. Janney, manager of the Minnesota By-Product Coke Co. It is not possible to successfully mix water gas with the coke-oven gas in quantities greater than 10 to 15 per cent of the total, and the quality of water gas is, of course, so different from that of coke-oven gas that the former can not be used in burners and other appliances which have been adjusted for the latter. Any change in adjustment of burners to take care of temporary conditions is impossible, as a period of several months is required, and a tremendous hardship to consumers results.

[5] This report was prepared from the records made by the operating force of the Minnesota By-Product Coke Co., and is presented here for comparison with the official record.

A preliminary test on Orient coal, made last spring, demonstrated that a satisfactory blast-furnace coke could be produced at about 19 hours' coking time, with flue temperatures about 2400° F (coke side corrected). It was decided to run the test on this basis, and in order to show the effect of longer coking period, producing larger sized and more blocky coke from coal of this character, a single oven (No. 1) was selected and operated at lower temperatures. Two charges were coked in this oven in about 23 hours and the third charge was coked in 25 hours. The effect of slow coking is, of course, interesting, but it unquestionably would be an impractical proposition to sacrifice the plant output for the sake of making bigger coke.

Previous to the test the ovens had been operating at less than 17 hours' coking time, using a mixture of Pittsburgh, Elkhorn, and Pocahontas coals. Directions were issued to lower the flue temperature to 2400° as soon as the Illinois coal was charged; but on account of the delay due to cleaning the bins when making the change, and to the uncertainty of the heaters as to the effect of the new gas upon the system, the flue temperatures were not brought down so rapidly as was desired. About 8 hours after the first oven had been charged, the temperatures were found still too high, so the gas was cut off entirely throughout the heating system until the right conditions were obtained. The coke made during the first 12 hours of the test was decidedly overcoked, but improvement was manifest as soon as the temperature regulation had been satisfactorily effected. With the exceptions just noted, no essential change was found necessary either in the temperature or in the coking time throughout the entire period of the test. The average gross coking time from September 29 to October 6, inclusive, was 19 hours and 23 minutes, or 1.06 hours per inch of oven width. The schedule of gas sent to the city during period of test shows that the requirements were satisfactorily met.

As will be explained under head of "Coke production" in the following summary of data, two systems were used for screening the coke. In the first system blast-furnace coke was made by the usual method with the use of the temporary bar screen. In the second system the coke was put through the entire series of screens. The results seem to indicate what might be expected, viz, a greater amount of breakage in the various operations of handling, dropping, and screening in the second system than in the first.

Summary of Data

First oven—No. 60	Charged 1:45 a. m., Sept. 28 Pushed 6:40 p. m., Sept. 28	
Last oven—No. 59	Charged 2:30 p. m., Oct. 5 Pushed 7:35 a. m., Oct. 6	
Number of ovens charged		603
Total wet coal unloaded (track scales)	tons	7609.36
Refuse Bradford breaker	do	14.49
Not used [6]	do	7.80
Net used	do	7587.07
Larry weight	do	7640.14
Correction factor	per cent	99.3
Water	do	7.04
Wet coal per oven	tons	12.58
Dry coal per oven [7]	do	11.69

[6] Comprising 5.88 tons used in oven No. 50 at beginning of test and 1.92 tons left over at end of test.

[7] This average figure is low because during the first day of the test low charges were used. The charging record of the last two days shows that in regular operation there could be charged 12.75 tons wet coal = 11.85 tons dry coal per oven.

The coal produced very little refuse in the Bradford breaker; approximately 60 tons went into the refuse bin during the course of the test, but this was all put back into the system and recirculated, leaving a final residue of 14.49 tons.

Coke Production

This falls in two divisions. Up to October 1 a 1¼-inch bar screen was laid over the rotary grizzly in the metallurgical screening station. The oversize was loaded as furnace coke. The undersize was separated as usual. After oven No. 65 had been pushed 3:41 p. m., October 1, all bins were cleaned out and weights of all products taken. The bar screen was removed and the coke was put through the regular system, making the following separations:

Through revolving screen ½ inch and under.....Breeze
Through revolving screen between ½ inch and 11/16 inch square.....Pea
Through revolving screen between 11/16 inch and 1⅜ inches square.....Nut
Through 1⅞-inch rotary grizzly and over 1⅜-inch square revolving screen.....Stove
Through 2½-inch rotary grizzly and over 1⅞-inch rotary grizzly.....Egg
Over 2½-inch rotary grizzly.....Foundry

COKE PRODUCTION, SEPT. 28 TO OCT. 1

	Tons wet	Per cent H_2O	Tons dry	Per cent yield
Larry coal corrected	2819.82	6.05	2649.22	.....
Furnace coke	1601.93	2.58	1560.60	58.91
Stove	142.62	8.00	131.21	4.95
Nut	113.27	12.50	99.11	3.74
Pea	19.87	12.50	17.39	.66
Breeze	101.32	15.00	86.12	3.25
Total	.....	.....	.....	71.51

COKE PRODUCTION, OCT. 1 TO OCT. 6

Larry coal corrected	4766.28	7.59	4404.52	.....
Foundry coke	566.77	3.19	548.69	12.46
Egg coke	703.08	3.19	680.66	15.45
Stove coke	1209.12	8.00	1112.39	25.26
Nut coke	510.94	12.00	449.63	10.28
Pea coke	97.58	12.00	85.87	1.94
Breeze coke	269.75	15.00	229.29	5.21
Total	.....	.....	.....	70.60

SUMMARY OF COKE YIELDS—DRY BASIS [a]

	Sept. 28 to Oct. 1.	Oct. 1 to Oct. 6.
	Per cent.	*Per cent.*
Furnace coke	58.91	53.17
Domestic coke	9.35	12.22
Breeze	3.25	5.21

[a] This classifies the coke made over 1⅜-inch square revolving screen Oct. 1 to 6 as furnace coke. Domestic includes stove, nut, and pea sizes previous to Oct. 1, and nut and pea sizes only Oct. 1 to 6.

By-Product Yields

For computing the by-product yields the period beginning 8 a. m., September 29 and ending 8 a. m., October 5 was taken. First oven, No. 61; last oven, No. 23; total ovens, 479; wet coal charged (larry weights corrected), 6030 tons; average moisture in coal, 7.57 per cent; dry coal charged, 5573.5 tons.

BY-PRODUCT YIELDS

		Produced	Yield per ton dry coal
Rich gas to city	M cubic feet	31 982	.....
Gas to boilers (lean gas)	do	1430	.....
Total surplus gas	do	33 412	5995
Gas to battery A	do	3026	.....
Gas to battery B	do	29 772	.....
Total gas to ovens	do	32 798	5885
Total gas made	do	66 210	11 880
Tar	gallons	47 560	8.53
Sulphate	pounds	153 455	28.79
Light oil (86.6 per cent)	gallons	22 236	3.98
Light oil under 200° C	do	.....	3.44
Benzene (by analysis)	do	.....	2.23
Toluene (by analysis)	do	.....	0.57

NOTE.—Above figures for tar and gas to ovens are those obtained by the Bureau of Standards, the plant records having been found inaccurate. All gas figures are corrected to 60° F and 30 inches of mercury. Gas to ovens was computed from charts of Venturi meters.

MISCELLANEOUS OPERATING DATA

Average coking time Sept. 29 to Oct. 4, inclusive	hours: min	19:23
Btu to coke 1 pound of dry coal		1430
Total gallons enricher used Sept. 29 to Oct. 4, inclusive		15 655
Gallons enricher per M cubic feet gas		0.49
Coal carbonized per man per day	tons	3.9
Flue temperature after reversal (coke side)	°F	2400

Most of the ovens pushed with about 130 amperes, but a considerable number required more on account of soft coke breaking up in front of the ram so that the average for the test was 172 amperes.

There were four stickers, viz: Oven No. 8, September 28, oven No. 49, September 29, and ovens Nos. 10 and 20, October 1. The writer did not observe oven No. 8, but the cause of the other three was undoubtedly undercoking, the last two ovens particularly having been opened sooner than usual in order to bring them into series after a previous delay.

LIGHT-OIL DISTILLATION

	Per cent
76.3° C	First drop
95° C	62.0
100° C	67.6
120° C	75.6
150° C	80.8
180° C	83.8
200° C	86.7

Analysis of light oil by Laclede still (sample being a 1-gallon portion of accumulated sample taken by Bureau of Standards).

	Per cent
Olefines	8.3
Benzene	56.1
Toluene	14.3
Solvent	3.6
Residue	17.7
Paraffins	None

PITTSBURGH, PA., October 14, 1918.