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COMPARISON OF BM-AGA AND SLOT-OVEN EXPERIMENTAL METHODS OF CARBONIZATION, WITH RESULTS FOR ELEVEN COALS

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FOREWORD

Since its creation by Congress in 1910, the Bureau of Mines has conducted scientific and technologic investigations on the composition, properties, mining, preparation, and utilization of coal with a view to improving efficiency, promoting health and safety, and conserving national fuel resources.

The early work was directed largely toward surveying the composition and properties of coals of different ranks and types, as expressed by heating value, fusibility of ash, and conventional proximate and ultimate analyses. These data were published and proved of great value to consumers of coal in selecting the kind of fuel best adapted to their particular equipment or purpose. However, an examination of this type, although adequate for dealing with fuels for combustion in the generation of heat and power, did not provide the data needed for evaluating coals for the production of coke, gas, and byproducts in manufactured-gas plants or byproduct coke ovens. The Bureau's attention was called to this need in 1927 by the Carbonization Committee of the American Gas Association, and under a cooperative agreement with this association the Bureau studied testing methods and developed a standard procedure known as the BM-AGA carbonization test. As stated by J. S. Haug, chairman of the Advisory Committee of the Association on Survey of Gas- and Coke-Making Properties of American Coals, the new test procedure has three distinctive characteristics as follows:

First, the quantity of coal per charge, 75 to 180 pounds,[1] is small enough to keep it within laboratory scope, make it convenient to operate, and permit reproducible control of test conditions. It is large enough to produce byproducts that have in general a similar nature to those obtained in large plants, and in quantity sufficient to permit analyses and tests of quality to be made, on which study and conclusions may be based.

Second, a series of tests is made on each coal at carbonizing temperatures from 600° to 1,000° C. at 100° intervals covering the low- and high-temperature range. This enables curves to be drawn showing trends of yields and qualities of products against temperature. This method brings out the idiosyncrasies of each coal in a unique manner.

Third, the temperatures of carbonization are inner-wall temperatures which are the real carbonization temperatures rather than the flue temperatures commonly referred to in large-scale work. These latter temperatures are higher than the inner-wall temperatures by the temperature gradient through the oven walls, a matter of several hundred degrees.

The value of this survey of the carbonizing properties of American coals by a standard method lies in the comparability of the results on different coals. It must be recognized that no standard laboratory method of carbonization, even on a large unit, can yield results that exactly duplicate those obtained in ovens and retorts. The commercial results vary with the type of oven or retort. Allowance must be

[1] Slightly larger charges (100 to 200 pounds) are now being used in the tests.

made for such differences in interpreting the BM-AGA test results in terms of commercial plants.

A comparison of BM-AGA tests and commercial-plant yields for 11 coals gives the following results:

1. Plant yields of coke, gas, and B. t. u. of gas per pound of coal usually fall between the test results obtained at carbonizing temperatures of 900° and 1,000° C. (1,652° and 1,832° F.).
2. The quantity of light oil scrubbed from the gas of the test apparatus is less than that scrubbed from the gas of commercial plants, because the test condensing train throws down more of the light oil with the tar; however, the total yields at 900° C. from gas plus light oil in the tar are approximately the same as the total from plants.
3. The yield of tar from the 1,000° C. carbonization shows the best agreement with plant yields, although on several coals the plant yields were 1 to 2 gallons per ton of coal less than those in the test apparatus.
4. The yields of tar and gas from the 18-inch retort usually are closer to those obtained in industrial practice than yields from the 13-inch retort.
5. The yield of ammonia from the test apparatus is low because of the decomposition induced by the iron of the retort. The yield at 800° C. approaches that obtained in industrial practice.
6. At a carbonizing temperature of 900° C. the 13-inch retort indicates the relative shatter and tumbler indexes of the coke, but the figures are lower than those obtained for the same coals in byproduct ovens. Much of this difference is eliminated by the use of the 18-inch-diameter retorts and a 1½-inch shatter index. The larger retort gives larger pieces of coke that are less fractured owing to the slower rate of heating.
7. The coke from the test retorts has a lower apparent density and a higher percentage of cells than byproduct-oven cokes made from the same coals. Tamping the charge of coal in the retort increases the apparent density and lowers the porosity to figures closely approaching those obtained in byproduct plants.

A secondary objective of the Bureau of Mines carbonization studies is to obtain information on the chemical and physical properties of different coals that may affect the yield and nature of the gas, coke, and byproducts. Microscopic examination, high- and low-temperature assays, and special physical tests to determine plasticity, agglutinating value, and friability have been made since the investigation was begun. The petrographic analyses based upon microscopic examination explain variation in carbonizing properties due to the types of coal making up the coal bed; plastic and agglutinating-value tests indicate to some extent the expansion or swelling of the coal during formation of coke; and the assays furnish an approximate measure of the yields of products at low and high coking temperatures.

In recent years the carbonization studies have been broadened to include tests of the expansion of coals and blends of coals while being heated under coke-oven conditions. Moreover, the effect of oxidation of coal during storage on its carbonizing properties is being determined by making carbonization tests on oxidized or unoxidized coals.

The BM-AGA test apparatus and method were first described in Bureau of Mines Bulletin 344, Method and Apparatus Used in Determining the Gas-, Coke-, and Byproduct-Making Properties of American Coals with Results on a Taggart-Bed Coal from Roda, Wise County, Va., published in 1931. They were discussed in detail in Bureau of Mines Monograph 5, Gas-, Coke-, and Byproduct-Making Properties of American Coals and Their Determination, published in 1934 and obtainable from the American Gas Association, 420 Lexington Avenue, New York City (164 pp., price $1.50). Recent improvements in the apparatus and method are published in Bureau of Mines Technical Paper 685, Procedure and Apparatus for Determining Carbonizing Properties of American Coals by the Bureau of Mines-American Gas Association Method.

A bibliography of other publications of the carbonization series that are obtainable from the Superintendent of Documents, Government Printing Office, Washington 25, D. C., is given at the end of this paper.

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COMPARISON OF BM-AGA AND SLOT-OVEN EXPERIMENTAL METHODS OF CARBONIZATION, WITH RESULTS FOR ELEVEN COALS [1]

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INTRODUCTION AND SUMMARY

The Bureau of Mines Coal Carbonization Laboratory has been interested for the past 20 years in the quality of coke in connection with the selection of coals for the manufacture of coke. The principal experimental method of carbonization, whereby 100- to 200-pound charges are carbonized in sheet-steel cylindrical retorts with recovery and determination of the properties of coke, gas, and products, was developed in cooperation with the American Gas Association,[4] [5] and it is known as the BM–AGA method. Results of the investigations of 90 coals included in the BM–AGA Survey of the Carbonizing Properties of American Coals have been published; [6] and, in addition to these, about 200 coals have been carbonized over limited temperature ranges.

Because coke from cylindrical retorts differs in shape from that made in rectangular ovens, the BM–AGA method has been criticized, although those who developed it have always believed that it served well as a means of measuring the relative strengths of cokes from different coals. It is recognized that no laboratory-method carbonization, even on a large unit, can yield results that exactly duplicate those obtained in commercial ovens and retorts. However, with the completion and satisfactory performance of an experimental vertical slot oven of 500-pound capacity at the University of Illinois Geological Survey Laboratory,[7] the opportunity to directly compare BM–AGA coke with coke made by two-sided heating became available and the necessary test apparatus was installed. The Bureau of Mines slot oven, which is similar to that designed by the University of Illinois Geological Survey, has been used to carbonize 11 coals (or blends) tested by the BM–AGA method. This report compares the results obtained by the two methods.

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[1] Work on manuscript completed Nov. 21, 1949.
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[4] Fieldner, A. C., and Davis, J. D., Gas-, Coke-, and Byproduct-Making Properties of American Coals and Their Determination: Bureau of Mines Mon. 5, 1934, 164 pp.
[5] Reynolds, D. A., and Holmes, C. R., Procedure and Apparatus for Determining Carbonizing Properties of American Coals by the Bureau of Mines-American Gas Association Method: Bureau of Mines Tech. Paper 685, 1946, 35 pp.
[6] For most recent list of publications see the end of this bulletin.
[7] Reed, F. H., Jackman, H. W., Rees, O. W., Yohe, G. R., and Henline, P. W., Use of Illinois Coal for Production of Metallurgical Coke: Illinois Geol. Survey Bull. 71, 1947, 132 pp.

Three high-volatile coals and eight blends of coals differing in rank were carbonized in BM–AGA retorts at 800° and 900° C., and in the slot oven at 870°–1,010° C. The average yields from BM–AGA tests at 800° and 900°, and the slot oven, respectively, were: Coke, percent, 70.5, 70.0, and 70.5; gas, cubic feet per ton, 8,900, 10,100, and 9,650; tar, gallons per ton, 13.0, 11.4, and 9.0; light oil, gallons per ton, 1.95, 2.39, and 1.75; and ammonium sulfate, pounds per ton, 27.2, 23.6, and 22.3. The slot-oven and 900° C. cokes were of similar chemical composition; the 800° C. cokes contained slightly more volatile matter and less fixed carbon. Generally, other physical properties of the slot-oven cokes were intermediate between those of the 800° and 900° C. BM–AGA cokes. The strength of the slot-oven cokes was similar to that of the 800° BM–AGA coke if gaged by the 1½- and 2-inch shatter indexes, but was more like that of the 900° BM–AGA coke if the 1- and ¼-inch tumbler indexes were compared. The specific gravity of the gas from the slot oven generally was intermediate between those of the gases from the 800° and 900° BM–AGA tests; heating values were lowest for the slot-oven gas. The tars from the 900° BM–AGA and slot-oven tests were similar; they differed significantly only in their content of solids (naphthalene, anthracene, and pitch), which was higher for the slot-oven tar. The light oils from the slot-oven tests contained greater proportions of benzene and lower proportions of paraffins and solvent naphtha.

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Acknowledgment is also made to E. J. Gardner, superintendent, Blast Furnace and Coke Plants, Inland Steel Co., Indiana Harbor, Ind., and R. W. Campbell, superintendent, Coke Division, Jones & Laughlin Steel Co., Pittsburgh, Pa., for supplying samples of coals carbonized in the plants of their respective companies.

The following members of the staff of the Bureau of Mines Central Experiment Station, Pittsburgh, Pa., cooperated in the investigation: H. M. Cooper, chemist, supervised analyses of the coals and cokes; A. Bartkowiak, H. R. Craig, and W. E. Erickson, scientific aides, assisted in preparing the coals, making the carbonization tests, and making the physical tests of cokes. Mary H. Cizmarik assisted with the calculations and preparation of the manuscript.

DESCRIPTION OF METHODS

The BM–AGA apparatus and test procedure have been described in detail.[8] In tests at high temperatures (800°, 900°, and 1,000° C.) about 200 pounds of coal is charged into an inverted sheet-steel retort 26 inches in height and 18 inches in diameter. The bottom of the retort is welded in place and is righted, bringing the 2-inch offtake pipe to the top to provide passage for volatile carbonization products. The

[8] See footnotes 4 and 5.

furnace is an electric resistance type and automatically controlled. It is preheated to a temperature 50° C. higher than that of the test to minimize the time required to attain test temperature after charging. Figure 1 shows the BM–AGA furnace, with an 18-inch retort being lowered into position for carbonization. The cabinet shown in the foreground contains a temperature indicator and controller, hand potentiometer, cold junction box, water manometer, mercury manometer, and indicating pressure gage. The manometers and gage measure gas pressures within the charge. The product-recovery train, which is not illustrated, consists of tar trap, water-cooled condenser, Cottrell precipitator, ammonia scrubbing tower, hydrogen sulfide tower, dehydrating condenser, benzol towers (two in series), and gas meter.

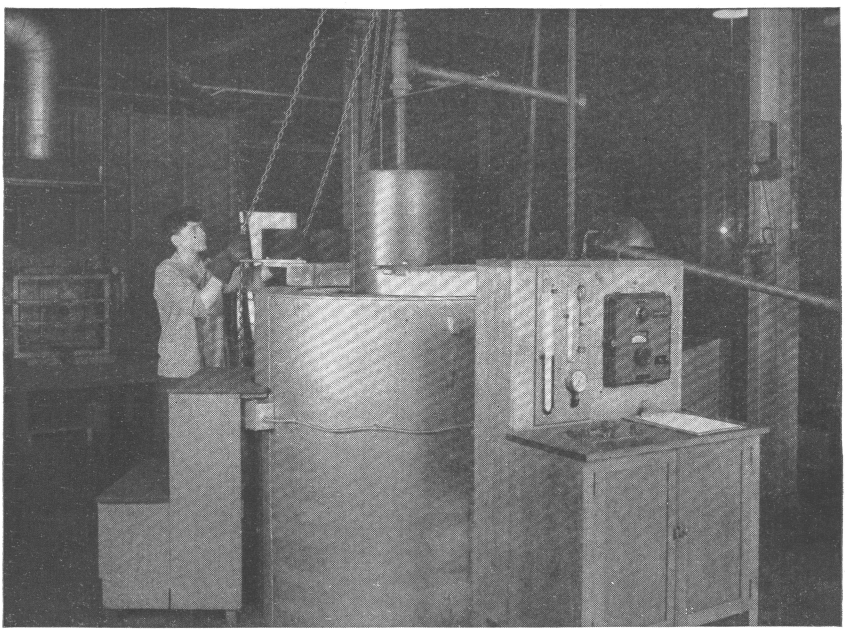


FIGURE 1.—BM–AGA furnace, with retort being charged; cabinet contains apparatus for measuring temperatures and gas pressures.

Figure 2 shows the slot oven with door removed and charging hopper in position. This oven was designed to duplicate a small portion of a commercial oven. The coking chamber is 36 inches long, 35 inches deep, and 14 inches (average) wide, and its volume is approximately 10 cubic feet. The side walls and floor are silicon carbide tile 2 inches thick. The chamber is electrically heated with globar resistors through flues on each side. Coal is charged from an overhead hopper through a 6-inch pipe, and the charge is leveled through a rectangular opening in the door, 35 inches above the floor. The volatile products pass through a 3-inch offtake extending through the top to the product-recovery train. Coke is discharged manually from the front after the door has been removed; it is quenched with water. Except for the door, which is removed as a unit, the oven does not differ materially from the original designed and used by the Illinois State Geological Survey at Urbana, Ill.

The oven is charged at an initial flue temperature of 1,600° F. (871° C.), and temperatures are so controlled that carbonization proceeds at the rate of 1.10 to 1.20 inches per hour. Temperatures within

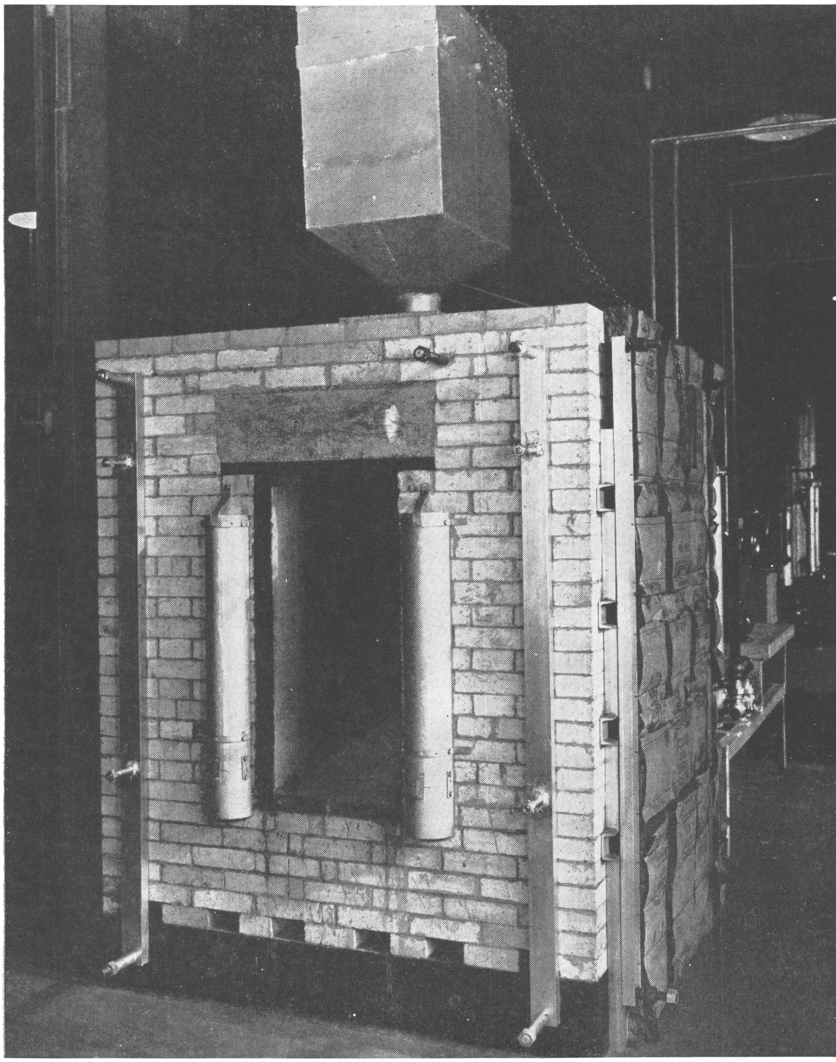


FIGURE 2.—Slot oven, with hopper in charging position and door removed.

the charge are measured at six points, using chromel-alumel thermocouples, and these are recorded automatically. The final flue temperature is 1,850° F. (1,010° C.), and when this temperature is attained the controls are set so that there is no further rise or fall in temperature. Carbonization is continued until the temperature at the center of the oven has remained constant for 30 minutes to 1 hour.

The volatile products pass through a tar trap, water-cooled condenser, and Cottrell precipitator in order. The gas is then divided into two approximately equal parts, half passing through a meter to waste and half passing through the BM–AGA product train, where ammonia, hydrogen sulfide, and benzol are removed before metering and sampling.

The chief difference in these two experimental carbonizing methods is in the size and shape of the coking chamber or retort. The coking rate in the slot oven, 1.1 to 1.2 inches per hour, is about the same as in the 800° C. BM–AGA test, which averages 1.1 inches per hour for high-volatile A coals; the corresponding rate in the 900° C. BM–AGA test is 1.7 inches per hour. The depth of charge in the slot oven—35 inches—is 10 to 11 inches greater than in BM–AGA retorts, although charge densities frequently are higher in the retorts because the retorts are handled some after charging causing the coal to settle. Final wall temperatures are 800° and 900° C. in BM–AGA retorts and 1,010° C. in the oven; maximum temperatures at the center of the charges are slightly lower (15°–25° C.) than the maximum wall temperatures.

DESCRIPTION OF COALS TESTED

In selecting the coals or blends for this investigation, two objectives were fulfilled: (1) Commercial blends were included to permit correlative experimental and coke-oven results, and (2) the composition of the charges was varied to obtain data on both weakly and strongly coking coals. Table 1 gives the source of coals and composition of blends carbonized.

TABLE 1.—*Description of coals and blends*

Coal No.	*Description and source*
94	Lower Cedar Grove–Alma A beds, Omar No. 5 mine, Logan County, W. Va.
94A	80 percent Lower Cedar Grove–Alma A (94) and 20 percent Pocahontas No. 3 (75).
b316	Corona bed, Corona mine, Walker County, Ala.
b316A	80 percent Corona (b316) and 20 percent Pocahontas No. 3 (75).
336	Blend used in byproduct ovens at Pittsburgh, Pa.
341	Pocahontas-bed coals blended at byproduct plant, Indiana Harbor, Ind.
342	Upper Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky., Slack coal.
342A	65 percent Upper Elkhorn No. 3 (342) and 35 percent Pocahontas (341).
342B	40 percent Upper Elkhorn No. 3 (342), 35 percent Pocahontas (341), and 25 percent Upper Elkhorn No. 3 (343).
343	Upper Elkhorn No. 3 bed, Wheelwright mine, Floyd County, Ky., Egg coal.
344	Corban: Mixture of various high-volatile Kentucky and West Virginia coals carbonized commercially at Indiana Harbor, Ind.
344A	65 percent Corban (344) and 35 percent Pocahontas (341).
344B	50 percent Corban (344), 35 percent Pocahontas (341), and 15 percent Upper Elkhorn No. 3 (343).
356	Imboden bed, Shady Side mine, Letcher County, Ky.
361	Illinois No. 5 bed, Sahara No. 16 mine, Saline County, Ill.
361A	80 percent Illinois No. 5 (361) and 20 percent Pocahontas No. 3 (75).
361B	70 percent Illinois No. 5 (361) and 30 percent Pocahontas No. 3 (75).
363	No. 2 Gas bed, Cannelton No. 100 mine, Fayette County, W. Va.

Eight blends containing low- and high-volatile coals and three high-volatile coals were carbonized by both methods. The blends were as follows: Coal 94A—80 percent Lower Cedar Grove and Alma A and 20 percent Pocahontas No. 3; b316A—80 percent Corona and 20 percent Pocahontas No. 3; 336—blend used in a commercial plant at Pittsburgh, Pa.; 342A—65 percent Upper Elkhorn No. 3 Slack and 35 percent Pocahontas; 342B—40 percent Elkhorn No. 3 Slack, 25 percent Elkhorn No. 3 Egg, and 35 percent Pocahontas; 344A—65 percent mixed high-volatile coals (Corban) and 35 percent Pocahontas; 344B—50 percent mixed high-volatile coals (Corban), 15 percent Upper Elkhorn Egg, and 35 percent Pocahontas; and 361A—80 percent Illinois No. 5 and 20 percent Pocahontas No. 3. Three unblended high-volatile coals were: Imboden from Kentucky, No. 5 from Illinois, and No. 2 Gas from West Virginia.

The Corban mixture, Elkhorn No. 3, and Pocahontas coals used in blends 342A, 342B, 344A, and 344B were crushed at an Indiana Harbor, Ind., coke plant before shipment to Pittsburgh; therefore their coking power may have deteriorated during transit and subsequent storage because they were contained in burlap bags. The blend used at the Pittsburgh coke plant was crushed when received but is believed to have been fresh because the delivery time was short. The other coals were crushed in the laboratory and stored in steel drums until used.

PREPARATION OF SAMPLES

The coals received from commercial plants at Indiana Harbor and Pittsburgh were crushed at the plant; coals received from mines were crushed at the laboratory in a hammer mill. Table 2 gives the screen analysis of each sample as carbonized.

The first three samples in table 2 (94A, b316A, and 336) contained 56.6 to 59.6 percent of minus 8-mesh coal; these are the coarsest samples. The following four samples (342A, 342B, 344A, and 344B) contained 71.7 to 74.0 percent of minus 8-mesh coal. Their proportions of the finer sizes were relatively high; the percentage passing the 200-mesh sieve ranged from 7.1 to 8.7. These coals had been crushed at the Indiana Harbor coke plant, which may account for their difference in size; however, three blends contained Elkhorn slack. The last four samples (356, 361, 361A, and 363) contained 78.2 to 81.2 percent of minus 8-mesh coal; these sieve analyses are similar, although the coals were from Kentucky, Illinois, and West Virginia.

The four Indiana Harbor blends (342A, 342B, 344A, and 344B) were moistened with 2 percent water to lower their charge density.

CHEMICAL ANALYSES OF SAMPLES

Table 3 gives chemical analyses of the coals and blends.

The volatile matter content of the 11 samples carbonized ranged from 27.8 to 36.6 percent, and the maximum content of ash was 9.5 percent. The blend of Corona and Pocahontas No. 3 (b316A) contained 2.4 percent sulfur, and Illinois No. 5 (361) contained 1.7 percent; the other samples contained no more than 1.4 percent sulfur.

TABLE 2.—*Sieve analysis, as-carbonized basis, percent*

Coal 94A—80 percent Lower Cedar Grove and Alma A (94) and 20 percent Pocahontas No. 3 (75)
Coal b316A—80 percent Corona (b316) and 20 percent Pocahontas No. 3 (75)
Coal 336—Blend used in by product ovens at Pittsburgh, Pa.
Coal 342A—65 percent Upper Elkhorn No. 3 (342) and 35 percent Pocahontas (341)
Coal 342B—40 percent Upper Elkhorn No. 3 (342), 35 percent Pocahontas (341), and 25 percent Upper Elkhorn No. 3 (343)
Coal 344A—65 percent Corban (314) and 35 percent Pocahontas (341)
Coal 344B—50 percent Corban (344), 35 percent Pocahontas (341), and 15 percent Upper Elkhorn No. 3 (343)
Coal 356—100 percent Imboden
Coal 361—100 percent Illinois No. 5
Coal 361A—80 percent Illinois No. 5 (361) and 20 percent Pocahontas No. 3 (75)
Coal 363—100 percent No. 2 Gas

Size [1]	Coal No.										
	94A	b316A	336	342A	342B	344A	344B	356	361	361A	363
On 4-mesh	14.8	15.2	36.1	10.9	10.6	13.4	11.2	1.6	1.7	2.4	1.5
Through 4- on 8-mesh	28.6	28.2	14.3	16.4	16.3	14.9	14.8	19.5	17.2	16.4	20.3
Through 8- on 14-mesh	22.2	21.9	13.2	18.0	18.9	17.0	17.7	28.1	29.9	29.1	29.7
Through 14- on 35-mesh	18.8	19.5	16.5	**25.7**	26.3	24.9	26.0	28.7	31.1	30.7	28.5
Through 35- on 80-mesh	7.5	7.7	10.5	**13.5**	13.3	13.5	14.0	11.4	10.0	11.8	10.6
Through 80- on 150-mesh	2.9	2.8	4.2	5.3	5.3	5.4	5.7	4.2	4.4	4.3	3.6
Through 150- on 200-mesh	1.0	1.1	1.4	2.3	2.2	2.2	2.3	1.8	1.9	1.9	1.6
Through 200-mesh	4.2	3.6	3.8	7.9	7.1	8.7	8.3	4.7	3.8	3.4	4.2
	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

[1] Tyler standard sieves.

TABLE 3.—*Analyses of coals, as-carbonized basis*[1]

Coal 94—100 percent Lower Cedar Grove and Alma A.
Coal 94A—80 percent Lower Cedar Grove and Alma A (94) and 20 percent Pocahontas No. 3 (75).
Coal b316—100 percent Corona.
Coal b316A—80 percent Corona (b316) and 20 percent Pocahontas No. 3 (75).
Coal 336—Blend used in byproduct ovens at Pittsburgh, Pa.
Coal 341—Pocahontas bed coals blended at byproduct plant, Indiana Harbor, Ind.
Coal 342—Upper Elkhorn No. 3.
Coal 342A—65 percent Upper Elkhorn No. 3 (342) and 35 percent Pocahontas (341).
Coal 342B—40 percent Upper Elkhorn No. 3 (342), 35 percent Pocahontas (341), and 25 percent Upper Elkhorn No. 3 (343).
Coal 343—100 percent Upper Elkhorn No. 3.
Coal 344—Corban: Mixture of various high-volatile Kentucky and West Virginia coals carbonized commercially at Indiana Harbor, Ind.
Coal 344A—65 percent Corban (344) and 35 percent Pocahontas (341).
Coal 344B—50 percent Corban (344), 35 percent Pocahontas (341), and 15 percent Upper Elkhorn No. 3 (343).
Coal 356—100 percent Imboden.
Coal 361—100 percent Illinois No. 5.
Coal 361A—80 percent Illinois No. 5 (361) and 20 percent Pocahontas No. 3 (75).
Coal 363—100 percent No. 2 Gas.
Coal 75—100 percent Pocahontas No. 3.

Coal No.	Dry, mineral-matter-free, fixed carbon, percent	Proximate, percent			Ultimate, percent						Air drying loss, percent	Heating value, B. t. u. per lb.	Softening temperature of ash, ° F.
		Moisture	Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur			
94	62.0	3.0	34.7	55.3	7.0	5.2	77.3	1.4	8.5	0.6	1.5	13,690	2,680
94A	66.1	2.8	31.1	59.2	6.9	5.1	78.1	1.4	7.9	.6	1.4	13,720	2,520
b316	56.1	3.1	38.7	47.9	10.3	5.4	70.7	1.6	9.4	2.6	1.6	12,850	2,280
b316A	62.6	2.5	33.7	54.3	9.5	5.1	73.7	1.6	7.7	2.4	1.3	13,260	2,250
336	64.3	4.7	32.0	56.0	7.3	5.3	75.1	1.5	9.5	1.3	3.6	13,440	2,600
341	81.5	1.7	17.4	73.1	7.8	4.4	81.8	1.2	4.0	.8	.9	14,160	2,550
342	62.1	3.0	34.4	54.9	7.7	5.3	75.0	1.4	9.7	.9	.5	13,350	2,340
342A	68.1	2.5	29.3	60.8	7.4	5.0	77.6	1.4	7.8	.8	.8	13,690	2,470
342B	68.9	2.5	28.9	62.5	6.1	5.1	78.8	1.4	7.8	.8	.8	13,880	2,390
343	60.7	2.6	37.2	56.9	3.3	5.6	79.7	1.6	9.0	.8	.5	14,180	2,210
344	62.8	2.7	33.5	54.8	9.0	5.2	74.4	1.3	9.1	1.0	.7	13,280	2,570
344A	69.2	3.5	27.8	60.3	8.4	5.0	76.2	1.3	8.2	.9	1.5	14,340	2,550
344B	68.6	3.5	28.5	60.6	7.4	5.1	77.0	1.3	8.4	.8	1.8	13,550	2,550
356	61.8	3.0	35.8	57.0	4.2	5.6	78.0	1.6	9.6	1.0	1.3	13,910	2,840
361	60.9	6.4	34.4	52.3	6.9	5.4	71.2	1.6	13.2	1.7	3.3	12,680	2,160
361A	65.8	5.5	30.6	57.2	6.7	5.3	73.4	1.5	11.7	1.4	3.7	13,020	2,160
363	61.0	1.7	36.6	56.3	5.4	6.0	77.4	1.5	8.6	1.1	.8	14,070	2,780
75	82.2	3.2	16.6	72.7	7.5	4.4	80.8	1.1	5.5	.7	2.7	13,990	2,400

[1] Analyses made under supervision of H. M. Cooper, chemist, Bureau of Mines.

RESULTS OF CARBONIZATION TESTS

BM–AGA tests are made in duplicate, except in a few instances when the size of sample received is too small to make all the tests desired. The amount of coal charged to the slot oven is about two and one-half times that charged in the 18-inch BM–AGA retort; therefore the quantities of carbonization products from single tests are large enough to make the various tests necessary to determine their properties. In this investigation the BM–AGA tests of the four Indiana Harbor plant blends (342A, 342B, 344A, and 344B) were not duplicated because the samples of several of the constituent coals were too small; slot-oven tests of the Pittsburgh-plant blend (336) and No. 2 Gas coal (363) were duplicated to determine how well the data could be checked.

YIELDS OF CARBONIZATION PRODUCTS

The yields of carbonization products obtained from the 11 coals in BM–AGA tests at 800° and 900° C., and the slot oven are given in table 4. They are compared graphically in figures 3 to 6, inclusive.

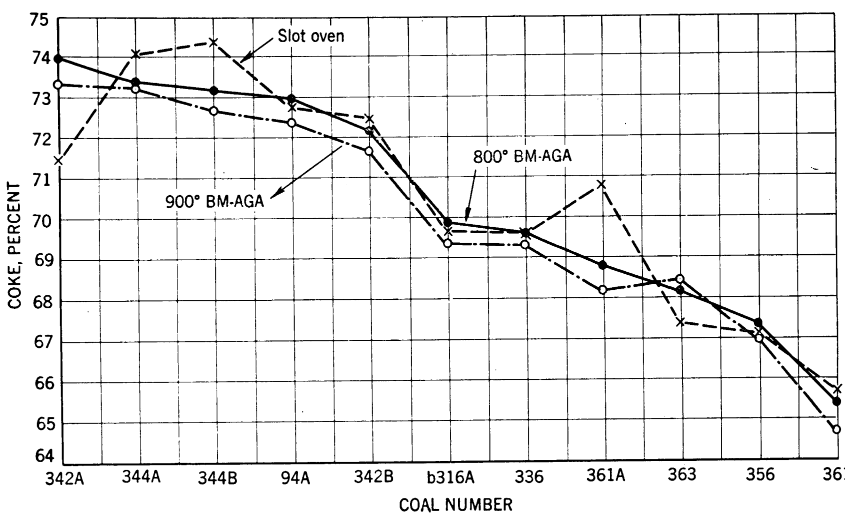


FIGURE 3.—Yield of coke, percent.

In these graphs and those showing the properties of the carbonization products, results for the nine coals are joined by lines only to facilitate comparison of the test methods. This comparison is primarily important in this study, otherwise the data would be presented to emphasize differences in the separate coals, or blends. The coal numbers are not plotted in the same order in each figure as it was necessary to change the order to have one ascending, or descending, curve in each. For example, in showing the composition of light oil (fig. 19, p. 32), the slot-oven yields of benzene determine the order, because benzene is the most important light-oil constituent and maximum yields were obtained in the slot oven.

COKE

Most of the yields of coke obtained in the three tests differed by less than 1 percent. The BM–AGA yields at 800° and 900° C. agreed more closely and averaged 70.5 and 70.0, respectively. Although the yields from the slot oven averaged the same as the 800° C. BM–AGA yields (70.5 percent), the yields from blends 342A and 361A appear to be inordinate. Facilities for drying the relatively large amounts of coke discharged from the slot oven were inadequate, therefore these

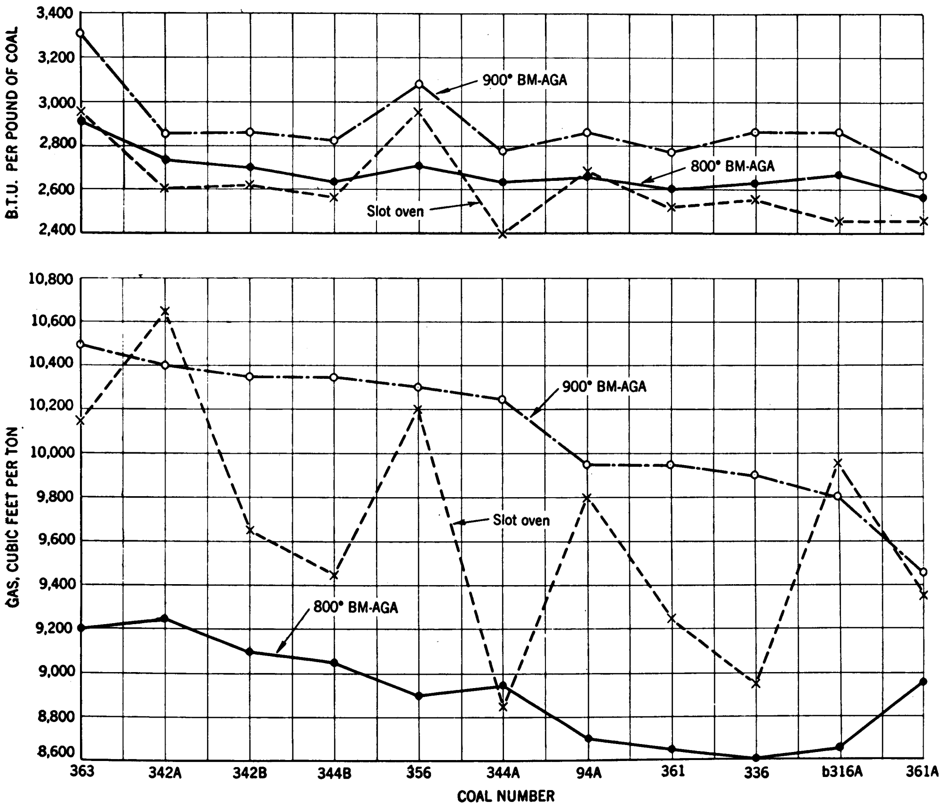


FIGURE 4.—Yield of gas, cubic feet per ton, and heating value of gas, B. t. u. per pound of coal.

yields were determined less accurately than in the BM–AGA tests wherein unquenched dry coke is weighed.

GAS

The average yields of gas, in cubic feet per ton of coal, were: BM–AGA 800° C., 8,900; BM–AGA 900° C., 10,100; and slot oven, 9,650. The curves in figure 4 show that the yields from the slot oven fluctuate more than in the BM–AGA tests. These differences were real because the gas volumes were determined in all tests with virtually the same degree of precision. However, the gas obtained in BM-AGA tests is derived wholly from the charge, whereas in the slot-oven test some air is drawn into the carbonizing chamber because it is not gas-tight and is maintained at a slightly reduced pressure. This inherent difference in the two test methods accounts for the shape of curves in figure 4.

TAR

The average yields of tar as gallons per ton were: 800° C. BM–AGA, 13.0; 900° C. BM–AGA, 11.4; and slot oven, 9.0. The yields from the

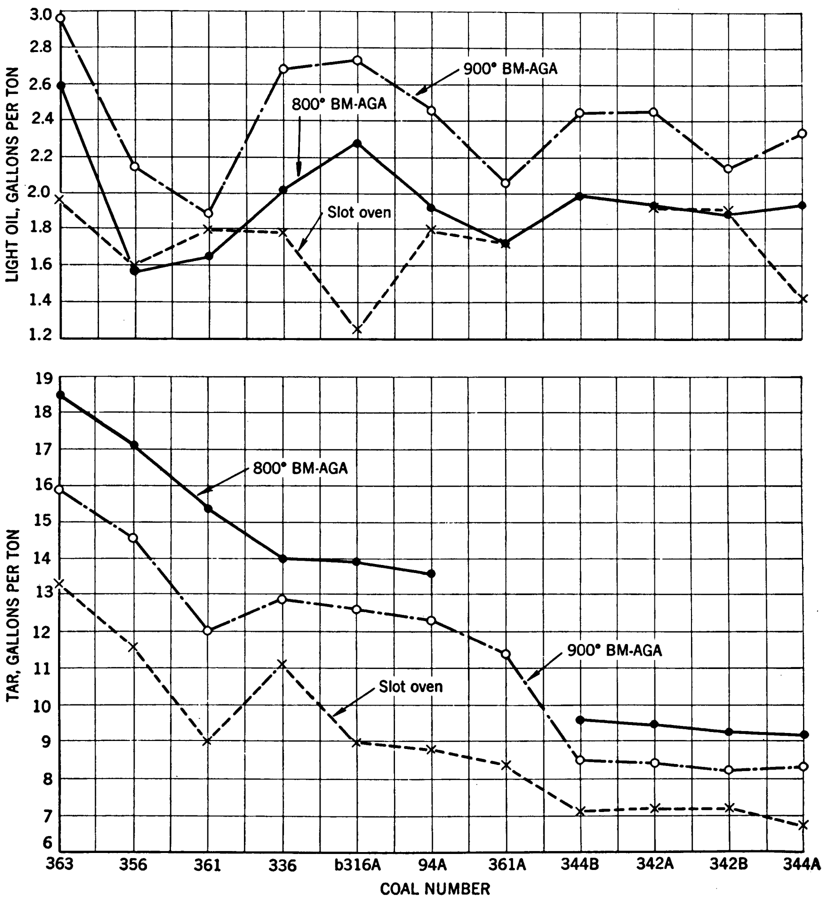


FIGURE 5.—Yields of tar and light oil, gallons per ton.

slot oven were lowest for each coal, indicating that the effluent carbonization products were cracked more than in BM–AGA tests at either temperature. Another indication that cracking is greater in this test is the high proportion of anthracene and naphthalene salts contained by the tars. Figure 5 shows rather wide ranges in the tar yields obtained in the three tests; the yields in the 800° C. test ranged from 18.5 gallons per ton for No. 2 Gas coal (363) to 9.2 gallons per ton for the blend (344A) of 65 percent Corban (mixed high-volatile coals) and 35 percent Pocahontas No. 3. The three high-volatile coals that were carbonized singly yielded more tar at 800° C. than the eight blends and this difference is normal because blending with low-volatile coal lowers tar yields. Four blends (344A, 344B, 342A, and 342B) of coals that were shipped to the carbonization laboratory from a coke plant at East Chicago, Ind., yielded less tar than the other samples. The low tar yields may have been due to oxidation. No tests were made to determine the amounts of oxygen absorbed by the coals during shipment and storage.

LIGHT OIL

The average yields of light oil, gallons per ton, were: 800° C. BM–AGA, 1.95; 900° C. BM–AGA, 2.39; and slot oven, 1.75. These

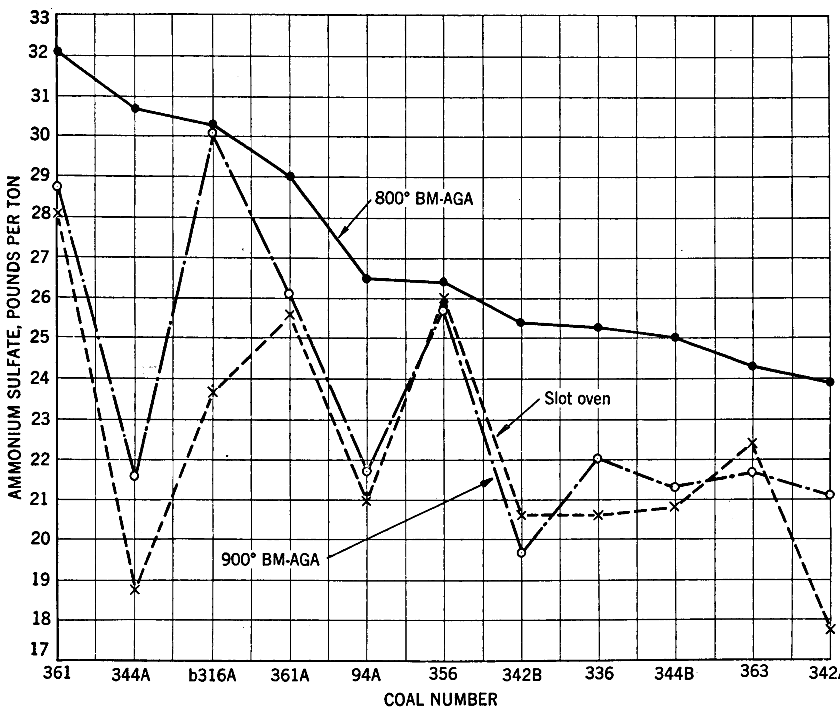


FIGURE 6.—Yield of ammonium sulfate, pounds per ton.

yields do not include the light oil in tar, which is appreciable because the vapors are cooled more efficiently than in oven practice. Figure 5 shows that generally the yield of light oil in the slot oven approximates that in the 800° BM–AGA test. These yields do not correlate well with the tar yields; the yields of light oil from the three high-volatile coals as a group do not differ materially from the yields derived from the blends.

AMMONIUM SULFATE

Figure 6 shows that similar yields of ammonium sulfate were obtained from the 900° BM–AGA and slot-oven tests. Average yields,

TABLE 4.—*Yields of carbonization products, as-carbonized basis*

Coal No.	Oven type	Final flue temperature, ° C.	Bulk density, lb. per cu. ft.	Coking time, hours	Coke yield, percent	Yields per ton of coal [1]			
						Gas, cubic feet	Tar, gallons	Light oil, gallons in gas	Ammonium sulfate, pounds
94A	BM-AGA	800	52.8	15.9	73.0	8,700	13.6	1.93	26.5
	do	900	53.7	11.4	72.4	9,950	12.3	2.46	21.7
	Slot	1,010	49.0	12.0	72.8	9,800	8.8	1.80	21.0
b316A	BM-AGA	800	52.7	15.9	69.9	8,650	13.9	2.28	30.3
	do	900	51.8	11.5	69.4	9,800	12.6	2.73	30.1
	Slot	1,010	47.2	11.5	69.7	9,950	9.0	1.56	23.7
336	BM-AGA	800	51.4	15.9	69.6	8,600	14.0	2.02	25.3
	do	900	51.7	11.7	69.3	9,900	12.9	2.69	22.0
	Slot	1,010	47.5	11.9	69.6	8,950	11.1	1.79	20.6
342A	BM-AGA	800	56.6	16.2	74.0	9,250	9.5	1.93	23.9
	do	900	[2] 48.9	11.6	73.4	10,400	8.4	2.46	21.1
	Slot	1,010	[2] 46.9	12.5	71.5	10,650	7.2	1.92	17.8
342B	BM-AGA	800	[2] 52.5	16.0	72.2	9,100	9.3	1.88	25.4
	do	900	[2] 53.5	11.1	71.7	10,350	8.2	2.14	19.7
	Slot	1,010	[2] 47.4	12.3	72.5	9,650	7.2	1.90	20.6
344A	BM-AGA	800	[2] 54.1	16.6	73.4	8,950	9.2	1.92	30.7
	do	900	[2] 54.1	11.6	73.3	10,250	8.3	2.32	21.6
	Slot	1,010	[2] 49.3	12.5	74.1	8,850	6.7	1.42	18.8
344B	BM-AGA	800	[2] 55.0	16.2	73.2	9,050	9.6	1.98	25.0
	do	900		11.3	72.7	10,350	8.5	2.45	21.3
	Slot	1,010	[2] 49.2	12.3	74.4	9,450	7.1		20.8
356	BM-AGA	800	49.9	14.5	67.4	8,900	17.1	1.57	26.4
	do	900		10.4	67.0	10,300	14.6	2.15	25.7
	Slot	1,010	46.6	11.8	67.1	10,200	11.6	1.60	26.0
361	BM-AGA	800	50.6	16.2	65.4	8,650	15.4	1.66	32.1
	do	900	[3] 49.4	11.3	64.7	9,950	12.0	1.89	28.7
	Slot	1,010	45.3	12.0	65.7	9,250	9.0	1.80	28.1
361A	BM-AGA	800		16.1	68.8	8,950		1.73	29.0
	do	900		10.9	68.2	9,450	11.4	2.05	26.1
	Slot	1,010	48.5	12.3	70.8	9,350	8.4	1.73	25.6
363	BM-AGA	800	51.1	14.9	68.2	9,200	18.5	2.60	24.3
	do	900	49.8	10.5	68.4	10,500	15.9	2.97	21.7
	Slot	1,010	49.0	12.0	67.4	10,150	13.3	1.97	22.4
Average		800	52.7	15.9	70.5	8,900	13.0	1.95	27.2
		900	51.6	11.2	70.0	10,100	11.4	2.39	23.6
		1,010	47.8	12.1	70.5	9,650	9.0	1.75	22.3

[1] Coke, tar, ammonia, and light oil are reported moisture-free; gas is reported as stripped of light oil and saturated with water vapor at 60° F. and under a pressure equivalent to 30 inches of mercury.
[2] Moisture added to lower bulk density.
[3] One-half percent moisture added.

as pounds per ton, by the three methods were: 800° C. BM-AGA, 27.2; 900° C. BM-AGA, 23.6; and slot oven, 22.3.

PROPERTIES OF COKE

Chemical analyses of the cokes are given in table 5. Various physical properties are given in tables 6 and 7, and the more significant of these are presented graphically in figures 7 to 9, inclusive. Figures 10 to 16, inclusive, show sections of the cokes made by three test methods from two unblended coals and five blends.

TABLE 5.—*Analysis of coke, dry basis*

Coal No.	Oven type	Final flue temperature, ° C.	Proximate, percent			Ultimate, percent					Heating value, B. t. u. per pound
			Volatile matter	Fixed carbon	Ash	Hydrogen	Carbon	Nitrogen	Oxygen	Sulfur	
94A	BM-AGA	800	2.7	86.6	10.7	1.0	85.6	1.3	0.8	0.6	13,010
	Do	900	1.5	87.7	10.8	.6	86.8	1.2	.1	.5	12,890
	Slot	1,010	.9	88.3	10.8	.6	86.7	1.2	.1	.6	12,880
b316A	BM-AGA	800	2.7	83.5	13.8	.8	82.2	1.2	.1	1.9	12,540
	Do	900	1.6	85.4	13.0	.5	83.4	1.1	.1	1.9	12,510
	Slot	1,010	1.7	85.2	13.1	.4	83.5	.9	.2	1.9	12,470
336	BM-AGA	800	1.4	88.1	10.5	.9	85.9	1.4	.2	1.1	13,000
	Do	900	1.0	88.1	10.9	.7	85.6	1.4	.3	1.1	12,820
	Slot	1,010	1.4	87.7	10.9	.4	86.1	1.4	.1	1.1	12,850
342A	BM-AGA	800	1.8	87.5	10.7	1.0	85.2	1.2	1.1	.8	12,960
	Do	900	1.8	87.2	11.0	.7	86.1	.9	.5	.8	12,850
	Slot	1,010	1.2	88.0	10.8	.7	86.3	1.1	.4	.7	12,860
342B	BM-AGA	800	1.9	88.8	9.3	1.0	86.8	1.2	1.0	.7	13,200
	Do	900	1.6	89.0	9.4	.6	87.9	1.1	.3	.7	13,120
	Slot	1,010	1.7	88.8	9.5	.7	87.4	1.1	.6	.7	13,070
344A	BM-AGA	800	3.5	84.6	11.9	.9	84.0	1.2	1.1	.9	12,740
	Do	900	1.8	86.6	11.6	.6	85.5	1.1	.3	.9	12,700
	Slot	1,010	2.5	85.8	11.7	.6	85.4	1.1	.3	.9	12,670
344B	BM-AGA	800	2.6	86.3	11.1	1.0	84.6	1.2	1.1	1.0	12,900
	Do	900	1.8	87.2	11.0	.6	85.8	1.1	.6	.9	12,810
	Slot	1,010	1.6	88.2	10.2	.6	86.6	1.1	.6	.9	12,880
356	BM-AGA	800	1.5	92.3	6.2	.8	89.8	1.5	.8	.9	13,560
	Do	900	.9	92.7	6.4	.6	90.5	1.5	.2	.8	13,490
	Slot	1,010	.9	92.7	6.4	.5	90.5	1.4	.4	.8	13,430
361	BM-AGA	800	1.7	87.6	10.7	.8	85.1	1.6	.4	1.4	12,920
	Do	900	1.2	88.1	10.7	.5	85.5	1.5	.4	1.4	12,810
	Slot	1,010	1.7	88.0	10.3	.5	86.2	1.3	.4	1.3	12,790
361A	BM-AGA	800	2.4	87.6	10.0	.8	86.1	1.4	.5	1.2	13,050
	Do	900	1.0	88.5	10.5	.5	86.2	1.3	.3	1.2	12,910
	Slot	1,010	1.3	88.8	9.9	.5	87.2	1.2	.0	1.2	12,950
363	BM-AGA	800	1.8	90.4	7.8	.8	88.2	1.5	.8	.9	13,350
	Do	900	.8	91.3	7.9	.5	89.0	1.5	.2	.9	13,260
	Slot	1,010	.9	90.9	8.2	.4	88.7	1.3	.5	.9	13,170
Average		800	2.2	87.6	10.2	.9	85.8	1.3	.7	1.0	13,020
		900	1.4	88.3	10.3	.6	86.6	1.2	.3	1.0	12,920
		1,010	1.4	88.4	10.2	.5	86.8	1.2	.4	1.0	12,910

CHEMICAL COMPOSITION

Table 5 shows that the 800° C. cokes contained more volatile matter and less fixed carbon than the 900° C. and slot-oven cokes. The average percentages of volatile matter were: 800° C. BM–AGA, 2.2; 900° C. BM–AGA, 1.4; and slot oven, 1.4. Generally, the slot-oven cokes did not differ materially from the 900° C. BM–AGA cokes.

APPEARANCE

The 800° C. cokes were fissured less than the 900° C. or slot-oven cokes; consequently the average size of the pieces was greater at the lower temperature. The BM–AGA coke pieces were longer than those from the slot oven because the diameter of the cylindrical retort exceeded the width of the slot oven chamber by 4 inches. Cell structure of the cokes from each coal or blend was fairly uniform. Imboden (356) and No. 2 Gas (363) coals yielded medium-grained cokes in each test, whereas the cokes from the blends were fine-grained.

The appearance of the cokes differed markedly with respect to the shape of individual pieces. In figures 10 to 16 the pyramidal pieces from BM–AGA retorts are shown as triangular sections and the prism-shaped pieces from the slot oven are shown as rectangular sections. The shape of BM–AGA coke pieces has caused some criticism of the method as a means of testing the coking power of coals,

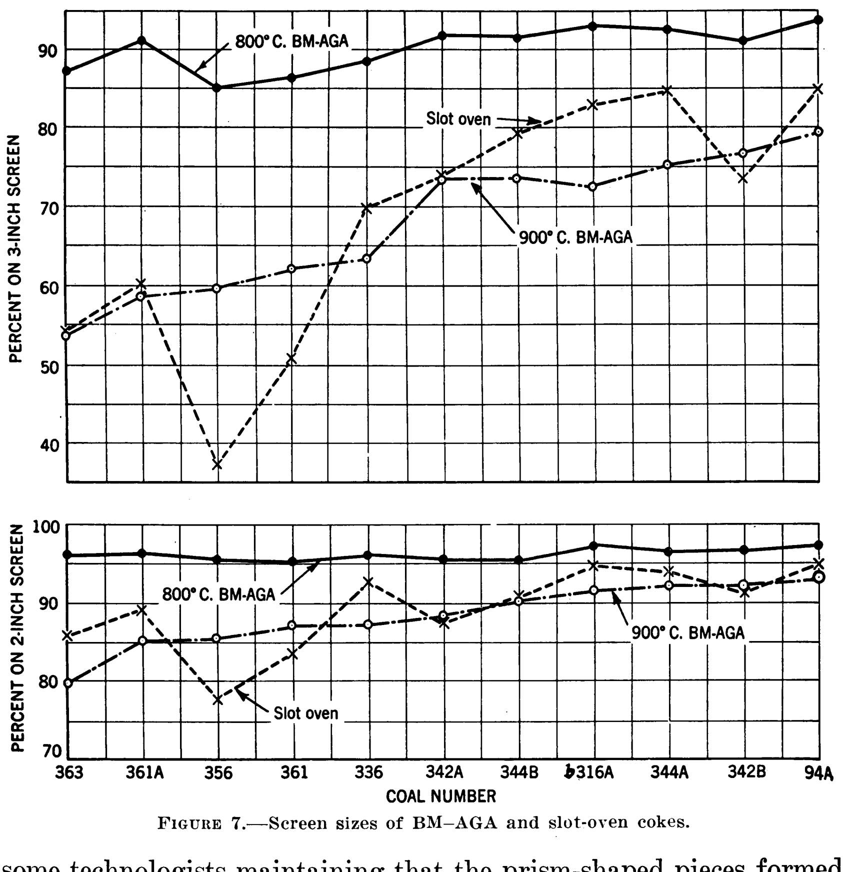


FIGURE 7.—Screen sizes of BM–AGA and slot-oven cokes.

some technologists maintaining that the prism-shaped pieces formed in two-sided heating, as in commercial ovens, are stronger. However, this contention is not substantiated by the results of this investigation, for it is shown in the comparison of shatter and tumbler indexes of cokes made by the BM–AGA and slot-oven methods that cokes having virtually equal strength may be produced by these methods.

SIZE

The screen analyses show rather large variations in the sizes of coke, especially of those made in the slot oven. The percentages of

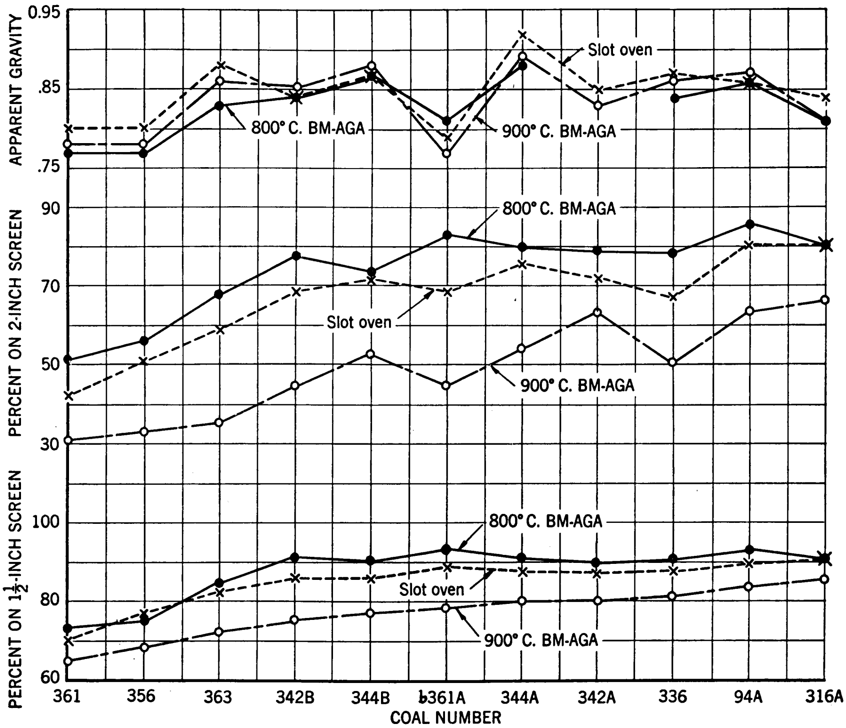


FIGURE 8.—Shatter indexes and apparent specific gravity of BM–AGA and slot-oven cokes.

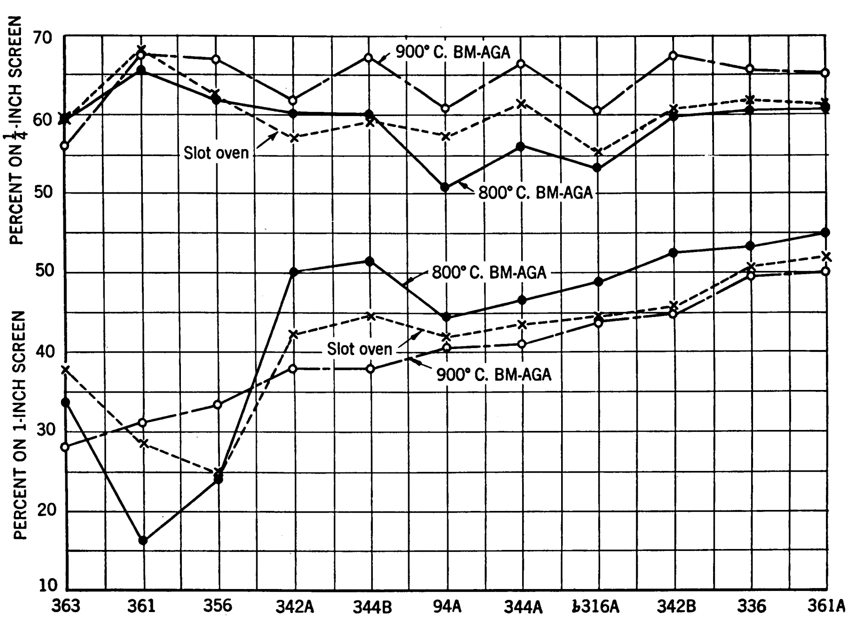


FIGURE 9—Tumbler indexes of BM–AGA and slot-oven cokes.

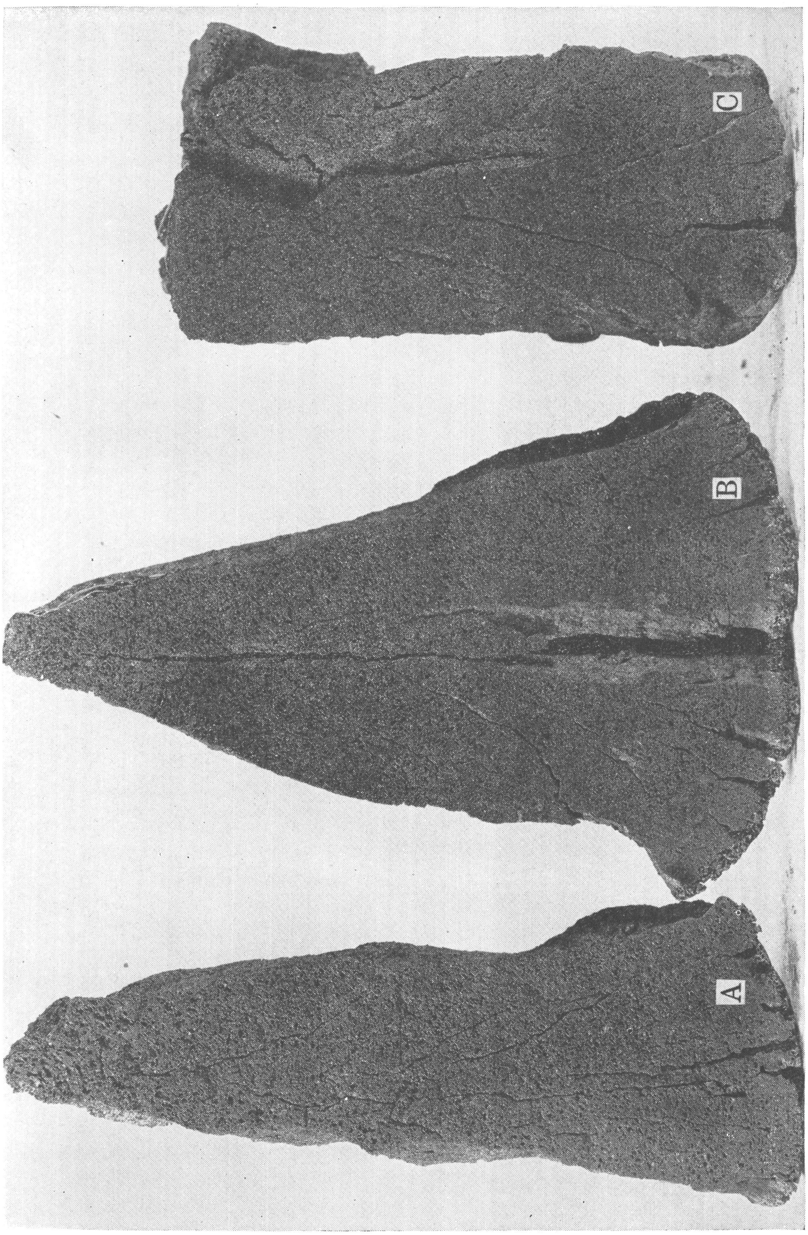


FIGURE 10.—Sections of coke from Imboden coal: *A*, BM–AGA, 800° C.; *B*, BM–AGA, 900° C.; *C*, 500-pound slot oven.

884097°—50——4

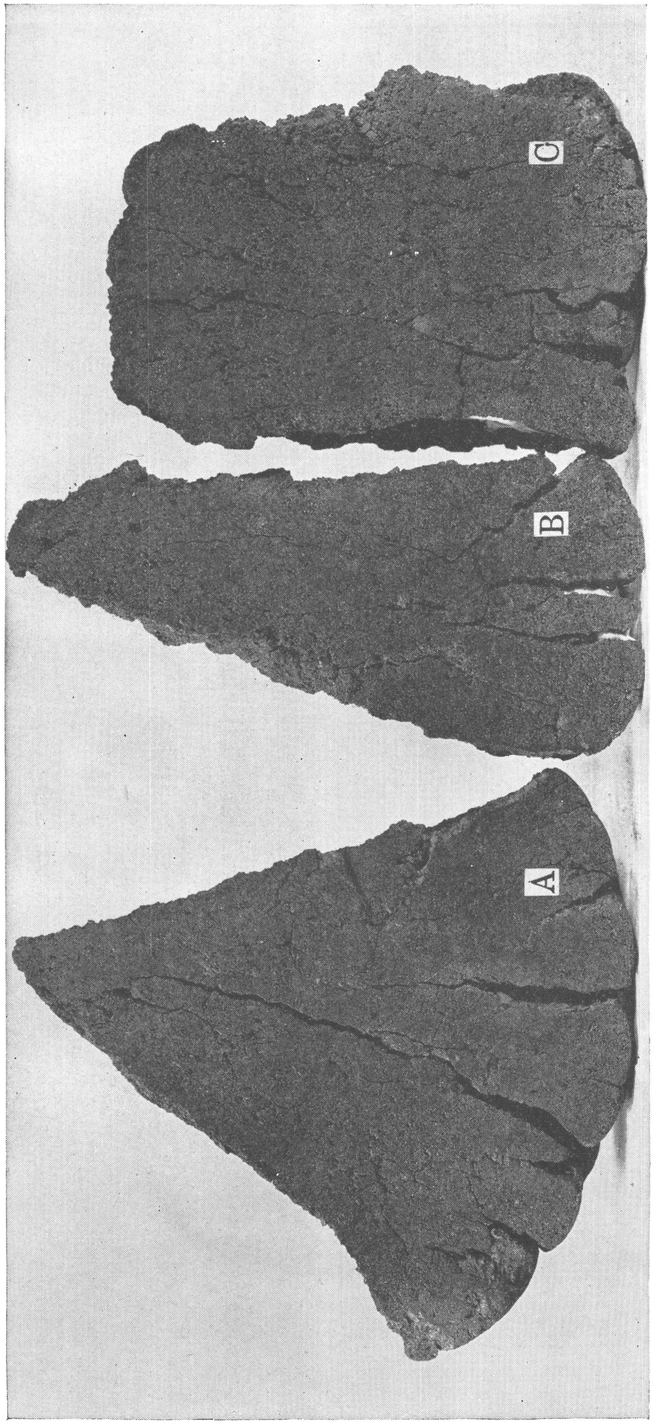


FIGURE 11.—Sections of coke from a blend of 65 percent Elkhorn (Wheelwright Slack) and 35 percent Pocahontas No. 3 coals: *A*, BM-AGA, 800° C.; *B*, BM-AGA, 900° C.; *C*, 500-pound slot oven.

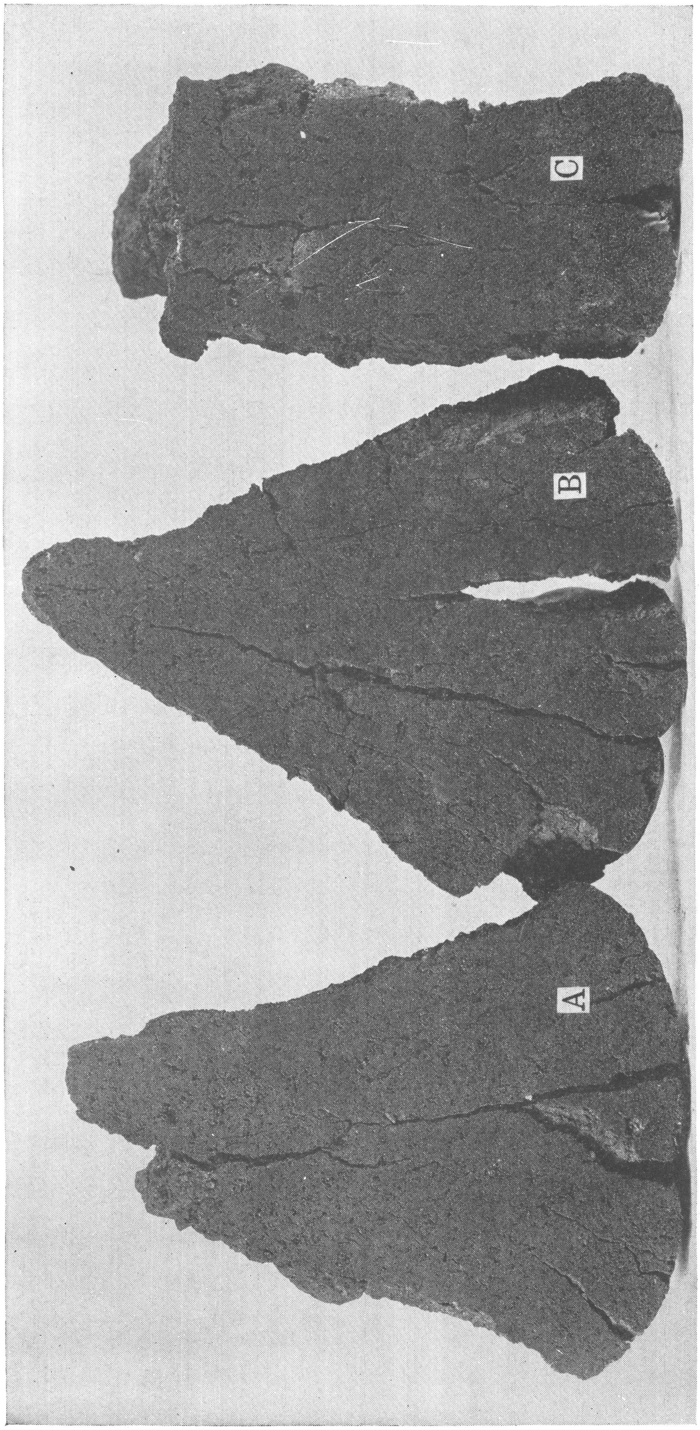


FIGURE 12.—Sections of coke from a blend of 40 percent Elkhorn (Wheelright Slack), 25 percent Elkhorn (Wheelright Egg), and 35 percent Pocahontas No. 3 coals: *A*, BM-AGA, 800° C.; *B*, BM-AGA, 900° C.; *C*, 500-pound slot oven.

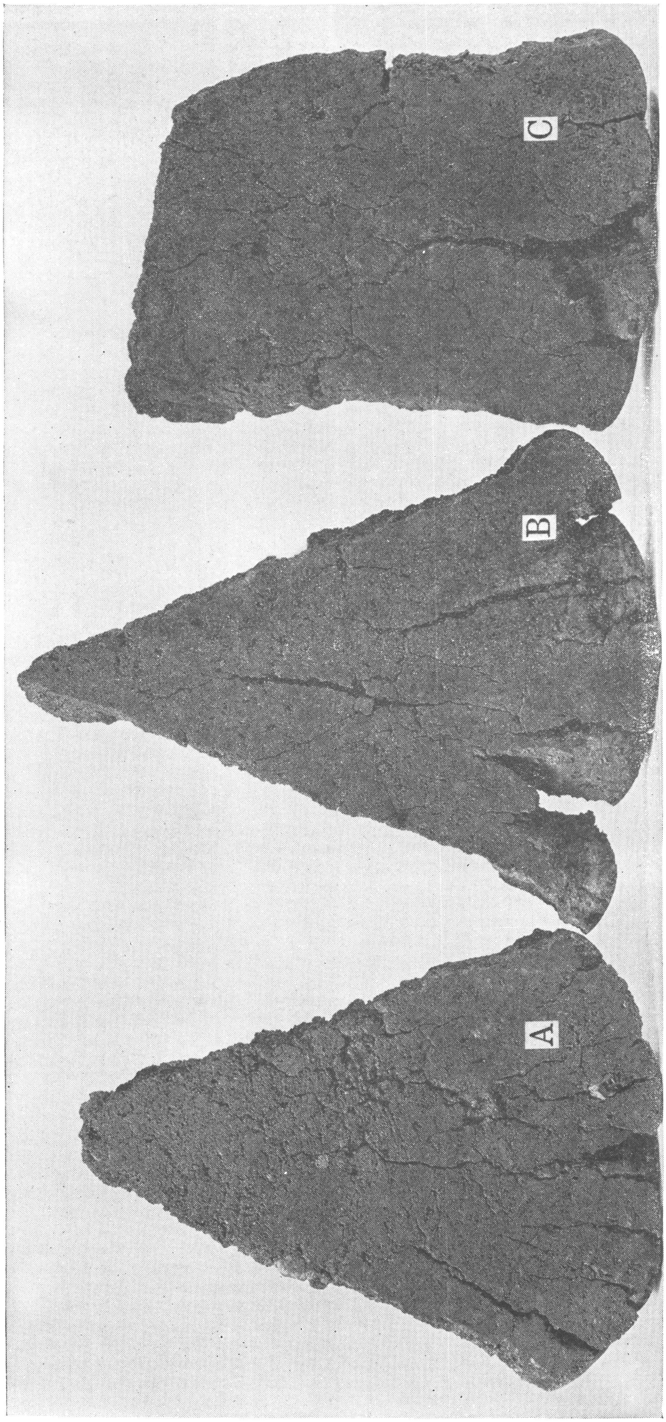


FIGURE 13.—Sections of coke from a blend of 65 percent Corban (mixed coals) and 35 percent Pocahontas No. 3 coals: *A*, BM–AGA, 800° C.; *B*, BM–AGA, 900° C.; *C*, 500-pound slot oven.

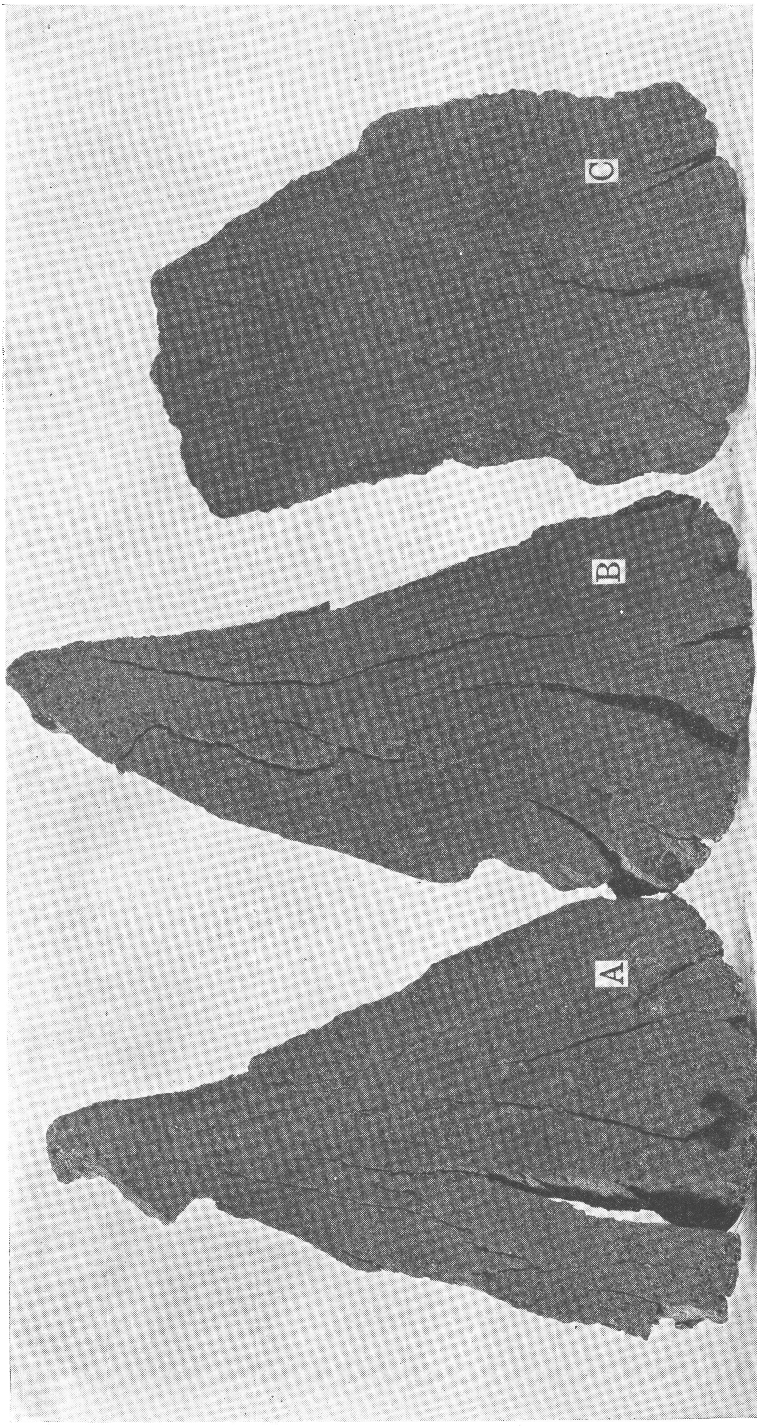
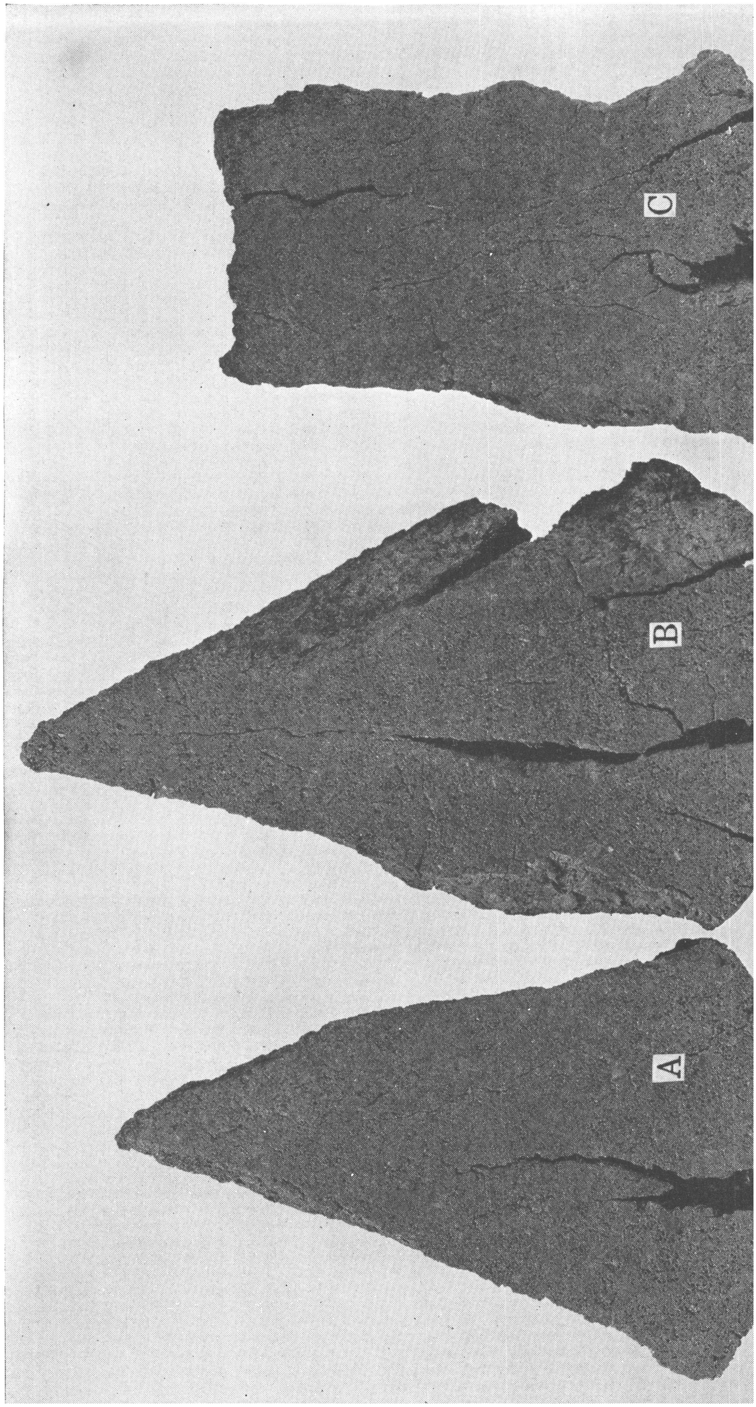


FIGURE 14.—Sections of coke from Illinois No. 5 coal: *A*, BM-AGA, 800° C.; *B*, BM-AGA, 900° C.; *C*, 500-pound slot oven.


A
B
C

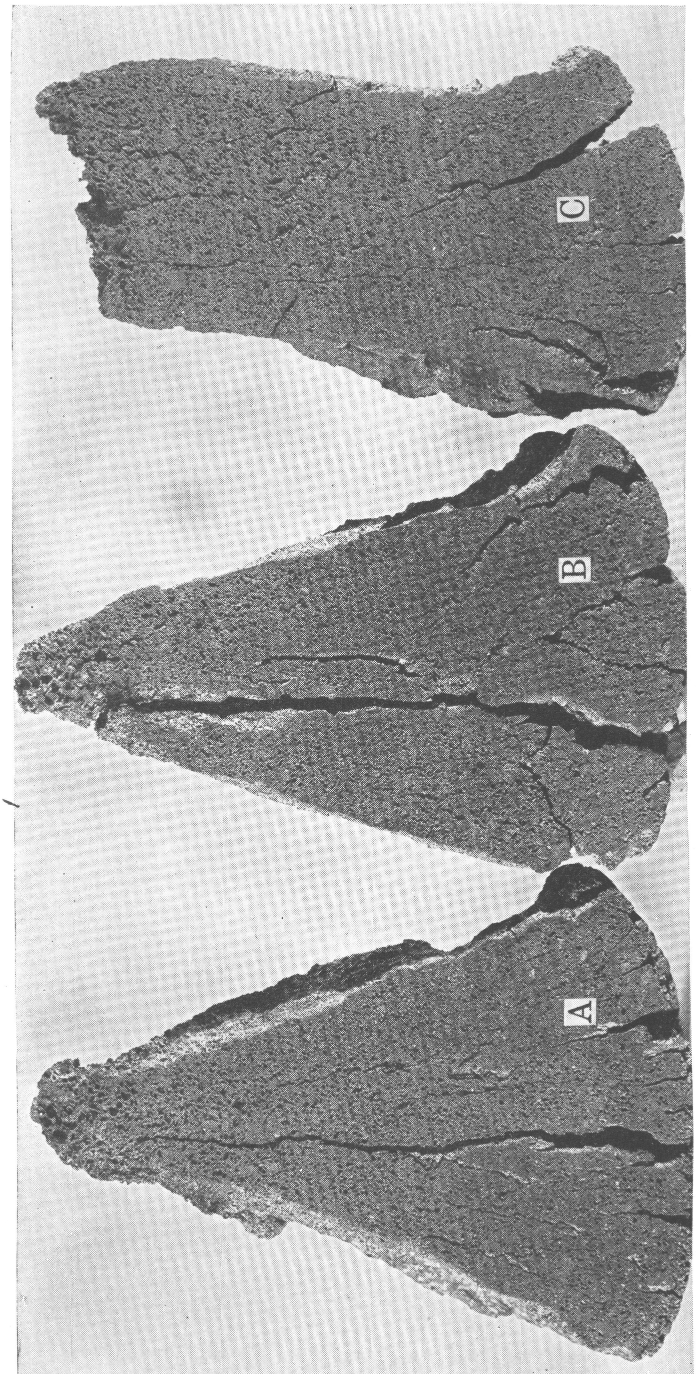


FIGURE 16.—Sections of coke from No. 2 Gas coal (363): *A*, BM-AGA, 800° C.; *B*, BM-AGA, 900° C.; *C*, 500-pound slot oven.

TABLE 6.—*Screen analysis of coke*

Coal No.	Oven type	Final flue temperature, ° C.	Screen sizes, cumulative percent upon—				
			4-inch screen	3-inch screen	2-inch screen	1½-inch screen	1-inch screen
94A	BM-AGA	800	82.7	94.0	97.3	98.5	99.2
	Do	900	54.0	79.5	93.2	97.2	98.6
	Slot	1,010	66.6	85.1	94.7	96.7	97.8
b316A	BM-AGA	800	82.8	93.2	97.2	98.4	98.9
	Do	900	42.5	72.7	91.4	96.0	97.9
	Slot	1,010	51.4	83.2	94.7	96.8	97.9
336	BM-AGA	800	74.5	88.6	96.1	98.1	99.3
	Do	900	33.1	63.6	87.1	95.1	98.1
	Slot	1,010	29.0	69.9	92.6	96.2	97.8
342A	BM-AGA	800	77.7	91.8	95.5	97.6	98.6
	Do	900	48.9	73.6	88.4	93.7	96.6
	Slot	1,010	45.8	73.8	87.7	91.0	93.0
342B	BM-AGA	800	74.1	91.2	96.7	97.3	98.2
	Do	900	49.9	76.9	92.2	96.3	98.6
	Slot	1,010	41.8	73.7	91.1	93.6	95.1
344A	BM-AGA	800	81.6	92.7	96.6	97.2	97.7
	Do	900	47.5	75.4	92.1	95.6	97.5
	Slot	1,010	66.0	84.8	93.9	96.3	97.4
344B	BM-AGA	800	82.4	91.3	95.4	96.9	97.9
	Do	900	49.5	73.8	90.2	95.0	97.9
	Slot	1,010	55.5	79.4	90.6	93.1	94.5
356	BM-AGA	800	63.1	85.2	94.6	97.0	98.4
	Do	900	32.4	59.7	85.6	95.0	98.2
	Slot	1,010	8.9	37.4	77.8	90.0	95.6
361	BM-AGA	800	70.5	86.5	95.4	97.2	98.7
	Do	900	30.6	62.3	87.1	94.8	98.0
	Slot	1,010	18.3	50.7	83.4	92.0	96.2
361A	BM-AGA	800	73.7	92.2	96.2	97.5	98.3
	Do	900	24.8	58.7	85.1	94.6	98.3
	Slot	1,010	23.6	60.3	89.3	95.4	97.6
363	BM-AGA	800	65.2	87.4	96.0	97.2	98.3
	Do	900	24.5	53.7	79.8	91.8	95.5
	Slot	1,010	17.2	54.3	85.7	94.2	96.8

plus 3-inch coke ranged as follows: 800° C., 85.2 to 94.0; 900° C., 53.7 to 79.5; and slot oven, 37.4 to 85.1. Variations in the proportions of the 2-inch size likewise were greatest for the slot oven, although the range (77.8 to 94.7) was much smaller. Most of the percentages for slot-oven cokes are between those for the 800° and 900° C. cokes and are closer to the 900° C. results. The greater variation in the size of slot-oven cokes may be due in part to the operators' lack of experience in discharging this type of oven. However, even though the operators had been experienced with this type of oven, the coke could not have been discharged as uniformly as from BM–AGA retorts because the latter are not opened until they are cold. Illinois No. 5 and Imboden cokes were highly fissured and the breakage in discharging from the slot oven resulted in low yields of the larger sizes.

PHYSICAL PROPERTIES

The average real specific gravities of the cokes were: 800° C. BM–AGA, 1.87; 900° C. BM–AGA, 1.90; and slot oven, 1.90. The apparent specific gravities, shown in figure 8, differ less than expected,

TABLE 7.—*Physical properties of coke*

Coal No.	Oven type	Final flue temperature, °C.	True specific gravity	Apparent specific gravity	Cells, percent	Shatter test, cumulative percent upon—				Tumbler test, cumulative percent upon—				
						2-inch screen	1½-inch screen	1-inch screen	½-inch screen	2-inch screen	1½-inch screen	1-inch screen	½-inch screen	¼-inch screen
94A	BM-AGA	800	1.87	0.86	54.0	85.5	92.8	96.4	98.4	11.5	31.4	44.5	50.3	50.9
	Do	900	1.94	.87	55.2	63.4	84.0	94.8	98.2	1.8	15.3	40.5	57.9	60.8
	Slot	1,010	1.91	.86	55.0	80.2	90.3	95.5	98.2	5.3	21.4	42.2	55.5	57.4
b316A	BM-AGA	800	1.91	.81	57.6	79.8	91.0	94.4	98.4	12.5	37.5	48.8	52.2	53.2
	Do	900	1.95	.81	58.5	66.8	85.7	93.9	97.7	.7	16.4	44.0	58.2	60.2
	Slot	1,010	1.93	.84	56.5	80.3	90.8	95.8	98.4	6.1	23.9	44.1	53.7	55.3
336	BM-AGA	800	1.90	.84	55.8	78.6	90.5	95.7	98.1	5.0	32.3	53.4	59.8	60.5
	Do	900	1.91	.86	55.0	50.5	81.7	94.7	98.3	.7	15.8	49.6	63.9	65.5
	Slot	1,010	1.90	.87	54.2	67.5	88.2	95.4	98.3	2.5	21.7	50.9	60.6	61.9
342A	BM-AGA	800	1.86			79.3	89.6	95.2	97.7	3.2	28.0	50.3	59.6	60.5
	Do	900	1.91	.83	56.5	62.9	80.3	93.2	97.1	1.0	10.2	38.0	55.5	61.9
	Slot	1,010	1.92	.85	55.7	72.6	87.6	94.4	97.3	1.7	13.5	42.5	55.7	57.2
342B	BM-AGA	800	1.87	.84	55.1	77.5	91.7	95.9	98.1	8.3	32.3	52.7	59.3	59.9
	Do	900	1.90	.85	55.3	44.7	75.3	93.8	98.1	.0	9.0	44.9	65.2	67.5
	Slot	1,010	1.89	.84	55.6	68.9	86.2	94.7	98.0	1.2	15.7	45.8	59.1	60.6
344A	BM-AGA	800	1.86	.88	52.7	80.0	91.0	94.9	97.2	7.2	28.1	46.7	54.5	56.0
	Do	900	1.92	.89	53.6	53.8	80.2	92.7	97.5	.0	10.0	41.1	63.4	66.4
	Slot	1,010	1.92	.92	52.1	75.8	88.1	94.3	97.6	2.0	13.2	43.7	58.8	61.5
344B	BM-AGA	800	1.86	.87	53.2	73.9	90.2	94.6	97.4	5.5	30.0	51.8	59.2	60.3
	Do	900	1.91	.88	53.9	52.4	77.3	93.0	97.8	.0	6.6	38.0	62.8	67.3
	Slot	1,010	1.92	.87	54.7	71.7	86.3	94.7	97.7	.6	17.1	44.9	57.5	59.9
356	BM-AGA	800	1.84	.77	58.2	56.1	75.9	89.1	96.1	.0	7.5	24.2	52.7	61.8
	Do	900	1.84	.78	57.6	33.2	68.4	91.3	96.8	.0	2.9	33.6	62.7	66.9
	Slot	1,010	1.86	.80	57.0	51.0	76.3	90.8	96.9	.0	5.0	24.9	55.7	62.2
361	BM-AGA	800	1.78	.77	58.8	50.8	73.3	89.3	96.6	.1	3.8	21.6	56.4	65.5
	Do	900	1.91	.78	59.2	31.0	65.1	91.1	96.9	.0	3.1	31.2	62.9	67.6
	Slot	1,010	1.90	.80	57.9	42.4	70.6	91.1	97.1	.5	5.3	28.7	60.7	67.8
361A	BM-AGA	800	1.87	.81	56.7	83.2	93.2	97.0	97.9	9.9	36.2	55.0	60.1	60.7
	Do	900	1.90	.77	59.5	44.7	78.8	94.9	97.9	.0	10.9	50.1	63.4	65.1
	Slot	1,010	1.90	.79	58.4	69.0	89.3	98.1	99.6	6.6	20.6	52.1	59.3	60.6
363	BM-AGA	800	1.86	.83	55.4	68.0	84.3	92.1	96.4	.9	12.3	33.9	54.1	59.3
	Do	900	1.86	.86	53.8	35.9	72.4	92.5	97.3	.0	2.4	28.3	51.6	56.0
	Slot	1,010	1.88	.87	53.7	58.9	83.3	94.3	97.4	.4	10.3	37.8	54.8	59.3

NOTE.—All tests made by A. S. T. M. standard methods.

considering that the slot-oven charge is 10 to 11 inches higher. Charge densities are slightly lower in the slot oven because loose coal is charged directly into the heated chamber, whereas the charged BM–AGA retorts are handled before placing into the furnace; consequently, the coal packs more or less.

The strength of the cokes as indicated by the results of shatter and tumbler tests ranged widely; these indexes, therefore, serve well as a basis for comparing the slot-oven and BM–AGA methods for determining the relative coking power of coals. The ranges in the indexes were: (1) 800° C. coke—2-inch shatter, 50.8 to 85.5; 1½-inch shatter, 73.3 to 92.8; 1-inch tumbler, 21.6 to 55.0; and ¼-inch tumbler, 50.9 to 65.5; (2) 900° C. coke—2-inch shatter, 31.0 to 66.8; 1½-inch shatter, 65.1 to 85.7; 1-inch tumbler, 28.3 to 50.1; and ¼-inch tumbler, 56.0 to 67.6; and (3) slot-oven coke—2-inch shatter, 42.4 to 80.3; 1½-inch shatter, 70.6 to 90.8; 1-inch tumbler, 24.9 to 52.1; and ¼-inch tumbler, 55.3 to 67.8.

The three coals that were carbonized singly, Illinois No. 5 (361), Imboden (356), and No. 2 Gas (363), had the lowest 2- and 1½-inch shatter and 1-inch tumbler indexes. However, Illinois No. 5 was so benefited by blending with 20 percent Pocahontas No. 3 that the blend (361A) coked about as strongly as any of the others. Imboden and No. 2 Gas coals were not blended with higher-rank coal. The blends (342A, 342B, 344A, and 344B) of Upper Elkhorn No. 3 and Corban high-volatile coals with low-volatile Pocahontas yielded cokes that were generally similar; none of these cokes was appreciably stronger than the others, if all of the indexes shown graphically were considered. The blend from a Pittsburgh byproduct plant (336) yielded coke that had higher-than-average tumbler indexes; however, this blend was trucked directly from the plant to the laboratory where it was carbonized after minimum storage time.

Comparison of the coke-strength indexes pictured in figures 8 and 9 shows that, with very few exceptions, the strength of the slot-oven coke is intermediate between that of the 800° and 900° C. BM–AGA cokes. The graph showing the 1½- and 2-inch shatter indexes of the slot-oven cokes is closer to that showing the 800° than the 900° C. BM–AGA shatter indexes. Conversely, the tumbler indexes of the slot-oven cokes agree with the 900° C. BM–AGA indexes better than with the 800° C. Most of these cokes do not qualify as top-quality blast-furnace cokes if they are judged by standards suggested by Gardner,[9] who gives the following ranges for three principal strength-test indexes; 2-inch shatter, 51–53; 1-inch tumbler, 47–49; and ¼-inch tumbler, 67–69. All 800° C. BM–AGA cokes had 2-inch shatter indexes equal to or exceeding Gardner's minimum of 51, and seven of these, which were made from blends, had satisfactorily high 1-inch tumbler indexes. Six 900° C. cokes, all made from blends, had 2-inch shatter indexes exceeding the standard minimum, but only two had 1-inch tumbler indexes meeting the minimum requirement. The slot-oven cokes were stronger; all but that from 100 percent Illinois (361) coal had high 2-inch shatter indexes, and two had high 1-inch tumbler indexes. Nearly all cokes made by both

[9] Gardner, E. J., Effect of Coke Quality on Blast-Furnace Iron Tonnage: Blast Furnace and Steel Plant, vol. 36, 1948, pp. 707–711.

methods had ¼-inch tumbler indexes lower than the suggested minimum (67); only the 900° C. BM–AGA cokes from the Pittsburgh plant blend (336), Illinois No. 5 (361), and the blend (361A) of Illinois No. 5 and Pocahontas No. 3 coals had indexes exceeding 67.

PROPERTIES OF GAS

The properties of the 800° and 900° C. BM–AGA and slot-oven gases are given in table 8. The specific gravities of the slot-oven gas from 9 of the 11 coals are intermediate between those of the BM–AGA gases obtained at the two temperatures. Generally, the slot-oven gas contained lower proportions of compounds of high calorific value, illuminants, methane, and ethane, and higher proportions of carbon dioxide and nitrogen, and these differences account for the lower heating values (cubic foot basis) of the slot-oven gas. Variations in heating value were smaller for the BM–AGA gases, probably because they flow under positive pressure from the retorts through the scrubbing train with no dilution by air. The graphs of figure 4, which show the heating values of the gases per pound of coal, show that the gas from the slot oven generally has less available heat than the 800° or 900° C. BM–AGA gases. In BM–AGA tests the heating value of gas, computed on this basis, increases with rise in carbonizing temperature because the volume of gas increases. For most coals the slot-oven gas contained less hydrogen sulfide, although the differences between the slot oven and 900° C. BM–AGA gases generally were small.

Excepting the hydrogen sulfide content, which depends upon the sulfur content of the coal carbonized, the properties of the gas were fairly uniform for the 11 coals. Two coals that were carbonized singly—No. 2 Gas and Imboden—had average determined heating values of 611 and 591 B. t. u. per cubic foot, respectively, whereas the averages for the eight blends and Illinois No. 5 coal ranged from 555 to 588 B. t. u. per cubic foot. The lower heating values of gas yielded by the blends reflect the gas-making property of the low-volatile coals which constituted appreciable proportions of the blends.

The rates of gasification for Imboden coal (356) and the blend (344B) of 50 percent Corban, 35 percent Pocahontas, and 15 percent Upper Elkhorn are compared in figure 17. These graphs are typical for a low-ranking, high-volatile A coal and a blend containing about one-third high-rank coal. The rates in BM–AGA tests are high at the start, depending upon temperature, and they decrease progressively as carbonization continues. The initial gasification rates are lower in the slot oven and are maintained with no significant decrease throughout most of the test. The curves for the slot oven show an increase in the rate during the latter part of the test, when the plastic layers coalesce at the middle of the charge.

PROPERTIES OF TAR

The properties of the tar are shown in table 9 and figure 18. The tars from the 900° C. BM–AGA test and slot oven are similar; both differ significantly from the 800° C. BM–AGA tar in composition and volatility. The proportions of anthracene and naphthalene salts

TABLE 8.—*Physical and chemical properties of gas*

Coal No.	Oven type	Final flue temperature, °C.	Specific gravity	Gross heating value[1]			H_2S, grains per 100 cubic feet	Composition, dry, percent by volume							
				B. t. u. per cubic foot		B. t. u. per pound of coal		CO_2	Illuminants	O_2	H_2	CO	CH_4	C_2H_6	N_2
				Determined	Calculated										
94A	BM-AGA	800	0.405	611	603	2,660	240	2.2	4.1	0.6	52.0	6.2	30.9	2.7	1.3
	Do	900	.370	574	574	2,860	250	1.9	4.1	.5	56.2	6.2	29.4	1.1	.6
	Slot	1,010	.385	544	540	2,670	160	3.0	3.7	.6	54.0	6.1	29.3	.0	3.3
b316A	BM-AGA	800	.427	618	623	2,670	980	2.7	4.3	.4	48.8	6.8	33.2	2.7	1.1
	Do	900	.394	586	587	2,870	950	2.4	4.4	.4	52.5	7.2	30.5	1.5	1.1
	Slot	1,010	.372	494	497	2,460	560	3.6	2.3	.5	57.3	10.1	24.8	.0	1.4
336	BM-AGA	800	.402	608	609	2,630	540	2.1	3.9	.4	50.4	6.2	33.7	2.0	1.3
	Do	900	.372	581	577	2,870	470	1.8	3.8	.6	54.2	6.3	31.3	.8	1.2
	Slot	1,010	.390	574	571	2,560	410	2.9	3.8	.3	52.3	6.0	31.8	.6	2.3
342A	BM-AGA	800	.393	590	601	2,730	240	2.1	4.3	.4	52.1	7.3	30.2	2.6	1.0
	Do	900	.373	548	560	2,850	230	2.2	3.9	.4	55.9	6.7	29.3	.5	1.1
	Slot	1,010	.414	491	494	2,610	200	3.1	3.1	.5	52.4	6.9	25.9	.0	8.1
342B	BM-AGA	800	.397	590	590	2,700	260	2.5	4.1	.2	52.3	6.4	31.5	1.5	1.5
	Do	900	.368	552	558	2,860	220	2.0	4.0	.4	55.8	7.2	29.0	.4	1.2
	Slot	1,010	.390	542	534	2,620	230	3.0	3.3	.6	53.7	6.6	29.3	.0	3.5
344A	BM-AGA	800	.390	587	572	2,630	220	2.4	3.8	.3	52.7	7.4	31.0	.8	1.6
	Do	900	.358	542	548	2,780	290	2.2	3.7	.4	57.4	6.7	27.8	.6	1.2
	Slot	1,010	.378	542	532	2,400	210	3.0	3.2	.4	55.0	6.5	28.3	.3	3.3
344B	BM-AGA	800	.390	581	576	2,630	300	2.7	3.3	.4	53.8	6.3	30.6	1.7	1.2
	Do	900	.359	544	547	2,820	270	2.5	3.6	.3	56.7	6.9	27.5	.9	1.6
	Slot	1,010	.382	543	541	2,570	220	3.0	3.2	.4	54.8	6.5	29.1	.4	2.6
356	BM-AGA	800	.425	607	609	2,710	450	2.1	4.4	.5	50.7	6.8	32.4	2.1	1.0
	Do	900	.413	596	598	3,080	410	1.7	5.0	.3	52.2	7.2	31.1	1.3	1.2
	Slot	1,010	.417	571	560	2,960	320	3.1	4.1	.3	50.6	7.2	29.9	.9	3.9
361	BM-AGA	800	.426	600	606	2,600	690	2.9	3.8	.5	48.9	8.8	29.6	3.9	1.6
	Do	900	.405	558	564	2,770	640	2.9	3.9	.3	52.2	8.9	29.4	1.0	1.4
	Slot	1,010	.412	544	535	2,520	450	4.0	3.2	.6	51.1	8.9	28.1	.9	3.2
361A	BM-AGA	800	.398	575	585	2,570	550	2.8	3.2	.5	52.9	7.4	28.4	3.5	1.3
	Do	900	.375	565	558	2,670	580	2.0	3.2	.5	55.5	7.4	28.5	1.4	1.5
	Slot	1,010	.397	525	526	2,460	410	3.5	3.2	.4	53.3	8.1	27.4	.5	3.6
363	BM-AGA	800	.429	642	621	2,950	610	1.9	5.2	.5	50.4	6.1	32.1	2.3	1.5
	Do	900	.389	630	601	3,310	510	1.9	5.4	.4	52.4	6.1	31.9	.8	1.1
	Slot	1,010	.409	584	571	2,960	460	2.7	4.5	.5	50.6	6.0	30.8	.8	4.1

[1] Stripped of light oil and saturated with water vapor at 60° F. and under a pressure equivalent to 30 inches of mercury.

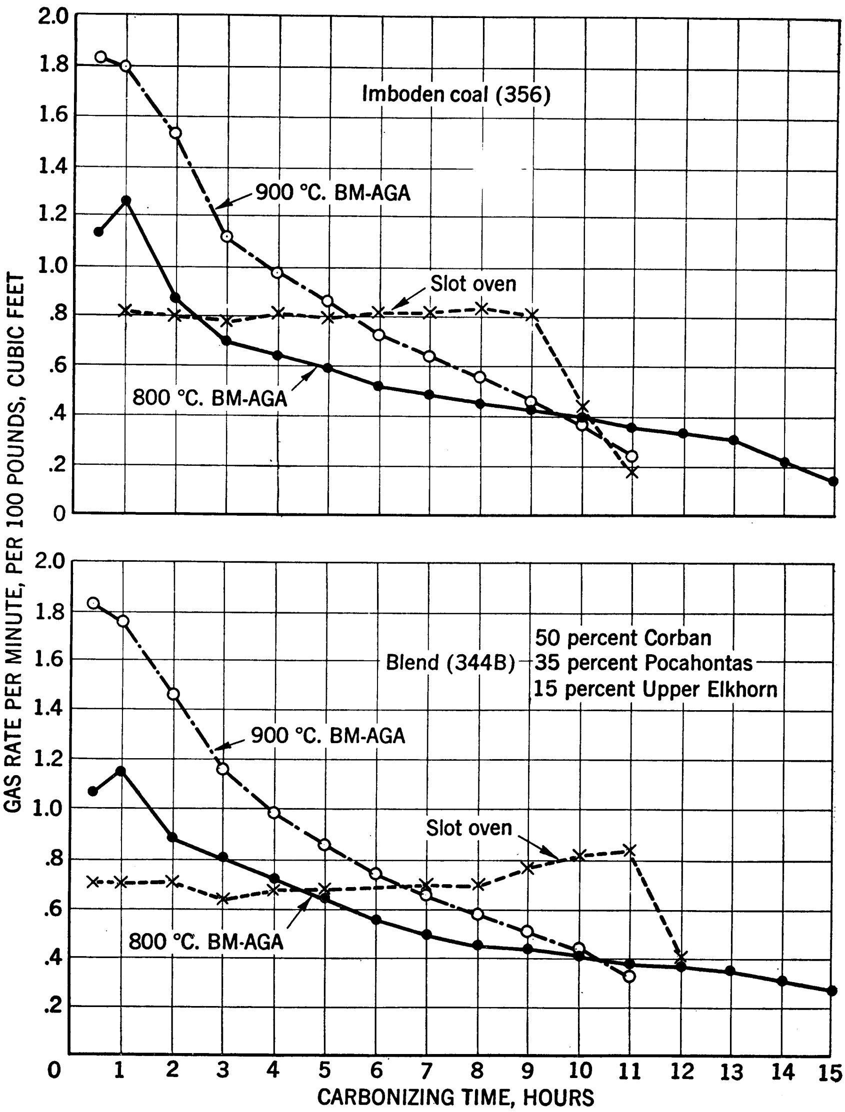


FIGURE 17.—Rates of gasification in 800° C. and 900° C. BM–AGA and slot-oven tests.

generally are greatest for the slot-oven tars, indicating greater cracking than in the 900° C. test. Seven of the slot-oven tars contained higher percentages of residue on distilling to 350° C., although most of the differences between these and the 900° C. tars were slight. Differences in composition of the tar distillate are significant only when the 800° C. distillates are compared with those from the 900° C. or slot-oven tests. The 800° C. distillates contained greater proportions (calculated as percent by volume of dry tar) of acids and neutral oils. The 800° C. neutral oils contained lower percentages

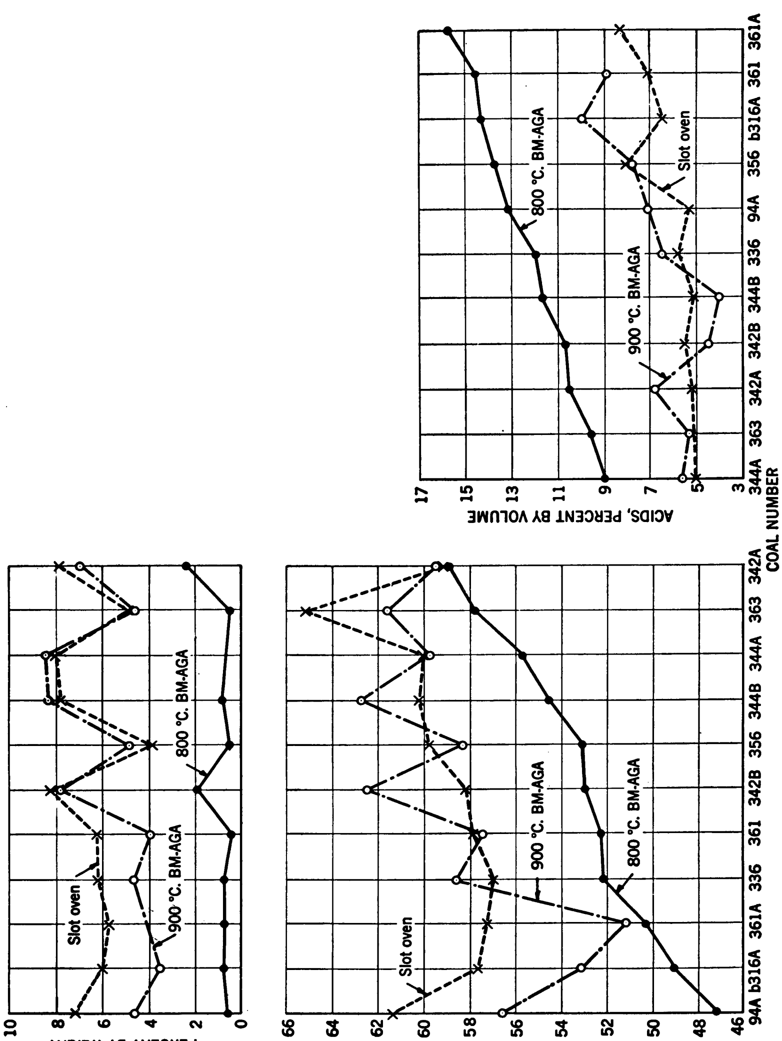


FIGURE 18.—Composition of tar.

of aromatic compounds and higher percentages of paraffins and naphthenes.

Previous investigations of the Bureau of Mines have shown that the composition of high-temperature tars depends more upon carbonizing conditions than upon the properties of coals carbonized, and table 9 shows that this generality holds true for the 11 coals carbonized in BM–AGA retorts at 800° and 900° C., and in the slot oven. Although the charges of 100 percent Illinois No. 5, No. 2 Gas, and Imboden coals differ from one another and rank lower than the blends containing Pocahontas coals, the data show no appreciable differences consistently obtained under the three conditions of heating that are correlative with the composition of the charges.

Table 9.—*Properties of tar*

Coal No.	Oven type	Final flue temperature, ° C.	Specific gravity 15.6° C./15.6° C.	Percent by weight		Boiling range, ° C., percent by volume					Distillate, percent by volume of dry tar			Neutral tar oil, percent by volume		
				Anthracene salts	Naphthalene salts	0–170	170–235	235–270	270–350	Residue	Acids	Bases	Neutral oils	Olefins	Aromatics	Paraffins and naphthenes
94A	BM-AGA	800	1.10	0.61	0.00	7.5	22.0	7.8	15.5	47.2	13.2	2.6	36.5	11.3	74.8	13.9
	Do	900	1.14	1.84	2.87	5.9	18.8	5.4	13.3	56.6	7.1	1.5	29.2	10.3	82.5	7.2
	Slot	1,010	1.16	2.22	5.10	5.6	19.3	3.9	9.8	61.4	5.3	2.5	23.4	9.4	90.1	.5
b316A	BM-AGA	800	1.12	.81	.00	6.9	23.5	7.0	13.5	49.1	14.3	2.8	33.0	13.2	79.0	7.8
	Do	900	1.14	1.64	1.93	6.4	21.5	5.3	13.6	53.2	10.0	3.3	30.0	12.0	85.1	2.9
	Slot	1,010	1.17	2.16	3.90	6.3	19.6	5.2	11.0	57.7	6.5	2.8	27.2	11.8	88.2	.0
336	BM-AGA	800	1.12	.80	.00	7.5	19.3	7.8	13.2	52.2	12.0	1.9	33.1	9.8	80.5	9.7
	Do	900	1.15	1.89	2.81	5.5	18.1	5.4	12.3	58.7	6.5	1.9	28.3	10.3	84.3	5.4
	Slot	1,010	1.16	2.37	3.93	7.5	18.9	4.7	11.9	57.0	5.7	2.4	28.5	10.0	89.3	.7
342A	BM-AGA	800	1.07	1.24	1.18	4.6	19.4	6.0	11.1	58.9	10.6	1.8	26.4	14.1	83.3	2.6
	Do	900	1.16	2.70	4.28	4.2	18.4	5.2	12.7	59.5	6.8	2.3	24.4	10.0	89.1	.9
	Slot	1,010	1.15	2.50	5.36	4.3	20.6	4.3	11.6	59.2	5.2	2.3	25.4	17.1	82.5	.4
342B	BM-AGA	800	1.14		.98	4.9	21.6	6.5	14.0	53.0	10.7	2.5	30.0	12.0	84.9	3.1
	Do	900	1.16	2.50	5.40	4.6	17.5	4.6	10.8	62.5	4.4	2.0	23.1	12.6	86.5	.9
	Slot	1,010	1.15	2.35	5.95	5.0	20.9	4.9	11.0	58.2	5.5	2.3	25.7	12.8	86.8	.4
344A	BM-AGA	800	1.14	1.16	.87	5.7	20.3	5.4	12.9	55.7	9.0	2.7	30.6	12.0	86.4	1.6
	Do	900	1.16	3.52	5.01	3.7	18.2	4.4	13.9	59.8	5.6	2.1	23.9	11.3	87.4	1.3
	Slot	1,010	1.16	2.28	5.91	4.1	18.9	4.7	12.4	59.9	5.0	2.2	24.6	9.9	89.6	.5
344B	BM-AGA	800	1.13	.91	.02	4.9	20.4	8.1	12.1	54.5	11.7	1.4	31.5	8.0	87.6	4.4
	Do	900	1.17	2.85	5.56	3.6	17.7	4.0	11.9	62.8	4.0	2.2	22.5	9.8	89.3	.9
	Slot	1,010	1.15	2.52	5.37	4.7	20.3	4.0	10.8	60.2	5.1	2.0	24.8	9.0	90.5	.5
356	BM-AGA	800	1.13	.57	.00	6.4	22.7	6.6	11.2	53.1	13.7	2.4	30.3	12.7	77.7	9.6
	Do	900	1.16	1.72	3.21	6.2	20.0	5.2	10.3	58.3	7.8	2.2	26.8	9.5	89.1	1.4
	Slot	1,010	1.16	1.50	2.41	5.1	19.4	5.2	10.5	59.8	8.0	2.1	26.2	12.5	84.4	3.1
361	BM-AGA	800	1.13	.46	.00	7.9	23.9	6.0	9.9	52.3	14.6	2.4	30.3	10.9	84.6	4.5
	Do	900	1.15	1.52	2.50	5.4	21.1	4.6	11.3	57.6	8.9	2.6	27.0	12.4	86.8	.8
	Slot	1,010	1.16	1.82	4.46	7.7	20.7	4.0	9.7	57.9	7.0	2.5	26.3	11.0	88.6	.4
361A	BM-AGA	800	1.12	.78	.00	6.1	25.5	5.4	12.7	50.3	15.8	2.2	31.0	12.0	85.2	2.8
	Do	900	1.14	1.16	.89	5.2	24.4	6.0	15.1	49.3	15.0	2.6	31.1	10.1	86.4	3.5
	Slot	1,010	1.15	2.02	3.78	5.3	22.1	4.3	11.0	57.3	8.3	2.4	26.2	10.0	89.4	.6
363	BM-AGA	800	1.14	.58	.00	7.9	18.1	5.7	10.5	57.8	9.6	2.0	30.1	8.8	83.1	8.1
	Do	900	1.16	1.24	3.39	7.4	17.5	3.7	9.7	61.7	5.3	1.9	26.5	8.7	88.4	2.9
	Slot	1,010	1.17	1.00	3.83	7.1	17.1	3.5	7.1	65.2	5.3	2.0	22.7	8.3	91.2	.5
Average		800	1.12	.79	.76	6.4	21.5	6.6	12.4	53.1	12.3	2.2	31.2	11.3	82.5	6.2
		900	1.15	2.05	3.44	5.3	19.4	4.9	12.3	58.1	7.4	2.2	26.6	10.6	86.8	2.6
		1,010	1.16	2.07	4.55	5.7	19.8	4.4	10.6	59.5	6.1	2.3	25.5	11.1	88.2	.8

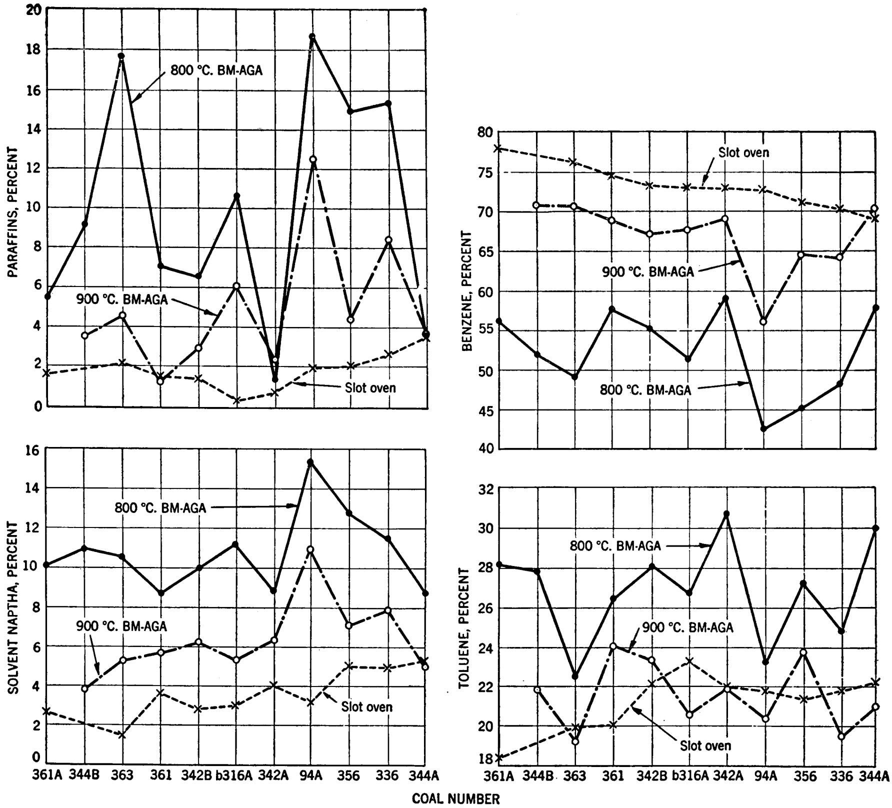


FIGURE 19.—Composition of light oil by volume.

PROPERTIES OF LIGHT OIL

The properties of the light oil are given in table 10 and figure 19. The refined light oils from the three test methods differed more than the tars. The chief difference was in the content of benzene, which averaged 52.3, 67.1, and 73.2 percent for the 800° C., 900° C., and slot-oven tests, respectively. The high proportion of benzene in light oil from the slot-oven tests was counterbalanced approximately by lower proportions of paraffins and solvent naphtha. The fourth light-oil constituent, toluene, was present in about the same proportions in the slot oven and 900° C. BM–AGA tests. The average percentages of toluene were: 800° C., 26.9; 900° C., 21.5; and slot oven, 21.3.

The crude light oils differed in their olefin content; the averages were: 800° C., 17.2; 900° C., 12.6; and slot oven, 9.2.

CONCLUSIONS

Yields of coke from the slot oven approximate those from the 800° C. BM–AGA test. The slot-oven yields of gas (volume basis) generally are intermediate between the 800° and 900° C. BM–AGA yields. Less tar, light oil, and ammonium sulfate are obtained from the slot oven than from BM–AGA tests at either temperature.

TABLE 10.—*Properties of light oil*

Coal No.	Oven type	Final flue temperature, °C.	Refined light oil from gas, percent by volume				Olefins in crude light oil from gas, percent by volume
			Benzene	Toluene	Paraffins	Solvent naphtha	
94A	BM-AGA	800	42.7	23.2	18.8	15.3	21.7
	Do	900	56.3	20.3	12.5	10.8	16.7
	Slot	1,010	72.9	21.8	2.0	3.3	7.6
b316A	BM-AGA	800	51.4	26.7	10.7	11.2	21.7
	Do	900	67.8	20.6	6.2	5.4	14.8
	Slot	1,010	73.2	23.3	.4	3.1	8.4
336	BM-AGA	800	48.3	24.8	15.4	11.5	16.7
	Do	900	64.1	19.5	8.5	7.9	11.6
	Slot	1,010	70.5	21.8	2.7	5.0	8.9
342A	BM-AGA	800	59.1	30.7	1.4	8.8	12.0
	Do	900	69.3	21.9	2.4	6.4	9.8
	Slot	1,010	73.2	21.9	.8	4.1	8.8
342B	BM-AGA	800	55.4	28.0	6.6	10.0	15.4
	Do	900	67.4	23.3	3.0	6.3	9.6
	Slot	1,010	73.5	22.1	1.5	2.9	9.4
344A	BM-AGA	800	57.7	30.0	3.6	8.7	12.0
	Do	900	70.2	21.0	3.7	5.1	10.0
	Slot	1,010	69.0	22.2	3.5	5.3	10.4
344B	BM-AGA	800	52.0	27.8	9.2	11.0	17.0
	Do	900	70.7	21.8	3.6	3.9	11.0
	Slot	1,010					
356	BM-AGA	800	45.1	27.2	15.0	12.7	18.8
	Do	900	64.8	23.7	4.4	7.1	12.7
	Slot	1,010	71.4	21.4	2.1	5.1	8.6
361	BM-AGA	800	57.8	26.4	7.1	8.7	17.5
	Do	900	69.0	24.0	1.3	5.7	12.6
	Slot	1,010	74.7	20.1	1.5	3.7	10.4
361A	BM-AGA	800	56.4	28.1	5.5	10.1	17.5
	Do	900					18.0
	Slot	1,010	77.2	18.4	1.7	2.7	10.0
363	BM-AGA	800	49.3	22.5	17.6	10.6	18.5
	Do	900	70.9	19.2	4.6	5.3	11.7
	Slot	1,010	76.4	19.9	2.1	1.6	9.7

The physical properties of the slot-oven cokes are intermediate between those of 800° and 900° C. cokes. Chemically, the slot-oven and 900° C. BM–AGA cokes are similar.

The gas from the slot oven is leaner than that from tests at either temperature.

Tars from the slot oven and 900° C. BM–AGA test are similar.

Light oil from the slot oven contains a higher proportion of benzene than BM–AGA light oils.

Wedge-shaped cokes from BM–AGA cylindrical retorts are not necessarily weaker than prism-shaped cokes from slot ovens.

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