COKE FROM ILLINOIS COALS
AN EXPERIMENTAL SLOT-TYPE OVEN

BY

FRANK H. REED, HAROLD W. JACKMAN, AND P. W. HENLINE

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Frank H. Reed, Harold W. Jackman, and P. W. Henline

ABSTRACT
Midwestern by-product coke ovens require annually millions of tons of high-volatile bituminous coals which are shipped from the Appalachian coal fields in West Virginia, Pennsylvania, and eastern Kentucky. Illinois has larger reserves of high-volatile bituminous coals than any other state east of the Rockies. Though the Appalachian coals are principally of higher rank than the midwestern, the reserves of these high-rank coals are being depleted rapidly. Because of this and the present critical transportation problem, the Illinois State Geological Survey, aided by the Office of Production Research and Development, War Production Board, initiated a research program to study the problem of substituting midwestern coals for a portion of the eastern high-volatile coals now being carbonized in midwestern coke ovens. Previous commercial and semicommercial experience has shown that metallurgical coke can be made from certain Illinois coals. The research program includes the design, construction, and operation of a pilot-size coke oven to duplicate carbonizing conditions in commercial slot-type ovens. A slot-type pilot-size coke oven of 500-pound coal capacity, electrically heated to ensure accurate temperature control, is described. The yields and properties of the coke and by-products recovered from this small experimental oven correlate closely with those obtained by carbonizing the same coals in commercial ovens. Thus, this oven is a reliable guide for commercial operations.

Midwestern by-product coke ovens use annually millions of tons of high-volatile bituminous coals which are shipped from the Appalachian coal fields in West Virginia, Pennsylvania, and eastern Kentucky. Illinois has larger reserves of high-volatile bituminous coal than any state east of the Rocky Mountains; only Colorado exceeds Illinois in reserves. Although the Appalachian coals are principally of higher rank than the midwestern coals, the reserves of these high-rank Appalachian coals are being depleted rapidly.

This growing scarcity of the best Appalachian coals and the critical transportation problem now confronting the nation, prompted the Illinois State Geological Survey, aided by the Office of Production Research and Development of WPB, to begin a research program to study the possibilities of substituting midwestern coals for a portion of the eastern high-volatile coals now being carbonized in the Chicago and St. Louis districts. Freight rates to the Gary—East Chicago—Chicago district by rail favor the southern Illinois coals over the Appalachian coals by more than one dollar per ton. When a combination of rail haul from the Appalachian fields to a Lake Erie port and then lake barge to the Chicago district is used, the southern Illinois coal can still be delivered with a saving in freight of 50 cents per ton. It costs over 2 dollars per ton more to deliver Appalachian coals by rail to the St. Louis district than to deliver southern Illinois coals to the same point.

Illinois coals contain more moisture than do the Appalachian coals, however, and a correspondingly lower amount of fixed carbon on the as-received basis. Thus a lower yield of coke per ton of coal is obtained from the Illinois coals. Previous commercial and semicommercial experience has shown that "a fairly satisfactory grade of metallurgical coke" (†) can be made from coal of certain southern Illinois mines. Undoubtedly the methods of coal preparation and the resulting quality of coal shipped from these mines are better today than they were during the last war, or during the period from 1921 to 1934 when Franklin
County, Ill., coal was used in the Roberts ovens at Granite City, Ill.

The comparison of costs to be obtained by coking the Appalachian coals alone or in combination with Illinois coals in any given plant can be determined only by commercial operation over an extended period of time. The suitability of the coke for blast furnace operation, the yield of coke from the coal, and the amount and evaluation of the by-products are among the principal items which must be considered, along with freight rates, cost, and uniformity of coal supply, to determine the over-all economic picture. However, the cost of experimentation with various blends of coal in commercial coke ovens is not only exceedingly high, but it also interferes with regular production. Consequently, only a minimum of such experimentation is carried out.

The first objective of the present research program was, therefore, the design and construction of a small-scale slot-type coke oven in which blends of coals could be carbonized under conditions approximating those obtained in commercial ovens closely enough to produce cokes with physical and chemical properties directly comparable to those of cokes produced from the same blends in commercial ovens. Representative
data selected from the first fifty runs are shown in Table I to indicate that this objective has been attained.

This paper gives briefly the construction and operation of the experimental slot-type oven, shows the duplicability of operating results, and compares results obtained with this experimental oven and with commercial slot-type ovens.

**DESIGN OF OVEN**

The primary objective in design of the experimental slot-type oven was to construct a unit which would duplicate essentially a small section of a commercial oven, and in which the process of coking coal would be controlled rigidly. This was based on the assumption that the coking process is a complex chemical reaction. Thus, duplication of operating conditions from one run to another with identical blends of coal should produce batches of coke with identical physical and chemical properties. In practice "identical blends" are not obtainable, but blends with similar average physical and chemical properties can be obtained; therefore the cokes produced from such blends should have similar physical and chemical properties.

Only in the width of the oven was an attempt made to duplicate any size dimension of a commercial oven. The average width of most commercial slot-type ovens ranges from 13 to 21 inches. The average width of the experimental oven is slightly above the lower limit of this range. Thus, the oven was designed so that it could be operated to give the same heat penetration (average width of oven in inches divided by coking time in hours) and final temperature as obtained in commercial practice.

Figure 1 shows the slot-type experimental oven being discharged and the coke being quenched. The uniform oven wall temperature up to the top of the charge and the slightly cooler space above for gas collection are apparent. Also visible are the coal-charging hole, the door with opening for leveling bar, and other details of oven construction, including buckstays and angle-iron supports in the side walls.

Figure 2 is a diagram showing cross-sectional views from the front and side of the oven. As in all slot-type coke ovens, heat is applied from flues placed on both sides of the oven chamber, 1. The inside of the oven chamber was designed to taper in width from 13.25 inches at the back to 13.75 inches at the front. On account of irregularities in the shapes received, the oven as constructed averages 14 inches in width instead of 13.5 inches as planned. The charging space in the oven chamber is 36 inches in length and 35 inches in depth, and holds approximately 10 cubic feet of coal per charge.

The side walls, 4, and floor, 5, of the oven are made of silicon carbide tile, 2 inches thick. Each side wall consists of a single tile, and the floor is formed from two tiles laid end to end with overlapping joint. The walls are anchored at the back of the oven and left free to expand vertically and horizontally. They are held in place at the top and bottom by the surrounding brickwork and are further supported on each side by two rows of long firebrick, 6, which touch the oven walls and are, in turn, strengthened by steel angles, 7, running the full length of the outside walls of the oven. These supporting firebrick are spaced from front to back of the flues, leaving 4.5 inches between bricks, so that approximately 50% of the flue space is left open (Figure 3, section C-C). These flue openings are staggered in the two rows of supporting brick in each flue. This leaves the three sections of each flue closely interconnected and allows the heat to equalize from top to bottom of each oven wall. The oven chamber is surrounded on the sides and top by vermiculite insulation, 8. This insulation acts not only as a heat baffle but, being soft, as a cushion against thermal expansion or swelling pressures which otherwise might crack the silicon carbide walls.

The top of the oven chamber, 9, is cast of refractory concrete. Coal is charged through a 6-inch pipe, 10, extending through the casting, and a 6-inch blank flange, 11, serves as a charge hole cover. Gas escapes from the oven through a 3-inch pipe, 12, extending through the top and
Fig. 2—Sketch of Slot-Type Experimental Coke Oven
Fig. 3.—Details of Slot-Type Oven Construction
connected to the by-product recovery equipment. The back of the oven chamber consists of permanent brickwork, whereas the front is covered by a refractory concrete door, 13, which is raised or lowered by a chain hoist and is mudded into place before the oven is charged. After charging, the coal is leveled through a rectangular opening, 14, in the door located 35 inches above the chamber floor. This level bar opening is then bricked and mudded. Between the door and the coal charge a temporary brick wall, 15, (9 inches in depth), extends from the floor to the coal level. This wall, which consists of one layer of firebrick next to the charge and one layer of insulating brick next to the door, is removed before a coke charge is pulled, and is replaced immediately after the oven is discharged. The oven structure is held together by tie rods, 16, extending through the top brickwork and foundation. These rods are anchored to heavy buckstays, 17, at each corner of the oven.

Figure 3 gives more details of the oven brickwork construction. Horizontal sections A-A, B-B, and C-C, which all refer to Figure 2, show the brick arrangement just below floor level, at the oven floor, and at a plane between the lower and middle flue sections. The back view shows the arrangement of the openings for heating units and thermocouples into the heating flues and the oven chamber. Thermocouples are never placed in all of the holes shown during any one run, but the holes are built into the oven to be available when and if desired.

TEMPERATURE CONTROL

Accurate control of the temperature and heating rate of the coal in the oven is maintained by the use of Globar heating units powered from a three-phase 230-volt 60-cycle source through a 50 kv.-amp. tap transformer as shown in the wiring diagram of Figure 4. Six AT type Globar brand nonmetallic heating elements (2, Figure 2), 67 inches long and having a middle heating section 36 inches in length and 1.25 inches in diameter, designed to carry a capacity load of 100 amperes at 136 volts, are placed horizontally in each flue and spaced as shown so that heat may be applied uniformly from top to bottom of the oven walls. In each of the top flue sections the two Globar elements are connected in series, and the two units thus formed are
connected in parallel across one secondary of the three-phase tap transformer. In the center and bottom flue sections the Globars are connected in the same manner across the other two secondaries. With this hookup are formed essentially, three independently controlled single-phase circuits of approximately 16.7 kv.-amp. each, which have proved adequate to provide uniform temperature in the oven chamber. Each Globar element is supported at the front and rear of the oven in special insulating shapes (3, Figure 2) as provided by the vendor of the Globar heating elements.

Flue temperatures are controlled by a Wheelco Capacitrol which is actuated by a No. 8 gage, chromel-alumel thermocouple placed in the center flue section on one side, and adjacent to but not touching the oven wall. This thermocouple activates the three-phase primary circuit. No appreciable temperature difference has been found to exist between the two flues, and thus it was not necessary to provide a means of controlling each of the flues independently. Temperatures inside the oven are recorded by a four-point Brown recording pyrometer attached to No. 14 gage chromel-alumel thermocouples inserted through the back of the oven chamber (18, Figure 2). Three thermocouples are located just inside the silicon carbide side wall near the top, center, and bottom of the coal charge, and extend lengthwise approximately to the center of the oven. Another is placed in the exact center of the coal charge, and a fifth is located in the free gas space above the coal. Temperatures recorded at these points show the progress of temperature change throughout the carbonizing period.

Figure 5 is a photograph of a typical time-temperature chart. This chart records a run in degrees centigrade, and the temperatures should not be confused with those on the Fahrenheit scale used otherwise throughout this paper. Total elapsed time for the carbonization period is 13 hours and 10 minutes. Curve (1) indicates the temperature of the gas in the free space above the coal charge. The thermocouple in use at the beginning of the operation was evidently defective and was reading too low. It was replaced after 1.75 hours by a new thermocouple. Curves (2), (3), and (4) represent, respectively, the temperatures of thermocouples placed at the top, middle, and bottom of the charge next to the side wall. These curves are representative of normal charts. At the early part of the run the highest temperature along the oven wall is recorded at the top of the charge and the lowest temperature at the bottom. All temperatures rise in practically parallel straight lines for about 11 hours, after which the temperature at the center crosses over and becomes the highest. Curve (5) indicates the temperature at the approximate geometric center of the charge. Here the temperature remains constant at about 125° C. (257° F.) for the first 5 hours, rises 100° C. (180° F.) in the next 2 hours, then 700° C. (1260° F.) in the next 5 hours and finally reaches the temperature of the charge at the side wall. Curves (4) and (5) are recorded by the No. 4 position on the temperature recorder by connecting it alternately with thermocouples 4 and 5. The circled points on the chart indicate the continuation of the curve for thermocouple 4, as shown by occasional recordings, while thermocouple 5 is being recorded continuously.

OPERATION OF OVEN

In operating the small scale slot-type oven, various charging temperatures and final flue temperatures have been tried. In all comparative tests an attempt is made to duplicate the average heat penetration through the charge and the average final coke temperature as attained by commercial batteries. As the silicon carbide walls of the experimental oven have a higher thermal conductivity than the silica brick walls of large scale ovens, it is possible to obtain approximately the same average penetration rate at a much lower flue temperature in the experimental oven than is required in commercial ovens. Results that duplicate closely those of commercial practice have been obtained by charging the oven at an initial flue temperature of 1600° F. and
raising this temperature 30° F. per hour to a maximum of 1850°. The coking time under these conditions is found to be 12.75 to 13.5 hours, or the average penetration is 1.04 to 1.10 inches per hour, depending upon such factors as bulk density, moisture content, and plastic characteristics of the coal. The final average coke temperature is 1770-1800°F.

The same by-product recovery equipment is used on the slot oven that was employed with the experimental sole-flue oven (3). When a test run is started, the tap transformer is set at approximately 70% of rated capacity on all heating sections, and the gas exhauster is started with the by-pass open. A charge of 10.1 cubic feet (approximately 500 pounds) of coal is dumped from an overhead hopper through the charge hole and leveled in the oven. Gases are vented to the outside until the level and charge holes are sealed. The gas is then pumped through the purifying equipment by the exhauster. The initial quenching effect of the coal on the flue temperature is insignificant, and it is believed that the unit has sufficient capacity to maintain a much higher initial charging temperature, although no initial temperature above 1700° F. has been tried. As in operating the sole-flue oven (3), a constant pressure of 0.02 inch of water is maintained in the oven chamber and approximately 0.5 inch of water at the meter outlet.

The setting of the tap transformer for each of the three heating sections is changed
from time to time as required to maintain a uniform wall temperature from the bottom to the top of the oven charge.

Rate of gas evolution is essentially constant until the plastic zone reaches the center of the charge. This rate increases gradually while the center is heating, then gradually decreases. The B.t.u. value of the gas decreases slowly from approximately 850 until the plastic zones meet, increases slightly over a short period, then drops sharply to about 300.

In all tests coking is continued until gas evolution has dropped to the rate of 50 cubic feet per hour. The oven is then opened, the brick retaining wall is removed, and the coke is pulled and quenched. The pyrometer temperature controller is set back to 1600°F, where it is maintained during all idle periods, the power is cut to 25% of rated capacity, and the firebrick retaining wall is replaced inside the oven door. Tar yield, gas make, and coke yield are computed as in the sole-flue oven tests (3).

Shatter and tumbler tests of the coke produced are made in accordance with standard methods adopted by the American Society for Testing Materials (1, 2).

**COKING RESULTS ON DUPLICATE SAMPLES**

The ability of the experimental oven to reproduce coking results under closely controlled operating conditions is shown in Table II; results are given of duplicate runs on each of two coal blends. Blend A is a mixture of Illinois and eastern coals, and blend B is all eastern coal. Operating conditions, such as coking time, rate of heat penetration, and final coke temperatures, were kept constant throughout these four runs. The degree of pulverization and the bulk density of the coal were as uniform as could be maintained experimentally.

Table II shows that coke yields checked within 0.5%. Of the physical tests, the closest checks were obtained on tumbler "stability", which is widely used in the metallurgical coke industry as an index of coke quality. Other physical properties such as apparent gravity, shatter test, and coke sizing also checked closely.

The yields and quality of the gas evolved during the coking period are shown. In Figure 6 the cubic feet of gas evolved during each hour of the coking period and the B.t.u. value of the gas are plotted from

![Graph](image-url)
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<th>S2</th>
<th>C1</th>
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<th>C2</th>
<th>C3</th>
<th>S23</th>
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<td>2</td>
<td>3</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Total</td>
<td>73.2</td>
<td>72.5</td>
<td>72.6</td>
<td>71.2</td>
<td>71.5</td>
<td>71.5</td>
<td>71.3</td>
<td>73.5</td>
<td>71.8</td>
<td>71.7</td>
<td>71.7</td>
<td>71.3</td>
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<tr>
<td>Furnace coke (+ 1 in.)</td>
<td>69.8</td>
<td>70.0</td>
<td>67.3</td>
<td>67.0</td>
<td>66.1</td>
<td>66.1</td>
<td>68.2</td>
<td>70.3</td>
<td>66.2</td>
<td>67.2</td>
<td>67.2</td>
<td>64.1</td>
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<tr>
<td>Breeze</td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
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<tr>
<td>−1/2 inch</td>
<td>1.8</td>
<td>1.5</td>
<td></td>
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<td>2.6</td>
<td>2.6</td>
<td>2.0</td>
<td>2.2</td>
<td></td>
<td>3.0</td>
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<tr>
<td>−5/8 inch</td>
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<td></td>
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<tr>
<td>Apparent sp. gr.</td>
<td>0.893</td>
<td>0.895</td>
<td>0.946</td>
<td>0.83</td>
<td>0.86</td>
<td>0.84</td>
<td>0.83</td>
<td>0.86</td>
<td>0.85</td>
<td>0.87</td>
<td>0.86</td>
<td>0.88</td>
</tr>
<tr>
<td>True sp. gr.</td>
<td>1.92</td>
<td>1.92</td>
<td></td>
<td>1.94</td>
<td>1.93</td>
<td>1.90</td>
<td>1.90</td>
<td>1.90</td>
<td>1.89</td>
<td>1.93</td>
<td>1.96</td>
<td>1.89</td>
</tr>
<tr>
<td>Porosity, %</td>
<td>53.5</td>
<td>53.4</td>
<td></td>
<td>57.0</td>
<td>55.4</td>
<td>55.8</td>
<td>56.4</td>
<td>54.6</td>
<td>55.0</td>
<td>55.0</td>
<td>56.1</td>
<td>53.4</td>
</tr>
<tr>
<td>Volatile matter, %</td>
<td>1.5</td>
<td>1.1</td>
<td>1.3</td>
<td>1.2</td>
<td></td>
<td></td>
<td>1.1</td>
<td>1.2</td>
<td>0.8</td>
<td>1.0</td>
<td>0.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Shatter test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% over 2 in.</td>
<td>47.6</td>
<td>60.4</td>
<td></td>
<td>69.6</td>
<td>76.2</td>
<td>75.6</td>
<td>54.4</td>
<td>60.9</td>
<td>59.6</td>
<td>74.6</td>
<td>79.4</td>
<td>79.1</td>
</tr>
<tr>
<td>% over 1 1/2 in.</td>
<td>73.4</td>
<td>83.3</td>
<td></td>
<td>86.3</td>
<td>88.1</td>
<td>90.0</td>
<td>80.3</td>
<td>82.0</td>
<td></td>
<td>86.7</td>
<td>87.7</td>
<td></td>
</tr>
<tr>
<td>Tumbler test</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% over 1 in.</td>
<td>32.0</td>
<td>47.7</td>
<td>49.8</td>
<td>46.7</td>
<td>49.5</td>
<td>51.3</td>
<td>40.7</td>
<td>45.6</td>
<td>47.9</td>
<td>37.7</td>
<td>36.2</td>
<td>37.4</td>
</tr>
<tr>
<td>% over 1 1/4 in.</td>
<td>66.0</td>
<td>69.1</td>
<td>67.7</td>
<td>65.5</td>
<td>67.2</td>
<td>66.5</td>
<td>65.1</td>
<td>66.9</td>
<td>66.8</td>
<td>56.8</td>
<td>58.6</td>
<td>58.3</td>
</tr>
</tbody>
</table>

a Average of 3-month commercial operation.
b Average of two commercial ovens.
c Average of three commercial ovens.
d Average of 4-month commercial operation.
e Average of 1-month commercial operation.
f Pounds of coal per cu. ft. as charged to oven.
g Screen analysis of coal as charged to oven.
h Estimated.
i Width of oven in inches divided by coking time in hours.
j Gallons of dry tar per ton of coal as charged.
k B.t.u. per pound of coal as charged (includes light oils).
l Dry coke, % of coal as charged.
m Calculated.
n Refers to yield of furnace coke, +1 1/4 inch instead of +1 inch.
o Corrected.
experimental data taken during both sets of duplicate runs. B.t.u. values are not shown for the gas beyond the tenth hour. Gas evolved during the balance of the coking period is very high in hydrogen, and the calorimeter is not adjusted to read accurately in this low range. These curves are typical of the results obtained under normal operating conditions.

Because of the close control of operation possible with the experimental oven, which cannot be realized in a gas-heated commercial size oven, the results on the experimental oven have been shown to be more dependable and more easily duplicated than those obtained from individual ovens of a commercial battery.

EXPERIMENTAL AND COMMERCIAL RESULTS

The extent to which the design of the oven is successful in permitting the duplication of commercial results is shown in Table I, which gives the results of four representative series of tests comparing experimental and commercial operations.

In evaluating coke quality the producers consider the shatter and tumbler tests to be most important. Special emphasis is given to the tumbler “stability” or the percentage of coke remaining over one inch in size in the tumbler test. Shatter tests are sometimes misleading, as in the case where larger pieces of soft coke give a higher shatter test than smaller pieces of a harder coke and thus indicate a superiority not borne out by use in the blast furnace. From the standpoint of production the yields of furnace coke and breeze require careful attention.

In studying the comparison of results in Table I, it is noted that experimental oven runs are compared with average commercial results over a period of one or more months. This is due to the inconsistency of coking results from individual commercial ovens.

It is probable that a commercial oven coal charge of 17 or more tons is not entirely uniform throughout, in either physical or chemical properties. The bulk density of the coal is largely controlled by moisture and size composition, both of which may vary within wide limits in different ovens. The bulk density varies from one part of the oven to another as a result of the method of coal charging and is probably greatest at the bottom of the oven under the charge holes. The coal blend also varies slightly in different ovens or parts of ovens due to mechanical difficulties in blending coals and to size segregation. Thus it is difficult, if not impossible, to obtain a 500-pound sample of coal for the experimental oven which is an exact duplicate of the coal in any one commercial oven.

Also, the temperature control of any two ovens in a commercial battery is such that the rate of heat input in one oven varies more or less from that of another oven. Even though the length of the heating cycle is the same for each oven, two adjacent ovens in the same battery are not charged at the same time, and the oven walls cannot be kept at identical temperatures throughout the greater part of the coking period.

On account of the variation in coal charges and heating conditions mentioned above, it seems evident that the degree of accuracy which may be obtained in comparing experimental oven results with average commercial results is a function of the accuracy of experimental sampling and of the duplication of average operating conditions. Therefore, it is believed that where proper care is taken in sampling a coal blend and in evaluating average operating conditions, the results obtained by coking this sample in the experimental oven operating under exact temperature control will compare closely with the average results obtained in a commercial oven battery over an extended period of time. Results obtained from any single commercial oven or any group of ovens taken over a single day’s operation will not necessarily duplicate the experimental oven results.

In the four series of comparisons shown in Table I, data for the runs in the experimental oven (prefix S) were obtained in our laboratories while data for the runs in commercial ovens (prefix C) were furnished by the cooperating industrial organizations. As would be expected, certain items of data taken in our laboratories are
Table II.—Duplicate Runs on Pilot Oven

<table>
<thead>
<tr>
<th></th>
<th>Blend A</th>
<th>Blend B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. 113</td>
<td>No. 116</td>
</tr>
<tr>
<td>Coke analysis, %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Volatile matter</td>
<td>1.2</td>
<td>1.1</td>
</tr>
<tr>
<td>Fixed carbon</td>
<td>90.9</td>
<td>91.3</td>
</tr>
<tr>
<td>Ash</td>
<td>7.9</td>
<td>7.6</td>
</tr>
<tr>
<td>Sulfur</td>
<td>0.83</td>
<td>0.73</td>
</tr>
<tr>
<td>Coke yields, % of dry coal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>71.7</td>
<td>72.2</td>
</tr>
<tr>
<td>Furnace (+1 in.)</td>
<td>68.7</td>
<td>68.7</td>
</tr>
<tr>
<td>Nut (1X⅜ in.)</td>
<td>0.9</td>
<td>1.0</td>
</tr>
<tr>
<td>Breeze (−⅛ in.)</td>
<td>2.1</td>
<td>2.5</td>
</tr>
<tr>
<td>Coke screen test, % of coke</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total +4 in.</td>
<td>4.1</td>
<td>1.8</td>
</tr>
<tr>
<td>Total +3 in.</td>
<td>31.6</td>
<td>29.2</td>
</tr>
<tr>
<td>Total +2 in.</td>
<td>79.3</td>
<td>78.2</td>
</tr>
<tr>
<td>Total +1 in.</td>
<td>95.8</td>
<td>95.2</td>
</tr>
<tr>
<td>Av. size, in.</td>
<td>2.61</td>
<td>2.54</td>
</tr>
<tr>
<td>Tumbler test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability (+1 in.)</td>
<td>55.9</td>
<td>55.4</td>
</tr>
<tr>
<td>Hardness (+½ in.)</td>
<td>69.2</td>
<td>68.9</td>
</tr>
<tr>
<td>Shatter test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>% of +2 in.</td>
<td>64.0</td>
<td>68.2</td>
</tr>
<tr>
<td>% of +1½ in.</td>
<td>88.8</td>
<td>87.8</td>
</tr>
<tr>
<td>Apparent gravity</td>
<td>0.824</td>
<td>0.825</td>
</tr>
<tr>
<td>Gas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cu. ft./lb. dry coal</td>
<td>6.50</td>
<td>6.42</td>
</tr>
<tr>
<td>B.t.u.</td>
<td>486</td>
<td>496</td>
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<tr>
<td>B.t.u. in gas/lb. coal</td>
<td>3159</td>
<td>3184</td>
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</table>

Table III.—Analyses of Coal Blends Designated in Table I
(As-Received Basis)

<table>
<thead>
<tr>
<th>Blend No.</th>
<th>Lab. No.</th>
<th>Coke Run No.</th>
<th>Moisture, %</th>
<th>Volatile Matter, %</th>
<th>Fixed C. %</th>
<th>Ash, %</th>
<th>S. %</th>
<th>Total</th>
<th>B.t.u. per Lb.</th>
<th>B.S.I. b</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>C3002</td>
<td>S1 &amp; S2</td>
<td>2.6</td>
<td>30.3</td>
<td>60.7</td>
<td>6.4</td>
<td>0.97</td>
<td>14,063</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>C1</td>
<td>3.1</td>
<td>29.6</td>
<td>61.6</td>
<td>5.7</td>
<td>0.79</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>C3078</td>
<td>S12</td>
<td>7.0</td>
<td>25.5</td>
<td>60.0</td>
<td>7.5</td>
<td>0.74</td>
<td>12,899</td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td>C3187</td>
<td>S23</td>
<td>3.8</td>
<td>28.5</td>
<td>62.0</td>
<td>5.7</td>
<td>0.71</td>
<td>13,927</td>
<td></td>
<td>6</td>
</tr>
<tr>
<td>5</td>
<td>C3191</td>
<td>S24</td>
<td>2.5</td>
<td>28.4</td>
<td>63.9</td>
<td>5.2</td>
<td>0.64</td>
<td>14,148</td>
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<td>6</td>
</tr>
<tr>
<td>6</td>
<td>C3263</td>
<td>S34 &amp; S35</td>
<td>3.5</td>
<td>28.1</td>
<td>60.3</td>
<td>8.1</td>
<td>0.76</td>
<td>13,388</td>
<td></td>
<td>4</td>
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</tbody>
</table>

a Analysis furnished by analytical laboratory of industrial plant.

b British Swelling Index.
not available from commercial operation. Also, certain items are not recorded on the same basis by our laboratory and the industrial companies. Thus, furnace coke is reported as $+1\frac{1}{4}$ inch size for the commercial runs in series 3 and 4, but as $+1$ inch in all other cases. Also, breeze is reported as the $-\frac{1}{2}$ inch coke from our laboratory, $-\frac{3}{8}$ inch coke for the commercial runs in series 1 and 2, and $-\frac{5}{8}$ inch coke for series 3 and 4. As the coke from commercial ovens is subject to rougher handling than that produced in an experimental oven, it is logical to expect that the percentage of breeze will be slightly higher than that obtained from a duplicate run in the experimental oven.

The principal difference in operation between runs S1 and S2 is in the coking time and appears in the “penetration” values. S1 was coked in 9 hours. This was considered too rapid a rate, the heating schedule was changed, and S2 was coked in 12 hours. This slower rate gave a penetration within 10% of the commercial rate. The effect of too rapid a coking rate on sample S1 is shown in the resulting lower values for shatter and tumbler tests for this run in comparison with the values for the same tests for runs S2 and C1.

The coal used in sample S12, series 2, had an unusually high moisture content, as shown in Table III. This high moisture value is reflected in the low bulk density of the charge, and may be responsible for the slightly low shatter and tumbler test values and also for the relatively high percentage of breeze.

Coal for runs S23 and S24, series 3, was taken as a single sample representative of commercial operation yielding the average results shown under C4. One portion of this sample was used without air-drying in run S23. Another portion was partially air-dried and used in run S24. Analyses of the coal used in these two runs (Table III) indicate that they were not entirely uniform. Also, the heating rate was reduced during run S24 to give a penetration more nearly comparable with plant practice during the period when data listed under C4 were collected. The results of this change in operation are evident in the closer agreement between data of S24 with C4 than was obtained between S23 and C4.

Even though there is some difference in size composition of the coals used in runs S34 and S35 and that shown as an average commercial value under C5, the results given under series 4 compare quite closely throughout.

Table I includes also data on the tar and gas yields obtained as by-products of the coking operation. Particularly during the early operation of the experimental oven, difficulty was encountered in obtaining checks on tar yields. This appears to be due to the inability to keep the tar held in the recovery system at a constant value. No appreciable trouble was encountered in getting checks on the over-all thermal values of the gas yields from comparable runs through the experimental oven.

Experience to date with this experimental oven has demonstrated that when blends of coals are coked in it under conditions rigidly controlled to duplicate bulk densities, average penetrations, and final temperatures of commercial ovens coking the same blends, the physical and chemical properties of the coke produced in the experimental oven will check closely the averages of the respective properties of the coke produced in commercial ovens. This is true not only with Illinois coal blends, but with eastern coal blends as well. Series 2, Table I, shows coking results from an Illinois coal blend, and series 1, 3, and 4 are the results of blends of all eastern coals. Thus, this experimental slot-type oven may be used to predict accurately the physical and chemical properties of the coke which will result from the carbonization of any given blend of coals in a commercial installation.

ACKNOWLEDGMENT

This study was made possible through the assistance of the Office of Production Research and Development of the War Production Board, Washington, D. C. Valuable counsel was received from A. C. Fieldner, U. S. Bureau of Mines, in the initiation of the project. M. D. Curran,
Coal Carbonizing Company, furnished fabricated steel for oven construction and for coke and by-product testing. Walsh Refractories Corporation furnished firebrick, bonding mortar, and refractory insulating brick. Without the extensive cooperation of Koppers United Company and the Inland Steel Company, it would have been impossible to compare the results of experimental work with those of commercial operation. The Chicago, Wilmington, and Franklin Coal Company, the Bell and Zoller Coal Company, the Franklin County Coal Corporation, and the Sahara Coal Company were generous and cooperative in furnishing samples of coal. Coal and coke analyses were made under the direction of O. W. Rees, and tar and by-product analyses under the direction of G. R. Yohe, both of the Illinois State Geological Survey. To all of these organizations and individuals we express our sincere appreciation.

LITERATURE CITED

(2) Ibid., Part 3, p. 76, Designation D294-29 (1942).