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PETROLEUM COKE IN ILLINOIS COAL BLENDS FOR BLAST FURNACE COKE

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ABSTRACT

Coke made in a pilot-oven from petroleum coke blended with Illinois coals tended to be somewhat larger and heavier than the coke made from Illinois and low-volatile Pocahontas coals. The best pilot-oven coke was produced from blends including 15 to 20 percent petroleum coke. Tumbler tests indicated that fine pulverization of the petroleum coke before it was blended improved coke strength.

Cokes of good quality also were produced when the low-volatile constituent was half petroleum coke and half medium-volatile coal. A minimum of coke breeze was obtained from such blends.

Extremely low ash and moderately high sulfur in the petroleum coke were reflected in the analyses of the cokes produced.

INTRODUCTION

One goal of the coke research project at the Illinois State Geological Survey has been to produce coke of metallurgical quality from Illinois products alone. As no low- or medium-volatile coals are mined in the state, one apparent way to accomplish this would be to add a noncoal material to the high-volatile Illinois coals.

At various times we have experimented with additives such as coke breeze, petroleum coke, char, and fusain. Coke with good physical properties has been produced from a strongly coking Illinois coal by adding char made from the same or similar coals (Reed et al., 1955). At current prices, however, char cannot compete with low-volatile coal delivered into this area. Coke breeze or a coal with high fusain content might substitute for a portion of the low-volatile coal normally used in blends, but neither material is considered suitable for total replacement of the low-volatile constituent. Of the materials tried, only petroleum coke is left as a possible replacement.

Petroleum coke, a by-product of the petroleum refining industry, is produced in many areas, including Illinois. It is extremely low in ash, but may contain more sulfur than the usual blending coals. Petroleum coke develops practically no plasticity, as indicated by the Gieseler plastometer, but it cannot be regarded as strictly inert inasmuch as we found it contained 12 to 17 percent volatile matter, most of which is evolved during carbonization.

Preliminary studies in 1944 indicated that petroleum coke blended in small percentages with Illinois coals tended to make the coke more blocky and to increase the strength indices. With this background, and at the request of a coke producer in the area, we made further tests on blends of petroleum coke with Illinois coals to determine whether or not coke of metallurgical quality could be produced. The coal blends tested were similar to those being coked in this area, except for the substitution of petroleum coke for low-volatile coal.

Acknowledgments

The petroleum coke used in this study was furnished by the Great Lakes Carbon Corporation, and the Illinois coals by Granite City Steel Company. We thank both these companies and appreciate their cooperation.

PROCEDURE

Coking tests were made in the Survey's movable-wall pilot oven, which is 17 inches wide and holds approximately 675 pounds of coal. Blends were pulverized to allow 80 to 85 percent of the material to pass through a 1/8-inch screen, and oven flue temperatures were adjusted to give a coking time of 16 1/2 hours while producing coke with 1.1 to 1.4 percent volatile matter.

Previous tests had indicated that 20 percent of petroleum coke probably was the maximum amount that could be blended with Illinois coals without too much reduction in the hardness index of the coke. The blends carbonized in this study, therefore, contained petroleum coke in proportions ranging from 10 to 20 percent.

No. 5 and No. 6 Coals from Illinois were used in all blends. Those blends containing petroleum coke all included 25 percent of No. 5. The remaining Illinois coal was No. 6. For comparison with the blend containing 20 percent petroleum coke a similar blend was carbonized in which 20 percent of Pocahontas Coal was used as the low-volatile constituent.

It is generally believed that an inert or semi-inert material that does not develop plasticity during carbonization should be pulverized more finely than the coals with which it is to be blended. To check the necessity for fine pulverization of the petroleum coke, two series of tests were made. In the first, the petroleum coke was prepulverized in the hammer mill to approximately 95 percent minus 8-mesh. To obtain this degree of pulverization a cradle screen with ½-inch holes was used in the mill. The finely pulverized petroleum coke was then mixed thoroughly with the Illinois coals and the mixture passed through the hammer mill, using a 1-inch cradle screen. Size analyses of the petroleum coke made after the initial pulverization, and of a typical blend containing 15 percent of this fine material, are shown in table 1.

Table 1. - Pulverization of Petroleum Coke and of a Typical Coal Blend

	Finely ground petroleum coke (% of total)	Coal blend containing 15% finely ground petroleum coke (% of total)
+6 mesh	2.3	14.8
6 x 8 mesh	3.5	10.4
8 x 20 mesh	28.2	33.6
20 x 48 mesh	33.5	22.5
48 x 100 mesh	16.4	9.7
-100 mesh	16.1	9.0

In the second series of tests the petroleum coke, in the size received, was mixed with the coals and the mixture pulverized normally. It is reasonable to assume that the petroleum coke was not as finely pulverized in this series.

All blends were charged to the coke oven at as near the same bulk density as possible. Density actually varied from 52.6 to 53.9 pounds per cubic foot of oven space. This degree of uniformity was obtained by air-drying the coals at room temperature to remove surface moisture before pulverization.

Following the tests in which only petroleum coke and Illinois coals were used, two additional blends were carbonized in which the low-volatile constituent consisted of one part petroleum coke to one part medium-volatile coal. The medium-volatile coal contained 22 percent volatile matter, so the half-and-half mixture had roughly the same volatile matter content as low-volatile Pocahontas Coal. One of the two blends tested contained 20 percent and the other 15 percent of this low-volatile mixture. In preparation of these blends the petroleum coke was mixed directly with the coals without prepulverization.

Analyses and plastic properties of the coals and petroleum coke used in this study are given in table 2. Analytical data for the blends tested and cokes produced are shown in table 6.

Table 2. - Average Analyses of Petroleum Coke and Coals

		Dry analysis					Maximum
	M.	V.M.	F.C.	Ash	Sulfur	F.S.I.	Gieseler fluidity
Petroleum coke Average of 2 samples	1.9	12.6	87.2	0.2	1.40	1.0	none
Illinois No. 6 coal Average of 4 samples (2 coals)	8.2	38.7	54.2	7.1	1.05	4.5	30
Illinois No. 5 coal Average of 3 samples	5.7	37.1	55.2	7.7	1.56	5.5	77
Medium-volatile	4.5	22.0	73.0	5.0	0.66	9.0	1160
Pocahontas	3.5	17.0	76.7	6.3	0.78	8.5	19

CARBONIZATION RESULTS

Blends with Prepulverized Petroleum Coke

First to be tested were blends of Illinois coals and the prepulverized petroleum coke. Blends containing from 10 to 20 percent of this more finely pulverized petroleum product were carbonized, and the results compared with those obtained by coking the Illinois coals by themselves (table 3 and figure 1).

As would be expected, the first 10 percent of petroleum coke added to the blend had the greatest effect on coke properties, increasing tumbler stability from 18 to 40 and raising the average coke size from 1.9 to approximately 2.3 inches. Successive increases in petroleum coke resulted in consistently higher tumbler stability indices to a maximum of 53.7. Average coke size increased to 2.5 inches when 15 percent of petroleum coke was added and remained approximately the same when 20 percent was added.

Table 3. - Blends of Illinois Coals and Finely Ground Petroleum Coke

	75% Ill. No. 6 25% Ill. No. 5	65% Ill. No. 6 25% Ill. No. 5 10% Petr. coke	62½% Ill. No. 6 25% Ill. No. 5 12½% Petr. coke	60% Ill. No. 6 25% Ill. No. 5 15% Petr. coke	55% Ill. No. 6 25% Ill. No. 5 20% Petr. coke
	Run 464E	Run 396E	Run 397E	Run 390E	Run 402E
Coke Physical Properties					
Tumbler test					
Stability	18.0	40.2	43.2	49.9	53.7
Hardness	67.1	65.2	64.3	63.0	61.9
Shatter test					
+2 inches	43.6	70.5	73.3	78.6	78.4
+1½ inches	72.0	87.5	88.9	90.0	92.3
Sizing					
+4 inches	0.0	3.4	2.9	3.6	6.4
4 x 3 inches	7.6	16.0	21.7	27.4	23.1
3 x 2 inches	33.9	45.5	45.0	44.0	45.8
2 x 1 inches	47.9	26.1	22.2	16.8	16.6
1 x ½ inch	6.3	4.2	3.3	3.5	2.5
-½ inch	4.3	4.8	4.9	4.7	5.6
Average size (in.)	1.89	2.29	2.39	2.51	2.56
Apparent gravity	0.75	0.79	0.80	0.81	0.84
Coke Yields (at 3% moisture)					
Total coke	65.2	67.4	68.3	68.7	69.5
Furnace (+1 inch)	58.3	61.4	62.8	63.1	63.9
Nut (1 x ½ inch)	4.1	2.8	2.1	2.4	1.7
Breeze (-½ inch)	2.8	3.2	3.4	3.2	3.9
Expansion Pressure					
Lbs. per sq. in.	0.9	1.0	1.0	-	1.1
Bulk density (Lbs. per cu. ft.)	52.4	53.5	53.1	53.8	53.9
Operating Data					
Pulverization (-1/8 inch)	81.6	80.5	83.7	83.7	81.7
Flue temperature (°F.)	1970	1950	1950	1950	1950
Coking time (hr.: min.) (17-inch oven)	16:30	16:30	16:30	16:30	16:30

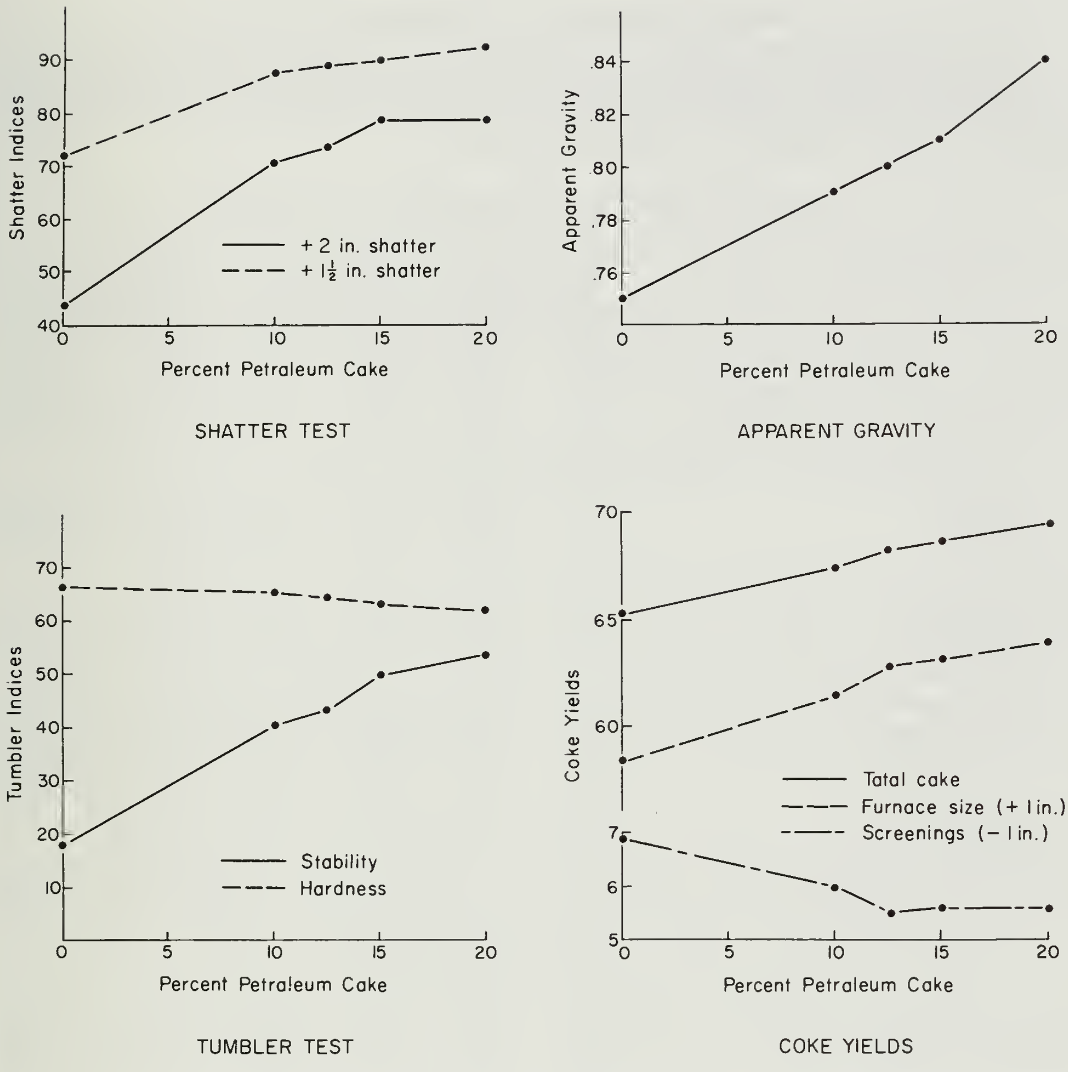

Fig. 1 - Comparison of properties of cokes made from blends of Illinois coals and various percentages of petroleum coke

Petroleum coke additions had the reverse effect on the tumbler hardness index, which dropped consistently from 67.1 for the straight Illinois coal blend to a low of 61.9 for the blend containing 20 percent of petroleum coke. The yield of coke fines (minus 1-inch) was reduced by the smaller additions of petroleum coke, and remained practically constant with additions of 12½ percent or more.

Apparent gravity of the coke increased directly with the percentage of petroleum coke added and reached a maximum of 0.84, a high value for coke containing so large a percentage of Illinois coals. Expansion pressure remained consistently low over the entire series.

Effect of Prepulverization of Petroleum Coke

To determine the effect of prepulverization, the cokes containing 10, 15, and 20 percent of finely pulverized petroleum coke were compared with cokes made from blends differing only in that the petroleum coke had not been prepulverized. Comparisons of coke properties are shown in table 4.

Table 4. - Effect of Finely Ground Petroleum Coke in Illinois Coal Blends

	55% Ill. No. 6 25% Ill. No. 5 20% Petr. coke		60% Ill. No. 6 25% Ill. No. 5 15% Petr. coke		65% Ill. No. 6 25% Ill. No. 5 10% Petr. coke	
	Run 402E	Run 483E	Run 390E	Run 392E	Run 396E	Run 481E
Pulverization of petroleum coke	Fine	Normal	Fine	Normal	Fine	Normal
Coke Physical Properties						
Tumbler test						
Stability	53.7	52.4	49.9	47.5	40.2	38.4
Hardness	61.9	60.5	63.0	58.8	65.2	62.6
Shatter test						
+2 inches	78.4	82.7	78.6	83.7	70.5	65.9
+1½ inches	92.3	92.2	90.0	93.6	87.5	86.2
Sizing						
+4 inches	6.4	8.2	3.6	8.3	3.4	3.7
4 x 3 inches	23.1	25.1	27.4	27.4	16.0	14.4
3 x 2 inches	45.8	43.5	44.0	41.0	45.5	48.6
2 x 1 inches	16.6	16.1	16.8	15.4	26.1	25.2
1 x ½ inch	2.5	2.7	3.5	3.2	4.2	4.0
-½ inch	5.6	4.4	4.7	4.7	4.8	4.1
Average size (inches)	2.52	2.61	2.51	2.62	2.29	2.30
Apparent gravity	0.84	0.83	0.81	0.82	0.79	0.78
Coke Yields (at 3% moisture)						
Total coke	69.5	70.0	68.7	68.9	67.4	67.4
Furnace (+1 inch)	63.9	65.0	63.1	63.5	61.4	62.0
Nut (1 x ½ inch)	1.7	1.9	2.4	2.1	2.8	2.6
Breeze (-½ inch)	3.9	3.1	3.2	3.3	3.2	2.8
Expansion Pressure						
Lbs. per sq. in.	1.1	0.7	-	1.0	1.0	0.7
Bulk density (Lbs. per cu. ft.)	53.9	52.5	53.8	53.1	53.5	51.4
Operating Data						
Pulverization - blend (-1/8 inch)	81.7	85.2	83.7	82.4	80.5	80.9
Flue temperature (°F.)	1950	1950	1950	1950	1950	1950
Coking time (hr.:min.) (17-inch oven)	16:30	16:30	16:30	16:30	16:30	16:30

From the pilot-plant test results it appears that cokes with higher tumbler strength indices are produced when the petroleum coke is more finely pulverized. Fine pulverization also tends to reduce the size of the product coke. Expansion pressures were consistently low, and were not affected by the method of pulverization.

Pocahontas Coal Compared with Petroleum Coke

The same Illinois coals were blended with 20 percent of Pocahontas Coal and the product compared with that from the blend containing an equal quantity of prepulverized petroleum coke. The Pocahontas Coal blend produced a product lighter in weight and slightly smaller than did the petroleum coke (table 5). Coke from the Pocahontas blend was slightly more stable and definitely harder, as shown by the tumbler indices. Total coke yields and expansion pressures were essentially the same.

Judging from these data it appears that the addition of petroleum coke to the blend will produce a heavier coke than will the addition of Pocahontas coal, but at the expense of a lower hardness index.

Blends Containing Medium-Volatile Coal and Petroleum Coke

When petroleum coke replaces Pocahontas coal in blends of the type studied, there is a reduction in the hardness index of the coke and a resultant tendency to a lower resistance to abrasion. An attempt to increase this hardness index was made by blending the Illinois coals with a mixture of equal parts of petroleum coke and medium-volatile coal. The coke from such a blend would have the advantage of the very low ash in the petroleum coke and of the low sulfur in the medium-volatile coal.

Results of tests on two blends containing 15 and 20 percent, respectively, of this petroleum coke — medium-volatile coal mixture are shown in table 5, where they are compared with similar blends without medium-volatile coal. Tumbler indices of the cokes were higher for the blends containing medium-volatile coal. The yields of furnace-size coke were increased, and the percentage of breeze reduced. Inclusion of medium-volatile coal in the blend also tended to lower the apparent gravity of the coke, and there was no effect on expansion pressure. Except for being slightly heavier, coke from the blend containing 20 percent of the petroleum coke — medium-volatile coal mixture compared closely with that from the blend containing 20 percent Pocahontas coal.

Effect of Nonuniformity of the Petroleum Coke

The two shipments of petroleum coke used in the tests described were nearly identical, the volatile matter of one being 12.0 and of the other, 13.2 percent. A third shipment with volatile matter of 17.6 percent was tested for comparison, and blends containing 10 and 20 percent of this material were coked in the same way as the others. Coke properties were quite similar to those of the cokes made previously except that hardness indices were 2 to 3 points higher, and the coke was slightly smaller. It appears, therefore, that volatile matter variations in this range are not critical.

Table 5. - Effect of Low-Volatile Constituents in Illinois Coal Blends

	55% Ill. No. 6 25% Ill. No. 5 20% No. 3 Pocahontas	55% Ill. No. 6 25% Ill. No. 5 20% Petr. coke	55% Ill. No. 6 25% Ill. No. 5 10% Med.-vol. 10% Petr. coke	60% Ill. No. 6 25% Ill. No. 5 15% Petr. coke	60% Ill. No. 6 25% Ill. No. 5 7½% Med.-vol. 7½% Petr. coke
	Runs 379E 403E	Run 402E	Run 394E	Run 390E	Run 418E
Coke Physical Properties					
Tumbler test					
Stability	54.9	53.7	55.6	49.9	51.8
Hardness	65.9	61.9	65.1	63.0	65.9
Shatter test					
+2 inches	80.8	78.4	78.2	78.6	73.3
+1½ inches	92.9	92.3	92.6	90.0	91.2
Sizing					
+4 inches	5.6	6.4	5.8	3.6	3.6
4 x 3 inches	20.1	23.1	24.7	27.4	13.6
3 x 2 inches	45.7	45.8	44.5	44.0	48.6
2 x 1 inches	21.4	16.6	18.2	16.8	27.3
1 x ½ inch	2.7	2.5	3.2	3.5	3.4
-½ inch	4.5	5.6	3.6	4.7	3.5
Average size (in.)	2.45	2.52	2.54	2.51	2.30
Apparent gravity	0.79	0.84	0.81	0.81	0.79
Coke Yields (at 3% moisture) (% of coal as received)					
Total coke	69.4	69.5	69.2	68.7	68.4
Furnace (+1 inch)	64.6	63.9	64.5	63.1	63.7
Nut (1 x ½ inch)	1.7	1.7	2.2	2.4	2.3
Breeze (-½ inch)	3.1	3.9	2.5	3.2	2.4
Expansion Pressure					
Lbs. per sq. in.	1.0	1.1	1.1	-	1.1
Bulk density (Lbs. per cu. ft.)	51.0	53.9	53.4	53.8	53.4
Operating Data					
Pulverization (% -1/8 inch)	79.2	81.7	83.3	83.7	84.5
Flue temperature (°F.)	1950	1950	1950	1950	1950
Coking time (hr.:min.) (17-inch oven)	16:30	16:30	16:30	16:30	16:30

Table 6. - Anaylses of Coal Blends and Cokes

Run no.		M.	Dry Analysis V.M.	F.C.	Ash	Sulfur	F.S.I.
			75% Ill. No. 6 25% Ill. No. 5				
464E	Coal blend	7.5	39.8	53.1	7.1	1.07	4
	Coke		1.7	88.0	10.3	0.89	
			65% Ill. No. 6 25% Ill. No. 5 10% Petr. coke				
396E, 417E	Coal blend	6.7	35.5	58.1	6.4	1.26	5
	Coke		1.3	89.7	9.0	1.03	
			62½% Ill. No. 6 25% Ill. No. 5 12½% Petr. coke				
397E	Coal blend	6.7	34.9	58.8	6.3	1.26	5
	Coke		1.4	89.7	8.9	1.01	
			60% Ill. No. 6 25% Ill. No. 5 15% Petr. coke				
390E, 392E	Coal blend	6.5	34.3	59.5	6.2	1.27	5
	Coke		1.1	90.2	8.7	1.00	
			55% Ill. No. 6 25% Ill. No. 5 20% Petr. coke				
402E, 423E	Coal blend	6.0	32.9	61.4	5.7	1.23	5
	Coke		1.3	90.7	8.0	1.07	
			55% Ill. No. 6 25% Ill. No. 5 20% Pocahontas				
379E, 403E	Coal blend	6.6	33.8	59.1	7.1	1.17	5
	Coke		1.2	88.9	9.9	0.92	
			60% Ill. No. 6 25% Ill. No. 5 7½% Med.-vol. 7½% Petr. coke				
418E	Coal blend	6.4	34.5	59.1	6.4	1.22	5
	Coke		1.4	89.3	9.3	0.98	
			55% Ill. No. 6 25% Ill. No. 5 10% Medium-vol. 10% Petr. coke				
394E	Coal blend	6.5	33.9	59.8	6.3	1.21	5½
	Coke		1.3	89.9	8.8	0.97	

Effect of Petroleum Coke on Chemical Analysis of Coke from Blends

Coke ash was lowered consistently when petroleum coke was used in the blends. The only direct comparison shown in table 6 is between the blends containing 20 percent Pocahontas Coal and 20 percent petroleum coke. The coke ash was reduced from 9.9 percent in the Pocahontas blend to 8.0 percent in the petroleum coke blend.

Coke sulfur, on the other hand, was increased by the higher sulfur content of the petroleum coke. The 20 percent Pocahontas blend had a coke sulfur content of 0.92 percent, whereas that of the petroleum coke blends was 1.07 percent. In evaluating these two low-volatile constituents, the question is which gives the greater advantage to any specific coke, lower sulfur or lower ash.

SUMMARY

Petroleum coke was tested in Illinois coal blends as a possible replacement for low-volatile coal in the production of metallurgical coke suitable for blast furnace use. Blends containing from 10 to 20 percent of petroleum coke were carbonized in the pilot oven. Higher percentages were not tried as previous tests had shown that over 20 percent of petroleum coke caused too great a reduction in the hardness index of the resulting product. Of the blends tested those containing from 15 to 20 percent petroleum coke produced cokes with physical properties most nearly suitable for blast furnace coke.

Blends containing petroleum coke produced a heavier, larger sized product than was obtained by using Pocahontas Coal in equal quantity. The yield of coke fines was increased slightly, however, by substituting petroleum coke for Pocahontas Coal.

Stability and hardness indices of the pilot-oven coke, as shown by the tumbler test, were improved by fine pulverization of the petroleum coke before blending.

Good quality coke was produced when the low-volatile constituent of the blend was half petroleum coke and half medium-volatile coal. Such blends produced the lowest yield of coke breeze, and both tumbler stability and hardness indices were high.

Petroleum coke was extremely low in ash but moderately high in sulfur. Both of these characteristics were reflected in the cokes produced in the pilot oven.

CONCLUSIONS

Cokes with properties suitable for blast furnace fuel have been made from blends of Illinois coal and petroleum coke in the pilot coke oven. However, pilot-oven data are not conclusive evidence of coke performance, and should petroleum coke become economically attractive for this use such blends should be tested on a scale large enough to prove their value. If such tests proved successful, blast furnace coke might then be made entirely of Illinois products.

REFERENCES

Reed, F. H., Jackman, H. W., and Henline, P. W., 1955, Char for metallurgical coke: Illinois Geol. Survey Rept. Inv. 187.

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