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A Survey of the Coking Properties of Illinois Coals

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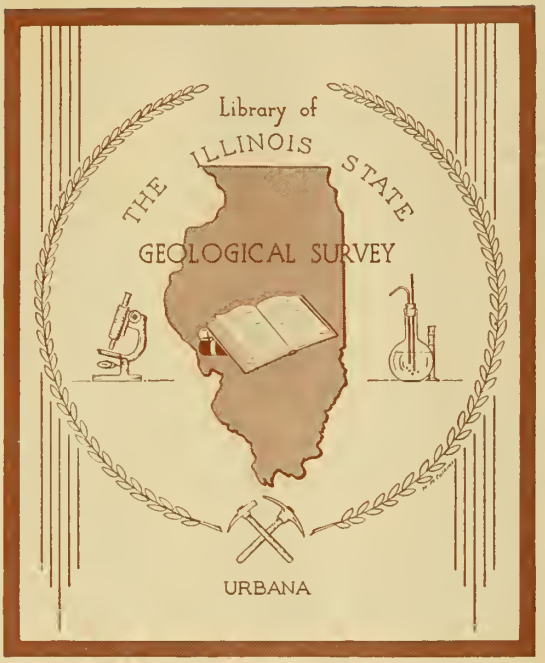

A SURVEY OF THE COKING PROPERTIES OF ILLINOIS COALS

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ABSTRACT

Illinois coals from all the mining areas and all the commercially mined seams in the state have been evaluated for their ability to produce both chemical and metallurgical coke. They have been coked both by themselves and in blends, and it has been found that many of these coals that are not suitable for metallurgical coke because of their ash and sulfur content might be used to produce chemical coke where these impurities are not too critical.

INTRODUCTION

Coking studies of Illinois coals from the low-sulfur area in southern Illinois have been made at the Illinois State Geological Survey since 1942. Many blends of these coals with high-, medium- and low-volatile eastern coals have been carbonized in pilot coke ovens, and the cokes have been evaluated for their use in the metallurgical industry as fuels for blast furnaces or iron cupolas.

Metallurgical cokes, when used as blast furnace fuel, perform three primary functions. They must burn at the tuyeres to supply reducing gases in order to convert iron ore into metallic iron; they must furnish heat to melt the iron and slag that are produced; and they must retain their size and shape as they travel through the furnace shaft in order to maintain a porous structure in the ore burden and allow the reducing gases to travel upward easily. In addition, metallurgical coke must contain a minimum of ash and sulfur, as these require additional fluxing agent and heat for removal with the slag. Metallurgical coke, therefore, must not only be low in these impurities but must have strength and size stability.

Study also has been made of the use of Illinois coals for the production of chemical coke—coke used in electric furnace reduction of ores or in conversion of limestone and carbon into calcium carbide. Chemical coke may have chemical and physical properties that differ from those required in the metallurgical product. Low

sulfur content is not necessarily a prerequisite, and although low ash content is desired, it may not be required, if a uniform analysis can be maintained. Likewise, the physical properties of chemical coke may vary from those of metallurgical cokes. Chemical coke is usually crushed by the producer to a maximum size not exceeding 3/4-inch. Coke fines of approximately 1/8-inch maximum size are screened out and sold separately, usually bringing a lower return than the larger sizes. It is imperative, therefore, to maintain coke fines at a minimum.

Studies have shown that a structurally weak coke (one with a low tumbler stability index) tends to produce less fines when crushed than does a strong coke (Jackman and Helfinstine, 1964). Studies also indicate that a brittle coke (one with a high tumbler hardness index) tends to produce less of the extremely fine coke sizes and dust. Therefore, for greatest realization, chemical coke should have low tumbler stability and high tumbler hardness indices.

Previous experience at Survey laboratories has shown that many Illinois coals that are carbonized by themselves or in certain blends with medium- or high-volatile coals produce cokes with the above physical characteristics. Likewise, when some of these Illinois coals are blended with coals of lower volatile content, they produce strong cokes with physical properties suitable for metallurgical use. It was decided, therefore, to study coals from the various coal seams and mining districts of Illinois, coking representative coals by themselves and in blends, in order to determine their potential value for both chemcal and metallurgical uses.

Procedure

Coals from 21 mines, representing 7 seams and 15 counties, were sampled for these tests. In choosing these coals, all of the major coal mining areas in the state, as well as all of the commercially mined seams, were included. In addition, one seam not mined commercially, but showing promise as a coking coal, was included.

Each coal taken from a commercial mine was sampled at the tipple in a regularly prepared size, usually one produced in a reasonably large tonnage. At mines equipped with washing facilities, a washed product was taken for the test. At a few mines, where no washed coal was produced, and where the ash content was known to be high, the raw coal was sampled and subsequently washed in the Geological Survey's pilot coal washer before testing.

Coal from the seam not mined commercially was sampled near the outcrop from a pit dug for this purpose. Although the sulfur content was higher than expected, coking tests were made on this coal as dug from the pit. The quantity of coal available was not sufficient to make coke tests on a washed product in the pilot oven, although it was found that the sulfur content could readily be reduced by washing.

In addition to coking these Illinois coals by themselves, they were coked in blends with higher rank coals from the Appalachian area. Medium- and low-volatile coals were used mainly for blending. The cokes produced from such blends usually were stronger and larger than those made from all-Illinois coals. When using low-sulfur Illinois coals in blends, cokes of metallurgical quality were produced.

All coking tests were made in the Geological Survey's pilot coke oven, a slot-type oven, 17 inches wide, with approximately 700 pounds coal capacity (Jackman et al., 1955). Cokes produced are very similar to those made in commer-

cial slot-type coke ovens. Limited experience has shown that satisfactory correlations also can be obtained with cokes produced in rectangular nonrecovery ovens.

All cokes produced in the Survey pilot oven were sampled and analyzed for volatile matter, ash, and sulfur by ASTM standard methods of analysis. In addition, each coke was dried, sized, and tested for drop-shatter and tumbler strengths, and for apparent specific gravity, by accepted ASTM procedures. Yields of the various sizes of coke were computed, and in certain cases, crushing tests were made on 25-pound samples of 3- by 2-inch and 2- by 1-inch sizes of coke in order to determine the amount of minus 1/8-inch screenings obtained from a jaw crusher set to produce a 3/4-inch maximum size product. No apparent differences were noted in crushing results from these two sizes of coke, and thus results have been averaged and reported as though 3- by 1-inch coke had been used.

Acknowledgments

We wish to express our appreciation to all of the Illinois coal producers who furnished coals for these tests. We also thank the eastern coal producers and the steel companies in the Chicago and St. Louis areas, who furnished the coals for blending.

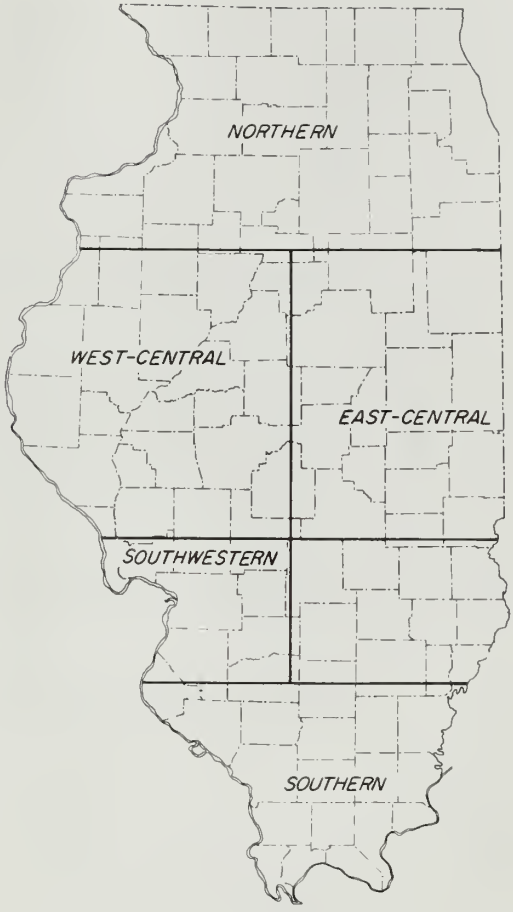

Figure 1 - Regional locations of Illinois coals tested.

EXPERIMENTAL RESULTS

For the purpose of this report, the Illinois coals tested have been divided into groups according to the section of the state in which the mines are located. A map of Illinois (fig. 1) shows these divisions. To avoid positive identification, each mine is listed only by coal seam plus a letter, such as Illinois No. 6-A.

Analyses of the Illinois coals tested are given in table 1. The size designations of all Illinois coals as sampled also are shown in this table. Table 2 gives the average analyses of all out-of-state coals used for blending. These coals are identified by their seam names.

TABLE 1 – ANALYSES OF ILLINOIS COALS TESTED[1]

Location	Mine designation	Mine size tested	Moisture (%)	Moisture-free basis				Free-swelling index	Maximum Gieseler fluidity (dial div per min)
				Volatile matter (%)	Fixed carbon (%)	Ash (%)	Sulfur (%)		
Northern Illinois	Ill. No. 2-A	Pit sample	14.3	45.6	50.0	4.4	2.21	2	119
	Ill. No. 6-A	7/8" x 1/4"	16.5	42.4	50.9	6.7	3.01	3 1/2	11
West-Central Illinois	Ill. No. 2-B	1 1/2" screenings	13.8	47.9	46.6	5.5	3.28	3 1/2	28,000
	Ill. No. 2-C	3/4" x 1/4"	12.9	43.0	51.0	6.0	3.41	4	557
	Ill. No. 6-B	3" x 1 1/2"	12.1	44.3	45.0	10.7	4.46	3 1/2	24
East-Central Illinois	Ill. No. 6-C	1 1/2" x 1/4"	11.4	44.7	48.4	6.9	2.20	3 1/2	8,600
	Ill. No. 7-A		12.0	45.2	46.0	8.8	3.11	3 1/2	6,000
Southwestern Illinois	Ill. No. 6-D	Run of mine; Float 1.34 sp. gr.	12.7	39.3	54.2	6.5	0.89	3	Very low
	Ill. No. 6-E	Screenings	14.0	40.0	49.5	10.5	1.88	3 1/2	4
	Ill. No. 6-F	1" x 1/4"	8.3	43.9	46.3	9.8	3.58	3 1/2	890
Southern Illinois	Ill. No. 5-A	3" x 0"	7.0	36 3	56.3	7.4	1.35	4 1/2	85
	Ill. No. 5-A	1/4" x 0"	9.5	37.6	55.6	6.8	1.73	5 1/2	98
	Ill. No. 5-B	1 1/4" x 1/4"	6.9	37.2	53.6	9.2	2.49	4	212
	Ill. No. 5-C	1 1/4" x 1/8"; Float 1.37 sp. gr.	3.9	40.7	52.6	6.7	2.43	6	24,100
	Ill. No. 6-G	3" x 0"	8.1	38.7	54.2	7.1	1.16	4 1/2	50
	Ill. No. 6-H	3" x 0"	9.0	36.8	55.2	7.8	0.90	3 1/2	30
	Ill. No. 6-J	1/4" x 28"	8.7	37.2	55.8	7.1	1.56	3 1/2	20
	Ill. No. 6-K	1" x 1/4"	6.8	41.4	51.1	7.5	2.79	4 1/2	1,110
	Ill. Davis and Dekovan (A)	1" x 1/4"	3.8	42.0	47.1	10.9	3.44	7	6,520
	Ill. Davis and Dekovan (B)	1" x 1/4"	5.2	40.9	51.3	7.8	2.73	6	3,360
	Ill. Willis (Float 1.35 sp. gr.)	1" x 1/4"	1.9	36.5	57.0	6.5	2.32	6 1/2	27,000
	Ill. Reynoldsburg	Pit sample	3.6	40.9	54.1	5.0	2.63	5 1/2	27,500

[1]Analytical data by the Coal Analysis Laboratory.

Coals from Northern Illinois

Two mines in the northern Illinois area were tested—one on the eastern and one on the western side of the state. These are both strip mines, as the Illinois coal measures outcrop across this northern portion of the state. Coals from this northern area are classified as high-volatile bituminous C rank and are consistently high in moisture and volatile matter. Sulfur content tends to be high, and coking properties are poor to medium.

Illinois No. 2-A mine mixes coals from two seams in its preparation plant. The sample was obtained, therefore, directly from the No. 2 seam. As shown in table 1, this pit sample had a very low ash content and only a medium high sulfur content. However, the very low free-swelling index indicated weak coking properties that were demonstrated subsequently when the coal was coked by itself in the pilot oven. The pilot oven coke had a very low tumbler stability index and contained a high percentage of screenings. However, a crushing test on the 3- by 1-inch size coke gave favorable results, indicating possible potential use as chemical coke. When blended with medium- or low-volatile coals, this No. 2-A Coal produced cokes that had medium strength but a higher sulfur content than is desired for metallurgical coke.

Illinois No. 6-A, the other northern Illinois coal tested, was sampled in the 7/8- by 1/4-inch size. It was relatively low in ash content and had somewhat stronger coking properties than the Illinois 2-A Coal. Illinois No. 6-A Coal might

TABLE 2 - ANALYSES OF OUT-OF-STATE COALS USED IN BLENDS[1]

Type	Coal	Moisture (%)	Moisture-free basis				Free-swelling index	Maximum Gieseler fluidity (dial div per min)
			Volatile matter (%)	Fixed carbon (%)	Ash (%)	Sulfur (%)		
High-volatile	Powellton	2.2	34.2	61.9	3.9	0.72	8	28,000
Medium-volatile	Jewell-A	2.4	22.5	73.7	3.8	0.74	9	1,480
	Jewell-B	3.6	21.7	74.7	3.6	0.59	9	1,200
	Sewell	4.0	23.5	73.4	3.1	0.67	9	2,150
	Splashdam	2.3	29.9	64.8	5.3	0.72	8	28,000
	Pocahontas No. 3	4.0	22.0	72.6	5.4	0.58	9	950
Low-volatile	Beckley	2.6	18.8	75.3	5.9	0.85	9	120
	Pocahontas No. 3-A	3.4	17.7	76.9	5.4	0.73	8	42
	Pocahontas No. 3-B	2.4	17.8	76.7	5.5	0.70	8	67
	Pocahontas No. 4-A	3.8	16.4	77.8	5.8	0.79	9	24
	Pocahontas No. 4-B	4.1	16.9	75.5	7.6	0.69	8	23

[1]Analytical data by the Coal Analysis Laboratory.

be suitable for chemical coke, also. When blended with sufficient medium-volatile coal, the No. 6-A coke appeared to be of metallurgical quality, except for a sulfur content of approximately 1.5 percent. This coal did not produce strong coke when blended with the low-volatile Beckley seam, probably due in part to its low fluidity. Physical and chemical properties of all cokes produced that contain northern Illinois coals are shown in tables 3 and 4.

TABLE 3 - RESULTS OF COKING TESTS ON ILLINOIS NO. 2-A COAL BLENDS (NORTHERN ILLINOIS)

	100% Ill. No. 2-A (Pit sample)	80% Ill. No. 2-A 20% Jewell-B	60% Ill. No. 2-A 40% Jewell-B	80% Ill. No. 2-A 20% Beckley	60% Ill. No. 2-A 40% Beckley
Date of test:	10-29-64	11-10-64	11-12-64	11-17-64	11-19-64
Coke Physical Properties					
Tumbler test					
Stability	0.3	42.7	53.8	40.7	52.9
Hardness	61.4	61.0	65.0	60.5	60.7
Shatter test					
+2"	—	65.0	70.4	68.8	78.0
+1 1/2"	—	87.6	87.4	88.8	93.0
Size					
+3"	2.4	13.1	13.4	18.5	28.5
3" x 1"	79.1	80.5	81.8	75.4	65.4
-1"	18.5	6.4	4.8	6.1	6.1
Apparent gravity	0.685	0.705	0.755	0.715	0.76
Coke Yield (at 3% moisture) (% of coal as received)					
Total coke	56.3	59.2	64.1	59.4	64.9
+1"	46.1	55.4	61.1	55.8	60.9
-1"	10.2	3.8	3.0	3.6	4.0
Expansion Pressure					
Lb per sq in	0.95	--	0.90	0.90	0.85
Bulk density (lb per cu ft)	47.5	50.3	50.3	49.8	50.0
Operating Data					
Pulverization (-1/8")	89.4	83.0	84.4	82.1	82.9
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
Crushing Test (3" x 1" coke)					
+3/4"	1.3				
3/4" x 1/2"	41.3				
1/2" x 1/4"	34.4				
1/4" x 1/8"	9.7				
-1/8"	13.3				
Coke Analysis (dry)					
Volatile matter	1.8	1.1	1.2	1.5	1.3
Fixed carbon	90.9	92.3	93.2	91.2	91.6
Ash	7.3	6.6	5.6	7.3	7.1
Sulfur	1.95	1.60	1.19	1.54	1.24

Coals from West-Central Illinois

Illinois No. 2 Coal outcrops in west-central Illinois where it is strip mined in large tonnages. Modern washing equipment reduces ash content to 5 to 6 percent. Sulfur content in the washed coal is high, however, and remains high in the coke produced from it.

Illinois No. 2-B Coal, which was sampled for this test, proved to be very plastic, as shown in table 1. When carbonized, this coal produced considerable spongy coke, even when blended with up to 20 percent of medium- or low-volatile coals. This property probably would prevent its successful use as chemical coke, at least without the addition of a large percentage of blending coals.

Illinois No. 2-C Coal proved to be less fluid than No. 2-B, and when coked by itself, produced only a small amount of spongy coke. Jaw-crushing tests indicated that the minus 1/8-inch screenings would be low if this coke were crushed to a 3/4-inch maximum size. Blending either of these coals with medium- or low-volatile coals produced strong cokes with low ash but high sulfur content.

TABLE 4 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-A COAL BLENDS (NORTHERN ILLINOIS)

	100% Ill. No. 6-A (7/8" x 1/4")	80% Ill. No. 6-A 20% Jewell 1-A	60% Ill. No. 6-A 40% Jewell-A	80% Ill. No. 6-A 20% Beckley	60% Ill. No. 6-A 40% Beckley
Date of test:	3-5-64	3-10-64	3-17-64	3-24-64	3-26-64
			Coke Physical Properties		
Tumbler test					
Stability	8.8	48.3	58.0	44.1	45.8
Hardness	65.0	62.4	65.0	55.1	52.4
Shatter test					
+2"	27.8	70.0	72.0	68.8	75.4
+1 1/2"	57.0	89.2	91.2	88.0	88.0
Size					
+3"	7.1	11.5	20.7	24.2	26.6
3" x 1"	80.3	80.9	73.3	63.3	54.0
-1"	12.6	7.6	6.0	12.5	19.4
Apparent gravity	0.645	0.695	0.74	0.73	0.785
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	54.7	60.0	64.4	59.7	64.9
+1"	47.8	55.4	60.5	52.3	52.3
-1"	6.9	4.6	3.9	7.4	12.6
			Expansion Pressure		
Lb per sq in	0.6	0.55	0.75	0.6	0.65
Bulk density (lb per cu ft)	48.5	50.7	50.2	50.8	50.9
			Operating Data		
Pulverization (-1/8")	91.2	83.8	87.0	82.7	82.4
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	1.6	1.4	1.0	1.1	1.2
Fixed carbon	87.6	89.4	91.4	89.3	90.0
Ash	10.8	9.2	7.6	9.6	8.8
Sulfur	2.43	1.90	1.56	1.97	1.52

Also tested from this area was the Illinois No. 6-B underground mine that produces a high ash and a high sulfur product used extensively for boiler fuel. This coal is probably not suitable for coke because of its chemical analysis. As with the other coals from this area, strong cokes were produced from the No. 6-B Coal when properly blended, but the sulfur content remains high.

All of these west-central Illinois coals are classified as high-volatile bituminous C. They are high in moisture and volatile matter and, consequently, give a low yield of coke. Results of these coking tests, shown in tables 5, 6, and 7, indicate, however, that they may be coked either by themselves or in blends.

TABLE 5 - RESULTS OF COKING TESTS ON ILLINOIS NO. 2-B COAL BLENDS (WEST-CENTRAL ILLINOIS)

	100% Ill. No. 2-B (1 1/2" crushed screenings)	60% Ill. No. 2-B 20% Jewell-B 20% Poca. A	60% Ill. No. 2-B 40% Jewell-B	60% Ill. No. 2-B 40% Poca. No. 4-A
Date of test:	5-17-62	6-1-62	5-22-62	5-24-62
		Coke Physical Properties		
Tumbler test				
Stability	6.8	53.7	52.4	53.3
Hardness	52.5	61.8	62.6	60.1
Shatter test				
+2"	—	73.4	—	79.5
+1 1/2"	—	92.2	—	89.0
Size				
+3"	15.6	20.2	13.9	27.3
3" x 1"	60.4	73.5	79.4	67.2
-1"	24.0	6.3	6.7	5.5
Apparent gravity	0.885	0.80	0.80	0.785
		Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	54.8	65.8	64.8	65.5
+1"	41.6	61.6	60.4	61.8
-1"	13.2	4.2	4.4	3.7
		Expansion Pressure		
Lb per sq in	0.65	0.7	0.8	0.8
Bulk density (lb per cu ft)	50.2	52.3	50.6	50.8
		Operating Data		
Pulverization (-1/8")	77.0	81.2	80.2	80.6
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30
		Coke Analysis (dry)		
Volatile matter	1.4	1.0	1.0	0.7
Fixed carbon	88.8	91.7	92.3	91.2
Ash	9.8	7.3	6.7	8.1
Sulfur	2.39	1.54	1.54	1.59

Use of the cokes would be seriously limited, however, by their sulfur content, and, in the case of No. 2-B, by formation of a spongy coke structure.

Coals from East-Central Illinois

Only a few coal mines are operated in east-central Illinois, and no coals from this section are presently used for production of coke. This is also true of coals from the northern and west-central sections previously discussed.

Two coals from east-central Illinois have been coked in this series of tests. Both coals develop unusually high Gieseler fluidity. Both are classified as high-

TABLE 6 - RESULTS OF COKING TESTS ON ILLINOIS NO. 2-C COAL BLENDS (WEST-CENTRAL ILLINOIS)

	100% Ill. No. 2-C (3/4" x 1/4")	80% Ill. No. 2-C 20% Jewell-B	60% Ill. No. 2-C 40% Jewell-B	80% Ill. No. 2-C 20% Poca. No. 3-B	60% Ill. No. 2-C 40% Poca. No. 3-B
Date of test:	1-17-63	1-22-63	1-30-63	3-7-63	3-12-63
Coke Physical Properties					
Tumbler test					
Stability	11.7	46.6	59.0	47.5	54.8
Hardness	60.0	61.1	67.0	59.3	64.8
Shatter test					
+2"	42.4	67.3	69.9	68.0	75.2
+1 1/2"	71.2	88.5	91.2	90.0	90.8
Size					
+3"	7.4	12.1	14.9	21.9	27.4
3" x 1"	79.4	81.7	79.7	71.8	64.6
-1"	13.2	6.2	5.4	6.3	8.0
Apparent gravity	0.745	0.745	0.79	0.76	0.81
Coke Yield (at 3% moisture) (% of coal as received)					
Total coke	56.3	61.0	67.3	62.5	67.7
+1"	48.8	57.2	63.7	58.5	62.3
-1"	7.5	3.8	3.6	3.9	5.4
Expansion Pressure					
Lb per sq in	0.7	0.45	0.6	0.65	0.75
Bulk density (lb per cu ft)	49.8	51.0	51.5	51.0	51.6
Operating Data					
Pulverization (-1/8")	82.4	81.6	86.0	83.2	85.4
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
Crushing Test (3" x 1" coke)					
3/4" x 1/2"	42.9				
1/2" x 1/4"	38.4				
1/4" x 1/8"	6.5				
-1/8"	12.2				
Coke Analysis (dry)					
Volatile matter	1.1	1.0	0.9	1.1	0.7
Fixed carbon	89.1	90.7	92.3	90.4	91.5
Ash	9.8	8.3	6.8	8.5	7.8
Sulfur	3.07	2.42	1.81	2.28	1.73

volatile bituminous C, and both contain high percentages of moisture, volatile matter, and sulfur. These coals may be blended with medium- or high-volatile coals to produce strong cokes that have relatively high sulfur content.

The Illinois No. 6-C Coal from this area produces spongy coke when carbonized alone. For this reason, it would probably have to be blended with another coal to make a suitable chemical coke.

The other coal tested, Illinois No. 7-A, when carbonized by itself, produces a product more suitable for chemical coke. Low stability and relatively high hardness indices indicate good crushing characteristics, and this is shown also

TABLE 7 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-B COAL BLENDS (WEST-CENTRAL ILLINOIS)

	100% Ill. No. 6-B (3" x 1 1/2")	80% Ill. No. 6-B 20% Jewell-B	60% Ill. No. 6-B 40% Jewell-B	80% Ill. No. 6-B 20% Beckley
Date of test:	1-30-64	2-4-64	2-6-64	2-11-64
		Coke Physical Properties		
Tumbler test				
Stability	12.8	51.3	58.7	49.6
Hardness	62.6	61.5	65.4	57.9
Shatter test				
+2"	43.4	77.6	79.8	78.0
+1 1/2"	71.2	92.0	92.2	93.0
Size				
+3"	14.3	25.4	24.7	34.9
3" x 1"	75.2	68.7	70.0	57.4
-1"	10.5	5.9	5.3	7.7
Apparent gravity	0.695	0.735	0.78	0.765
		Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	57.0	61.8	65.9	62.8
+1"	51.2	58.2	62.4	58.0
-1"	6.0	3.6	3.5	4.8
		Expansion Pressure		
Lb per sq in	0.95	0.45	0.75	0.65
Bulk density (lb per cu ft)	49.8	50.4	50.5	50.5
		Operating Data		
Pulverization (-1/8")	89.4	85.0	84.5	84.9
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30
		Coke Analysis (dry)		
Volatile matter	1.8	1.3	1.0	1.1
Fixed carbon	82.2	85.6	89.0	85.2
Ash	16.0	13.1	10.0	13.7
Sulfur	3.27	2.44	1.86	2.47

by the crushing test. The minus 1/8-inch screenings produced in the crusher are increased by blending this Illinois coal with coals of higher rank.

Results of coking tests on these east-central Illinois coals are shown in tables 8 and 9.

Coals from Southwestern Illinois

Three coals from southwestern Illinois were sampled and coked. All were from the Illinois No. 6 Coal seam, and all differed in analyses and coking properties.

Low-sulfur coal was mined for many years in south-central Madison County. Poor mining conditions and lack of cleaning facilities, however, caused this small mine to cease operations following World War II. Before this, it was found that although this coal had very poor coking properties by itself, it could be used as a minor constituent of certain coal blends without detriment to the physical properties of the resulting cokes.

TABLE 8 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-C COAL BLENDS (EAST-CENTRAL ILLINOIS)

	100% Ill. No. 6-C (1 1/2" x 1/4")	80% Ill. No. 6-C 20% Jewell-B	60% Ill. No. 6-C 40% Jewell-B	80% Ill. No. 6-C 20% Poca. No. 4-A	60% Ill. No. 6-C 40% Poca. No. 4-A
Date of test:	2-13-62	1-30-62	2-1-62	2-15-62	2-27-62
			Coke Physical Properties		
Tumbler test					
Stability	13.5	43.9	55.5	46.1	54.4
Hardness	60.0	57.3	64.5	56.1	62.2
Shatter test					
+2"	46.8	72.7	73.6	79.9	80.0
+1 1/2"	69.8	88.9	90.7	91.6	92.6
Size					
+3"	14.0	22.8	20.5	28.2	29.8
3" x 1"	71.8	70.1	73.5	64.6	64.1
-1"	14.2	7.1	6.0	7.2	6.1
Apparent gravity	0.785	0.79	0.815	0.74	0.80
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	56.7	62.1	66.6	62.4	67.6
+1"	48.7	57.7	62.6	57.9	63.5
-1"	8.0	4.4	4.0	4.5	4.1
			Expansion Pressure		
Lb per sq in	0.5	0.45	0.65	0.6	0.85
Bulk density (lb per cu ft)	50.3	50.0	51.2	50.2	50.3
			Operating Data		
Pulverization (-1/8")	82.6	78.4	77.8	78.3	82.7
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	0.9	1.0	0.8	0.9	0.9
Fixed carbon	88.8	89.9	91.6	89.7	90.3
Ash	10.3	9.1	7.6	9.4	8.8
Sulfur	1.63	1.42	1.12	1.35	1.16

Coal from this location for this series of tests, called here Illinois No. 6-D, was obtained from the bottom of an old shaft that was sunk many years ago but never developed. An entry was driven back several feet into the coal bed to get beyond any weathered coal. Samples were taken and were washed to 6.5 percent ash content at the Geological Survey's laboratory. They were coked in a variety of blends, some of which are reported in table 10. This No. 6-D Coal develops practically no Gieseler fluidity and has a sulfur content of only about 0.9 percent.

A coking test on 100 percent of this No. 6-D Coal yielded coke, over 50 percent of which was smaller than one inch. Attempts to blend more than 20 per-

TABLE 9 - RESULTS OF COKING TESTS ON ILLINOIS NO. 7-A COAL BLENDS (EAST-CENTRAL ILLINOIS)

	100% Ill. No. 7-A	80% Ill. No. 7-A 20% Jewell-B	60% Ill. No. 7-A 40% Jewell-B	80% Ill. No. 7-A 20% Poca. No. 4-A	60% Ill. No. 7-A 40% Poca. No. 4-A
Date of test:	4-16-63	5-21-63	5-23-63	4-23-63	4-25-63
Coke Physical Properties					
Tumbler test					
Stability	15.1	43.7	53.5	49.3	55.9
Hardness	56.6	56.2	65.9	58.8	63.5
Shatter test					
+2"	60.0	72.0	69.8	81.4	80.0
+1 1/2"	72.8	89.6	90.0	93.0	93.0
Size					
+3"	22.4	24.9	19.7	38.1	36.5
3" x 1"	65.5	68.6	75.0	56.0	58.5
-1"	12.1	6.5	5.3	5.9	5.0
Apparent gravity	0.775	0.765	0.825	0.745	0.79
Coke Yield (at 3% moisture) (% of coal as received)					
Total coke	56.6	60.7	65.7	63.0	68.3
+1"	49.7	56.7	62.2	59.4	64.9
-1"	6.9	4.0	3.5	3.6	3.4
Expansion Pressure					
Lb per sq in	0.8	0.6	0.8	0.55	0.85
Bulk density (lb per cu ft)	51.8	51.3	51.8	51.8	51.8
Operating Data					
Pulverization (-1/8")	83.6	84.6	86.1	84.6	86.1
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
Crushing Test (3" x 1" coke)					
+3/4"	0.4	2.0	2.0	1.2	1.6
3/4" x 1/2"	38.2	32.5	31.9	31.7	29.7
1/2" x 1/4"	33.6	28.5	32.0	30.1	31.2
1/4" x 1/8"	11.3	11.5	11.4	13.1	12.5
-1/8"	16.5	25.2	22.7	23.9	25.5
Coke Analysis (dry)					
Volatile matter	1.5	1.1	0.8	1.2	0.8
Fixed carbon	84.6	87.3	89.8	86.7	88.4
Ash	13.9	11.6	9.4	12.1	10.8
Sulfur	2.44	2.21	1.54	1.85	1.48

cent of the No. 6-D Coal with other Illinois coals and low-volatile Pocahontas all resulted in weak cokes and excess of coke fines. However, when Pocahontas was replaced by a more fluid, medium-volatile coal, satisfactory coke was made when 30 to 60 percent of the No. 6-D Coal was used. Results of these tests are shown in table 10.

A second coal, Illinois No. 6-E, mined in southwestern Illinois, not far from the low-sulfur area, was also unusually low in fluidity. This coal, as received, had much higher ash and sulfur contents than the No. 6-D Coal, and when carbonized by itself, produced a normally strong chemical coke. Washing this coal at 1.33 specific gravity to under 7.0 percent ash and 1.44 percent sulfur, and coking as before, improved the coke analysis but had a detrimental effect on coke physical properties. Because of the low fluidity of this No. 6-E Coal, no attempt was made to coke it in blends with low-volatile Pocahontas coal. However, when blend-

TABLE 10 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-D COAL BLENDS (SOUTHWESTERN ILLINOIS)

	100% Ill. No. 6-D (Run of mine, 1.335 sp. gr.)	60% Ill. No. 6-D 40% Jewell-B	45% Ill. No. 6-D 25% Ill. No. 5-A 30% Jewell-B	30% Ill. No. 6-D 15% Ill. No. 6-G 25% Ill. No. 5-A 30% Jewell-B	20% Ill. No. 6-D 30% Ill. No. 6-G 25% Ill. No. 5-A 25% Poca. No. 4-A
Date of test:	1-16-59	3-19-59	2-6-59	4-15-59	1-22-59
		Coke Physical Properties			
Tumbler test					
Stability	17.3	55.6	57.5	58.7	56.3
Hardness	46.8	62.0	65.5	67.0	64.6
Shatter test					
+2"	51.6	77.7	77.4	78.7	77.1
+1"	73.2	92.1	90.9	92.5	92.2
Size					
+3"	4.0	19.6	17.2	15.7	25.1
3" x 1"	45.1	71.1	75.3	78.5	67.2
-1"	50.9	9.3	7.5	5.8	7.7
Apparent gravity	0.65	0.795	0.78	0.79	0.80
		Coke Yield (at 3% moisture) (% of coal as received)			
Total coke	57.2	68.3	66.6	68.3	67.7
+1"	28.1	62.0	61.6	64.4	62.5
-1"	29.1	6.3	5.0	3.9	5.2
		Expansion Pressure			
Lb per sq in	1.0	1.2	1.25	1.15	1.05
Bulk density (lb per cu ft)	49.8	52.5	53.2	50.2	52.0
		Operating Data			
Pulverization (-1/8")	82.2	87.6	83.6	84.7	84.3
Coking time (hr:min) (17" oven)	18:00	16:30	16:30	16:30	16:30
		Coke Analysis (dry)			
Volatile matter	1.3	1.8	1.4	1.4	1.3
Fixed carbon	89.1	89.1	90.1	89.0	89.1
Ash	9.6	9.1	8.5	9.6	9.6
Sulfur	0.74	0.68	0.86	0.70	0.87

ed with medium-volatile coal, strong cokes were produced. Coking results are shown in table 11.

A third coal tested from this area in Illinois is strip mined and designated here as Illinois No. 6-F. It is quite typical of coals used extensively from the Belleville area for boiler fuel. This coal has high ash and sulfur contents and medium high fluidity. When coked alone, the resulting product was probably of chemical coke quality, except for high ash and sulfur contents. Blends with medium- and low-volatile coals produced strong cokes, but their chemical analyses would prevent their metallurgical use. Table 12 shows coking results.

TABLE 11 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-E COAL BLENDS (SOUTHWESTERN ILLINOIS)

	100% Ill. No. 6-E (crushed screenings)	80% Ill. No. 6-E 20% Jewell-B	60% Ill. No. 6-E 40% Jewell-B	40% Ill. No. 6-E 60% Jewell-B	100% Ill. No. 6-E (Washed at 1.33 sp. gr.)
Date of test:	10-26-62	11-8-62	11-6-62	10-30-62	11-19-62
		Coke Physical Properties			
Tumbler test					
Stability	21.9	54.9	58.5	61.4	22.2
Hardness	62.0	64.5	67.6	70.0	57.7
Shatter test					
+2"	51.0	73.4	74.7	72.7	—
+1 1/2"	75.6	90.6	90.0	91.7	—
Size					
+3"	7.7	23.8	19.9	20.9	6.4
3" x 1"	75.9	68.2	72.4	74.0	67.2
-1"	16.4	8.0	7.7	5.1	26.4
Apparent gravity	0.69	0.75	0.795	0.845	0.67
		Coke Yield (at 3% moisture) (% of coal as received)			
Total coke	59.6	62.3	67.1	70.6	57.6
+1"	49.8	57.3	60.5	67.0	42.4
-1"	9.8	5.0	5.0	3.6	15.2
		Expansion Pressure			
Lb per sq in	0.55	0.7	0.9	1.3	0.6
Bulk density (lb per cu ft)	50.5	51.9	51.6	51.7	50.6
		Operating Data			
Pulverization (-1/8")	79.2	79.1	80.7	84.8	78.9
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
		Crushing Test (3" x 1" coke)			
+3/4"		—			—
3/4" x 1/2"		35.8			31.7
1/2" x 1/4"		30.9			25.8
1/4" x 1/8"		15.2			15.4
-1/8"		18.1			27.1
		Coke Analysis (dry)			
Volatile matter	1.2	1.3	1.0	0.7	1.5
fixed carbon	83.2	85.9	89.1	91.5	88.0
Ash	15.6	12.8	9.9	7.8	10.5
Sulfur	1.61	1.29	0.99	0.88	1.18

Coals from Southern Illinois

All of the Illinois coals commercially used to date for metallurgical and chemical coke are of high-volatile bituminous B rank and are mined in southern Illinois from the No. 5 and No. 6 seams. No. 5 Coal is more strongly coking than No. 6; however, it is higher in sulfur content than the No. 6 Coal now being coked. Presently, approximately 1,600,000 tons of Illinois No. 6 Coal and 250,000 tons of Illinois No. 5 Coal are coked per year, all of which are mined in Jefferson, Franklin, Williamson, and Saline Counties.

Three mines in the No. 5 seam have been tested, and the coking results are shown in tables 13 to 16. The first of these, Illinois No. 5-A Coal, is used commercially for coke. It may be coked alone or in blends with medium- or low-volatile coals. Commercially, No. 5-A Coal in the 3- by 0-inch size is used as 20 percent of a blend containing Illinois No. 6 and low-volatile coals. Its strong

TABLE 12 – RESULTS OF COKING TESTS ON ILLINOIS NO. 6-F COAL BLENDS (SOUTHWESTERN ILLINOIS)

	100% Ill. No. 6-F (1" x 1/4")	80% Ill. No. 6-F 20% Jewell-B	60% Ill. No. 6-F 40% Jewell-B	80% Ill. No. 6-F 20% Beckley	60% Ill. No. 6-F 40% Beckley
Date of test:	12-19-63	12-23-63	1-2-64	1-7-64	1-9-64
			Coke Physical Properties		
Tumbler test					
Stability	17.0	48.0	56.6	49.9	56.7
Hardness	55.4	60.1	64.7	58.5	62.7
Shatter test					
+2"	59.0	82.0	79.0	82.0	81.0
+1 1/2"	74.0	92.8	93.0	92.0	95.0
Size					
+3"	28.6	34.3	22.7	39.7	43.2
3" x 1"	61.8	60.4	71.8	54.3	50.8
–1"	9.6	5.3	5.5	6.0	6.0
Apparent gravity	0.76	0.775	0.805	0.78	0.805
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	60.2	64.5	68.4	65.5	69.5
+1"	54.4	61.1	64.7	61.5	65.3
–1"	5.8	3.4	3.7	4.0	4.2
			Expansion Pressure		
Lb per sq in	0.60	0.60	0.65	0.75	0.75
Bulk density (lb per cu ft)	50.6	51.4	50.8	51.2	50.1
			Operating Data		
Pulverization (–1/8")	89.7	83.5	84.4	82.7	83.3
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	1.5	1.3	1.2	1.3	1.1
Fixed carbon	82.5	86.0	88.6	85.1	87.1
Ash	16.0	12.7	10.2	13.6	11.8
Sulfur	2.60	2.07	1.64	2.05	1.70

coking properties and relatively high Gieseler fluidity add to the quality of the coke produced, and its sulfur content of 1.4 percent or less is not objectionable in the small percentage used.

The 1/4- by 0-inch size of this No. 5-A Coal was also tested and was coked by itself and blended with medium-volatile Jewell seam coal. Coking results (table 14) are similar to those in which the 3- by 0-inch size coal was used. Crushing tests again illustrate the relationship between tumbler stability and the amount of fines produced in the crusher.

In addition to the Illinois No. 5-A Coal, two others from the No. 5 seam, called here Illinois No. 5-B and Illinois No. 5-C, were tested in this study. Both of these coals were coked alone and in the usual blends with medium- and low-volatile coals. Illinois No. 5-B Coal is similar to No. 5-A in analysis and coking properties, except for higher sulfur content. Illinois No. 5-C Coal is more nearly like an eastern high-volatile coal, with low moisture and a very high Gieseler fluidity. Although this coal was high in ash and sulfur contents when mined, it

TABLE 13 - RESULTS OF COKING TESTS ON ILLINOIS NO. 5-A COAL (3" x 0") BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 5-A (3" x 0")	80% Ill. No. 5-A 20% Sewell	60% Ill. No. 5-A 40% Sewell	40% Ill. No. 5-A 60% Sewell	20% Ill. No. 5-A 80% Sewell
Date of test:	1-9-62	1-11-62	1-16-62	1-18-62	1-23-62
			Coke Physical Properties		
Tumbler test					
Stability	23.5	53.7	59.6	63.0	64.4
Hardness	66.5	66.1	67.9	69.3	69.3
Shatter test					
+2"	50.4	67.7	72.4	77.1	84.1
+1 1/2"	75.2	89.2	92.9	93.5	95.2
Size					
+3"	6.7	19.2	20.4	16.8	27.6
3" x 1"	83.8	74.6	74.4	78.3	67.6
-1"	9.5	6.2	5.2	4.9	4.8
Apparent gravity	0.765	0.795	0.81	0.86	0.845
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	65.7	67.6	70.3	72.8	75.3
+1"	59.5	63.5	66.6	69.2	71.7
-1"	6.2	4.1	3.7	3.6	3.6
			Expansion Pressure		
Lb per sq in	0.6	0.7	0.9	0.95	1.9
Bulk density (lb per cu ft)	50.2	50.3	50.2	50.2	50.5
			Operating Data		
Pulverization (-1/8")	73.2	77.0	79.4	80.1	81.6
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	1.0	0.7	0.8	0.7	0.5
Fixed carbon	89.0	90.7	92.0	92.7	94.3
Ash	10.0	8.6	7.2	6.6	5.2
Sulfur	1.15	0.99	0.81	0.73	0.62

was washed to less than 7 percent ash. Sulfur content remained high, however, at 2.4 percent. Both of these coals coked well by themselves, and both produced strong cokes with good physical properties in blends with lower volatile coals.

Illinois No. 6 coals from the southern Illinois area, which are used commercially in the production of metallurgical and chemical cokes, are designated

TABLE 14 - RESULTS OF COKING TESTS ON ILLINOIS NO. 5-A COAL (1/4" x 0") BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 5-A (1/4" x 0")	80% Ill. No. 5-A 20% Jewell-A	65% Ill. No. 5-A 35% Jewell-A	50% Ill. No. 5-A 50% Jewell-A
Date of test:	11-29-62	12-11-62	12-6-62	11-21-62
		Coke Physical Properties		
Tumbler test				
Stability	32.6	56.0	57.1	58.8
Hardness	64.8	65.5	66.1	65.7
Shatter test				
+2"	—			
+1"	—			
Size				
+3"	12.0	18.0	19.5	22.8
3" x 1"	81.7	77.1	75.8	72.9
-1"	6.3	4.9	4.7	4.3
Apparent gravity	0.715	0.775	0.795	0.835
		Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	63.6	66.8	68.8	70.6
+1"	59.5	63.5	65.5	67.7
-1"	4.1	3.3	3.3	2.9
		Expansion Pressure		
Lb per sq in	0.6	0.7	0.6	0.8
Bulk density (lb per cu ft)	47.5	48.9	48.9	47.7
		Operating Data		
Pulverization (-1/8")	83.6	86.5	84.7	85.5
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30
		Crushing Test (3" x 1" coke)		
+1/2"	49.6	38.3	38.0	41.1
1/2" x 1/4"	26.8	32.5	28.9	27.6
1/4" x 1/8"	9.4	9.1	9.1	10.2
-1/8"	14.2	20.1	24.0	21.1
		Coke Analysis (dry)		
Volatile matter	1.1	0.8	0.8	0.6
Fixed carbon	89.3	90.5	91.6	92.4
Ash	9.6	8.7	7.6	7.0
Sulfur	1.32	1.11	1.03	1.01

here as Illinois No. 6-G, Illinois No. 6-H, and Illinois No. 6-J. They range in sulfur content from 0.9 to 1.5 percent. Blends including from 25 to 60 percent of these coals have been coked since 1944 to produce blast furnace cokes. They have been blended with high-, medium-, and low-volatile coals throughout this period, and the cokes produced have been, and continue to be, satisfactory for blast furnace use. One of these coals also has been used in blends to produce chemical coke for calcium carbide production in electric arc furnaces. Pilot oven coking results of blends of Illinois No. 6-G and Illinois No. 6-H with medium- and low-volatile coals are shown in tables 17 and 18. Results of blending Illinois No. 6-J with Splashdam and Powellton medium- and high-volatile coals, in order to produce chemical cokes with relatively low tumbler stabilities, are shown in table 19.

One other Illinois No. 6 mine in the southern Illinois area was sampled, and the coal was tested in the usual manner in the pilot coke oven. This coal, designated as Illinois No. 6-K, was shown to have satisfactory coking properties,

TABLE 15 - RESULTS OF COKING TESTS ON ILLINOIS NO. 5-B COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 5-B (1 1/4" x 1/4")	80% Ill. No. 5-B 20% Jewell-B	60% Ill. No. 5-B 40% Jewell-B	80% Ill. No. 5-B 20% Beckley	60% Ill. No. 5-B 40% Beckley
Date of test:	2-13-64	2-18-64	2-20-64	2-25-64	2-27-64
			Coke Physical Properties		
Tumbler test					
Stability	34.4	56.0	62.4	58.0	59.2
Hardness	65.2	67.3	70.2	66.0	66.1
Shatter test					
+2"	56.8	68.0	72.0	77.0	77.0
+1 1/2"	83.0	88.0	92.0	91.6	94.0
Size					
+3"	14.1	21.4	18.4	25.4	30.0
3" x 1"	79.1	73.6	77.2	68.9	64.2
-1"	6.8	5.0	4.4	5.7	5.8
Apparent gravity	0.745	0.80	0.85	0.80	0.825
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	65.1	68.4	71.1	69.2	72.0
+1"	60.8	65.0	68.0	65.2	67.8
-1"	4.3	3.4	3.1	4.0	4.2
			Expansion Pressure		
Lb per sq in	0.45	0.65	0.95	—	0.75
Bulk density (lb per cu ft)	48.8	51.2	50.6	50.5	50.1
			Operating Data		
Pulverization (-1/8")	84.6	81.3	83.6	82.3	82.6
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	1.1	1.4	0.8	1.2	0.9
Fixed carbon	85.9	87.9	90.3	87.2	88.7
Ash	13.0	10.7	8.9	11.6	10.4
Sulfur	2.03	1.67	1.34	1.63	1.39

both when coked by itself and in blends with medium- and low-volatile coals. It cannot be utilized for metallurgical coke under present conditions, however, because of its sulfur content. Results of the pilot oven tests are shown in table 20.

The remaining coals tested in this series of coking studies all were taken from seams lower in geological sequence than those mentioned previously. These coals all outcrop and are strip mined in southern Illinois. In contrast to the other Illinois coals sampled, they may be classified as high-volatile bituminous A rank. They all have low moisture and are very plastic, having Gieseler fluidities in the range with the best eastern coking coals. They all may be washed to a low ash content, but, with one probable exception, they are all high in sulfur content.

First to be tested were the Davis and Dekoven seams that outcrop and are mined in Williamson and Saline Counties. These seams are in close proximity and are mined together. Two mines were sampled. Coal from one, designated as Illinois D&D(A), was coked by itself and was shown to have normally strong coking

TABLE 16 - RESULTS OF COKING TESTS ON ILLINOIS NO. 5-C COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 5-C (1 1/4" x 1/8") (Float at 1.37 sp. gr.)	80% Ill. No. 5-C 20% Jewell-B	60% Ill. No. 5-C 40% Jewell-B	80% Ill. No. 5-C 20% Poca. No. 3-B	60% Ill. No. 5-C 40% Poca. No. 3-B
Date of test:	12-3-63	12-5-63	12-10-63	12-12-63	12-17-63
		Coke Physical Properties			
Tumbler test					
Stability	31.3	54.4	60.0	55.5	56.4
Hardness	61.5	64.9	69.3	64.9	63.6
Shatter test					
+2"	56.2	68.6	76.0	74.0	75.6
+1 1/2"	81.6	90.6	90.8	90.4	93.4
Size					
+3"	16.7	19.6	16.2	26.2	28.4
3" x 1"	76.7	74.9	79.4	69.4	67.3
-1"	6.6	5.5	4.4	4.4	4.3
Apparent gravity	0.77	0.815	0.865	0.795	0.81
		Coke Yield (at 3% moisture) (% of coal as received)			
Total coke	66.0	69.2	72.4	69.5	72.6
+1"	61.6	65.4	69.1	66.4	69.5
-1"	4.4	3.8	3.2	3.1	3.1
		Expansion Pressure			
Lb per sq in	0.55	0.9	0.95	1.35	2.0
Bulk density (lb per cu ft)	48.9	51.2	51.2	51.7	51.9
		Operating Data			
Pulverization (-1/8")	88.9	84.8	85.5	84.9	84.5
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
		Coke Analysis (dry)			
Volatile matter	1.5	1.1	0.8	0.8	0.9
Fixed carbon	88.3	90.3	91.8	90.1	90.7
Ash	10.2	8.6	7.4	9.1	8.4
Sulfur	1.86	1.43	1.18	1.40	1.19

properties. Coal from the other, Illinois D&D(B), was coked as 10 to 20 percent of coal blends that included Illinois No. 6 and Pocahontas coals. In each case, strong cokes with metallurgical coke properties were produced. This Illinois D&D (B) coal was later washed at 1.40 specific gravity in the Geological Survey's pilot washer. Ash content was reduced from 7.8 to 6.6 percent and sulfur from 2.73 to 2.44 percent. Use of the washed coal in place of the raw coal as 15 percent of a blend with Illinois No. 6 and Pocahontas coals had no apparent effect on coke properties, except for a reduction in ash and sulfur contents. Results of these coking tests are shown in table 21.

Another coal sampled in this southern Illinois area was from the Willis seam, about which very little is known. This coal, called Illinois Willis, had a low moisture content of 1.9 percent, the lowest of any coal sampled. The coal was washed at 1.35 specific gravity to 6.5 percent ash and 2.3 percent sulfur. Free-swelling index and Gieseler fluidity were high compared to other Illinois coals. Coking tests

TABLE 17 – RESULTS OF COKING TESTS ON ILLINOIS NO. 6–G COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 6–G (3" x 0")	80% Ill. No 6–G 20% Jewell–B	60% Ill. No. 6–G 40% Jewell–B	40% Ill. No. 6–G 60% Jewell–B	75% Ill. No. 6–G (1.30 sp. gr.) 25% Poca. No. 4–A
Date of test:	12–14–61	12–18–61	12–20–61	12–22–61	10–1–57
			Coke Physical Properties		
Tumbler test					
Stability	21.9	56.1	61.6	63.1	53.3
Hardness	65.4	67.2	69.9	70.1	65.4
Shatter test					
+ 2"	44.0	67.9	72.2	76.0	75.0
+ 1 1/2"	69.0	90.0	92.1	93.2	91.3
Size					
+3"	5.4	17.6	15.1	21.7	23.4
3" x 1"	84.0	76.2	79.6	73.7	69.9
–1"	10.6	6.2	5.3	4.6	6.7
Apparent gravity	0.735	0.75	0.805	0.82	0.775
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	62.9	66.7	69.6	72.5	68.4
+1"	56.3	62.6	65.9	69.2	63.8
–1"	6.6	4.1	3.7	3.3	4.6
			Expansion Pressure		
Lb per sq in	0.65	0.8	0.85	0.95	1.0
Bulk density (lb per cu ft)	50.8	50.2	50.4	50.7	51.6
			Operating Data		
Pulverization (–1/8")	76.1	76.6	78.8	81.0	85.6
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	1.3	1.0	0.9	1.0	1.7
Fixed carbon	88.6	89.8	91.5	92.3	91.8
Ash	10.1	9.2	7.6	6.7	6.5
Sulfur	1.00	0.89	0.82	0.66	0.80

showed this coal to be very strongly coking, both by itself and in blends. Coke sulfur remained high, however, with from 60 to 80 percent Willis in the blend. Coking results are shown in table 22.

The final coal tested in this series, called here Illinois Reynoldsburg, was from a seam that had been mined near the outcrop in small "dog-holes" many years before and about which very little is known. Pieces picked up near one of these workings had indicated that this is a high rank coal that is probably low in both ash and sulfur contents. To get samples for coking tests and analyses, an opening was dug into the seam far enough back from the outcrop to avoid oxidized coal. Several truck loads of coal were removed, and channel samples were taken at four places in this opening. In addition, sufficient coal was mined and brought to our laboratories for coking tests. Results of these tests are shown in table 23. This coal by itself produced a higher than normal gravity coke that would appear to be very satisfactory for chemical use. Its blends with medium- and low-volatile coals also produced cokes of good quality, although with slightly lower tumbler indices

TABLE 18 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-H COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 6-H (3" x 0")	60% Ill. No. 6-H 40% Jewell-B	50% Ill. No. 6-H 50% Jewell-B	90% Ill. No. 6-H 10% Beckley	70% Ill. No. 6-H 30% Poca. No. 4-B
Date of test:	4-14-61	3-27-62	12-10-64	3-2-66	1-14-65
		Coke Physical Properties			
Tumbler test					
Stability	31.3	61.1	58.7	44.6	54.4
Hardness	68.9	68.8	69.8	64.9	63.9
Shatter test					
+2"	43.6	74.0	66.8	72.0	77.4
+1 1/2"	76.8	91.6	91.4	86.0	92.8
Size					
+3"	7.3	17.0	20.1	24.9	33.1
3" x 1"	83.2	77.7	75.0	67.5	59.7
-1"	9.5	5.3	4.9	7.6	7.2
Apparent gravity	0.755	0.84	0.855	0.77	0.79
		Coke Yield (at 3% moisture) (% of coal as received)			
Total coke	65.5	70.0	70.8	66.2	71.0
+1"	59.3	66.3	67.3	61.2	66.0
-1"	6.2	3.7	3.5	5.0	5.0
		Expansion Pressure			
Lb per sq in	0.75	0.90	—	0.35	0.55
Bulk density (lb per cu ft)	51.9	51.2	50.2	50.8	50.1
		Operating Data			
Pulverization (-1/8")	84.0	84.8	82.0	76.8	82.8
Coking time (hr:min) (17" oven)	15:45	16:30	16:10	—	16:10
		Coke Analysis (dry)			
Volatile matter	1.3	1.0	1.0	1.6	1.8
Fixed carbon	86.8	91.0	91.6	87.1	87.3
Ash	11.9	8.0	7.4	11.3	10.9
Sulfur	0.79	0.79	0.61	0.69	0.62

than obtained with certain other Illinois coals of lower rank. Proper blending probably could improve this strength factor.

Although the Reynoldsburg coal used for the pilot oven coking tests was not washed, it contained only 5.0 percent ash. A high Gieseler fluidity of 27,500 dial divisions per minute was obtained. The sulfur that might be expected in a raw sample of this coal is questionable. The coal used for the coking tests had 2.63 percent sulfur. Channel samples taken from nearby locations had sulfur percentages varying from 0.52 to 1.97.

A small sample of the coal used for the coking tests was floated in carbon tetrachloride (1.59 specific gravity). Although about 97 percent of the coal floated,

TABLE 19 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-J COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 6-J (1/4" x 28")	80% Ill. No. 6-J 20% Splashdam	65% Ill. No. 6-J 35% Splashdam	80% Ill. No. 6-J 20% Powellton	65% Ill. No. 6-J 35% Powellton
Date of test:	6-27-62	7-12-62	7-3-62	7-6-62	6-14-62
		Coke Physical Properties			
Tumbler test					
Stability	20.5	33.0	36.1	25.8	30.8
Hardness	65.9	56.0	55.7	61.1	61.7
Shatter test					
+2"	—	—	—	—	—
+1 1/2"	—	—	—	—	—
Size					
+3"	6.7	26.4	33.3	21.5	20.6
3" x 1"	82.8	66.0	59.8	69.3	71.9
-1"	10.5	7.6	6.9	9.2	7.5
Apparent gravity	0.735	0.76	0.815	0.76	0.78
		Coke Yield (at 3% moisture) (% of coal as received)			
Total coke	63.3	65.5	67.1	64.9	66.4
+1"	56.7	60.5	62.5	58.9	61.4
-1"	6.6	5.0	4.6	6.0	5.0
		Expansion Pressure			
Lb per sq in	0.55	0.55	0.55	0.55	0.6
Bulk density (lb per cu ft)	50.4	49.1	50.5	50.1	50.3
		Operating Data			
Pulverization (-1/8")	84.5	50.2	57.1	51.5	61.5
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
		Crushing Test (all coke)			
3/4" x 1/2"	41.5	35.1	35.1	37.7	42.8
1/2" x 1/4"	32.4	35.5	38.7	36.0	33.3
1/4" x 1/8"	9.1	12.2	8.5	10.1	10.7
-1/8"	17.0	17.2	17.7	16.2	13.2
		Coke Analysis (dry)			
Volatile matter	1.1	0.8	0.9	1.0	0.7
Fixed carbon	89.1	89.9	90.3	90.0	90.8
Ash	9.8	9.3	8.8	9.0	8.5
Sulfur	1.24	1.10	0.95	1.09	0.96

the sulfur in this float fraction was reduced to 1.01 percent, dry basis. Not enough coal was available to make tests in the pilot oven with the cleaned Reynoldsburg coal. With such a small percentage of reject, however, no major difference in coke physical properties would be expected.

CONCLUSIONS

A study of Illinois coals from the various mining areas and coal seams of the state has shown that these coals all exhibit coking properties when heated in

TABLE 20 - RESULTS OF COKING TESTS ON ILLINOIS NO. 6-K COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. No. 6-K (1" x 1/4")	80% Ill. No. 6-K 20% Jewell-B	60% Ill. No. 6-K 40% Jewell-B	80% Ill. No. 6-K 20% Poca. No. 3-B	60% Ill. No. 6-K 40% Poca. No. 3-B
Date of test:	7-2-63	7-9-63	7-11-63	7-16-63	7-18-63
			Coke Physical Properties		
Tumbler test					
Stability	16.6	51.7	58.1	53.9	58.4
Hardness	64.4	64.1	67.1	63.5	65.6
Shatter test					
+2"	46.0	71.0	76.8	74.4	79.0
+1 1/2"	71.0	88.0	92.6	90.8	92.8
Size					
+3"	14.1	18.9	20.6	22.6	28.4
3" x 1"	76.2	75.3	74.6	72.5	66.5
-1"	9.7	5.8	4.8	4.9	5.1
Apparent gravity	0.765	0.80	0.835	0.795	0.825
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	63.9	67.1	70.6	67.8	71.5
+1"	57.7	63.3	67.2	64.5	67.8
-1"	6.2	3.8	3.4	3.3	3.7
			Expansion Pressure		
Lb per sq in	0.75	0.65	0.85	1.0	1.2
Bulk density (lb per cu ft)	50.6	51.6	51.9	52.0	51.9
			Operating Data		
Pulverization (-1/8")	81.8	84.1	84.2	82.8	84.9
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Crushing Test (3" x 1" coke)		
+3/4"	0.9	1.3	1.4	0.9	1.9
3/4" x 1/2"	40.6	32.7	32.8	31.5	29.8
1/2" x 1/4"	33.6	33.4	33.1	33.2	32.9
1/4" x 1/8"	10.8	11.9	12.4	14.3	12.3
-1/8"	14.1	20.7	20.3	20.1	23.1
			Coke Analysis (dry)		
Volatile Matter	1.4	1.2	1.0	1.0	1.2
Fixed Carbon	87.1	89.1	90.5	88.6	89.5
Ash	11.5	9.7	8.5	10.4	9.3
Sulfur	2.19	1.67	1.42	1.60	1.33

the pilot coke oven. When carbonized alone, they generally produce cokes with low strength but with physical properties often suitable for chemical coke. When blended with medium- or low-volatile coals, hard, strong cokes can be produced that may be of metallurgical coke quality, provided the ash and sulfur values in the coals are sufficiently low.

The lowest sulfur coals tested were from southern Illinois; one was from southwestern Illinois. Those mined in southern Illinois, from both the No. 5 and No. 6 seams, are used in commercial production of metallurgical coke. Coal from this area also has been carbonized in rectangular beehive coke ovens to produce chemical coke.

Although most Illinois coals are either bituminous B or C in rank, some coal seams outcropping in southern Illinois are of bituminous A rank and have produced coals with coking properties similar to those of the high-volatile coking

TABLE 21 - RESULTS OF COKING TESTS ON ILLINOIS DAVIS AND DEKOVAN COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. D&D(A) (1" x 1/4")	20% Ill. D&D(B) (1" x 1/4") 55% Ill. No. 6-H 25% Poca. No. 4-A	15% Ill. D&D(B) 60% Ill. No. 6-G 25% Poca. No. 4-A	15% Ill. D&D(B) (Float 1.40 sp. gr.) 60% Ill. No. 6-G 25% Poca. No. 4-A	10% Ill. D&D(B) 65% Ill. No. 6-G 25% Poca. No. 4-A
Date of test:	4-2-59	6-20-61	10-13-59 1-8-60	10-8-59	10-6-59 1-12-60
		Coke Physical Properties			
Tumbler test					
Stability	27.3	55.6	54.8	54.9	54.0
Hardness	55.4	66.5	64.7	65.1	64.8
Shatter test					
+2"	73.4	74.4	75.6	74.7	73.0
+1 1/2"	85.7	90.4	91.0	89.9	90.6
Size					
+3"	24.8	26.7	24.4	22.0	22.4
3" x 1"	64.5	66.2	69.4	71.4	70.7
-1"	10.7	7.1	6.2	6.6	6.9
Apparent gravity	0.78	0.825	0.80	0.795	0.8
		Coke Yield (at 3% moisture) (% of coal as received)			
Total coke	66.2	69.9	69.8	70.3	70.0
+1"	59.1	64.9	65.5	65.6	65.4
-1"	7.1	5.0	4.3	4.7	4.6
		Expansion Pressure			
Lb per sq in	0.95	1.05	0.9	0.8	1.0
Bulk density (lb per cu ft)	52.5	53.3	52.9	52.4	53.0
		Operating Data			
Pulverization (-1/8")	80.1	80.3	81.4	78.4	80.0
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
		Coke Analysis (dry)			
Volatile matter	1.4	1.2	1.1	1.0	1.4
Fixed carbon	82.3	88.7	89.1	90.4	88.8
Ash	16.3	10.1	9.8	8.6	9.8
Sulfur	2.75	0.94	0.87	0.75	0.81

coals of the Appalachian area. With one possible exception, these A-rank Illinois coals are high in sulfur content, making them unsuited for use as major constituents in metallurgical coke.

TABLE 22 - RESULTS OF COKING TESTS ON ILLINOIS WILLIS COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. Willis (Washed at 1.35 sp. gr.)	80% Ill. Willis 20% Med.-vol. B	60% Ill. Willis 40% Med.-vol. B	80% Ill. Willis 20% Poca. No. 3-A	60% Ill. Willis 40% Poca. No. 3-A
Date of test:	11-24-64	1-19-65	2-9-65	12-1-64	12-3-64
			Coke Physical Properties		
Tumbler test					
Stability	48.0	59.8	62.6	55.1	58.8
Hardness	60.0	66.9	68.9	63.4	65.6
Shatter test					
+3"	69.8	72.0	79.8	78.0	79.6
+1 1/2"	88.2	91.4	93.6	93.8	93.6
Size					
+3"	24.1	22.3	17.2	26.7	29.9
3" x 1"	71.4	73.2	78.6	68.8	65.8
-1"	4.8	4.5	4.2	4.5	4.3
Apparent gravity	0.82	0.855	0.865	0.84	0.855
			Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	70.5	72.8	74.2	71.5	74.0
+1"	67.1	69.4	71.1	68.3	70.8
-1"	3.4	3.4	3.1	3.2	3.2
			Expansion Pressure		
Lb per sq in	0.95	0.65	0.7	—	—
Bulk density (lb per cu ft)	50.2	50.2	50.7	50.8	50.6
			Operating Data		
Pulverization (-1/8")	80.8	81.9	84.3	73.1	73.1
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30	16:30
			Coke Analysis (dry)		
Volatile matter	0.9	0.8	1.0	0.9	0.9
Fixed carbon	90.6	92.2	92.7	91.0	91.0
Ash	8.5	7.0	6.3	8.1	8.1
Sulfur	1.77	1.25	1.03	1.45	1.30

TABLE 23 - RESULTS OF COKING TESTS ON ILLINOIS REYNOLDSBURG COAL BLENDS (SOUTHERN ILLINOIS)

	100% Ill. Reynoldsburg (Pit sample)	70% Ill. Reynoldsburg 30% Poca. No. 3	70% Ill. Reynoldsburg 30% Poca. No. 3-B	65% Ill. Reynoldsburg 35% Poca. No. 4-B
Date of test:	7-14-65	7-23-65	7-21-65	8-10-65
		Coke Physical Properties		
Tumbler test				
Stability	7.7	46.1	50.3	51.5
Hardness	63.9	63.7	62.8	63.4
Shatter test				
+2"	——	66.0	74.0	75.6
+1 1/2"	——	86.0	90.2	91.2
Size				
+3"	8.2	14.7	25.0	26.4
3" x 1"	71.6	79.2	69.4	68.6
-1"	20.2	6.1	5.6	5.0
Apparent gravity	0.865	0.83	0.84	0.86
		Coke Yield (at 3% moisture) (% of coal as received)		
Total coke	66.8	70.5	71.1	71.7
+1"	53.3	66.2	67.1	68.0
-1"	13.5	6.3	4.0	3.7
		Expansion Pressure		
Lb per sq in	0.6	——	0.9	1.15
Bulk density (lb per cu ft)	48.7	49.5	50.9	51.0
		Operating Data		
Pulverization (-1/8")	86.8	83.7	85.0	84.3
Coking time (hr:min) (17" oven)	16:30	16:30	16:30	16:30
		Crushing Test (3" x 1" coke)		
+3/4"	1.4			
3/4" x 1/2"	36.7			
1/2" x 1/4"	36.6			
1/4" x 1/8"	11.2			
-1/8"	14.1			
		Coke Analysis (dry)		
Volatile matter	1.4	1.2	1.0	1.1
Fixed carbon	90.4	91.1	90.4	91.7
Ash	8.2	7.7	8.6	7.2
Sulfur	2.04	1.60	1.65	1.39

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