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SOME OBSERVATIONS ON THE BLENDING OF COALS FOR METALLURGICAL COKE

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Some Observations On The Blending Of Coals For Metallurgical Coke

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COKE OVENS—by product and beehive combined—consumed approximately 114 million tons of soft coal in 1951; the estimated consumption for 1952 is 121 million tons. Excluding exports to Canada and overseas, these ovens consumed 24.6 per cent of the soft coal used in the United States last year and are expected to account for one-fourth of the total U. S. consumption this year. Thus the metallurgical coke industry is the largest consumer of soft coal in the United States. As requests for more and more steel are met, an ever-increasing demand for coal for metallurgical coke must not only be met, but the coal must be obtained almost completely from the higher quality bituminous coals.

Metallurgical coke is made principally from a blend of the two highest quality soft coals available—low-volatile Pocahontas and high-volatile A bituminous. Naturally the higher the percentage of low-volatile Pocahontas used, the higher the yield of coke, and assuming identical coking-time cycles, the higher the production capacity of a coke oven.

However, the percentage of low-volatile coal which can be used in a blend is limited for two reasons. The first is the inherent property of the coal to expand when heated, creating pressure in a coke oven sufficient to shorten the useful life of the oven. This has resulted in recent years in a wide use of special pilot-size coke ovens to determine experimentally the expansion pressures of various coals and coal blends.

The second reason for limiting the quantity of low-volatile coal to be used in a blend is the decrease in reserves of desirable Pocahontas coal, which, in turn, increases the price of that which has to be purchased on an open market. Thus, while some companies possessing adequate supplies of Pocahontas may use in the order of 50 per cent low-volatile coal in a blend, many companies now are happy to be able to use as little at 20 per cent Pocahontas and produce a coke having the stability and other properties necessary to operate their blast furnaces satisfactorily.

The low-volatile Pocahontas and high-volatile A coals of the Appalachian region are not only the premimum fuels for coke ovens but also for export, domestic uses, and many other purposes. Fifty per cent of the coal exported is eastern coking coal, and sixty per cent of that is low-volatile coal. It is only natural therefore that much of the cream has already been skimmed off our reserves, and the process is continuing. While coal reserves as a whole are estimated in plentiful supply to last for centuries, the known reserves of our premium fuels—particularly Pocahontas—have a life expectancy estimated in decades and fractions thereof. Already many companies have had to give up the desirable two-way blends which include only low-volatile Pocahontas with their particular favorite brand of high-volatile A coal. Before the end of World War II some found it necessary to accept coals from 20 to 30 sources in a single month.

The process of converting a suitable blend of coals into metallurgical coke and numerous by-products is a chemical process, and as such it is most easily controlled by standardizing not only the operating conditions in the plant, but also the uniformity of the individual coals and their proportions in the blends. That such standardization is necessary and is recognized by producers of coke is evidenced by the increased interest in coal-preparation plants at captive mines, as well as by greatly increased interest in all kinds of experimental procedures which may serve as a guide in the section of suitable coal blends for coke ovens. Small experimental coke ovens and expansion ovens, as well as increased plant blending facilities, are all definite sign posts along the road to better control of uniformity of raw materials for the coke oven.

Experimental work on the blending of coals for metallurgical coke does not have to be pursued very long to learn that the properties of a coke obtained from a simple two-way blend of low-volatile Pocahontas and high-volatile. A bituminous

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coal may be changed either slightly or markedly by the addition of various percentages of another coal. Immediately arises the question as to what criteria should be used in the selection of the third coal. Naturally any coal used should be available in sufficient quantity to furnish a steady supply of uniform composition over a reasonable period of time—several years. Many attributes appear to be desirable, such as low ash, sulphur, and moisture-content, etc., all of which are controllable to some extent. A relatively high coking power as indicated by FSI determinations has appeared to be desirable in most cases. However, all of these detailed queries lead up to just two fundamental questions:

(1) What coals can be blended to produce a satisfactory coke? and,

(2) What will be the cost of the coke produced?

There is no simple formula by which these questions can be answered, as each plant and firm has its own specific problems to solve. Location of the plant, its primary sources of supply, end use for the coke produced, market value for the several byproducts as well as the coke—all of these and many other considerations enter into the final solution of this problem. However, the same pattern of experimentation is applicable to each individual plant. Coordination of laboratory analysis and testing data with pilot-plant experimentation is undoubtedly the cheapest and most satisfactory method of approach.

Plants in the western half of the United States are too far removed from the high quality coals of the Appalachian range to consider their use, as the freight rate alone would make their cost prohibitive. Plants in the Chicago district have grown accustomed to the use of the coals of Pennsylvania, West Virginia, and eastern Kentucky, and are loath to make any drastic changes in source of supply, even though during the last few years they have been forced to use many different high-volatile coals from the eastern field. At the same time the Chicago district is close enough to the high-volatile B-rank coals of southern Illinois to invite a certain amount of experimentation with them. At least one plant in the Chicago district has operated with an appreciable percentage of southern Illinois coal in the coal blend for several years. It is not reasonable to expect that this would be done unless it were financially profitable. That it is technically feasible to make a satisfactory metallurgical coke from a blend of low-volatile Pocahontas and Illinois high-volatile coal only has been amply demonstrated by the former Koppers Co. plant at Granite City, now owned and operated by the Granite City Steel Co. Its location makes the use of southern Illinois coal particularly desirable because of the lower freight rates and mine costs.

Preparation of Illinois coking coal differs markedly from that of the eastern high-rank coals. In the East the minus 2-inch sizes of both low and high-volatile coals are used predominately for coking while the larger sizes are sold as premium fuels in other markets. When Illinois coals are crushed the fusain which is noncoking collects in the fines and must be removed from the larger sizes which are used for metallurgical coke blends. Most of the Illinois coking coal is delivered in screened and washed sizes between ¾ of an inch and 3 inches, although appreciable quantities of coal up to 6 inches to size have been used successfully.

The laboratories of the Illinois Geological Survey have been actively engaged on the problem of using Illinois coals in blends with eastern coals—our pilot-plant coke oven has been in operaton, as required, since January 1944. Results obtained in this oven have been found to be an excellent guide in predicting plant operation.

The two questions most frequently asked in recent months have been:

(1) Of what use is the Gieseler plastometer in our work? and,

(2) What effect does the use of Illinois coal have on the production cost of coke?

These two questions will be considered briefly.

Use of Gieseler Plastometer

Early in our work we learned that certain high-volatile eastern coals having exceedingly high fluidities (10,000 and above), as measured by the Gieseler plastometer, gave spongy coke when used in a two-way blend with 20 per cent Pocahontas. Replacement of reasonable percentages of the eastern high-volatile coal by Illinois coal resulted in a blockier coke with high stability and completely eliminated the spongy structure. Further experimental studies showed, on the other hand, that the complete replacement of the highly fluid eastern coal by Illinois No. 6 seam coal to flow fluidity resulted in rough-structured coke with high breeze. These faults were eliminated by the introduction into the blend of certain amounts of the more highly fluid (10-100) Illinois No. 5 seam coal. These observations caused us to give considerable attention to the fluidities of blends and of individual coals, particularly Illinois coals, which may be considered as borderline in their use for metallurgical coke.

In studying the use of these lower-rank coals in blends for making metallurgical coke, the plastic properties of the individual coals have been found useful in selecting satisfactory blends. Of the various plastometers studied, the Gieseler plastometer has been found best suited for this purpose. Temperature values obtained with this apparatus may be duplicated reasonably well, but maximum fluidity values are found to fluctuate. Furthermore, the freshness of the sample tested is important, as it has been shown that maximum fluidity decreases with both time and temperature of exposure. However, data obtained do permit qualitative grouping of coals as regards to their plastic characteristics.

By way of explanation, it should be stated that the various values determined with the Gieseler plastometer are defined as follows:

Softening Temperature—The temperature (°C.) at which dial-pointer movement reaches 0.5 dial divisions per minute.

Fusion Temperature—The temperature (°C.) at which dial-pointer movement reaches 5.0 dial divisions per minute.

Maximum Fluid Temperature—The temperature (°C.) of maximum rate of dial-pointer movement.

Setting Temperature—The temperature (°C.) at which dial-pointer movement stops.

Maximum Fluidity—The maximum rate of dial-pointer movement in dial divisions per minute.

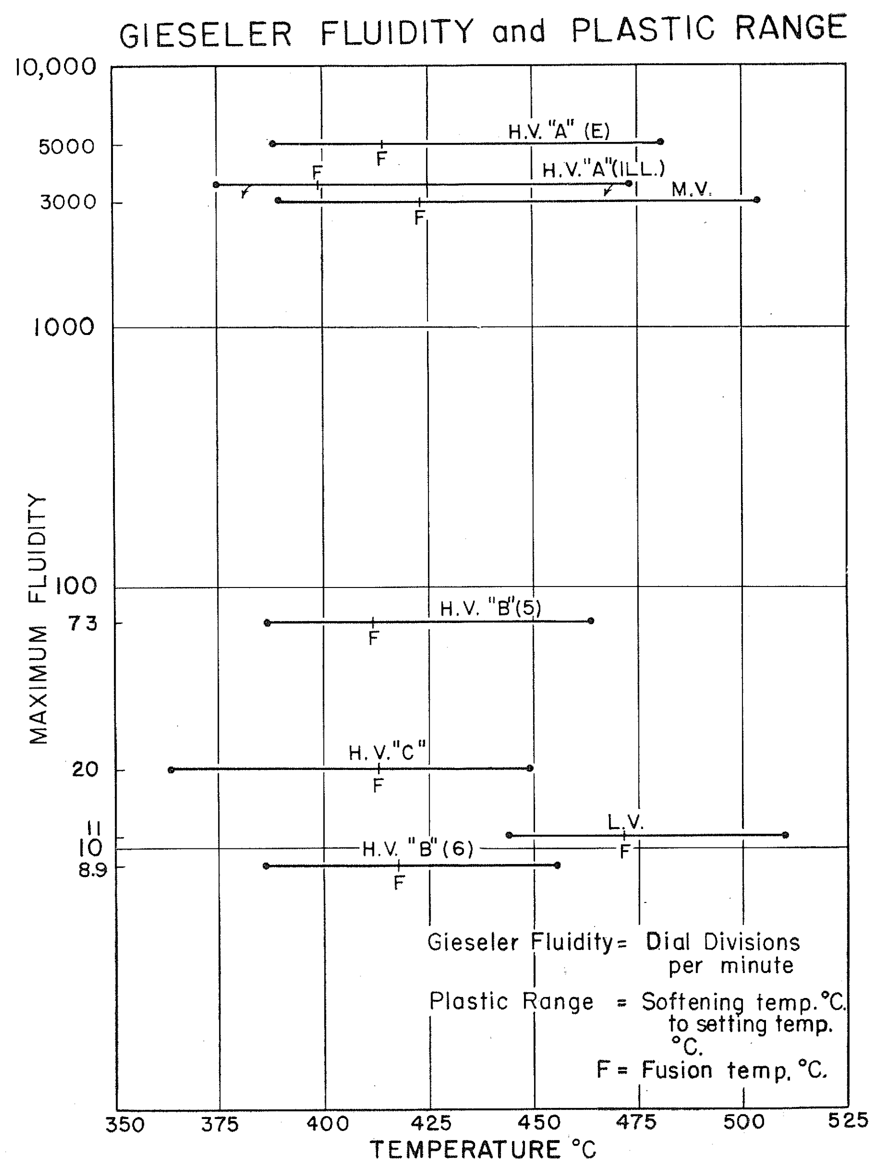
Plastic Range—The temperature range, from the softening temperature to the setting temperature, in which range the coal is plastic.

The qualitative groupings of bituminous coals in accordance with plastic properties are illustrated in Fig. 1. Semilogarithmic paper was used in preparing this figure, the vertical fluidity scale being logarithmic and the horizontal or temperature scale being arithmetic. Values used in preparation of the figure are averages of from 3 to 74 determinations. The high-volatile bituminous B coals from the Illinois No. 6 seam fall in the lowest group (1-10). Low-volatile bituminous, high-volatile bituminous C, and high-volatile bituminous B (Illinois No. 5 seam) coals fall in the next higher group (10-100). Medium-volatile bituminous and high-volatile bituminous A coals fall in the highest grouping (1,000 and up).

Fig. 1 shows also that the temperatures at which coals of different rank are plastic vary definitely as do the plastic ranges. Low-volatile bituminous coals are plastic at higher temperatures and have short plastic ranges. High-volatile bituminous B coals from the Illinois No. 6 seam have short plastic ranges but are plastic at lower temperatures. High-volatile bituminous C and high-volatile bituminous B. (Illinois No. 5 seam) coals are plastic at lower temperatures, but have somewhat longer plastic ranges. Medium-volatile and high-volatile A bituminous coals have long plastic ranges.

Fig. 2 shows the relationship of maximum fluidity temperature and setting temperature to rank of coal as indicated by average calorific values on the moist mineral-matter-free basis. It will be seen that these temperature values increase with increase in rank.

Fig. 1



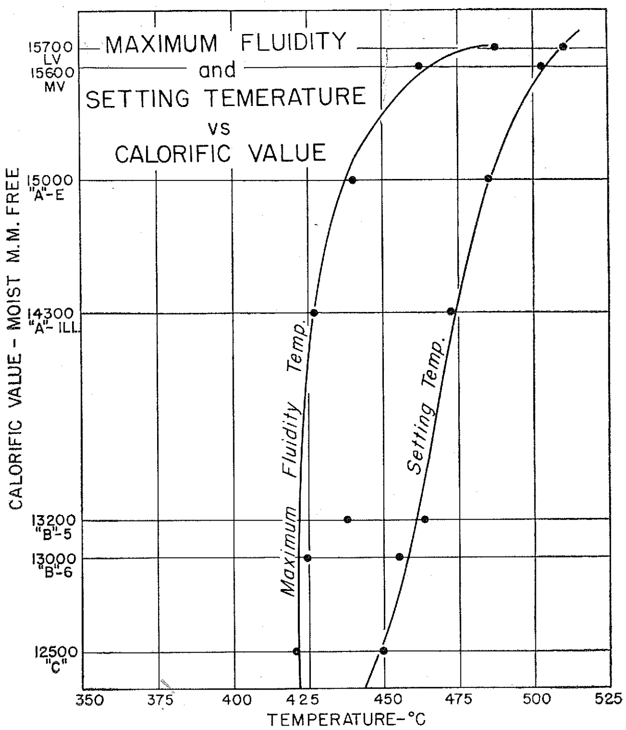


Fig. 2

It is not possible to predict or compute the maximum fluidity of a coal blend from the fluidities of the individual coals. Neither does the maximum fluidity appear to be dependent on the amount of overlap of the plastic ranges of the coals in the blend.

The principal use of Gieseler plasticity data in our laboratory has been in the selection of coals for blends in the metallurgical-coke research program.

TABLE I
Gieseler Fluidity vs. Coke Breeze

Coal blend	Maximum fluidity Dial Div. per Min.	Breeze Per cent of coal
80% Ill. No. 6 20% Poca. No. 3	2.3	3.4
55% Ill. No. 6 20% Ill. No. 5 25% Poca. No. 3	4.2	2.8
80% Ill. No. 6 20% Poca. No. 5	4.8	2.8
75% Ill. No. 6 25% Poca. No. 3	5.0	2.6
75% Ill. No. 6 15% Hernshaw 10% Poca. No. 3	5.3	2.1
80% Ill. No. 5 20% Poca. No. 3	7.5	2.1
70% Ill. No. 6 15% No. 2 Gas 15% Poca. No. 3	12.9	2.3
65% Ill. No. 6 25% No. 2 Gas 10% Poca. No. 3	48	2.1
80% No. 2 Gas 20% Poca. No. 3	233	2.2
70% Hernshaw 30% Poca. No. 3	6000	2.2

TABLE II
Representative Analyses of Illinois Coal Seams
(as prepared for metallurgical-coke use)

		Dry basis			
	M.	V.M.	F.C.	Ash	Sulfur
No. 6 Seam	8.0	37.0	55.5	7.5	1.0
No. 5 Seam	7.0	37.0	55.5	7.5	2.0

Our results indicate that a correlation does exist between the maximum fluidity of a coal blend and the amount of breeze that may be obtained when it is coked. This correlation is shown in Table I. It will be noted that blends having maximum fluidities of approximately 5.0 or less show higher breeze production. These blends of low maximum fluidity usually have a granular or pebbly structure. In Fig. 3 have been plotted maximum fluidities versus breeze values for a large number of blends carbonized in the survey pilot oven. In a general way the same trend is shown as in Table I. Attempts to correlate blend fluidities with coke stability (tumbler drum) have been unsuccessful.

It has been suggested that the Gieseler test may be used to detect oxidation of coal, either while in plant storage or in exposed sections of the mine before recovery. It is true that oxidation causes a decrease in the maximum fluidity that may be shown by the Gieseler plastometer, but, in our opinion, the free-swelling index shows this condition equally well and is a simpler test.

Cost Analysis

It is understood that Illinois coal will be used in the Chicago (or any other) district only if its use results in a profit to the user.

Profits may result from operation of captive mines at an optimum rate to secure minimum mining costs or to lengthen the life of a mine, and from diversion of premium-size captive coals to the retail market. If either of these operating procedures results in the increased purchase of outside coals for the coke plant, it will be profitable to consider coals which can be mined cheaply, have a low freight rate to the plant, have a uniform chemical composition, and may be blended with the captive coals available to maintain or improve the physical properties of the coke produced. There is no overall rule to apply which will obviate the necessity of experimental test runs to determine whether such coals may profitably be used in blends with the basic captive coals. Here again each change is a separate problem.

TABLE III
Coal Costs Delivered to Chicago by Rail

	Mine cost	Freight	Delivered cost
Eastern high-volatile coal	$6.00	$4.48	$10.48
Pocahontas coal	6.25	4.68	10.93
Southern Illinois coal	5.25	3.1882	8.4382

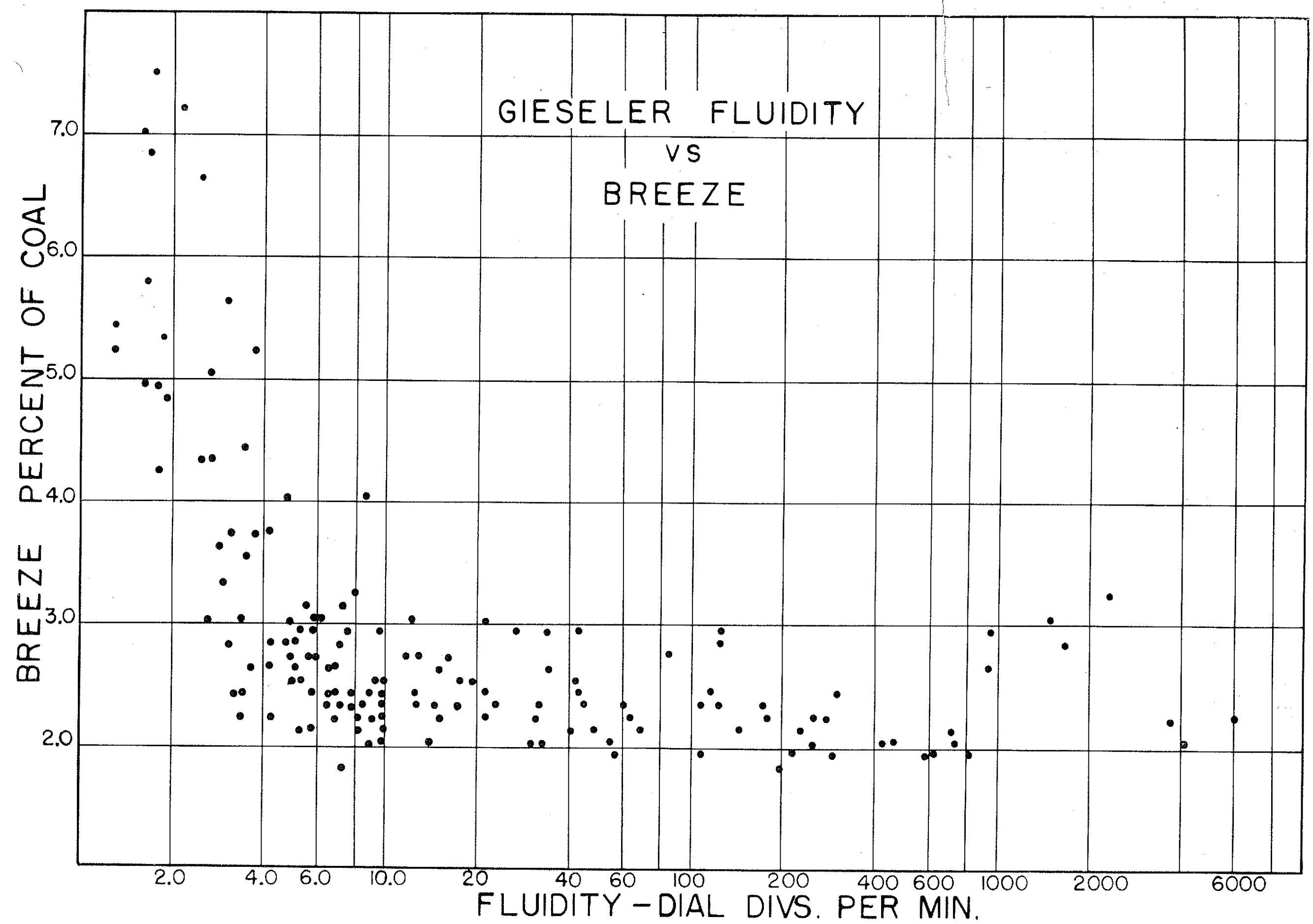


Fig. 3

TABLE IV
Cost Analysis
Coals blended—Illinois No. 6 seam
West Virginia high-volatile
Pocahontas

	80% W. Va. high-vol. 20% Pocahontas		10% Ill. No. 6 70% W. Va. high-vol. 20% Pocahontas		30% Ill. No. 6 50% W. Va. high-vol. 20% Pocahontas		50% Ill. No. 6 30% W. Va. high-vol. 20% Pocahontas	
	Yield	Value	Yield	Value	Yield	Value	Yield	Value
By-product credits								
Breeze at $3.25/ton	2.9	$0.094	2.8	$0.091	2.8	$0.091	2.7	$0.088
Tar at 9c/gal.	9.4	0.846	9.2	0.828	9.2	0.828	9.2	0.828
Sulfate at $20/ton (net - acid deducted)	22.0	0.220	22.0	0.220	22.0	0.220	22.0	0.220
Light oils at 25c/gal.	3.0	0.750	3.0	0.750	3.0	0.750	3.0	0.750
Surplus gas at 15c/M	6675	1.001	6575	0.986	6375	0.956	6175	0.926
Total credits		2.911		2.875		2.845		2.812
Cost coal delivered		10.570		10.366		9.957		9.549
Net cost coal/ton		7.659		7.491		7.112		6.737
Coke yield (percent)	71.5		70.9		69.1		67.8	
Cost coal/ton of coke		10.712		10.566		10.292		9.937
Saving/ton coke (due to Ill. coal)				0.146		0.420		0.775
Coke strength								
Tumbler stability	40.2		40.6		42.5		44.4	
Tumbler hardness	62.1		62.1		63.5		64.1	

TABLE V

Cost Analysis

Coals blended—Illinois No. 5 seam
Pennsylvania
Pocahontas

	80% Pennsylvania 20% Pocahontas		10% Ill. No. 5 70% Pennsylvania 20% Pocahontas		30% Ill. No. 5 50% Pennsylvania 20% Pocahontas		50% Ill. No. 5 30% Pennsylvania 30% Pocahontas	
	Yield	Value	Yield	Value	Yield	Value	Yield	Value
By-product credits								
Breeze at $3.25/ton	2.6	$0.084	2.2	$0.072	2.2	$0.072	2.2	$0.072
Tar at 9c/gal.	10.9	0.981	10.8	0.972	10.6	0.954	9.8	0.882
Sulfate at $20/ton (net - acid deducted)	22.0	0.220	22.0	0.220	22.0	0.220	22.0	0.220
Light oils at 25c/gal.	3.0	0.750	3.0	0.750	3.0	0.750	3.0	0.750
Surplus gas at 15c/M	6375	0.956	6350	0.953	6300	0.945	6250	0.938
Total credits		2.991		2.967		2.941		2.862
Cost coal delivered		10.570		10.366		9.957		9.549
Net cost coal/ton		7.579		7.399		7.016		6.687
Coke yield (percent)	70.6		70.0		69.5		68.8	
Cost coal/ton of coke		10.735		10.570		10.095		9.719
Saving/ton of coke (due to Ill. coal)				0.165		0.640		1.016
Coke strength								
Tumbler stability	47.4		50.2		51.8		48.5	
Tumbler hardness	61.8		63.0		63.8		63.4	

Our experience over the last several years has shown that the composition of the washed, prepared sizes of coal from the low-sulfur mines of southern Illinois is very uniform. Deliveries do not vary appreciably from day to day, and coals from different mines in the same seam in this area may be used interchangeably. Typical analyses of washed coal available are shown in Table II.

The thick seams of this district lend themselves admirably to mechanical mining and to the operation of medium and large-size mines. The lower mining costs which result are responsible for mine prices on washed, double-screened coal which are consistently lower than those normally quoted from eastern coal prices (which vary widely) but we believe will average about $6.00 per ton.

Likewise, freight rates to the Chicago area on southern Illinois coal are approximately $3.19 per ton compared with the all-rail rate of $4.48 from the high-volatile coal fields of eastern Kentucky, West Virginia, or Pennsylvania. In Table III are shown the average costs of coals delivered to the Chicago district. For any specific comparison actual prices of the coals in question may be substituted and compared.

While laboratory tests such as the Gieseler have helped in determining procedure, actual pilot-plant tests are necessary to evaluate any given blend. In Tables IV, V, VI, and VII the results of certain coking studies are shown in which Illinois coals have been blended with eastern coking coals used in the Chicago area. Using the present all-rail delivered cost of coal, and allowing for by-product credits in the range of those being received in Chicago, the net cost of each coal blend per ton of coke has been computed.

Yields of coke, breeze, tar and gas shown in the tables have been determined in the pilot oven. Coke yields include all coke over a one-half inch screen, and are computed at 3 per cent moisture. Breeze yields are computed at 15 per cent moisture and constitute the minus one-half inch size. Plant yields of breeze ordinarily are about one and one-half times as great as these pilot plant yields due to more severe handling. Plant yields of coke would be correspondingly lower. It is assumed in all blends that 4550 cu. ft. of gas at 550 B.t.u. are used per ton of coal carbonized for underfiring the coke ovens. This corresponds to 1250 B.t.u. per pound of coal. Surplus gas shown in the tables is the total gas produced corrected to 550 B.t.u. less that used for underfiring.

Sulfate and light oil yields cannot be determined on our equipment. Plant practice has never, to our knowledge, shown any appreciable difference in the yields of these two by-products due to Illinois coals in the blend, so average sulfate and light-oil yields are used in all computations.

Discussion

In Tables IV, V, VI, and VII there is an indicated saving in the cost of coal per ton of coke produced of from 14 cents to 21 cents for each 10 per cent of Illinois coal used in the blends. Although not shown in the tables, the equivalent savings would be from 3 cents to 10 cents if the eastern coals were received by lake-boat delivery.

Illinois coals may be blended with coals from either eastern Kentucky, West Virginia or Pennsylvania, and the results vary in yields of coke and by-products, in coke quality, and in the indicated saving per ton, depending upon the coals used. Also,

TABLE VI

Cost Analysis

Coals blended—Illinois No. 6 seam
Eastern Kentucky
Pocahontas

	80% Eastern Ky. 20% Pocahontas Yield	Value	20% Ill. No. 6 60% Eastern Ky. 20% Pocahontas Yield	Value	30% Ill. No. 6 50% Eastern Ky. 20% Pocahontas Yield	Value	40% Ill. No. 6 40% Eastern Ky. 20% Pocahontas Yield	Value
By-product credits								
Breeze at $3.25/ton	2.35	$0.076	2.5	$0.081	2.5	$0.081	2.35	$0.076
Tar at 9c/gal.	10.5	0.945	10.0	0.900	9.7	0.873	9.3	0.837
Sulfate at $20/ton (net - acid deducted)	22.0	0.220	22.0	0.220	22.0	0.220	22.0	0.220
Light oils at 25c/gal.	3.0	0.750	3.0	0.750	3.0	0.750	3.0	0.750
Surplus gas at 15c/M	6800	1.020	6500	0.975	6250	0.938	5900(?)	0.885
Total credits		3.011		2.926		2.862		2.768
Cost coal delivered		10.270		10.162		9.957		9.753
Net cost coal/ton		7.559		7.236		7.095		6.985
Coke yield (percent)	68.8		68.3		68.1		67.8	
Cost coal/ton of coke		10.987		10.594		10.419		10.302
Saving/ton of coke (due to Ill. coal)				0.393		0.568		0.685
Coke strength								
Tumbler stability	40.5		41.1		40.1		46.3	
Tumbler hardness	64.9		64.1		64.4		63.8	

Illinois coals may replace completely the eastern high-volatile coal to produce a highly satisfactory metallurgical coke at a distinct saving in cost per ton of coke.

Coke yields are shown to decrease when using Illinois coals in approximate proportion to the increased moisture of the Illinois coal in the blends. Tar and gas yields decrease, also, due in part at least to coal moisture. As noted in the tables these reductions in yields are more than offset by the lower cost of the coal.

Normally, Illinois coals, when properly blended, improve the coke stability. They also tend to open up coke structure.

Illinois No. 5 seam coal is more strongly coking in blends than No. 6 seam and is used at present in commercial plants as 20 per cent of the total blend.

No mention has been made of the ash and sulfur contents of the various cokes. These will depend on the analyses of the coals used and should be taken into consideration for any specific blend.

TABLE VII

Cost Analysis

Comparison of Cokes Produced Using Pocahontas with All Eastern High-Volatile and with All Illinois Coals

	80% W. Va. high-vol. 20% Pocahontas Yield	Value	60% Ill. No. 6 20% Ill. No. 5 20% Pocahontas Yield	Value	55% Ill. No. 6 20% Ill. No. 5 25% Pocahontas Yield	Value
By-Product credits						
Breeze at $3.25/ton	2.9	$0.094	2.9	$0.094	3.3	$0.107
Tar at 9c/gal.	9.4	0.846	8.7	0.783	8.1	0.729
Sulfate at $20/ton (net - acid deducted)	22.0	0.220	22.0	0.220	22.0	0.220
Light oils at 25c/gal.	3.0	0.750	3.0	0.750	3.0	0.750
Surplus gas at 15c/M	6675	1.001	5650	0.847	5525	0.829
Total credits		2.911		2.694		2.635
Cost coal delivered		10.570		8.936		9.062
Net cost coal/ton		7.659		6.242		6.427
Coke yield (percent)	71.5		67.0		67.2	
Cost coal/ton of coke		10.712		9.312		9.564
Saving/ton coke (due to Ill. coal)				1.396		1.148
Coke strength						
Tumbler stability	40.2		48.8		47.6	
Tumbler hardness	62.1		67.2		65.6	

The final test of any coke that is used for blast furnace fuel is how it performs in the furnace, and this again is an individual problem to be determined in actual plant operation. Furnace operators know that any change in burden may upset furnace operation until adjustments in operating procedure have compensated for the change. It has been the experience of those who have used Illinois coal consistently for metallurgical coke that after proper blends have been developed and operating procedures modified where necessary, excellent furnace operation has been obtained.

Conclusions

From the foregoing data and discussion the following general conclusions may be drawn:

1. Due to decreasing supplies of premium coals for making metallurgical coke, the use of lower-rank coals for this purpose may of necessity increase.
2. Adaption of these lower rank coals to the making of metallurgical coke necessitates carefully controlled experimental work.
3. Qualitative grouping of coals by means of Gieseler plastometer data is useful in selecting coals for blends in making metallurgical coke, especially when lower rank coals are used.
4. Coal blends having Gieseler values below four or five have a strong tendency to produce cokes with a granular structure and a relatively high percentage of breeze.
5. If properly prepared and blended, lower rank coals may be used for the production of metallurgical coke of satisfactory quality.
6. Lower mining costs of southern Illinois coals and lower freight rates to the Chicago district may permit appreciable savings in the cost of coke.