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A STUDY OF THE RELATION BETWEEN THE PROPERTIES OF COKES PRODUCED BY MEANS OF TWO LABORATORY METHODS AND COKE PRODUCED INDUSTRIALLY

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FUELS DIVISION

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U. S. BUREAU OF MINES

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ABSTRACT

This report presents the results of a study of the relation between the physical properties of metallurgical cokes produced industrially in Canada, and those made from the same coals by means of laboratory methods using (1) the 25 lb. sole-heated Bethlehem Expansion tester at the Fuels Division and (2) the Bureau of Mines - American Gas Association (BM-AGA) 90 and 185 lb. capacity cylindrical carbonizing units at the U. S. Bureau of Mines laboratory, Pittsburgh, Pa. The results indicate that the laboratory equipment might be used to evaluate individual coals and blends for the manufacture of oven coke.

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SUMMARY

The aim of this study was to determine to what extent certain small scale carbonization tests, already developed, would be suitable for evaluating the coking properties of coals when dealing with limited quantities of samples, with a maximum of, say, 500 pounds.

The report presents comparative data for two coal blends of 29.4 and 33.1 percent volatile matter and an individual coal of 39.3 percent volatile matter (dry, mineral matter free basis) carbonized at three coke plants in Canada and in a 25 lb capacity modified Bethlehem tester at the Fuels Division, Department of Mines and Technical Surveys, Ottawa and at Pittsburgh, Pennsylvania in the U. S. Bureau of Mines BM-AGA 13- and 18-inch retorts (ca. 90 and 185 lb capacity, respectively). The quality of cokes from the F. R. L.* Bethlehem oven was determined by size distribution and a Jar Mill tumbler test, whereas strength indices for the industrial cokes and those from the BM-AGA retorts were determined by ASTM methods.

Correlating tendencies, as measured by coefficients of variation, indicate the following relationships between physical properties of the industrial and experimental cokes:

(a) 1-1/2 inch Shatter Index - Good correlation is indicated between the industrial coke and (1) the 1-inch and 3/4-inch Jar Mill Stability of the Bethlehem oven coke, (2) the plus 1-1/2 inch size of the run of oven coke from the Bethlehem

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oven, and (3) the 1-1/2 inch shatter index of BM-AGA 18-inch retort coke. There also appears to be a fair degree of correlation between the industrial 1-1/2 inch shatter and the 1-inch tumbler indices of BM-AGA 13- and 18-inch retort cokes.

(b) 1-inch Tumbler Stability - The stability indices of the industrial cokes showed poor correlation with those of the experimental cokes, although there was close agreement of BM-AGA and industrial values for two of the coals.

(c) 1/4-inch Tumbler Hardness - Good correlation is indicated between the hardness index of the industrial coke and (1) the 1-inch Jar Mill Stability of the Bethlehem oven coke and (2) 1/4-inch Tumbler Hardness of the BM-AGA 13- and 18-inch retort cokes.

The apparent specific gravities of the industrial cokes were intermediate between the Bethlehem oven coke, which gave high values, and the BM-AGA cokes, which were low.

Yields of carbonization products from the BM-AGA retorts and the Sperr and Rose assay test, except for tar and coke yields, showed no consistent relationships to the industrial yields reported. It is indicated that further work is required to establish correlation between laboratory tests and industrial yield values.

Also, there appeared to be no relation between coke properties and agglutinating value, plasticity or swelling indices of the coals except that the F. R. L. Swelling Indices, associated with the evolution of volatile matter, afforded an approximate prediction of physical quality of industrial cokes.

The results of the work described in this report indicate that the stability tests of coke produced by small scale equipment, including the Bethlehem expansion test oven, might be used for evaluating individual coals and coal blends for the manufacture of oven coke.

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INTRODUCTION

This study was undertaken to re-explore the possibility of predicting the quality of industrial cokes from tests carried out in small scale equipment. If correlations of a reliable character could be evolved, a very useful procedure would be established in evaluating rapidly individual coals and blends of coal in the manufacture of industrial cokes.

This report represents a phase of the investigation and is therefore a progress report.

In studying the coking properties of coals in relation to the quality of resultant metallurgical high temperature oven coke that can be produced from them, in addition to evaluating the general coking characteristics by means of such laboratory tests as plasticity and free swelling, it is necessary to assess the physical quality of the cokes that result from the carbonization of coal in laboratory scale ovens. There is at present a choice of several laboratory scale retorts requiring from about seven (7) pounds through a range of over 500 pounds of coal per charge, the largest ones simulating sections of by-product ovens and yielding cokes almost identical with the industrial products both in visual appearance and as assessed by various standarized tests.

As the U. S. Bureau of Mines had accumulated data with the BM-AGA retorts the largest of which required only about 185 pounds of coal per charge, this apparatus and the smaller Bethlehem Test oven available at the Fuels Division were chosen for comparing the resultant coke with that produced industrially.

The investigation reported herewith was thus conducted in 1956, in cooperation with the U. S. Bureau of Mines, with a view to determining to what extent the results of the two laboratory carbonization tests could be correlated with the physical properties of coke manufactured for metallurgical purposes in industrial slot-type coke ovens.

Samples of coal collected by the Fuels Division at three Canadian steel plants in Central and Eastern Canada were carbonized by the U. S. Bureau of Mines in the cylindrical 18 in. and 13 in. Bureau of Mines - American Gas Association (BM-AGA) retorts at 900°C, and by the Fuels Division, Department of Mines and Technical Surveys, Canada, in a 25-pound capacity modified version of the sole-heated Bethlehem (Brown) test oven, in which the final sole temperature was approximately 1950°F. (1065°C.).

The physical properties of the coke made in these test ovens were compared with those made in the industrial coke ovens where the samples of coal were collected. Where possible, standard A.S.T.M. tests were employed for assessing the physical quality of the cokes, but where insufficient coke was available, as in the case of the Bethlehem Oven test, a modification of the A.S.T.M. Tumbler Test for Coal was employed.

As the study was confined to the cokes produced at three plants, and as in one case the coking time was substantially longer than in the others, an overall statistical analysis of the data was not attempted. However, the variance in, and probable reliability of, certain of the data concerning the physical coke quality has been indicated in terms of the standard deviation and the coefficient of variation.

Insufficient data were available to correlate statistically the physical properties of the industrial cokes with those made by either of the laboratory tests. An alternative method was used whereby probable correlations were indicated by means of the ratios between the various quantitative measurements of physical quality. It is postulated that the lower the coefficient of variation of the ratios the greater is the probability of correlation.

In addition to the above laboratory tests where coke is produced under conditions simulating, to a degree, industrial practice, small scale laboratory tests determining certain physico-chemical characteristics of the coals during thermal decomposition were also employed. The plastic properties were determined by the Gieseler method and the free-swelling properties by both the A.S.T.M. and F.R.L.* methods. The U.S. Bureau of Mines also

* Fuel Research Laboratories, Fuels Division, Department of Mines and Technical Surveys.

determined the agglutinating index by means of a standarized test. These tests were conducted for comparative purposes and to build up a fund of data for eventually establishing, if possible, correlations between such basic physico-chemical properties of the coals and the properties of resultant oven cokes.

The expansion characteristics of the coals were measured at the Fuels Division by means of the modified Bethlehem oven, and at the Bureau of Mines in their sole-heated oven, which is also a modification of the Bethlehem oven.

In addition to the above, yields of the products of carbonization as obtained by laboratory methods were compared with industrial plant yields.

ACKNOWLEDGMENTS

Acknowledgment is due Mr. D. A. Reynolds, Chief, Coal Carbonization Section, U. S. Bureau of Mines, and various members of his staff for the cooperation in this investigation. Acknowledgment is also due W. J. Montgomery of the Fuels Division, Department of Mines and Technical Surveys, Ottawa, under whose supervision the coal and coke analyses were conducted, and to C. H. Glaude, T. A. Lloyd and A. J. Reynolds, of the same Division, who assisted in the conducting of carbonization tests, high temperature assays, and physical testing of the coke and coal, and in the preparation of the report.

III

COKE PLANTS, COALS USED, SAMPLE COLLECTION

1. Coke Plants

Two coke plants in Central Canada using blends of United States coals and one Eastern Canadian plant using a Nova Scotia coal were chosen for this investigation as representing a cross-section of metallurgical coke production in Canada. The pertinent details regarding the type of ovens, their size, carbonizing time, etc., are shown in Table I.

TABLE - I

PERTINENT DETAILS OF COKE PLANTS

	Central Canada		Eastern Canada
	Plant A	Plant B	Plant C
No. of Batteries used during tests	2	2*	2
No. of Ovens	60	143	114
Type of Ovens	Koppers	Koppers Underjet	Koppers Becker Underjet
Capacity per Oven - tons	17.2	17.5	17.5
Width of Oven - in.	17	17	17
Coking Time - hrs.	17	17	23.38
Size of Coal as charged, 0 x 1/8 in. ** - %	Approx. 75.0	Approx. 78.0	Approx. 50.0
Bulk Density of Coal ** Lb./Cu.Ft.	50.0	49.3	52.0
Moisture of Coal as Charged - %	7.0	4.5	11.0

* This plant has four batteries consisting of 251 ovens, but testing was confined to two batteries.

** Average values obtained from plants.

It is to be noted that the ovens were very similar in all respects but operation at Plant C varied from the other two. The coking time was much longer at 23.38 hours and the coal, as charged, was coarser with only approximately 50 percent 1/8 x 0 in., as indicated by average values obtained from the plants. Table II shows the detailed screen analyses and bulk densities of the coals determined at the Fuels Division laboratory.

TABLE - II

SCREEN ANALYSES AND BULK DENSITY OF COALS
AS CHARGED TO COMMERCIAL OVENS *

	Coal A	Coal B	Coal C
Screen Analysis			
Plus 3/4 in. rd ...... %	0.1	0.1	1.1
3/4 x 1/2 in. rd ...... %	0.6	0.8	2.3
1/2 x 1/4 in. rd ...... %	9.6	8.8	11.5
1/4 x 1/8 in. rd ...... %	19.0	17.0	22.7
1/8 x 1/16 in. rd. ..... %	20.6	19.4	16.0
1/16 x 1/32 in. rd ..... %	16.6	16.3	17.4
1/32 x 0 in. rd. .... %	33.5	37.6	29.0
1/8 x 0 in. rd .... %	70.7	73.3	62.4
Bulk Density			
Lbs./Cu.Ft.	50.6	51.0	49.6
Cu. Ft./Ton.	39.5	39.2	40.3

* The coal as prepared for the commercial ovens was used for the laboratory tests using the BM-AGA and Bethlehem Expansion Testers.

2. Coals Used

The types and origin of the coals used either in blends or alone as the case may be, are shown in Table III. The two Central Canadian plants used blends of 77.5% high volatile A bituminous coals with 22.5% low volatile bituminous coals, whereas the Eastern Canadian plant employed only high volatile A bituminous coal coming from three mines operating on the same (Harbour) seam. The U.S. high volatile A bituminous coals used in the Central Canadian plants originated from six seams in Virginia, West Virginia and Kentucky and were mixed at random. The U.S. low volatile bituminous coals used originated mainly from the Pocahontas No. 3 seam in West Virginia, although Plant B also used coal from the Beckley seam.

As it was not possible to obtain samples of the individual U.S. coals used in Plants A and B, Table IV presents typical analyses of the coals. These data were, in some cases, obtained from the steel plants and in others from the U.S. Bureau of Mines Publication, Bulletin No. 466, entitled "Typical Analyses of Coals of the United States".

It is of interest to note that the high volatile A bituminous coals used at Plant B were, on the average, higher in volatile matter than those employed at Plant A. This is reflected in the higher volatile matter of the Plant B blend as charged to the ovens (see Table VI). On the dry mineral matter free basis the volatile matter of the coal or blends charged to the ovens was as follows: Plant A: 29.4%; Plant B: 33.1%; Plant C: 39.3%.

TABLE - III

COALS USED IN PREPARING COKE OVEN CHARGES

Coals Used	Central Canada Plant A	Central Canada Plant B	Eastern Canada Plant C
High Volatile A bituminous	1. Clintwood seam, Dickenson Co., Virginia. 2. Elkhorn seam, Pike Co., Kentucky.	1. No. 2 Gas seam, Fayette Co., W. Virginia. 2. Clintwood seam, Dickenson Co., Virginia. 3. A mix of Powellton, No. 2 Gas and Eagle seams, Kanawha Co., W. Virginia. 4. Big Eagle seam, Nicholas Co., W. Virginia.	1. Harbour seam, Sydney area, Nova Scotia.
Low Volatile bituminous	1. Pocahontas No. 3 seam, McDowell Co., W. Virginia. (From 5 mines of one producer).	1. Pocahontas No. 3 seam, McDowell Co., W. Virginia. 2. Beckley seam, Wyoming Co., W. Virginia.	Nil
Charge to Ovens	77.5% High vol. A. bit. 22.5% Low vol. bit.	77.5% High vol. A. bit. 22.5% Low vol. bit.	100% High vol. A. bit.
Analysis (as charged) +			
Moisture .... %	7.0	4.5	11.0
Volatile Matter .... %	26.3	30.2	32.8
Ash .... %	5.8	6.5	5.5

\+ See Table - VI for complete analyses.

TABLE - IV

TYPICAL ANALYSES OF U.S. COALS USED IN BLENDS

	Proximate				
	Moisture %	Ash %	Volatile Matter %	Fixed Carbon %	Sulphur %
Plant A					
High Vol. A bituminous					
1. Clintwood seam, Dickenson Co.	3.1	4.5	31.9	60.5	0.85
2. Elkhorn seam, Pike Co.	2.5	6.0	31.4	60.1	0.61
Low Vol. bituminous					
1. Pocahontas No. 3 seam, McDowell Co.	2.9	6.4	16.2	74.5	0.65
Plant B					
High Vol. A bituminous					
1. No. 2 Gas seam, Fayette Co.	2.5	6.1	33.8	57.6	1.3
2. Clintwood seam, Dickenson Co.	3.1	4.5	31.9	60.5	0.8
3. A mix of No. 2 Gas, Eagle and Powellton seams, Kanawha Co.	2.8	4.1	34.2	58.9	0.7
4. Big Eagle seam, Nicholas Co.	3.0	6.2	33.4	60.4	0.7
Low Vol. bituminous					
1. Beckley seam, Wyoming Co.	2.6	5.7	18.2	73.5	1.1
2. Pocahontas No. 3 seam, McDowell Co.	2.9	6.4	16.2	74.5	0.65

3. Sampling of Coal and Coke

Table V presents the pertinent data with regard to the sampling of the coal and coke at the coke oven plants. It should be noted that the coke samples were taken during a period at which it was estimated the coal sampled for charging would be discharged as coke. In the case of both coal and coke the samples were taken from a stream of the material on a conveyor belt.

IV

METHODS FOR TESTING THE COALS AND COKES

The general quality of the coal and coke samples was determined by means of the standard proximate and ultimate analyses, calorific value and ash softening temperature determinations (see Tables VI and VII for the coal and Tables VIII and IX for the industrial and Bethlehem tester cokes respectively).

With a view to comparatively assessing the coking properties of the coals and the physical characteristics of the industrial and laboratory test cokes, the coals and cokes were examined by the following test methods.

1. Tests for Coking Properties of Coals

(a) Free Swelling Properties (Tables VI and VII)

Both the A.S.T.M. (1) and F.R.L. (2) Free Swelling Tests were used to assess this property of the coals.

TABLE - V

SAMPLING OF COAL AND COKE

		Plant A	Plant B	Plant C
1. Sampling of Coal				
Date of Sampling		April 17, 1956	April 24, 1956	May 8, 1956
Point of Sampling		Belt leading to coal storage bins at ovens		
Nature of Sample		Crushed for charging		
Period of Sampling	hrs.	11.0	11.6	6.5
Size of Increment	lbs.	2.0	2.0	4.0*
Increment Intervals	min.	1	1	1
Gross Sample	lbs.	1050	1050	2000
Tonnage Sampled (approx.)	ton.	1325	2500	1900
2. Sampling of Coke				
Date of Sampling		April 18, 1956	April 25, 1956	May 10, 1956
Point of Sampling		Belt leading from coke wharf		
Nature of Sample		Half-oven pieces: hand picked		
Period of Sampling	hrs.	9.0	8.0	5.0
Gross Sample	lbs.	800 +	800 +	800 +

* Larger increments collected at this plant as coal was coarser.

\+ 600 lbs. of coke sample was used for shatter tests, and 200 lbs. for A.S.T.M. Tumbler Tests.

At the Fuels Division the A.S.T.M. method has been modified by employing a 350-watt electric cone-shaped heater and 15 cc. platinum crucibles(3), the coal being heated at 650°C. for a period of 4 minutes (4). In the standard test 1 gram samples of coal are heated in quartz crucibles in a gas flame to a maximum temperature of 820 ± 50°C. In either case the resultant "coke buttons" are graded according to size and contour in accordance with a series of standard profiles increasing by half-units from 1 to 9.

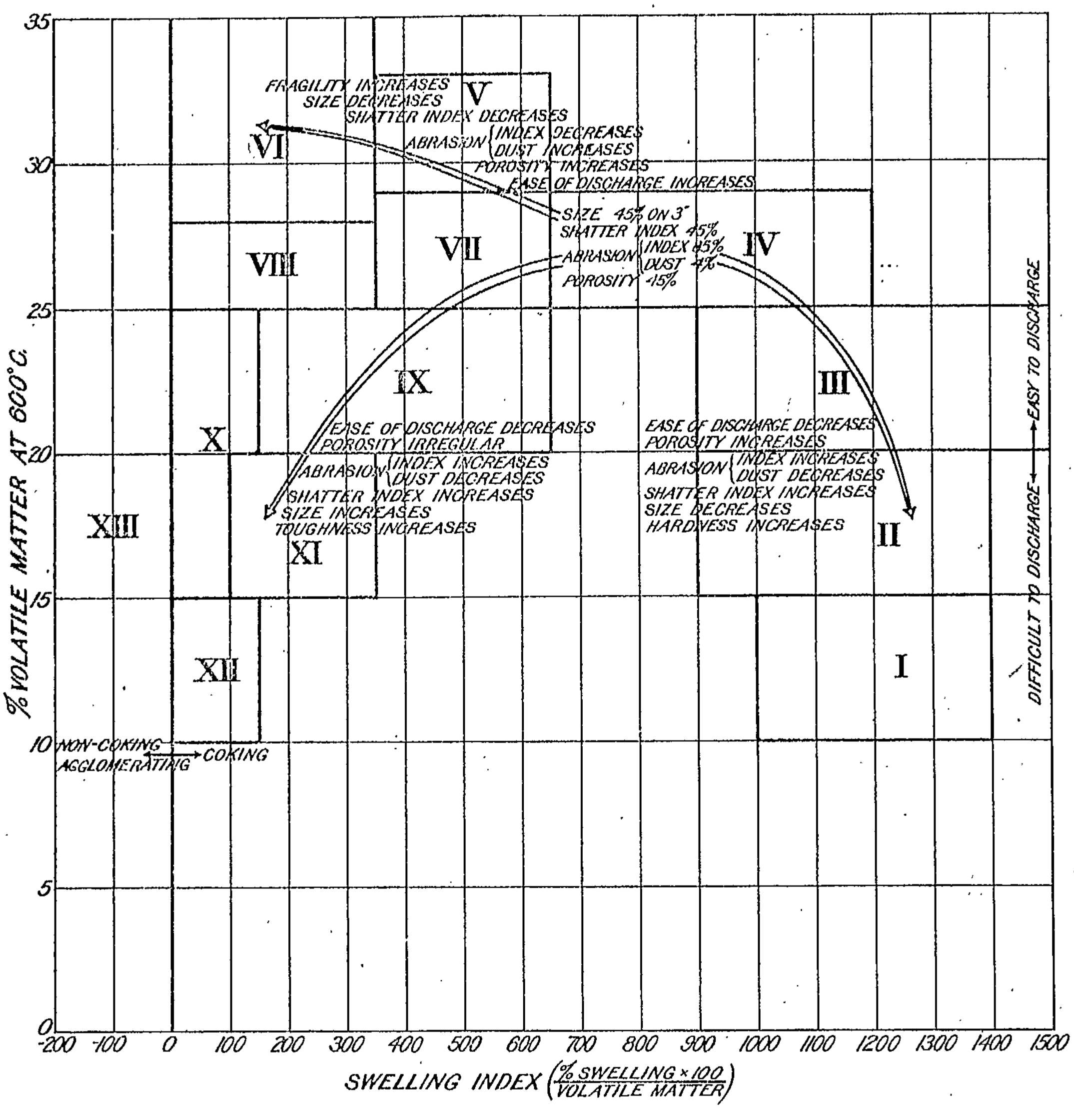
Although the results of the test are suggested as being useful "as an indication of the coking characteristics of the coal when burned as a fuel", they have been, and are also being, used as a guide to the comparative coking properties of coal when carbonized for the production of various types of cokes. However, no correlation has been established between the A.S.T.M. Free Swelling Index of a coal and the properties of, for example, the high temperature oven coke that could be produced from a given coal or blend.

In the F.R.L. Swelling Test 1-gram samples of coal are heated in 15 cc. platinum crucibles at 600°C. for 15 minutes using a short cylindrical electrical heater. The volume of the resultant "button" is measured, the per cent swelling over and above the original volume of the coal (average 2 cc.) calculated, and from this value the swelling index per unit (1%) of volatile matter (dry basis) evolved at 600°C. is calculated. The resultant value is multiplied by 100 to yield comparative indices that may be readily differentiated. In this case also the free swelling is limited by the size of the crucible.

Figure 1 presents a chart relating the F.R.L. Swelling Index to the volatile matter evolved at 600°C. The chart has been arbitrarily divided into regions in accordance with the known physical properties of oven coke made from coals occurring in these groups. It should be noted that the physical coke properties indicated are those of cokes manufactured in an experimental 2-1/2 ton, 12 in. by-product oven, and thus may not be comparable in all respects to oven cokes manufactured in modern wider ovens. Table X presents the predicted approximate quality of oven coke to be expected from the coals collected at the three plants. Figure 1 shows the position of the coals on the chart.

(b) Gieseler Plasticity (Table VI)

The comparative degree to which a coking coal becomes plastic during thermal decomposition in the absence of air was tested by means of the Gieseler type plastometer (5). In this small scale laboratory method the resistance of a coal, during its plastic state, to the movement of a stirring rod fitted with rabble arms embedded in the coal, gives an index measure of the fluidity of the plastic mass. As the heated coal softens its fluidity increases and the rate of rotation of the stirrer increases to some maximum value referred to as maximum fluidity. This empirical test is very sensitive to small changes in the design of the apparatus and in the procedure of conducting the test, and with present



SECTION	ASH %	SIZE ON WHARF		SHATTER		ABRASION		DENSITY		TRANSVERSE SHRINKAGE	APPEARANCE OF NATURAL SURFACE	SHAPE	STRENGTH	CROSS FRACTURE	LONGITUDINAL FRACTURE	CELL STRUCTURE	SPONGE	PEBBLY SEAM
		% ON 3"	BREEZE	INDEX	BREEZE	INDEX	DUST	APP. S.G.	LB. C.F.									
I		POCAHONTAS TYPE BLENDING COALS								NIL			HARD				VERY LITTLE	NONE
II		25-40	2·5-1·0	65-55	3·0-2·0	85-95	3·5 2·0	·85-·95	24-26	FAIR*	STEEL GREY AND SMOOTH	SQUARE	HARD	MEDIUM TO LARGE AMOUNT STRAIGHT	SMALL TO MEDIUM AMOUNT	DENSE	VERY LITTLE	NONE
III		30-45	2·5-1·0	50-65	3·0-2·0	85-95	3·5-2·0	·90-1·0	25-28	FAIR TO GOOD	STEEL GREY AND SMOOTH	SQUARE	HARD	MEDIUM AMOUNT, SQUARE	SMALL TO MEDIUM AMOUNT	DENSE	VERY LITTLE	NONE
IV		40-50	3·0-2·0	45-55	3·0-2·0	90-90	5·0-3·0	1·0-1·1	26-29	GOOD	STEEL GREY, FAIRLY SMOOTH	SLIGHTLY TRIANGULAR	HARD	MEDIUM AMOUNT, STEPPY	MEDIUM AMOUNT	DENSE	VERY LITTLE	NONE
V		30-50	4·0-2·0	40-50	6·0 4·0	75-85	5·0-3·0	1·0-0·9	26-29	GOOD	STEEL GREY, IRREGULAR	TRIANGULAR FINGERY	FRAG.	MEDIUM TO LARGE AMOUNT STEPPY	MEDIUM TO LARGE AMOUNT	MEDIUM	SMALL TO MEDIUM AMOUNT	NONE
VI		30-50	2·0-5·0	25-40	6·0-4·0	55-80	7·0-3·0	·85-·09	25	VERY GOOD	STEEL GREY, IRREGULAR	TRIANGULAR VERY FINGERY	VERY FRAGILE	MEDIUM TO LARGE AMOUNT STEPPY	LARGE AMOUNT	MEDIUM TO LARGE	MEDIUM AMOUNT	NONE
VII	0-5	40-50	4·0	55-70	3·0	80-95	2·5-5·0	·83	23·5	GOOD	STEEL GREY, IRREGULAR	BLOCKY; SLIGHTLY TRIANGULAR	HARD TO FRAGILE	SMALL TO MEDIUM, SLIGHTLY STEPPY	MEDIUM TO SMALL AMOUNT	MEDIUM TO SMALL	SMALL AMOUNT	NONE
	5-10	50-70	4·0	55-70	3·0	80-95	2·5-5·0	·83-·95	23·5-26	"	"	"	"	"	"	"	"	"
	10-15	70-50	5·0	55-70	3·0	80-95	2·5-5·0	·95	26	"	"	"	"	"	"	"	"	"
VIII		50-70	2·0-5·0	45-65	4·0-5·0	60-80	2·5-7·0	·85-·95	24-26	GOOD	STEEL GREY, IRREGULAR	SLIGHTLY TRIANGULAR AND FINGERY	HARD TO FRAGILE; FRIABLE	MEDIUM AMOUNT; SLIGHTLY STEPPY	MEDIUM AMOUNT	MEDIUM, IRREGULAR	SMALL AMOUNT	NONE
IX	0-5	45-55	4·0	70	3·0	93	2·5	·80-·86	22-25	GOOD	STEEL GREY, SLIGHTLY IRREGULAR	BLOCKY, SLIGHTLY TRIANGULAR	TOUGH TO HARD	SMALL TO MEDIUM; SLIGHTLY STEPPY	SMALL TO MEDIUM AMOUNT	SMALL TO MEDIUM	SMALL AMOUNT	NONE
	5-10	55-80	2·0	70-60	3·0-5·0	90	2·5	·86-1·1	25-31·5		"	"	"	"	"	"	"	"
	10-15	80-55	2·0-4·0	70-60	3·0-5·0	90	2·5	1·1-·92	31·5-25		"	"	"	"	"	"	"	"
X		70-80	3·0-5·0	65-80	10·0-5·0	70-80	10·0-7·0	·95-1·1	26-30	FAIR TO GOOD	DULL; GRANULAR	BLOCKY; IRREGULAR	TOUGH; FRIABLE	SMALL AMOUNT, SLIGHTLY STEPPY	SMALL AMOUNT	SMALL TO MEDIUM	GRANULAR ENDS	PEBBLY
XI		70-80	3·0	70-80	5·0	85-90	3·0-4·0	1·0-1·1	30-31	FAIR	DULL TO STEEL GREY; IRREGULAR	BLOCKY; SQUARE	TOUGH	SMALL AMOUNT; VERY SLIGHTLY STEPPY	SMALL AMOUNT	IRREGULAR	VERY LITTLE	NONE
XII		80	3·0	80	5·0	85	4·0	1·0-1·1	30-31	FAIR TO POOR	DULL GREY, IRREGULAR	BLOCKY; IRREGULAR	TOUGH; FRIABLE	VERY SMALL AMOUNT; IRREGULAR	VERY LITTLE	IRREGULAR	VERY LITTLE	NONE
XIII		25-70	4·0-3·0	30-70	20·0-5·0	50-80	15·0-5·0	·85-1·1	23·5-28	GOOD	DULL GREY, GRANULAR	BLOCKY; IRREGULAR	FRIABLE	SMALL TO MED. AMOUNT; IRREGULAR	SMALL TO MEDIUM AMOUNT	VERY LITTLE TO NONE	GRANULAR ENDS	PEBBLY TO NON COKING

*DIFFICULT TO DISCHARGE.

Figure-1 Classification for By-product Cokes according to their physical properties, employing Volatile Matter and "Swelling Index" at 600° C. of the coal.

design and procedures repeatability and reproducibility of results have been so variable that the test cannot be considered as satisfactory for precision work (6). However, it does make possible a separation of coals into varying types in accordance with their plastic behaviour.

(c) Agglutinating Value (Table VII)

The U.S. Bureau of Mines method of determining the agglutinating value (7) of coals consists of mixing 1.25 grams of finely ground coal with 18.75 grams of sized silicon carbide (silicon carbide: coal ratio of 15:1) compressing the mixture in a cylindrical crucible and carbonizing for 20 minutes at 950°C. The resulting carbonized button is crushed in a compression testing machine, and the crushing strength, expressed in kilograms, is taken as the agglutinating value. The value obtained is an approximate measure of that material in coal which fuses and becomes plastic on heating.

The above test is not used at the Fuels Division, but has been described as the U.S. Bureau of Mines employ it in assessing coking coals.

2. Laboratory Carbonization Tests

As indicated in the introduction to this report the basic reason for conducting this investigation was to attempt to correlate the physical properties of the cokes produced by means of certain laboratory carbonization tests with that manufactured industrially for metallurgical use. The tests used were as follows:

(a) Bureau of Mines - American Gas Association (BM-AGA) Carbonizing Test

This test (8), which was developed in 1929 as a result of co-operative effort between the U. S. Bureau of Mines and the American Gas Association, is used by the Bureau of Mines as the principal method for determining the carbonizing properties as well as yields of products of coking coals. In this test coal is carbonized in either, or both, of an 18 in. diameter (approximately 185 lb. capacity) and a 13 in. diameter (approximately 90 lb. capacity) welded, cylindrical sheet-steel retort in an electrically heated resistance furnace at a temperature of 900°C.*

Although it is conceded (8) that the BM-AGA test "does not yield results that exactly duplicate those obtained in commercial ovens or retorts, the quantity of coal charged in each test is large enough to yield products that are in general similar to those obtained in large plants and in quantity sufficient to permit analyses and tests of quality to be made".

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*Duplicate tests were made in both retorts.

The physical properties of the cokes were determined by means of the A. S. T. M. Standard Shatter and Tumbler Tests, but in the case of the 13 in. retort insufficient coke is available for both the Shatter and the Tumbler Tests (see Table XI).

(b) Bethlehem Test Oven

The Fuels Division has, for some time, been using the coke prepared in a modification of the sole-heated Bethlehem Expansion Tester (9) as an indication of the physical quality of coke that could be made from coals, alone or in blends.

The Fuels Division test oven varies from the A. S. T. M. proposed method in dimension and manner of heating. The carbonizing chamber is smaller, being 8 in. wide, 18-1/2 in. long, and 9 in. deep, and is charged with 25 pounds of coal to a depth of approximately 5 in. Sole heating is effected electrically by means of two Globar elements (1 in. diameter, 24 in. effective length) inserted immediately below the floor of the chamber. The chamber is charged when the sole plate temperature has stabilized at 1350°F. and carbonization carried to completion in 5 to 6 hours, at which time the sole plate temperature has reached a level of 1950°F. and the temperature of the top of the charge about 1200°F. (see Table XII for operating data).

As the amount of the coke produced is rather small, neither the standard Shatter nor Tumbler tests can be employed to determine coke quality. Instead, a modification of the A. S. T. M. Tumbler Test for coal, described later, was used. Table XIII gives a description of coke from this test and Table XIV the data on the physical properties.

3. Expansion Tests

Both the U. S. Bureau of Mines and the Fuels Division determine the expansion or contraction characteristics of coals by means of modified Bethlehem Expansion Testers. The Bureau of Mines' apparatus and that of the Fuels Division, described above, differ in the size of coking chamber, and in the heating schedule. The coking chamber in the Bureau of Mines' tester (10, 11, 12, 13) is 11 inches wide, 24 inches long, and 11 inches deep. The quantity of coal charged is adjusted to give a final coke thickness of about 5 inches (about 35 pounds required). The initial floor temperature of 550°C. at the start of a test is increased to 950°C. on a fixed schedule; and carbonization is continued until the top of the charge reaches a temperature of 500°C. This normally requires about 7 hours. The coal is heated by 9 nickel-chromium resistors, placed longitudinally below the silicon carbide floor-plate, and a constant pressure of 2.2 pounds per square inch is applied to the coal charge through a cast iron cover plate.

The expansion testers are used in both laboratories for obtaining information which aids in choosing coals or blends that will not damage the brick linings of coke ovens during carbonization. The results are shown in Table XVI.

4. Tests for Physical Properties of Cokes

Wherever the carbonization test yielded sufficient coke, standard A. S. T. M. tests were used for assessing their physical properties. Otherwise special tests, as described below, were employed. The test methods used were as follows:

(a) Drop Shatter Test for Coke - A. S. T. M.
Designation: D-141-48

In the case of the industrially produced cokes both the 2 in. and 1-1/2 in. shatter indices were reported (Table XV). In the case of the BM-AGA test cokes (Table XI) using the 18 in. retort, only the 1-1/2 in. index was reported, because according to Smith and Reynolds (14) it has been found to be more reliable for the size of coke pieces obtained from this retort.

(b) Tumbler Test for Coke - A. S. T. M.
Designation: D-294-50

In this test approximately 22 pounds of dried 2 x 3 in. square mesh pieces of coke is tumbled in a 36 in. diameter drum fitted with two 2 in. wide lifters at a rate of 24 r. p. m. for a total of 1400 revolutions. As the result of a thorough investigation by the steel and coke industries in the U. S. (15) it was concluded that the test could be modified without impairing the results by reducing tumbling time to a total of 400 revolutions. In view of this the Fuels Division conducted the test on the industrial cokes by both methods (see Table XV). Both the Stability Factor, per cent material retained on a 1 in. sieve after tumbling, and the Hardness Factor, per cent material retained on a 1/4 in. sieve, are reported. For results on BM-AGA cokes see Table XI.

(c) Jar Mill Test

Where insufficient coke was available for the Tumbler Test for coke, as in the case of the Fuels Division Bethlehem Test, a modification of the Tumbler Test for Coal: - A. S. T. M. Designation D-441-45 was used.

In this test approximately 800 grams of 1 x 1-1/2 in. square mesh coke, carefully prepared by gently breaking larger pieces, is tumbled in a 7-1/4 in. diameter porcelain jar fitted on the inside with three equally spaced 3/4 in. wide lifters. The jar is rotated at 40 r.p.m. for 1 hour. For comparison two values were used for the Stability Factor, namely, the material retained on a 1 in. sieve after tumbling and that retained on a 3/4 in. sieve (see Table XIV for detailed results).

(d) Screen Analysis of Run-of-Oven Coke

In addition to the Jar Mill test, in the case of the Bethlehem tester, a screen analysis, using a series of square mesh screen from 2 in. to 1/8 in., was conducted on the coke as discharged from the oven.

(e) Apparent Specific Gravity

This was determined at the Bureau of Mines by A. S. T. M. methods and at the Fuels Division by a modification of the A. S. T. M. water displacement method (16). In the latter case, the difference in weight of the coke in air and water is used to calculate the apparent specific gravity. For detailed results on all cokes see Tables XI, XIV and XV.

(f) Bulk Density

This was determined in accordance with a standard method (17) on 2 x 3 in. square mesh pieces of dry coke. The test was only applied to the industrial coke, as the laboratory carbonization tests yielded insufficient material (see Table XV).

5. Tests for Carbonization Yields

(a) Industrial Plant Yields

Where possible the yields of the products of carbonization were obtained from plant data for a period of time including the test data. The data obtained were rather limited and included yields of coke, gas, tar, light oil, ammonium sulphate and hydrogen sulphide in the gas. The yields were on the basis of the coal as charged and are shown in Table XXXII.

(b) BM-AGA Test Yields

The BM-AGA test retort is connected with a condensing tar-precipitating and scrubbing train for the recovery of by-products, thus enabling data to be obtained for the yields and quality of all the products of carbonization. According to the Bureau of Mines (8), although the

BM-AGA test does not yield results that exactly duplicate those obtained industrially, tests on a series of coals have shown that "most of the plant yields of coke, gas, and B. T. U. of gas per pound of coal fall between the 900°C. and 1000°C. test results". The yield of ammonium sulphate from the test at 900°C. approximates that from industrial plants, whereas the tar yields at 1000°C. in the 18 in. retort agree closely with industrial yields, and the light oil distilled at 900°C. in the 18 in. retort "is about the same as that obtained in by-product ovens if light oil in the BM-AGA tar is included". The detailed results on the coals used in this investigation are shown in Table XVII.

(c) Sperr and Rose (Koppers) Tube Test

This small scale laboratory high temperature carbonization assay test is a modified version of that used for years by the U. S. Steel Corporation (18). Sperr and Rose replaced the gas burners with a system of electric heaters, and used the large fund of industrial yield data available to them to establish suitable correction factors to convert the test data to commercial yields.

In the test 20 grams of fine coal is spread out in a uniform layer in a hard glass tube packed at its open end with broken firebrick to permit cracking of evolved tar, and fitted with a train to collect tar, water, ammonia, hydrogen sulphide, light oil and gas. The tube is, in accordance with a predetermined schedule, progressively heated from the closed to the exit end by means of a series of horseshoe-shaped electric elements to a maximum temperature at a given point along the tube of 850°C.

The corrected yield data so obtained have been found to be quite comparable with commercial yields, except in some cases in so far as tar yield is concerned where it has been noted that the higher volatile matter coals do not give the high tar yields noted in industrial data. The results of the assays are presented in Table XVIII.

V

DETAILS OF RESULTS

The detailed data obtained in this study are presented in Tables VI to XVIII. The general properties of the coals are given first in Tables VI and VII. This is followed by the analyses of the cokes in Tables VIII and IX. The significant physical properties of the cokes as predicted from the F. R. L. Swelling Index are then given in Table X and this is followed by a detailed summary of the physical properties of the cokes prepared on both the laboratory and industrial scale in Tables XI to XV. The expansion properties of the coals in the Bethlehem oven are given in Table XVI, while the carbonization yields are presented in Tables XVII and XVIII.

TABLE - VI

ANALYSES OF COALS AS CHARGED TO OVENS
(ANALYSED BY FUELS DIVISION)

		Coal A (Blend)		Coal B (Blend)		Coal C (Single Coal)	
Laboratory No.		2603-56		2604-56		2605-56	
		As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analysis							
Moisture	%	7.0	0.0	4.5	0.0	11.0	0.0
Ash	%	5.8	6.2	6.5	6.8	5.5	6.2
Vol. Matter	%	26.3	28.3	30.2	31.6	32.8	36.9
Fixed Carbon	%	60.9	65.5	58.8	61.6	50.7	56.9
Sulphur	%	0.9	0.9	0.9	1.0	2.1	2.3
Calorific Value							
B.T.U./Lb. Gross		13355	14355	13570	14215	12535	14080
Ash Fusibility							
Initial	°F	1980		2370		1870	
Softening	°F	2140		2580		2050	
Fluid	°F	2420		2750+		2150	
Swelling Properties							
Free Swelling Index (A.S.T.M.)*		7.5		7.5		6.5	
F.R.L. Swelling Test							
Vol. Matter at 600°C	%	23.0		25.2		29.4	
Swelling Index		1155		686		833	
Plasticity (Gieseler Test)							
Temp. of Maximum Fluidity	°C	434		432		420	
Maximum Fluidity	D.D.M.+	1187		2134		3174	
Solidification Temp.	°C	467		464		458	
Melting Range	°C	66		67		72	
Specific Vol. Index		176.3		171.5		162.2	
Vol. Matter - d.m.m. free ++	%	29.4		33.1		39.3	
Rank by S.V.I. **		G-orthobituminous		E-parabituminous		D-parabituminous	

\+ D.D.M. = Dial divisions per minute.

* F.R.L. modification using electric cone heaters.

++ Dry mineral matter free.

** Specific volatile index.

TABLE - VII

ANALYSES OF COALS AS CHARGED TO OVENS
(ANALYSED BY U. S. BUREAU OF MINES)

		Coal A		Coal B		Coal C	
Bureau of Mines Sample No.		801		799		802	
		As Rec'd	Dry	As Rec'd	Dry	As Rec'd	Dry
Proximate Analysis							
Moisture	%	7.4	0.0	4.9	0.0	10.7	0.0
Ash	%	6.5	7.0	6.3	6.7	5.8	6.5
Volatile Matter	%	27.1	29.2	30.2	31.8	32.7	36.6
Fixed Carbon	%	59.0	63.8	58.6	61.5	50.8	56.9
Ultimate Analysis							
Carbon	%	75.2	81.2	76.9	80.9	70.1	78.5
Hydrogen	%	5.4	4.9	5.3	4.9	5.9	5.3
Sulphur	%	0.7	0.8	0.8	0.9	2.2	2.4
Nitrogen	%	1.5	1.6	1.4	1.5	1.2	1.4
Oxygen	%	10.7	4.5	9.3	5.1	14.8	5.9
Swelling Properties							
Free Swelling Index (A.S.T.M.)		8.0		7.5		7.5	
Agglutinating Value(1)		6.4		6.6		7.1	
Fixed Carbon - Dry Mineral Matter Free	%	69.1		66.5		61.4	
Bulk Density - Lb./Cu. Ft.		50.5		51.3		50.5	

(1) American Society for Testing Materials. Proposed Method of Test for Agglutinating Value of Coal. A.S.T.M. Standards on Coal and Coke, September, 1951, Appendix VIII.

TABLE - VIII.

ANALYSIS OF INDUSTRIAL COKE SAMPLES
(HALF-OVEN PIECES - DRIED)

		Coal A	Coal B	Coal C
Proximate				
Moisture	%	0.5	0.3	0.2
Ash	%	10.6	9.5	8.7
Volatile Matter ...	%	1.8	1.1	1.2
Fixed Carbon	%	87.1	89.1	89.9
Sulphur	%	1.0	0.7	1.9
Calorific Value, B.T.U./Lb.		12,575	12,575	12,840

TABLE - IX

ANALYSIS OF COKE FROM BETHLEHEM TESTER
(DRIED)

		Coal A	Coal B	Coal C
Proximate				
Moisture	%	0.2	0.3	0.3
Ash	%	11.2	10.5	10.5
Volatile Matter....	%	1.3	1.7	2.5
Fixed Carbon	%	87.3	87.5	86.7
Sulphur	%	0.8	0.6	2.0

TABLE - X

PREDICTED APPROXIMATE QUALITY OF OVEN COKE (1)
(FROM F.R.L. SWELLING INDEX)

		Coal A	Coal B	Coal C
F.R.L. Swelling Index		1155	696	833
Vol. Matter at 600°C	%	23.0	25.2	29.4
Ash	%	6.2	6.8	6.2
Location on Chart	group (2)	III	IV near VII	IV near V
<u>Predicted Quality of Coke</u>				
Size on Wharf				
On 3 in.	%	35-45	40-50	35-45
0 x 1/2 in. (Breeze)	%	1.5-2.5	2-4	2-4
Shatter Test				
Plus 2 in. Index	%	50-65	60-70	45-55
0 x 1/2 in. (Breeze)......	%	2-3	2-3	3-5
Abrasion (3)				
Plus 1-1/2 in. Index	%	85-95	85-90	80-90
Dust - Minus 10 Mesh	%	2-3.5	3-4	3-5
Density				
Apparent Specific Gravity		.90-1.0	.83-.90	.90-1.0
Bulk Density - Lb./Cu. ft.		25-26	24-26	26-28
Transverse Shrinkage		Fair to Good	Good	Good
Shape		Square	Slightly Triangular	Triangular, Somewhat Fingery
Strength		Hard	Hard	Fragile
Cross Fracture		Med. amt. Square	Med. amt. Steppy	Med. to large amt. Steppy
Longitudinal Fracture		Small to Med. amt.	Med. amt.	Med. to large amt.
Cell Structure		Dense	Small to Med. amt.	Medium
Sponge		Very Little	Small amt.	Small to med. amt.
Pebbly Seam		None	None	None

(1) For comparison with industrial coke - see Table XV. (2) See Figure 1.
(3) Sheffield Test.

TABLE - XI

PHYSICAL PROPERTIES OF COKE - BM-AGA TESTS

Test No.	True Specific Gravity (1)	Apparent Specific Gravity	Cells Percent	Shatter Index 1-1/2 - Inch	Tumbler Index, (2) 1-inch	Tumbler Index, (2) 1/4-inch
			(18-inch Retort)			
Coal A						
801-1	1.890	.881	53.4	81.6	43.4;42.3	60.6;62.2
801-2	1.890	.832	56.0	85.5	44.2;44.9	61.2;62.2
Average	1.890	.857	54.7	83.6	43.7	61.6
Coal B						
799-1	1.888	.826	56.3	84.2	48.2;50.2	64.2;63.2
799-2	1.888	.841	55.5	83.2	51.4;48.8	63.8;64.4
Average	1.888	.834	55.9	83.7	49.7	63.9
Coal C						
802-1	1.883	.796	57.7	77.0	34.7	59.3
802-2	1.883	.803	57.4	76.7	36.7;33.7	62.0;59.2
Average	1.883	.800	57.6	76.9	35.0	60.2
			(13-inch Retort)			
Coal A						
801-3	1.890	.832	56.0	---	38.3;36.3	62.7;62.6
801-4	1.890	.850	55.0	---	40.3;41.4	61.4;61.6
Average	1.890	.841	55.5	---	39.1	62.1
Coal B						
799-3	1.888	.807	57.3	---	47.1;46.5	64.3;64.2
Average					46.8	64.3
Coal C						
802-3	1.883	.801	57.5	---	33.6;31.7	60.7;58.7
Average					32.7	59.7

(1) Estimated from ash content of coal. (2) A.S.T.M. Tumbler Test.

TABLE - XII

OPERATING DATA RE COKING TESTS IN BETHLEHEM EXPANSION (BROWN) TESTER

		Coal A		Coal B		Coal C	
		Test 1	Test 2	Test 1	Test 2	Test 1	Test 2
Coal as Charged							
Size - 0 x 1/8 in.	%	70.7	79.7	73.3	73.3	62.4	62.4
Weight	lbs.	25	20	25	25	25	25
Depth in Oven...	in.	5.0	4.25	5.13	4.75	5.0	5.0
Bulk Density ...	Lb./Cu. Ft.	58.5	57.1	58.1	62.5	59.0	59.0
Moisture	%	6.0	6.0	4.0	4.0	10.0	10.0
Carbonization Data							
Coking Time	hrs.	5.5	5.33	5.0	5.17	6.08	5.0
Temp. of Oven Floor							
Initial	°F.	1350	1350	1330	1350	1400	1350
Final	°F.	1950	1950	1950	1950	1950	1950
Temp. of Top of Charge							
Final	°F.	1200	1370	----	1200	1260	1300
Yield of Coke							
(Dry Basis)	%	74.7	73.2	71.5	70.9	67.3	67.6

TABLE - XIII

DESCRIPTION OF COKE FROM BETHLEHEM EXPANSION TESTER

	Coal A	Coal B	Coal C
Shape	Medium Blocky	Blocky	Fingery
Colour	Steel Grey	Steel Grey	Steel Grey
Cross Fracture	Small amt. Square	Small amt. Square	Medium amt. Steppy
Longitudinal Fracture	Medium amt.	Small to med. amt.	Medium to large amt.
Cell Structure	Dense	Dense	Dense
Spongy End	Small amt.	Small amt.	Small amt.
Pebbly Seam	None	None	None

TABLE - XIV

PHYSICAL PROPERTIES OF COKE FROM BETHLEHEM EXPANSION TESTER

	Coal A			Coal B			Coal C		
	Test 1	Test 2	Average	Test 1	Test 2	Average	Test 1	Test 2	Average
Screen Analysis - Run of Retort Coke									
Plus 2 in. sq. .... %	41.8	41.1	41.5	58.8	53.2	56.0	22.6	21.8	22.2
2 x 1-1/2 in. sq....... %	32.8	30.5	31.7	24.3	21.7	23.0	44.4	44.1	44.2
1-1/2 x 1 in. sq....... %	18.2	18.4	18.3	10.2	18.4	14.3	23.5	23.6	23.6
1 x 3/4 in. sq......... %	3.5	4.8	4.1	3.0	2.9	3.0	4.4	5.4	4.9
3/4 x 1/2 in. sq....... %	1.3	1.6	1.5	0.6	1.3	1.0	1.8	1.6	1.7
1/2 x 1/4 in. sq....... %	1.1	1.6	1.3	1.3	1.2	1.2	1.5	0.9	1.2
1/4 x 1/8 in. sq....... %	0.6	0.8	0.7	0.5	0.7	0.6	0.7	0.9	0.8
1/8 x 0 in. sq. .... %	0.7	1.2	0.9	1.3	0.6	0.9	1.1	1.7	1.4
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

	Coal A Test 1		Coal A Test 2		Coal A Average	Coal B Test 1		Coal B Test 2		Coal B Average	Coal C Test 1		Coal C Test 2		Coal C Average
Jar Mill Tumbler Test	a	b	a	b		a	b	a	b		a	b	a	b	
Plus 1 in. .... %	64.2	54.6	60.9	50.1	57.4	58.7	67.6	55.1	59.8	60.3	58.5	41.0	58.9	51.3	52.4
1 x 3/4 in............ %	24.2	32.7	25.2	32.0	28.5	29.3	17.8	30.5	26.3	25.9	26.4	35.7	21.5	30.3	28.5
3/4 x 1/2 in. .... %	2.5	2.9	3.0	6.6	3.8	2.5	3.4	3.8	3.1	3.2	3.8	11.7	6.3	7.8	7.4
1/2 x 1/4 in. .... %	0.8	1.4	1.5	1.9	1.4	1.1	1.4	0.9	1.4	1.2	2.0	1.4	2.7	1.4	1.9
1/4 in. x 14 mesh..... %	1.1	1.1	1.4	1.4	1.2	1.0	1.1	1.1	1.1	1.1	1.2	1.4	1.2	0.7	1.1
14 x 48 mesh. .... %	0.6	0.7	0.9	0.7	0.7	0.6	1.0	0.7	0.9	0.8	1.2	1.1	1.4	0.9	1.1
48 x 0 mesh. .... %	6.6	6.6	7.1	7.3	7.0	6.8	7.7	7.9	7.4	7.5	6.9	7.7	8.0	7.6	7.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plus 1 in. Stability .... %	64.2	54.6	60.9	50.1	57.4	58.7	67.6	55.1	59.8	60.3	58.5	41.0	58.9	51.3	52.4
Standard Deviation (S) ... %					6.8					6.1					8.7
Coefficient of Variation (V)%					11.8					10.1					16.6
Plus 3/4 in. Stability .... %	88.4	87.3	86.1	82.1	85.9	88.0	85.4	85.6	86.1	86.2	84.9	76.7	80.4	81.6	80.9
Standard Deviation (S)... %					3.1					1.3					4.0
Coefficient of Variation(V) %					3.6					1.5					4.9
Hardness Factor (+ 1/4 in.) %	91.7	91.6	90.6	90.6	91.1	91.6	90.2	90.3	90.6	90.6	90.7	89.8	89.4	90.8	90.2
Apparent Specific Gravity	0.97	0.99	0.99	0.99	0.99	0.87	0.91	0.91	0.90	0.90	0.95	0.93	0.92	0.92	0.94

TABLE - XV

PHYSICAL PROPERTIES OF INDUSTRIAL COKE

		Plant A		Plant B		Plant C	
		Range	Average (1)	Range	Average (1)	Range	Average (1)
Shatter Test (A.S.T.M.)							
Plus 2 in. Index	%	60.9-70.2	65.6	60.4-72.5	66.0	55.4-60.7	59.4
Standard Deviation (S)	%		4.0		5.2		2.3
Coefficient of Variation (V)	%		6.1		7.9		3.9
Plus 1-1/2 in. Index	%	81.7-85.6	83.9	83.0-87.0	85.0	75.6-78.2	76.1
Standard Deviation (S)	%		1.7		1.7		1.1
Coefficient of Variation (V)	%		2.0		2.0		1.4
Minus 1/2 in. Fines (Breeze)	%	3.0- 4.0	3.3	2.0- 3.0	2.6	3.0- 4.8	4.0
Standard Deviation (S)	%		0.4		0.4		0.8
Tumbler Test (A.S.T.M.) - (1400 revs)							
Stability Factor (+ 1 in.)	%	42.9-45.1	44.2	46.4-51.2	48.2	19.7-22.1	21.0
Standard Deviation (S)	%		0.9		2.1		1.0
Coefficient of Variation (V)	%		2.0		4.4		4.8
Hardness Factor (+ 1/4 in.)	%	63.9-65.5	64.9	64.7-68.2	65.9	60.2-63.7	61.9
Standard Deviation (S)	%		0.7		1.5		3.5
Coefficient of Variation (V)	%		1.1		2.3		5.7
Tumbler Test (Modified A.S.T.M.) - (400 revs)							
Stability Factor (+ 1 in.)	%	65.3-67.2	66.2	67.2-72.1	70.0	39.9-46.1	42.7
Standard Deviation (S)	%		0.8		2.1		2.7
Coefficient of Variation (V)	%		1.2		3.0		6.3
Hardness Factor (+ 1/4 in.)	%	81.1-82.5	81.7	82.8-84.7	83.8	78.6-79.6	79.0
Standard Deviation (S)	%		0.6		0.8		0.4
Coefficient of Variation (V)	%		0.7		1.0		0.5
Density							
Apparent Specific Gravity		0.92-0.95	0.93 (2)	0.86-0.87	0.86	0.90-0.96	0.92
Standard Deviation (S)			0.012		.004		.026
Coefficient of Variation (V)			1.3		0.5		2.8
Bulk Density (3)	Lb./Cu.Ft.	24.4-24.6	24.5	24.62-24.75	24.7	24.1-24.6	24.4
Standard Deviation (S)	lb.		0.12		0.08		0.30

(1) Averages are of 5 determinations unless otherwise stated. (2) Average of 6 determinations. (3) Average of 3 determinations on 2 x 3 in. pieces.

TABLE - XVI

EXPANSION CHARACTERISTICS
(BETHLEHEM SOLE-HEATED OVENS: 2.2 P.S.I. LOAD)

	Coal A		Coal B		Coal C	
	1. Fuel Division Expansion Test					
Expansion .... %	Nil	Nil	Nil	Nil	Nil	Nil
Contraction............. %	10.0	12.0	5.9	- *	22.0	- *
Contraction Calculated to Bulk Density of 55 lbs/ cu. ft. + ... %	10.9	10.7	8.1	-	20.0	-
	2. U. S. Bureau of Mines Expansion Test					
Expansion .... %	Nil	Nil	Nil	Nil	**	
Contraction Calculated to Bulk Density of 55 lb/ cu. ft. + ... %	9.0	10.2	0.8	1.1	**	

* Trouble with pen of recorder.

\+ Calculation made in accordance with method described in U. S. Bureau of Mines Report of Investigations 5295, "Expansion of Coal in the Sole-Heated Oven, Quantitative Effects of Dry Bulk Density, Moisture Content, and Particle Size", by B. W. Naugle, J. E. Wilson and F. W. Smith, January 1957.

Formula: $$E_{(55)(1)(1)} = \left[\frac{54.45\ (1 + E_t)}{BD_t\ \ (1 - M_t)} - 1\right] + 0.13\ (X_c - 0.01).$$

where $E_{(55)(1)(1)}$ = fractional expansion at a reference bulk density of 55.0 lb. of coal per cu. ft. with 1% moisture and a particle size such that 1% is retained on a 4-mesh sieve, and

X_c = measure of the "as tested" particle size of coal-fraction retained on a 4-mesh sieve.

** Expansion tests not made on Coal C as it contained only 61.4% dry mineral-matter-free fixed carbon, and it is standard practice of the Bureau of Mines to make expansion tests only of coals containing more than 65% dry mineral-matter-free fixed carbon.

TABLE - XVII

YIELD OF CARBONIZATION PRODUCTS - BM-AGA TEST
(AS CARBONIZED BASIS)

Test No.	Retort Size Inches	Yields, Percent of Coal by Weight							H_2S Grains Per 100 Cu. Ft.	Yields Per Ton of Coal			
		Coke	Gas	Tar	Light Oil	NH_3	Liquor	Total		Gas Cu. Ft.	Tar Imp. Gal.	Light Oil, Imp. Gal. In Gas	Ammonium Sulphate, Pounds
							Coal A						
801-1	18	70.5	13.8	4.7	1.12	.181	10.0	100.3	211	10,017	7.8	2.50	25.2
801-2	18	70.1	13.6	4.5	1.12	.177	10.2	99.7	201	9,976	7.4	2.50	25.0
Average		70.3	13.7	4.6	1.12	.179	10.1	100.0	206	9,997	7.6	2.50	25.1
801-3	13	70.1	14.1	4.9	1.07	.184	10.3	100.6	235	9,831	8.1	2.50	25.0
801-4	13	70.3	13.7	4.7	1.17	.191	10.0	100.1	262	9,883	7.7	2.61	24.6
Average		70.2	13.9	4.8	1.12	.188	10.2	100.4	249	9,857	7.9	2.58	24.8
							Coal B						
799-1	18	70.5	13.6	5.7	1.22	.152	8.9	100.1	239	9,822	9.7	2.73	24.3
799-2	18	70.1	13.4	5.5	1.25	.154	9.1	99.5	293	9,683	9.4	2.78	24.6
Average		70.3	13.5	5.6	1.24	.153	9.0	99.8	266	9,750	9.6	2.76	24.5
799-3	13	69.9	14.2	6.1	1.26	.168	9.0	100.6	357	9,870	10.2	2.80	25.2
							Coal C						
802-1	18	62.6	14.6	6.9	1.47	.146	13.8	99.5	824	9,622	11.4	3.27	21.4
802-2	18	62.5	14.5	6.7	1.68	.147	13.6	99.1	730	9,722	11.2	3.74	22.3
Average		62.6	14.6	6.8	1.58	.147	13.7	99.4	777	9,672	11.3	3.50	21.9
802-3	13	61.9	14.9	7.1	(1)	.138	14.0	98.0(1)	870	9,746	11.7	(1)	21.5

(1) Light oil yield not determined.

TABLE - XVIII

HIGH TEMPERATURE CARBONIZATION ASSAY (SPERR AND ROSE TUBE METHOD)
(DRY COAL BASIS)

		Coal A +	Coal B*	Coal C*
Proximate Analysis (Dry Basis)				
Volatile Matter	%	28.3	31.6	36.9
Fixed Carbon	%	65.5	61.6	55.9
Ash	%	6.2	6.8	6.2
Sulphur	%	0.94	0.95	2.31
Fusion point of ash	°F	2140	2580	2050
Products of Distillation				
Water	%	3.751	4.333	5.060
Carbon Dioxide	%	1.216	1.213	1.608
Hydrogen Sulphide	%	0.221	0.239	0.774
Ammonia	%	0.398	0.379	0.387
Light Oils	%	1.043	1.283	1.244
Tar	%	2.564	2.392	2.990
Gas	%	12.706	12.509	13.478
Composition of Gas (Calculated Free of Oxygen, Carbon Dioxide, and H_2S)				
Illuminants	%	4.0	3.5	3.5
Carbon Monoxide	%	5.9	6.2	7.7
Hydrogen	%	60.3	57.8	51.8
Methane	%	27.3	27.8	31.5
Nitrogen	%	2.5	4.7	5.5
Density (Air = 1)		0.314	0.334	0.373
B.T.U. in gas per lb. of dry coal (inclusive of light oils)		2849	2931	3007
Practical Yields (Per Net Ton Dry Coal)				
Total Gas, cu. ft. (inclusive of light oils) (1)		10,428	10,940	10,736
B.T.U. of Gas per cu. ft.		546	536	560
H_2S in Gas	grains/100 cu.ft.	297	306	1012
Tar, (2)	Imp. Gals.	5.79	5.40	6.75
Light Oil, (3)	Imp. Gals.	2.39	2.94	2.85
Ammonium Sulphate, pounds		31.2	26.8	27.2
Ammonia Liquor (4)	Imp. Gals.	8.3	9.4	10.9
Total Dry Coke: per cent of coal		74.8	73.7	70.4

(1) Saturated at 15°C and 760 mm.
(2) 135% of Tube Test Results (11.96 lbs. per Imp. Gal.)
(3) Light Oil = 8.73 lbs. per Imp. Gal.
(4) The Liquor includes the Ammonia carried over with the water but is exclusive of the Ammonia in the tar filter.

\+ Average of Three Tests. * Average of Two Tests.

VI

DISCUSSION OF RESULTS

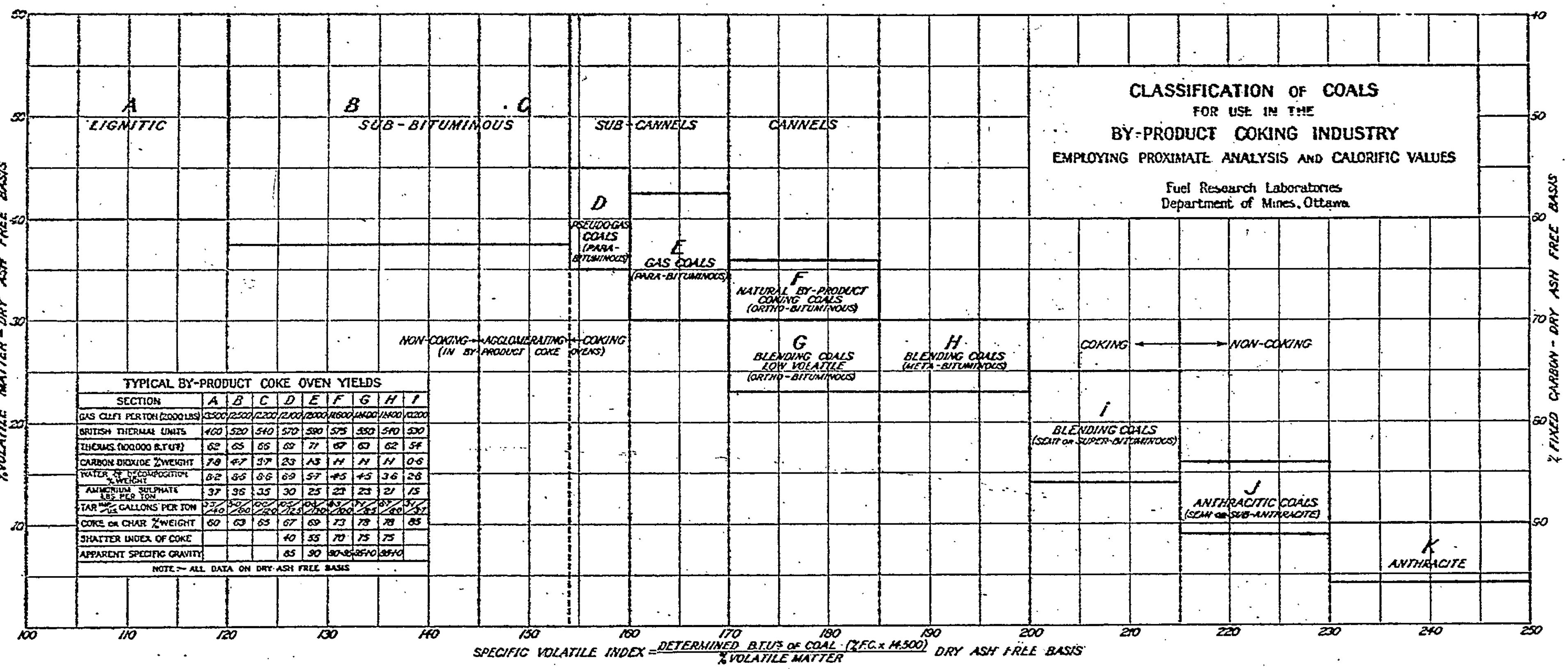
1. General Properties of the Coal Vs. Coke Quality

(a) Volatile Matter and Rank

The three plants considered in this study used different types of charges to their coke ovens. Plants A and B employed blends consisting of 77.5% high volatile A bituminous coals with 22.5% low volatile bituminous coals, whereas Plant C used a very high volatile matter, high volatile A bituminous coal by itself. The volatile matter contents of the coals as charged, and on the dry and dry mineral-matter-free basis are shown in Table XIX. In addition the rank of coal and blends as indicated by the A.S.T.M. method of classification and by the Specific Volatile Index (19) are also given.

In accordance with what is considered to be best coke oven practice, only Plant A appears to have used a charge that should result in the coke with the best physical qualities, all other things being equal.

This is also indicated by the Specific Volatile Index of the coals, where the higher the index the higher the rank. In accordance with the coal classification based on the Specific Volatile Index and Volatile Matter content of the coal (see Fig. 2), coal A falls into Group G of the orthobituminous coals which contain those coals or blends considered



TYPICAL BY-PRODUCT COKE OVEN YIELDS

SECTION	A	B	C	D	E	F	G	H	I
GAS CU.FT PER TON (2000 LBS)	13500	12500	12200	12100	12000	11600	11400	11400	11200
BRITISH THERMAL UNITS	460	520	540	570	590	575	550	540	530
THERMS (100,000 B.T.U'S)	62	65	66	69	71	67	63	62	54
CARBON DIOXIDE % WEIGHT	7.8	4.7	3.7	2.3	1.5	1.4	1.4	1.4	0.6
WATER OF DECOMPOSITION % WEIGHT	8.2	8.5	8.6	6.9	5.7	4.5	4.5	3.6	2.8
AMMONIUM SULPHATE LBS PER TON	37	36	35	30	25	23	23	21	15
TAR IMP/US GALLONS PER TON	33/40	50/60	100/120	105/125	108/130	83/100	71/85	67/80	31/37
COKE OR CHAR % WEIGHT	60	63	65	67	69	73	78	78	85
SHATTER INDEX OF COKE				40	55	70	75	75	
APPARENT SPECIFIC GRAVITY				85	90	90-95	95-10	95-10	

NOTE:— ALL DATA ON DRY-ASH FREE BASIS

Figure - 2

TABLE - XIX

VOLATILE MATTER AND RANK

	Coal A	Coal B	Coal C
Volatile Matter			
As Charged .... %	26.2	30.2	32.8
Dry Basis .... %	28.3	31.6	36.9
Dry, Mineral-matter-free basis .... %	29.4	33.1	39.3
Classification by Rank (A.S.T.M.)+	MV	HVA	HVA
Specific Volatile Index*	176.3	171.5	162.2
Rank by S.V.I.	G-orthobituminous	E-parabituminous	D-parabituminous

\+ MV = Medium Volatile Bituminous.
HVA = High Volatile A Bituminous.

* Specific Volatile Index = Heating Value of Volatile Matter per unit of Volatile Matter.

most suitable for production of metallurgical coke. Coal B is somewhat lower in rank falling into Group E of the parabituminous coals, sometimes referred to as "true gas coals" because of past preference for their use in continuous vertical gas retorts. These coals usually require blending with a moderate amount of high free-swelling low volatile bituminous coals to improve coke quality. Coal C is, relatively, much lower in rank than the other two blends, falling in Group D of the parabituminous coals, often referred to in the past as "pseudo-gas coals". Such coals require blending with fairly large quantities of high free-swelling low volatile bituminous coals for production of coke with more suitable physical properties.

(b) Ash

The ash contents of all the coals were uniformly low and thus may be ruled out as a factor in producing variation in physical quality between the cokes.

(c) Free-Swelling Properties - Predicted Coke Quality

The results of the A.S.T.M. test indicate very little difference between the coals. All the coals show a high and relatively uniform free-swelling index at between 6.5 and 8.0 (see Tables VI and VII).

The F.R.L. Swelling Index (Table VI), on the other hand, indicates Coal A to have the highest index and Coal B the lowest.

However, as the intermediate swelling index of Coal C is associated with a high evolution of volatile matter (at 600°C.) it is in a different category in so far as coke making is concerned. This is shown in Table X which derives its data from the position of the coals in Figure 1. It is to be noted that Coal C should produce a triangular, somewhat fingery coke containing a medium to large amount of longitudinal and steppy cross fracture in comparison with the other coals. These characteristics usually result in a more friable coke which has a lower shatter index and produces more breeze on shattering and more fines on abrasion. In addition, the cells of the coke are larger and less uniform. Generally it may be concluded from the parameters of F.R.L. Swelling Index and volatile matter evolved at 600°C. that, from a physical standpoint, Coal A should make the best coke; Coal B a coke very similar in quality but with a lower apparent specific gravity and slightly higher fines production on abrasion; and Coal C a coke with, comparatively, the least attractive physical qualities. Pinpointing of oven coke quality is not possible with the above discussed test, but the ranges within which the quality might be expected to fall is in agreement with the actual results of the industrial tests.

(d) Plasticity

The maximum fluidity of the three coals as determined by means of the Gieseler plastometer (see Table VI) increases with the volatile matter from 1187 D.D.M. for Coal A to 3174 D.D.M. for Coal C, and decreases as the rank of the coal or blends increases, Coal B lying practically mid-way between the other two coals. Although it is agreed that the fluidity (viscosity) of the coal during carbonization must be a significant factor in relation to the quality of the resultant solidified coke, to date no correlation has been established. Recent work by the British National Coal Board (20) indicated that for a certain series of high volatile (30% to 35%) coal blends the "1-1/2 in. shatter index of the coke was related to:- (a) the fluid range of the coal (correlation coefficient 0.69)", and "(b) the actual volatile content of the coal (correlation coefficient 0.67)". From the data an equation which predicted coke shatter index from fluid range and volatile content of the coal was derived. However, "the accuracy of prediction was not high".

(e) Agglutinating Value (see Table VII)

This value, giving a relative index of the cementing power of the coal which on heating becomes plastic and then solidifies, does not appear to show significant differences between the coals examined, ranging between 6.4 and 7.1. The values, for the coals studied, increase with the volatile matter and with the maximum fluidity. However, it should be noted that Coal C with the highest agglutinating value resulted in the coke with the lowest shatter and stability indices. Thus although there may be a relationship between the agglutinating value and some of the other inherent coking characteristics of the coals as indicated by certain laboratory tests, these relationships do not apparently lend themselves readily to correlation with the physical quality of the resultant oven coke. This can be seen from the data presented below in Table XX. It should be borne in mind, however, that it would be erroneous to draw firm conclusions from the testing of only three coals.

TABLE - XX

RELATIONSHIP OF AGGLUTINATING VALUE TO FLUIDITY OF COAL AND COKE QUALITY

		Coal A	Coal B	Coal C
Agglutinating Value		6.4	6.6	7.1
Volatile Matter - Dry Mineral Matter Free.........	%	29.4	33.1	39.3
Maximum Fluidity	DDM	1187	2134	3174
Quality of Industrial Coke				
2 in. Shatter Index	%	65.6	66.0	59.4
Stability Factor (+1"). .	%	44.2	48.2	21.0
Apparent Specific Gravity..............		0.93	0.86	0.92

(f) General Remarks

Of all the small scale laboratory tests discussed above it would appear that the F. R. L. Swelling Index used in conjunction with the volatile matter evolved at 600°C. gives the most reliable comparative indication as to the physical properties of oven cokes that would be obtained from different coals under similar processing conditions.

2. Quality of Laboratory Carbonization Coke Vs. Industrial Coke

(a) BM-AGA Test Coke Vs. Industrial Coke

(i) Shatter and Tumbler Indices

It is of importance to note that although the BM-AGA retorts are cylindrical, yielding triangular shaped pieces of coke, the 1-1/2 in. Shatter Index and, except in one case, the 1 in. Tumbler Index (Stability Factor) of the coke from the 18 in. retort checked closely with those of the industrial cokes. This is indicated in Table XXI which presents average values.

TABLE - XXI

COMPARATIVE SHATTER AND TUMBLER INDICES OF COKES

		Coal A	Coal B	Coal C
BM-AGA Coke				
1. 18 in. Retort				
1-1/2 in. Shatter Index	%	83.6	83.7	76.9
1 in. Tumbler Index	%	43.7	49.7	35.0
2. 13 in. Retort*				
1 in. Tumbler Index	%	39.1	46.8	32.7
Industrial Coke				
1-1/2 in. Shatter Index	%	83.9	85.0	76.1
1 in. Tumbler Index	%	44.2	48.2	21.0

* Shatter tests are not done, because insufficient coke is available.

The exception is the 1 in. Tumbler Index of the coke from the high volatile Coal C which showed a substantially higher value than the industrial coke. The reason for this is not obvious, especially since the 1-1/2 in. shatter indices checked so closely. This anomalous result might be accounted for by either one or both of the following considerations: If it is assumed that the Tumbler test measures other characteristics in addition to resistance to shatter by impact, it is possible that carbonization in a cylindrical retort progresses in a somewhat different manner for coals of very high volatile matter content in comparison with carbonization in an industrial coke oven. In the second place, it should be noted that in Plant C the coal was coked for 23.25 hours instead of 17 hours, though the ovens were the same width in all cases. However, if such procedure has a deleterious effect on coke quality it was not obvious from the shatter test results, but certainly was quite evident from the Tumbler Index. In view of the fact, however, that the company operating Plant C has apparently for some years obtained coke with a low 1 in. Tumbler Index (average about 26), (21), even with normal coking rates it must be assumed that this is characteristic of the coal.

In all cases the cokes from the 13 in. BM-AGA retort showed somewhat lower 1 in. Tumbler indices than the coke from the 18 in. retort. In view of this, and as insufficient coke is produced in the 13 in. retort to run both shatter and tumbler tests, it seems that, of the two, the 18 in. retort would be the more reliable guide to assessing the quality of coke to be expected from any coal or blend.

(ii) <u>Apparent Specific Gravity</u>

As indicated in Table XXII the apparent specific gravities of the BM-AGA cokes are substantially lower than that of the industrial cokes.

TABLE - XXII

COMPARATIVE APPARENT SPECIFIC GRAVITIES OF COKES

	Coal A	Coal B	Coal C
BM-AGA Coke			
1. 18 in. retort	0.86	0.83	0.80
13 in. retort	0.84	0.81	0.80
Industrial Coke	0.93	0.86	0.92

This is characteristic not only of BM-AGA cokes but also of cokes produced in experimental slot-type ovens employing two-sided heating (22, 23). There is no entirely satisfactory explanation for this, but the data show that charge density is a minor factor.

(b) Bethlehem Test Coke Vs. Industrial Coke

(i) Jar Mill Tumbler Test

As the charge to the Bethlehem test oven is small, approximately 25 lbs., insufficient coke is available for any of the standard tests. Because of this the Jar Mill Tumbler test, described earlier, and using 1 x 1-1/2 in. pieces of coke, was used to yield comparative data on the physical quality of the coke. As the ratio of the area of the cold walls and top to the heated sole of the oven is rather high, and as the thickness of coal charge is limited to about 5 in., bias in sampling of the coke was unavoidable. This is reflected in the variability of the test results (see Table XIV). However, if one takes the stability index as the material retained on the 3/4 in. screen instead of on the 1 in. screen, much better repeatability is attained as shown below by the lower coefficient of variation*.

TABLE - XXIII

JAR MILL STABILITY OF BETHLEHEM TEST COKES

	Coal A	Coal B	Coal C
Plus 1 in. Stability			
Average .... %	57.4	60.3	52.4
Coefficient of Variation* .. %	11.8	10.1	16.6
Plus 3/4 in. Stability			
Average .... %	85.9	86.2	80.9
Coefficient of Variation* .. %	3.6	1.5	4.9

* Coefficient of variation = $\frac{\text{Standard Deviation}}{\text{Mean Value}} \times 100 = x$ per cent.

As indicated in Table XXIV the 3/4 in. Jar Mill Stability indices of the Bethlehem test coke compare favourably with the 1-1/2 in. shatter indices of the industrial cokes, although the degree of correlation is not the same in all cases.

TABLE - XXIV

JAR MILL STABILITY BETHLEHEM COKE VS.SHATTER INDEX OF INDUSTRIAL COKE

	Coal A	Coal B	Coal C
Bethlehem Test Coke 3/4 in. Jar Mill Stability ....%	85.9	86.2	80.9
Industrial Coke 1-1/2 in. Shatter Index ....%	83.9	85.0	76.1

(ii) Screen Analysis of Run-of-Retort Coke

Because, as indicated previously, the Bethlehem tester yields such a small quantity of coke that limited testing of quality is possible, it was considered that the size distribution of the coke as discharged from the test oven might yield a correlating factor.

As can be seen in the data below (Table XXV),there would appear to be some relationship between the quantity of Bethlehem tester coke retained on the 1-1/2 in. screen and the 1-1/2 in. shatter index of the industrial coke.

TABLE - XXV

RELATIONSHIP OF SIZE OF BETHLEHEM COKE TO SHATTER INDEX OF INDUSTRIAL COKE

	Coal A	Coal B	Coal C
Bethlehem Tester Coke as Discharged - plus 1-1/2 in. .... %	73.2	79.0	66.4
Industrial Coke 1-1/2 in. Shatter Index .... %	83.9	85.0	76.1
Apparent Specific Gravity			
Bethlehem Test Coke	0.99	0.90	0.94
Industrial Coke	0.93	0.86	0.92
Bulk Density of Charge in Bethlehem Tester Lb/ Cu. Ft.	57.8	60.3	59.5
Bulk Density of Coal before Charging Lb/ Cu. Ft.	50.6	51.0	49.6

(iii) Apparent Specific Gravity

Because of the higher charge density in the Bethlehem oven, as compared with the average that might be expected in a coke oven, the apparent specific gravities of the Bethlehem tester cokes are higher than the industrial cokes (see Table XXV). However, they follow the variations indicated by the industrial cokes.

(c) Correlation of the Properties of Industrial and Laboratory Test Cokes

In view of the fact that only the results of three coking tests were available it was not possible to apply the r-correlation factor test to any of the data. However, probable correlations may be indicated by means of the ratios between the various quantitative measurements of physical quality, it being assumed that the lower the coefficient of variation of the ratios the greater is the probability of correlation.

The data used for the above type of correlation are presented in Table XXVI, which give the average values for the various physical properties of the cokes.

TABLE - XXVI

DATA ON PHYSICAL PROPERTIES OF COKE USED IN ESTIMATING CORRELATIONS BETWEEN BM-AGA, BETHLEHEM TESTER AND INDUSTRIAL COKES

	Coal A	Coal B	Coal C
Industrial Coke			
(a) 1-1/2 " Shatter Index %	83.9	85.0	76.1
(b) 1" Tumbler Stability %	44.2	48.2	21.0
(c) 1/4" Tumbler Hardness %	64.9	65.9	61.9
(x) Apparent Specific Gravity	0.93	0.86	0.92
BM-AGA: 18 Inch Retort Coke			
(d) 1-1/2" Shatter Index %	83.6	83.7	76.9
(e) 1" Tumbler Stability %	43.7	49.7	35.0
(f) 1/4" Tumbler Hardness %	61.6	63.9	60.2
(y) Apparent Specific Gravity	0.86	0.83	0.80
BM-AGA: 13 Inch Retort Coke			
(g) 1" Tumbler Stability %	39.1	46.8	32.7
(h) 1/4" Tumbler Hardness %	62.1	64.3	59.7
(i) Apparent Specific Gravity	0.84	0.81	0.80
Bethlehem Expansion Tester Coke			
(j) Plus 2" on Wharf* %	41.5	56.0	22.2
(k) Plus 1-1/2 " on Wharf* %	73.2	79.0	66.4
(l) 1" Jar Mill Stability %	57.4	60.3	52.5
(m) 3/4" Jar Mill Stability %	85.9	86.2	80.9
(z) Apparent Specific Gravity	0.99	0.90	0.94

* As Discharged from the Oven.

(i) Correlation of Strength and Abrasion Characteristics

From the various ratios presented in Table XXVII, which are assumed to be indicative of the relationships between the strength and abrasion characteristics of the laboratory and industrial cokes, the following conclusions may be drawn:

18 in. and 13 in. BM-AGA Coke Vs. Industrial Coke

The 1-1/2 in. Shatter Index and the 1/4 in. Tumbler Hardness appeared to give the best correlations, as follows:

(a) 1-1/2 in. Shatter Index - Industrial Vs. 18 in. BM-AGA coke. Average ratio 1.003, coefficient of variation of ratios: 1.5%.

(b) 1/4 in. Tumbler Hardness - Industrial Vs. 18 in. BM-AGA coke. Average ratio 1.038, coefficient of variation of ratios: 1.4%.

(c) 1/4 in. Tumbler Hardness - Industrial Vs. 13 in. BM-AGA coke. Average ratio 1.036, coefficient of variation of ratios: 1.2%.

Probable correlation between the 1 in. Tumbler stability of the Industrial and BM-AGA cokes is poor because of the relatively wide difference between these values for the high volatile Coal C.

It is of interest to note that although there is little or no indication of correlation between the 1-1/2 in. Shatter Index and the 1 in. Tumbler Stability of the industrial cokes (coefficient of variation of ratios: 45.3%), a characteristic noted by other observers, the same two quantitative measurements of physical quality for the 18 in. BM-AGA cokes appear to indicate better correlation (coefficient of variation of ratios: 15.7%). A similar probable relationship appears to exist between the 1-1/2 in. Shatter Index of the industrial cokes and the 1 in. Tumbler Index of BM-AGA cokes (coefficient of variation of ratios: using 18 in. BM-AGA coke results, 14.2%; using 13 in. BM-AGA coke results, 14.3%). More data would be required to determine whether this relationship is close enough for coals or blends with rather widely varying volatile matter contents.

It is also worthy of note that there appears to be a correlation between the 1/4 in. Tumbler Hardness of the BM-AGA and industrial coke (coefficient of variation of ratios: industrial Vs. 18 in. BM-AGA cokes, 1.4%; industrial Vs. 13 in. BM-AGA cokes, 1.2%).

Bethlehem Test Coke Vs. Industrial Coke

As standard tests could not be applied to the Bethlehem tester cokes because of the small quantity of coke produced, correlations were sought between the strength characteristics of the laboratory cokes as indicated by special tests and the industrial cokes as evinced by standard tests. The following appear to show the best relationships:

(a) 1-1/2 in. Shatter Index of Industrial coke Vs. 1 in. Jar Mill Stability of Bethlehem tester coke. (average ratio: 1.441; coefficient of variation of ratios: 2.2%).

(b) 1-1/2 in. Shatter Index of industrial coke Vs. 3/4 in. Jar Mill Stability of Bethlehem coke (average ratio: 0.968; coefficient of variation of ratios: 2.9%). This latter correlation has been included only because the actual numerical values for the 3/4 in. Jar Mill Stability of the laboratory coke approach those of the 1-1/2 in. Shatter Indices of the industrial cokes. This may be a coincidence but it is worthy of note that in both tests the next screen smaller in size than the bottom screen size of the original coke pieces tested yields values which are numerically similar (3 x 2 in. coke used for Shatter Test and 1-1/2 x 1 in. for the Jar Mill Tumbler Test).

(c) 1-1/2 in. Shatter Index of industrial coke Vs. plus 1-1/2 in. size as discharged from Bethlehem tester (average ratio: 1.123; coefficient of variation of ratios: 3.7%).

(d) 1/4 in. Tumbler Hardness of industrial coke Vs. 1 in. Jar Mill Stability of Bethlehem coke(average ratio: 1.135; coefficient of variation of ratios: 4.6%).

From the above it would appear that there is probably a strong relationship between the 1-1/2 in. Shatter Index of the industrial coke and the 1 in. or 3/4 in. Jar Mill Tumbler Stability and the quantity of plus 1-1/2 in. coke as discharged from the Bethlehem tester. In addition, the 1/4 in. Tumbler Hardness of the industrial cokes appears to be related to the 1 in. Jar Mill Stability of the Bethlehem cokes.

Correlation between the 1 in. Tumbler Stability of the industrial cokes and the 1 in. Jar Mill Stability of the Bethlehem coke appears to be very poor.

Bethlehem Vs. 18 in. BM-AGA Test Coke Vs. Industrial Coke

Table XXVIII presents the correlation ratios of BM-AGA to Bethlehem tester cokes for two quantitatively assessed physical properties of the BM-AGA cokes which, as shown above, indicated correlation with industrial cokes.

TABLE - XXVII

CORRELATION OF PHYSICAL PROPERTIES OF COKES INDICATIVE OF STRENGTH FROM BM-AGA AND BETHLEHEM EXPANSION TESTERS WITH INDUSTRIAL COKE

	Ratios *		Coal A	Coal B	Coal C	Average	Standard Deviation S	Coefficient of Variation %
1.	Industrial: 1-1/2" Shatter Index / 18" BM-AGA: 1-1/2" Shatter Index	= a/d	1.004	1.016	0.990	1.003	0.015	1.5
2.	Industrial: 1-1/2" Shatter Index / 18" BM-AGA: + 1" Tumbler Stability	= a/e	1.920	1.710	2.174	1.935	0.274	14.2
3.	Industrial: + 1-1/2" Shatter Index / 13" BM-AGA: + 1" Tumbler Stability	= a/g	2.146	1.816	2.324	2.095	0.300	14.3
4.	Industrial: 1" Tumbler Stability / 18" BM-AGA: 1" Tumbler Stability	= b/e	1.011	0.970	0.600	0.860	0.243	28.3
5.	Industrial: 1" Tumbler Stability / 13" BM-AGA: 1" Tumbler Stability	= b/g	1.130	1.030	0.642	0.934	0.288	30.8
6.	Industrial: 1-1/2" Shatter / Industrial: 1" Tumbler Stability	= a/b	1.898	1.763	3.624	2.428	1.099	45.3
7.	18" BM-AGA: 1-1/2" Shatter / 18" BM-AGA: 1" Tumbler Stability	= d/e	1.913	1.684	2.197	1.931	0.303	15.7
8.	Industrial: 1-1/2" Shatter / Bethlehem: 1" Jar Mill Stability	= a/l	1.462	1.410	1.452	1.441	0.031	2.2
9.	Industrial: 1-1/2" Shatter / Bethlehem: 3/4" Jar Mill Stability	= a/m	0.977	0.986	0.941	0.968	0.028	2.9
10.	Industrial: 1" Tumbler Stability / Bethlehem: Plus 2 in. on Wharf	= b/j	1.065	0.861	0.946	0.957	0.120	12.5
11.	Industrial: 1" Tumbler Stability / Bethlehem: 1" Jar Mill Stability	= b/l	0.770	0.799	0.401	0.657	0.235	35.8
12.	Industrial: 1-1/2" Shatter Index / Bethlehem: Plus 1-1/2" on Wharf +	= a/k	1.146	1.076	1.146	1.123	0.041	3.7
13.	Industrial: 1/4" Tumbler Hardness / 18" BM-AGA: 1/4" Tumbler Hardness	= c/f	1.054	1.031	1.028	1.038	0.015	1.4
14.	Industrial: 1/4" Tumbler Hardness / 13" BM-AGA: 1/4" Tumbler Hardness	= c/h	1.045	1.025	1.037	1.036	0.012	1.2
15.	Industrial: 1/4" Tumbler Hardness / Bethlehem: 1" Jar Mill Stability	= c/l	1.131	1.093	1.181	1.135	0.052	4.6

* Symbols such as a/d etc. refer to the items in Table - XXVI. + As discharged from oven.

TABLE - XXVIII

CORRELATION RATIOS BETWEEN BM-AGA AND BETHLEHEM TEST COKE

Ratios *	d/l	f/l	d/k
Coal A	1.457	1.073	1.141
Coal B	1.388	1.060	1.060
Coal C	1.468	1.149	1.158
Average	1.438	1.094	1.119
Coefficient of Variation .... %	3.3	4.8	5.2

* d = 18 in. BM-AGA:- 1-1/2 in. Shatter Index.
f = 18 in. BM-AGA:- 1/4 in. Tumbler Hardness.
l = Bethlehem:- 1 in Jar Mill Stability.
k = Bethlehem:- Plus 1-1/2 in. coke as discharged from oven.

The relatively low coefficients of variation of the ratios appear to indicate probable correlations of the physical properties of the cokes from the two laboratory tests.

Table XXIX compares the average ratios and coefficients of variation of the above with similar correlation data between the Industrial and Bethlehem Test cokes.

TABLE - XXIX

CORRELATION RATIOS BETWEEN BETHLEHEM AND INDUSTRIAL COKE

	*	Ratios	Coefficient of Variation %
1.	d/1	1.438	3.3
	a/1	1.441	2.2
2.	f/1	1.094	4.8
	c/1	1.135	4.6
3.	d/k	1.119	5.2
	a/k	1.123	3.7

* a = Industrial coke : 1-1/2 in. Shatter Index.
c = Industrial coke : 1/4 in. Tumbler Hardness.
d, f, k, 1 - As in Table XXVIII.

The fact that the ratios of groups 1 and 3 (Table XXIX) are very similar and the coefficients of variation of the ratios are relatively low and uniform appears to indicate that the 1-1/2 in. Shatter Indices of the 18 in. BM-AGA and industrial cokes are closely related to both the 1 in. Jar Mill Stability of the Bethlehem coke, and the quantity of plus 1-1/2 in. Bethlehem coke as discharged from the test oven.

A correlation between the 1 in. Tumbler Stability of the BM-AGA and industrial cokes with the 1 in. Jar Mill Stability of the Bethlehem coke does not appear to be as firm, although some relationship is evident.

It should be cautioned that more data are required to establish the above relationships before they can be applied with certainty.

(ii) Correlation of Apparent Specific Gravities of the Cokes

Table XXX presents the ratios and the coefficients of variation of the ratios between the apparent specific gravities of the cokes made by each of the laboratory tests and the industrial cokes (see Table XXVI for average apparent specific gravity values).

TABLE - XXX

RATIOS OF APPARENT SPECIFIC GRAVITIES OF INDUSTRIAL TO BM-AGA AND BETHLEHEM TESTER COKES

	Ratios		
	Industrial / 18 in. BM-AGA	Industrial / 13 in. BM-AGA	Industrial / Bethlehem Test
Coal A	1.081	1.107	0.939
Coal B	1.036	1.062	0.956
Coal C	1.150	1.150	0.979
Average	1.089	1.106	0.958
Standard Deviation S	0.067	0.052	0.024
Coefficient of Variation ....%	6.2	5.7	2.5

From the above data it would appear that the Bethlehem test coke is in better correlation with the industrial coke than is that from the BM-AGA testers. Although the Bethlehem test coke shows a higher apparent specific gravity than the industrial coke, because of the higher charge density, it follows the same trend as the latter.

3. Laboratory Vs. Industrial Carbonization Yields

As some uncertainty existed concerning the results of the plant yields, especially with regard to coke, comparisons between industrial and laboratory yields are very tentative.

The yields of carbonization products, on the dry and charged basis, as determined by the BM-AGA and Sperr and Rose tests are shown, in comparison with the industrial yield values, in Tables XXXI and XXXII respectively. Generally, the results indicated the following:

(a) Coke Yields

The BM-AGA and Sperr and Rose test coke yields for the three coals checked very closely with the industrial yields.

(b) Gas Yields

The BM-AGA and Sperr and Rose gas yields for the three coals showed some deviations from each other as well as from the industrial yields.

A better comparison would be the B. T. U. in the gas per pound of coal. These are shown in Table XXXIII in comparison with the volatile matter on the dry basis.

TABLE - XXXI

COMPARISON OF YIELDS OF CARBONIZATION PRODUCTS - DRY COAL BASIS

	Yields: Weight %	Yields: Per Ton of Coal					
	Coke	Gas Cu. Ft.	Tar Imp. Gal.	Light Oil Imp. Gal.	Ammonium Sulphate Lbs.	H_2S Gr./100 Cu. Ft. of Gas	Calorific Value of Gas BTU/ Cu. Ft.
Coal A							
BM-AGA Test							
18 in. retort	75.6	10,749	8.2	2.7	27.0	206	566
13 in. retort	75.5	10,599	8.5	2.8	26.7	249	568
Sperr and Rose Test	74.8	10,428	5.8	2.4	31.2	297	546
Industrial Test	(1)	10,475	5.8	2.9	----	270	518
Coal B							
BM-AGA Test							
18 in. retort	73.6	10,209	10.1	2.9	25.7	266	585
13 in. retort	73.2	10,335	10.7	2.9	26.4	357	585
Sperr and Rose Test	73.7	10,940	5.4	2.9	26.8	306	536
Industrial Test	74.9	11,769	6.9	2.7	19.0	250-310	535
Coal C							
BM-AGA Test							
18 in. retort	70.3	10,867	12.7	3.9	24.6	777	603
13 in. retort	69.6	10,950	13.1	---	24.2	870	605
Sperr and Rose Test	70.4	10,736	6.8	2.9	27.2	1012	560
Industrial Test	69.4	11,140	11.5	3.5	20.3	---	---

(1) Only yield of Blast Furnace Coke given (See Table - XXXII).

TABLE - XXXII

COMPARISON OF YIELDS OF CARBONIZATION PRODUCTS -
BASIS OF COAL AS CHARGED

	Moisture in Coal %	Yields, Per Cent of Coal by Weight				Yields, Per Ton of Coal				H_2S
		Gas	Tar	Light Oil	Coke (1)	Gas Cu. Ft.	Tar Imp. Gal	Light Oil Imp. Gal.	Ammonium Sulphate Lbs.	Gr./100 Cu. Ft. of Gas
				Coal A						
BM-AGA Test										
18 in. retort	7.0	13.7	4.6	1.12	70.3	9997	7.6	2.50	25.1	206
13 in. retort	7.0	13.9	4.8	1.12	70.2	9857	7.9	2.58	24.8	249
Sperr and Rose Test	7.0	11.8	2.4	0.97	69.6	9700	5.4	2.22	29.0	297
Industrial Test	7.0	-	-	-	70.0 (2)	9742	5.4	2.72	-	270
				Coal B						
BM-AGA Test										
18 in. retort	4.5	13.5	5.6	1.24	70.3	9750	9.6	2.76	24.5	266
13 in. retort	4.5	14.2	6.1	1.26	69.9	9870	10.2	2.80	25.2	357
Sperr and Rose Test	4.5	11.9	2.3	1.23	70.4	10,448	5.2	2.72	25.6	306
Industrial Test	4.5	-	-	-	71.5	11,239	6.6	2.59	18.1	250-310
				Coal C						
BM-AGA Test										
18 in. retort	11.0	14.6	6.8	1.58	62.6	9672	11.3	3.50	21.9	777
13 in. retort	11.0	14.9	7.1	-	61.9	9746	11.7	-	21.5	870
Sperr and Rose Test	11.0	12.0	2.7	1.11	62.7	9555	6.0	2.54	24.2	1012
Industrial Test	11.0	-	-	-	61.8	9915	10.2	3.10	18.1	-

(1) In the case of the BM-AGA and Sperr and Rose Test the coke yield is calculated on basis of dry coke.
(2) Referred to as "Blast Furnace Coke" and therefore not total coke yield. The total yield would be about 4% higher.

TABLE - XXXIII

COMPARISON OF B.T.U. IN GAS/LB. OF COAL TO VOLATILE MATTER

	B.T.U. in Gas Per Lb. of Dry Coal				Volatile Matter (Dry Basis) %
	BM-AGA		Sperr and Rose Test	Industrial	
	13 in.	18 in.			
Coal A	3010	3042	2849	2713	28.3
Coal B	3028	2986	2931	3148	31.6
Coal C	3312	3276	3007	-	36.9

(c) Tar Yields

In all cases the tar yields as obtained by the BM-AGA test were higher than those given by the Sperr and Rose test. In the case of the high volatile Coal C the BM-AGA and industrial tar yields checked more closely. The Sperr and Rose tar yields were, on the other hand, lower in most cases than the industrial yields, the difference increasing with increase in volatile matter of coal. This has been noted previously.

(d) Light Oil

The light oil yields of the laboratory tests showed reasonably good agreement with the industrial yields, especially in the case of the BM-AGA test.

(e) Ammonium Sulphate

The laboratory tests generally showed higher yields of ammonium sulphate than indicated by the industrial yields available. It should also be noted that in all cases the Sperr and Rose test results were higher than those from the BM-AGA test.

(f) General Remarks

From the data presented in this report it would appear that neither of the laboratory tests seems capable of giving yields of all products of carbonization comparable to that obtained industrially, especially in view of the fact that variations in plant operation will often result in substantial changes in the yields of the various products. For ordinary comparative purposes it would seem that, probably with the exception of the tar yield, the Sperr and Rose test gives reasonably good results. Because it is a test that is run with a very small amount of coal on a laboratory bench for a relatively short period, it is preferable to larger scale tests for yield comparisons. However, where it is desirable to study the quality of the products in addition to yields there is no question as to the preference of a larger scale test such as the BM-AGA retort.

4. Expansion Characteristics

The expansion characteristics of the coals as determined in Bethlehem type sole-heated ovens, by both the U. S. Bureau of Mines and the Fuels Division, are shown in Table XVI.

The three coals showed no expansion, contracting to varying degrees. Although the results of the tests by the two laboratories gave reasonably reproducible results for Coal A, such was not the case with Coal B. It is noteworthy that, although Coal B was higher in volatile matter than Coal A (Coal B - 31.6%, Coal A - 28.3% V. M. dry basis), the former exhibited less contraction, especially in the case of the Bureau of Mines test. The opposite effect was actually expected, but the reason for the reversal is not obvious. In accordance with the Bureau of Mines results, Coal B might be considered as a borderline case with respect to possible expansion. However, even though the Fuels Division results indicate Coal B to be less contracting than Coal A there is no question as to the coal being non-expanding. Such a result would appear to be more in accordance with what might be expected.

Coal C ran true to form. It had the highest volatile matter content (36.9%, dry basis) and exhibited the greatest contraction.

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