COAL FRIABILITY TESTS

A COMPARATIVE STUDY OF METHODS FOR DETERMINING THE FRIABILITY OF COAL AND SUGGESTIONS FOR TUMBLER AND DROP SHATTER TEST METHODS

R. E. GILMORE, J. H. H. NICOLLS AND G. P. CONNELL

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BY

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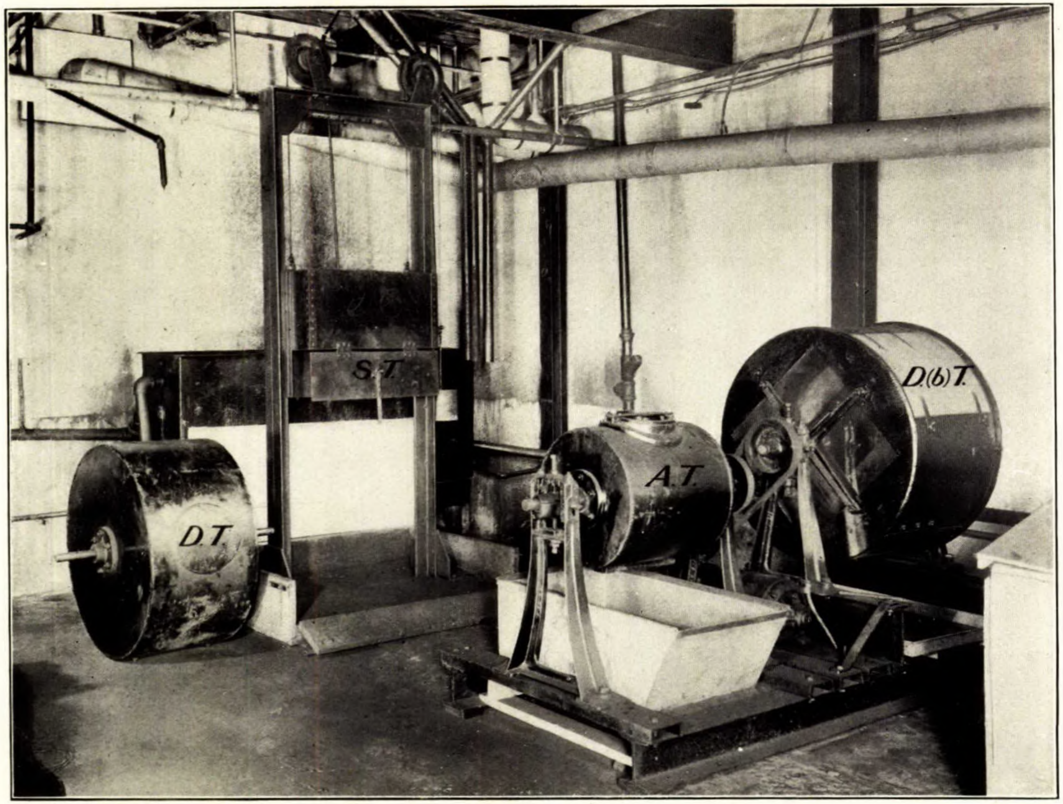

Corner of laboratory with shatter and tumbler test apparatus employed in friability tests on coal: **ST** is the A.S.T.M. (coke) shatter test apparatus, and **AT** the Sheffield (coke) abrasion tumbler; **DT** is A.S.T.M. (coke) tumbler drum removed from its bearings and frame in which it is rotating during test, and **D(b)T** is an experimental drum (box) tumbler, interchangeable with **DT**, and fitted with glass windows for observing the tumbling of the coal during tests.

COAL FRIABILITY TESTS

PREFACE AND REVIEW

R. E. Gilmore*

This report comprises the results of friability tests on coal conducted at the Fuel Research Laboratories of the Department of Mines at Ottawa during 1932, 1933, and 1934. The tests had the dual objective of developing a method for testing the comparative handling properties of ton-lot samples of coal incident to "an investigation of the chemical and physical characteristics of different sizes of coal from Canadian collieries", and also of comparing different laboratory friability methods in connexion with the program of the "Coal Friability" Sub-committee of the American Society for Testing Materials (A.S.T.M.). The function of this sub-committee is to advance a method or methods for the determination of the friability of coal which may be adopted, first tentatively, and which, according to the rules of the Society, may eventually be accepted as a "standard method" of test.

It is realized that the most practical and comprehensive method of ascertaining the comparative handling properties of coal in respect to friability is to examine by screening or other suitable method, shipments at different stages during mining, preparation, and transportation from the mine seam to its ultimate use by the consumer. In fact, it is by observations during these stages that the general handling qualities of coals as mined and marketed are known. However it is realized that, due to the widely varying friability of coals and to the varying handling they receive, comparisons are general only, and that the standardizing of such a large-scale test method is not so simple and practical as it would, on first thought, appear. Therefore, in the opinion of the members of the sub-committee and its sponsors, what is required is a laboratory method, or methods, that may serve as a definite measure of the comparative friability of coals. Such a laboratory method should be simple and the apparatus sufficiently inexpensive so that it would find ready use at collieries, as well as in testing laboratories of the large consumers of coal, and in government, university, and other coal-testing and research laboratories.

Two methods of laboratory procedure have been considered, namely; (a) the measuring of the work done to break down a coal from a given size to a definite lower size, and (b) the performing of a uniform amount of work on the sample and then measuring the reduction in average size of the coal lumps or particles. The latter method has to date received more attention than the former, and the tendency is to endeavour to apply to coal the main features of the standard A.S.T.M. shatter and tumbler test methods for testing coke, in which a fixed amount of work is applied to the sample and the breakage expressed as either a friability or a size stability index.

*Superintendent of Fuel Research Laboratories, and Chairman of Sub-committee XI on Coal Friability A.S.T.M. Committee D-5 on Coal and Coke.

RELATION OF FRIABILITY, GRINDABILITY AND SCREEN SIZE

Friability is an important factor in the selection of coal for various uses, and is closely associated with grindability and screen size. For use in ordinary household furnaces and hand-fired steam boiler installations, it is generally appreciated that sized lump coal having high size stability is a premium fuel, whereas for use in mechanical stokers, by-product coke ovens, etc., the coal may vary widely in friability. For use as pulverized fuel a very friable coal is desired, providing that its rank, grade and storage properties are satisfactory. As to the relation of friability and grindability, tests at the Fuel Research Laboratories indicate that while the grindability indices for different sizes of the same coal may not vary appreciably, grindability does vary directly with friability for a given size of different coals. The details of this general relation will not be discussed further in this report.

In order to measure the friability of a coal as mined, it would obviously be necessary either to pack and carefully ship sections of the seam to the testing laboratory, or to conduct tests on the freshly mined lumps in the mine or at the pithead, with as little handling of the coal as possible from the time it was removed from the seam. It is evident that in coal mining and preparation operations, the tendency is for the weaker lumps to be broken first, the breakage varying directly with the relative friability of different coals mined. This breakage of the weaker lumps progresses every time the coal is handled during transportation, storage, and marketing, so that the unbroken coal eventually delivered to the consumer represents the more stable lumps of the original coal as mined. Furthermore, the breakage of the larger lumps is lessened by the cushioning of the smaller lumps and fines during handling. Hence, interpretation of friability tests on lumps of a given coal should be made with a knowledge of previous handling, and the screen analysis of a representative sample of the supply of coal from which the lumps for test are taken should be known and recorded.

DEFINITION OF TERMS

By "friability of coal", as the term is used in this report, is meant the readiness of coal to crumble or to break into smaller pieces. Friability is a physical characteristic of coal rather than chemical, and implies size deterioration or degradation due to breakage along fracture lines, or due to inherent weakness in the coal lump, big and small. Slacking due to loss of moisture by natural or artificial drying is not to be confused with friability, although it may be the cause of size degradation, especially in the case of low-rank lignite coals. The antonym of friability, as applied to coal, may be said to be "size stability" and, on the assumption that friability may be measured by an index or percentage, it may also be assumed that the complement of a given friability index will be the corresponding size stability index. Since these and other terms are repeatedly employed in this report, explanation of terms used are in order here.

Weight, and Size Degradation. Per cent weight degradation, Dw, and per cent size degradation, Ds, are terms introduced by Smith[4,5], for expressing the friability of a coal as a single number or index. As described by him, Dw is a measure of "true" degradation and was used for expressing the relative degree to which the coal lumps and particles are reduced in weight during test, whereas Ds, a measure of apparent degradation, is employed for expressing the relative extent to which the coal is reduced in screen size. A given lump or lumps of coal may suffer breakage with consequent loss of weight, without being degraded in respect to size, because of the more or less wide variation in the size of lumps in the individual screen sizes selected. Despite the fact that Ds fails to show "true" degradation, it is considered to have practical advantages over Dw in that it is related to screen sizing and, therefore, would apply to the commercial preparation of coal. According to its author, Dw "expresses the reduction in average weight per piece which the test coal undergoes in being dropped, as a percentage of its average weight per piece before dropping", and the term "per cent size degradation" is likewise to be defined as the reduction in average size of the coal lumps, effected during test, as a percentage of the average size in the sample tested. The similarity of other terms to this is elucidated below.

Friability, per cent, is the term introduced by Yancey and Zane[11] for expressing "per cent degradation in size". As defined by these investigators

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Friability, per cent = (original average size − final average size) × 100 original average size.

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$$\text{Friability, per cent} = \frac{(\text{original average size} - \text{final average size}) \times 100}{\text{original average size.}}$$

originally expressed in millimetres, but the use of inches and the arithmetical mean of the passing and retaining screen openings, especially for round hole screens, were considered satisfactory. Although identical with "per cent size degradation" and "percentage size index reduction", the term "friability, per cent" has been adopted in this report for repeated use in the context and in the tables.

Size Index. This term, introduced by Dummett and Greenfield[13], has been found serviceable for shatter tests on both single and mixed sizes. It is derived by means of a planimeter from the screen analysis curve where the accumulative percentage weight is plotted against the size of screen openings, and represents "the characteristic grading index" of the coal screened. It is based on the mathematical observation that the area under the screen analysis curve is a measure of the size grading, being larger for coarser and smaller for finer sizes. The method used by these men and an alternative method for obtaining size indices of coal before and after test is illustrated in Figure 1.

Size Index Reduction, meaning the reduction of "size index" by handling, has been employed by Strong, Burrough, and Swartzman of the Carbonization Section of the Fuel Research Laboratories, and is especially adaptable for friability tests on mixed sizes. The difference between the size indices of the coal before and after test is expressed as a percentage of the size index of the coal sample before test. The percentage size index reduction obtained in this manner represents breakage during the friability test, as illustrated in Figure 1, and is identical with "friability, per cent" and "per cent size degradation".

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Friability, per cent, is the term introduced by Yancey and Zane[11] for expressing "per cent degradation in size". As defined by these investigators,

Friability, per cent = (original average size − final average size) × 100 original average size.

The average size of the coal lumps and particles is calculated from the average areas of the square hole screen openings—the factor for a given screen size being the square root of half of the sum of the squares of the passing and retaining screen openings. The average of the individual screen sizes and the average size of the coal before and after testing were originally expressed in millimetres, but the use of inches and the arithmetical mean of the passing and retaining screen openings, especially for round hole screens, were considered satisfactory. Although identical with "per cent size degradation" and "percentage size index reduction", the term "friability, per cent" has been adopted in this report for repeated use in the context and in the tables.

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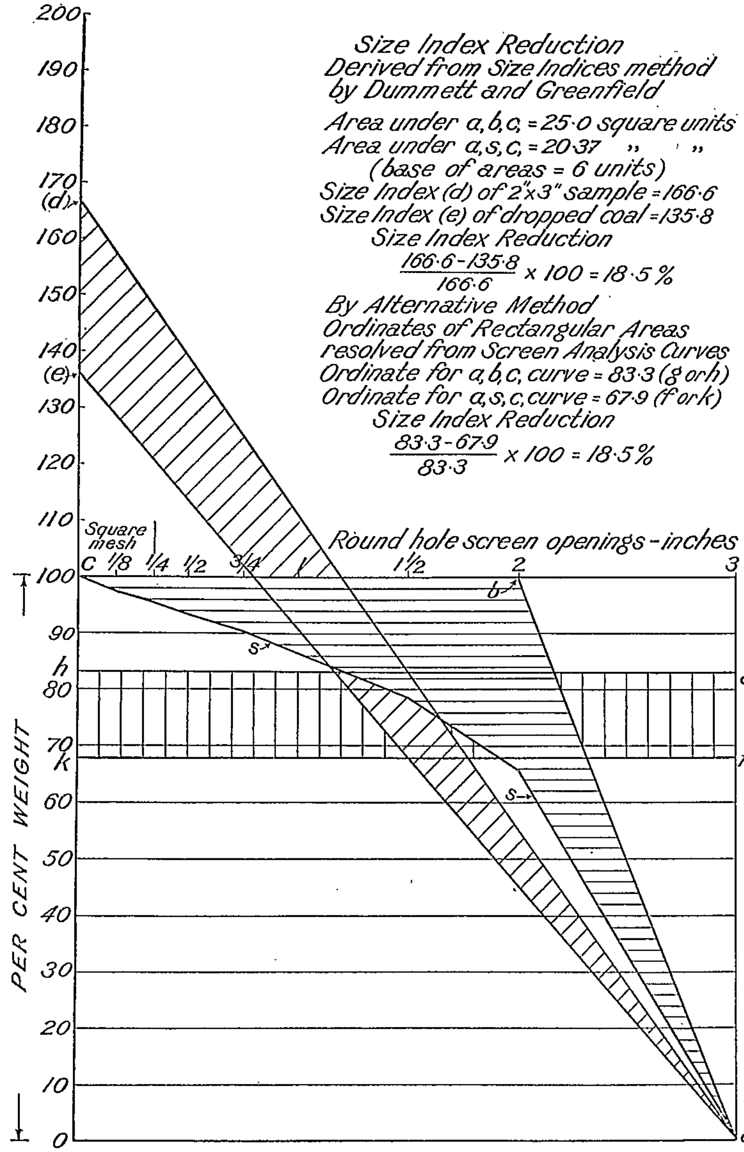

Figure 1. Illustration of derivation of "size index" and method of calculating "size index reduction" for the 2-drop shatter test on 50 pounds of coal No. 4A. Curve ***abc*** represents cumulative screen analysis for the 2- to 3-inch lumps before test, and curve ***asc*** the screen analysis of the mixed sizes after dropping. Areas ***abcs***, ***ade***, and ***fghk*** are equal and represent breakage during the shatter test, to be recorded as size index reduction; (*d*) and (*e*) are the respective size indices for the coal before and after test.

"*Unbroken*", as employed by Nicolls, in Part I of this report represents the lumps remaining on the smaller screen used in preparing the sample as a percentage of the weight of the sample tested. Although strictly speaking it is not a measure of the lumps not broken at all during the test, it does represent the proportion of coal unbroken to the extent that they are retained on the smaller size screen used in preparing the sample.

Size Stability Index A (SSI-A). This term is identical with "unbroken" and is to be defined as the accumulative percentage of the dropped coal remaining on the smaller size screen used in preparing the sample. Though employed in this report in connexion with shatter tests, it is applicable to other drop and tumbler test methods.

Size Stability Index B (SSI-B) is to be defined as the accumulative percentage of the dropped coal remaining on the screen lower and next in the series to the smaller screen used in preparing the sample for test. The series of screens implied are those tabulated below, the size of the holes for every second screen of which bears the ratio of the square root of 4. Hence, the screen size designating size stability index B is half that of the larger screen used in preparing the sample. This index is limited to the testing of lump coal having maximum and minimum size limits corresponding to successive screen sizes in the series and, like size stability index A, it may serve in both drop and tumbler methods for single sizes only. It is applicable to both round and square hole screens, providing the successive screens bear a constant ratio to each other.

Mixed versus Single Sizes. The term "mixed sizes" is used to designate mixtures or blends of two or more single sizes of coal. For example, $1\frac{1}{2}$- to 4-inch, $\frac{3}{4}$- to $1\frac{1}{2}$-inch, $1\frac{1}{2}$-inch slack, and $\frac{3}{4}$-inch slack, are mixed sizes, whereas 3- to 4-inch, 2- to 3-inch, $1\frac{1}{2}$- to 2-inch, 1- to $1\frac{1}{2}$-inch, $\frac{3}{4}$- to 1-inch and $\frac{1}{2}$- to $\frac{3}{4}$-inch are, for the purposes of this report, designated as single sizes.

Size Stability Per Cent is the difference between 100 and any one of the terms, per cent size degradation, friability per cent, or per cent size index reduction, and is therefore the complement of any one of these three identical terms. The term "size stability," though opposite in meaning, is considered preferable to friability, especially in drop shatter tests where the breakage taking place is much less than in the tumbler test methods. To those producers and distributors of coal who like to consider their product as stable in respect to size and would not like to have it reported and advertised as friable or liable to size degradation during mining and transportation, the term size stability per cent would no doubt be preferred to the term, friability, per cent.

To recapitulate, it is assumed that any given friability index may have a complementary size stability index and vice versa. A summary of the terms defined above and their interrelation may be listed as follows:

Friability indices	*Size stability indices*
(a) Per cent size degradation (b) Friability, per cent (c) Per cent size index reduction	(d) Size stability per cent, the complement of any one of (a), (b), or (c) (e) Size stability index A, and (f) Unbroken, are identical. (g) Size stability index B (SSI-B)

SCREENS OR SIEVES

In the different methods advanced and employed by the various investigators for testing the friability of coal, both square and round hole screens have been used. The shatter and tumbler test methods [1,3] specified by the American Society for Testing Materials (A.S.T.M.) for testing coke specify square hole screens, and it is to be noted that square hole screens have been favoured generally for such laboratory tests. For this reason the screens used in the tests reported in Part I were mostly of the square hole variety, either made of wire cloth or stamped out of steel plate. The square hole screens from which selected sizes were used in the comparison of different friability methods had the following sized openings (expressed in inches): 3, 2, $1\frac{1}{2}$, 1, 1·05, $\frac{3}{4}$, 0·742, 0·525, $\frac{1}{2}$, 0·371, $\frac{1}{4}$, 0·263, 0·0116, 0·0058, and 0·0029, the sizes underlined being the regular Tyler wire mesh screens, and those not underlined being the stamped steel plate screens.

The "Illinois Shatter Test" method recommended round hole screens and recently the "Sub-committee on defining coal sizes and coal friability" of the Sectional Committee for the Classification of Coal has recommended them in order to comply with their commercial use in the bituminous coal industry. For this reason, in the development of a shatter test method for coal as outlined in Appendix II of this paper, round hole screens were used for size openings larger than $\frac{1}{2}$ inch. The screens with openings 4 inches to $\frac{1}{2}$ inch inclusive were made from steel plate 3 feet square and fitted with a sheet iron frame 6 inches high. For openings $\frac{1}{4}$ inch and below, square mesh wire screens were used. A special screen with four round holes having openings of 5, 6, 7, and 8 inches respectively was used for sizes of lump coal larger than 4 inches. The complete series of screens employed in the supplementary shatter tests was as follows:

Round hole screen openings:

8-inch	
	Ratio (a) 8 to 6 = 1·333
6-inch	
	" (b) 6 to 4 = 1·500
4-inch	
	" (c) 4 to 3 = 1·333
3-inch	
	" (d) 3 to 2 = 1·500
2-inch	
	" (e) 2 to $1\frac{1}{2}$ = 1·333
$1\frac{1}{2}$-inch	
	" (f) $1\frac{1}{2}$ to 1 = 1·500
1-inch	
	" (g) 1 to $\frac{3}{4}$ = 1·333
$\frac{3}{4}$-inch	
	" (h) $\frac{3}{4}$ to $\frac{1}{2}$ = 1·500
$\frac{1}{2}$-inch	

Square hole screen openings:

3-mesh	with 0·263-inch openings	($\frac{1}{4}$-inch)
6-mesh	with 0·131-inch openings	($\frac{1}{8}$-inch)
48-mesh	with 0·0116-inch openings	

The 3-, 6- and 48-mesh screens were used in conjunction with the round hole screens for screening the dropped coal. These square hole screens are replaceable by the $\frac{1}{4}$-, $\frac{1}{8}$- and $\frac{1}{16}$-inch round hole screens for use in the shatter test method as designated in Appendix II, where, it is to be noted, the $\frac{3}{8}$-inch screen is added.

For the round hole screen sizes $\frac{1}{2}$ inch and larger, it will be noticed that the ratio of every second screen, viz., 8, 4, 2, 1 and $\frac{1}{2}$, or 6, 3, $1\frac{1}{2}$ and $\frac{3}{4}$, is 2, and that the average of any two successive ratios designated (a) to (h) inclusive, as above, is 1·414, the square root of 2. The choice of this set of round hole screens for friability tests is significant in that when the accumulative percentage of the dropped coal retained on either the smaller screen used in preparing the sample or the screen next lower in the series is chosen as a size stability index, the screen size so chosen will bear a constant relation to the original size of the coal tested. The following table demonstrates the meaning and application of the two size stability indices SSI-A and SSI-B, as defined above.

Size of coal tested	SSI-A	SSI-B
	Accumulative percentage of dropped coal retained on	
3″ × 4″	3″ screen	2″ screen
2″ × 3″	2″ "	$1\frac{1}{2}$″ "
$1\frac{1}{2}$″ × 2″	$1\frac{1}{2}$″ "	1″ "
1″ × $1\frac{1}{2}$″	1″ "	$\frac{3}{4}$″ "
$\frac{3}{4}$″ × 1″	$\frac{3}{4}$″ "	$\frac{1}{2}$″ "

The index A is to be considered in view of its recommended use in the coke shatter test as described in Gas Chemists' Handbook (2nd Edition, 1922), but for coal the B index has been found to represent more consistent results, as demonstrated in Part II of this report.

EXAMPLES OF CALCULATIONS FOR PER CENT SIZE DEGRADATION AND FRIABILITY PER CENT

The derivation of size indices of a coal before and after test and the calculation of percentage size index reduction are illustrated in Figure 1. Employing the same screen analysis data afforded by the (two drop) shatter test on the 2- to 3-inch lumps of coal No. 4A, the method of calculating both per cent size degradation (Smith) and friability, per cent (Yancey) may be shown in tabular form as follows:

Screen analysis (round hole screens)			Size degradation factors (Smith method)				Friability, per cent (Yancey & Zane)	
Coal size, in.	Weight recorded, lb.	Per cent of coal on this size	Average hole diameter, in.	Unit size factor	S–s	Weight times S–s	Average size, mm.	Weight per cent times average size
Sample								
3 × 2........	50	100·0	2·50	10(S)	....	....	44·89	44·89
Coal after dropping								
3 × 2........	33	66·0	2·50	10(s)	0	....	44·89	29·63
2 × 1½........	6¼	12·5	1·75	7(s)	3	18·75	31·43	3·93
1½ × 1........	4	8·0	1·25	5(s)	5	20·00	22·45	1·80
1 × ¾........ }	3¼ {	3·5	} 0·75	3(s)	7	22·75 {	15·71	0·55
¾ × ½........ }		3·0					11·22	0·34
½ × 0........	3½	7·0	0·25	1(s)	9	31·50	4·49	0·31
Total, after dropping..............			....	....	....	93·00	....	36·56

$$\text{Per cent size degradation (Ds)} = \frac{100 \times \text{sum of weight} \times (S-s)}{\text{weight of sample} \times S} = \frac{100 \times 93}{50 \times 10} = 18{\cdot}60$$

$$\text{Friability, per cent} = \frac{100 \times \text{difference between average size before and after test}}{\text{Average size of lumps in sample}} =$$

$$\frac{100(44{\cdot}89 - 36{\cdot}56)}{44{\cdot}89} = 18{\cdot}55$$

An alternative method for calculating per cent size degradation, as prescribed by Smith, is the multiplying of the weight of the sample and of each screen size by their respective average screen hole diameter in inches to obtain the average size of the coal lumps before and after test. The average sizes in millimetres given above under per cent friability are the sides of squares inscribed in circles of the arithmetical mean of the diameters of the respective passing and retaining screens. This, it should be noted, is the method adopted by Yancey and Zane[11] for round hole screens based on the assumption that coal breaks into more or less cubical pieces, whereas the average size for square hole screens as derived by these investigators is the square root of half of the sum of the squares of the openings of the passing and retaining screens, expressed in millimetres.

The agreement of the per cent size degradation and the friability, per cent results as in the foregoing numerical example, with each other and with the 18·5 percentage size reduction figure for the same coal sample, as in Figure 1, demonstrates that all three of these expressions for calculating the results of a friability test as a single percentage are, for practical purposes, identical. The difference between 100 and 18·5, namely, 81·5, will be the size stability per cent for this particular 2- to 3-inch size of the coal tested.

COALS SELECTED FOR TEST

No. 1—Pennsylvania anthracite
No. 2—Welsh anthracite
No. 3—Pennsylvania bituminous
No. 4—Nova Scotia bituminous
No. 5—Alberta bituminous
No. 6—British Columbia (Crowsnest area) bituminous
No. 7—British Columbia (Nicola area) bituminous

Coal No. 1 was chosen as a typical high-rank, hard and tough coal with a high size stability index and correspondingly low friability value, and No. 7 as a lower rank (high volatile) bituminous coal with a distinctly high friability index. Coals Nos. 2 to 6 inclusive, according to the shatter test methods, had friability values intermediate between the two extremes. Although the analyses of the seven coals selected are given, it should be emphasized that it was the friability methods that were studied rather than the coals. The order of the coals effected by the different friability methods is significant, and the merits of the friability methods were judged by the spread indicated between the indices of the different coals, and particularly of the least and most friable coals.

PART I—COMPARISON AND INTERRELATION OF LABORATORY METHODS FOR DETERMINING THE FRIABILITY OF COAL

This part of the report, by J. H. H. Nicolls, comprises comparative friability tests on all seven coals. A list of the different friability methods and their original use, whether for coal or coke, is as follows:

1. *Small Jar Tumbler* method advanced by the Fuel Research Laboratories at Ottawa, and adopted in the Seattle Experiment Station of the United States Bureau of Mines, for coal friability experiments.
2. *A.S.T.M. (Coke) Drum Tumbler* method, a modification of A.S.T.M. Serial Designation D294-29.
3. *Box Tumbler* method advanced by Professor E. Stansfield of the University of Alberta for coal friability tests.
4. *Drum (Box) Tumbler* designed and employed at the Fuel Research Laboratories to correlate the drum and box tumbler methods as per 2 and 3, and to study modifications of testing procedure.
5. *Sheffield (Coke) Abrasion Tumbler* method as described by Mott and Wheeler[6] and as used in the Carbonization Section of the Fuel Research Laboratories for coke abrasion tests.
6. *A.S.T.M. (Coke) Shatter Test* method as per Serial Designation D141-23.
7. *Illinois Shatter Test* method advanced by Professor C. M. Smith of the University of Illinois for friability tests on coal.

Following is a summary of the details of tests by six of these methods:—

Method	Amount and size of coal	Time tumbled, number of drops, and nature of breakage	Factors varied in tests here described
Small Jar Tumbler....	1000 grm. 1 × 1½-inch lumps (square hole screen size)	7200 revs., 3 hr., both shattering and attrition	Size of lumps, time tumbled, cushioning, weight of charge, 2-vane versus 3-vane frame, and iron versus porcelain jar
A. S. T. M. (Coke) Drum Tumbler	22 lb., 2 × 3-inch lumps (square hole screen size)	50 revs., 2 min., mostly shattering, some abrasion	Time tumbled
Box Tumbler..........	1000 grm. 1 × 1½-inch lumps (square hole screen size)	Tumbled until 20 per cent through ¼ inch, mostly shattering	Size of lumps, cushioning, and size of holes in apparatus screen
Sheffield (Coke) Abrasion Tumbler	2 cu. ft., 2 × 3-inch lumps (square hole screen size)	690 revs. in 33 min. both shattering and abrasion	Time of tumbling and size of coal
A. S. T. M. (Coke) Shatter Test	50 lb., 2 × 3-inch lumps (square hole screen size)	Dropped 6 ft., four times, practically all shattering	Size of lumps, number of drops, effect of cushioning and weight of sample.
Illinois Shatter Test..	60 lumps, 2½ × 3-inch coal (round hole screen size)	Dropped 10 ft. once, practically all shattering	Size of lumps, number of drops and weight of sample

All Methods Serviceable. Specific conclusions for the several variations of the different friability methods examined are given in the summary at the end of Part I. A general conclusion of the comparative tests is that, since the seven coals are placed approximately in the same order in respect to friability by selected modifications of the different methods, any of these methods may be considered satisfactory for determining the relative friabilities of coals. In addition to the illustration of this conclusion in Figure 2, the minimum and maximum friability indice for the least and most friable coals respectively may be summarized as follows:

Method	Friability, per cent		Difference
	Minimum	Maximum	
Small Jar Tumbler	27 (Coal No. 1)	70 (Coal No. 6)	43
A.S.T.M. (Coke) Drum Tumbler	31 (Coal No. 1)	75 (Coal No. 6)	44
Box Tumbler	741 revs. (Coal No. 1)	33 revs. (Coal No. 6)	708 revs.
Box Tumbler (Drum)	109 revs. (Coal No. 1)	26 revs. (Coal No. 5)	83 revs.
Sheffield (Coke) Abrasion	11 (Coal No. 1)	62 (Coal No. 6)	51
A.S.T.M. (Coke) Shatter Test	18 (Coal No. 1)	57 (Coal No. 7)	39
Illinois Shatter Test	13 (Coal No. 1)	38 (Coal No. 7)	25

Shatter versus Tumbler Test Methods. In the shatter test methods the breakage is mainly caused by impact of the lumps dropping a comparatively long distance on a hard surface, whereas in the tumbler test methods both shattering and abrasion (i.e. attrition) by the lumps falling short distances and against one another take place. That appreciably more breakage occurs in the tumbler tests than in the shatter test methods is evident by the higher friability indices shown by the former. It will be noted that by the two shatter test methods, listed last in the tabulation immediately above, the friability indices range from 13 to 57 for the least and most friable coals with the medium friable coals varying from 23 to 30, whereas by the first two tumbler test methods the range is from 27 to 75 for the least and most friable coals, with a corresponding variation of 40 to 50 for the medium friable coals. This means that nearly double the amount of breakage takes place in the tumbler tests to that which takes place in the shatter tests, and for this reason the conclusion may be drawn that the tumbler tests are more suitable for testing the inherent weakness of coal lumps after a certain amount of breakage of large lumps from which they were derived has taken place, than they are for testing the comparative friability of the different commercial sizes of lump coal as mined or with the minimum amount of handling. Furthermore, in the opinion of the writer, although a tumbler test could no doubt be developed suitable for such lump coal, the tumbler test methods, especially those requiring 1000 grammes or so of 1- to $1\frac{1}{2}$-inch size for best results, should be considered as tests that indicate comparative friability of lumps after a certain amount of handling has taken place and during preliminary plant-crushing operations rather than friability indicative of general handling properties of run-of-mine or screened lump coal from the colliery to the retailer's yard. Shatter tests, on the other hand, would serve better to indicate the relative stability or resistance to breakage of different single or mixed sizes prior to plant crushing, and a shatter test in which the breakage approaches that occurring in the commercial handling from the mine to the consumer should be the aim of the investigators along this line.

PART II—SUPPLEMENTARY SHATTER TESTS

The supplementary shatter tests reported in Part II were made according to A.S.T.M. (Coke) Shatter Test method and are supplementary to those reported in Part I as having been made by this method. For these extra tests, fresh lots of three coals designated as 1A, 4A, and 7A, corresponding with coals Nos. 1, 4, and 7, previously used, were employed, and these represent the least, medium, and most friable of the series of seven coals originally selected for friability tests. In addition to screening tests on 500-pound lots of the three coals to ascertain the relation of square and round hole screen sizes, five series of shatter tests were conducted as follows:—

Tests on 50-pound samples of different single sizes of each coal, with screen analyses after the 1st, 2nd, 3rd, and 4th drop, followed by similar tests with screen analyses of the dropped coal after the 2nd and 4th drops.

Determination of the duplicability of the 2- and 4-drop modifications of the shatter test method using 50-pound samples of the 2- to 3-inch size of coals 1A and 4A.

Comparison of concrete floor versus iron plate as base of apparatus.

Application of shatter test to mixed sizes of coal using the following sizes of coal 4A, namely, $\frac{3}{4}$-inch slack, $\frac{3}{4}$- to $1\frac{1}{2}$-inch lumps, $1\frac{1}{2}$-inch slack, $1\frac{1}{2}$- to 4-inch lumps, and minus 4-inch coal.

The conclusions of these supplementary shatter tests are summarized in Part II immediately preceding Tables XXII to XXVI inclusive, in which the detailed results are given. They need not be further summarized here.

TWO METHODS SELECTED FOR SPECIAL CONSIDERATION

As the friability tests reported in Parts I and II progressed, it was apparent that two methods, namely, the Small Jar Tumbler and the A.S.T.M. (Coke) Shatter Test methods, had sufficient advantages over the others to warrant their selection for special consideration. This was on the assumption that at least two methods, requiring different amounts of sample and size of lumps, could be advanced for tentative consideration by the A.S.T.M. Sub-committee on Coal Friability. Accordingly, in Part I special attention was paid to the Small Jar Tumbler method, the reason being, first, that it was a method which would allow the use of the jar mills already available in coal testing laboratories using the pebble mill method for preparing pulverized coal samples for analyses; and second, it has already been employed in two state university laboratories, namely, North Dakota and West Virginia, as well as in the Seattle Experiment Station of the United States Bureau of Mines, and at the Fuel Research Laboratories, Ottawa, where it was introduced and found useful for studying comparative friabilities of coals and cokes. Likewise, in Part II, the A.S.T.M. (Coke) Shatter Test method received special attention for the purpose of ascertaining what modifications, if any, should be made to make it suitable as a standard method for determining the friability of coal. The fact that the shatter test apparatus is available in testing laboratories throughout the United States and Canada owing to its being specified in A.S.T.M. D141-31—Standard Method of Shatter Test for Coke—is also a reason of prime importance for its special consideration.

It is the purpose and intention of the writer to point out here the merits of the two methods selected rather than to enumerate the less attractive features of those not selected. Some factors influencing their non-selection may be briefly mentioned, however. The A.S.T.M. (Coke) Drum Tumbler method, even after reducing the number of revolutions to 50, requiring two minutes only, did not afford results on the 2- to 3-inch lumps of any additional value to those obtainable on the 1- to $1\frac{1}{2}$-inch coal by the Small Jar Tumbler, and in respect to cost of apparatus and simplicity of test procedure the Small Jar Tumbler method was considered preferable. After due consideration, the principle of performing a uniform amount of work on the sample and then measuring the breakage using screen analysis data appeared to be preferable to the principle of measuring the work done to break down coal lumps from a larger to smaller size, in terms of time required to reduce the lumps to a given size. The latter is the principle involved in the Box Tumbler and the Drum (Box) Tumbler methods, and it is for this reason that these methods have not been considered so satisfactory as the Small Jar Tumbler and the A.S.T.M. (Coke) Shatter Test methods. The Sheffield (Coke) Abrasion Tumbler test method has features that make it attractive as a coal friability method, nevertheless, despite the finding that it had merits superior to the A.S.T.M. (Coke) Drum Tumbler because of the wider range of friability, the Small Jar Tumbler was preferred to it, on account of its requiring a more costly apparatus and a more elaborate procedure for making a test. The Illinois Shatter Test was judged as satisfactory as the A.S.T.M. (Coke) Shatter Test, but the latter method was considered preferable, mainly owing to its already being a standard A.S.T.M. method.

APPENDICES I AND II

In these appendices the two methods selected for further special consideration are presented somewhat in the style adopted in A.S.T.M. "Standards" and "Tentative Standards" publications. Appendix I, it will be noticed, is entitled "Tumbler Test for Coal", for testing the relative friability of lump coal, and Appendix II, "Drop Shatter Test for Coal", for testing the relative size stability of different sizes of coal.

Tumbler Test for Coal. The details of the method as now recommended are much the same as employed in the four government laboratories referred to above. There are two important modifications, however, that need to be specially mentioned, namely, that the tumbling time be *one hour* instead of three hours, and that, providing four jars fitted with frames are available, the tumbling of four 1000-gramme lots of the 1- to $1\frac{1}{2}$-inch coal sample proceed simultaneously and the required screen analysis be made on the 4000 grammes of tumbled coal, instead of each individual lot. The latter modification, which is recommended because the capacity of a single rack tumbling frame is usually four jars, is, however, optional for use when the supply of the sample is ample. The use of iron jar or jars with the same inside dimensions of the porcelain jars is also optional.

By this method friability indices expressed as friability, per cent will range from about 20 for low friable coal to 60 or higher for very friable coals, with indices slightly less than 30 for the medium friable coals reported.

Drop Shatter Test for Coal. The apparatus required for this method is essentially the same as that described in A.S.T.M. D141-23, namely, Shatter Test for Coke. However, modifications in design, of both the box from which the coal is dropped and the superstructure for raising and lowering the box are recommended. The height of the box may be reduced from 15 inches to half this height, and the vertical iron standards supporting the box should be attached to the sides of the bottom cast iron plate. Two drops are recommended instead of four as specified for tests on coke. A feature of this method is that it is applicable for testing different sizes of the same coal as well as a given size of different coals. When a standard size of different coals is to be specified, as in the method for coke, the 3- to 4-inch round hole screen size of coal is recommended. The screens adopted are round hole screens selected from those specified in A.S.T.M. E17-33, in which selected series the ratio of alternate screens is the square root of 4. The breakage by the two-drop modification of this method using the 3- to 4-inch size is approximately the same as in the one-hour tumbler test using the 1- to $1\frac{1}{2}$-inch size. The stability of a given coal, however, increases as the size of the lumps decrease, and for the same size, namely, the 1- to $1\frac{1}{2}$-inch size, the stability by the Shatter Test method is appreciably greater than in the Small Jar Tumbler test. It is for this reason that the expression of the results of the Drop Shatter test in terms of size stability per cent as specified in Appendix II is preferred to the term friability, per cent. The hard (non-friable) coals will show by this method size stability per cent values of about 90 for the 3- to 4-inch lumps, and values of 60 or lower for the same size of the very friable coals. The corresponding size stability per cent for a medium friable coal will be midway between these two limits, that is, about 75.

Recording and Reporting of Results. Tabular forms for recording the data and for calculating the results of tests are given in Appendices I and II for the tumbler and drop shatter tests respectively. In both methods of test, the average or mean openings of the retaining and passing screens used to obtain the different screened products are given in inches. The (weighted) average size of the coal before and after test is designated as S for the larger sample size, and s for the smaller sized product after tumbling or dropping.

In the Tumbler Test—"Friability, per cent" $= \frac{100\ (S-s)}{S}$, and in the Drop Shatter Test—"Size Stability per cent" $= \frac{100 \times s}{S}$.

Numerous tests on the 1- to $1\frac{1}{2}$-inch size of different coals by the Small Jar Tumbler method demonstrated that the accumulative percentage passing the $\frac{3}{4}$-inch screen agreed remarkably well with the calculated friability, per cent. This is the complement of size stability index B (SSI-B), the accumulative percentage remaining on the screen with openings half the size of those in the larger size screen used in preparing the sample. Despite the findings that in the drop shatter test the SSI-B did not agree so closely for the larger sizes of the medium and very friable coals as it did for the smaller sizes of these coals and for all sizes of the more stable coals, it is recommended as optional for reporting the results. Therefore, for the tumbler test, the accumulative per cent passing the ¾-inch screen to be reported as the "*¾-inch friability index*" is specified as optional and likewise in the drop shatter test, the reporting of the SSI-B accumulative percentage simply as the *size stability index* is optional. These are recommended as alternative terms, in the belief that they would be welcomed by the so-called practical coal operators in preference to the term friability, per cent or its complement size stability per cent, which requires considerable calculation.

The use of these optional terms is restricted to the size specified in the tumbler test, and to single sizes only in the drop shatter test, and the series of screens specified in each method must be used, whereas the calculated friability, per cent and its complement size stability per cent are applicable to both single and mixed sizes, and variation in the screens is allowable. Hence, in the tumbler and drop shatter test methods as finally adopted, it will be advisable to specify either the accumulative percentage on a given screen or the calculated (friability or size stability) per cent for reporting the results of test. As explained in the footnotes on the first page of each of the appendices, the drafts of the respective test methods are preliminary only and for the details eventually adopted the reader is referred to the latest editions of "Tentative Standards" or "Book of Standards" of the American Society for Testing Materials.

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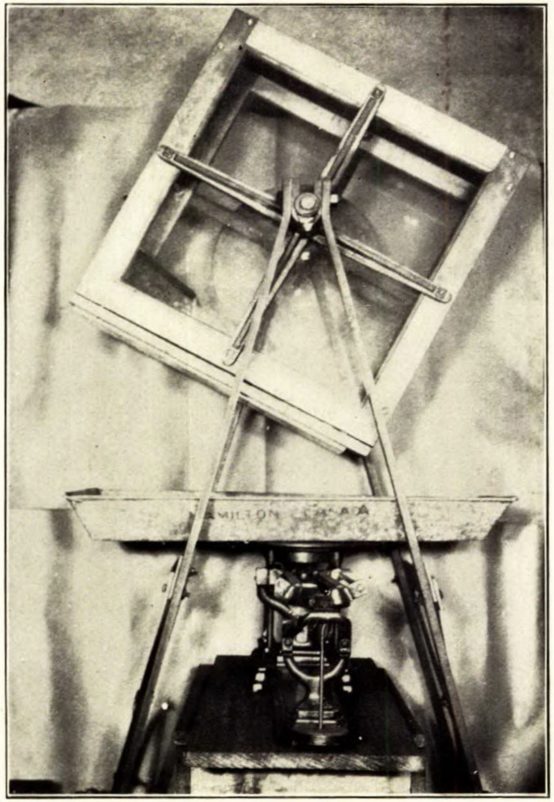
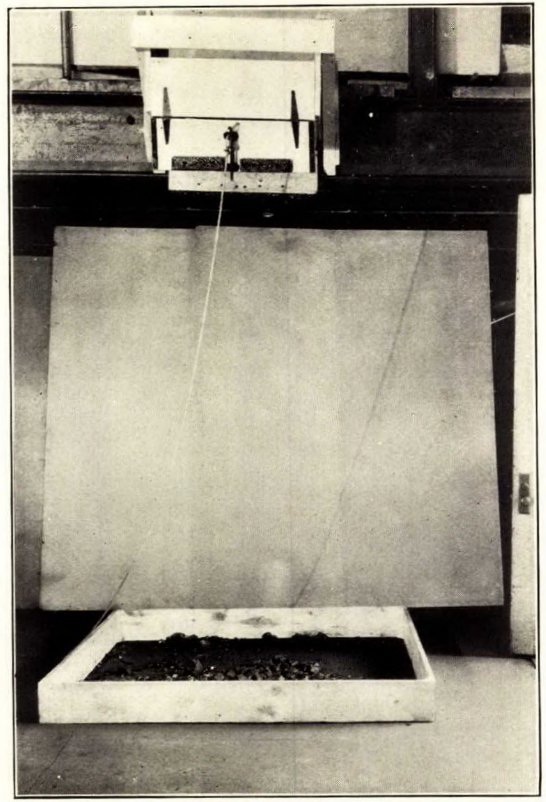


A. Box tumbler test apparatus (**BT**) built according to specifications supplied by Prof. E. Stansfield, with the exception of the glass windows. These were inserted for the purpose of observing the tumbling of coal during experimental tests.



B. Illinois drop shatter test apparatus (**I.S.T.**) as provisionally installed at Fuel Research Laboratories for comparative friability tests. Distance from floor to bottom of box from which coal is dropped is 10 feet.

PART I

COMPARISON AND INTERRELATION OF METHODS FOR THE DETERMINATION OF FRIABILITIES OF COALS

J. H. H. Nicolls

INTRODUCTORY

During the past few years various methods have been proposed for determining the friability, or readiness to break, or, conversely, the size stability, or resistance to breakage, of solid fuel. Such a property is of interest principally to the mine operators and distributors of coal, because of the amount of small sizes that will be produced from a friable coal during mining and shipment, necessitating screening in many cases. It is, also, of some interest to the retailer and consumer when the questions of breakage during delivery and of dust produced during the filling of house-bins are considered.

According to present indications, the classification of coal in North America is to be based principally upon the results of chemical analyses. However, such physical properties as ability to form an agglomerate and liability to disintegrate during exposure to the weather are very likely to carry some weight in classification. Since coals of different ranks vary in friability, either in the total amount of breakage or in the quantities of certain sizes produced, it is not unlikely that friability may also be a useful adjunct to the scheme of classification finally adopted.

It was with this idea in view that the series of tests herewith described was carried out. This is composed of two drop tests, in which the breakage is due almost entirely to shatter or impact, and five tumbling tests in which breakage is due to abrasion or attrition; in three of the tumbling tests there is also a certain amount of shatter effect. Three of the tests have been accepted as standard when used for coke, one of them [2, 7, 8, 9, 10*] has been employed for coal to some extent in Canada and the United States, while the other three have been confined to one or two laboratories.

The purpose of this report is to describe in some detail various tests carried out in the different forms of apparatus upon certain selected coals, and a number of modifications of these tests. The information thus made available may be of service in comparing and correlating friability values obtained by various methods, as has already been done by Yancey and Zane.[11] It is hoped that, from this and other available information, a standard test, or tests, for the determination of friability of North American coal may be selected or developed.

Description of Test Methods

Small Jar Tumbler Test,[2,3] *Sometimes Called the "Small Mill Method."* (Plate III). The apparatus consists, primarily, of a cylindrical porcelain jar such as is often used, when charged with quartz pebbles, for pulverizing

References cited throughout this section will be found on page 14 coal samples. The jar is uniformly dimensioned, being some 7¼ inches deep and having the same measurement for its internal diameter. A cylindrical iron frame consisting of two rings, connected by three strips of iron which project into the jar as vanes or shelves, is fitted into the jar, which is otherwise empty. This is fixed, as nearly in the centre as is feasible, by means of wooden wedges. The frame is constructed of ¾-inch by ⅛-inch material, with the exception of the shelves which are made of iron of ⅝- by ⅛-inch size. The length of the frame is 6½ inches, and its diameter 6⅞ inches. The vanes or shelves, which are supported by brackets attached to the inner surfaces of the rings, are ⅝ inch from the wall of the jar, so that they actually project 1¼ inches into it. Rivets are used in making the frames, rather than bolts, so as to occupy less space and to keep the shelves rigidly attached.

A charge of 1000 grammes (plus or minus 10 grammes) of coal, passed through a screen with 1½-inch square openings and retained upon one with 1-inch openings, is usually placed in the jar for a test. The jar is closed by a set-in porcelain lid, resting upon a heavy rubber gasket, and sealed tightly according to the customary procedure with such jars, that is by means of a bolt working against the lid. The bolt is set in a crossbar, the ends of which are held by a brass strip which fits around the body of the jar. For tumbling, the jar is laid in a horizontal position in a rack, and rotated about its cylindrical axis at the rate of 40 revolutions per minute. The racks usually employed hold from four to twelve jars, and at least four tests are made at the same time for each fuel.

According to the procedure considered as standard in the series of tests herewith described, the coal is tumbled for three hours. (It is, however, believed that it may be advisable to decrease the time to one hour, or at least to 2 hours.) After tumbling, the coal is thoroughly screened, either by hand or machine, upon square-mesh sieves having openings of the following dimensions, in inches: 1·05, 0·742, 0·525, 0·371, 0·0164 (35-mesh), 0·0116 (48-mesh), 0·0058 (100-mesh), and 0·0029 (200-mesh). It has been found satisfactory to screen the broken coal from all four tests at once, and to report the average values obtained.

A.S.T.M. (Coke) Drum Tumbler Test.[3] (Plate I.) The apparatus has been developed as standard by the American Society for Testing Materials, under Designation D294-29, so that it will not be described in detail here. It consists of a steel drum with an inside diameter of 36 inches and an internal length of 18 inches. Two iron shelves, each 2 inches deep, extending across the drum and 180° apart, are riveted to the periphery of the drum for the purpose of picking up the coal, and then dropping it. For introducing and removing the coal the drum is provided with a manhole, the cover for which is made so that its inner surface is flush with that of the drum. It is mounted on two journals, or trunnions, flanged on to its ends, so that its shell is entirely hollow except for the two shelves. It is made to rotate at the rate of 24 revolutions per minute.

Coal passing through a 3-inch square mesh screen and retained on a 2-inch screen was used in this tumbling test. As recommended for the coke test, 22 pounds (approximately 10,000 grammes) was the standard

*As the jars are not of absolutely standard size, the measurements of the frames may be slightly varied to suit individual cases.

quantity used. However, because of the comparative friability of coal, the number of revolutions of the tumbler was reduced from 1400 (1 hour) to 50. After tumbling, the coal, which could be completely removed with a brush, was screened, and its friability calculated as described later. The following screens were used: 2-inch, $1\frac{1}{2}$-inch, 1-inch, 0·742-inch, 0·525-inch, 0·263-inch (3-mesh), 0·131-inch (6-mesh), and 0·0164-inch (35-mesh).

Box Tumbler Test. (Plate IIA.) The apparatus, with a very few modifications, is one designed by Stansfield and Gilbart of the University of Alberta, and described in their correspondence with the Fuel Research Laboratories. It consists of a box 20 inches square by 8 inches deep, all inside dimensions. Three sides of the box are made of $\frac{7}{8}$-inch birch wood and the fourth consists of a wire screen with $\frac{1}{4}$-inch square openings. For purposes of observation, the top and bottom of the box are made up of sheets of heavy glass 18 inches square, centred and mounted in wood. In operation, the box is turned on end and rotated in a vertical plane. For this purpose it is mounted on two journals, or trunnions, which are connected to iron crosses spanning the glass sheets and attached to the wood surrounding them.

To the side of the box next to, and behind (in order of rotation), the wire screen, and six inches from it, there is attached an iron shelf at right angles to the side of the box and projecting for 6 inches into the interior. The width of the shelf is 8 inches, so that it may pick up all the coal under test. There is also, in this side of the box, a trap-door, approximately $5\frac{1}{2}$ inches square, for putting in and removing the coal. The next side is entirely plain, while the third side is covered by a $\frac{1}{8}$-inch steel plate on to which the coal falls and is broken. Outside the screen there is fastened a shallow sheet-iron trough, closed except for its end at the corner near the shelf.

Either $1\frac{1}{2}$- to 1-inch or 1- to $\frac{1}{2}$-inch coal is suitable for this test, 1000 grammes being the weight of the charge. The box is rotated at the rate of 12 revolutions per minute. As the coal breaks, the small fragments pass through the $\frac{1}{4}$-inch screen, out of the opening in the trough and into a tray placed beneath it. The tray is set upon the pan of a suitable balance, so that the weight of material smaller than $\frac{1}{4}$-inch is always available. When 20 per cent (200 grammes) of the coal has passed through the screen, the test is complete. The friability of the coal is denoted either by the number of revolutions of the tumbler or by the time elapsed in seconds. It is clear that true friabilities would be arranged in the order of the reciprocals of the numbers so obtained.

Drum (Box) Tumbler Test. (Plate I.) The apparatus was designed by Gilmore, of the Fuel Research Laboratories, in order to study the combined principles of the A.S.T.M. (Coke) Drum Tumbler and the Box Tumbler. It consists, essentially, of a steel drum of 36-inch inside diameter and 20-inch inside length. In the centre of each end there is cut an opening 22 inches square. Inside the drum there are two circular plates, of 36-inch diameter, made of $\frac{7}{8}$-inch birch wood. In order to observe what takes place inside the drum, a pane of heavy glass, 22 inches square, is let into the centre of each of the wooden plates. One of the plates is attached to the end of the drum, while the other is movable. An oblong opening, 16 by 18 inches, is cut into the periphery of the drum. This can be closed, either by a door made of double thickness sheet iron, with the inner sheet raised so as to be flush with the inside of the drum, or by a round hole screen, consisting of the piece of steel cut from the periphery of the drum drilled with $\frac{21}{64}$-inch openings. The round hole screen is covered, on the outside, by a shield or trough. One end of this trough—that facing backwards when the drum is rotated—is left open so as to allow the broken coal to fall out on to a tray supported on a balance pan, as is the case with the Box Tumbler.

The wooden plate which is not fixed is attached to the end of the drum by a set of four $\frac{3}{4}$-inch expansion bolts. Several sets of expansion bolts are provided, in order to permit the study of the effects of tumbling coal in chambers of various widths. To correspond with these sets of expansion bolts there are shelves, each 6 inches deep, made so that each of them will bridge the gap between the wooden plates at one particular setting. It was decided that the most suitable position for these shelves was about 17 inches behind the open end of the trough. In addition, the tumbler was equipped with two shelves, each 18 by 2 inches, in order to permit tests in comparison with those in the Drum Tumbler. Like the Box Tumbler, the drum is mounted on two journals, or trunnions, which are connected to iron crosses spanning the glass sheets and attached to the ends of the drum. For tumbling tests, the drum is mounted on the same bearings as are used for the Drum Tumbler, and is rotated at a speed of 24 revolutions per minute.

Sheffield (Coke) Abrasion Tumbler Test[6]. (Plate I.) The apparatus consists of a hollow steel drum 18 inches in diameter by 18 long, designed to cause abrasion of coke without any impact or shatter effect. In order to confine the breakage to abrasion, the charge for a determination is fixed at 2 cubic feet. The drum is provided with an 8-inch manhole, the cover of which is made in such a way that its inner surface is flush with that of the drum. Like the A.S.T.M. coke tumbler, this drum is mounted on journals or trunnions flanged on to its ends. The description of the Sheffield test calls for 30 minutes' rotation of the drum at the rate of 23 revolutions per minute, or 690 revolutions. When the drum was set up in the Fuel Research Laboratories, it was found to run at about 21 revolutions per minute. Therefore, 33 minutes were chosen for the normal period of tumbling.

A.S.T.M. (Coke) Shatter Test[1]. (Plates I and IV.) This is a test sponsored by the American Society for Testing Materials, under their Designation D141-23. The apparatus consists primarily of an open iron box, 28 inches long, 18 inches broad and some 15 inches deep. The bottom of the box consists of two equal-sized doors, hinged lengthwise, and meeting so as to make a close joint. These doors are secured by some form of bolt that is readily released, and open downwards and outwards in such a way as not to impede the fall of the fuel under test.

For convenience, the box is attached to a frame in which it can be lowered almost to floor level, or raised to a specified maximum height. A charge of 50 pounds of coal, passing a 3-inch, and retained on a 2-inch, square screen, is placed gently and evenly in the box, which is then raised to the maximum height. Exactly 6 feet below the floor of the box, when it is at the maximum height, there is a plate, of cast-iron or steel, at least half an inch thick and with an area of 38 × 48 inches or larger. This is surrounded by a wall of boards about 8 inches high. In the course of the test specified, the solid fuel is dropped from the maximum height on to the plate. The whole of it is gathered up, returned carefully to the box, and again dropped. This procedure is continued until 4 drops have been made, when the fuel is screened on square hole sieves, having sizes of 2-inch, $1\frac{1}{2}$-inch, 1-inch, $\frac{3}{4}$-inch, $\frac{1}{2}$-inch, $\frac{1}{4}$-inch, and 0·0164-inch (35-mesh).

Illinois Shatter Test[4]. (Plate IIB.) This is similar to the A.S.T.M. shatter test. It was included in the present series principally because of the thorough, and readily available, description of its employment by Smith[4,5] of the University of Illinois, in a study of the friability of certain coals of the United States. The box used is practically identical with that just described, having floor dimension of 30 by 18 inches. The test calls for 60 lumps of coal to be dropped once through a distance of 10 feet on to a concrete floor.

For convenience, and because the availability of the standard test apparatus for coke rendered this test unnecessary except for study, the box employed was not made of iron, but of heavy wood lined with sheet iron. The doors were weighted with lead so that they would quickly fall away from the coal. The box was fixed, by means of scaffolding, so that its floor was exactly 10 feet above a concrete pavement. Sixty lumps of coal passing through a 3-inch round screen, and retained upon a $2\frac{1}{2}$-inch round screen, (the weight of the coal being expressed in pounds) were employed for the test. (These were often replaced, during the tests here described, by 55 lumps of coal of 3- to 2-inch, square, size, in which cases square screens were used following the drop.) The lumps were spread uniformly upon the bottom of the box. In order to avoid scattering, a board enclosure, measuring 72 by 60 inches, by 12 inches deep, was placed on the concrete pavement so that its central point was directly under that of the box. Following the drop, the broken coal was screened through punched plates, or screens, with, respectively, $2\frac{1}{2}$-inch, 2-inch, $1\frac{1}{2}$-inch, 1-inch, $\frac{3}{4}$-inch and $\frac{1}{2}$-inch round holes, and the finest sizes through $\frac{1}{4}$-inch and 0·0164-inch (35-mesh) square screens.

COALS SELECTED

Seven coals, ranging from tough, hard anthracite to distinctly friable bituminous coal, were employed in the tests. These were usually obtained as mixed sizes, or run-of-mine coal, in lots of at least half a ton, and the desired sizes screened out, generally without breaking up the lumps. On account of the quantity of coal required, there was not a very wide field for selection. Furthermore, it was difficult to obtain, from any one consignment, enough 3- to 2-inch (or 3- to $2\frac{1}{2}$-inch round) coal for the four kinds of test in which this size is specified, particularly as each individual test required many pounds of coal. Although it is realized that the friability values obtainable would not necessarily correspond with those of freshly mined coals, it would probably have been advantageous to employ certain other coals, for instance the lower-rank Alberta coals and, perhaps, a typical low-volatile-bituminous (semi-bituminous) coal. However, it is believed that a sufficiently wide range was covered to form a basis for comparison

The following is a list of the coals tested.

1. *Pennsylvania anthracite coal.* A typical hard and tough coal, selected as a representative fuel of low friability. This is sold in large quantities in eastern Canada.

2. *Welsh anthracite coal.* A representative of the more friable type of anthracite, which is sold in large quantities in eastern Canada.

3. *Pennsylvania bituminous coal.* This came from the Pittsburgh seam in Fayette county, and is, presumably, typical of the Pennsylvania bituminous coal imported into Ontario and western Quebec in large quantities. Unfortunately, the laboratory supply of it was soon exhausted.

4. *Nova Scotia bituminous coal.* This is mined in the Sydney area, and is representative of coal shipped in large quantities to Quebec and, to a certain extent, to eastern and central Ontario.

5. *Alberta bituminous coal.* This came from the Mountain Park area, and is typical of coal sold in considerable quantities in the western provinces of Canada. It was employed, principally, in the Drum (Box) Tumbler Test, after the supply of large sizes of other bituminous coals was almost depleted.

6. *British Columbia bituminous coal (a) from the Crowsnest Pass area.* This is representative of coal sold in the Canadian western provinces and in the northwestern United States.

7. *British Columbia bituminous coal (b) from the Nicola area.* This is believed to be sold very largely locally. It is representative of the high-volatile bituminous coals which are affected by impact or shatter rather than by abrasion. Such impact breakage is particularly marked by the amount of the intermediate composite size designated as "smalls", particularly in the tumbler tests. This coal sample was obtained from well below the surface of a storage pile two years old.

The analyses of these samples, or of samples believed to correspond to them, are shown in Table I.

STUDY OF THE METHODS WHEN APPLIED TO THE SELECTED COALS

Tables II and III, and the corresponding Figures 2 and 3, show the applications of a selected modification of each test method to the various coals. Except in the case of the Drum Test of the Pennsylvania bituminous coal and the Illinois Shatter Test of the Nicola coal, each modification is uniform throughout the tables. These tables, and the corresponding diagrams, each contain the same information, but differently arranged so as to assist in studying the effects of the methods. The first table and figure group together the results of each test method when applied to each of the coals, and permit comparison and interrelation of the friabilities of the coals. The second table and figure group together all the results obtained with each individual coal, and allow comparisons of the test methods.

In order to make them as clear as possible, both the tables and diagrams have been planned so as to allocate a definite position to each test of each coal. In any cases where such tests are not available, columns have purposely been left blank. The tables indicate the number of individual tests carried out in order to obtain the average results shown. These amount to 24 in one case. Table III contains a line designated "variant", which is composed of values that may vary when the one form of test is applied to different kinds of coal, or of values that have been altered to suit circumstances.

Throughout the tests, irrespective of whether the test under consideration was of the nature of abrasion or shatter, all the material remaining on the 0·742-inch screen was described as "lumps", that between 0·742- and 0·0164-inch as "smalls", that between 0·0164- and 0·0029-inch as "fines", and the remainder as "dust". All the material on the 0·0164-inch (35-mesh) screen was considered as produced by shatter or impact, and the "fines" and "dust" as due to attrition or abrasion. Recent study of results has indicated that the 0·0116-inch (48-mesh) screen is probably nearer to the dividing line between the results of impact and abrasion than is the 0·0164-inch screen, so that it has been employed, whenever available, to define this line. The principal size divisions are shown in the diagrams, though in some cases "fines" and "dust" have been combined. There is also shown the quantity of material retained by the smaller of the two screens used to prepare the sample, which has been designated as "unbroken".

In addition to the determination of the various sizes, from "lumps" to "dust", produced during the tests, the "friability, per cent" was calculated according to the formula [8, 9, 11], employed by Yancey of the staff of the United States Bureau of Mines, and is shown in the tables and diagrams. This is similar in principle to an earlier formula derived by Smith of the University of Illinois. It represents the reduction in size of the coal during a test procedure, and is determined by means of the calculations described in the following paragraph.

The average diameter of any square screen size of coal is estimated by obtaining the square of the length of the side of the hole through which the coal passed, adding to it the square of the length of the side of the hole upon which it was retained, dividing by 2, and extracting the square root. This has been modified for round hole screens by estimating the average diameter of any size of coal as the length of the side of the largest square (or the diameter of the circle divided by the square root of 2) which could be described in a circle of the mean diameter of the holes in the screens delimiting the size. The "friability, per cent", of a coal, resulting from a test procedure, is obtained by the following means. The percentage of each size produced is multiplied by the average diameter of that size and divided by 100, and the sum of the values thus calculated is subtracted from the average diameter of the original lumps of coal. The difference (reduction in size) so obtained is estimated as a percentage of the original average diameter. It seems to the writer that it will be entirely satisfactory to shorten the calculation by taking the average diameter of all the material smaller than 0·0164 inch and multiplying it by the percentage of this material. In a communication to the writer, Messrs. Yancey and Zane suggested that the usefulness of their friability value might be enhanced by appending to it a figure representing the sum of "fines" and "dust", as above described.

The values just described are all shown for the Box Tumbler Test, though it seems that, if this test were perfect, all such values derived from it might be expected to be identical. The critical value for the Box Test is the number of revolutions made (or the number of minutes elapsed), while 20 per cent of coal is passing through the screen which forms one side of the box. This value is shown in both tables and diagrams, as it is the proper basis by which to compare the friabilities of the fuels submitted to the Box Tumbler Test.

In two cases the values shown result from procedures not quite in agreement with what came to be regarded as normal. The first of these is the Drum Tumbler Test of the Pennsylvania bituminous coal. The earlier tests, including that on this coal, were extended to 100 revolutions. When, subsequently, the tests were reduced to 50 revolutions, it was found that there was no more of the Pennsylvania bituminous coal available. The analysis obtained after 100 revolutions is included in the tables, but has been omitted from the diagrams in order to avoid confusion. Three of the other coals were submitted to tests both of 100 and 50 revolutions, and from these tests a factor was deduced in order to determine the approximate relation between the respective friability percentages. The friability, per cent, of the Pennsylvania bituminous coal, after 100 revolutions, was multiplied by this factor, and the resultant value considered as the friability after 50 revolutions. It is shown in both the tables and figures.

The second case is that of the Illinois Shatter Test of the Nicola coal. This test, in contrast to the others shown with it, is actually in agreement with the standard procedure as used by Smith[4] and described in the earlier part of this report, in that it employs 60 lumps of coal between 3- and $2\frac{1}{2}$-inch round hole screens. Similar tests were carried out with some of the other coals, but it was thought advisable, wherever possible, to use tests with coal prepared, as was prevalent, by square hole screens (which was not at hand from the Nicola sample) when comparing the results obtainable by the different methods. For this purpose, 55 lumps of coal between the 3- and 2-inch square hole screens were assumed to correspond to 60 lumps of coal prepared on the standard round hole screens. When comparing the screen analyses following the test procedures, it was assumed that a $2\frac{1}{2}$-inch round hole corresponds, approximately, with a 2-inch square one, a 2-inch round with a $1\frac{1}{2}$-inch square, a $1\frac{1}{2}$-inch round with a 1-inch square, a 1-inch round with a $\frac{3}{4}$-inch square, a $\frac{3}{4}$-inch round with a $\frac{1}{2}$-inch square, and a $\frac{1}{2}$-inch round with a 0·37-inch square hole.

The test methods will be dealt with individually in the remainder of this report. However, at this point, the following general observations are in order.

The Small Jar Tumbler is notable for the production of "fines" and "dust", more particularly the latter. The Drum Tumbler and the Abrasion Tumbler are the only other forms of test producing these sizes, of less than 0·01 inch, to any degree, and they do so to a much smaller extent than does the Jar Tumbler.

Both the Shatter tests are characterised by almost complete failure to produce "fines" and "dust".

Friability, per cent, as proposed by Yancey and his associates, is a satisfactory value for comparing the friabilities of coals. "Unbroken" coal (the material remaining on the smaller of the two screens used in sizing the coal) and "lumps" (material on $\frac{3}{4}$-inch) will also serve for general comparisons of this nature. When the results of any one form of test are plotted together (Figure 2), "lumps" appear to be the preferable value; when the results of all the tests upon each coal are plotted together (Figure 3), "unbroken" may be the more satisfactory value. While the values just discussed may certainly be used in tests in which speed rather than extreme accuracy is the principal consideration, friability, per cent, is considered as a more satisfactory value, and is given prime consideration throughout this report.

No. 1 is shown to be, distinctly, the least friable coal by all six forms of test. Coals Nos. 2, 3, and 4 are about equally friable, though their order varies slightly according to the different methods. Casual examination indicates that the average friabilities are in the same order as the numbering of the coals. Coals Nos. 5 and 6 are distinctly more friable in every way than the preceding coals. This is shown particularly forcibly by the few revolutions required in the Box Tumbler Test. Coal No. 7, as would be expected from its nature, is less friable than No. 6 by the abrasion tests, and more so by the shatter tests.

The observations lead to the conclusion that any of these tests, when standardized, will be satisfactory for determining friabilities of coals. As has been stated, four of the tests are already in use for the determination of friability. However, results of abrasion tests might be misleading with such coals as that from the Nicola area in British Columbia, and with many of the so-called "domestic" coals of Alberta, for instance Coalspur coal.

STUDY OF VARIATIONS OF THE TEST METHODS

Small Jar Tumbler[2, 8]

Variation of Weight of Coal. The method, as originally described by the writer[1], called for 1200 grammes of coal of $1\frac{1}{2}$- to 1-inch size. Yancey, with his respective associates,[8, 9, 11] and Lawall and Holland[10], subsequently used 1000 grammes. At the beginning of the present series, the writer ran tests both with 1200 and with 1000 grammes of $1\frac{1}{2}$- to 1-inch lumps of No. 3 coal, and found that the effect produced by using the smaller quantity was of the nature of a steady increase in friability, per cent, and in the production of small coal, and that the changes brought about were not very great. Therefore, as Yancey had carried out several series of tests, the writer decided to retain 1000 grammes as a satisfactory weight of coal. To complete this part of the investigation, tests were carried out with 800 and 600 grammes of coal, respectively.

Table IV and Figure 4 contain the results obtained with four weights of coal ranging from 1200 to 600 grammes. They show that friability, per cent increases steadily but slowly as a result of using the smaller weights of coal. Furthermore, they indicate that there is very little rise in the amount of "dust" produced, the principal increase consisting of "lumps" broken so as to pass through the screen upon which they were originally retained. There is, actually, a greater effect produced by changing from

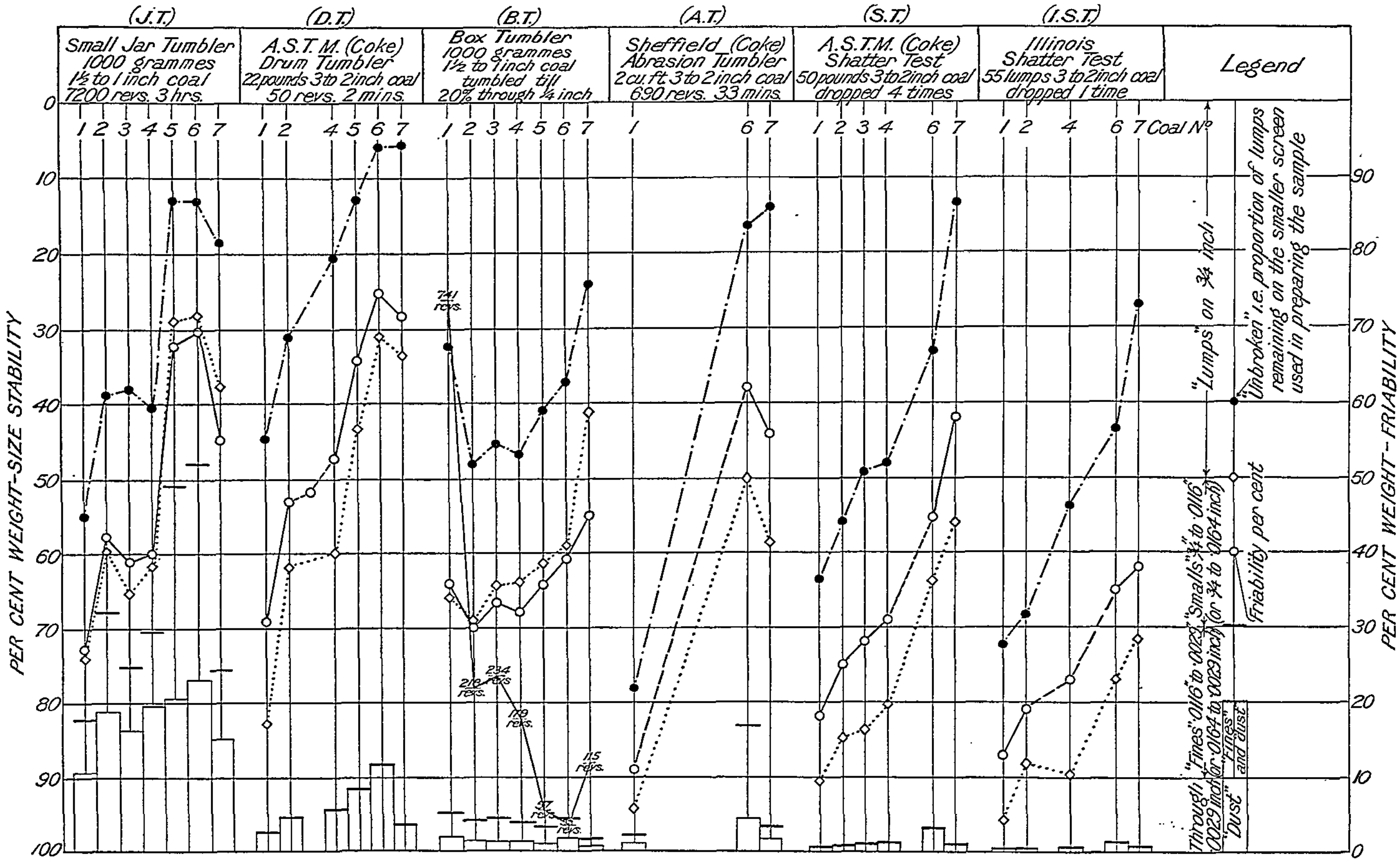


Figure 2. Six friability tests on seven selected coals—comparison of the individual coals by each test.

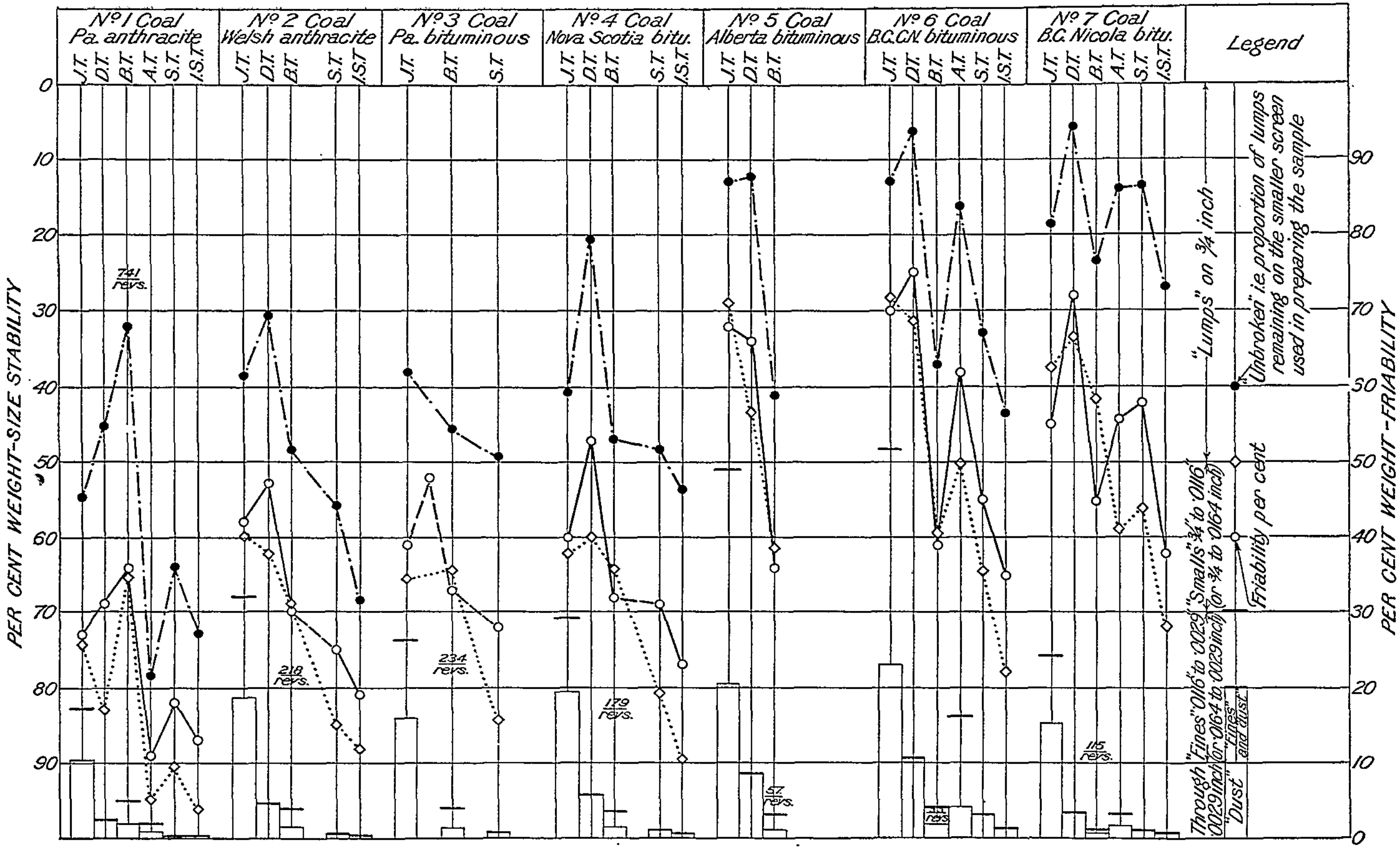


Figure 3. Seven selected coals tested by six friability methods—comparison of the individual tests as applied to each coal. NOTE: J.T., D.T., B.T., A.T., S.T., and I.S.T. are abbreviations for friability test methods as designated in Figure 2.

1200 to 1000 grammes, which has already been estimated as of comparatively little moment, than by either of the changes to still smaller weights of coal.

The values obtained with 1000 grammes, contained in Table IV, are not identical with those of the general average employed elsewhere, but are confined to those obtained at about the same period of time and from the same portion of coal as was used for the larger and smaller charges. As a general rule, various desired sizes were prepared from each coal, all at once, and stored in sacks, so that segregation of sizes may have slightly affected any of the tests described in this report.

Variation of Size of Coal. Table V contains the results of tests of three sizes, 2- to 1½-inch, 1½- to 1-inch, and 1- to ½-inch, of six of the coals employed in the tests; Figure 4 shows the results obtained with three coals selected from the six. The total amounts of "lumps" (on 0·742-inch screen) are about the same from the two larger sizes of coal, but the "smalls" are always greater in quantity from the 1½- to 1-inch size, perhaps because the original "lumps" are smaller. The products of abrasion, namely "fines" plus "dust", were generally greater from the two larger sizes than from the small size, owing, principally, to the fact that, as the size of coal tested is reduced, the amount of "fines" produced is nearly always markedly lessened. Such a condition does not necessarily apply to the "dust" produced. The friabilities, per cent, of the coals show a much greater spread with the larger sizes than with the small size, there being differences, between the maximum and minimum, of 28 with the 2- to 1½-inch size, of 27 with the intermediate size, and of only 12 (excepting No. 6 coal) with the 1- to ½-inch size. There is, therefore, comparatively little difference between the results of tests with the 1½- to 1-inch and the 2- to 1½-inch size, respectively, but a great difference between the results with the two smaller sizes.

The small friability, per cent, range obtainable with 1- to ½-inch coal renders this size unsuitable, as compared with the two larger sizes. Either of the larger sizes is suitable for the tests, but the writer prefers the 1½- to 1-inch size because (1) it has been generally employed, (2) its lumps are likely to be more regular in shape than the large ones, and (3) a greater number of lumps of it is required, affording an opportunity for a more representative sample of coal.

Variation of Frame Producing Tumbling. It has already been pointed out that the Small Jar Tumbler Test is remarkable for the amount of abrasion, or attrition, that it produces. It was suggested to the writer that the three iron shelves, or vanes, might cause a great deal of abrasion, and also that the coal from one shelf, or vane, might fall upon another shelf, and thus be shattered more than by falling against either the wall of the jar or other pieces of coal.

Accordingly, new frames were constructed with only two vanes, 180 degrees apart. A series of tests was carried out with these frames, employing 5 coals of 1½- to 1-inch size. Table VI shows the results of these tests, compared with those of the usual tests with three-vane frames. General, rather than specific, consideration of the table indicates that there is somewhat more of both shatter and abrasion caused by the frames with the three shelves than by the two-vane frames, but that the change is not sufficiently great to warrant substitution.

A sheet-glass end was substituted for the cover of the jar, so that the tumbling effects produced by each kind of frame might be observed. It was found that the two-vane frame dropped the coal either upon the wall of the jar or upon other coal. The three-vane frame dropped a little of the coal upon the shelf following that which picked it up. This shelf soon filled with coal, so that the remainder fell either upon the wall or upon other coal. It is suggested by the writer that the differences in breakage resulting from using the respective frames are due entirely to what happens while the coal is falling upon the empty shelf.

Variation of Material of Construction of Jar. After this report had been practically completed, information was received through the A.S.T.M. friability committee to the effect that some laboratories would prefer to use jars made of iron. In order to ascertain whether this material would prove to be a satisfactory substitute for porcelain, an iron jar was cast, having somewhat greater external and lesser internal dimensions than the porcelain jars. This was machined down to the same inside dimensions as the porcelain jar from which it was modelled, and fitted with the frame and lid belonging to it. It had the same external diameter at the top and bottom, but the greater part of the side wall was machined down to a thickness of $\frac{1}{4}$ inch, in order to avoid excessive weight. This iron jar was employed repeatedly and exclusively.

Four coal samples were used in the tests with this jar, covering a large range of friability. Three of them corresponded closely to Nos. 1, 4, and 7 coals, while the selected sample of Nova Scotia bituminous coal, which happened to be available at the time of the tests, came from a specific locality in the Sydney area, instead of, perhaps, being a mixture of coals from various locations. Table VI A clearly indicates that the results obtainable with iron jars agree closely with those obtained with porcelain jars, and that there is no distinct evidence that one type of jar promotes greater breakage than the other. The one consistent result of the tests is the production of more "smalls" in the porcelain than in the iron jar, and even here, the differences appear to be too small to carry any weight.

Variation of Time of Tumbling. Table VII and Figure 4 each give results obtained, after 1, 2, and 3 hours of tumbling, with six coals of $1\frac{1}{2}$- to 1-inch size. They also show the effect of extending the time to 5 hours in one case. Yancey, with Zane[11], has clearly demonstrated that shatter or impact is the principal form of breakage during the first hour of the test, but that, after that, it is replaced by abrasion. This is confirmed by the data herewith reported. The amounts of "fines" and "dust", and particularly of "dust", continue to increase, while there is little change in the "smalls" produced by impact. The production of "fines" and "dust" does not become uniform until after 2 hours, when the gain in "dust" begins to correspond closely with the loss in "unbroken", except with the very friable coals. In other words, the "dust" must probably come from a rubbing together of the large lumps.

Table VIII is supplementary, and shows the magnitude of the variations to be anticipated in a series of individual tests upon a coal. For this exposition, four coals, two of them very friable, were selected. The table shows, for most of the criteria upon which conclusions as to the results of

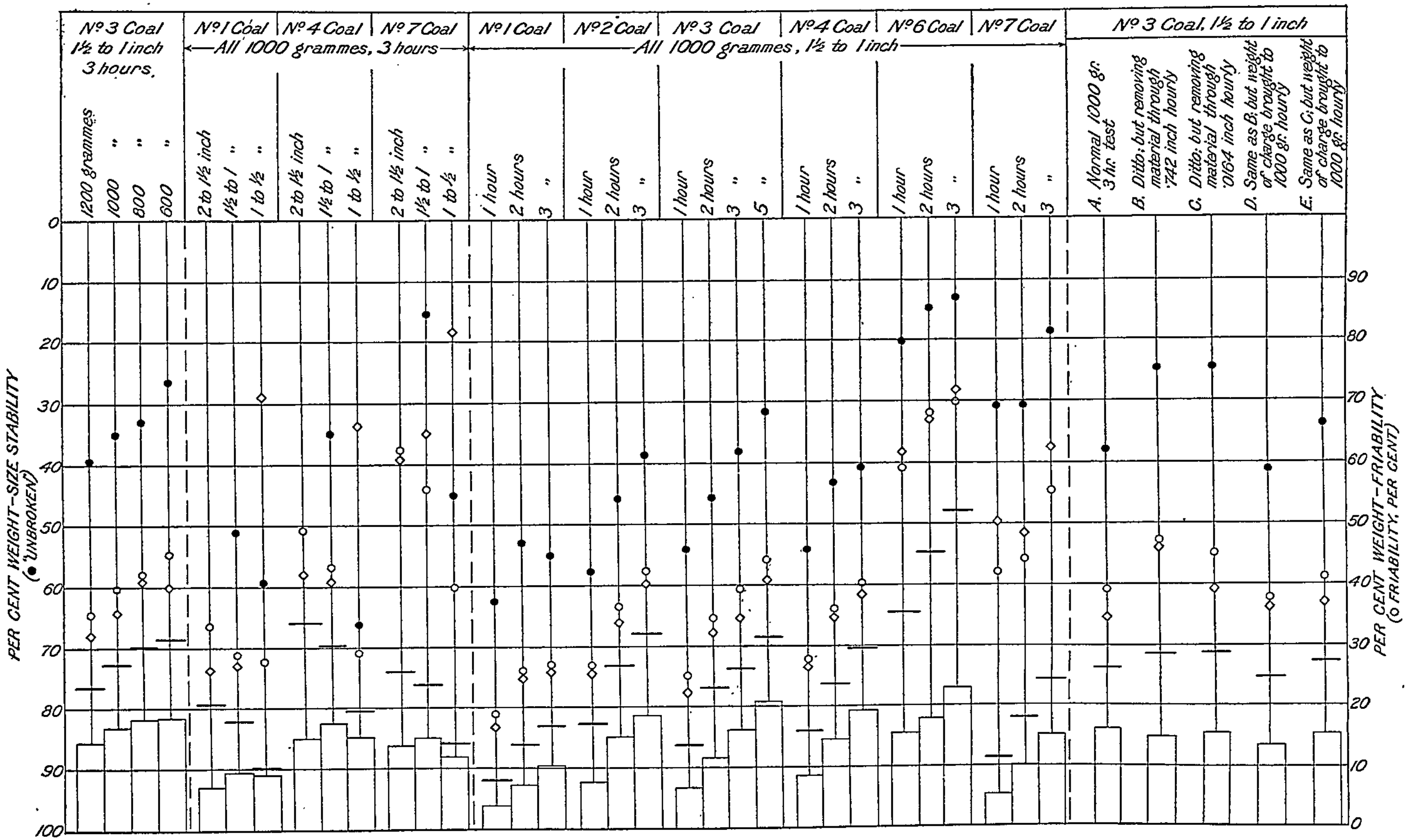


Figure 4. Modifications of Small Jar Tumbler test.

the tests were based, (1) the spread between the highest and lowest individual values obtained, (2) the greatest divergence from the mean of the individual values, and (3) the average of all such divergences. In the opinion of the writer, the third value is decidedly the most important, as showing how regular are the criteria upon which conclusions are based, a small average divergence indicating a more satisfactory series of values than does a larger one.

The table shows how much more uniform than the results of single tests are the results of screening the coal residues from 4 tests together or of averaging the figures from 4 individual tests. The 2-hour tests give closer extreme values, and smaller divergences, than the other tests, owing, probably, to the fact that only a few of such tests were made, and there were, therefore, not the same chances for extreme variation. It seems likely that the divergences in the values from the 3-hour tests would correspond closely to those from the 2-hour tests, if the same number of tests were made in each case, with somewhat more uniform values in the 3-hour tests, especially as regards friability, per cent. The 1-hour test gives distinctly less uniform results than those of greater duration, with the exception of the values for "fines" plus "dust".

However, consideration of any of the distinctive criteria in Table VII, i.e. "lumps", "unbroken" or "friability, per cent", shows that 1-hour tests give as great contrasts between the various coals as the 3-hour tests. Actually, in the tests presented here, the ranking or order of the coals appeared slightly more satisfactory from the 1-hour than from the 3-hour tests. The 5-hour test serves only to confirm the hypothesis that breakage after two hours is caused almost entirely by attrition. Therefore, the 1-hour test is recommended as being, on the whole, the most satisfactory, particularly as several such tests can be carried out during the time required for a few 3-hour tests. Perhaps, a 2-hour test should be substituted where it is desired to emphasize the effects of abrasion.

Variation of Size or Amount of Material in Jars during Test; Removing of Cushioning Effect of Fine Coal. Table IX, and the five last columns of Figure 4, show the results of hourly screening out of "smalls", "fines" and "dust", or of the two last only, from the coal in each individual jar, with a consequent hourly decrease in weight of the contents of the jar. These weight charges, in grammes, were approximately as follows: Removing "smalls", "fines", and "dust"—No. 1 coal, 2- to 1½-inch, 1015, 855, 740; 1½- to 1-inch, 1000, 820, 710; No. 2 coal, 2- to 1½-inch, 1005, 755, 595; 1½- to 1-inch, 1005, 785, 645. Removing "fines" and "dust" only—No. 1 coal, 2- to 1½-inch, 1005, 905, 795; 1½- to 1-inch, 1000, 910, 845; No. 2 coal, 2– to 1½-inch, 1000, 815, 685; 1½- 1-inch, 1005, 865, 770; 1- to ½-inch, 1005, 915, 855. The tests shown are all of 3 hours' duration.

Removal of small material has little effect upon the friability of coal of 1- to ½-inch size, but a very distinct effect upon larger coal, particularly the bituminous coal tested. There is comparatively little difference between the values for "friability, per cent", "unbroken" or "lumps" (all of which are markedly affected by the test), whether 0·742-inch or 0·0164-inch is used for the removal of small material, but a decided difference in the values for "smalls", "fines" and "dust". Employment of the 0·742-inch screen is accompanied by a distinct increase in the amount of "smalls", produced by impact or shatter, while the use of the 0·0164-inch screen is attended by an increase in "fines" and "dust" produced by abrasion, particularly with the 2- to 1½-inch size of coal. The results of all these tests differ from those obtained by employing, and maintaining constant, different weights of coal for the 3-hour test, as regards the amounts of breakage due to impact, or the production of "smalls". The procedure in which the 0·0164-inch screen is used hourly to remove broken coal gives results closer to those obtained with the different weights of coal than does the variation in which the larger screen is used. The effect produced by screening hourly with the 0·0164-inch screen is roughly the same as that caused by changing the original charge of coal from 1000 to 600 grammes, and maintaining the weight constant throughout the test.

In addition, the table and Figure 4 show the results of tests differing from the foregoing in that the contents of each jar after screening (on 0·742- or 0·0164-inch as the case might be) were brought up to 1000 grammes hourly. This was brought about by beginning the test with an extra large number of jars, or eight instead of four. At the end of each hour all the material remaining upon the previously designated screen, from all the jars, was mixed together, and the jars charged, in turn, with 1000 grammes each until there was insufficient coal remaining for a full charge. In both cases the number was reduced from the initial eight jars to five at the beginning of the third hour. These tests were made with more recently prepared coal than were the corresponding tests in which the weights of the charges were allowed to decrease, but it is believed that any resultant difference between them would be negligible. As shown clearly in the diagram, friability values from these tests were very close to those obtained in the ordinary 3-hour test. There is so little marked difference between any of the values obtained that no attempt has been made to draw any specific conclusions.

After consideration of the second type of test just described, it was decided to carry out a series of tests employing the "sweetening" effect used by Baltzer and Hudson, of these Laboratories, in their "Grindability" Test[12]. The principle of this test differs from that immediately preceding in that all the coal is rejected except that retained by the smaller of the two screens used in preparing the coal for the tests, in other words what the writer has designated as "unbroken". Moderately large quantities of five of the coals were prepared in two sizes, namely 1½- to 1·05-inch, and 1- to 0·525-inch. Charges of 1000 grammes were used, and at the end of each hour the material passing through the 1·05-inch, or 0·525-inch, opening was discarded and replaced by fresh material. This procedure was continued until the coal had been tumbled for 6 hours.

Table X and Figure 5 show the results of the tests. It is clear that the "sweetening" process greatly diminishes the amount of breakage, this being particularly marked with the more resistant coals. The effect upon the softer coals is less pronounced, but the tendency in all cases is in the direction of lower friability values. "Smalls" produced from the larger of the two sizes quickly diminish, particularly with the more resistant coals. The "smalls" from the 1- to ½-inch size are irregular (there having been "smalls" present at the start of the test), in fact coal of this size has, once more, proved to be less satisfactory for this type of tumbling

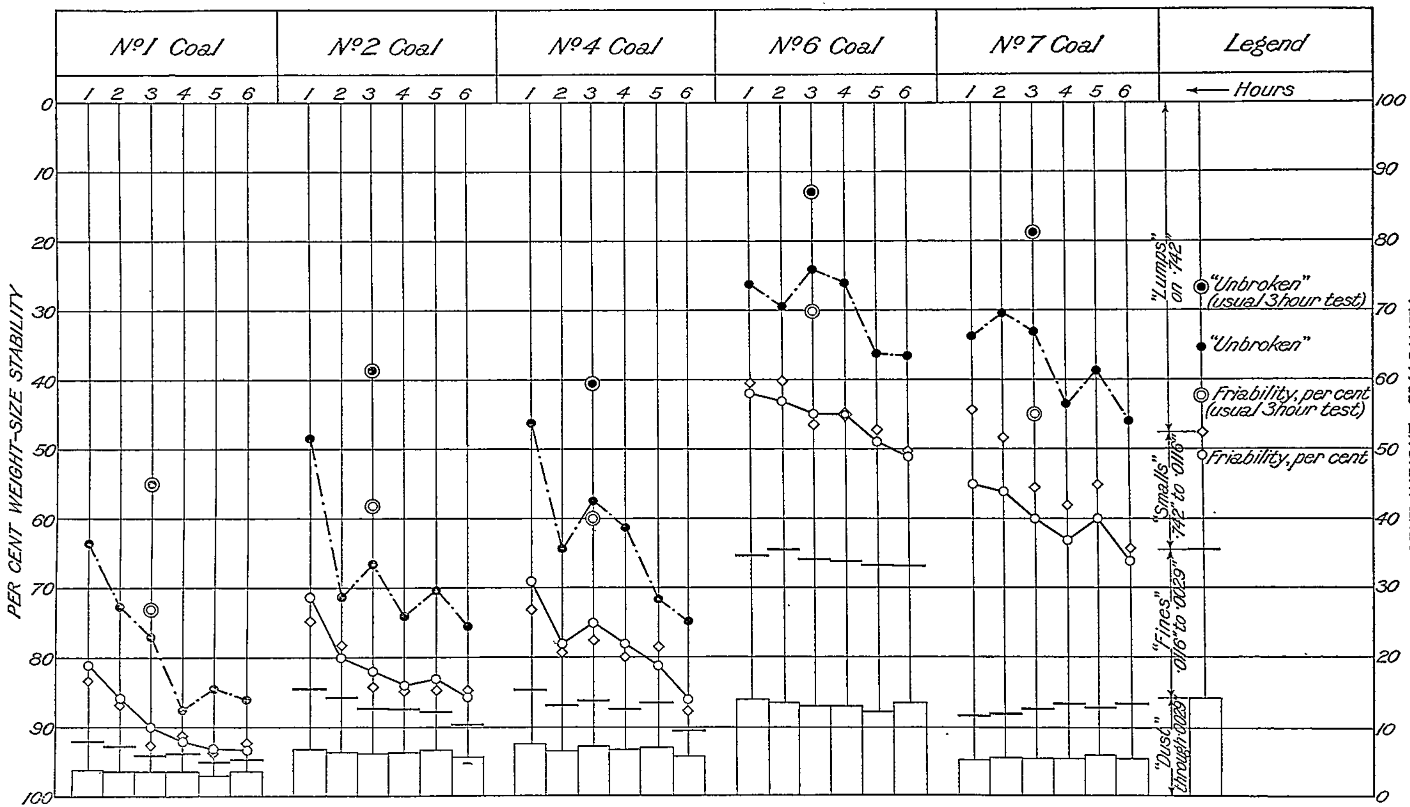


Figure 5. "Sweetening" tests in small jar tumbler, removing "broken" material hourly and replacing it by original material (1000 grammes; 1½- to 1-inch coal).

test than larger coal. "Fines" become less during the course of the test, though to a smaller degree than do the "smalls", while the changes in the amounts of "dust" are even less pronounced.

The points in the diagram surrounded by double circles show the "friability, per cent", and "unbroken" values obtained from the usual continuous 3-hour test; these are very much higher up in the diagram than the corresponding values from the 3-hour "sweetening" test. As was indicated by Yancey's investigation, the amount of fine coal produced by abrasion is nearly constant after the first hour's tumbling. However, the amount tends to decrease slightly with the harder coals, probably after the sharp edges have been rubbed off. The amount of abrasion with the softer coals is somewhat different; with the Crowsnest coal it remains practically constant and with the Nicola coal it even seems to increase slightly.

All the tests covered by the preceding paragraphs indicate that the weight or volume of coal in the tumbler governs the friability, per cent, or the amount of breakage produced, more so at least than the presence or absence of fine material. However, they also indicate that lumps remaining after tumbling are generally tougher, on the average, than those of the original charge, and consequently decrease the friability, per cent. One more series of tests, having in view the study of the "sweetening" effect, was accordingly carried with coal No. 6. This sample was selected because of its comparatively large friability, whereas information now available shows that it would have been wiser to select a more resistant coal in order to observe the desired effect.

Seventy-five pounds, or almost a normal charge, of coal No. 6 of 3- to 2- inch size were tumbled for 10 minutes, or about one-third of the normal period, in the Sheffield Abrasion Tumbler. This tumbling produced 20 per cent of material on 2 inches, 25 per cent between 2 and $1\frac{1}{2}$ inches, 17 per cent between $1\frac{1}{2}$ and 1 inches, and 11 per cent between 1 and $\frac{1}{2}$ inch. Tests of 3 hours were then carried out in the Small Jar Tumbler with material of the three sizes last named. The results of these are shown in Table XI, in comparison with the results obtained with the coal as originally prepared by screening alone. The coal which had been previously tumbled is less friable, according to Yancey's value, than the coal as originally prepared by screening, and the smaller sizes of coal show this better than does the large size. The values obtained show clearly that there is a tendency for the large material, in the coal which had been previously tumbled, to shatter less than the corresponding material prepared by screening alone, but at the same time to produce more "dust".

A.S.T.M. (Coke) Drum Tumbler[3]

Table XII shows the few modifications of the method that were investigated. Since it was believed that 1400 revolutions of the tumbler, as employed for coke, would break the coal very much, the number was first reduced to 100 revolutions. Even this treatment seemed to produce very much breakage, and the number of revolutions was further reduced to 50, representing about 2 minutes' tumbling. So much of the material designated as "smalls" was produced that it was deemed advisable to introduce three more comparatively fine mesh screens.

The values in the table indicate that the result obtained on coal No. 4 after 100 revolutions is irregular, and that, quite apart from this, the modification of the test with only 50 revolutions shows more clearly the degrees to which coals differ as to friability. Furthermore, the results of the 50-revolution test agree more closely with those from the Small Jar Tumbler than do those of the 100-revolution test, except as regards abrasion, which is not produced in the A.S.T.M. drum, to any notable degree, until after prolonged tumbling. Tests in which smaller sized coal is tumbled for 3 hours show that, for the bituminous coals used, there was little breakage after 1½ hours, and that nearly all attrition. Therefore, under such drastic conditions, the friability values of all coals tend to approach one another closely. The table shows the ratios between friabilities after 50 and 100 revolutions, the average of which was used in the case of No. 3 coal; this ratio is uniform, except for No. 4 coal.

Box Tumbler

This apparatus has been designed to measure friability by the time required to break up coal, and not by the amount of breakage produced under pre-determined conditions. Therefore, the screen analyses and friability percentages shown in Table XIII are only of secondary importance, except in the few cases where the box was closed by an iron plate replacing the screen. Screen analyses show clearly that, when 20 per cent of the coal has passed through the screen, the material remaining in the box may contain as much as 5 per cent (of the total sample) of material smaller than ¼-inch, with an average of from 1 to 2 per cent. There is little variation of Yancey friability percentages throughout the table, except in the case of No. 7 coal, which is distinctly susceptible to impact or shatter. On the other hand, there is a very large difference between the friabilities of Nos. 1 and 6 coals, as based in this test upon the number of revolutions or time of tumbling. "Smalls", resulting from impact, are produced in this test, rather than "fines" and "dust" resulting from abrasion.

The largest size of coal, 2- to 1½-inch, was employed only in the case of the Nicola coal. Its lumps were somewhat less regular in volume and shape than those of the next size of coal, fewer of them were required, and they did not seem to be picked up or fall so satisfactorily in the tumbler. The intermediate size has been given the preference for much the same reasons as governed its selection for the Small Jar Tumbler. In this test, the 1- to ½-inch size, although it breaks up to a slightly lesser degree, may have an advantage in that its employment sometimes prolongs the time of tumbling over that with the 1½- to 1-inch size, and may thus spread out the friability scale.

Stansfield and Gilbart employed a ¼-inch square hole wire screen in the tumbler, but recommended a round hole screen. This would be superior because it would not bend so readily as the wire from the impact of the rolling coal. Most of the present tests were carried out with a wire screen, but the round hole plate with ¼-inch openings was introduced with coal No. 4. This resulted in a somewhat longer time required to produce 20 per cent passing through the screen, accompanied by a slight but distinct increase in breakage of all kinds. Because of the use, in the two laboratories, of the method employing the screen with square openings, an endeavour was made to reproduce its results with a round hole screen. The diameter of the holes was therefore increased to $\frac{5}{16}$ inch, with the results shown in Table XIII. As these results were still intermediate between those with the $\frac{1}{4}$-inch square and $\frac{1}{4}$-inch round holes, the diameter was extended to $\frac{21}{64}$ inch in preparing the screen for the Drum (Box) Tumbler.

Certain tests were made with the Small Jar Tumbler in order to study the effects of the removal of the small sizes of coal. In order to observe such effects further, the screen in the Box Tumbler was sometimes replaced by a thin sheet of iron. The tests in which this was done are shown in the columns headed by the word "Plate", in which cases the friability percentages and screen analyses are informative. It is to be noted that the tests with the closed box were made for periods of time equal to those found to be requisite for breaking the respective coals so that 20 per cent should pass through the screen, in order that the respective results might be compared. There seems to be no doubt that the amount of breakage was less in the box when closed than when fitted with a screen. It was considered, from studying the tests with the Small Jar Tumbler, that the increased breakage was due to the fact that, after the small coal was screened out, the lumps broke up because they had a smaller volume and fell farther and harder, rather than because the cushioning effect was removed. The principal difference between conditions in the Box Tumbler tests with the screen or plate is that, in the first case, the fine material is very gradually removed. Since the friability is somewhat greater in this case, it may be that the cushioning effect of the fine material is, after all, a factor of some importance. In this case there are, invariably, more "smalls", resulting from impact, produced than when the box is closed. The amount of "unbroken" is greater in the second case, and is accompanied by small increases in "fines" and "dust" due to abrasion. The prolonged tests with the more resistant fuels show more distinctly the different amounts of abrasion produced, respectively, when the plate or screen is employed.

Drum (Box) Tumbler

This apparatus was designed for studying the effects of tumbling under various controllable conditions, rather than with the idea that it should replace already existing equipment. It can be made to be almost identical with the Drum Tumbler but, as employed in the present series of tests, it has more in common with the Box Tumbler. The movable plate, or end, was designed for studying the effects produced when coal is tumbled in spaces varying in width from that of the Drum Tumbler to that of the Box Tumbler.

The purpose of Table XIV is to correlate tests with the two forms of drum tumbler, beginning with the A.S.T.M. Tumbler and finishing with the new tumbler when fitted with the round hole screen. It shows that the changes of result were not great when the closed modification of the Drum (Box) Tumbler fitted with two shelves was used. The principal difference between the results was the replacement of "unbroken" by smaller sized "lumps" to a considerably greater degree in the solid drum than in the one equipped with a sheet-iron door. Breakage in the Drum

(Box) Tumbler was increased by replacing the two smaller shelves with one deep shelf, though it was not yet of the dimensions produced in the A.S.T.M. Tumbler.

There are only two cases in which there is a continuous and complete series of tests, one with coal No. 1 (anthracite), in which there is an irregularity due to the passage from the 3- to 2-inch to the 2- to 1½-inch size, the other with coal No. 5 (bituminous) of 3- to 2-inch size. Furthermore, at the change from the sheet-iron door to the perforated screen, the conditions are different in the two cases. In the case of the anthracite, the coal was tumbled with the screen in place until 20 per cent had passed through, after which a second sample was tumbled in the closed drum for the period of time required for the first test. In the case of the Alberta sample, the coal was tumbled in the closed drum for 50 revolutions, as was done with the other coals tabulated, and then, with the screen in place, until 20 per cent had passed, or for 24 revolutions. The last case indicates the relation between the full-width Drum (Box) and the Box Tumbler tests, in the latter of which 57 revolutions, or 283 seconds, were required for 20 per cent of the same coal, of 1½- to 1-inch size, to pass through the screen. This, in turn, may be compared with the test shown in Table XVI, in which 9000 grammes of 1½- to 1-inch coal required 32 revolutions, or 80 seconds, in the Drum (Box) Tumbler when narrowed to the same width as that of the Box Tumbler.

The results from the anthracite show, once again, that there is more breakage, particularly production of "smalls", in the tumbler from which the fine coal is removed than in the closed tumbler. In a tumbler of such large size as that under discussion, removal of fine coal would have a negligible effect upon the relation of the volume of coal to the volume of the tumbler (as discussed in connexion with the Small Jar) or upon the distance through which the coal would fall. It seems, therefore, that, in tumbling tests in general, the cushioning effect of fine material cannot be entirely overlooked.

The conditions governing the last two tests tabulated are so different that it is difficult to make any comparisons between the results obtained. The screen analyses and friability, per cent, do show that there is nearly as much breakage in the test with the screen, which lasted for only 24 revolutions, as in the test with the closed drum, which lasted for 50 revolutions. This, once again, supports in principle the theory that greater breakage takes place in a drum fitted with a screen, than in a similar drum closed completely. However, it seems that this theory would hardly account for the difference between the results of the tests under consideration, when it is realized that the period of tumbling with the screen was less than half of that with the closed drum. It seems more reasonable to suppose that breakage takes place to the greatest degree during the first minute, or few minutes, of any test. This is in agreement with the results shown in Table XII for 50 and 100 revolutions of the Drum Tumbler.

Table XV contains results obtained with the same two coals, the Alberta bituminous being in three sizes, when different weights of coal were used, and the width of the tumbler was altered in about the same proportions as the weight of coal. The number of revolutions required for 20 per cent of coal to pass the screen was always large with 6750 grammes of coal and the tumbler $12\frac{1}{2}$ inches wide, and this was accompanied by comparatively small breakage. However, although the numbers of revolutions with the anthracite, at widths of $11\frac{1}{2}$ and $10\frac{1}{2}$ inches were also large, one of these settings corresponded with large breakage, the other with small breakage. Furthermore, the results obtained, at settings of $11\frac{1}{2}$ and $10\frac{1}{2}$ inches, with the bituminous coal give no indication that such settings correspond with long periods of tumbling. Plotting the results graphically shows no definite relation between width of tumbler and time of tumbling. Therefore, the contents of the table may best be summarized by stating that, if the weight of coal tumbled and the width of the tumbler be altered proportionately, the time required for 20 per cent of the coal to pass through the screen will change only very little, and the amount of breakage will not greatly vary.

Table XVI adds to the foregoing in that it provides data showing the effects of altering either the size of the coal, its weight, or the width of the tumbler. As was found to be the case with the Small Jar tests, reduction of the size of coal tumbled corresponds with less breakage, even though the time required for 20 per cent to pass the screen be greater with the smaller coal. Reduction of the weight of coal used was accompanied by only a very slight increase in the amount of breakage, but it very much lessened the time required for 20 per cent to pass through the screen, particularly with the more resistant anthracite. The effect of lessening the width of the tumbler, while the weight and size of coal remained constant, was not great, consisting of a slight lengthening of the time required for 20 per cent to pass and, probably, a very small decrease in the amount of breakage. Therefore, the net effect of reducing the width of the tumbler, with other conditions remaining constant, is to lessen the breakage taking place in the coal.

It was pointed out, in opening the discussion of the tests with the Drum (Box) Tumbler, that this apparatus was designed for study of tumbling methods, rather than, necessarily, to replace, as standard, equipment already available. The foregoing data have dealt largely with variations of procedure and with their effects. However, there is no reason why this tumbler should not be used to compare the friabilities of different coals, as shown in Table XVII. This contains the results obtained, from five of the coals, with one of the procedures designated in Table XV. As was the case with the Box Tumbler, friability percentages show comparatively small differences, except in the case of No. 7 coal which is so sensitive to impact. The values designated "unbroken" are slightly more informative. However, with such a test as this, the only satisfactory values are the time required for 20 per cent of the coal to pass through the screen, or the corresponding number of revolutions of the tumbler. The use of these criteria places the coals in such an order as agrees closely with those obtained by the other methods described in this report

Sheffield (Coke) Abrasion Tumbler[6]

This apparatus is little, if ever, used in America, so that less attention was given to it than to the A.S.T.M. Tumbler, and only three coals were tested. Since abrasion was supposed to be the principal effect of this test, both the 0·0116- and 0·0029-inch screens were used, in order to measure both "fines" and "dust". Furthermore, the "abrasion index", as defined by those responsible for the test, or the material on a 1½-inch screen, has been included in the table.

Table XVIII shows clearly that this tumbler does not cause great abrasion of coal, that is according to the terminology that has been adopted for this report, and that, as would be expected, the breakage due to shatter or impact is not great. This form of test is commendable in that it furnishes a very wide range of friability, varying from 11 for the anthracite to 62 for No. 6 coal. As has been shown previously in this report, reduction of the size of the coal employed distinctly lowers the friability value obtained. In this test, in the case of the Pennsylvania anthracite, the reduction is very marked, proportionately more so than for the same coal as shown in Table V.

It is of considerable interest to compare the values in Table XVIII with those in Table XII, the latter resulting from the A.S.T.M. Tumbler Test. There is much greater breakage of the anthracite after 50 revolutions in the A.S.T.M. Tumbler than there is after 690 revolutions in the Sheffield Tumbler, and somewhat greater breakage of the Crowsnest coal. Table XII shows that breakage of No. 4, Nova Scotia, coal, even of the smaller size, is complete, to a very large degree (there being no "unbroken" material), after 1½ hours, or 2,160 revolutions, in the Drum Tumbler; it, therefore, seems reasonable to suppose that the breakage of the Pennsylvania anthracite, particularly of the larger 3- to 2-inch size, which is about half as friable as No. 4 coal, would also have increased very considerably under such conditions. As a contrast, Table XVIII shows that, after 690 revolutions of the Sheffield Tumbler, 78 per cent of the Pennsylvania anthracite remained as "unbroken" and that, even after 3,780 revolutions or 3 hours, 36 per cent remained on the screen used to prepare the sample. The results with No. 6 coal are chiefly notable for the fact that there is little breakage except abrasion, and not a great deal of that, between 690 and 3,780 revolutions in the Sheffield Tumbler. Furthermore, it seems clear that very prolonged tests in this tumbler will not produce as much breakage due to shatter or impact as is obtained in the A.S.T.M. (Coke) Drum Tumbler.

A.S.T.M. (Coke) Shatter Test[1]

This test calls for 4 drops, or falls, of coal on to an iron plate. Table XIX shows the effects of extending the number of drops to 8 and 12, respectively. The total amount of "lumps" does not decrease very rapidly, except with coal No. 6, but the material designated as "unbroken" is diminished much more rapidly; in other words, the lumps begin at once to break down from their original sizes, but are not rapidly reduced to smaller size than ¾ inch. "Smalls", considered throughout this report as indicating breakage due to impact, increase steadily throughout the test. "Fines" and "dust" appear of no import, except in the case of coal No. 6. There is no indication that breakage has approached a limit after the 12th drop, though the change in friability is somewhat less between the 8th and 12th than between the 4th and 8th drops. The 4th and 5th, 8th and 9th, and 12th and 13th columns of figures in Table XIX compare results obtained with round hole screens with those obtained with the square hole screens believed to correspond to them. These figures, with the exception of those from the Nicola coal, are in fair agreement.

Throughout the tumbler tests, various attempts were made to determine the effect of a cushion of fine coal in preventing breakage, with the eventual conclusion that such a cushioning effect was not an entirely negligible factor. The first four columns of figures in Table XX show a corresponding modification of a shatter test. In this modification, all material passing the $\frac{1}{4}$-inch screen was removed after each individual drop; after the 4th, 8th, and 12th drops the fine material was put back with the coarse coal before the screen analyses were made. The figures in the table show no appreciable differences between the results obtained, respectively, with and without the fine material.

Table XX also shows the effects of changing either the weight or size of coal used for this shatter test. Reduction of the weight from 50 to 25 pounds increases the "friability, per cent", very slightly. As was found to be the case with the tumbler tests, reduction of the size of the coal somewhat reduces the "friability, per cent".

Illinois Shatter Test[4]

This test originally called for round hole screens but, for the sake of uniformity, values previously reported for comparison with those from the other tests were obtained with square hole screens. Table XXI shows, in two pairs of columns, comparisons of results obtained from square hole screens with those obtained from round hole screens. These results are not quite so satisfactory as most of those in Table XIX, particularly as regards the percentages of "smalls". At the outset of the study of the Illinois test, 55 lumps of material between the 3- and 2-inch square screens were assumed to be the equivalent of the 60 lumps of 3- to $2\frac{1}{2}$-inch, (round hole) coal called for by the test. This was not found to be the case with the coals shown in Table XXI, where the 60 lumps of round hole coal weigh, in each case, decidedly more than the 55 lumps of square hole coal. This irregularity may account, in part, for the lack of entire agreement between the values shown in the respective 1st and 2nd and 7th and 8th columns of the table.

Prolonged tests were carried out, to a limit of 8 drops. Speaking generally, the values obtained from these tests correspond satisfactorily with those obtained from the prolonged tests with the A.S.T.M. apparatus. The decrease in "lumps" was gradual and very distinct, the decrease in "unbroken" being marked, while the increase in "smalls" was notable. It seemed as if all these occurred to a slightly greater degree than in the A.S.T.M. test. There was, again, no indication that the breakage had approached a limit. Examination of Tables III, XIX, and XXI led to the conclusion that the respective friability percentages resulting from 4 drops in the A.S.T.M. shatter test are intermediate between those obtained after 1 and 2 drops in the Illinois test, and a little nearer to those obtained after 2 drops.

The last three columns of Table XXI confirm the conclusions drawn from Table XX, and similar conclusions dealt with in other parts of this report. These are to the effect that reduction in the weight of sample used increases the "friability, per cent"; also that reduction in the size of the coal lowers the friability, even though the weight used be slightly reduced.

SUMMARY AND CONCLUSIONS

Friability, or size stability, of coal is important primarily to the producer, retailer, or consumer. However, in this report it is under consideration as an adjunct to the scheme of coal classification, by rank and grade, at present in preparation in Canada and the United States. With that end in view, methods of determining friability based upon various principles, and modifications thereof, are described. It is hoped that consideration of the data presented here may be of assistance in the selection or derivation of a standard procedure for North American coal.

The following types of apparatus were employed:—

(1) Small Jar Tumbler, in which friability is measured by size degradation.

(2) A.S.T.M. (Coke) Drum Tumbler, in which friability is measured as above.

(3) Box Tumbler, in which friability is measured by the number of revolutions, or the corresponding time, required to produce a definite amount of broken coal of less than a specified size.

(4) Drum (Box) Tumbler, designed to correlate the two previously named tumblers, and to study modifications of their principles.

(5) Sheffield (Coke) Abrasion Tumbler, designed to cause abrasion, without shattering, when used under specified conditions. Friability is measured by size degradation.

(6) A.S.T.M. (Coke) Shatter Test, designed to produce breakage due to impact, in which friability is measured as in the last case.

(7) Illinois Shatter Test, which is similar to the last test in all its principles.

Seven coals were selected for the tests, ranging from one with a very high size stability to one with a high friability. One of the more friable coals was noteworthy as being subject to breakage from impact, without being greatly affected by abrasion.

Various criteria, based upon screen analyses before and after the respective tests, are suggested for the numerical definition of friability, when measured by size degradation. The most promising of these are "Friability, per cent", as employed by Yancey, "Unbroken", per cent, and "Lumps", the last being the per cent of material retained by a $\frac{3}{4}$-inch square screen.

A specific modification of each of six of the test methods was selected for purposes of comparison. These were applied to each of the seven coals whenever the selected size was still available. The results obtained are shown in detail by tables and diagrams.

Each selected modification places the friabilities, or size stabilities, of the coals in, approximately, the same order. Therefore, any of them ought to be satisfactory for determining the relative friabilities of a series of coals.

The selected modifications, together with other variations of the test methods, supply the following information concerning the respective methods.

(1) The Small Jar Tumbler causes breakage of all kinds, but particularly attrition which is marked by a large amount of "dust".

In this tumbler, reduction of the weight of coal employed for a 3-hour test results in increased breakage of all kinds, though the effects of shattering increase more than those due to attrition.

Coal of 2- to $1\frac{1}{2}$-inch, or of $1\frac{1}{2}$- to 1-inch, size breaks up more, and produces a greater friability range for a series of coals, than does coal of 1- to $\frac{1}{2}$-inch size. The smaller of the two large sizes usually gives the more satisfactory results.

Substitution of a frame with two vanes for the usual three-vane frame decreases breakage of all kinds, but only to an exceedingly small degree.

Substitution of a cast-iron jar for the regular porcelain one gives values corresponding closely to those obtained in the regular jar.

Tests of one, two or three hours' duration show that, during the first hour of tumbling, shattering takes place, with a certain amount of abrasion; during the second hour, abrasion very largely replaces shattering; during the third hour, the breakage is almost entirely due to abrasion, and this appears to continue steadily thereafter. These conclusions support those of Yancey and Zane[11].

Irregularities of results obtained from single tests are greater from one-hour than from three-hour tests, but not to a very marked degree. One-hour tests seem to show as great contrasts between the respective coals as do the three-hour tests. It is, therefore, recommended that the one-hour test be adopted as standard, particularly as more of them than of the three-hour tests can be made in a certain period of time. The two-hour test is advisable where a study of the effects of abrasion is desired.

Hourly removal of finely broken material, without replacing it, has little effect upon 1- to $\frac{1}{2}$-inch coal, but a marked effect upon the larger sizes. There is little difference in the friability, per cent, resulting from 3 hours' total tumbling whether a 0·742-inch or a 0·0164-inch screen is employed to remove the fine coal, but there is a marked difference in the nature of the resultant smaller sizes. Removal of material through 0·742-inch produces principally "smalls", or impact breakage; removal of material through 0·0164-inch promotes abrasion.

The values obtained when the 0·0164-inch screen is used are close to the values from the tests in which smaller than normal weights of coal are tumbled for 3 hours, and particularly close to those from the 600-gramme test.

Changes in friability caused by hourly removal of fine material are probably due to changes of weight or volume of the coal, rather than to removal of the cushioning effect of such material.

Hourly removal of fine material, with return of the residual charge to full weight by reduction in the number of jars charged, gives values corresponding closely to those from the normal 3-hour test.

Hourly removal of all material except the "unbroken", or that remaining upon the smaller of the two screens used to prepare the sample, with return of the residual charge to full weight by adding fresh coal of the size used for the tests, distinctly lowers friability, per cent. This is shown by a reduction in the amount of "smalls", rather than by any rapid alteration in the results of abrasion. It is particularly marked in the more resistant coals.

Treatment of 3- to 2-inch coal in the Sheffield Abrasion Tumbler broke it into lumps which gave lower friability in the Small Jar Tumbler than lumps of the same coal prepared by screening alone. The lower friability was shown by reduction in "smalls" and "fines" produced, but not by a similar change in "dust", this being greater from the previously-tumbled coal.

(2) The A.S.T.M. (Coke) Drum Tumbler promotes breakage due to shattering, coupled with a small amount of abrasion. On account of heavy impact breakage, the number of revolutions was reduced to 50 per test.

Prolonged tumbling, for 1 to 3 hours, reduces "lumps" to very small dimensions, and does away with all kinds of breakage except abrasion. Such tumbling produces so much breakage as to shorten greatly the friability range of a series of coals.

(3) The Box Tumbler causes shattering, with a limited amount of attrition. Coal of $1\frac{1}{2}$- to 1-inch size is recommended for this test, though the 1- to $\frac{1}{2}$-inch size may give a greater friability range.

A wire screen with $\frac{1}{4}$-inch square holes was used almost entirely, but a round hole screen is recommended.

Tests showed that, when $\frac{1}{4}$-inch and $\frac{5}{16}$-inch round screens were used, longer time was required to produce the specified amount of fine coal than when the square screen was employed, and more breakage was produced.

There is more breakage in the tumbler when fitted with a screen than when fitted with a sheet of iron in place of the screen. In the first case, the breakage is principally due to shattering; in the second case, it is due to abrasion to a greater degree than in the first case.

Such a test indicates that the cushioning effect of fine coal in preventing breakage ought not to be disregarded.

(4) The Drum (Box) Tumbler, when closed with the sheet-iron door and fitted with two 2-inch shelves, gives values corresponding to those obtained from the A.S.T.M. Tumbler, though the breakage due to impact is distinctly less. Substitution of one 6-inch shelf for the two shallow ones gives results nearer to those from the Drum Tumbler.

The number of revolutions necessary for 20 per cent of 3- to 2-inch coal to pass through the screen in the full-width Drum (Box) Tumbler is less than half the number of revolutions necessary for $1\frac{1}{2}$- to 1-inch coal in the Box Tumbler, and requires about one-fifth of the time. The revolutions and time are increased by one-third when the Drum (Box) Tumbler is narrowed to the width of the Box Tumbler, and $1\frac{1}{2}$- to 1-inch coal is employed instead of the large size.

There is more breakage, particularly shattering, when small coal is removed from the tumbler, by falling through a $\frac{21}{64}$-inch round screen, than when the tumbler is closed. In a tumbler of so large a capacity this must indicate that the fine coal, when present, acts as a cushion to prevent disintegration.

Breakage is very heavy indeed during the first minute of tumbling.

If the weight of coal and the width of the tumbler be altered proportionately, the time requisite for 20 per cent of the coal to pass through the screen in the tumbler, and the amount of breakage, will change very little.

The following data, obtained from a series of tests in each of which one of three variables was changed, show that:—

Reduction in the size of coal employed results in less breakage, notwithstanding the fact that the time required to complete the test is increased.

Reduction of the weight of coal causes a slight increase in breakage, and a considerable shortening of the time required for the test.

Reduction of the width of the tumbler has only slight effects, shown as a probable decrease in breakage and a lengthening of the time necessary for such a reduction in size of the coal that it will pass through the screen in the tumbler

A series carried out according to one modification of the Drum (Box) Tumbler Test, in which friability was based upon revolutions of the tumbler or the corresponding time, placed five of the selected coals in an order that agreed reasonably well with the results from the other types of test apparatus.

(5) The Sheffield (Coke) Abrasion Tumbler produces much less impact breakage than the A.S.T.M. Tumbler, and only about the same amount of abrasion, when used with coal. Even very prolonged tests will not produce so much impact breakage. Therefore, the Sheffield Tumbler will give a longer range of friability values than the A.S.T.M. Tumbler.

Modifications of this test show very clearly that reduction of the size of coal employed corresponds with lessened breakage.

(6) The A.S.T.M. (Coke) Shatter Test produces almost entirely impact breakage, the amounts of "fines" and "dust" being negligible except with very friable coals. As a test proceeds, the material designated as "unbroken" gradually decreases to form smaller material of "lump" size, which, in turn, is gradually replaced by "smalls".

Tests extended to a total of 12 drops give no indication of completion of breakage, though the change in friability between the 8th and 12th drops was less than those in the corresponding earlier periods.

Removal of material passing a $\frac{1}{4}$-inch screen, after each individual drop, fails to produce any more breakage than in the test in which no material is removed.

(7) The Illinois Shatter Test causes effects similar to those produced by the test just discussed.

A series of tests extended to 8 drops furnished information of the same general nature as that from the A.S.T.M.Test when extended to 12 drops. The breakage produced was somewhat more intensive.

The following conclusions apply to both shatter tests.

Results obtained with round hole screens agree moderately well with those with the square hole screens considered as corresponding to them.

Reduction of the weight of sample somewhat increases friability, per cent. Reduction of the size of coal lowers the friability, even though the weight be slightly lessened.

TABLE I

Analyses of Coal Samples Employed in Friability Tests (or of Samples Believed to Correspond to Them)

	No. 1, Pennsylvania Anthracite		No. 2, Welsh Anthracite		No. 3, Pennsylvania Bituminous		No. 4, Nova Scotia Bituminous		No. 5, Alberta Bituminous		British Columbia Bituminous			
											No. 6, Crowsnest		No. 7, Nicola	
	R	D	R	D	R	D	R	D	R	D	R	D	R	D
Proximate Analysis—														
Moisture..........per cent	3·4	......	1·7	......	3·2	......	2·8	......	1·1	......	1·0	......	9·5	......
Ash.............. "	9·5	9·8	5·0	5·1	6·1	6·3	8·5	8·7	12·1	12·2	5·3	5·3	10·8	11·9
Volatile matter... "	5·4	5·6	8·0	8·1	32·7	33·8	34·1	35·1	25·8	26·1	27·3	27·6	36·0	39·8
Fixed carbon..... "	81·7	84·6	85·3	86·8	58·0	59·9	54·6	56·2	61·0	61·7	66·4	67·1	43·7	48·3
Ultimate Analysis—														
Carbon...........per cent	......	......	......	......	78·4	80·9	75·5	77·7	76·4	77·3	81·8	82·7	63·8	70·5
Hydrogen .... "	......	......	......	......	5·7	5·5	5·1	5·0	4·6	4·5	4·9	4·9	5·7	5·1
Ash.............. "	9·5	9·8	5·0	5·1	6·1	6·3	8·5	8·7	12·1	12·2	5·3	5·3	10·8	11·9
Sulphur........... "	0·8	0·8	1·0	1·0	0·8	0·9	2·6	2·7	0·3	0·3	0·6	0·6	0·6	0·6
Nitrogen......... "	......	......	......	......	1·6	1·6	1·4	1·4	1·1	1·1	1·5	1·5	1·7	1·9
Oxygen........... "	......	......	......	......	7·4	4·8	6·9	4·5	5·5	4·6	5·9	5·0	17·4	10·0
Calorific Value—														
Calories per gramme, gross	7,185	7,435	7,985	8,120	7,800	8,060	7,485	7,700	7,500	7,580	8,050	8,140	6,345	7,005
B.T.U. per lb., gross......	12,930	13,390	14,370	14,620	14,040	14,500	13,470	13,860	13,500	13,650	14,490	14,650	11,420	12,610
Fuel ratio..................	14·95		10·65		1·75		1·60		2·35		2·45		1·20	
*Coking properties**...........	Non-coking		Non-coking		Good		Good		Good		Good		Poor	

NOTE: R—As received. D—Dry basis.

*As indicated by residue (coke button) from volatile matter determination.

TABLE II

Comparison of the Individual Coals by each Friability Test

JT—Small Jar Tumbler Test—1000 grammes of 1½- to 1-inch coal; 7200 revolutions, 3 hours

Sizes of Screen Openings, inches	No. 1, Pennsylvania Anthracite	No. 2, Welsh Anthracite	No. 3, Pennsylvania Bituminous	No. 4, Nova Scotia Bituminous	No. 5, Alberta Bituminous	No. 6, B.C., Crowsnest Bituminous	No. 7, B.C., Nicola Bituminous
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	54·8	38·6	38·2	40·5	12·9	12·9	18·7
1·05 to 0·742	19·4	21·1	27·1	21·1	15·9	15·3	18·9
0·742 to 0·525	4·7	4·6	5·2	5·0	8·2	6·7	12·4
0·525 to 0·371	1·9	1·3	1·7	2·1	4·0	2·3	9·2
0·371 to 0·0164	1·7	1·4	1·0	1·6	5·4	5·5	15·3
0·0164 to 0·0116	0·4	1·0	0·4	0·5	4·6	5·4	1·3
0·0116 to 0·0058	2·1	6·5	2·4	4·3	14·7	16·0	4·2
0·0058 to 0·0029	4·6	6·8	7·8	5·5	14·0	12·9	4·9
Through 0·0029	10·4	18·7	16·2	19·4	20·3	23·0	15·1
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps"— On 0·742	74·2	59·7	65·3	61·6	28·8	28·2	37·6
"Smalls"— 0·742 to 0·0116	8·7	8·3	8·3	9·2	22·2	19·9	38·2
"Fines"— 0·0116 to 0·0029	6·7	13·3	10·2	9·8	28·7	28·9	9·1
"Dust"— Through 0·0029	10·4	18·7	16·2	19·4	20·3	23·0	15·1
"Unbroken"— On 1·05	54·8	38·6	38·2	40·5	12·9	12·9	18·7
Number of tests	24	12	16	12	4	20	16
Friability, per cent	27	42	39	40	68	70	55

DT—A.S.T.M. (Coke) Drum Tumbler Test—22 pounds of 3- to 2-inch coal; 50 revolutions, approximately 2 minutes.

Sizes of Screen Openings, inches.	No. 1, Pennsylvania Anthracite	No. 2, Welsh Anthracite	No. 3, Pennsylvania Bituminous	No. 4, Nova Scotia Bituminous	No. 5, Alberta Bituminous	No. 6, B.C., Crowsnest Bituminous	No. 7, B.C., Nicola Bituminous
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	45·4	30·8	11·7	20·5	12·5	6·2	5·7
2 to 1½	22·8	17·7	17·9	18·8	12·6	9·7	6·8
1½ to 1	11·3	8·5	15·9	14·2	10·2	9·1	10·8
1 to 0·742	3·4	5·1	7·9	6·3	7·9	6·2	10·2
0·742 to 0·525	2·3	3·9	6·3	5·1	6·8	5·7	13·1
0·525 to 0·263	4·0	7·4	33·2 (0·525 to 0·0164)	10·2	11·9	12·5	26·2
0·263 to 0·0164	8·5	22·1		19·3	29·6	39·2	23·8
Through 0·0164	2·3	4·5	7·1	5·6	8·5	11·4	3·4
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps"— On 0·742	82·9	62·1	53·4	59·8	43·2	31·2	33·5
"Smalls"— 0·742 to 0·0164	14·8	33·4	39·5	34·6	48·3	57·4	63·1
"Fines and Dust"— Through 0·0164	2·3	4·5	7·1	5·6	8·5	11·4	3·4
"Unbroken"— On 2	45·4	30·8	11·7	20·5	12·5	6·2	5·7
Number of tests	2	2	4	2	2	2	2
Revolutions	50	50	100	50	50	50	50
Friability, per cent	31	47	(59) 48 Calc. for 50 revs.	53	66	75	72

TABLE II—Continued

Comparison of the Individual Coals by each Friability Test—Continued

BT—Box Tumbler Test—1000 grammes of 1½- to 1-inch coal

Sizes of Screen Openings, Inches	No. 1, Pennsylvania Anthracite	No. 2, Welsh Anthracite	No. 3, Pennsylvania Bituminous	No. 4, Nova Scotia Bituminous	No. 5, Alberta Bituminous	No. 6, B.C., Crowsnest Bituminous	No. 7, B.C., Nicola Bituminous
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	32·2	48·6	45·7	46·8	41·3	37·3	23·7
1·05 to 0·742	33·3	20·6	18·7	17·4	20·1	22·0	17·9
0·742 to 0·525	6·3	4·5	7·2	7·2	6·0	6·7	15·0
0·525 to 0·371	5·1	2·6	4·2	4·4	4·9	5·8	12·5
0·371 to 0·263	2·5	2·1	2·7	2·9	3·8	3·6	8·4
0·263 to 0·0164	14·7	16·7	16·3	16·9	19·9	9·3	20·5
0·0164 to 0·0116	1·1	1·2	1·2	1·0	0·9	11·3	0·5
0·0116 to 0·0058	1·8	1·6	1·8	1·4	1·2	1·6	0·6
0·0058 to 0·0029	1·1	0·6	0·8	0·7	0·8	0·7	0·3
Through 0·0029	1·9	1·5	1·4	1·3	1·1	1·7	0·6
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps"— On 0·742	65·5	69·2	64·4	64·2	61·4	59·3	41·6
"Smalls"— 0·742 to 0·0116	29·7	27·1	31·6	32·4	35·5	36·7	56·9
"Fines"— 0·0116 to 0·0029	2·9	2·2	2·6	2·1	2·0	2·3	0·9
"Dust"— Through 0·0029	1·9	1·5	1·4	1·3	1·1	1·7	0·6
"Unbroken"— On 1·05	32·2	48·6	45·7	46·8	41·3	37·3	23·7
Number of tests	2	3	2	9	1	2	3
Revolutions	741	218	234	179	57	33	115
Time, minutes	61¾	18¼	19½	15	4¾	2¾	10
Friability, per cent	36	30	33	32	36	39	45

AT—Sheffield (Coke) Abrasion Tumbler Test—2 cubic feet of 3- to 2-inch coal; 690 revolutions, 33 minutes.

Sizes of Screen Openings, inches	No. 1, Pennsylvania Anthracite	No. 2, Welsh Anthracite	No. 3, Pennsylvania Bituminous	No. 4, Nova Scotia Bituminous	No. 5, Alberta Bituminous	No. 6, B.C., Crowsnest Bituminous	No. 7, B.C., Nicola Bituminous
	per cent					per cent	per cent
3 to 2	78·4	....	....	....	....	16·3	14·0
2 to 1½	11·3	....	....	....	....	16·3	15·1
1½ to 1	3·9	....	....	....	....	12·0	17·4
1 to ¾	1·0	....	....	....	....	5·4	12·2
¾ to ½	0·5	....	....	....	....	4·6	14·6
½ to ¼	0·6	....	....	....	....	4·9	10·4
¼ to 0·0164	2·1	....	....	....	....	19·4	12·5
0·0164 to 0·0116	0·4	....	....	....	....	4·9	0·7
0·0116 to 0·0058	0·8	....	....	....	....	6·9	1·2
0·0058 to 0·0029	0·2	....	....	....	....	5·1	0·4
Through 0·0029	0·8	....	....	....	....	4·2	1·5
	per cent					per cent	per cent
"Lumps"— On ¾	94·6	....	....	....	....	50·0	58·7
"Smalls"— ¾ to 0·0116	3·6	....	....	....	....	33·8	38·2
"Fines"— 0·0116 to 0·0029	1·0	....	....	....	....	12·0	1·6
"Dust"— Through 0·0029	0·8	....	....	....	....	4·2	1·5
"Unbroken"— On 2	78·4	....	....	....	....	16·3	14·0
Weight of coal, lb	97	....	....	....	....	87½	86
Friability, per cent	11	....	....	....	....	62	56

TABLE II—Concluded

Comparison of the Individual Coals by each Friability Test—Concluded

ST—A.S.T.M. (Coke) Shatter Test—50 pounds of 3- to 2-inch coal; four 6-foot drops

Sizes of Screen Openings, inches	No. 1, Pennsylvania Anthracite	No. 2, Welsh Anthracite	No. 3, Pennsylvania Bituminous	No. 4, Nova Scotia Bituminous	No. 5, Alberta Bituminous	No. 6, B.C., Crowsnest Bituminous	No. 7, B.C., Nicola Bituminous
	per cent	per cent	per cent	per cent		per cent	per cent
3 to 2	63·8	56·0	49·6	48·3	....	33·0	13·5
2 to 1½	16·9	16·0	19·2	18·1	....	17·0	13·0
1½ to 1	7·0	9·0	11·2	9·1	....	9·5	17·5
1 to ¾	3·0	4·0	4·0	5·0	....	5·0	12·0
¾ to ½	3·0	2·5	5·1	3·0	....	4·5	14·5
½ to ¼	3·0	5·0	4.0	7·0	....	9·0	16·0
¼ to 0·0164	3·0	7·0	6·1	8·5	....	19·0	12·5
Through 0·0164	0·3	0·5	0·8	1·0	....	3·0	1·0
"Lumps"—	per cent	per cent	per cent	per cent		per cent	per cent
On ¾	90·7	85·0	84·0	80·5	....	64·5	56·0
"Smalls"— ¾ to 0·0164	9·0	14·5	15·2	18·5	....	32·5	43·0
"Fines and Dust"— Through 0·0164	0·3	0·5	0·8	1·0	....	3·0	1·0
"Unbroken"— On 2	63·8	56·0	49·6	48·3	....	33·0	13·5
Friability, per cent	18	25	28	30	....	44	57

IST—Illinois Shatter Test—55 lumps of 3- to 2-inch coal; one 10-foot drop

Sizes of Screen Openings, inches	No. 1, Pennsylvania Anthracite	No. 2, Welsh Anthracite	No. 3, Pennsylvania Bituminous	No. 4, Nova Scotia Bituminous	No. 5, Alberta Bituminous	No. 6, B.C., Crowsnest Bituminous	No. 7, B.C., Nicola Bituminous
	per cent	per cent		per cent		per cent	* per cent
3 to 2	73·0	68·4	....	53·6	....	43·5	26·9[1]
2 to 1½	12·0	9·7	....	24·9	....	14·9	15·8[2]
1½ to 1	8·3	6·6	....	6·2	....	11·8	15·3[3]
1 to ¾	3·0	3·6	....	5·0	....	7·5	13·7[4]
¾ to ½	1·2	2·6	....	2·5	....	3·7	8·2[5]
½ to 0·39 } 0·39 to ¼	1·2	4·1	....	3·7	....	6·8	7·6[6]
0·39 to ¼							6·0
¼ to 0·0164	1·2	4·6	....	3·7	....	10·6	6·0
Through 0·0164	0·1	0·4	....	0·4	....	1·2	0·5
"Lumps"—	per cent	per cent		per cent		per cent	per cent
On ¾	96·3	88·3	....	89·7	....	77·7	71·7
"Smalls"— ¾ to 0·0164	3·6	11·3	....	9·9	....	21·1	27·8
"Fines and Dust"— Through 0·0164	0·1	0·4	....	0·4	....	1·2	0·5
"Unbroken"— On 2	73·0	68·4	....	53·6	....	43·5	26·9
Number of tests	2	2	....	1	....	2	2
Weight of coal, lb.	21½	24½	....	20	....	20	22¾
Friability, per cent	13	19	....	23	....	35	38

* 60 lumps of 3- to 2½-inch, round hole, coal.
[1] 3- to 2½-inch, round hole.
[2] 2½- to 2-inch, round hole.
[3] 2- to 1½-inch, round hole.
[4] 1½- to 1-inch, round hole.
[5] 1- to ¾-inch, round hole.
[6] ¾- to ½-inch, round hole.

TABLE III

Comparison of the Friability Tests on Each Coal

—	JT, Small Jar Tumbler Test, 1000 gm., 1½- to 1-inch, 7200 revs., 3 hrs.	DT, A.S.T.M. (Coke) Drum Tumbler Test, 22 lb., 3- to 2-inch, 50 revs., 2 min.	BT, Box Tumbler Test, 1000 gm., 1½- to 1-inch,	AT, Sheffield (Coke) Abrasion Tumbler Test, 2 cu. ft., 3- to 2-inch, 690 revs., 33 min.	ST, A.S.T.M. (Coke) Shatter Test, 50 lb., 3- to 2-inch, 4 6-foot drops	IST, Illinois Shatter Test, 55 lumps, 3- to 2-inch, 1 10-foot drop

No. 1. Pennsylvania Anthracite

Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	....	45·4	....	78·4	63·8	73·0
2 to 1½	....	22·8	....	11·3	16·9	12·0
1½ to 1	54·8[1]	11·3	32·2[1]	3·9	7·0	8·3
1 to ¾	19·4[2]	3·4[4]	33·3[2]	1·0	3·0	3·0
¾ to ½	4·7[3]	2·3[3]	6·3[3]	0·5	3·0	1·2
½ to 0·371	1·9	4·0[5]	5·1[6]	0·6	3·0	1·2
0·371 to ¼	1·7		2·5[7]			
¼ to 0·0164		8·5	14·7	2·1	3·0	1·2
0·0164 to 0·0116	0·4	2·3	1·1	0·4	0·3	0·1
0·0116 to 0·0058	2·1		1·8	0·8		
0·0058 to 0·0029	4·6		1·1	0·2		
Through 0·0029	10·4		1·9	0·8		
Number of tests	24	2	2	1	1	2
Variant	None	50 revs. 2 min.	741 revs. 61¾ min.	97 lb.	None	21½ lb.
Friability, per cent	27	31	36	11	18	13

No. 2. Welsh Anthracite

Sizes of Screen Openings, inches	per cent	per cent	per cent		per cent	per cent
3 to 2	....	30·8	....	....	56·0	68·4
2 to 1½	....	17·7	....	....	16·0	9·7
1½ to 1	38·6[1]	8·5	48·6[1]	....	9·0	6·6
1 to ¾	21·1[2]	5·1[4]	20·6[2]	....	4·0	3·6
¾ to ½	4·6[3]	3·9[3]	4·5[3]	....	2·5	2·6
½ to 0·371	1·3	7·4[5]	2·6[6]	....	5·0	4·1
0·371 to ¼	1·4		2·1[7]	....		
¼ to 0·0164		22·1	16·7	....	7·0	4·6
0·0164 to 0·0116	1·0	4·5	1·2	....	0·5	0·4
0·0116 to 0·0058	6·5		1·6	....		
0·0058 to 0·0029	6·8		0·6	....		
Through 0·0029	18·7		1·5	....		
Number of tests	12	2	3	....	1	2
Variant	None	50 revs. 2 min.	18 revs. 118¼ min.	....	None	24½ lb.
Friability, per cent	42	47	30	....	25	19

[1] 1½- to 1·05-inch.
[2] 1·05- to 0·742-inch.
[3] 0·742- to 0·525-inch.
[4] 1- to 0·742-inch.
[5] 0·525- to 0·263-inch.
[6] 0·525- to 0·371-inch.
[7] 0·371- to 0·263-inch.

TABLE III—Continued

Comparison of the Friability Tests on Each Coal—Continued

—	JT, Small Jar Tumbler Test, 1000 gm., 1½- to 1-inch, 7200 revs., 3 hrs.	DT, A.S.T.M. (Coke) Drum Tumbler Test, 22 lb., 3- to 2-inch, 50 revs., 2 min.	BT, Box Tumbler Test, 1000 gm., 1½- to 1-inch,	AT, Sheffield (Coke) Abrasion Tumbler Test, 2 cu. ft., 3- to 2-inch, 690 revs., 33 min.	ST, A.S.T.M. (Coke) Shatter Test, 50 lb., 3- to 2-inch, 4 6-foot drops	IST, Illinois Shatter Test, 55 lumps, 3- to 2-inch, 1 10-foot drop
			No. 3. Pennsylvania Bituminous			
Sizes of Screen Openings, inches	per cent	per cent	per cent		per cent	
3 to 2	....	11·7	....	....	49·6	....
2 to 1½	....	17·9	....	....	19·2	....
1½ to 1	38·2[1]	15·9	45·7[1]	....	11·2	....
1 to ¾	27·1[2]	7·9[4]	18·7[2]	....	4·0	....
¾ to ½	5·2[3]	6·3[3]	7·2[3]	....	5·1	....
½ to 0·371	1·7	33·2 (½ to 0·0164)	4·2[6]	....	4·0 (½ to ¼)	....
0·371 to ¼	1.0 (0·371 to 0·0164)		2·7[7]	....		....
¼ to 0·0164			16·3	....	6·1	....
0·0164 to 0·0116	0·4	7·1 (0·0164 to through 0·0029)	1·2	....	0·8 (0·0164 to through 0·0029)	....
0·0116 to 0·0058	2·4		1·8	....		....
0·0058 to 0·0029	7·8		0·8	....		....
Through 0·0029	16·2		1·4	....		....
Number of tests	16	4	2	....	1	....
Variant	None	100 revs. 4 min.	234 revs. 19½ min.	....	None	....
Friability, per cent	39	(59) 48 calc. for 50 revs.	33	....	28	....
			No. 4. Nova Scotia Bituminous			
Sizes of Screen Openings, inches	per cent	per cent	per cent		per cent	per cent
3 to 2	....	20·5	....	....	48·3	53·6
2 to 1½	....	18·8	....	....	18·1	24·9
1½ to 1	40·5[1]	14·2	46·8[1]	....	9·1	6·2
1 to ¾	21·1[2]	6·3[4]	17·4[2]	....	5·0	5·0
¾ to ½	5·0[3]	5·1[3]	7·2[3]	....	3·0	2·5
½ to 0·371	2·1	10·2[5] (½ to ¼)	4·4[6]	....	7·0 (½ to ¼)	3·7 (½ to ¼)
0·371 to ¼	1·6 (0·371 to 0·0164)		2·9[7]	....		
¼ to 0·0164		19·3	16·9	....	8·5	3·7
0·0164 to 0·0116	0·5	5·6 (0·0164 to through 0·0029)	1·0	....	1·0 (0·0164 to through 0·0029)	0·4 (0·0164 to through 0·0029)
0·0116 to 0·0058	4·3		1·4	....		
0·0058 to 0·0029	5·5		0·7	....		
Through 0·0029	19·4		1·3	....		
Number of tests	12	2	9	....	1	1
Variant	None	50 revs. 2 min.	179 revs. 15 mins.	....	None	20 lb.
Friability, per cent	40	53	32	....	30	23

[1] 1½- to 1·05-inch.
[2] 1·05- to 0·742-inch.
[3] 0·742- to 0·525-inch.
[4] 1- to 0·742-inch.
[5] 0·525- to 0·263-inch.
[6] 0·525- to 0·371-inch.
[7] 0·371- to 0·263-inch.

TABLE III—Continued

Comparison of the Friability Tests on Each Coal—Continued

—	JT, Small Jar Tumbler Test, 1000 gm., 1½- to 1-inch, 7200 revs., 3 hrs.	DT, A.S.T.M. (Coke) Drum Tumbler Test, 22 lb., 3- to 2-inch, 50 revs., 2 min.	BT, Box Tumbler Test, 1000 gm., 1½- to 1-inch,	AT, Sheffield (Coke) Abrasion Tumbler Test, 2 cu. ft., 3- to 2-inch, 690 revs., 33 min.	ST, A.S.T.M. (Coke) Shatter Test, 50 lb., 3- to 2-inch, 4 6-foot drops	IST, Illinois Shatter Test, 55 lumps, 3- to 2-inch, 1 10-foot drop

No. 5. Alberta Bituminous

Sizes of Screen Openings, inches	per cent	per cent	per cent			
3 to 2	....	12·5	....	....	....	....
2 to 1½	....	12·6	....	....	....	....
1½ to 1	12·9[1]	10·2	41·3[1]	....	....	....
1 to ¾	15·9[2]	7·9[4]	20·1[2]	....	....	....
¾ to ½	8·2[3]	6·8[3]	6·0[3]	....	....	....
½ to 0·371	4·0	11·9[5]	4·9[6]	....	....	....
0·371 to ¼	5·4		3·8[7]	....	....	....
¼ to 0·0164		29·6	19·9	....	....	....
0·0164 to 0·0116	4·6		0·9	....	....	....
0·0116 to 0·0058	14·7	8·5	1·2	....	....	....
0·0058 to 0·0029	14·0		0·8	....	....	....
Through 0·0029	20·3		1·1	....	....	....
Number of tests	4	2	1	....	....	....
Variant	None	50 revs. 2 min.	57 revs. 4¾ min.	....	....	....
Friability, per cent	68	66	36	....	....	....

No. 6. British Columbia, Crowsnest, Bituminous

Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	....	6·2	....	16·3	33·0	43·5
2 to 1½	....	9·7	....	16·3	17·0	14·9
1½ to 1	12·9[1]	9·1	37·3[1]	12·0	9·5	11·8
1 to ¾	15·3[2]	6·2[4]	22·0[2]	5·4	5·0	7·5
¾ to ½	6·7[3]	5·7[3]	6·7[3]	4·6	4·5	3·7
½ to 0·371	2·3	12·5[5]	5·8[6]	4·9	9·0	6·8
0·371 to ¼	5·5		3·6[7]			
¼ to 0·0164		39·2	9·3	19·4	19·0	10·6
0·0164 to 0·0116	5·4		11·3	4·9		
0·0116 to 0·0058	16·0	11·4	1·6	6·9	3·0	1·2
0·0058 to 0·0029	12·9		0·7	5·1		
Through 0·0029	23·0		1·7	4·2		
Number of tests	20	2	2	1	1	2
Variant	None	50 revs. 2 min.	33 revs. 2¾ min.	87½ lb.	None	20 lb.
Friability, per cent	70	75	39	62	44	35

[1] 1½- to 1·05-inch.
[2] 1·05- to 0·742-inch.
[3] 0·742- to 0·525-inch.
[4] 1- to 0·742-inch.
[5] 0·525- to 0·263-inch.
[6] 0·525- to 0·371-inch.
[7] 0·371- to 0·263-inch.

TABLE III—Concluded

Comparison of the Friability Tests on Each Coal—Concluded

—	JT, Small Jar Tumbler Test, 1000 gm., 1½- to 1-inch, 7200 revs., 3 hrs.	DT, A.S.T.M. (Coke) Drum Tumbler Test, 22 lb., 3- to 2-inch, 50 revs., 2 min.	BT, Box Tumbler Test, 1000 gm., 1½- to 1-inch,	AT, Sheffield (Coke) Abrasion Tumbler Test, 2 cu. ft., 3- to 2-inch, 690 revs., 33 min.	ST, A.S.T.M. (Coke) Shatter Test, 50 lb., 3- to 2-inch, 4 6-foot drops	IST, Illinois Shatter Test, 55 lumps, 3- to 2-inch, 1 10-foot drop
No. 7. British Columbia, Nicola, Bituminous						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent*
3 to 2	....	5·7	....	14·0	13·5	26·9[8]
2 to 1½	....	6·8	....	15·1	13·0	15·8[9]
1½ to 1	18·7[1]	10·8	23·7[1]	17·4	17·5	15·3[10]
1 to ¾	18·9[2]	10·2[4]	17·9[2]	12·2	12·0	13·7[11]
¾ to ½	12·4[3]	13·1[3]	15·0[3]	14·6	14·5	8·2[12]
½ to 0·371	9·2	26·2[5]	12·5[6]	10·4	16·0	7·6[13]
0·371 to ¼	15·3		8·4[7]			6·0
¼ to 0·0164		23·8	20·5	12·5	12·5	6·0
0·0164 to 0·0116	1·3	3·4	0·5	0·7	1·0	0·5
0·0116 to 0·0058	4·2		0·6	1·2		
0·0058 to 0·0029	4·9		0·3	0·4		
Through 0·0029	15·1		0·6	1·5		
Number of tests	16	2	3	1	1	2
Variant	None	50 revs. 2 min.	115 revs. 10 min.	86 lb.	None	22¾ lb.
Friability, per cent	55	72	45	56	57	38

* 60 lumps of 3- to 2½-inch, round hole, coal.

[1] 1½- to 1·05-inch.
[2] 1·05- to 0·742-inch.
[3] 0·742- to 0·525-inch.
[4] 1- to 0·742-inch.
[5] 0·525- to 0·263-inch.
[6] 0·525- to 0·371-inch.
[7] 0·371- to 0·263-inch.
[8] 3- to 2½-inch, round.
[9] 2½- to 2-inch, round.
[10] 2- to 1½-inch, round.
[11] 1½- to 1-inch, round.
[12] 1- to ¾-inch, round.
[13] ¾- to ½-inch, round.

TABLE IV

Effects of Varying Weight of Coal in Small Jar Tumbler Test

No. 3. Pennsylvania Bituminous Coal; 1½ to 1 inch, 3 hours.

Weight of coal, grammes	1200	1000	800	600
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent
1½ to 1·05	39·2	35·0	32·9	26·5
1·05 to 0·742	28·7	29·3	26·2	33·6
0·742 to 0·525	5·3	5·8	7·3	5·4
0·525 to 0·371	1·9	1·7	2·2	1·8
0·371 to 0·0164	1·3	1·1	1·1	1·2
0·0164 to 0·0116	2·1	2·6	0·3	0·5
0·0116 to 0·0058			3·6	3·5
0·0058 to 0·0029	7·0	7·7	8·1	9·0
Through 0·0029	14·5	16·8	18·3	18·5
	per cent	per cent	per cent	per cent
"Lumps"— On 0·742	67·9	64·3	59·1	60·1
"Smalls"— 0·742 to 0·0116	8·5*	8·6*	10·6	8·4
"Fines"— 0·0116 to 0·0029	9·1	10·3	12·0	13·0
"Dust"— Through 0·0029	14·5	16·8	18·3	18·5
"Unbroken"— On 1·05	39·2	35·0	32·9	26·5
Number of tests	8	8	4	4
Friability, per cent	35	40	42	45

*Actually on 0·0164.

TABLE V

Small Jar Tumbler Tests of Three Sizes of Six Selected Coals

(1000 *grammes, 3 hours*)

Coal	No. 1. Pennsylvania Anthracite			No. 2. Welsh Anthracite		
Size, inches	2 to 1½	1½ to 1	1 to ½	2 to 1½	1½ to 1	1 to ½
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	70·6	51·0	....	53·3	43·7	....
1·05 to 0·742	3·3	21·8	29·0	5·4	16·1	31·3
0·742 to 0·525	1·6	5·1	30·0	0·9	4·0	28·8
0·525 to 0·371	0·4	2·1	21·5	0·3	1·2	12·0
0·371 to 0·0164	1·6	2·0	9·5	2·8	1·4	4·4
0·0164 to 0·0116	1·8	0·5	0·1	3·0	1·6	0·2
0·0116 to 0·0058	6·7	2·5	0·2	11·4	7·4	1·2
0·0058 to 0·0029	6·8	5·4	0·6	9·3	9·1	6·2
Through 0·0029	7·2	9·6	9·1	13·6	15·5	15·9
Number of tests	4	8	4	4	4	4
"Unbroken", per cent	....	51·0	59·0	....	43·7	60·1
Friability, per cent	34	29	28	48	41	33

Coal	No 3. Pennsylvania Bituminous			No. 4. Nova Scotia Bituminous		
Size, inches	2 to 1½	1½ to 1	1 to ½	2 to 1½	1½ to 1	1 to ½
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	58·8	38·2	....	50·8	34·9	....
1·05 to 0·742	5·6	27·1	18·3	7·2	24·3	33·7
0·742 to 0·525	1·8	5·2	40·1	1·7	4·9	32·5
0·525 to 0·371	0·3	1·7	19·3	0·6	2·8	9·9
0·371 to 0·0164	1·1	1·0	5·8	3·2	1·9	4·2
0·0164 to 0·0116	9·0	2·8	0·1	2·6	0·7	0·1
0·0116 to 0·0058			0·3	9·9	4·8	0·8
0·0058 to 0·0029	5·6	7·8	1·7	8·9	8·2	3·5
Through 0·0029	17·8	16·2	14·4	15·1	17·5	15·3
Number of tests	4	16	4	4	4	4
"Unbroken," per cent	....	38·2	58·4	....	34·9	66·2
Friability, per cent	43	39	34	49	43	29

Coal	No. 6. B.C., Crowsnest Bituminous			No. 7. B.C., Nicola Bituminous		
Size, inches	2 to 1½	1½ to 1	1 to ½	2 to 1½	1½ to 1	1 to ½
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	22·7	14·5	....	25·2	16·4	....
1·05 to 0·742	6·8	14·6	6·1	14·0	18·9	18·3
0·742 to 0·525	2·4	5·2	17·2	11·0	13·2	26·9
0·525 to 0·371	1·1	1·7	18·4	6·9	10·3	19·0
0·371 to 0·0164	11·3	7·2	12·9	14·6	16·5	21·8
0·0164 to 0·0116	8·8	5·6	1·1	2·3	1·0	0·2
0·0116 to 0·0058	19·0	19·4	6·1	6·8	3·9	0·5
0·0058 to 0·0029	10·0	11·6	10·6	5·6	4·8	1·4
Through 0·0029	17·9	20·2	27·6	13·6	15·0	11·9
Number of tests	4	4	4	8	8	8
"Unbroken", per cent	....	14·5	23·3	....	16·4	45·2
Friability, per cent	73	70	65	62	56	40

TABLE VI

Comparison of Two-Vane Frames with Usual Three-Vane Frames in Small Jar Tumbler Test

(1000 grammes; $1\frac{1}{2}$ to 1 inch; 3 hours)

Coal	No. 1		No. 2		No. 4		No. 6		No. 7	
Frames	2-vane	3-vane	2-vane	3-vane	2-vane	3-vane	2-vane	3-vane	2-vane	3-vane
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
$1\frac{1}{2}$ to 1·05	48·8	54·8	45·1	38·6	37·1	40·5	20·5	12·9	23·2	18·7
1·05 to 0·742	27·2	19·4	20·1	21·1	23·5	21·1	14·3	15·3	21·6	18·9
0·742 to 0·525	4·5	4·7	3·1	4·6	6·4	5·0	5·2	6·7	12·9	12·4
0·525 to 0·371	2·1	1·9	1·1	1·3	2·2	2·1	2·2	2·3	8·3	9·2
0·371 to 0·0164	2·3	1·7	1·0	1·4	2·0	1·6	3·5	5·5	11·2	15·3
0·0164 to 0·0116	0·2	0·4	0·4	1·0	0·3	0·5	3·2	5·4	0·7	1·3
0·0116 to 0·0058	0·9	2·1	4·0	6·5	2·9	4·3	13·5	16·0	2·5	4·2
0·0058 to 0·0029	4·4	4·6	9·1	6·8	7·6	5·5	13·4	12·9	5·3	4·9
Through 0·0029	9·6	10·4	16·1	18·7	18·0	19·4	24·2	23·0	14·3	15·1
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps"— $1\frac{1}{2}$ to 0·742	76·0	74·2	65·2	59·7	60·6	61·6	34·8	28·2	44·8	37·6
"Smalls"— 0·742 to 0·0116	9·1	8·7	5·6	8·3	10·9	9·2	14·1	19·9	33·1	38·2
"Fines"— 0·0116 to 0·0029	5·3	6·7	13·1	13·3	10·5	9·8	26·9	28·9	7·8	9·1
"Dust"— Through 0·0029	9·6	10·4	16·1	18·7	18·0	19·4	24·2	23·0	14·3	15·1
"Unbroken"— $1\frac{1}{2}$ to 1·05	48·8	54·8	45·1	38·6	37·1	40·5	20·5	12·9	23·2	18·7
Number of tests	8	24	8	12	8	12	8	20	16	16
Friability, per cent	27	27	38	42	41	40	65	70	49	55

TABLE VIA

Small Jar Tumbler Test. Comparison of Tests in Iron Jars with Those in Porcelain Jars

(1000 grammes; 1½- to 1-inch coal; 3 hours)

Coal	Pennsylvania Anthracite		Nova Scotia Bituminous				British Columbia, Nicola Bituminous	
			Selected sample		General sample			
Jar	Porcelain	Iron	Porcelain	Iron	Porcelain	Iron	Porcelain	Iron
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	39·8	43·8	26·1	26·8	45·2	41·8	24·1	21·8
1·05 to 0·742	36·7	34·3	14·6	17·4	13·2	15·9	17·2	20·3
0·742 to 0·525	5·3	3·3	6·0	7·0	5·0	5·0	12·9	12·6
0·525 to 0·371	1·6	1·7	2·9	2·4	1·9	1·7	8·5	7·9
0·371 to 0·0164	1·4	1·5	6·2	3·9	1·9	1·8	11·5	10·9
0·0164 to 0·0116	0·1	0·2	3·1	2·9	0·7	0·7	1·3	1·2
0·0116 to 0·0058	1·2	1·1	7·2	7·8	5·8	6·7	4·2	4·3
0·0058 to 0·0029	5·3	5·5	17·0	14·5	10·0	10·7	8·1	8·8
Through 0·0029	8·6	8·6	16·9	17·3	16·3	15·7	12·2	12·2
"Lumps" (S.S. Index B)—	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 0·742	76·5	78·1	40·7	44·2	58·4	57·7	41·3	42·1
"Smalls"— 0·742 to 0·0116	8·4	6·7	18·2	16·2	9·5	9·2	34·2	32·6
"Fines"— 0·0116 to 0·0029	6·5	6·6	24·2	22·3	15·8	17·4	12·3	13·1
"Dust"— Through 0·0029	8·6	8·6	16·9	17·3	16·3	15·7	12·2	12·2
"Unbroken"	39·8	43·8	26·1	26·8	45·2	41·8	24·1	21·8
Friability, per cent	29·1	28·4	57·6	54·9	40·9	42·3	51·2	51·8
Number of tests	8	8	8	12	16	8	8	8

TABLE VII

Small Jar Tumbler Tests of Different Durations

(1000 grammes; 1½ to 1 inch)

Coal	No. 1. Pennsylvania Anthracite			No. 2. Welsh Anthracite			No. 3. Pennsylvania Bituminous			
Duration of test	1 hour	2 hours	3 hours	1 hour	2 hours	3 hours	1 hour	2 hours	3 hours	5 hours
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	62·5	53·0	54·8	57·9	45·7	38·6	54·2	45·6	38·2	31·9
1·05 to 0·742	20·7	22·6	19·4	16·6	20·3	21·1	23·4	22·3	27·1	27·4
0·742 to 0·525	3·3	5·0	4·7	3·2	3·1	4·6	4·5	4·5	5·2	5·9
0·525 to 0·371	1·6	2·2	1·9	1·2	1·3	1·3	1·7	2·2	1·7	2·0
0·371 to 0·0164	3·1	2·6	1·7	2·4	1·7	1·4	1·7	1·5	1·0	0·9
0·0164 to 0·0116	0·8	0·8	0·4	1·5	0·9	1·0	0·8	0·6	0·4	0·2
0·0116 to 0·0058	2·1	2·6	2·1	4·6	6·0	6·5	2·7	4·0	2·4	1·5
0·0058 to 0·0029	2·0	3·8	4·6	4·8	5·7	6·8	4·2	7·7	7·8	9·5
Through 0·0029	3·9	7·4	10·4	7·8	15·3	18·7	6·8	11·6	16·2	20·7
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps"— 1½ to 0·742	83·2	75·6	74·2	74·5	66·0	59·7	77·6	67·9	65·3	59·3
"Smalls"— 0·742 to 0·0116	8·8	10·6	8·7	8·3	7·0	8·3	8·7	8·8	8·3	9·0
"Fines"— 0·0116 to 0·0029	4·1	6·4	6·7	9·4	11·7	13·3	6·9	11·7	10·2	11·0
"Dust"— Through 0·0029	3·9	7·4	10·4	7·8	15·3	18·7	6·8	11·6	16·2	20·7
"Unbroken"— 1½ to 1·05	62·5	53·0	54·8	57·9	45·7	38·6	54·2	45·6	38·2	31·9
Number of tests	20	12	24	16	8	12	4	4	16	4
Friability, per cent	19	26	27	27	36	42	25	34	39	44

TABLE VII—Concluded

Small Jar Tumbler Tests of Different Durations—Concluded

(1000 grammes; 1½ to 1 inch—Concluded)

Coal	No. 4. Nova Scotia Bituminous			No. 6. B.C., Crowsnest Bituminous			No. 7. B.C., Nicola Bituminous		
Duration of test	1 hour	2 hours	3 hours	1 hour	2 hours	3 hours	1 hour	2 hours	3 hours
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	54·1	43·2	40·5	20·3	15·0	12·9	30·9	30·6	18·7
1·05 to 0·742	19·2	22·4	21·1	18·2	18·1	15·3	18·8	20·8	18·9
0·742 to 0·525	4·3	5·9	5·0	7·0	5·8	6·7	12·0	10·8	12·4
0·525 to 0·371	2·1	1·9	2·1	2·9	2·6	2·3	8·2	7·0	9·2
0·371 to 0·0164	3·4	2·2	1·6	11·6	7·1	5·5	17·3	11·4	15·3
0·0164 to 0·0116	1·0	0·6	0·5	4·8	6·1	5·4	1·6	1·5	1·3
0·0116 to 0·0058	4·3	4·4	4·3	12·5	15·4	16·0	2·8	3·2	4·2
0·0058 to 0·0029	2·9	4·7	5·5	7·1	12·0	12·9	3·3	4·5	4·9
Through 0·0029	8·7	14·7	19·4	15·6	17·9	23·0	5·1	10·2	15·1
	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps"— 1½ to 0·742	73·3	65·6	61·6	38·5	33·1	28·2	49·7	51·4	37·6
"Smalls"— 0·742 to 0·0116	10·8	10·6	9·2	26·3	21·6	19·9	39·1	30·7	38·2
"Fines"— 0·0116 to 0·0029	7·2	9·1	9·8	19·6	27·4	28·9	6·1	7·7	9·1
"Dust"— Through 0·0029	8·7	14·7	19·4	15·6	17·9	23·0	5·1	10·2	15·1
"Unbroken"— 1½ to 1·05	54·1	43·2	40·5	20·3	15·0	12·9	30·9	30·6	18·7
Number of tests	8	8	12	16	8	20	16	8	16
Friability, per cent	28	36	40	59	68	70	42	44	55

TABLE VIII

Comparison of Results of Tests of Different Durations in Small Jar Tumbler

(1000 grammes; 1½ to 1 inch)

Basis of Comparison	Time of test, hours	Single tests or average of 4 tests	"Un-broken," 1½ to 1·05 inches, per cent	"Lumps" 1½ to 0·742 inches, per cent	"Smalls" 0·742 to 0·0116 inches, per cent	"Fines and Dust," through 0·0116 inches, per cent	Fria-bility, per cent
No. 1. Pennsylvania Anthracite							
Difference between highest and lowest values from screen analysis.	1	16 single	40·66	8·43	6·98	2·86	16·3
	1	5 average	22·77	3·84	3·26	1·37	8·0
	2	3 "	8·07	2·61	0·79	4·36	4·5
	3	6 "	13·50	4·42	4·73	5·28	5·4
Maximum divergence from average value.	1	16 single	23·30	4·35	3·89	1·60	8·5
	1	5 average	12·03	1·96	1·77	0·78	4·0
	2	3 "	4·97	1·52	0·47	2·32	2·7
	3	6 "	8·53	2·80	2·54	3·64	2·8
Mean divergence from average value.	1	16 single	7·67	2·13	1·78	0·64	2·7
	1	5 average	6·59	1·38	1·16	0·37	2·2
	2	3 "	3·27	1·01	0·32	1·54	1·8
	3	6 "	3·90	1·07	1·10	1·35	1·5
No. 2. Welsh Anthracite							
Difference between highest and lowest values from screen analysis.	1	12 single	18·73	7·30	6·88	4·89	8·1
	1	4 average	12·54	2·30	2·59	3·13	4·5
	2	2 "	2·24	1·01	0·21	4·62	1·2
	3	3 "	7·83	1·88	1·35	11·52	2·2
Maximum divergence from average value.	1	12 single	12·42	3·74	3·87	2·82	5·0
	1	4 average	6·78	1·23	1·34	1·63	2·4
	2	2 "	1·12	0·50	0·11	2·31	0·6
	3	3 "	5·11	0·98	0·71	6·29	1·2
Mean divergence from average value.	1	12 single	3·93	2·56	1·97	1·16	1·9
	1	4 "	3·92	1·07	1·15	1·17	1·2
	2	2 "	1·12	0·50	0·11	2·31	0·6
	3	3 "	3·41	0·65	0·47	4·19	0·8
No. 6. B.C., Crowsnest Bituminous							
Difference between highest and lowest values from screen analysis.	1	12 single	21·96	11·66	12·68	10·02	9·8
	1	4 average	9·61	8·23	7·68	7·68	5·8
	2	2 "	6·72	0·24	1·08	0·52	6·7
	3	5 "	7·32	5·26	7·63	9·14	3·2
Maximum divergence from average value.	1	12 single	12·17	6·09	6·57	5·85	4·9
	1	4 average	5·17	4·47	4·46	3·95	3·2
	2	2 "	3·36	0·12	0·54	0·26	3·3
	3	5 "	4·34	2·66	4·23	4·88	1·8
Mean divergence from average value.	1	12 single	6·52	3·60	3·64	3·24	2·5
	1	4 average	3·42	3·16	3·15	3·54	1·7
	2	2 "	3·36	0·12	0·54	0·26	3·3
	3	5 "	2·00	1·45	1·71	2·94	1·0
No. 7. B.C., Nicola Bituminous							
Difference between highest and lowest values from screen analysis.	1	12 single	37·57	23·19	23·51	3·86	18·6
	1	4 average	19·38	18·11	17·51	1·62	12·2
	2	2 "	0·04	4·65	4·28	3·43	1·9
	3	4 "	9·91	12·33	13·50	6·42	7·5
Maximum divergence from average value.	1	12 single	22·40	15·62	15·51	2·04	13·2
	1	4 average	10·63	9·54	9·07	0·93	6·2
	2	2 "	0·02	2·32	2·14	1·71	0·9
	3	4 "	7·24	8·43	9·56	3·72	5·0
Mean divergence from average value.	1	12 single	8·24	6·18	6·43	0·97	4·7
	1	4 average	7·91	7·47	7·32	0·55	5·5
	2	2 "	0·02	2·32	2·14	1·71	0·9
	3	4 "	3·61	4·21	4·78	2·28	2·5

TABLE IX

Study of Results of Removing Cushioning Effect of Fine Coal in Small Jar Tumbler Test

(3-hour tests)

No. 1. Pennsylvania Anthracite

Size of coal	2 to 1½ inch			1½ to 1 inch		
Variation of test	A. Normal test, 1000 grammes	B. Ditto, but removing material through 0·742 inch hourly	C. Same as A, but removing material through 0·0164 inch hourly	A. Normal test, 1000 grammes	B. Ditto, but removing material through 0·742 inch hourly	C. Same as A, but removing material through 0·0164 inch hourly
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	70·6	60·1	60·3	51·0	29·5	29·0
1·05 to 0·742	3·3	4·3	4·2	21·8	33·5	34·4
0·742 to 0·525	1·6	2·3	2·7	5·1	10·9	8·0
0·525 to 0·371	0·4	1·1	1·4	2·1	4·1	4·7
0·371 to 0·0164	1·6	7·1	2·0	2·0	4·2	3·6
0·0164 to 0·0116	1·8	4·0	5·1	0·5	1·2	1·3
0·0116 to 0·0058	6·7	7·2	8·5	2·5	3·1	3·4
0·0058 to 0·0029	6·8	5·9	6·6	5·4	5·7	6·0
Through 0·0029	7·2	8·0	9·2	9·6	7·8	9·6
"Lumps"—	per cent	per cent	per cent	per cent	per cent	per cent
On 0·742	73·9	64·4	64·5	72·8	63·0	63·4
"Smalls"—						
0·742 to 0·0116	5·4	14·5	11·2	9·7	20·4	17·6
"Fines"—						
0·0116 to 0·0029	13·5	13·1	15·1	7·9	8·8	9·4
"Dust"—						
Through 0·0029	7·2	8·0	9·2	9·6	7·8	9·6
"Unbroken"*	....	....	....	51·0	29·5	29·0
Friability, per cent	34	41	41	29	38	39

*Not determined for 2- to 1½-inch size: on 1·05 for 1½- to 1-inch size

TABLE IX—Concluded

Study of Results of Removing Cushioning Effect of Fine Coal in Small Jar Tumbler Test—Concluded

(3-hour tests—Concluded)

No. 3. Pennsylvania Bituminous

Size of coal	2 to 1½ inch			1½ to 1 inch					1 to ½ inch	
Variation of test	A. Normal test, 1000 grammes	B. Ditto, but removing material through 0·742 inch hourly	C. Same as A, but removing material through 0·0164 inch hourly	A. Normal test, 1000 grammes	B. Ditto, but removing material through 0·742 inch hourly	C. Same as A, but removing material through 0·0164 inch hourly	D. Same as B, but weight of charge brought to 1000 grammes hourly	E. Same as C, but weight of charge brought to 1000 grammes hourly	A. Normal test, 1000 grammes	C. Ditto, but removing material through 0·0164 inch hourly
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	58·8	39·0	45·5	38·2	24·8	24·4	41·1	33·9	....	....
1·05 to 0·742	5·6	8·6	8·7	27·1	29·2	36·1	22·5	29·0	18·3	22·0
0·742 to 0·525	1·8	6·8	2·1	5·2	9·5	6·8	5·9	5·1	40·1	35·4
0·525 to 0·371	0·3	2·4	0·9	1·7	3·8	1·6	2·5	2·4	19·3	17·4
0·371 to 0·0164	1·1	5·4	0·8	1·0	3·0	1·2	2·4	1·1	5·8	5·8
0·0164 to 0·0116	9·0 (0·0164 to 0·0058)	11·7 (0·0164 to 0·0058)	14·0 (0·0164 to 0·0058)	0·4	1·1	1·0	1·0	1·0	0·1	0·2
0·0116 to 0·0058				2·4	4·8	4·8	4·1	4·3	0·3	0·7
0·0058 to 0·0029	5·6	4·7	6·2	7·8	8·9	8·4	6·9	7·7	1·7	2·9
Through 0·0029	17·8	21·4	21·8	16·2	14·9	15·7	13·6	15·5	14·4	15·6
"Lumps"—	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 0·742	64·4	47·6	54·2	65·3	54·0	60·5	63·6	62·9	18·3	22·0
"Smalls"— 0·742 to 0·0116	3·2**	14·6**	3·8**	8·3	17·4	10·6	11·8	9·6	65·3	58·8
"Fines"— 0·0116 to 0·0029	14·6†	16·4†	20·2†	10·2	13·7	13·2	11·0	12·0	2·0	3·6
"Dust"— Through 0·0029	17·8	21·4	21·8	16·2	14·9	15·7	13·6	15·5	14·4	15·6
"Unbroken"*	....	....	....	38·2	24·8	24·4	41·1	33·9	58·4	57·4
Friability, per cent	43	56	53	39	47	45	38	41	34	35

*Not determined for 2- to 1½-inch size; on 1·05 for 1½- to 1-inch size; on 0·525 for 1- to ½-inch size. **0·742 to 0·0164. †0·0164 to 0·0029.

TABLE X

Study of Effects of Removing "Broken" Material Hourly, and Replacing it by Material as Originally Used for the Test; "Sweetening" Tests in Small Jar Tumbler

(1000 grammes; 1½ to 1·05 inch)

Time elapsed	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours
No. 1. Pennsylvania Anthracite						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	63·4	72·5	76·7	87·2	84·5	86·0
1·05 to 0·742	19·8	14·0	16·1	4·3	8·9	6·3
0·742 to 0·525	3·3	3·4	0·7	1·0	1·0	1·1
0·525 to 0·371	1·9	1·1	0·1	0·4	0·2	0·4
0·371 to 0·0164	2·6	1·2	0·3	0·6	0·2	0·6
0·0164 to 0·0116	0·7	0·4	0·2	0·1	0·2	0·1
0·0116 to 0·0058	2·0	1·4	0·6	0·8	0·5	0·4
0·0058 to 0·0029	2·3	2·1	1·6	1·8	1·5	1·4
Through 0·0029	4·0	3·9	3·8	3·7	3·1	3·7
"Lumps," 1½ to 0·742	83·2	86·5	92·8	91·5	93·4	92·3
"Smalls," 0·742 to 0·0116	8·5	6·1	1·2	2·2	1·5	2·2
"Fines," 0·0116 to 0·0029	4·3	3·5	2·2	2·6	2·0	1·8
"Dust," through 0·0029	4·0	3·9	3·8	3·7	3·1	3·7
"Unbroken," 1½ to 1·05	63·4	72·5	76·7	87·2	84·5	86·0
Friability, per cent	19	14	10	8	7	7
No. 2. Welsh Anthracite						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	48·5	71·0	66·4	73·9	70·2	75·5
1·05 to 0·742	26·1	7·2	17·9	10·8	14·6	10·2
0·742 to 0·525	3·3	3·7	1·7	1·2	1·5	2·5
0·525 to 0·371	2·2	1·1	0·4	0·3	0·6	0·7
0·371 to 0·0164	2·5	1·4	0·4	0·5	0·5	0·3
0·0164 to 0·0116	1·8	1·3	0·6	0·5	0·3	0·3
0·0116 to 0·0058	4·2	3·2	2·3	2·4	1·8	1·2
0·0058 to 0·0029	4·4	4·6	3·9	4·0	3·6	3·4
Through 0·0029	7·0	6·5	6·4	6·4	6·9	5·9
"Lumps," 1½ to 0·742	74·6	78·2	84·3	84·7	84·8	85·7
"Smalls," 0·742 to 0·0116	9·8	7·5	3·1	2·5	2·9	3·8
"Fines," 0·116 to 0·0029	8·6	7·8	6·2	6·4	5·4	4·6
"Dust," through 0·0029	7·0	6·5	6·4	6·4	6·9	5·9
"Unbroken," 1½ to 1·05	48·5	71·0	66·4	73·9	70·2	75·5
Friability, per cent	29	20	18	16	17	14
No. 4. Nova Scotia Bituminous						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	46·2	64·2	57·3	61·1	71·6	74·3
1·05 to 0·742	26·9	15·0	20·1	18·8	6·7	13·5
0·742 to 0·525	4·0	1·7	3·4	3·8	4·0	0·7
0·525 to 0·371	1·6	2·2	1·7	1·3	1·6	0·2
0·371 to 0·0164	4·2	2·4	2·6	1·6	1·8	1·0
0·0164 to 0·0116	1·8	1·1	1·0	0·7	0·7	0·5
0·0116 to 0·0058	3·3	3·0	2·9	2·7	2·7	1·6
0·0058 to 0·0029	4·3	3·8	3·8	3·3	3·9	2·3
Through 0·0029	7·7	6·6	7·2	6·7	7·0	5·9
"Lumps," 1½ to 0·742	73·1	79·2	77·4	79·9	78·3	87·8
"Smalls," 0·742 to 0·0116	11·6	7·4	8·7	7·4	8·1	2·4
"Fines," 0·0116 to 0·0029	7·6	6·8	6·7	6·0	6·6	3·9
"Dust," through 0·0029	7·7	6·6	7·2	6·7	7·0	5·9
"Unbroken," 1½ to 1·05	46·2	64·2	57·3	61·1	71·6	74·3
Friability, per cent	30	22	25	22	19	14

TABLE X—Continued

Study of Effects of Removing "Broken" Material Hourly, and Replacing it by Material as Originally Used for the Test; "Sweetening" Tests in Small Jar Tumbler—Continued

(1000 grammes; 1½ to 1·05 inch—Concluded)

Time elapsed	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours
No. 6. B.C., Crowsnest Bituminous						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	26·3	29·1	24·0	25·9	36·0	36·4
1·05 to 0·742	14·0	11·0	22·4	19·0	11·1	13·8
0·742 to 0·525	4·6	6·1	4·3	5·7	4·3	4·1
0·525 to 0·371	2·5	2·0	1·6	2·2	1·1	1·1
0·371 to 0·0164	11·3	9·9	7·6	8·0	8·4	6·6
0·0164 to 0·0116	6·7	6·3	5·9	5·2	5·9	4·7
0·0116 to 0·0058	11·6	13·0	11·7	11·2	10·7	9·2
0·0058 to 0·0029	9·0	8·9	9·3	9·8	10·2	10·6
Through 0·0029	14·0	13·7	13·2	13·0	12·3	13·5
"Lumps," 1½ to 0·742	40·3	40·1	46·4	44·9	47·1	50·2
"Smalls," 0·742 to 0·0116	25·1	24·3	19·4	21·1	19·7	16·5
"Fines," 0·0116 to 0·0029	20·6	21·9	21·0	21·0	20·9	19·8
"Dust," through 0·0029	14·0	13·7	13·2	13·0	12·3	13·5
"Unbroken," 1½ to 1·05	26·3	29·1	24·0	25·9	36·0	36·4
Friability, per cent	57	57	55	55	51	49

No. 7. B.C., Nicola Bituminous

Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1½ to 1·05	33·6	30·5	32·9	43·4	38·6	45·9
1·05 to 0·742	10·7	17·8	22·6	14·6	16·5	18·2
0·742 to 0·525	12·9	13·5	12·8	9·1	8·1	5·7
0·525 to 0·371	8·6	7·4	5·0	5·1	6·2	3·5
0·371 to 0·0164	20·1	17·0	12·4	11·8	15·6	10·9
0·0164 to 0·0116	2·2	1·7	1·7	2·5	2·1	2·2
0·0116 to 0·0058	3·4	3·2	3·1	3·7	3·3	3·8
0·0058 to 0·0029	3·4	3·2	3·9	4·5	3·7	4·4
Through 0·0029	5·1	5·7	5·6	5·3	5·9	5·4
"Lumps," 1½ to 0·742	44·3	48·3	55·5	58·0	55·1	64·1
"Smalls," 0·742 to 0·0116	43·8	39·6	31·9	28·5	32·0	22·3
"Fines," 0·0116 to 0·0029	6·8	6·4	7·0	8·2	7·0	8·2
"Dust," through 0·0029	5·1	5·7	5·6	5·3	5·9	5·4
"Unbroken," 1½ to 1·05	33·6	30·5	32·9	43·4	38·6	45·9
Friability, per cent	44	43	40	37	39	34

No. 1 Pennsylvania Anthracite
(1000 grammes; 1 to 0·525 inch)

Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1 to 0·742	47·4	52·6	53·2	56·4	54·7	58·2
0·742 to 0·525	31·4	33·7	37·9	37·0	38·0	36·8
0·525 to 0·371	9·9	7·1	3·8	2·8	3·0	1·4
0·371 to 0·0164	5·6	2·7	1·7	1·1	1·7	1·1
0·0164 to 0·0116	0·2	0·1	0·1	0·1	0·0	0·0
0·0116 to 0·0058	0·4	0·2	0·1	0·1	0·1	0·0
0·0058 to 0·0029	1·3	0·6	0·3	0·2	0·2	0·2
Through 0·0029	3·8	3·0	2·9	2·3	2·3	2·3
"Lumps," 1 to 0·742	47·4	52·6	53·2	56·4	54·7	58·2
"Smalls," 0·742 to 0·0116	47·1	43·6	43·5	41·0	42·7	39·3
"Fines," 0·0116 to 0·0029	1·7	0·8	0·4	0·3	0·3	0·2
"Dust," through 0·0029	3·8	3·0	2·9	2·3	2·3	2·3
"Unbroken," 1 to 0·525	78·8	86·3	91·1	93·4	92·7	95·0
Friability, per cent	15	10	8	6	7	5

TABLE X—Continued

Study of Effects of Removing "Broken" Material Hourly, and Replacing it by Material as Originally Used for the Test; "Sweetening" Tests in Small Jar Tumbler—Continued

(1000 grammes; 1 to 0·525 inch—Continued)

Time elapsed	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours
No. 2. Welsh Anthracite						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1 to 0·742	45·8	50·4	48·4	50·1	51·4	50·6
0·742 to 0·525	29·7	32·1	37·3	36·6	38·1	39·3
0·525 to 0·371	6·8	4·9	5·1	4·0	2·7	4·1
0·371 to 0·0164	4·2	2·1	1·5	2·0	1·4	0·6
0·0164 to 0·0116	0·5	0·2	0·1	0·1	0·1	0·0
0·0116 to 0·0058	1·9	0·6	0·3	0·2	0·1	0·1
0·0058 to 0·0029	4·3	2·6	1·6	1·3	0·9	0·5
Through 0·0029	6·8	7·1	5·7	5·7	5·3	4·8
"Lumps," 1 to 0·742	45·8	50·4	48·4	50·1	51·4	50·6
"Smalls," 0·742 to 0·0116	41·2	39·3	44·0	42·7	42·3	44·0
"Fines," 0·0116 to 0·0029	6·2	3·2	1·9	1·5	1·0	0·6
"Dust," through 0·0029	6·8	7·1	5·7	5·7	5·3	4·8
"Unbroken," 1 to 0·525	75·5	82·5	85·7	86·7	89·5	89·9
Friability, per cent	20	15	13	12	11	10
No. 4. Nova Scotia Bituminous						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1 to 0·742	20·3	24·5	27·9	29·0	31·6	24·2
0·742 to 0·525	54·5	57·3	57·0	59·0	57·1	64·7
0·525 to 0·371	13·2	9·5	7·7	5·7	5·1	5·9
0·371 to 0·0164	4·1	2·8	2·0	1·3	1·4	0·9
0·0164 to 0·0116	0·1	0·1	0·1	0·1	0·0	0·0
0·0116 to 0·0058	0·3	0·1	0·1	0·1	0·1	0·0
0·0058 to 0·0029	1·4	0·7	0·7	0·5	0·5	0·4
Through 0·0029	6·1	5·0	4·5	4·3	4·2	3·9
"Lumps," 1 to 0·742	20·3	24·5	27·9	29·0	31·6	24·2
"Smalls," 0·742 to 0·0116	71·9	69·7	66·8	66·1	63·6	71·5
"Fines," 0·0116 to 0·0029	1·7	0·8	0·8	0·6	0·6	0·4
"Dust," through 0·0029	6·1	5·0	4·5	4·3	4·2	3·9
"Unbroken," 1 to 0·525	74·8	81·8	84·9	88·0	88·7	88·9
Friability, per cent	25	21	18	17	16	18
No. 6. B.C., Crowsnest Bituminous						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1 to 0·742	13·6	9·0	15·3	15·4	9·0	12·6
0·742 to 0·525	27·5	36·4	35·6	38·0	44·1	39·1
0·525 to 0·371	11·5	14·4	11·7	13·2	11·4	12·8
0·371 to 0·0164	11·3	9·7	8·2	7·6	6·6	6·8
0·0164 to 0·0116	2·2	1·1	1·0	0·8	0·9	0·8
0·0116 to 0·0058	8·0	5·0	4·6	3·3	5·0	4·5
0·0058 to 0·0029	10·7	10·2	9·0	8·0	8·5	9·1
Through 0·0029	15·2	14·2	14·6	13·7	14·5	14·3
"Lumps," 1 to 0·742	13·6	9·0	15·3	15·4	9·0	12·6
"Smalls," 0·742 to 0·0116	52·5	61·6	56·5	59·6	63·0	59·5
"Fines," 0·0116 to 0·0029	18·7	15·2	13·6	11·3	13·5	13·6
"Dust," through 0·0029	15·2	14·2	14·6	13·7	14·5	14·3
"Unbroken," 1 to 0·525	41·1	45·4	50·9	53·4	53·1	51·7
Friability, per cent	53	49	45	42	46	45

TABLE X—Concluded

Study of Effects of Removing "Broken" Material Hourly, and Replacing it by Material as Originally Used for the Test; "Sweetening" Tests in Small Jar Tumbler—Concluded

(1000 grammes; 1 to 0·525 inch—Concluded)

Time elapsed	1 hour	2 hours	3 hours	4 hours	5 hours	6 hours
No. 7. B.C., Nicola Bituminous						
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
1 to 0·742	26·4	32·2	43·1	44·0	43·6	40·9
0·742 to 0·525	30·4	37·8	35·6	37·6	41·1	43·0
0·525 to 0·371	17·1	13·7	9·6	7·7	6·9	6·6
0·371 to 0·0164	18·2	10·2	6·4	5·4	4·3	5·7
0·0164 to 0·0116	0·4	0·2	0·1	0·1	0·1	0·1
0·0116 to 0·0058	0·7	0·4	0·2	0·2	0·1	0·1
0·0058 to 0·0029	2·1	1·1	0·8	0·9	0·5	0·4
Through 0·0029	4·7	4·4	4·2	4·1	3·4	3·2
"Lumps," 1 to 0·742	26·4	32·2	43·1	44·0	43·6	40·9
"Smalls," 0·742 to 0·0116	66·1	61·9	51·7	50·8	52·4	55·4
"Fines," 0·0116 to 0·0029	2·8	1·5	1·0	1·1	0·6	0·5
"Dust," through 0·0029	4·7	4·4	4·2	4·1	3·4	3·2
"Unbroken," 1 to 0·525	56·8	70·0	78·7	81·6	84·7	83·9
Friability, per cent	31	23	16	15	14	15

TABLE XI

Study of "Sweetening" Effect Produced by Tumbling Large-sized Coal Previous to Screening for Small Jar Tumbler Test

1000 grammes of B.C., Crowsnest Bituminous Coal; 3 hours

Size of coal	2 to 1½ inch		1½ to 1 inch		1 to ½ inch	
	Screening only	Tumbling followed by screening	Screening only	Tumbling followed by screening	Screening only	Tumbling followed by screening
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	22·7	21·6	14·5	18·2	....	....
1·05 to 0·742	6·8	9·4	14·6	13·5	6·1	13·4
0·742 to 0·525	2·4	3·4	5·2	4·8	17·2	21·5
0·525 to 0·371	1·1	0·5	1·7	2·1	18·4	11·8
0·371 to 0·0164	11·3	5·4	7·2	4·5	12·9	6·3
0·0164 to 0·0116	8·8	9·6	5·6	4·3	1·1	0·9
0·0116 to 0·0058	19·0	18·8	19·4	16·7	6·1	6·6
0·0058 to 0·0029	10·0	4·9	11·6	10·3	10·6	6·9
Through 0·0029	17·9	26·4	20·2	25·6	27·6	32·6
"Lumps," on 0·742	29·5	31·0	29·1	31·7	6·1	13·4
"Smalls," 0·742 to 0·0116	23·6	18·9	19·7	15·7	49·6	40·5
"Fines," 0·0116 to 0·0029	29·0	23·7	31·0	27·0	16·7	13·5
"Dust," through 0·0029	17·9	26·4	20·2	25·6	27·6	32·6
"Unbroken"	....	....	14·5	18·2	23·3	34·9
Friability, per cent	73	73	70	67	65	59

TABLE XII

Variations of A.S.T.M. (Coke) Drum Tumbler Test

(22 pounds (10,000 grammes) of coal)

Coal number and rank	1. Anthracite		2. Anthracite		4. Bituminous				6. Bituminous		
Size, inches	3 to 2		3 to 2		3 to 2		2 to 1½		3 to 2	2 to 1½	
Duration of test	50 revs.	100revs.	50 revs.	100revs.	50 revs.	100revs.	1½ hours	3 hours	50 revs.	1½ hours	3 hours
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	45·4	31·5	30·8	15·6	20·5	18·0	....	....	6·2	....	....
2 to 1½	22·8	23·9	17·7	13·1	18·8	13·3	0·0	0·0	9·7	0·0	0·0
1½ to 1	11·3	12·2	8·5	10·5	14·2	9·4	4·5	2·3	9·1	0·0	0·0
1 to 0·742	3·4	4·8	5·1	6·8	6·3	6·8	4·5[1]	3·4[1]	6·2	1·1[1]	1·1[1]
0·742 to 0·525	2·3	3·1	3·9	4·5	5·1	5·7	5·7[2]	4·5[2]	5·7	2·3[2]	1·2[2]
0·525 to 0·371	4·0		7·4		10·2		10·4[3]	7·2[3]	12·5	6·9[3]	5·0[3]
0·371 to 0·263		20·5		41·2		39·7	17·7	16·8		15·1	13·9
0·263 to 0·131	2·8		6·8		7·4				12·0		
0·131 to 0·0164	5·7		15·3		11·9		25·8	25·5	27·2	33·9	32·0
0·0164 to 0·0058							10·5	13·2		18·4	20·1
0·0058 to 0·0029	2·3	4·0	4·5	8·3	5·6	7·1	5·1	6·9	11·4	6·7	8·6
Through 0·0029							15·8	20·2		15·6	18·1
"Lumps," on 0·742	82·9	72·4	62·1	46·0	59·8	47·5	9·0	5·7	31·2	1·1	1·1
"Smalls," 0·742 to 0·0164	14·8	23·6	33·4	45·7	34·6	45·4	59·6	54·0	57·4	58·2	52·1
"Fines," 0·0164 to 0·0029	2·3	4·0	4·5	8·3	5·6	7·1	15·6	20·1	11·4	25·1	28·7
"Dust," through 0·0029							15·8	20·2		15·6	18·1
"Unbroken"	45·4	31·5	30·8	15·6	20·5	18·0	0·0	0·0	6·2	0·0	0·0
Friability, per cent	31	40	47	60	53	58	86	89	75	93	94
Friability, per cent, ratio of 50 to 100 revs.	76/100	....	78/100	....	91/100	....	....	....	....	....	....

Values bracketed in the original span the adjoining size rows.

[1] 1 to ¾. [2] ¾ to ½. [3] ½ to 0·371.

TABLE XIII

Box Tumbler Test

Coal	No. 1. Anthracite			No. 2. Anthracite			No. 3. Bituminous		
Size	1½- to 1-inch		1- to ½-inch	1½- to 1-inch		1- to ½-inch	1½- to 1-inch		1- to ½-inch
Screen or plate	¼-inch square screen	Plate	¼-inch square screen	¼-inch square screen	Plate	¼-inch square screen	¼-inch square screen	Plate	¼-inch square screen
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	32·2	51·4	....	48·6	49·7	....	45·7	50·2	....
1·05 to 0·742	33·3	14·7	21·6	20·6	17·1	36·9	18·7	20·2	23·0
0·742 to 0·525	6·3	6·2	37·8	4·5	6·4	26·1	7·2	6·0	34·6
0·525 to 0·371	5·1	3·1	14·0	2·6	3·2	11·1	4·2	3·0	15·7
0·371 to 0·0116	18·3	16·9	22·2	20·0	18·1	22·9	20·2	14·8	22·2
0·0116 to 0·0029	2·9	4·8	2·3	2·2	3·6	2·0	2·6	3·9	2·7
Through 0·0029	1·9	2·9	2·1	1·5	1·9	1·0	1·4	1·9	1·8
Time	61 min. 45 sec.	61 min. 45 sec.	63 min. 30 sec.	18 min. 10 sec.	18 min. 10 sec.	15 min.	19 min. 30 sec.	19 min. 30 sec.	26 min.
Revolutions	741	741	762	218	218	180	234	234	312
Friability, per cent	36	31	32	30	31	26	33	29	32

TABLE XIII—Continued

Box Tumbler Test—Continued

Coal	No. 4. Bituminous							No. 5. Bituminous	
Size	1½- to 1-inch				1- to ½-inch			1½- to 1-inch	1- to ½-inch
Screen or plate	¼-inch square screen	Plate	¼-inch round screen	5/16-inch round screen	¼-inch square screen	Plate	¼-inch round screen	¼-inch square screen	¼-inch square screen
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	46·8	43·9	31·8	36·8	....	....	....	41·3	....
1·05 to 0·742	17·4	24·1	27·3	26·3	30·8	36·4	32·7	20·1	31·6
0·742 to 0·525	7·2	7·7	9·8	8·0	28·8	26·6	24·5	6·0	25·2
0·525 to 0·371	4·4	3·4	4·9	4·2	13·4	11·5	13·8	4·9	12·0
0·371 to 0·0116	20·8	16·2	22·2	21·3	22·6	18·8	24·1	24·6	28·0
0·0116 to 0·0029	2·1	2·7	2·6	2·2	2·6	3·7	2·8	2·0	1·9
Through 0·0029	1·3	2·0	1·4	1·2	1·8	3·0	2·1	1·1	1·3
Time	14 min. 55 sec.	14 min. 45 sec.	18 min. 15 sec.	15 min. 45 sec.	23 min. 23 sec.	23 min. 30 sec.	23 min. 15 sec.	4 min. 43 sec.	4 min. 28 sec.
Revolutions	179	177	219	189	281	282	279	57	54
Friability, per cent	32	32	39	36	29	27	30	36	31

TABLE XIII—Concluded

Box Tumbler Test—Concluded

Coal	No. 6. Bituminous			No. 7. Bituminous			
Size	1½- to 1-inch		1- to ½-inch	2- to 1½-inch	1½- to 1-inch		1- to ½-inch
Screen or plate	¼-inch square screen	Plate	¼-inch square screen	¼-inch square screen	¼-inch square screen	Plate	¼-inch square screen
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent
On 1·05	37·3	42·9	....	25·8	23·7	25·5	....
1·05 to 0·742	22·0	20·4	18·4	17·5	17·9	19·2	21·7
0·742 to 0·525	6·7	7·3	31·3	13·4	15·0	13·0	27·2
0·525 to 0·371	5·8	4·2	17·7	12·0	12·5	12·6	18·0
0·371 to 0·0116	24·2	21·4	28·9	29·9	29·4	27·7	31·9
0·0116 to 0·0029	2·3	3·0	2·5	0·9	0·9	1·4	0·8
Through 0·0029	1·7	0·8	1·2	0·5	0·6	0·6	0·4
Time	2 min. 45 sec.	2 min. 45 sec.	3 min. 8 sec.	8 min. 30 sec.	9 min. 34 sec.	9 min. 45 sec.	9 min. 23 sec.
Revolutions	33	33	38	102	115	117	113
Friability, per cent	39	34	38	56	45	45	34

TABLE XIV

Correlation of Tests in A.S.T.M. (Coke) Drum Tumbler and Drum (Box) Tumbler

(22 pounds of 3- to 2-inch coal)

Coal	No. 2. Welsh Anthracite		No. 6. B.C., Crowsnest, Bituminous		No. 7. B.C., Nicola, Bituminous		
Tumbler	Drum	Drum (Box)	Drum	Drum (Box)	Drum	Drum (Box)	
Number of shelves	2	2	2	2	2	2	1
Screen or plate	....	Plate	....	Plate	....	Plate	Plate
Revolutions	50	50	50	50	50	50	50
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	30·8	42·2	6·2	5·1	5·7	8·5	3·4
2 to 1½	17·7	6·8	9·7	10·2	6·8	9·1	14·2
1½ to 1	8·5	9·1	9·1	10·7	10·8	13·1	14·2
1 to 0·742	5·1	4·5	6·2	6·2	10·2	13·6	11·4
0·742 to 0·525	3·9	4·5	5·7	5·7	13·1	11·9	11·4
0·525 to 0·0164	29·5	29·5	51·7	49·5	50·0	41·0	42·7
Through 0·0164	4·5	3·4	11·4	12·6	3·4	2·8	2·7
"Lumps"	62·1	62·6	31·2	32·2	33·5	44·3	43·2
"Smalls"	33·4	34·0	57·4	55·2	63·1	52·9	54·1
"Fines" and "Dust"**	4·5	3·4	11·4	12·6	3·4	2·8	2·7
"Unbroken"	30·8	42·2	6·2	5·1	5·7	8·5	3.4
Friability, per cent	47	44	75	75	72	66	68

**Actually material passing 0·0164-inch screen.

TABLE XIV—Concluded

Correlation of Tests in A.S.T.M. (Coke) Drum Tumbler and Drum (Box) Tumbler—Concluded

(22 pounds of 3- to 2-inch coal—Concluded)

Coal	No. 1. Pennsylvania Anthracite					No. 5. Alberta Bituminous			
Tumbler	Drum	Drum (Box)				Drum	Drum (Box)		
Number of shelves	2	2	1	1	1	2	2	1	1
Screen or plate	....	Plate	Plate	Plate	21/64-inch round screen	....	Plate	Plate	21/64-inch round screen
Revolutions	50	50	50	110	110	50	50	50	24
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	45·4	56·9	49·4	*	*	12·5	17·1	14·8	15·4
2 to 1½	22·8	14·8	23·3	35·4	33·4	12·6	11·4	13·0	18·0
1½ to 1	11·3	6·8	8·0	29·1	23·2	10·2	9·1	11·4	13·1
1 to 0·742	3·4	3·9	3·9	8·1	10·5	7·9	7·2	5·7	7·3
0·742 to 0·525	2·3	2·3	2·3	4·7	5·4	6·8	5·7	4·5	5·6
0·525 to 0·0164	12·5	11·9	10·8	19·4	24·5	41·5	41·5	41·6	36·8
Through 0·0164	2·3	3·4	2·3	3·3	3·0	8·5	8·0	9·0	3·8
"Lumps"	82·9	82·4	84·6	72·6	67·1	43·2	44·8	44·9	53·8
"Smalls"	14·8	14·2	13·1	24·1	29·9	48·3	47·2	46·1	42·4
"Fines" and "Dust"**	2·3	3·4	2·3	3·3	3·0	8·5	8·0	9·0	3·8
"Unbroken"	45·4	56·9	49·4	35·4	33·4	12·5	17·1	14·8	15·4
Friability, per cent	31	26	28	35	40	66	63	64	58

*These tests with 2- to 1½-inch coal.

**Actually material passing 0·0164-inch screen.

TABLE XV

Drum (Box) Tumbler Test

Variation of Weight of Coal with Width of Tumbler

Coal	Size, inches	Weight, grammes	Width, inches	Time, seconds	Revolutions	Screen Analysis: "Unbroken," per cent	Screen Analysis: "Lumps," per cent	Screen Analysis: "Smalls," per cent	Screen Analysis: "Fines and "Dust," per cent	Friability, per cent
No. 1. Pennsylvania Anthracite......	2 to 1½	10,000	17½	275	110	33·4	67·1	30·7	2·2	40
" " "	"	8,900	16½	265	106	30·8	68·7	29·3	2·0	40
" " "	"	8,350	15½	273	109	30·7	66·4	31·3	2·3	41
" " "	"	7,800	14½	255	102	31·1	67·3	30·7	2·0	40
" " "	"	7,300	13½	275	110	32·2	66·7	31·2	2·1	40
" " "	"	6,750	12½	298	119	41·7	69·8	27·8	2·4	35
" " "	"	6,200	11½	300	120	26·7	66·1	31·6	2·3	42
" " "	"	5,650	10½	305	122	45·8	69·5	28·5	2·0	34
" " "	"	5,700	10	275	110	37·4	67·6	30·3	2·1	38
" " "	"	4,550	8	283	113	32·9	67·6	29·8	2·6	40
No. 5. Alberta Bituminous...........	3 to 2	10,000	17½	61	24	15·4	53·8	43·5	2·7	58
" " "	"	5,650	10½	64	26	24·5	54·6	42·1	3·3	54
No. 5. Alberta Bituminous...........	2 to 1½	10,000	17½	65	26	20·5	55·8	41·1	3·1	50
" " "	"	8,900	16½	63	25	22·6	52·8	44·0	3·2	51
" " "	"	8,350	15½	65	26	24·6	54·1	43·1	2·8	49
" " "	"	7,800	14½	55	22	20·4	53·7	43·2	3·1	51
" " "	"	7,300	13½	55	22	19·0	52·9	43·7	3·4	52
" " "	"	6,750	12½	70	28	25·4	54·7	42·4	2·9	49
" " "	"	6,200	11½	58	23	25·4	52·5	44·7	2·8	50
" " "	"	5,650	10½	67	27	21·1	52·1	44·9	3·0	51
No. 5. Alberta Bituminous...........	1½ to 1	10,000	17½	74	30	22·2	48·8	47·6	3·6	48
" " "	"	8,350	15½	68	27	24·7	47·2	49·8	3·0	47
" " "	"	6,750	12½	88	35	25·3	52·3	44·7	3·0	45
" " "	"	5,650	10½	70	28	25·1	48·9	47·8	3·3	47
" " "	"	5,700	10	70	28	26·6	48·7	48·0	3·3	47
" " "	"	4,550	8	68	27	22·0	47·1	49·5	3·4	49

TABLE XVI

Drum (Box) Tumbler Test

Variations of Size of Coal, Weight of Coal or Width of Tumbler

Coal	Size, inches	Weight, grammes	Width, inches	Time, seconds	Revolutions	Screen Analysis				Friability, per cent
						"Unbroken," per cent	"Lumps," per cent	"Smalls," per cent	"Fines and "Dust," per cent	
Size of coal varying; weight of coal and width of tumbler fixed										
No. 5. Alberta Bituminous..........	3 to 2	10,000	17½	61	24	15·4	53·8	43·5	2·7	58
" " "	2 to 1½	10,000	17½	65	26	20·5	55·8	41·1	3·1	50
" " "	1½ to 1	10,000	17½	74	30	22·2	48·8	47·6	3·6	48
" " "	2 to 1½	8,350	15½	65	26	24·6	54·1	43·1	2·8	49
" " "	1½ to 1	8,350	15½	68	27	24·7	47·2	49·8	3·0	47
" " "	2 to 1½	6,750	12½	70	28	25·4	54·7	42·4	2·9	49
" " "	1½ to 1	6,750	12½	88	35	25·3	52·3	44·7	3·0	45
" " "	3 to 2	5,650	10½	64	26	24·5	54·6	42·1	3·3	54
" " "	2 to 1½	5,650	10½	67	27	21·1	52·1	44·9	3·0	51
" " "	1½ to 1	5,650	10½	70	28	25·1	48·9	47·8	3·3	47
Weight of coal varying; size of coal and width of tumbler fixed										
No. 1. Pennsylvania Anthracite......	2 to 1½	8,000	8	340	136	36·1	66·8	31·0	2·2	39
" " "	"	4,550	8	283	113	32·9	67·6	29·8	2·6	40
" " "	"	3,500	8	235	94	29·7	64·2	34·2	1·6	41
No. 5. Alberta Bituminous..........	1½ to 1	8,850	15½	75	30	29·3	49·2	47·4	3·4	45
" " "	"	8,350	15½	68	27	24·7	47·2	49·8	3·0	47
" " "	1½ to 1	7,150	12½	70	28	30·1	49·4	47·4	3·2	45
" " "	"	6,750	12½	88	35	25·3	52·3	44·7	3·0	45
" " "	1½ to 1	10,000	10	85	34	26·7	53·2	43·2	3·6	45
" " "	"	5,700	10	70	28	26·6	48·7	48·0	3·3	47
" " "	"	4,500	10	63	25	24·0	47·9	49·0	3·1	48
" " "	1½ to 1	9,000	8	80	32	26·5	52·2	44·1	3·7	45
" " "	"	4,550	8	68	27	22·0	47·1	49·5	3·4	49
" " "	"	3,500	8	65	26	23·4	47·4	49·6	3·0	48
Width of tumbler varying; size and weight of coal fixed										
No. 5. Alberta Bituminous..........	1½ to 1	10,000	17½	74	30	22·2	48·8	47·6	3·6	48
" " "	"	10,000	10	85	34	26·7	53·2	43·2	3·6	45
" " "	1½ to 1	4,500	10	63	25	24·0	47·9	49·0	3·1	48
" " "	"	4,550	8	68	27	22·0	47·1	49·5	3·4	49

TABLE XVII

Drum (Box) Tumbler Test. Comparison of Friabilities (Size Stabilities) of Five Coals by an Arbitrarily Chosen Modification of the Test

(8350 grammes; 2- to 1½-inch size; 15½-inch width of tumbler)

Coal	No. 1. Pennsylvania Anthracite	No. 2. Welsh Anthracite	No. 4. Nova Scotia Bituminous	No. 5. Alberta Bituminous	No. 7. B.C., Nicola Bituminous
Time of tumbling, seconds	273	160	133	65	130
Revolutions	109	64	53	26	52
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent
2 to 1½	30·7	39·2	29·2	24·6	8·0
1½ to 1	25·7	20·6	20·7	21·2	16·9
1 to 0·742	10·0	6·5	9·4	8·3	13·4
0·742 to 0·525	5·7	4·0	6·3	6·4	15·0
0·525 to 0·371	3·8	3·7	6·8	5·7	14·7
0·371 to 0·263	2·7	2·3	3·8	4·3	7·0
0·263 to 0·131	9·8	8·1	8·3	10·9	12·0
0·131 to 0·0116	9·3	13·5	13·2	15·8	11·5
Through 0·0116	2·3	2·1	2·3	2·8	1·5
	per cent	per cent	per cent	per cent	per cent
"Lumps," 2 to 0·742	66·4	66·3	59·3	54·1	38·3
"Smalls," 0·742 to 0·0116	31·3	31·6	38·4	43·1	60·2
"Fines" and "Dust," through 0·0116	2·3	2·1	2·3	2·8	1·5
"Unbroken," 2 to 1½	30·7	39·2	29·2	24·6	8·0
Friability, per cent	41	38	45	49	60

TABLE XVIII

Sheffield (Coke) Abrasion Tumbler Test

(2 cubic feet of coal)

Coal	No. 1. Pennsylvania Anthracite				No. 6. British Columbia, Crowsnest Bituminous		No. 7. British Columbia, Nicola Bituminous
Weight, pounds	97		95		87½		86
Size, inches	3 to 2		1½ to 1		3 to 2		3 to 2
Time, minutes	33	180	33	180	33	180	33
Revolutions	690	3,780	690	3,780	690	3,780	690
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	78·4	36·3	....	....	16·3	14·9	14·0
2 to 1½	11·3	32·1	....	....	16·3	15·2	15·1
1½ to 1	3·9	7·3	84·6	63·7	12·0	11·1	17·4
1 to ¾	1·0	2·8	8·4	18·7	5·4	4·9	12·2
¾ to ½	0·5	2·1	2·4	5·8	4·6	4·3	14·6
½ to ¼	0·6	1·6	1·6	3·2	4·9	3·1	10·4
¼ to 0·131	0·5	0·7	0·5	1·5	4·3	4·4	5·8
0·131 to 0·0116	2·0	3·4	1·1	1·5	20·0	13·3	7·4
0·0116 to 0·0029	1·0	9·7	0·7	2·0	12·0	19·3	1·6
Through 0·0029	0·8	4·0	0·7	3·6	4·2	9·5	1·5
	per cent	per cent	per cent	per cent	per cent	per cent	per cent
"Lumps," on ¾	94·6	78·5	93·0	82·4	50·0	46·1	58·7
"Smalls, ¾ to 0·0116	3·6	7·8	5·6	12·0	33·8	25·1	38·2
"Fines," 0·0116 to 0·0029	1·0	9·7	0·7	2·0	12·0	19·3	1·6
"Dust," through 0·0029	0·8	4·0	0·7	3·6	4·2	9·5	1·5
"Unbroken"	78·4	36·3	84·6	63·7	16·3	14·9	14·0
Friability, per cent	11	36	8	19	62	65	56
Abrasion Index, per cent	89·7	68·4	....	....	32·6	30·1	29·1

TABLE XIX

A.S.T.M. (Coke) Shatter Test

Comparison of Round with Square Hole Screens and Study of Effects of Increasing the Number of Drops

(50 pounds of coal)

Coal		No. 1. Pennsylvania Anthracite			No. 4. Nova Scotia Bituminous				No. 6. B.C., Crowsnest Bituminous				No. 7. B.C., Nicola Bituminous	
Size, inches		3 to 2			3 to 2½	3 to 2			3 to 2½	3 to 2			3 to 2½	3 to 2
Shape of hole in screen		Square			Round	Square			Round	Square			Round	Square
Number of drops		4	8	12	4	4	8	12	4	4	8	12	4	4
Sizes of Screen Openings, inches		per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Round	Square													
3 to 2½	3 to 2	63·8	49·0	40·4	42·2	48·3	30·2	19·4	32·0	33·0	16·1	6·6	17·0	13·5
2½ to 2	2 to 1½	16·9	20·4	21·2	15·1	18·1	20·1	19·4	11·0	17·0	15·1	12·1	13·0	13·0
2 to 1½	1½ to 1	7·0	11·2	13·1	11·6	9·1	14·1	17·4	11·0	9·5	11·6	12·1	13·0	17·5
1½ to 1	1 to ¾	3·0	5·1	6·1	9·1	5·0	8·0	8·2	9·0	5·0	6·0	6·6	15·0	12·0
1 to ¾	¾ to ½	3·0	4·1	5·0	4·0	3·0	6·0	6·1	5·0	4·5	5·0	6·0	11·0	14·5
¾ to ½		......	......	......	5·0	......	......	......	5·0	......	......	......	11·0	......
½ to ¼*	½ to ¼	3·0	4·1	6·1	5·0	7·0	10·1	11·2	5·5	9·0	12·1	13·6	9·0	16·0
¼ to 0·0164		3·0	5·6	7·1	7·0	8·5	10·0	16·3	18·5	19·0	28·6	35·9	10·5	12·5
Through 0·0164		0·3	0·5	1·0	1·0	1·0	1·5	2·0	3·0	3·0	5·5	7·1	0·5	1·0
"Lumps," on ¾ (1-inch round)		90·7	85·7	80·8	78·0	80·5	72·4	64·4	63·0	64·5	48·8	37·4	58·0	56·0
"Smalls," ¾ to 0·0164		9·0	13·8	18·2	21·0	18·5	26·1	33·6	34·0	32·5	45·7	55·5	41·5	43·0
"Fines" and "Dust," through 0·0164		0·3	0·5	1·0	1·0	1·0	1·5	2·0	3·0	3·0	5·5	7·1	0·5	1·0
"Unbroken"		63·8	49·0	40·4	42·2	48·3	30·2	19·4	32·0	33·0	16·1	6·6	17·0	13·5
Friability, per cent		18	27	33	30	30	42	51	42	44	60	70	48	57

*All screens of ½-inch and smaller size had square holes.

TABLE XX

A.S.T.M. (Coke) Shatter Test

Effects of Removing Material Passing ¼-in Screen after Each Drop; also of Using Different Weights or Sizes of Coal

(All with square hole screens)

Coal	No. 3. Pennsylvania Bituminous						No. 7. B.C., Nicola Bituminous		
Weight, pounds	50				50	25	50	25	25
Size, inches	3 to 2				2 to 1½	2 to 1½	3 to 2	3 to 2	2 to 1½
Material passing ¼-inch	In coal dropped	Removed	In coal dropped	Removed	In coal dropped		In coal dropped		
Number of drops	4	4	12	12	4	4	4	4	4
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
3 to 2	49·6	50·7	25·5	27·6	......	......	13·5	10·2	......
2 to 1½	19·2	17·6	20·4	17·4	51·6	50·6	13·0	14·3	18·0
1½ to 1	11·2	11·4	14·3	14·3	24·1	23·8	17·5	17·4	18·9
1 to ¾	4·0	5·2	7·2	6·1	7·0	6·9	12·0	11·2	15·0
¾ to ½	5·1	4·1	8·2	7·1	5·5	6·0	14·5	10·2	14·0
½ to ¼	4·0	4·1	8·2	8·2	5·0	6·0	16·0	21·4	20·9
¼ to 0·0164	6·1	6·2	14·3	17·4	6·0	6·0	12·5	14·3	12·0
Through 0·0164	0·8	0·7	1·9	1·9	0·8	0·7	1·0	1·0	1·2
"Lumps," on ¾	84·0	84·9	67·4	65·4	82·7	81·3	56·0	53·1	51·9
"Smalls," ¾ to 0·0164	15·2	14·4	30·7	32·7	16·5	18·0	43·0	45·9	46·9
"Fines and Dust," through 0·0164	0·8	0·7	1·9	1·9	0·8	0·7	1·0	1·0	1·2
"Unbroken"	49·6	50·7	25·5	27·6	51·6	50·6	13·5	10·2	18·0
Friability, per cent	28	27	46	46	24	24	57	60	50

TABLE XXI

Illinois Shatter Test

Square and Round Hole Screens; Effects of Increasing the Number of Drops; Different Weights or Sizes of Coal

Coal	No. 2. Welsh Anthracite						No. 4. Nova Scotia Bituminous						No. 7. B.C., Nicola Bituminous		
Weight, pounds	24½	29					20	30½					25	20	20
Number of lumps	55	60					55	60					No record		
Size, inches	3 to 2	3 to 2½					3 to 2	3 to 2½					3 to 2	3 to 2	2 to 1½
Shape of hole in screen	Square	Round					Square	Round					Square		
Number of drops	1	1	2	4	6	8	1	1	2	4	6	8	1	1	1
Sizes of Screen Openings, inches	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent	per cent
Square — Round															
3 to 2 — 3 to 2½	68·4	64·3	37·5	24·6	18·4	12·7	53·6	59·3	40·5	27·9	17·9	14·6	35·8	27·4	......
2 to 1½ — 2½ to 2	9·7	17·9	22·8	17·8	13·4	10·4	24·9	12·7	17·1	11·9	13·4	13·4	17·9	11·2	37·3
1½ to 1 — 2 to 1½	6·6	5·5	9·9	12·1	12·9	12·3	6·2	7·8	9·8	11·2	10·0	9·2	14·9	21·1	22·4
1 to ¾ — 1½ to 1	3·6	3·8	8·6	12·6	12·0	13·4	5·0	7·1	11·1	14·8	15·9	13·8	9·0	12·5	9·9
¾ to ½ — 1 to ¾	2·6	1·3	3·9	5·2	6·9	7·4	2·5	2·9	4·5	6·2	7·5	7·9	7·0	8·7	9·9
.... — ¾ to ½	....	1·7	3·9	6·5	7·3	8·2	....	3·2	4·9	7·4	8·8	9·6	....	....	......
½ to ¼ — ½ to ¼*	4·1	1·7	3·9	5·7	7·7	8·6	3·7	2·9	4·5	7·4	8·3	9·6	9·9	12·4	12·5
¼ to 0·0164	4·6	3·4	8·6	13·9	19·4	24·2	3·7	3·7	7·0	11·9	16·3	19·6	5·0	6·2	7·4
Through 0·0164	0·4	0·4	0·9	1·6	2·0	2·8	0·4	0·4	0·6	1·3	1·9	2·3	0·5	0·5	0·6
"Lumps," on ¾ (1-inch round)	88·3	91·5	78·8	67·1	56·7	48·8	89·7	86·9	78·5	65·8	57·2	51·0	77·6	72·2	69·6
"Smalls," ¾ to 0·0164	11·3	8·1	20·3	31·3	41·3	48·4	9·9	12·7	20·9	32·9	40·9	46·7	21·9	27·3	29·8
"Fines and Dust," through 0·0164	0·4	0·4	0·9	1·6	2·0	2·8	0·4	0·4	0·6	1·3	1·9	2·3	0·5	0·5	0·6
"Unbroken"	68·4	64·3	37·5	24·6	18·4	12·7	53·6	59·3	40·5	27·9	17·9	14·6	35·8	27·4	37·3
Friability, per cent	19	14	30	42	49	56	23	19	30	43	50	54	37	45	34

*All screens of ¼-inch and smaller had square holes.

PART II

SUPPLEMENTARY SHATTER TESTS

G. P. Connell

After due consideration of the comparative friability results reported in Part I, it was decided that further tests by the A.S.T.M. (Coke) Shatter Test method should be made, the main objective being the formulation of a procedure suitable for coal. For this purpose fresh lots of three of the seven coals previously selected as standards were used. They were as follows:—

No. 1A—Pennsylvania anthracite, having the same trade name as coal No. 1 previously used and representing a fuel of high size stability. Quantities of egg, stove, and nut sizes were obtained as required from a local dealer.

No. 4A—Nova Scotia bituminous, a representative medium friable coal, from the same lot of mixed lumps from which the different sizes of coal No. 4 previously tested were taken. The screen analysis using round hole screens of a fresh one-ton lot of this coal, known as "steam lump", was as follows: On 4-in., 15 per cent; on 3-in. (through 4-in.), 11 per cent; on 2-in. (through 3-in.), 15 per cent; on 1½-in. (through 2-in), 14 per cent; on 1-in. (through 1½-in.), 16 per cent; on ¾-in. (through 1-in.), 7 per cent; on ½-in. (through ¾-in.), 6 per cent; through ½-in., 16 per cent.

No. 7A—Bituminous coal, originally from the Nicola area, British Columbia, representative of a quite friable, high volatile coal. The different sizes used in the supplementary tests were from the same storage pile as that from which coal No. 7 was taken, the total duration of storage in the open being three years.

The fresh lots of these coals were not analysed, but it may be assumed that their analyses would agree closely with those shown in Table I. As inferred above, the apparatus employed in the supplementary shatter tests was that described in Serial Designation D141-23 of the American Society for Testing Materials, and as described in Part I under A.S.T.M. (Coke) Shatter Test.

EXPERIMENTAL, AND DISCUSSION OF RESULTS

The following series of tests were conducted:—

(1) Relation of square and round hole screen sizes.
(2) Comparison of the effect of one, two, three, and four drops using different sizes of the three selected coals.
(3) The duplicability of the two- and four-drop modifications.
(4) Concrete floor versus iron plate as apparatus base.
(5) Applicability of shatter test to mixed sizes of coal.

The details of the experimental tests and a discussion of the results obtained may be given in the order just outlined.

Relation of Square and Round Hole Screen Sizes

All the screen analyses involved in the friability tests reported in Part I were conducted on square hole screens, with the exception of certain experiments pertaining to the Illinois and the A.S.T.M. (Coke) Shatter

Tests. In order to conform with the tentative procedure advanced by Sub-committee VII "on defining coal sizes and coal friability" of the Sectional Committee for the Classification of Coal, in which round hole screens are recommended on account of their use in the coal mining and preparation industry, it was decided to adopt the round hole screens for the supplementary shatter tests. It was therefore considered of interest to ascertain the relation of square and round hole screen sizes of the three selected coals. Five hundred pounds of each of coals Nos. 1A, 4A, and 7A were screened, first on square hole screens and then twice on a set of round hole screens, the objective of the latter double screening being to obtain data on the breakage of the particular coals used during screening. The results of the comparison are given in Table XXII, and are discussed below with reference to similar results reported by Yancey and Zane[14].

The form of the data presented in Table XXII corresponds generally to that given by Yancey and Zane, except that the screen sizes shown are in inches throughout, rather than in millimetres, and the square hole screen analyses which were obtained first are used as the basis for comparison. The ratios of round to square hole screen sizes averaged 1·15, 1·13, and 1·14 for coals Nos. 1A, 4A, and 7A respectively, despite the fact that this ratio varied from a minimum of 1·06 to 1·25 for individual sizes of a given coal. The grand average for the three coals was 1·14 as compared with 1·23 reported for the same number of coals by Yancey and Zane, their variation in the different sizes being from 1·20 to 1·28 only. Just why the difference between the two series of results occurs is not readily evident. However, it should be pointed out that the square hole screens used at the Fuel Research Laboratories were stamped steel plates and not wire screens, and that single lots of 500 pounds of each coal were screened, as compared with twenty screen analyses on 25-pound lots of each coal by Yancey and Zane. The 500-pound samples were composites of different sized lumps from friability tests, and hence had received considerable handling. That they were fairly resistant to breakage by screening is shown by the "check" screen analyses shown in column 5 of Table XXII, and it may be that freshly prepared lumps would give different results. However, it is significant that the average ratios of round to square holes for the three coals agreed so closely, especially since coal No. 1A was Pennsylvania anthracite, and coals Nos. 4A and 7A were bituminous originating in Nova Scotia and British Columbia respectively. Using the figure of 1·14 as the average ratio between round and square hole screens means that (for the particular coals tested) a given square hole screen will retain the same percentage as a round hole screen of which the diameter is 1·14 times the side of the square hole opening, and vice versa, a given round hole screen will retain the same percentage of coal as the square hole screen of which the side of the square opening is 0·88 (the reciprocal of 1·14) times the diameter of the round hole screen. For example, the 3- to 4-inch round hole screen size, recommended specially in the Shatter Test method, Appendix II, will be equivalent to 2·64- to 3·52-inch square hole screen size and the 1- to 1½-inch square hole size specified for use in the Small Jar Tumbler test, Appendix I, will be equivalent to the 1·14- to 1·71-inch round hole size.

Comparison of One, Two, Three, and Four Drops

Previous results showed that the Shatter Test method, in which 50-pound lots of the 2- to 3-inch size were dropped four times from a height of six feet, gave a satisfactory spread between the least and most friable coals, according to the different friability indices indicated—*see* Figure 2. It was believed, however, that the breakage at the end of the fourth drop was excessive as compared with that occurring in the normal handling of coal. For this reason it was considered desirable to ascertain the progressive breakage on different sizes of coal resulting from one to four drops. The first series of shatter tests comprised the progressive dropping of the same 50-pound sample one, two, three, and four times, with screening after each drop. The second series was on two 50-pound lots dropped separately two and four times with screen tests after the second and fourth drops.

The results given in Table XXIII and illustrated in Figures 6 and 7, will bear considerable study and discussion. A few salient points only, however, will be mentioned here. In the first place, for the three coals tested, the breakage caused by dropping one to four times was due almost entirely to shattering, the amount of fines and dust passing the 48-mesh screen not exceeding 1·0 per cent. At this point it may be stated that the minus 48-mesh material was in each case weighed and represents the net weight of fines and dust, and that the unaccounted for loss during a screen analysis averaged about ¼ pound, equal to approximately ½ per cent of the 50-pound sample taken for the drop test. Since the scales used were not readable to closer than this amount any loss was absorbed proportionately among the larger sizes.

Relation between Friability, Per Cent (Yancey), Size Stability Index-B

In addition to ascertaining the progressive breakage by one, two, three and four drops as indicated by either a size stability or friability index, the purpose of the three series of tests reported in Table XXIII was to show the relation of Size Stability Index B (SSI-B) and Friability, per cent as determined for the different sizes of the three coals tested. This relation plotted—as friability and size stability indices respectively—for the two- and four-drop tests on the three coals is illustrated in Figure 8. In general it will be noticed that these two indices agree quite closely for the ¾- to 1-inch size of all three coals, and not so closely for the smaller and larger sizes. For coal No. 1A the agreement was, however, remarkably close for all the sizes and in general is close enough for the different sizes of the other two coals to warrant recommending Size Stability Index B as a suitable index to express size stability when testing single sizes by the Shatter Test method.

2- to 3- inch size	Friability, per cent		SSI-B	
	2 drops	4 drops	2 drops	4 drops
Least friable coal—No. 1A	7·2	13·4	92·7	83·6
Most friable coal—No. 7A	32·1	44·5	58·9	42·4
Difference	24·9	31·1	33·8	41·2

The above table shows that for the 2- to 3-inch size the difference or spread between the Size Stability Indices B was greater for the four drops than for the two drops, but that the SSI-B spread for two drops was comparable with the friability, per cent indices for four drops. This observation applies also to the 3- to 4-inch size as well as to the $1\frac{1}{2}$- to 2-inch and the 1- to $1\frac{1}{2}$-inch sizes of the two coals concerned. It is for this reason that for the two-drop modification of the Shatter Test method the Size Stability Index B is considered as satisfactory for practical purposes as the calculated friability, per cent index.

x′ Ordinate of area for original coal sample = 87·5
a′ " " " " screen curve after 1st drop = 65·3
b′ " " " " " " " 2nd " = 55·0
c′ " " " " " " " 3rd " = 49·7
d′ " " " " " " " 4th " = 45·1

Progressive size index reduction

1st Drop size index reduction $= \frac{87\cdot5-65\cdot3}{87\cdot5} \times 100 = 25\cdot5\%$

2nd " " " " $= \frac{65\cdot3-55\cdot0}{65\cdot3} \times 100 = 15\cdot8\%$

3rd " " " " $= \frac{55\cdot0-49\cdot7}{55\cdot0} \times 100 = 9\cdot6\%$

4th " " " " $= \frac{49\cdot7-45\cdot1}{49\cdot7} \times 100 = 9\cdot3\%$

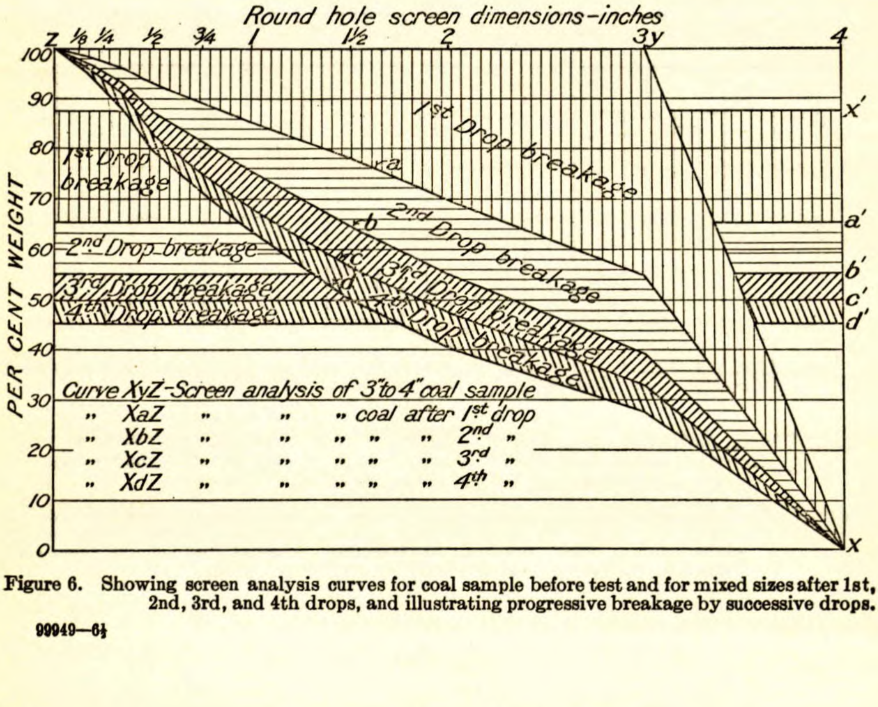


Figure 6. Showing screen analysis curves for coal sample before test and for mixed sizes after 1st, 2nd, 3rd, and 4th drops, and illustrating progressive breakage by successive drops.

99949—6½

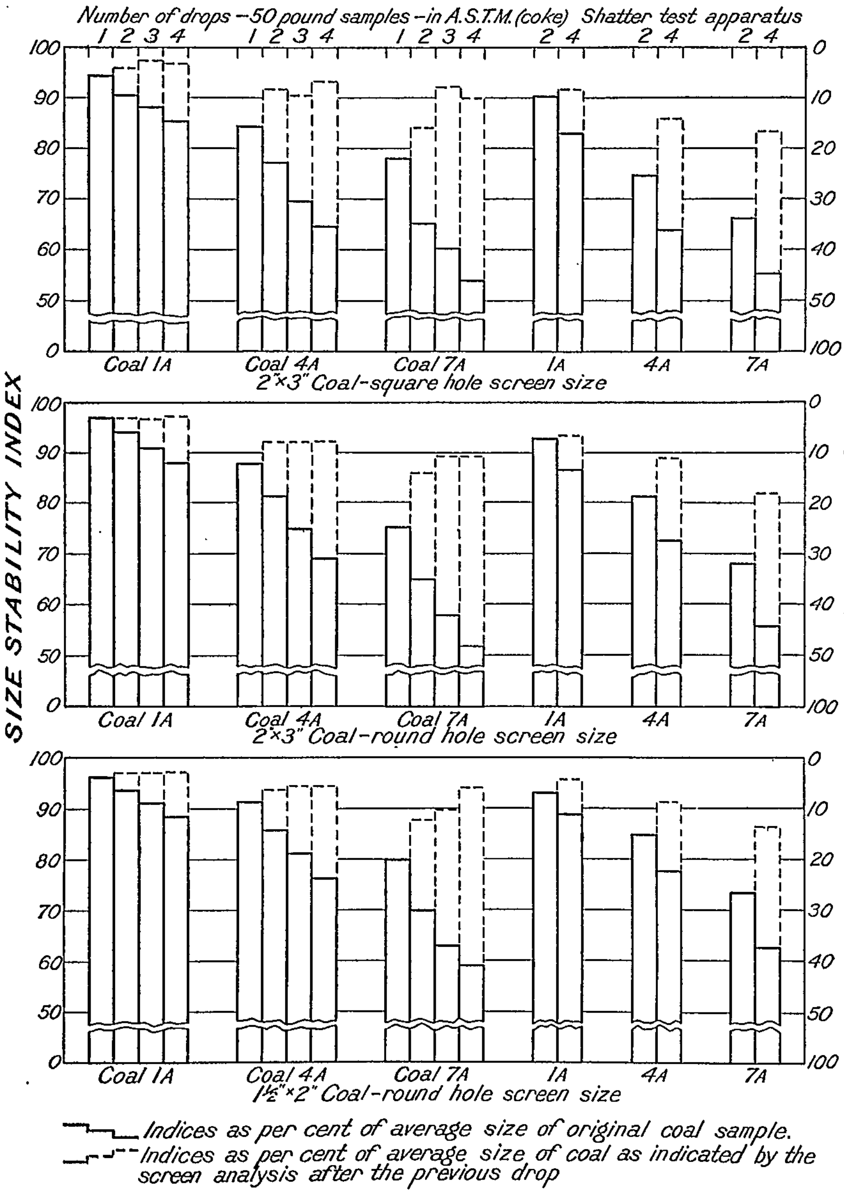


Figure 7. Columns illustrating the progressive breakage of three sizes of coals Nos. 1A, 4A, and 7A by 1st, 2nd, 3rd, and 4th drops. Areas between 0 friability index and tops of columns represent breakage or friability, whereas the columns themselves represent relative size stability.

Variation of Friability According to Sizes Tested. As shown in Table XXIII and in Figure 8, there was found a fairly wide variation in the friability of the different sizes of each of the three coals examined. The friability indices of the 3- to 4-inch and the 2- to 3-inch did not vary greatly, but below this the friability became progressively lower for the smaller sizes. Another way of expressing this relation is that the stability varied inversely with the size of lumps of each coal. Below is a comparison of the spread of the SSI-B and friability, per cent indices for two and four drops between the most friable (2- to 3-inch) size and the most stable (½- to ¾-inch) size.

—	Difference of indices for 2- to 3-inch lumps and for ½- to ¾-inch size		
	Coal No. 1A	Coal No. 4A	Coal No. 7A
Friability, per cent (Yancey)			
2 drops	4·8	13·5	24·9
4 drops	9·3	19·5	33·1
Size Stability Index (SSI-B)			
2 drops	5·5	17·7	35·7
4 drops	13·3	25·7	48·9

As shown above, and as illustrated in Figure 8, the variation was comparatively small for coal No. 1A, the least friable, and large for coal No. 7A, the most friable, with a midway variation for medium friable coal No. 4A. That is, the variation in the friability indices of different sizes of lumps varies directly with the general friability of the coals examined. Another observation to be noted is that, whereas the spread between the most and the least friable size was greater when using SSI-B as an index, there was a fair agreement between the SSI-B values for two drops and the Yancey friability, per cent values for four drops. This is a further point in favour of the use of Size Stability Index B in the two-drop modification of the Shatter Test method.

Furthermore, it is to be noted from the results for coals Nos. 4A and 7A that the friability indices for the 3- to 4-inch round hole size closely approach those for the 2- to 3-inch square hole size. It is for this reason, and also because the 2- to 3-inch square hole size is specified in the shatter test for coke as per A.S.T.M. D141-23, that the 3- to 4-inch round hole size is favoured as the standard size for the shatter test method as applied to coal when it is desired to test one single size only of a given coal.

Progressive Breakage by Successive Drops. On page 83 are shown two ways of expressing progressive breakage by successive drops of the same sample of coal. These results are for the 3- to 4-inch size of coal No. 7A, those under (a) being from Table XXIII and those under (b) as illustrated in Figure 6. The two ways of expressing progressive breakage are also shown in Figure 7 for three sizes of lumps of the three coals. Examination of the breakage expressed as per (b) shows that generally speaking the rate of breakage has reached a maximum at the end of the second drop for coals Nos. 1A and 4A—the Pennsylvania anthracite and Nova Scotia bituminous respec-

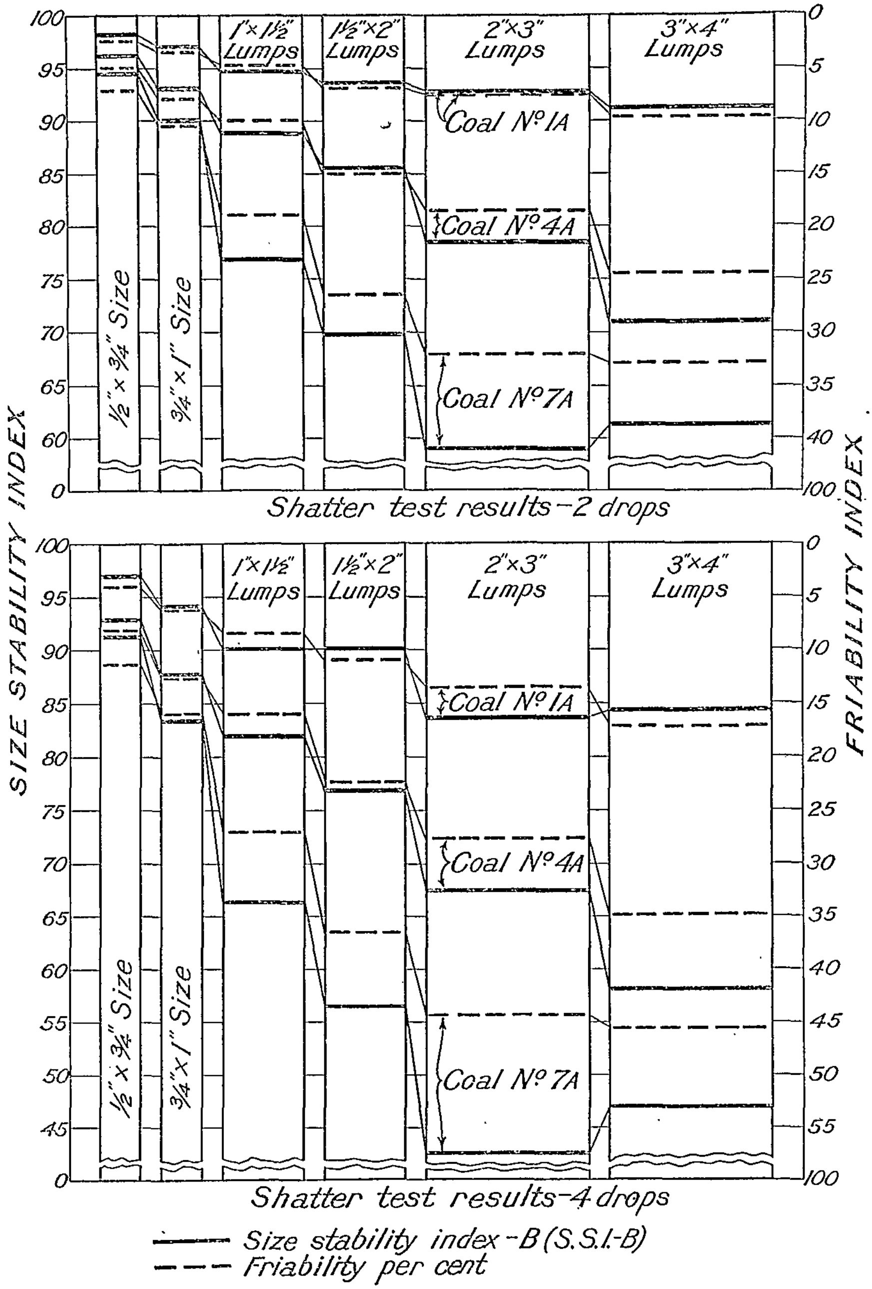


Figure 8. Illustrating relation of "Friability, per cent" and "Size stability index B" (SSI-B) for different sizes of lumps of coals Nos. 1A, 4A, and 7A.

tively—while for coal No. 7A, the most friable, the rate of breakage did not "level off" until after the third drop. Hence, for all coals except the very

—	Size index reduction (or friability per cent) expressed as a percentage of	
	(a) Average size of lumps of original sample	(b) Average size of lumps or particles as indicated by screen analysis of coal after preceding drop
After 1st drop	25·5	25·5
" 2nd "	37·1	15·8
" 3rd "	43·3	9·6
" 4th "	48·5	9·3

friable ones, two drops are as effective as four in giving sufficient spread of indices to differentiate between different sizes of the same coals as well as a selected size of different coals.

Comparison of the Duplicability of Two and Four Drops

Study of the results of the two series of tests just outlined indicated that a two-drop method had merits worthy of further consideration. However, these results were masked by the successive screening of the dropped coal, made necessary on account of the limited amount of the different sizes available. It was therefore decided to make a third series of tests on a given size of two coals in order to compare the duplicability of the results of the two and four-drop methods. For this purpose ten 50-pound lots of each of coals Nos. 1A and 4A were tested, four lots being dropped twice before screening and six lots dropped four times as in the standard method for coke. The results of this third series of friability tests are given in Table XXIV.

For the two coals compared, it is evident that the results of repeated tests, expressed in terms of either friability, per cent or Size Stability Index B, are capable of being duplicated equally as well by the two-drop modification of the shatter test as by the four-drop procedure specified in the Shatter Test method for coke.

Concrete Floor versus Iron Plate as Apparatus Base

In the apparatus as described in A.S.T.M. D141-23 (method of shatter test for coke) the base on which the coke drops is specified as a "rigidly mounted cast-iron or steel plate, not less than ½ inch in thickness." With the idea that the apparatus may be simplified for use as a standard shatter test for coal by specifying that the coal be dropped on say a smooth concrete floor instead of on an iron plate, a series of tests to ascertain the comparative merits of these two bases was made. Accordingly, duplicate tests using the 2- to 3-inch size of each of the three coals were made in which the samples were dropped a distance of 6 feet onto a concrete floor as base. This was accomplished by simply removing the superstructure of the Shatter Test apparatus supporting the iron box from its cast-iron base onto the concrete floor and then proceeding to make the drop tests in the usual way. The two-drop modification of the method was adopted and the results are given in Table XXV.

The results indicate that a smooth concrete floor is equally as satisfactory as the specified iron plate as the base on which the coal is to be dropped. Although this tentative conclusion agrees with that of Professor E. M. Smith in his shatter test experiments on Illinois coal, further tests on coals differing widely in friability should be made and the results compared before final conclusions are drawn.

Applicability of Shatter Test to Mixed Sizes

The A.S.T.M. Shatter Test as originally adopted for coke and as experimented with in Part I and in Part II up to this point, as well as by Yancey and Zane[11], called for lumps sized within fairly narrow screen size limits, for example, 1 × 1½ inches, 1½ × 2 inches, 2 × 3 inches, etc. Inasmuch as coal operators would likely be interested in a method suitable for mixed sizes, a series of tests was made on a fresh lot of coal No. 4A, from the heating plant at the Fuel Research Laboratories, known as "steam lump". The effect of dropping 100-pound samples in individual tests was compared with that on the usual 50-pound sample, and the relation of the breakage by two and four drops compared. The mixed sizes tested comprised ¾-inch slack, ¾- to 1½-inch size, 1½-inch slack, 1½- to 4-inch size, and the 4-inch resultant. For purposes of comparison, these were supplemented by tests on the 3- to 4-inch and smaller single sizes. The results of the tests on the 50-pound samples only are given in Table XXVI and are illustrated in Figure 9.

The screen analysis of the minus 4-inch coal was roughly 50 per cent retained on the 1½-inch screen, 25 per cent of the ¾- to 1½-inch size, and 25 per cent passing the ¾-inch screen. Friability, per cent, is employed as the friability index in Table XXVI for the mixed sizes and in the discussion below, as obviously SSI-B is not suitable.

The friability index for the ¾-inch slack was less than 2·0 and that for the 1½-inch slack averaged 3·3. For the ¾- to 1½-inch lumps the average index of two tests was 8·0; the difference between this and that for the 1½-inch slack represents the cushioning effect of minus ¾-inch smalls and fines. Likewise, the difference between the index of approximately 16·5 for the 1½- to 4-inch lumps, and the index of 6·3 for the minus 4-inch coal, is due to the cushioning effect of the 1½-inch slack proportion of the latter. The lower indices, not given in Table XXVI, obtained when 100-pound lots of the mixed sizes are dropped instead of the usual 50-pound lots, are evidently also caused by cushioning.

The plotting of the friability indices, as in Figure 9, for mixed sizes given in Table XXVI against the average sizes of the respective samples shows that the points obtained for the ¾- to 1½-inch and the 1½- to 4-inch sizes of lumps fall on, or are close to, a curve joining similar points for the different single sizes; illustrative curves and diagrams are not presented as figure. The joining of points obtained in the same way for tests on the three slack sizes, including the minus 4-inch resultant as one, gives, as indicated, a curve, approximately a straight line, and quite unlike the curve for the single sizes. This means that, whereas the friability index of a mixed size of lumps—for example, the $1\frac{1}{2}$- to 4-inch size comprised of three single approximately equal sizes—will coincide with that of the middle 2- to 3-inch size, no such relation exists between indices for a given slack coal and the single sizes comprising it.

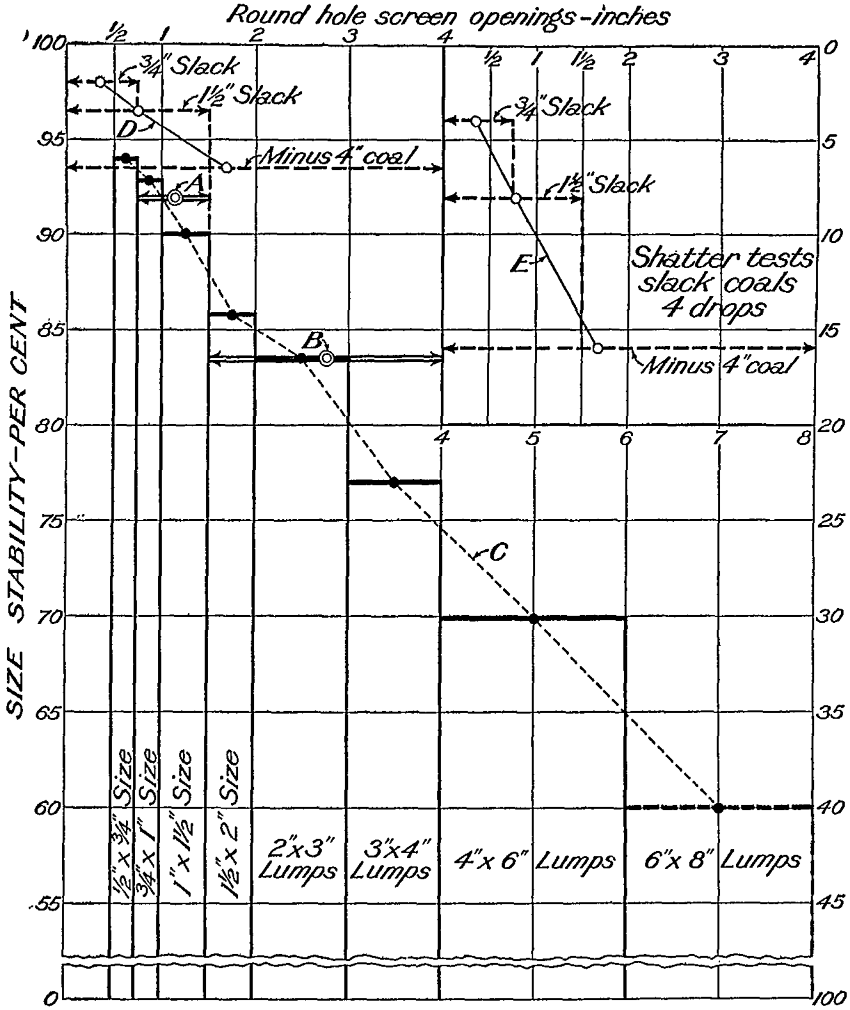


Figure 9. Diagram illustrating shatter test results on single and mixed sizes of coal No. 4A reported in Table XXVI—50-pound samples dropped *twice* in A.S.T.M. (coke) Shatter Test apparatus with 4-drop tests on "slack" sizes shown in upper right-hand corner. Area above columns represents the friability of the different sizes, and the columns indicate relative "size stability". *A* is the average size of the ¾-inch and $1\frac{1}{2}$-inch lumps, and *B* is the corresponding average size of two samples of $1\frac{1}{2}$-inch to 4-inch lumps. *C*, *D*, and *E* are curves joining the points representing the calculated average sizes of lumps before dropping, respectively, in the 2-drop tests on single sizes, in the 2-drop tests on slack coal mixed sizes, and in the 4-drop tests on the same slack coals.

When applied to the "slack" sizes, in which the smalls and fines, say below ¾ inch, produce a pronounced cushioning effect, the Shatter Test method does give friability indices that can be duplicated within reasonable limits, and these indices will be indicative of the relative commercial handling properties of the different "slack" coals tested. This is providing the samples of the slack size of the same coal to be tested are uniform in respect to their screen analysis, and providing the sample is loaded into the box and dropped in a similar manner in successive tests. Results at date of writing, not all recorded in this report, show that the friability indices for the 100-pound samples dropped twice are consistently and appreciably lower than for the corresponding 50-pound samples. The use of a 100-pound sample instead of 50 pounds may be a means of obtaining more uniform samples, and for slack coal sizes four drops instead of two may be advisable. However, before such changes can be recommended, further comparative tests and a study of the results are required.

A typical calculation using the results of the first test of the 1- to 4-inch lumps reported in Table XXVI is given below:—

Screen analysis of coal—before and after dropping Round hole screens designated "rd" Square " " " "No"	Before	After	Mean of screen size, inches	Average size % wt. × mean of screen size: Before dropping	Average size % wt. × mean of screen size: After 2 drops
Retained on 3″ rd., passing 4″ rd.	59·5	40·0	3·500	2·083	1·400
" " 2″ " " 3″ "	32·5	29·5	2·500	0·813	0·738
" " 1½″ " " 2″ "	8·0	9·5	1·750	0·140	0·166
" " 1″ " " 1½″ "	....	11·0	1·250	....	0·137
" " ¾″ " " 1″ "	....	0·5	0·875	....	0·004
" " ½″ " " ¾″ "	....	3·0	0·625	....	0·019
" " No. 3 (0·263″) passing ½″ rd.	....	2·5	0·435	....	0·011
" " No. 6 (0·131″) " No. 3	....	....	0·280	....	....
" " No. 48 (0·0116″) " No. 6	....	....	0·100	....	....
passing No. 48	....	....	0·010	....	....
Total passing No. 3 (¼″ square screen)	....	4·0	0·185	....	0·007
" " No. 6 (⅛″ " ")	....	....	0·095	....	....
Average size of coal before and after dropping				3·036	2·482

Breakage expressed as friability, per cent (Yancey) to the nearest 0·5 is $\frac{3\cdot036 - 2\cdot482}{3\cdot036} \times 100 = 18$

Size Stability Index will be 100 − 18 = 82.

The mean screen size in inches for the square hole screens was obtained by first converting them to their round hole equivalents by multiplying the square hole opening by the square root of 2, and then taking the arithmetical mean of the calculated diameters of the retaining and passing screens. The square mesh screens designated as ¼ and ⅛ inch used in these tests were Tyler wire cloth screens corresponding to the No. 3 (0·263 inch) and No. 6 (0·131 inch) screens respectively. The friability, per cent values obtained by the use of the mean sizes in inches as above, have been found to agree sufficiently well with those obtained by the use of the average openings in millimetres specified by Yancey and Zane, to warrant their adoption. For practical purposes it is maintained that "to the nearest 0·5" or perhaps to the nearest whole number is satisfactory for reporting friability and size stability indices.

SUMMARY AND CONCLUSIONS OF SUPPLEMENTARY SHATTER TESTS

(a) The average ratio of round to square hole screen sizes for the three coals tested varied from 1·07 for the $\frac{3}{4}$-inch hole to 1·17 for the $1\frac{1}{2}$-inch screen hole, with an average of 1·14 for $\frac{1}{2}$-, $\frac{3}{4}$-, 1-, $1\frac{1}{2}$-, 2- and 3-inch screen openings. This result is appreciably different from the 1·23 ratio reported by Yancey and Zane[14] for three different coals tested at the Seattle Experiment Station of the United States Bureau of Mines, but agrees fairly well with the average of 1·16 for Pittsburgh seam coal reported by J. R. Campbell (Discussion, same reference).

(b) It was found that in accordance with the results reported in Part I the friability indices varied directly with the size of lumps of the three coals, that is, the larger lumps were more friable than the smaller, and conversely, the Size Stability Index B (SSI-B) for the most friable coal, No. 7A, varied from roughly 59 for the 2- to 3-inch lumps to 95 for the $\frac{1}{2}$- to $\frac{3}{4}$-inch size.

(c) As shown in Figure 8, friability per cent and size stability index B plotted as friability and size stability indices respectively, agreed closely for the $\frac{3}{4}$- to 1-inch size of all three coals, and for all sizes of the most stable anthracite coal, No. 1A. Although the difference between these two indices varied somewhat for the sizes of the bituminous coals Nos. 4A and 7A, smaller and larger than the size just mentioned, the agreement is considered close enough to warrant recommending the use of Size Stability Index B (SSI-B) as a suitable index to express comparative size stability when testing single sizes of coal by the Shatter Test method outlined in Appendix II.

(d) The difference between the Size Stability Index B for coal No. 7A, the most friable, and that for the least friable coal, 1A, for two drops correspond closely with the difference between the friability, per cent indices for these two coals after four drops. This, coupled with the same relation in respect to the spread or difference of indices for the most and least friable size of individual coals, is considered an important point in favour of the use of Size Stability Index B in the two-drop modification of the Shatter Test method for coal.

(e) A study of the progressive breakage of lump coal by one, two, three, and four drops revealed that the rate of breakage reached the maximum at the end of the second drop for the different sizes of the least and medium friable coals. It was therefore concluded that two drops are as effective as four in giving sufficient spread or range of indices to differentiate between different sizes of the same coal as well as a selected size of different coals.

(f) A series of five tests, each on coals No. 1A and No. 4A, showed that in respect to duplicability of friability and size stability indices, the two-drop modification of the shatter test was as satisfactory as the four-drop procedure specified in the Shatter Test method for coke.

(g) Tests on the 2- to 3-inch size of all three coals indicated that comparable results are obtainable using either a smooth concrete floor or an iron plate as the base on which the coal is dropped. Hence, the apparatus for shatter tests on coal may be simplified by allowing a concrete base where the specified iron plate is not readily available.

(h) When it is desired to compare the relative stabilities of one size only of lumps of different coals, the 3- to 4-inch round hole screen size is recommended. The Shatter Test method is, however, equally serviceable for different "single" sizes of the same coal.

(i) The two-drop modification of the Shatter Test is suitable for mixed sizes of lumps, and also for "slack coal" sizes. The friability index of a slack size of a given coal may vary widely according to the proportion of smalls and fines below say $\frac{3}{4}$ inch, which causes appreciable cushioning effect. The avoidance of cushioning should not, however, in the opinion of the writer, be the aim in the development and selection of a laboratory friability method, inasmuch as in the commercial handling of coal, especially the more friable coals, the cushioning of the larger lumps by the smalls and fines practically always takes place.

TABLE XXII

Relationship of Round and Square Hole Screen Sizes

(Obtained by screening 500 pounds of each of three coals)

Coal used	Size of screen openings either square or round holes, inches	Accumulative percentage weight retained on: Square hole screen	Round hole screen: 1st screening	Round hole screen: (2nd screening)	Equivalent* square hole screen inches	Ratio** of round to square hole
1.	2	3	4	(5)	6	7
No. 1A (Pennsylvania Anthracite)	2 (2·00)	19·6	25·3	(24·6)	1·87	1·07
	1½ (1·50)	41·6	60·3	(59·2)	1·21	1·24
	1 (1·00)	74·2	81·2	(80·7)	0·80	1·25
	¾ (0·75)	83·0	84·7	(84·3)	0·71	1·06
	Average...	....	....	....	....	1·15
No. 4A (Nova Scotia Bituminous)	3 (3·00)	4·4	15·2	(14·7)	2·67	1·12
	2 (2·00)	36·7	50·5	(50·1)	1·72	1·16
	1½ (1·50)	61·2	68·0	(68·0)	1·32	1·13
	1 (1·00)	80·1	84·4	(84·5)	0·84	1·19
	¾ (0·75)	86·9	88·1	(88·1)	0·67	1·12
	½ (0·50)	90·7	91·3	(91·2)	0·46	1·08
	Average...	....	....	....	....	1·13
No. 7A (British Columbia—Nicola—Bituminous)	3 (3·00)	14·1	19·5	(19·1)	2·78	1·08
	2 (2·00)	38·7	50·8	(50·0)	1·70	1·17
	1½ (1·50)	59·0	66·8	(66·1)	1·32	1·13
	1 (1·00)	80·8	85·8	(84·4)	0·84	1·19
	¾ (0·75)	88·6	89·3	(88·4)	0·72	1·04
	½ (0·50)	94·3	95·6	(95·1)	0·40	1·25
	Average...	....	....	....	....	1·14

Summary

—	Coal No. 1A	Coal No. 4A	Coal No. 7A	Average	Average ratio of round to square hole
Equivalent square hole screen size of					
3-inch round hole screen size...........	....	2·665	2·780	2·722	1·10
2 " " " " "	1·870	1·720	1·700	1·763	1·13
1½ " " " " "	1·210	1·320	1·322	1·284	1·17
1 " " " " "	0·800	0·840	0·840	0·827	1·21
¾ " " " " "	0·710	0·670	0·722	0·701	1·07
½ " " " " "	....	0·463	0·400	0·431	1·16
Average of					
Round hole size to square hole..........	1·15	1·13	1·14	....	1·14
Square " " " round "		reciprocal of 1·140 =			0·88

*The sizes in inches in this column (namely 6) are obtained from the curves of the square hole screen analyses, plotted from data in columns 3 and 2 (curves not shown) and represent the size equivalent in inches corresponding with the accumulative percentage on the respective round hole screen size in column 2. Example: 1·87, obtained from abscissa of curve, is the square hole size, retaining 25·3% of coal 1A, which is the percentage retained on the 2-inch round screen reported in column 4. Hence, 1·87-inch square hole size is the equivalent to a 2-inch round hole size for this coal.

**These are the ratios of the round hole sizes in column 2 to their square hole equivalents in column 6.

TABLE XXIII

Shatter Tests on Coal No. 1A—Pennsylvania Anthracite

(Comparative results of one, two, three and four drops using 50-pound samples of different sizes of coal)

2- to 3-inch coal—square hole screen size

Times* dropped	Per cent retained on square hole screen 2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B **	100 minus SSI-B	Friability, per cent.
1..........	87·6	7·4	2·4	0·8	0·7	0·5	0·2	0·3	0·1	95·0	5·0	5·5
2..........	79·2	12·3	3·5	1·5	1·3	0·9	0·6	0·6	0·1	91·5	8·5	9·5
3..........	76·3	11·6	4·7	2·1	1·8	1·5	0·9	1·0	0·1	87·9	12·1	11·8
4..........	71·0	13·8	6·1	2·5	2·0	1·8	1·2	1·4	0·2	84·8	15·2	14·6
2..........	79·0	12·2	3·8	1·6	1·2	0·9	0·6	0·6	0·1	91·2	8·8	9·6
4..........	63·0	21·5	6·0	2·8	2·1	2·0	1·1	1·4	0·1	84·5	15·5	17·2

2- to 3-inch coal—round hole screen size

Times* dropped	Per cent of dropped coal retained on: Round hole screens 2"	1½"	1"	¾"	½"	Square hole screens ¼"	⅛"	48	−48	SSI-B **	100 minus SSI-B	Friability, per cent
1..........	94·0	2·6	1·3	0·6	0·5	0·3	0·3	0·3	0·1	96·6	3·4	3·1
2..........	88·5	4·4	3·1	1·0	0·9	0·7	0·6	0·7	0·1	92·9	7·1	6·1
3..........	82·3	7·3	4·3	1·5	1·5	1·1	0·9	1·0	0·1	89·6	10·4	9·2
4..........	77·8	8·8	5·4	2·0	1·8	1·3	1·3	1·4	0·2	86·6	13·4	11·7
2..........	85·2	7·5	2·9	1·3	1·0	0·7	0·6	0·7	0·1	92·7	7·3	7·2
4..........	75·6	8·0	7·0	2·6	2·0	1·4	1·8	1·4	0·2	83·6	16·4	13·4

1½- to 2-inch coal—round hole screen size

Times* dropped	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1................	90·5	6·5	1·2	0·7	0·4	0·3	0·3	0·1	97·0	3·0	3·8
2................	85·1	9·3	1·8	1·5	0·8	0·7	0·7	0·1	94·4	5·6	6·5
3................	79·2	12·5	3·0	2·0	1·1	1·0	1·1	0·1	91·7	8·3	9·2
4................	73·3	16·5	3·7	2·3	1·5	1·3	1·2	0·2	89·8	10·2	11·6
2................	85·0	8·5	2·5	1·4	1·0	0·8	0·7	0·1	93·5	6·5	6·8
4................	75·5	14·8	3·2	2·2	1·5	1·2	1·4	0·2	90·3	9·7	10·9

1- to 1½-inch coal—round hole screen size

Times* dropped	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1................	......	92·8	4·0	1·7	0·6	0·4	0·4	0·1	96·8	3·2	3·2
2................	......	89·1	5·8	2·3	1·2	0·8	0·7	0·1	94·9	5·1	5·0
3................	......	84·6	7·7	3·5	1·8	1·2	1·1	0·1	92·3	7·7	7·3
4................	......	82·7	8·0	4·0	2·3	1·4	1·4	0·2	90·7	9·3	8·4
2................	......	89·5	5·2	2·5	1·3	0·7	0·7	0·1	94·7	5·3	4·9
4................	......	82·6	7·7	4·7	2·2	1·3	1·3	0·2	90·3	9·7	8·5

¾- to 1-inch coal—round hole screen size

Times* dropped	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1................	......	......	94·8	3·3	1·0	0·4	0·4	0·1	98·1	1·9	2·1
2................	......	......	91·2	5·5	1·6	0·9	0·7	0·1	96·7	3·3	3·7
3................	......	......	88·2	7·5	2·1	1·1	0·9	0·2	95·7	4·3	4·9
4................	......	......	85·7	8·8	2·7	1·4	1·2	0·2	94·5	5·5	6·0
2................	......	......	91·3	5·5	1·8	0·7	0·6	0·1	96·8	3·2	3·5
4................	......	......	85·9	8·2	3·0	1·5	1·2	0·2	94·1	5·9	6·1

½- to ¾-inch coal—round hole screen size

Times* dropped	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
2................	......	......	......	94·2	4·0	1·0	0·7	0·1	98·2	1·8	2·4
4................	......	......	......	90·4	6·5	1·7	1·2	0·2	96·9	3·1	4·1

*Two series of tests were made on each size of coal. In the first (1, 2, 3, 4) series, the same 50-pound sample was dropped four times, the broken coal being screened after each drop. In the second (2, 4) series, two 50-pound lots were dropped and the resultant 100 pounds screened after the 2nd and 4th drop.

**SSI-B; "Size Stability Index B" is the total percentage retained on the screen next lower in the series to the smaller screen used in preparing the sample. For the round hole screens selected this is the screen with holes half the size of those in the larger screen used in preparing the sample.

TABLE XXIII—Continued

Shatter Tests on Coal No. 4A—Nova Scotia Bituminous

(Comparative results of one, two, three and four drops using 50-pound samples of different sizes of coal)

2- to 3-inch coal—square hole screen size

Times* dropped	Per cent coal retained on square hole screen									SSI-B **	100 minus SSI-B	Friability, per cent
	2″	1½″	1″	¾″	½″	¼″	⅛″	48	−48			
1	70·5	11·9	6·6	2·9	2·8	2·5	9·8	1·8	0·2	82·4	17·6	15·7
2	59·6	13·7	8·8	4·4	4·5	3·8	2·2	2·6	0·4	73·3	26·7	23·0
3	49·5	14·6	10·3	5·6	5·7	6·5	3·6	3·6	0·6	64·1	35·9	30·4
4	43·3	14·7	11·6	6·6	6·2	7·5	4·1	5·2	0·8	58·0	42·0	35·2
2	55·0	15·5	11·0	4·1	4·2	4·4	2·6	2·8	0·4	70·5	29·5	25·3
4	39·8	17·9	14·0	5·0	6·0	7·5	4·3	5·0	0·5	57·7	42·3	35·9

3- to 4-inch coal—round hole screen size

Times dropped	Per cent of dropped coal retained on										SSI-B **	100 minus SSI-B	Friability, per cent
	Round hole screens						Square hole screens						
	3″	2″	1½″	1″	¾″	½″	¼″	⅛″	48	−48			
1	66·9	15·8	4·2	3·5	2·5	2·0	1·8	1·7	1·5	0·1	82·7	17·3	17·1
2	54·1	17·8	6·7	5·7	3·3	3·5	3·0	2·5	3·2	0·2	71·9	28·1	25·6
3	44·5	19·5	7·5	7·0	4·5	4·8	4·5	3·5	3·8	0·4	64·0	36·0	32·4
4	40·8	19·2	7·3	7·5	4·7	5·7	5·3	4·0	5·0	0·5	60·0	40·0	35·8
2	61·0	10·0	5·5	5·5	4·5	4·5	3·7	2·0	3·2	0·1	71·0	29·0	24·5
4	42·5	19·3	6·0	7·5	5·0	4·7	5·5	4·0	5·2	0·3	61·8	38·2	34·8

2- to 3-inch coal—round hole screen size

1	....	76·9	9·7	5·7	2·0	1·7	1·5	1·0	1·2	0·3	86·6	13·4	11·9
2	....	64·4	14·6	8·0	3·4	3·6	2·0	2·0	1·6	0·4	79·0	21·0	18·6
3	....	54·6	16·5	9·8	4·8	4·3	3·8	2·7	3·0	0·5	71·1	28·9	25·1
4	....	47·0	16·7	11·7	5·0	5·3	5·3	3·6	4·7	0·7	63·7	36·3	30·8
2	....	66·0	12·5	8·0	3·5	3·0	2·6	1·9	2·2	0·3	78·5	21·5	18·5
4	....	53·0	14·5	10·0	4·5	5·0	4·5	3·5	4·2	0·8	67·5	32·5	27·6

1½- to 2-inch coal—round hole screen size

1	....	....	81·5	10·4	2·5	1·3	1·8	1·0	1·3	0·2	91·9	8·1	8·6
2	....	....	72·0	13·1	4·0	3·5	2·5	2·0	2·5	0·4	85·1	14·9	14·3
3	....	....	63·4	16·2	5·6	4·6	4·0	2·7	2·8	0·7	79·6	20·4	19·0
4	....	....	56·0	18·6	6·5	5·5	4·6	3·5	4·5	0·8	74·6	25·4	23·5
2	....	....	69·0	16·5	4·0	3·5	2·5	2·0	2·2	0·3	85·5	14·5	14·9
4	....	....	56·8	20·1	5·5	5·0	4·5	3·0	4·5	0·6	76·9	23·1	22·4

1- to 1½-inch coal—round hole screen size

1	....	....	....	88·5	5·5	3·0	1·0	0·9	0·9	0·2	94·0	6·0	5·6
2	....	....	....	80·6	8·5	4·5	2·5	1·5	2·0	0·4	89·1	10·9	9·8
3	....	....	....	76·0	9·5	6·0	3·5	2·0	2·5	0·5	85·5	14·5	12·4
4	....	....	....	70·0	12·5	6·0	4·5	3·0	3·4	0·6	82·5	17·5	15·7
2	....	....	....	80·8	7·9	4·0	3·0	2·0	2·0	0·3	88·7	11·3	10·0
4	....	....	....	68·6	13·4	7·0	4·5	3·0	3·0	0·5	82·0	18·0	16·0

¾- to 1-inch coal—round hole screen size

1	....	....	....	....	89·7	6·7	1·7	0·9	0·8	0·2	96·4	3·6	4·3
2	....	....	....	....	85·0	8·2	2·8	1·9	1·7	0·4	93·2	6·8	6·9
3	....	....	....	....	77·3	13·0	4·2	2·3	2·7	0·5	90·3	9·7	10·2
4	....	....	....	....	72·6	15·2	5·4	2·8	3·2	0·8	87·8	12·2	12·5
2	....	....	....	....	82·0	11·0	3·3	1·8	1·7	0·2	93·0	7·0	7·7
4	....	....	....	....	72·5	15·0	5·5	3·0	3·3	0·7	87·5	12·5	12·6

½- to ¾-inch coal—round hole screen size

1	....	....	....	....	....	90·5	6·5	2·0	0·8	0·2	97·0	3·0	3·9
2	....	....	....	....	....	84·5	10·7	2·5	1·8	0·5	95·2	4·8	6·6
3	....	....	....	....	....	79·9	13·6	3·2	2·6	0·7	93·5	6·5	8·7
4	....	....	....	....	....	77·3	14·2	4·0	3·5	1·0	91·5	8·5	10·3
2	....	....	....	....	....	88·2	8·0	2·0	1·5	0·3	96·2	3·8	5·0
4	....	....	....	....	....	82·7	10·5	3·0	3·0	0·8	93·2	6·8	8·1

TABLE XXIII—Concluded

Shatter Tests on Coal No. 7A—British Columbia (Nicola) Bituminous

(Comparative results of one, two, three and four drops using 50-pound samples of different sizes of coal)

2- to 3-inch coal—square hole screen size

Times* dropped	Per cent retained on square hole screen 2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B **	100 minus SSI-B	Friability, per cent
1..........	63·2	8·5	9·8	6·0	5·2	4·0	2·0	1·2	0·1	71·7	28·3	21·8
2..........	43·9	12·5	12·7	8·5	8·5	7·8	2·7	3·2	3·2	56·4	43·6	34·5
3..........	36·1	15·1	12·7	8·0	10·5	9·7	4·0	3·5	0·4	51·2	48·8	39·7
4..........	29·6	12·5	14·0	10·2	11·7	11·5	5·0	5·0	0·5	42·1	57·9	45·9
2..........	44·5	13·0	12·8	8·5	7·2	8·0	3·0	2·5	0·5	57·5	42·5	33·8
4..........	31·0	11·5	16·5	9·0	9·5	12·0	5·2	4·2	1·1	42·5	57·5	44·8

3- to 4-inch coal—round hole screen size

Times dropped	Per cent of dropped coal retained on: Round hole screens 3"	2"	1½"	1"	¾"	½"	Square hole screens ¼"	⅛"	48	−48	SSI-B **	100 minus SSI-B	Friability, per cent
1...........	54·5	15·3	8·5	7·0	4·2	3·5	3·2	2·5	1·2	0·1	69·8	30·2	25·5
2...........	30·3	16·0	9·2	11·0	5·7	6·2	5·7	4·0	2·6	0·3	55·3	44·7	37·1
3...........	33·2	14·2	9·2	11·7	7·0	7·5	8·0	5·0	3·8	0·4	47·4	52·6	43·3
4...........	27·3	13·2	9·5	13·5	7·8	8·5	8·0	7·0	4·7	0·5	40·5	59·5	48·5
2...........	46·3	15·0	7·2	9·0	5·2	5·5	5·2	3·7	2·7	0·2	61·3	38·7	32·8
4...........	29·5	17·5	7·5	11·0	7·0	7·7	7·5	6·5	5·5	0·3	47·0	53·0	45·6

2- to 3-inch coal—round hole screen size

Times dropped	3"	2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1...........	.....	54·0	15·5	13·0	5·8	4·7	3·5	1·7	1·6	0·2	69·5	30·5	24·5
2...........	.....	38·0	16·5	17·2	8·5	8·2	5·2	3·0	3·1	0·3	54·5	45·5	35·6
3...........	.....	28·3	18·0	17·8	10·7	9·2	6·7	5·0	4·0	0·3	46·3	53·7	42·2
4...........	.....	22·1	15·3	18·3	12·0	12·4	8·9	5·7	4·7	0·6	37·4	62·6	48·3
2...........	.....	43·6	15·3	15·5	7·5	7·3	5·0	3·0	2·5	0·3	58·9	41·1	32·1
4...........	.....	27·3	15·1	18·1	10·0	10·8	9·0	4·8	4·5	0·4	42·4	57·6	44·5

1½- to 2-inch coal—round hole screen size

Times dropped	3"	2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1...........	.....	.....	57·0	22·5	7·2	6·2	3·3	2·5	1·1	0·2	79·5	20·5	19·8
2...........	.....	.....	40·0	26·3	12·5	8·7	5·7	3·5	3·0	0·3	66·3	33·7	29·6
3...........	.....	.....	30·0	26·3	13·0	12·5	9·2	5·0	3·6	0·4	56·3	43·7	36·9
4...........	.....	.....	25·7	25·0	14·0	14·0	9·5	6·0	5·2	0·6	50·7	49·3	40·7
2...........	.....	.....	47·3	22·5	10·0	8·2	5·5	3·5	2·6	0·4	69·8	30·2	26·6
4...........	.....	.....	32·0	24·5	12·5	12·5	8·2	5·8	4·0	0·5	56·5	43·5	36·5

1- to 1½-inch coal—round hole screen size

Times dropped	3"	2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1...........	.....	.....	.....	72·0	12·8	7·7	4·0	2·2	1·2	0·1	84·8	15·2	13·2
2...........	.....	.....	.....	59·4	16·0	11·5	6·7	3·7	2·5	0·2	75·4	24·6	20·3
3...........	.....	.....	.....	52·9	16·0	13·8	9·0	5·2	2·8	0·3	68·9	31·1	24·4
4...........	.....	.....	.....	46·3	18·0	15·8	10·5	5·5	3·5	0·4	64·3	35·7	28·0
2...........	.....	.....	.....	62·5	14·2	10·5	7·5	2·4	2·7	0·2	76·7	23·3	18·9
4...........	.....	.....	.....	49·0	17·3	13·5	10·7	5·0	4·0	0·5	66·3	33·7	26·9

¾- to 1-inch coal—round hole screen size

Times dropped	3"	2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1...........	.....	.....	.....	.....	78·4	12·5	5·5	2·5	1·0	0·1	90·9	9·1	9·0
2...........	.....	.....	.....	.....	66·0	20·0	7·5	4·0	2·3	0·2	86·0	14·0	14·4
3...........	.....	.....	.....	.....	60·5	20·5	10·5	5·0	3·2	0·3	81·0	19·0	17·6
4...........	.....	.....	.....	.....	55·5	22·0	12·0	6·5	3·6	0·4	77·5	22·5	20·2
2...........	.....	.....	.....	.....	77·4	15·4	5·8	2·7	1·6	0·1	89·8	10·2	10·6
4...........	.....	.....	.....	.....	63·8	19·7	9·5	3·7	3·0	0·3	83·5	16·5	15·8

½- to ¾-inch coal—round hole screen size

Times dropped	3"	2"	1½"	1"	¾"	½"	¼"	⅛"	48	−48	SSI-B	100 minus SSI-B	Friability, per cent
1...........	.....	.....	.....	.....	.....	83·0	13·0	2·7	1·1	0·2	96·0	4·0	6·5
2...........	.....	.....	.....	.....	.....	78·0	15·5	4·0	2·2	0·3	93·5	6·5	9·0
3...........	.....	.....	.....	.....	.....	72·0	20·0	4·5	3·1	0·4	92·0	8·0	11·5
4...........	.....	.....	.....	.....	.....	69·0	20·0	7·0	3·5	0·5	89·0	11·0	13·3
2...........	.....	.....	.....	.....	.....	82·4	12·2	3·5	1·7	0·2	94·6	5·4	7·2
4...........	.....	.....	.....	.....	.....	72·8	18·5	5·5	2·8	0·4	91·3	8·7	11·4

TABLE XXIV

Shatter Tests on Two Selected Coals—Comparative Results of Two and Four Drops

(50-pound samples of the 2- to 3-inch size dropped 6 feet)

—	Per cent of sample on 2½" screen	Screen Analysis of "Dropped" Coal										Friability, per cent
		Accumulative percentage retained on									−48 mesh %	
		Round hole screens						Square mesh				
		2½"	2"	1½"*	1"	¾"	½"	¼"	⅛"	(48)		
Coal No. 1A (Pennsylvania Anthracite)—2 drops												
Test No. 1	37·0	30·2	80·2	*90·2*								
" " 2	33·5	25·2	81·8	*90·8*								
" " 3	30·0	22·4	84·4	*91·0*								
" " 4	23·5	22·0	80·6	*90·6*								
Average of												
Nos. 1 & 2	35·2	27·7	81·0	*90·5*	95·5	96·6	97·6	98·4	99·2	99·9	0·1	8·8
" 3 & 4	26·7	22·2	82·5	*90·8*	95·5	96·8	98·0	98·7	99·2	99·9	0·1	7·9
" a & b**	61·5	43·2	85·2	*92·7*	95·6	96·9	97·9	98·6	99·2	99·9	0·1	7·2
Coal No. 1A—4 drops												
Test No. 5	31·0	23·5	70·5	*85·5*								
" " 6	24·4	17·0	71·0	*84·4*								
" " 7	38·0	26·0	75·0	*86·0*								
" " 8	34·0	24·4	68·9	*83·9*								
" " 9	29·0	21·5	71·5	*82·7*								
" " 10	32·0	24·0	69·4	*82·8*								
Average of												
Nos. 5 & 6	27·7	20·3	70·7	*85·0*	91·1	93·7	95·6	97·2	98·3	99·9	0·1	13·5
" 7 & 8	36·0	25·2	71·8	*84·9*	91·5	93·6	95·7	97·1	98·3	99·9	0·1	13·7
" 9 & 10	30·5	22·8	70·4	*82·8*	91·4	94·0	95·9	97·2	98·3	99·9	0·1	13·9
Coal No. 4A (Nova Scotia Bituminous)—2 drops												
Test No. 11	31·5	022·6	64·6	*80·0*								
" " 12	26·0	17·0	62·0	*78·0*								
" " 13	36·5	27·2	69·6	*82·6*								
" " 14	37·5	22·0	65·4	*78·8*								
Average of												
Nos. 11 & 12	28·8	19·8	63·3	*79·0*	86·8	90·3	93·5	95·8	97·5	99·7	0·3	18·2
" 13 & 14	37·0	24·6	67·5	*80·7*	87·9	90·6	93·8	96·0	97·7	99·7	0·3	16·9
" c & d**	....	.....	66·0	*78·5*	86·5	90·0	93·0	95·6	97·5	99·7	0·3	18·5
Coal No. 4A—4 drops												
Test No. 15	35·0	12·4	51·0	*67·0*								
" " 16	43·5	13·6	53·6	*70·6*								
" " 17	39·6	17·0	56·0	*69·4*								
" " 18	32·0	16·6	54·6	*69·2*								
" " 19	37·0	18·4	55·4	*68·4*								
" " 20	42·4	19·0	52·6	*69·0*								
Average of												
Nos. 15 & 16	39·3	13·0	52·3	*68·8*	79·3	83·8	88·5	92·5	95·5	99·5	0·5	28·0
" 17 & 18	35·8	16·8	55·3	*69·3*	80·0	84·5	89·0	92·8	95·8	99·5	0·5	25·7
" 19 & 20	39·7	18·7	54·0	*68·7*	78·7	83·7	88·4	92·6	95·8	99·5	0·5	26·6

*Percentages in this column—the total on the 1½" screen—are the size stability indices for the respective tests, selected for reporting here.

**Tests a and b for coal 1A and tests c and d for coal 4A, which are also shown in Table XXIII were on different lots of these coals from the other tests reported.

TABLE XXIV—Concluded

Shatter Tests on Two Selected Coals—Comparative Results of Two and Four Drops—Concluded

(50-pound samples of the 2- to 3-inch size dropped 6 feet)

Summary of Table XXIV

—	2 drops		4 drops	
	Coal 1A	Coal 4A	Coal 1A	Coal 4A
Number of individual 50-pound tests	4	4	6	6
Average percentage; lumps on 2″ screen	81·7	65·4	71·0	53·9
Maximum variation from average 2″ screen	2·7	4·2	4·0	2·1
Size Stability Indices (SSI)—average	90·7	79·9	84·2	68·9
Maximum SSI variation from average	0·5	1·9	1·8	1·9
Number of double tests (two 50-lb. lots)	3	3	3	3
Size Stability Indices (SSI)—average	91·3	79·4	84·2	68·9
Maximum SSI variation from average	1·4	1·3	1·4	0·4
Average of friability percentages	8·0	17·9	13·7	26·8
Maximum variation from average of percentages	0·8	1·0	0·2	1·2

TABLE XXV

Shatter Test Results Using Cement (Concrete) as Base of Apparatus Compared with Results Using Cast Iron as Base

(50-pound samples of 2 to 3 inch size of each of three coals dropped twice)

—	Base:—cement or iron	Screen Analysis of "Dropped" coal									Friability, per cent
		Accumulative percentage retained on								−48 mesh %	
		Round hole screens					Square mesh				
		2″	1½″	1″	¾″	½″	¼″	⅛″	(48)		
Coal No. 1A (Pennsylvania Anthracite)											
Test (a)	cement	78·5	*89·5*	94·5							
" (b)	"	74·5	*88·5*	94·5							
Average (a) & (b)	"	76·5	*89·0*	94·5	96·3	97·8	98·6	99·4	99·9	0·1	10·8
Test (c)*	iron	82·3	*91·7*	94·1	95·5	96·5	97·5	98·5	99·9	0·1	8·8
Coal No. 4A (Nova Scotia Bituminous)											
Test (a)	cement	69·5	*83·5*	90·5							
" (b)	"	71·0	*81·5*	89·5							
Average (a) & (b)	"	70·2	*82·5*	90·0	92·3	94·5	96·5	98·0	99·7	0·3	15·5
Test (c)*	iron	69·3	*82·3*	89·3	92·3	95·3	97·3	99·3	99·8	0·2	15·7
Coal No. 7A (British Columbia—Nicola—Bituminous)											
Test (a)	cement	41·0	*61·0*	74·5							
" (b)	"	41·0	*59·5*	74·0							
Average (a) & (b)	"	41·0	*60·2*	74·2	81·7	89·2	94·2	97·2	99·7	0·3	32·7
Test (c)*	iron	41·8	*58·7*	74·2	82·2	89·7	94·7	97·7	99·7	0·3	32·6

NOTE:—The percentages in italic in the 1½″ column are the Size Stability Indices—B (SSI-B) for the respective tests.

*These are single tests on 2- to 3-inch lumps of the three coals that had received previous handling. The (c) samples, however, were from the same lot as for tests (a) and (b)

TABLE XXVI

Results of Shatter Tests on Mixed and Single Sizes of Coal 4A

—	Screen analysis of coal before and after dropping, Per cent weight retained on									Average size of lumps before and after dropping, inches	Friability, per cent		Size Stability, per cent	SSI-B
	Round hole screens							Square						
	4"	3"	2"	1½"	1"	¾"	½"	¼"	(−¼")		(1)**	(2)***		
Mixed Sizes—														
¾-inch slack														
Sample							25·5	21·0	53·5	0·350				
2 drops							23·0	22·5	54·5	0·343	1·7	2·0	98·0	
Sample							27·5	20·0	52·5	0·356				
2 drops							26·0	19·5	54·5	0·349	1·7	2·0	98·0	
4 drops							24·0	20·5	55·5	0·342	3·1	3·9	96·1	
1½-inch slack														
Sample					36·0	14·0	15·0	13·0	22·0	0·764				
2 drops					33·5	14·0	14·0	16·0	22·5	0·740	3·0	3·1	96·9	
Sample					36·0	15·0	14·5	11·5	23·0	0·765				
2 drops					33·0	15·0	14·5	12·5	25·0	0·735	3·6	3·9	96·1	
4 drops					29·0	16·5	14·0	13·0	27·5	0·702	7·6	8·2	91·8	
−4-inch coal														
Sample		13·5	25·0	11·5	21·0	4·0	9·0	6·5	9·5	1·698				
2 drops		13·5	21·0	12·0	18·0	6·5	9·0	7·5	12·5	1·601	5·6	5·7	94·3	
Sample		13·0	27·0	10·0	15·0	10·0	9·5	6·5	9·0	1·684				
2 drops		13·0	20·5	11·5	14·5	10·5	10·5	7·5	12·0	1·562	7·1	7·2	92·8	
4 drops		10·0	18·0	11·0	15·5	11·0	10·5	9·5	14·5	1·416	15·6	15·9	84·1	
−4-inch coal (100 lb.)*														
Sample		11·0	24·0	15·0	17·0	8·0	9·0	6·0	10·0	1·631				
2 drops		11·0	21·3	14·7	15·8	8·2	9·3	7·5	12·2	1·557	4·4	4·5	95·5	
Sample		13·3	23·0	13·7	17·2	7·8	8·5	6·5	10·0	1·663				
2 drops		11·5	22·0	12·8	16·7	8·0	9·0	8·0	12·0	1·569	5·6	5·7	94·3	
4 drops		11·0	20·0	13·3	14·7	8·0	9·5	8·5	15·0	1·496	9·9	10·1	89·9	
¾" to 1½" lumps														
Sample					71·5	28·5				1·143				
2 drops					59·0	28·0	7·0	2·5	3·5	1·044	8·5	8·7	91·3	
Sample					67·0	33·0				1·126				
2 drops					58·0	29·0	7·0	3·0	3·0	1·041	7·4	7·6	92·4	
4 drops					50·5	28·5	9·0	5·0	7·0	0·972	13·3	13·7	86·3	
1½" to 4" lumps														
Sample		59·5	32·5	8·0						3·036				
2 drops		40·0	29·5	9·5	11·0	0·5	3·0	2·5	4·0	2·482	18·1	18·2	81·8	
Sample		24·0	43·5	32·5						2·496				
2 drops		14·5	40·0	25·5	9·0	2·5	3·0	1·5	4·0	2·121	14·9	15·0	85·0	
4 drops		9·5	32·0	28·0	12·0	3·0	5·0	3·0	7·5	1·857	25·4	25·6	74·4	
Single Sizes—														
½- to ¾-inch lumps										0·625				
2 drops							86·0	10·0	4·0	0·588	5·5	5·9	94·1	96·0
¾- to 1-inch lumps										0·875				
2 drops						82·3	11·7	3·0	3·0	0·812	7·0	7·2	92·8	94·0
1- to 1½-inch lumps										1·250				
2 drops					79·5	10·3	3·7	2·5	4·0	1·125	9·8	10·0	90·0	89·8
1½- to 2-inch lumps										1·750				
2 drops				70·8	14·7	4·5	3·3	2·5	4·2	1·501	14·1	14·2	85·8	85·5
2- to 3-inch lumps										2·500				
2 drops			70·0	11·3	7·0	2·5	2·5	2·3	4·4	2·090	16·2	16·4	83·6	81·3
3- to 4-inch lumps										3·500				
2 drops		58·0	17·5	5·5	5·7	3·0	3·0	2·5	4·8	2·700	22·8	22·9	77·1	75·5
4- to 6-inch lumps										5·000				
2 drops	48·9	13·7	14·0	5·6	4·6	2·7	3·1	2·6	4·8	3·493	30·1	30·1	69·9	62·6

*These data for the minus 4-inch coal are the only 100-pound results reported here, although tests on 100-pound samples of other mixed sizes were made. The results for the single sizes are the averages for two 50-pound lots dropped.

**Friability, per cent (1) is that obtained by the use of the average openings in millimetres specified by Yancey and Zane.

***Friability, per cent (2) is that obtained by the use of the "mean screen sizes" in inches indicated on page 86 of Part II.

APPENDIX I

TUMBLER TEST FOR COAL*

(For testing the relative friability of lump coal)

APPARATUS

Porcelain jar tumbler

1. The tumbler shall consist of a uniformly dimensioned cylindrical porcelain jar $7\frac{1}{4}$ in. deep and having the same measurement for its diameter, such as is employed for pulverizing coal samples. The jar shall be fitted with a cylindrical frame of iron, consisting of two rings, connected by three strips of iron which project into the jar as ledges or shelves. The frame shall be fixed, as nearly as possible, in the centre of the jar by means of wedges, and shall be constructed of $\frac{3}{4}$-in. by $\frac{1}{8}$-in. iron, with the exception of the shelves which shall be made of $\frac{5}{8}$-in. by $\frac{1}{8}$-in. iron. The length of the frame shall be $6\frac{1}{2}$ in. and its diameter $6\frac{7}{8}$ in. (As the jars are not of absolutely standard size, the measurements of the frames may be slightly varied to suit individual cases). The ledges or shelves, which shall be supported by brackets attached to the inner surfaces of the rings, shall be $\frac{5}{8}$ in. from the wall of the jar, so that they actually project $1\frac{1}{4}$ in. into it. Rivets should be used in making the frames, since they occupy less space than bolts and keep the shelves rigidly attached.

The jar shall be closed by a set-in porcelain lid, resting upon a heavy rubber gasket, and sealed tightly according to the customary procedure with such jars, that is, by means of a bolt working against the lid. The bolt shall be set in a crossbar, the ends of which are held by a metal strip which fits around the body of the jar. For tumbling, the jar shall be laid in a horizontal position, in a suitable support or rack, and rotated about its cylindrical axis at the rate of 40 revolutions per minute.

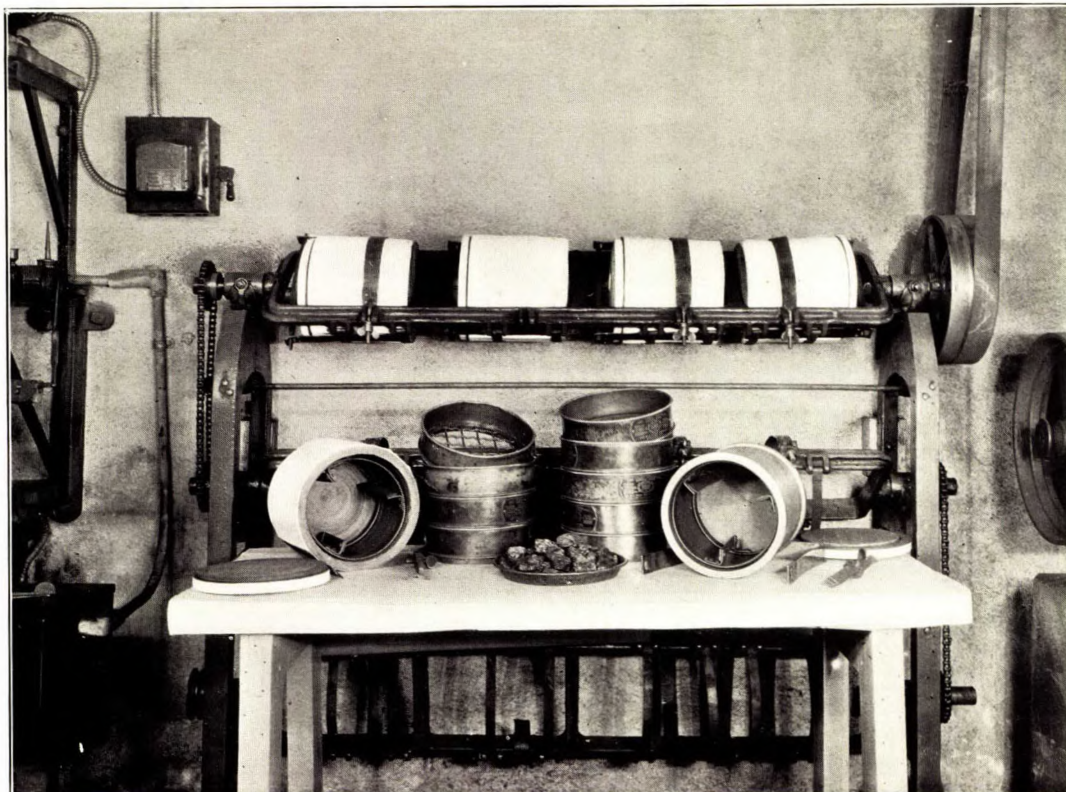
Iron jar optional

1. An iron jar may be substituted for the porcelain jar specified above, provided it has approximately the same internal dimensions, namely, $7\frac{1}{4}$-in. diameter by $7\frac{1}{4}$-in. depth. This jar may be of cast iron construction or made from an iron pipe with a bottom attached by welding. The interior shall be machined to the required dimensions and the lid shall be similar in design to that for the porcelain jar.

Screens (or sieves)

2. For sizing the sample for test, square-mesh screens having 1·5 in. and 1·05 actual openings between the wires shall be used. For screening the coal after the tumbler test square-mesh screens or sieves having 1·05-in., 0·742-in., 0·525-in.,

*This is a preliminary draft, subject to revision. For the method of test adopted, see latest editions of A.S.T.M. Tentative Standards or Book of Standards.



Small jar tumbler test apparatus (**J.T.**): On the bench are shown typical jar mills in which the three-vane iron frames are fitted, together with a set of 8-inch diameter screens and a 1000-gramme charge of 1- to 1½-inch lumps of coal. The jar to the left is one of the regular porcelain jars, and that to the right an optional iron jar.

0·371-in., 0·0469-in., and 0·0117-in. actual openings between the wires shall be used, the last two sieves being No. 16 United States sieve series (14 mesh Tyler) and No. 50 United States sieve series (48 mesh Tyler).

PREPARATION OF COAL

Size and amount of sample for each test

3. The coal for the test shall pass through a 1·5-in. screen and be retained by the 1·05-in. screen. For suitable preparation, only a thin layer of coal shall be placed on the screen, and the lumps of coal turned around until it is ascertained that they, individually, will not in any position pass through the screen. In order to provide sufficient sample material for four tests, at least 12 pounds of coal should be available. Since the prepared lumps may represent a considerable range of size, it is recommended that double this amount or more be prepared, and that lumps covering the full range of the 1·05- to 1·5-in. size be selected insofar as is feasible.

PROCEDURE

Procedure

4. Approximately 1000 grammes of the prepared coal shall be weighed and placed in the jar for each test, and the jar rotated at 40 r.p.m. for one hour. After tumbling, the coal shall be thoroughly screened upon the screens and sieves above designated, in such small increments as to permit satisfactory contact between the individual pieces of coal and the screen. Screening may be carried out either by hand or mechanically, though the former method is preferable. At least four individual tests shall be made, and, provided sufficient sample is available, it is recommended that two or more series of quadruplicate tests be made. When making only four individual tests, the contents of the jars shall be screened separately in order to ascertain whether there is satisfactory agreement between the results obtained. When two or more quadruplicate tests are made, the contents of four jars may be mixed and screened together.

Reporting of results as friability, per cent

5. The results of test shall be reported as friability, per cent, which is the percentage reduction in average size of the coal during the tumbling test. A numerical example of the method for calculating friability, per cent is shown in tabular form below. The average size of the sample, and each of the different screen products of the shattered coal, is the square root of half the sum of the squares of the openings of the retaining and passing screens, expressed in inches. It is from these average sizes that the approximate relative size factors as indicated are derived. "S" represents the average size of the coal before test, and "s" the average size of the coal after test. The percentage weight screen analysis shall be reported to the nearest 0·1 and the friability, per cent to the nearest 0·5.

—	Square mesh, screen analysis of coal, openings in inches			Average of openings		Product of (1) and (3)
	Retained on	Passing	Weight, per cent (1)	Inches (2)	Factor (3)	
Sample	1·05	1·5	100·0	1·295	1·0	100·00=S
Tumbled coal	1·05	1·5	74·0	1·295	1·0	74·00
	0·742	1·05	9·4	0·910	0·7	6·58
	0·525	0·742	2·0	0·645	0·5	1·00
	0·371	0·525	1·0	0·455	0·35	0·35
	0·0469	0·371	0·3	0·265	0·20	0·06
	0·0117	0·0469	0·2	0·034	0·025	0·005
	....	0·0117	13·1	0·008	0·005	0·0065
	(Weighted average size of tumbled coal) =					82·06=s

$$\text{Friability, per cent} = \frac{100\,(S - s)}{S} = \frac{100\,(S - s)}{100} = S - s = 100 - 82{\cdot}1 = 17{\cdot}9$$

to be reported as 18·0.

Lumps, smalls, fines, and dust

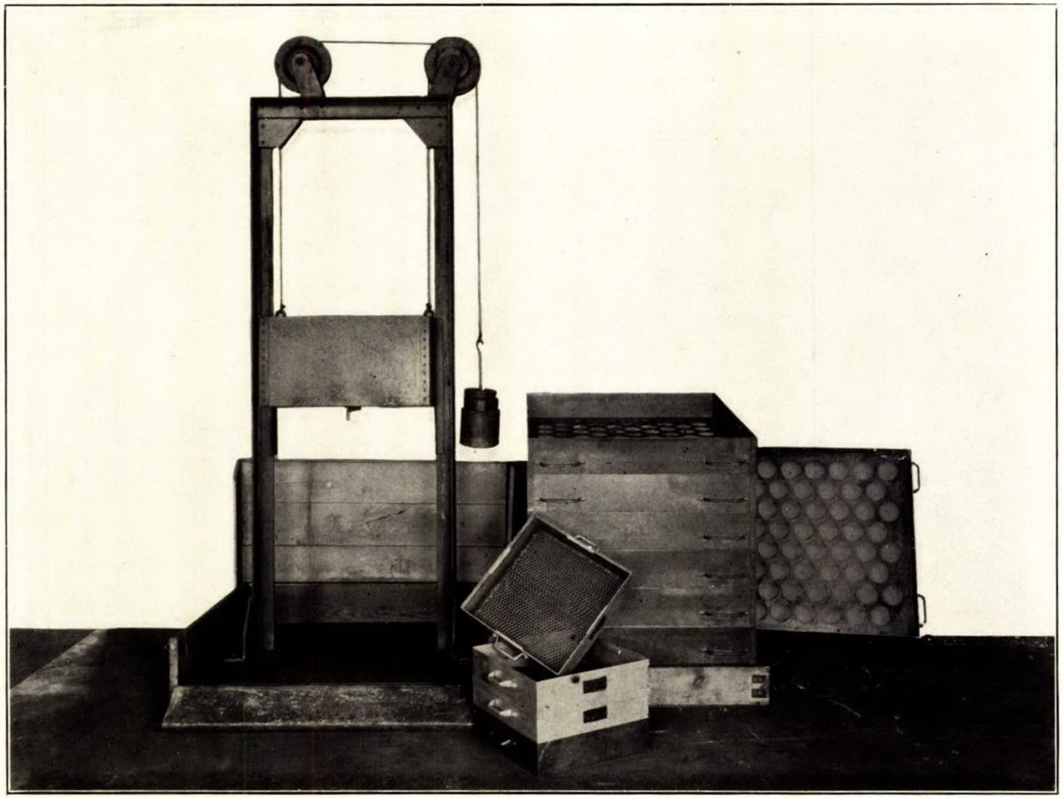
6. As supplementary (optional) data the following may be reported:

"Lumps" retained on 0·742-in. ($\frac{3}{4}$-in.) screen.................... per cent
"Smalls" on 0·0117-in. (48 mesh), through $\frac{3}{4}$-in. screen........... "
"Fines" and "dust" passing 0·0117-in. (48 mesh) screen.......... "

3/4 inch "friability index"

Minus 48 mesh attrition product indicative of dust-producing properties

For medium and less friable coals, and especially when the lumps in the sample cover the full range of 1·05- to 1·5-inch screen size limits, the total smalls, fines, and dust will correspond roughly with the calculated friability, per cent. This total—the difference between 100 and the percentage of lumps retained on the 0·742-in. screen—may be termed, for practical purposes, the $\frac{3}{4}$-in. friability index. The "fines and dust" passing the 48-mesh screen represent the proportion of the breakage due to attrition, or abrasion, rather than to shattering, and may be considered a measure of the relative dust-producing properties of coals when subjected to severe handling.



Drop shatter test machine and round hole screens with iron frames. Dimensions of the screen plates in the two sets of screens, shown in the centre and to the right, are 18 by 18 inches, and 3 by 3 feet, respectively.

APPENDIX II

DROP SHATTER TEST FOR COAL*

(For testing the relative size stability of "single" and "mixed" sizes of coal)

APPARATUS

Shatter test machine

1. The shatter test machine shall consist of a box 18 in. in width, 28 in. in length, and approximately 15 in. in depth, supported above a rigidly mounted cast-iron or steel plate, not less than $\frac{1}{2}$ in. in thickness, 38 in. in width and 48 in. in length. The inside of the bottom of the box shall be 6 ft. above the plate. The bottom of the box shall consist of two doors hinged lengthwise and latched so that they will swing open freely and not impede the fall of the coal. Boards about 8 in. in height shall be placed around the plate so that no coal is lost. To prevent the breakage of coal, which may occur while placing the sample in the box, the box shall be constructed so that it can be lowered to a convenient level, which is best done by means of a pulley and counterweight.

Optional concrete floor as base

This apparatus is the same as that described under A.S.T.M. Designation D141-23, namely, "Standard Method of Shatter Test for Coke" and there shown as Figure 1. Improvement in design may be effected by having the vertical iron standards supporting the box and pulleys attached to the sides of the bottom cast-iron plate so that the coal may fall on the plate clear of the vertical posts. The depth of the box need be only about half of that specified, and when it is desirable or necessary to reduce the expense of the apparatus, the box may be installed in a fixed position rather than installed so that it may be lowered and raised. Should a cast-iron or steel plate not be readily available, the box may be so placed that the coal being tested drops a distance of 6 feet onto a smooth concrete floor, since, as indicated by comparative tests, the breakage occurring by the use of a concrete floor practically agrees with that taking place when using the iron plate as the base.

Screens

2. Round hole screens having 4-in., 3-in., 2-in., $1\frac{1}{2}$-in., 1-in., $\frac{3}{4}$-in., $\frac{1}{2}$-in., $\frac{3}{8}$-in., $\frac{1}{4}$-in., $\frac{1}{8}$-in. and $\frac{1}{16}$-in. diameter openings shall be used. These screens are selected from the series specified in A.S.T.M. Designation E17-33—"Standard Specifications for Round Hole Screens for Testing Purposes." A feature of this selection is that for screen sizes $\frac{1}{4}$-in. and larger, the openings in alternate screens increase in the ratio of two. The thickness of

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the rigid metal plates from which the screens are made and the spacing of the openings shall conform with the specifications in E17-33. Frames for the screens may be of either hardwood or metal, and may be square, rectangular, or round. A nest comprising all the screens in the series, with plates each having an area of two square feet, is to be recommended, although plates with areas of six to nine square feet, either rectangular or square, are suitable for the larger screen openings, say larger than $\frac{3}{8}$ in. For use in testing lump coal sizes larger than 4 in., rings with diameters 6 in. and 8 in. may be used, or a single plate with one each of these sizes is suitable.

Sizes and amount of sample for each test

3. *Applicability of Test.* The test is applicable to different "single" and "mixed" sizes of lump coal and may be used for testing the same size of different coals, or different sizes of the same coal, the amount dropped in each test being 50 pounds. For comparing the stability of different coals the 3- to 4-in. size is recommended, as a standard single size. For comparing the stability of different single sizes of the same coal, this 3- to 4-in. and the smaller sizes prepared by the screens designated above may be used. By single sizes of lump coal is meant those designated in section 5 (a) below, and by mixed sizes is meant either "slack coal" or a mixture of two or more single sizes.

SAMPLING AND PREPARATION OF SAMPLE FOR TEST

Place of sampling

4. *(a)* When the shatter test is for indicating the probable breakage of lump coal as mined, the sample should be taken at the mine before it is subjected to screening and to loading into cars, at the tipple.

(b) When the test is for comparing the stability of the same size of different coals or different sizes of the same coal subsequent to time of mining, the sample may be taken at any stage in its transportation from the mine to the place in which it is to be used. For the correct interpretation of the results when comparing the friability of certain coals, the elapsed time since mining as well as the handling and storage of the coal should be noted in order to explain possible effects of weathering. The screen analysis of the lot of coal from which the lumps selected for test are taken should also be noted.

Single sizes

5. *(a)* For the 3- to 4-in. size, the coal shall be sized without crushing, in order to obtain a sample that will pass the larger and be retained on the smaller screen. In sizing the sample each piece of coal shall be upended on the screen, that is, tested to see if it will in any position pass the screen opening. These instructions shall also apply to the 2- to 3-in., the $1\frac{1}{2}$- to 2-in.,

the 1- to $1\frac{1}{2}$-in., and the $\frac{3}{4}$- to 1-in. single sizes of lump coal. For the $\frac{1}{2}$- to $\frac{3}{4}$-in., the $\frac{3}{8}$- to $\frac{1}{2}$-in., and smaller sizes the sample may be prepared by having the coal come into intimate contact with the screen either by shaking or rolling with the hand, without upending of individual lumps.

Mixed sizes and slack coal

(b) For slack coals and for mixed sizes composed of mixtures or blends of two or more single sizes, the sample shall be carefully prepared, either by the process of quartering or by re-assembling the different sizes in the proportion indicated by the screen analysis of the lot of coal to be tested. For $\frac{3}{4}$-in. or smaller slack coals the former method, by quartering, is satisfactory, while for larger slack coals and for blends of two or more single sizes, the latter method is recommended. Before dropping the sample shall be screened on the same series of screens used for the dropped coal as indicated below.

PROCEDURE FOR BOTH SINGLE AND MIXED SIZES

Procedure

6. Fifty pounds of the sample shall be placed in the box of the shatter test machine, the coal levelled, and then dropped *twice*, a distance of six feet, on the plate. The small material produced by the first drop shall be returned to the box with the large coal. To prevent breakage of the coal, the box should be lowered to a convenient height when transferring the sample into it. After the second drop, the material shall be successively run through the screens specified below. The coal should be screened in such increments as will allow all pieces to be in direct contact with the screen openings.

In screening, care should be taken to prevent further breakage of the coal. The coal remaining on each screen, and that which passes through the bottom screen, shall be weighed separately. If the sum of these weights shows a loss of over 1·0 per cent, the test shall be rejected and another made. Two or more tests should be made and the average result reported. When using large screens, say two feet square or larger, as specified above, it is recommended that, after dropping two individual samples twice as required, the screen analysis be made on the 100 pounds of dropped coal instead of screening each 50 pounds separately, in which case the result should be checked by dropping and screening a second two lots of 50 pounds, providing sufficient sample is available.

7. The percentage weight results of the screen analysis before and after two drops shall be indicated to the nearest 0·1, and the resultant size stability per cent shall be reported to the nearest 0·5. The recording of the screen analysis and the calculation of the results may be in accordance with the following tabular form containing the mean of the screen openings for the respective screen sizes, in inches, to the nearest 0·005; (S) and (s) represent the average size of the coal before and after dropping.

Reporting of results

Screen analysis of coal before and after two drops; per cent weight (not accumulative) using round hole (rd) screens				Mean of screen size openings, inches	Product of per cent weight and mean of screen openings, inches	
Retained on	Passing	Before	After		Sample	After 2 drops
8-in. rd.						
6- "	8-in rd.			7·000		
4- "	6- "			5·000		
3- "	4- "			3·500		
2- "	3- "			2·500		
1½- "	2- "			1·750		
1- "	1½- "			1·250		
¾- "	1- "			0·875		
½- "	¾- "			0·625		
⅜- "	½- "			0·435		
¼- "	⅜- "			0·315		
⅛- "	¼- "			0·185		
1/16 "	⅛- "			0·095		
	1/16 "			0·030		
Total passing	⅜-in.			0·185		
" "	¼-in.			0·125		
" "	⅛-in.			0·060		
Average size of coal before and after two drops					Total (S)	Total (s)

Size stability per cent

$$\text{Size stability per cent} = \frac{(s) \times 100}{(S)}.$$

(Friability, per cent will be 100 − size stability per cent).

Optional "size stability index" for single sizes

7. Providing the series of selected screens specified in 2 above are used, where the openings in alternate screens, from small to large, increase in the ratio of two, the results of tests on single sizes may be reported as the amount remaining on a given screen. The accumulative percentage remaining on the screen having openings half the diameter of those in the larger screen used in preparing the sample may be reported optionally as the *Size Stability Index* of the particular single size of lump coal tested. For drop tests on the (larger) single sizes, the percentage passing the ¾-in. screen may also be reported as supplementary information indicating the comparative amount of "slack" coal produced in the test.

Note:—

8. When reporting the results of the drop shatter test it shall be clearly stated to which single or mixed size each size stability per cent or (index) applies; e.g.,

Size stability per cent by drop shatter test for—

Single sizes	3- to 4-inch lumps	= ....
	2- to 3- " "	= ....
	1½- to 2- " "	= ....
	1- to 1½- " "	= ....
	¾- to 1- " "	= ....
Mixed sizes	¾- to 4-inch lumps	= ....
	¾-inch slack	= ....
	etc.	= ....

GILMORE, Ross Earlby.
Coal friability tests; a comparative study of methods for determining the friability of coal and suggestions for tumbler and drop shatter test methods.

DATE	ISSUED TO