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REPORT OF INVESTIGATIONS—NO. 151

CORRELATION OF DOMESTIC STOKER COMBUSTION WITH LABORATORY TESTS AND TYPES OF FUELS

IV. COMBUSTION TESTS OF ILLINOIS AND OTHER COALS

BY

Roy J. Helfinstine

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CORRELATION OF DOMESTIC STOKER COMBUSTION WITH LABORATORY TESTS AND TYPES OF FUELS

IV. COMBUSTION TESTS OF ILLINOIS AND OTHER COALS

BY

ROY J. HELFINSTINE

VARIOUS SMALL-SCALE TESTS are used as indexes of the character of coal. These tests include the proximate analysis, ultimate analysis, heating value, ash-fusion temperatures, free-swelling index, Gieseler plasticity, and petrographic analysis. In 1937 the Illinois Geological Survey began a series of tests to determine the value of these analyses (chiefly petrographic analysis) as indexes to the performance characteristics of coals in a domestic stoker. The results of these tests were published in 1942, as Part I[1] of this series of studies.

Part II, published in 1946,[2] is a comprehensive study of Illinois coals that received special preparation in the Survey laboratory. As the size range of coal used was kept constant, further investigation of the effect of coal size upon performance characteristics in a domestic stoker was required. The results of this study were published in 1948 as Part III.[3]

With the exception of the two coals used in the preliminary studies, Illinois coals were used for all the tests in this series thus far published. In order to extend the range of coal characteristics included in the study, samples of coals from Arkansas, Indiana, Iowa, Kentucky, Missouri, West Virginia, and Wyoming were tested. It also seemed desirable to make tests with "commercial" coals, that is, those available on the open market. The results of these tests constitute the new data in this report. In order to provide a complete picture, data from the previously published reports are incorporated in some of the graphs.

[1] McCabe, L. C., Konzo, S., and Rees, O. W., Correlation of domestic stoker combustion with laboratory tests and types of fuels. I Preliminary studies: Illinois Geol. Survey Rept. Inv. 78, 20 pp., 1942.

[2] Helfinstine, Roy J., and Boley, Charles C., Correlation of domestic stoker combustion with laboratory tests and types of fuels. II. Combustion tests and preparation studies of representative Illinois coals: Illinois Geol. Survey Rept. Inv. 120, 62 pp., 1946.

[3] Helfinstine, Roy J., Correlation of domestic stoker combustion with laboratory tests and types of fuels. III. Effect of coal size upon combustion characteristics: Illinois Geol. Survey Rept. Inv. 133, 47 pp., 1948.

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The investigation was carried out under the general direction of G. H. Cady, Head of the Coal Division of the Geological Resources Section of the Survey. The chemical analyses were made by the Analytical Division of the Geochemistry Section under the direction of O. W. Rees.

Most of the coal samples used for the tests were contributed by coal companies, whose cooperation is sincerely appreciated.

OBJECTIVE

The primary objective of the tests described in this report was to determine the relationship between coal composition (as determined by standard analytical tests) and the performance characteristics of coals that exhibit a wide range in combustion behavior when burned in a domestic stoker.

EQUIPMENT

The stoker and boiler used for all the reported tests are standard commercial units which were installed according to the manufacturers' instructions. The auxiliary equipment and instruments did not affect the performance of the unit.

The boiler is rated at 570 sq. ft. of equivalent direct radiation (136,800 B.t.u. per hr.). A maximum coal-feeding rate of 28 lb. per hr. is also given by the boiler manufacturer. The unit was operated as a forced-circulation hot-water boiler, with the water being recirculated at a constant rate during all tests. The quantity of water flowing through the boiler was indicated by a hot-water meter. The meter was occasionally checked by weighing the water passing through it, but no appreciable error was found. The temperature of the inlet boiler-water was maintained at approximately 160°F. by an automatic valve that regulated the quantity of cooling water supplied to an indirect heat exchanger.

The entire stoker-boiler unit, including the heat exchanger, was mounted on a platform scale with dial graduations of one-half pound. All connections to equipment not on the scales were flexible.

A two-pen, mercury-actuated, recording thermometer provided a continuous record of the temperature of the inlet and outlet boiler-water. The temperatures of the air entering the stoker and of the stack gas were recorded by means of a multipoint potentiometer and thermocouples. A photoelectric cell and the recording potentiometer were used to provide a record of the opacity of the stack gas. A chemical-type meter recorded the percentage of CO_2 in the stack gas. The static pressure in the stoker air duct was recorded by a pressure gage.

Indicating instruments measured the power required by the stoker and the drafts in the stack and combustion chamber.

A 16-mm. motion picture camera with a special timer was used for taking pictures of the fuel bed at the rate of one frame every 2½ seconds. When the film was viewed at the rate of 16 frames per second the action appeared 40 times faster than the actual rate.

When the camera was not being used for taking pictures of the fuel bed, it was used to take single frame pictures of the scale dial and a clock at appropriate intervals (usually one-half hour), thereby furnishing a record of the loss in weight of the stoker-boiler unit without continuous attention. The weight at the indicated time could be determined rapidly and conveniently by viewing the film through a low-power microscope.

The coal-washing unit used for a few of the coals described in this report was a laboratory-size concentrating table, equipped with a diagonal, linoleum-covered deck with wooden riffles. The dimensions of the deck were 8 ft. 8 in. by 4 ft. 7 in. A complete description of this table and its action has been published.[4, 5]

A shatter-test machine, similar to that described in A.S.T.M. Standard D 141–48, was used to determine the resistance of the been published.[4, 5]

PROCEDURE

The tests described in this report are divided into two phases. For the first phase, coals from four Arkansas mines were tested as received and also after passing over the concentrating table with a "normal" reject. One Illinois coal from Douglas County was tested in the "washed" condition only. The second phase consisted of tests on commercially prepared stoker coals obtained from several Illinois mines and from a number of mines in other states. Table 1 gives additional information about the source of the coals tested.

The coal samples from Illinois, Indiana, Iowa, and Missouri were obtained directly from the mines by truck. The samples from Arkansas were obtained from the mines by B. C. Parks, Bureau of Research, University of Arkansas, and shipped in an open car to Urbana. The Wyoming coal was obtained at the mine by C. C. Boley, Natural Resources Research Institute, University of Wyoming, and shipped to Urbana in sealed barrels. Three samples from Kentucky (Ky. 1, Ky. 3, and Ky. 4) were obtained from railroad cars upon receipt at local coal dealers. The remaining samples were obtained from bins at nearby retail yards.

Although there is a possibility of error in identification of the coals not obtained directly from the mine, only the source of the Ohio coal sample seems doubtful to the author.

The samples are not considered representative of the seams, or even the mines. It was obviously impractical, and of no particular importance, to obtain representative samples for this study. Coals from a large number of sources were used in

[4] Helfinstine, Roy J., and Boley, Charles C., *op. cit.*
[5] Boley, Charles C., Analysis of coal cleaning on a concentrating table: Illinois Geol. Survey Rept. Inv. 136, 63 pp., 1949.

order to compare widely varying characteristics.

Considerable care was taken to obtain representative samples of the coals as burned which were used for size and chemical analyses. Standard or proposed methods of the American Society for Testing Materials were used wherever they were applicable.

The size composition of the coals was determined with mechanically vibrated test sieves with square openings. All mesh sieves were of the "Tyler" series. As shown in table 7 (appendix) the size composition of the coal varied widely. Maintenance of a constant size composition might have been desirable but it was not feasible for the present studies.

Previous tests made on Illinois coals indicated that the size composition of coal burned did not greatly influence its combustion characteristics in a domestic stoker.[6] Of course, a difference in composition of various size fractions of a coal will probably result in a corresponding change in combustion characteristics. However, such changes should not be attributed to change in size but to change in composition.

Combustion Testing Schedule

The combustion testing schedule included tests with the stoker operating 60, 45, 30, and 15 minutes out of each hour. Approximately 300 pounds of coal were burned during each of these four tests. The intermittent test with the stoker operating 15 minutes out of each hour was followed by a hold-fire test of two days with the stoker operating about three minutes out of each one and three-fourths hours. The hold-fire test was followed by a two-hour test with continuous stoker operation.

The test with the stoker operating continuously was started on a clean hearth. Only the clinker was removed before all tests with intermittent stoker operation. All coal, clinker, and ash were removed at the end of the series of tests with a given coal. About 50 pounds of coal were burned before starting the actual test after changing the stoker operation rate and removing the clinker. Motion pictures of the combustion chamber were taken for approximately one-half hour at a definite time during each test with a given operation rate.

The chronological test schedule follows:

	Tuesday
7:00 a.m.	Start fire on clean hearth. Cause stoker to operate continuously.
10:00 a.m.	Beginning of test period for continuous stoker operation.
3:45 p.m.	Start taking motion pictures of fuel bed.
4:25 p.m.	Stop taking motion pictures of fuel bed.
8:00 p.m.	End of test period with continuous stoker operation. Remove clinker, fill hopper, and change stoker operating rate to 45 minutes on and 15 minutes off.
10:15 p.m.	Beginning of test period with stoker operating 45 minutes out of each hour.
	Wednesday
10:15 a.m.	Start taking motion pictures of fuel bed.
11:05 a.m.	Stop taking motion pictures of fuel bed.
11:13 a.m.	Start taking motion pictures of fuel bed.
11:40 a.m.	Stop taking motion pictures of fuel bed.
1:15 p.m.	End of test period with stoker operating 45 minutes out of each hour. Remove clinker, fill hopper, and change stoker operating rate to 30 minutes on and 30 minutes off.
4:30 p.m.	Beginning of test period with stoker operating 30 minutes out of each hour.
	Thursday
10:45 a.m.	Start taking motion pictures of fuel bed.
11:05 a.m.	Stop taking motion pictures of fuel bed.
11:28 a.m.	Start taking motion pictures of fuel bed.
11:45 a.m.	Stop taking motion pictures of fuel bed.
2:30 p.m.	End of test period with stoker operating 30 minutes out of each hour. Remove clinker, fill hopper, and change stoker operating rate to 15 minutes on and 45 minutes off.
6:30 p.m.	Beginning of test period with stoker operating 15 minutes out of each hour.
	Friday
8:43 a.m.	Start taking motion pictures of fuel bed.
9:05 a.m.	Stop taking motion pictures of fuel bed.
9:43 a.m.	Start taking motion pictures of fuel bed.
9:55 a.m.	Stop taking motion pictures of fuel bed.
	Saturday
10:30 a.m.	End of test period with stoker operating 15 minutes out of each hour. Remove clinker and change stoker operating rate to hold-fire (3 minutes out of each 1¾ hours).

[6] Helfinstine, Roy J., *op. cit.*

MONDAY

11:45 a.m. Start stoker operating continuously.
1:45 p.m. Stop stoker. Quench fire, remove clinker and ash from hearth and fly ash from boiler passages. Remove coal from hopper, worm, and retort.

Records were made of the weights of all coal placed in the hopper, and of the coal, clinker, fly ash, and refuse removed. A representative sample of refuse was analyzed for percentage of ash. This information permitted the calculation of the average relationship between the loss in weight of the stoker-boiler unit and the coal burned.[7]

The heat output from the boiler was determined for each 20-minute interval of the test with continuous stoker operation, and for each hour with the three tests with intermittent stoker operation. Average values for each operation rate were determined for pressure in the stoker windbox, temperature of the room, temperature of the stack gases during stoker operation, percentage of CO_2 in the stack gases during stoker operation, boiler output, rate of coal feed, and coal burning rate.

Air Setting

Before starting a fire with any coal, the air control was adjusted to what seemed most reasonable. During the first two and one-half hours of operation, minor adjustments of the air control were made if necessary to provide what was considered the optimum setting for the coal being burned. All adjustments were completed before the beginning of the test period.

Combustion Rating Criteria

The many factors that govern the suitability of coals for domestic stokers include: (1) amount of heat obtained per dollar; (2) attention required by heating plant; (3) ability to maintain the desired temperature in the house; (4) smoke emitted; (5) ability to maintain fire at low rates of operation; (6) cleanliness; (7) appearance of the fuel bed and fire; (8) odors given off by clinkers during their removal; (9) quietness of operation; and (10) appearance of the coal. These factors vary in relative importance, depending upon the heating system and also upon personal preference of the operator.

Objective measurement of each of these factors would have been desirable, but no such measures for all have been devised, and probably are not possible. Certain objective measurements were made that should reveal the relative merits of the various stoker coals tested. Most of these are discussed in some detail in Part II of this series of reports, and are described only briefly in this report. A few criteria have been added and a few modified for these tests.

The heat absorbed by the boiler per pound of coal burned is a fairly reliable index of the cost of heat if the hold-fire characteristics of the coals being compared are similar. Illinois coals usually require less stoker operation to hold fire than do many of the eastern coals, hence the "heat obtained" is not always a fair basis for cost comparison between coals from these two areas.

Although the cost of heat may not be of primary importance in the selection of stoker coal, it is an important consideration for many people. This does not mean that other factors such as convenience, cleanliness, reliability, and ability to maintain the desired comfortable conditions are disregarded. As cost probably has far more influence than most people will admit, test results that give information about cost are included.

The percentage of ash, which can be determined by proximate analysis, is a good index to attention required by the heating plant. The pounds of ash per million B.t.u. is probably a fairer measure.

Other criteria which were used for the present tests (but not in those reported in R.I. 120 or R.I. 133) are the density and friability of the clinker. Density of the clinker was determined by a slight modification of the A.S.T.M. procedure for determining the density of coke. The friability of clinkers was determined by dropping the clinker twice from a height of 6 feet, and determining the percentage of clinker by weight that broke into pieces

[7] $$\text{Ratio} = \frac{\text{coal fed} - (\text{clinker removed} + \text{ash in refuse} + \text{fly ash in boiler passages})}{\text{coal fed into combustion chamber}}$$

weighing less than ¼ lb. Although the percentage of ash removed in the form of clinker has been determined for all tests in this series, this information is published for the first time in this report. The subjective clinker rating given in previous reports is also included in this report, although its value is quite limited.

The ability of a stoker-fired heating system to maintain the desired temperature in a dwelling depends largely upon the physical characteristics of the heating system and the construction of the house. A tightly constructed, well-insulated dwelling with a good heating system will be easier to heat than a poorly constructed house with an obsolete heating system. However, certain performance characteristics of the coal are thought to exert influence on "comfort conditions" irrespective of where it is burned. These are: (1) uniformity of rate of burning, (2) responsiveness of the fire after a prolonged hold-fire period, (3) responsiveness of the fire after a short "off" period (called *pickup* in this report), and (4) the tendency for over-heating (called *overrun* in this report).

Uniformity of rate of burning is regarded as one of the most influential of these factors. It seems reasonable, at least, to believe that a uniform temperature can be more readily maintained if the furnace or boiler releases heat at a uniform rate during stoker operation.

There are several ways to indicate the degree of variability of rate of heat release. One of the simplest was used for the tests described in this report. Although knowledge about the method of calculating *uniformity*, or any of the other indexes used in this report, is not essential for a full use of the information presented, a description of the procedure follows.

For the test with continuous stoker operation, the rate of heat output was determined for each 20-minute interval. The percentage difference between the rate of heat output for each 20-minute interval and the average rate of heat output during the entire test with continuous stoker operation was calculated. These differences were added, irrespective of algebraic sign, and then divided by the number of cycles (30) to give the average percent variation in rate of heat output for the test with continuous stoker operation. The same general procedure was used for the tests with 45, 30, and 15 minutes of stoker operation per hour, except that the cycle period was considered as one hour instead of 20 minutes. The percentage variations for the four operation rates were averaged, and these average values are used for all graphs and tables in this report.

Another measure of uniformity of rate of heat release which is included is the ratio of the minimum rate of heat release during any cycle of stoker operation to the average rate of heat release per cycle.

Responsiveness (after a prolonged hold-fire period) is the heat output in B.t.u. during the 30 minutes of continuous stoker operation immediately following the hold-fire period. The responsiveness ratio is the ratio of heat output during the first 30-minute period and the average output for 30 minutes during the test with continuous stoker operation. As results are based on only one cycle of operation for each coal, variations of 0.03 or less in the ratio are not considered significant.

Pickup is the rate of heat release during the first five minutes of stoker operation following a 45-minute period without stoker operation. The average pickup for 40 cycles is given in this report. The pickup ratio is the ratio of the rate of heat release during this five-minute period to the rate of heat release during the test with continuous stoker operation.

Overrun is the rate of heat output during the first five minutes of the off period following a 15-minute period of stoker operation. The numerical value is largely dependent upon the equipment used. An overrun ratio was also calculated; this is the ratio of overrun to the rate of heat release during the test with continuous stoker operation. Overrun will not be important unless the heating system causes the temperature to rise above the desired level because of excessive heat release after the stoker shuts off.

RESULTS

Method of Describing Degree of Correlation

The degree of correlation of two variables may be expressed as a correlation coefficient, such as the Pearson product-moment coefficient. Although a numerical value is thus obtained, it is difficult to evaluate its significance. Probably most people would prefer to base their judgment of significance of a given relationship upon the scatter of points in a graph. The data are presented in full so that anyone who desires may do the time-consuming labor required to determine the coefficients.

Correlation of Combustion Criteria with Standard Chemical Analyses

heat obtained

The heat obtained from the test coals correlated very well with the heating value of the coal, on the as-fired basis, as shown in figure 1. The solid line in this graph appears to be the best straight line to represent the points shown. All points between the dashed lines are within 5 percent of the value indicated by the solid line.

The solid line of figure 1 does not represent a direct proportionality. An extension of the line intersects the axis at 2200 B.t.u instead of 0 as required of a direct proportionality (fig. 2). The line that best represents the test data and also passes through the origin is shown in figure 2 as the "best direct proportionality" line. Within the range of heating values included in this investigation, the "direct proportionality" line does not vary from the "best straight line" more than 5 percent. This means that the heating value may be used for determining the relative cost of heat in many cases without making any correction for the increase in efficiency which usually accompanies an increase in heating value. Of course figure 1 should be used as a basis of comparison if available. Part II[8] in this series includes a table and chart to enable rapid calculation of relative cost of heat.

The tests disclosed that the heat obtained correlates very well with the percentage of carbon, on the as-fired basis (fig. 3). Fewer plotted points are outside the ± 5 percent lines than in the case of heating value. Although the correlation of heat obtained and percentage of carbon is good, the relationship will not be as useful as the one between heat obtained and heating value, because the percentage of carbon is more difficult to determine than the heating value.

The percentage of ash also has a fair correlation with the heat obtained, as shown in figure 4. If the coals are divided into groups with similar percentages of oxygen the correlation is good enough to be of considerable value. Figure 5 shows the relationship when all coals with less than 6 percent oxygen, on the moisture and ash-free basis, are eliminated. The subbituminous coal from Wyoming, which has nearly 18 percent oxygen, is likewise excluded from the graph. All the Illinois, Indiana, and western Kentucky coals tested are included except those from Gallatin County, Ill. Although the correlation between heat obtained and ash is poorer than with heating value, ash is readily determined, hence the relationship is of considerable value.

Numerous other items and combinations of items have been found to give fairly good correlation with heat obtained, such as the sum of the percentages of ash, oxygen, and nitrogen (fig. 6), fixed carbon, fixed carbon X heating value, and carbon ÷ (oxygen + ash).

uniformity of combustion rate

The uniformity of the rate of heat release during stoker operation is considered to be a good index of stoker coal performance. This characteristic is expressed as "percent variation," which is explained in detail on page 11. A low figure means the coal burns relatively uniformly (with less variation) and is therefore an indication that the coal is superior in this respect.

The degree of uniformity of combustion in domestic stokers burning Midwestern coals appears to be largely dependent upon the behavior of the ash. Frequently with some coals the fire will be nearly smothered by a large clinker forming in the combus-

[8] Helfinstine, Roy J., and Boley, Charles C., *op. cit.*

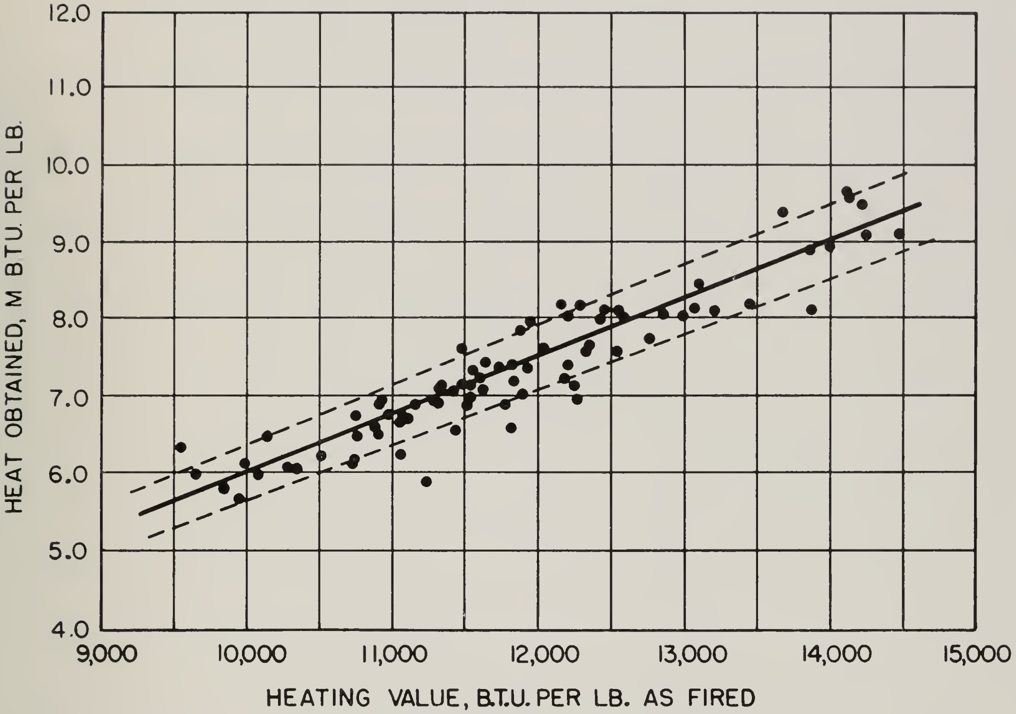

FIG. 1.—Relationship of heat obtained per pound of coal to the heating value, on the as-fired basis. Data from R.I. 120 included.

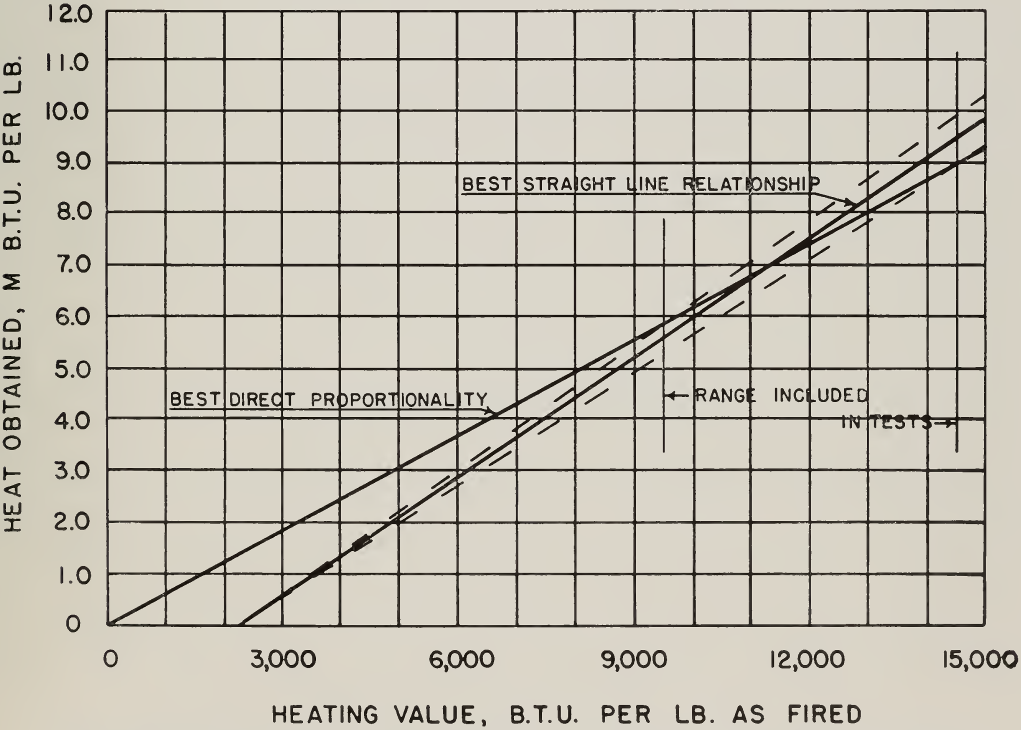

FIG. 2.—Best direct proportionality relationship of heat obtained per pound of coal to the heating value, on the as-fired basis.

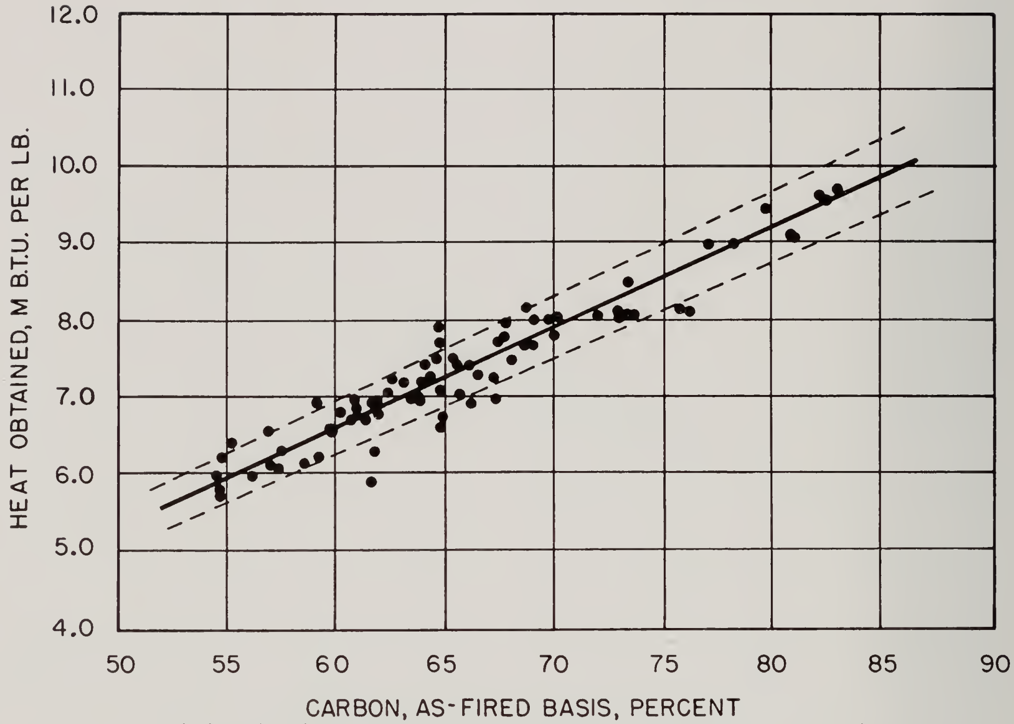

Fig. 3.—Relationship of heat obtained per pound of coal to the percentage of carbon, on the as-fired basis. Data from R.I. 120 included.

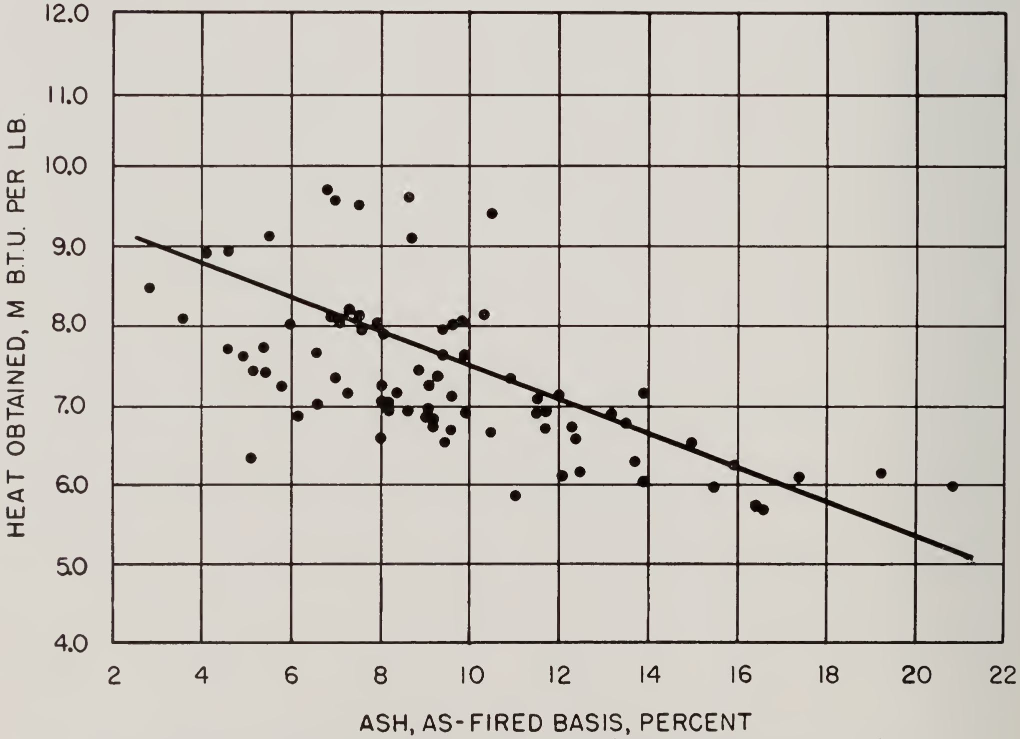

Fig. 4.—Relationship of heat obtained per pound of coal to the percentage of ash, on the as-fired basis. Data from R.I. 120 included.

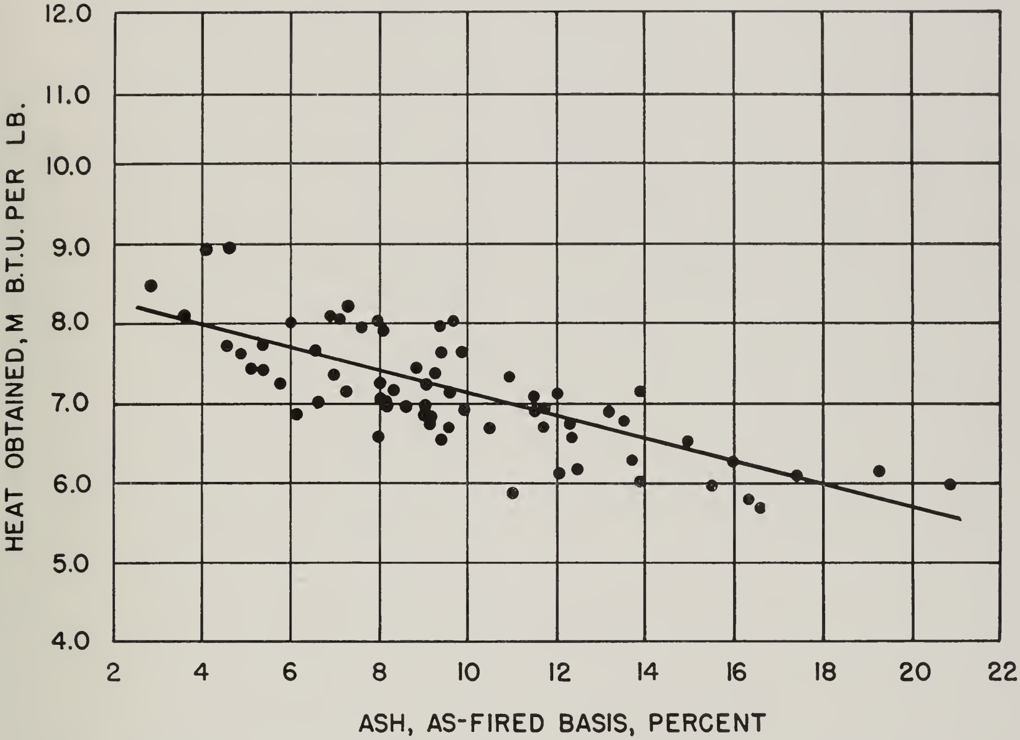

FIG. 5.—Relationship of heat obtained per pound of coal (in the 6 to 17 percent O_2 range) to the percentage of ash, on the as-fired basis. Data from R.I. 120 included.

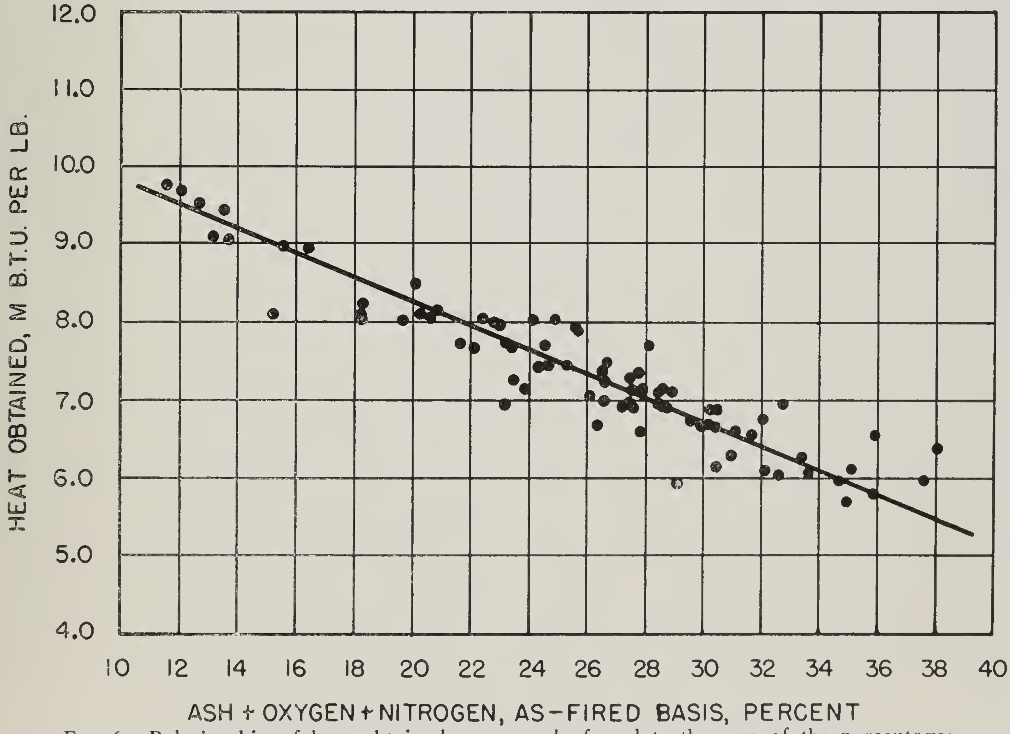

FIG. 6.—Relationship of heat obtained per pound of coal to the sum of the percentages of ash, oxygen, and nitrogen, on the as-fired basis. Data from R.I. 120 included.

tion zone. This clinker will be gradually raised by the incoming coal, and the flames will emerge around the edges of the clinker. In a few minutes the fire becomes quite active, and the rate of heat release will be high. This cycle of clinker formation may be repeated at frequent intervals.

Although a coal with a high percentage of ash may tend to cause nonuniform combustion (fig. 7), the behavior of the ash in the fuel bed may be even more important. The ash-softening temperature is the most common criterion for forecasting ash behavior. The initial deformation and fluid temperatures are less commonly used, but are also determined by many laboratories, including the Survey's Analytical Division. The softening temperature corresponds with the loosely applied term *ash-fusion temperature*.[9]

Figure 8 shows the relationship between the variation in rate of heat release and the ash-softening temperatures for the coals tested. Little or no correlation is evident. The same is true with regard to the initial deformation and fluid temperatures as shown in figures 9 and 10. The furnace used by the Analytical Division for determining the ash-fusion temperatures had a temperature limit of 2600° F. In a few cases, the ash-fusion temperature exceeded this by an unknown amount. The temperatures for such cases are given as 2600°+ F. When plotted on the graphs, arrows are added to these points.

The spread between the temperature at which the ash first softens and that at which it becomes fluid is often considered influential on clinker formation. However, the correlation between this temperature difference and the variations in rate of heat release is poor, as shown in figure 11.

The lack of correlation of ash-fusion temperatures with the uniformity of combustion does not prove that the clinkering characteristics of a coal have no influence on the uniformity of combustion, but it does prove that the commonly used indexes of clinkering characteristics are of little value for predicting how uniformly a coal will burn in a domestic stoker.

Although the periodic formation of clinker, previously described, appeared to have the greatest influence on the uniformity of combustion with Midwestern coals, this did not seem to be true with the Eastern coals tested. With these coals, the variation in rate of heat release appeared to be most dependent upon the periodic formation and combustion of "coke trees." The formation and combustion of "coke trees" likewise affected the uniformity of combustion with Midwestern coals, but to a lesser extent.

The A.S.T.M. has a standard method (D 720–46) for "obtaining information regarding the free-swelling properties of coal," which is called the "free-swelling index," and is occasionally referred to as the "British swelling index." Figure 12 was prepared to show the value of this small-scale analytical test as an index to the variation of rate of heat released with domestic stokers. No useful correlation is evident. The coal with the highest free-swelling index (from Sebastian County, Ark.) released heat at one of the most uniform rates of any tested. It is of interest to note that the ash-softening temperature of this Arkansas coal was less than 2100° F. Four coals with free-swelling indexes of 8.0 burned fairly uniformly.

The coals from Wabash County, Ill. (coordinates of 20.8 and 8.3), and the Pittsburgh seam (coordinates of 7.5 and 16.9) appear to be at the greatest variance from the trend indicated by the graph showing the relationship of uniformity and percent ash (fig. 7). A study of the data revealed that one of the most pronounced differences in characteristics of these two coals was exhibited by their fluid properties as determined by the Gieseler plastometer.[10] Figure 13 was plotted to show the relationships between this characteristic and the variation in rate of heat release for all coals tested. Although the Pittsburgh seam coal, with a fluidity of 6000 dial divisions per minute (16.9 percent variation), and the Wabash County coal with 6.7 dial divisions per minute (8.3 percent variation) fall in line with the general tendency, there

[9] More detailed information about fusibility of ash and its determination can be found in *A.S.T.M. Standards on Coal and Coke*, pp. 24–26, September 1948.

[10] This test is described in detail in *A.S.T.M. Standards on Coal and Coke*, pp. 129–133, September 1948.

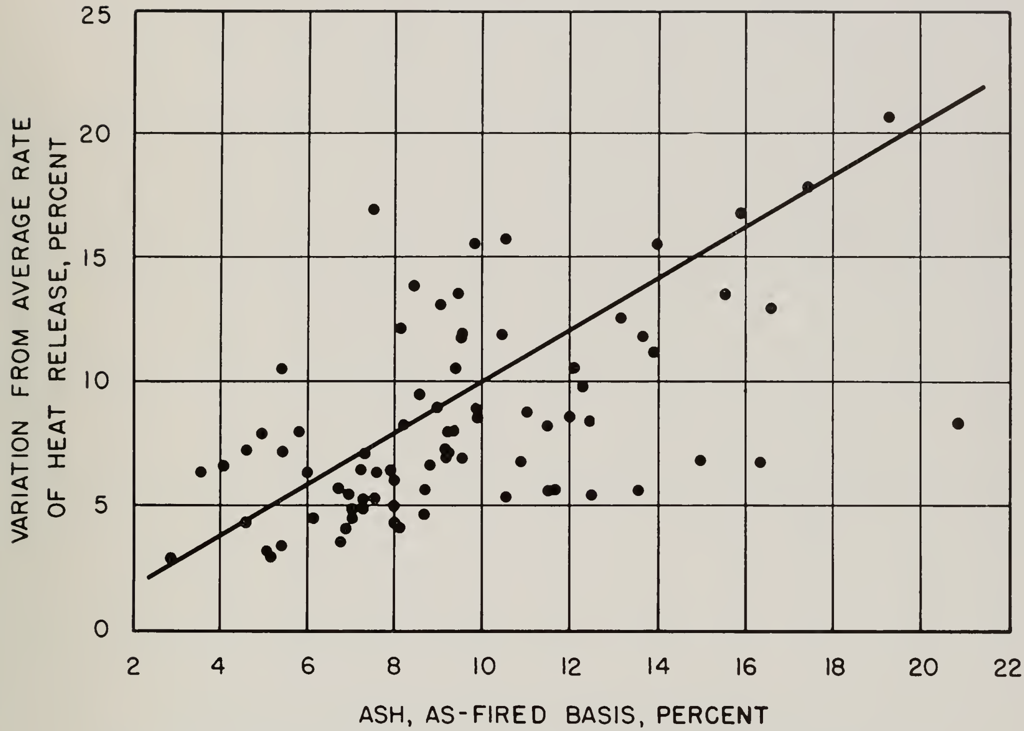

FIG. 7.—Relationship of uniformity of rate of heat release to the percentage of ash, on the as-fired basis. Data from R.I. 120 included.

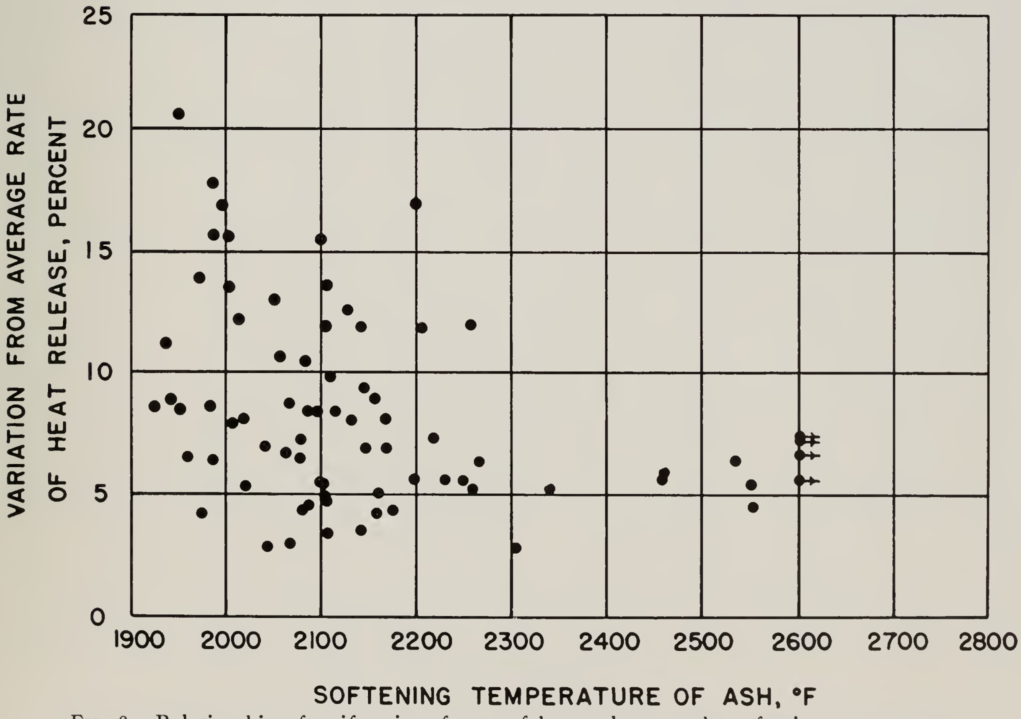

FIG. 8.—Relationship of uniformity of rate of heat release to the softening temperature of ash. Data from R.I. 120 included.

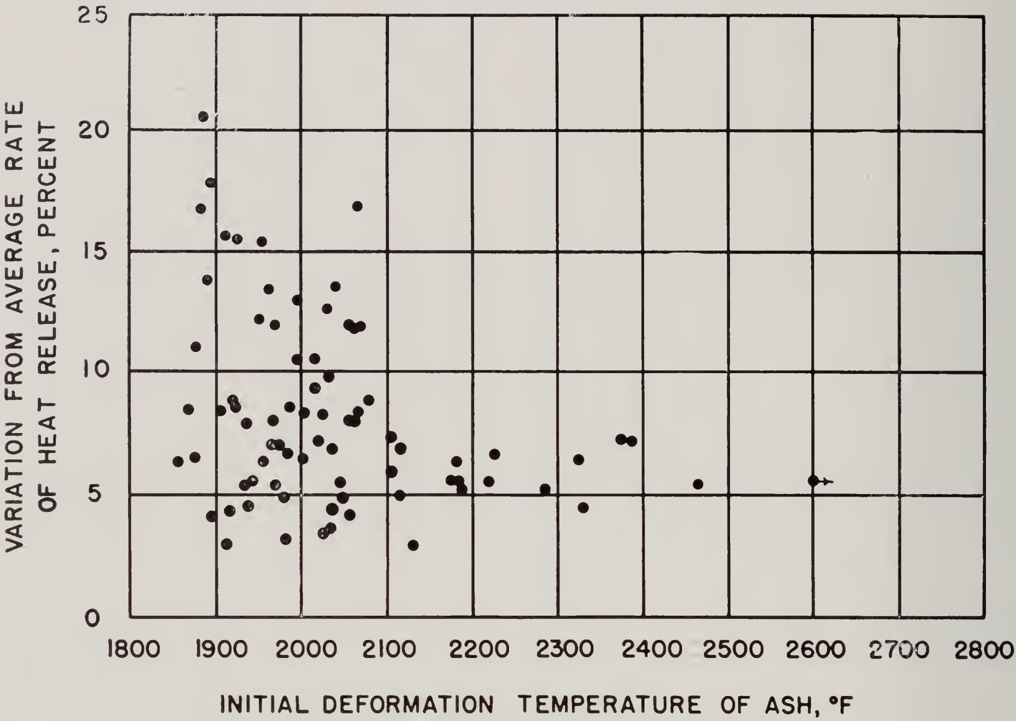

Fig. 9.—Relationship of uniformity of rate of heat release to the initial deformation temperature of the ash. Data from R.I. 120 included.

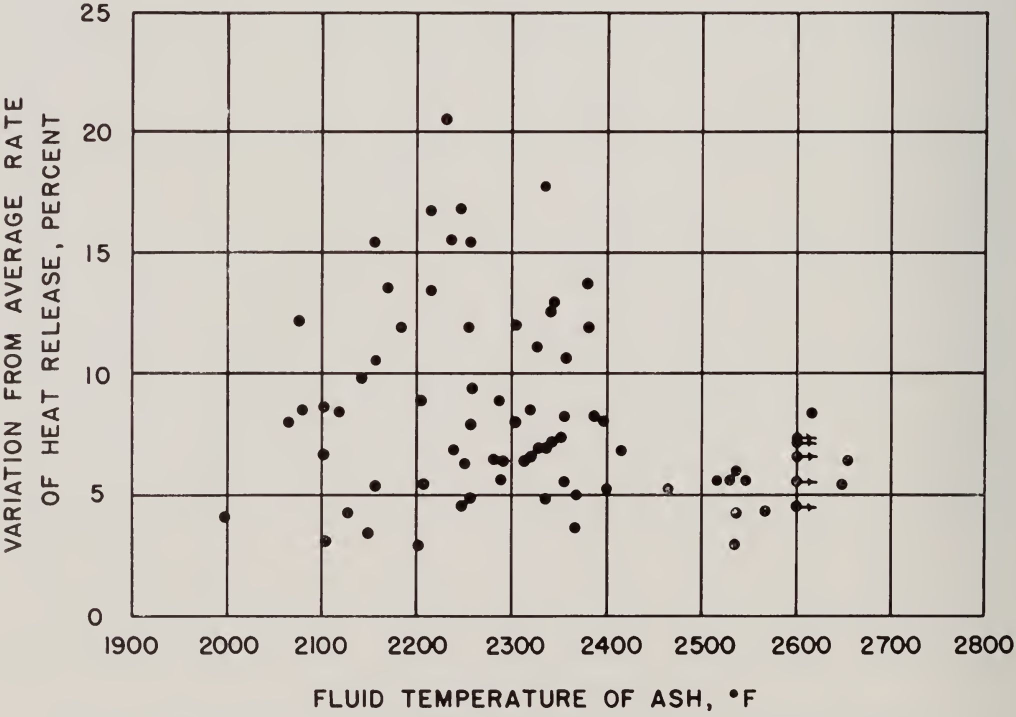

Fig. 10.—Relationship of the uniformity of rate of heat release to the fluid temperature of the ash. Data from R.I. 120 included.

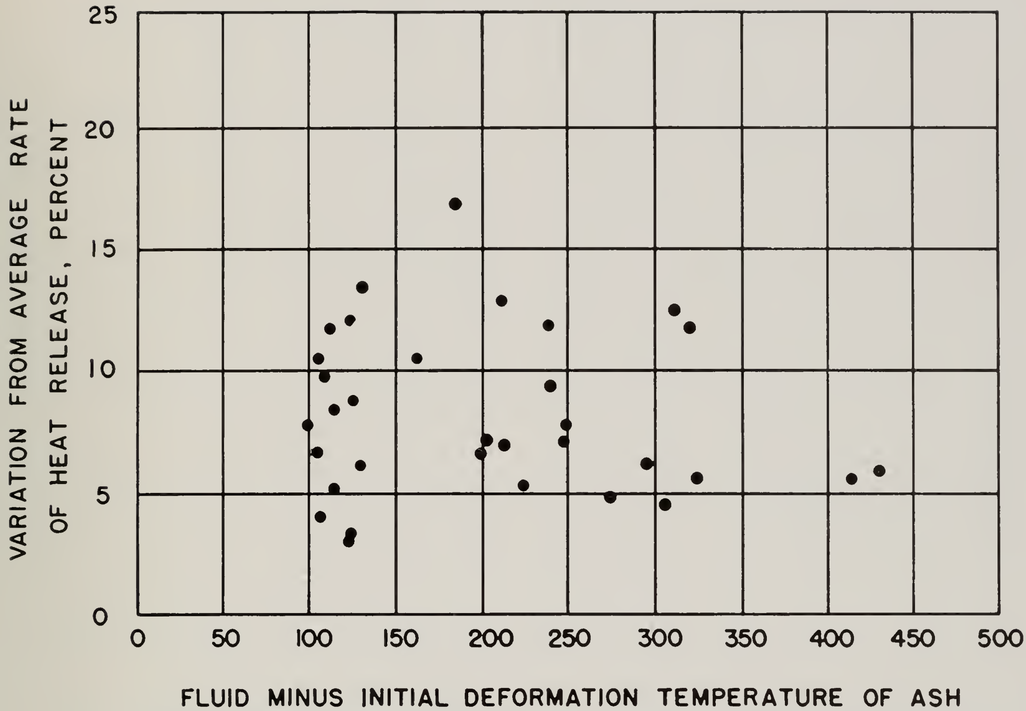

FIG. 11.—Relationship of the uniformity of rate of heat release to the difference between the fluid temperature and the initial deformation temperature of the ash.

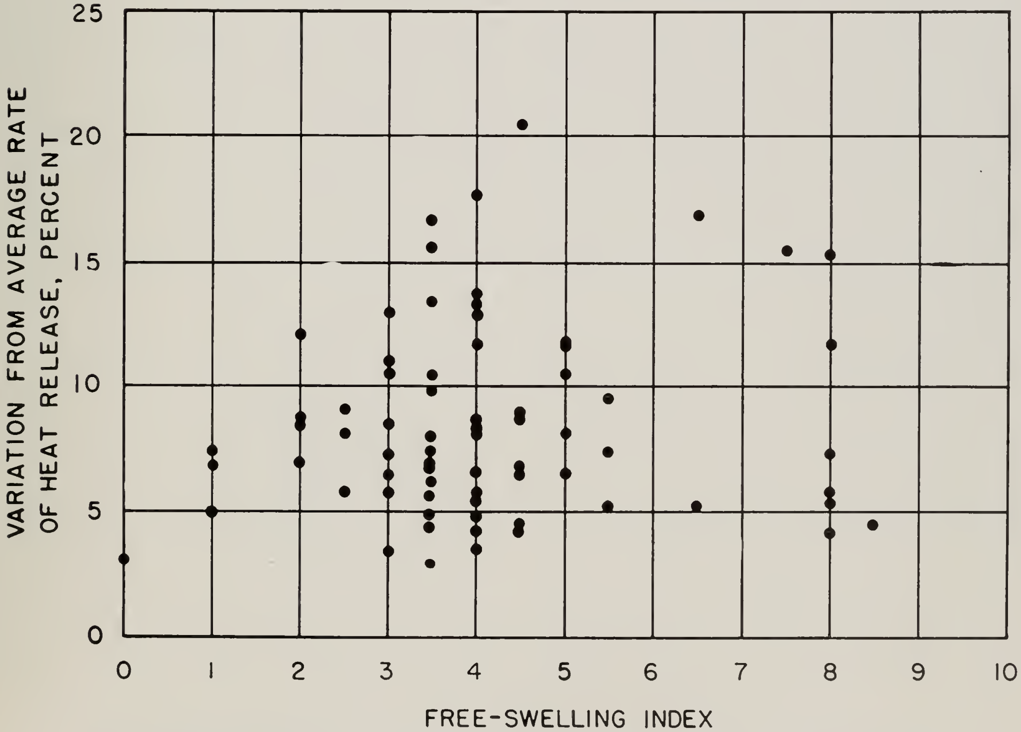

FIG. 12.—Relationship of the uniformity of rate of heat release to the free-swelling index. Data from R.I. 120 included.

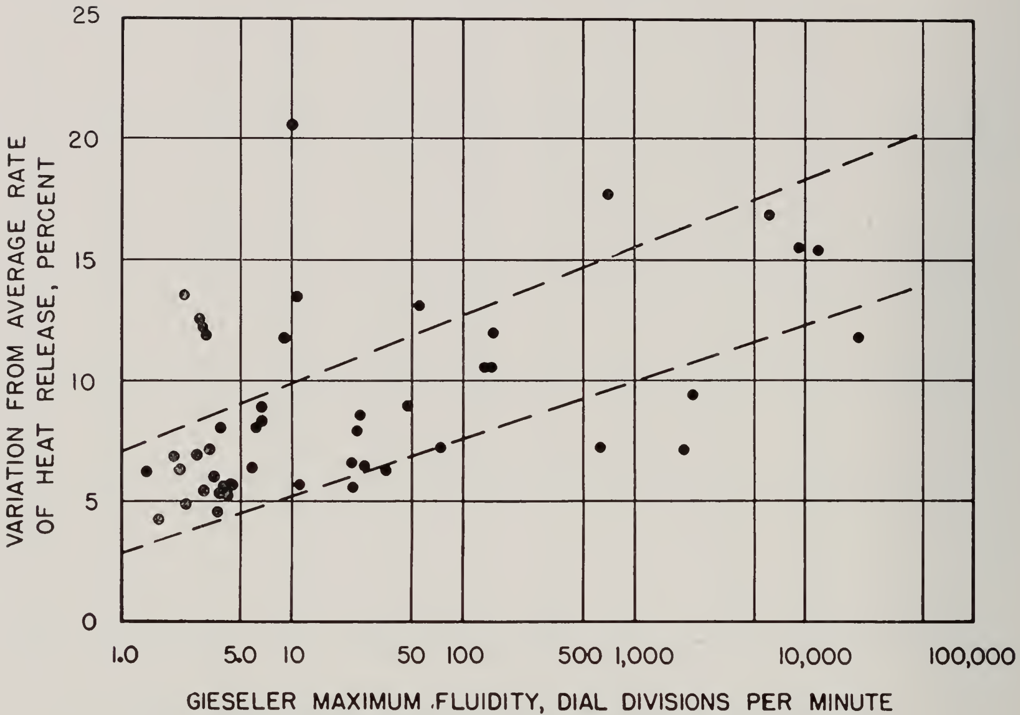

FIG. 13.—Relationship of the uniformity of rate of heat release to Gieseler maximum fluidity. Data from R.I. 120 included.

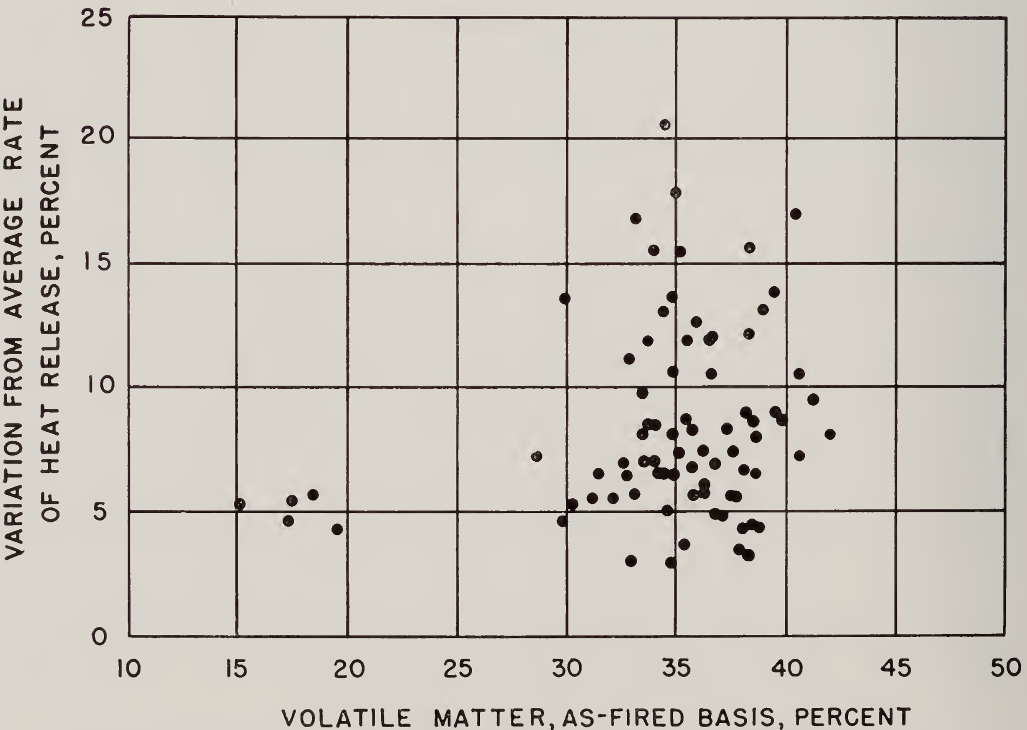

FIG. 14.—Relationship of the uniformity of rate of heat release to the percentage of volatile matter, on the as-fired basis. Data from R.I. 120 included.

are numerous other coals that are exceptions to the general trend. The major exception is an unprepared coal from St. Clair County, Ill. (coordinates of 10.0 and 20.5).

Little or no correlation was evident between the percentage of volatile matter in the coal and the uniformity with which it burned. Figures 14 and 15 show these relationships with volatile matter expressed on two different bases. While it is evident that all the coals that had less than 20 percent volatile matter on the as-fired basis did burn fairly uniformly, there were numerous high-volatile coals that performed equally well in this respect. In fact, the subbituminous coal from Wyoming, which had the highest percentage of volatile matter of the coals tested (on the ash- and moisture-free basis), burned more uniformly than any of the low-volatile coals.

RESPONSIVENESS OF FIRE TO HEAT DEMANDS

None of the items obtained from standard analytical tests gave very useful correlations with the responsiveness of the fire after a prolonged hold-fire period. The relationships with heating value, free-swelling index, and volatile matter are shown in figures 16, 17, and 18. Inasmuch as the responsiveness is based upon only one 30-minute test, a considerable part of the scatter of points may be attributed to the fact that the values for responsiveness may not be typical for each coal.

PICKUP

The pickup (responsiveness of the fire to a heat demand after the stoker has been off for 45 minutes) does not correlate very well with any of the items from the available standard analytical tests. Although the coking and clinkering characteristics of a coal might be expected to exert considerable influence on the pickup, the correlations with the free-swelling index and ash-softening temperature were found to be poor (figs. 19 and 20). This poor correlation does not mean that the coking and clinkering characteristics do not exert an influence on the pickup. The most logical explanation is that the free-swelling index and ash-softening temperature are not suitable measures of coking and clinkering characteristics. Evidence of this probability is presented in another section of this report.

The correlation between pickup and percentage of ash is shown to be poor in figure 21. The same is true in regard to percentage of volatile matter, as indicated in figure 22.

OVERRUN

No useful correlation could be found between the tendency for the coal to cause overheating, which is called overrun in this report, and any of the items from small-scale analytical tests. The relationship between overrun and the free-swelling index is shown in figure 23, and the relationship between overrun and the Gieseler softening temperature is given in figure 24. Numerous other plots, not shown in this report, exhibited the same scatter of points.

CLINKERING CHARACTERISTICS

The clinkering characteristics of a coal are quite important when the coal is burned in the type of stoker used for these tests. As all the ash should be removed in the form of clinker, the ratio of ash released to clinker removed should become unity after a normal fuel bed is established. The relatively short test period (one week) used in this investigation precludes a value of unity and probably fails to determine the ability of an individual coal to form the desired amount of clinkers. However, the tests were considered adequate to reveal any general relationship between the ability of a coal to clinker and its ash-softening temperature. Figure 25 shows that the correlation is very poor. The Paris seam coal from Arkansas had the lowest clinker-ash ratio (0.22) although its softening temperature was only 2021° F. The Indiana IV seam coal behaved in a reverse fashion. Its softening temperature was 2552° F., which is above the range usually considered satisfactory for clinkering-type domestic stokers, yet 62 percent of the ash released during the test was removed in the form of clinker. Anomalies of this magnitude certainly cannot be credited to test vagaries. The only reasonable conclusion is that the ash-softening temperature is of little or no

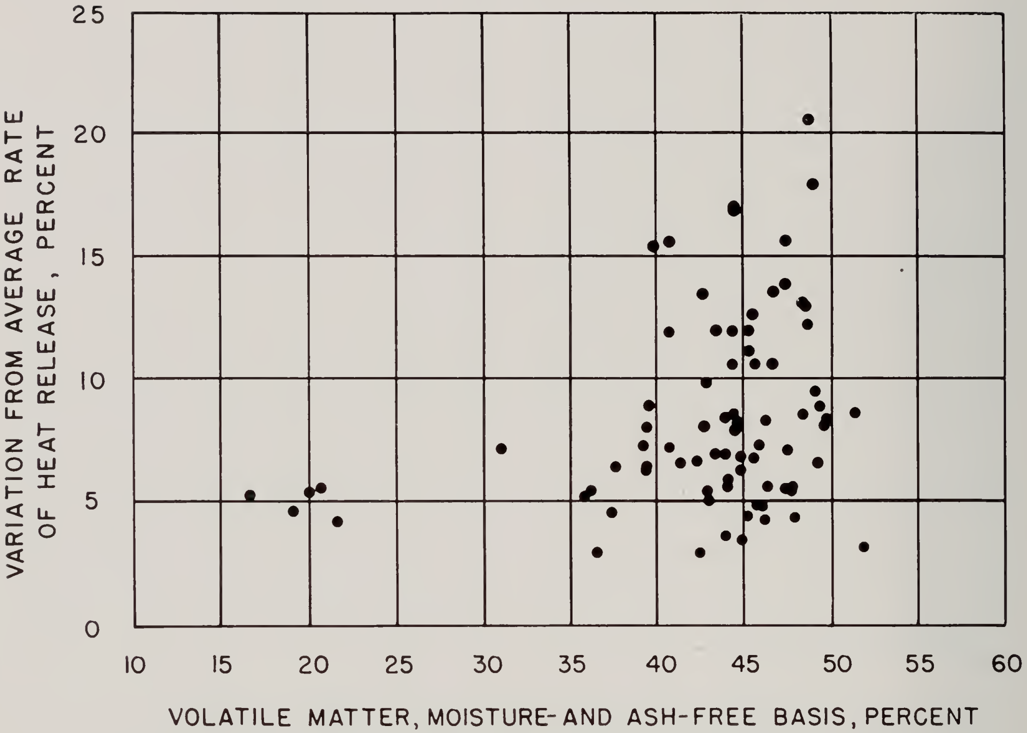

FIG. 15.—Relationship of the uniformity of rate of heat release to the percentage of volatile matter, on the moisture and ash-free basis. Data from R.I. 120 included.

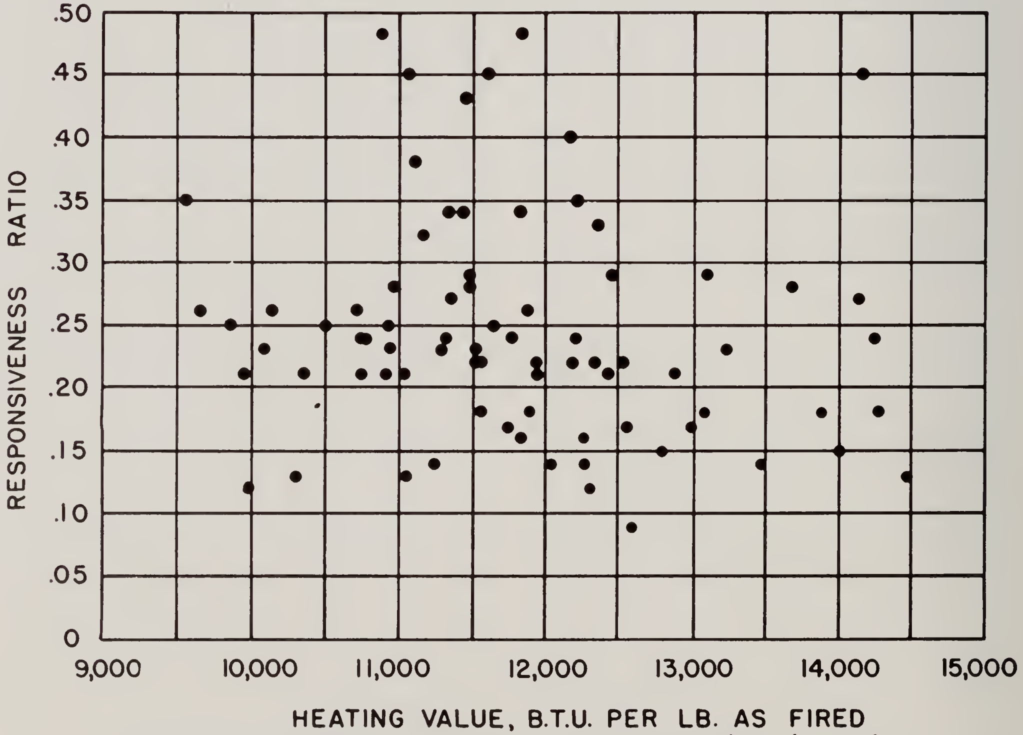

FIG. 16.—Relationship of the responsiveness ratio to the heating value, on the as-fired basis. Data from R.I. 120 included.

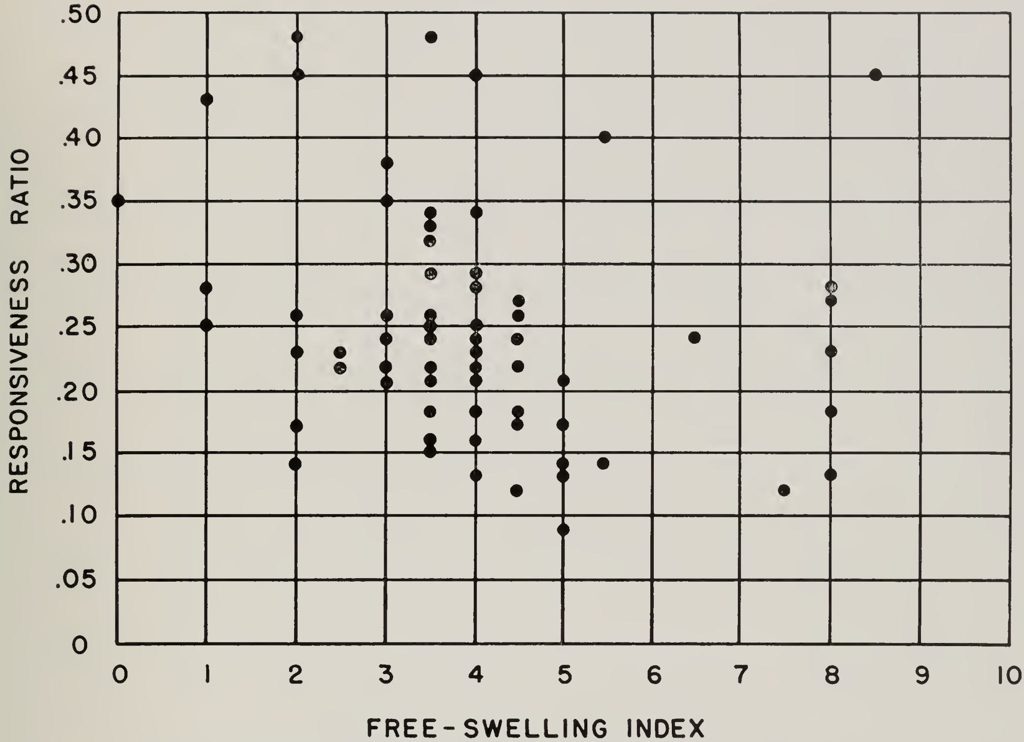

FIG. 17.—Relationship of the responsiveness ratio to the free-swelling index. Data from R.I. 120 included.

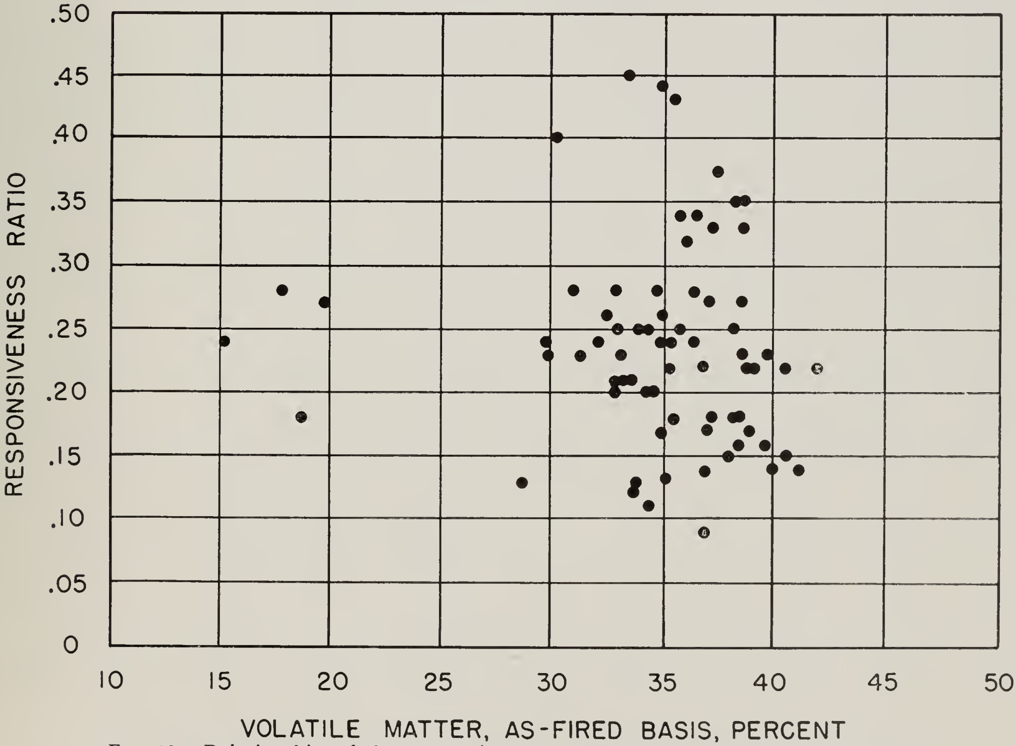

FIG. 18.—Relationship of the responsiveness ratio to the volatile matter, on the as-fired basis. Data from R.I. 120 included.

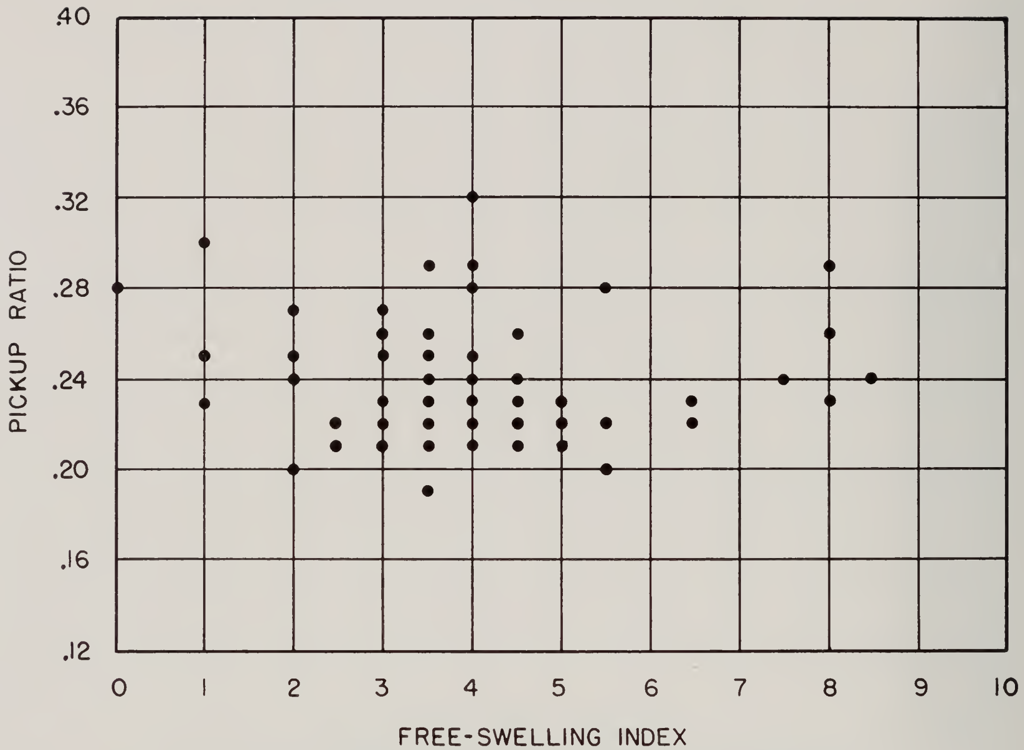

FIG. 19.—Relationship of the pickup ratio to the free-swelling index. Data from R.I. 120 included.

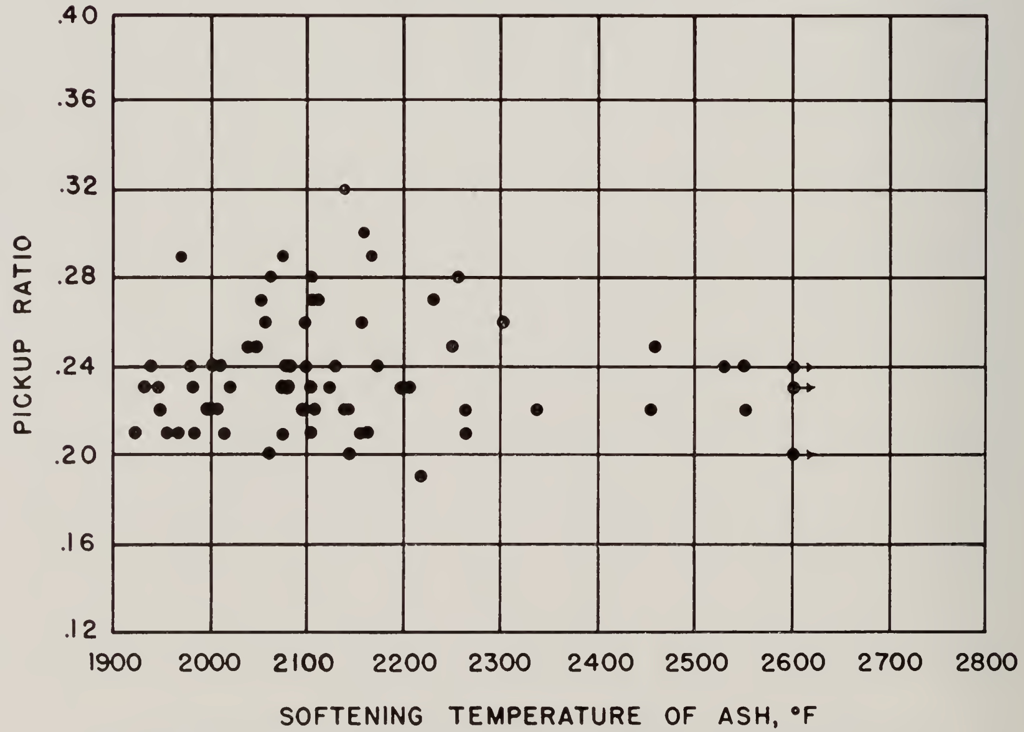

FIG. 20.—Relationship of the pickup ratio to the softening temperature of the ash. Data from R.I. 120 included.

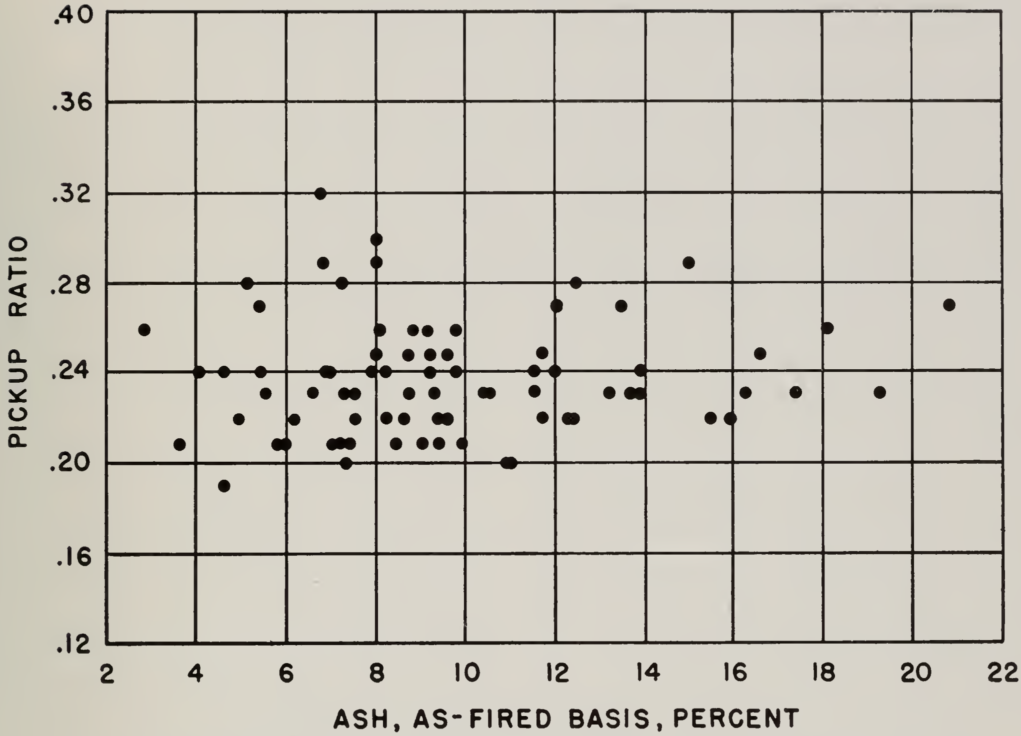

Fig. 21.—Relationship of the pickup ratio to the percentage of ash, on the as-fired basis. Data from R.I. 120 included.

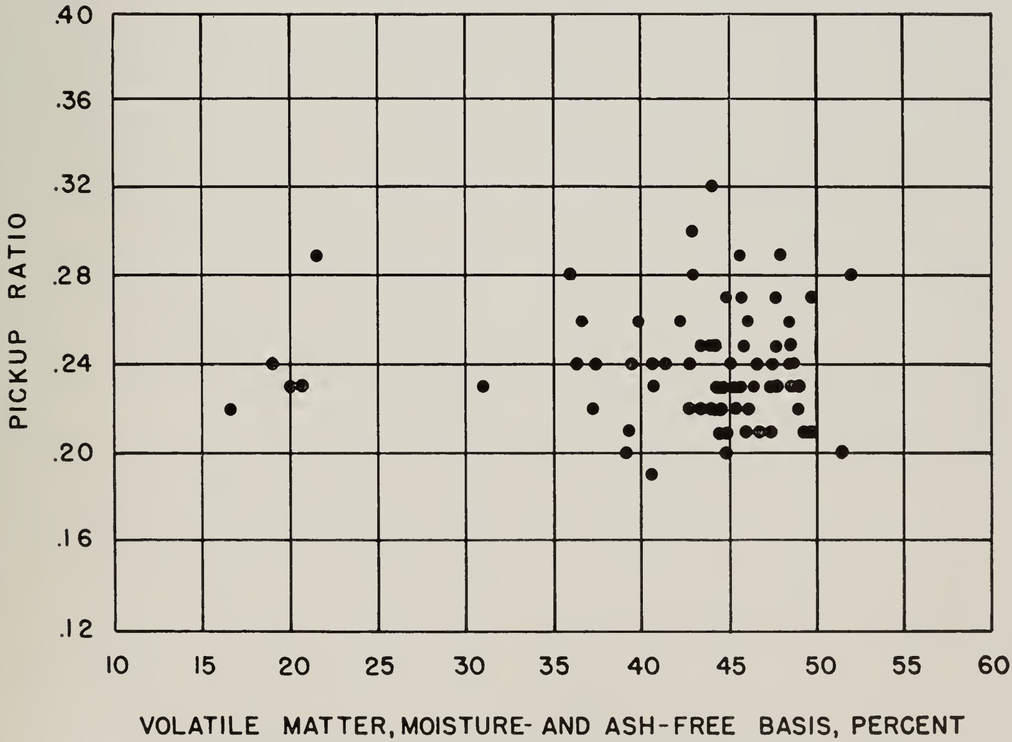

Fig. 22.—Relationship of the pickup ratio to the percentage of volatile matter, on the moisture- and ash-free basis. Data from R.I. 120 included.

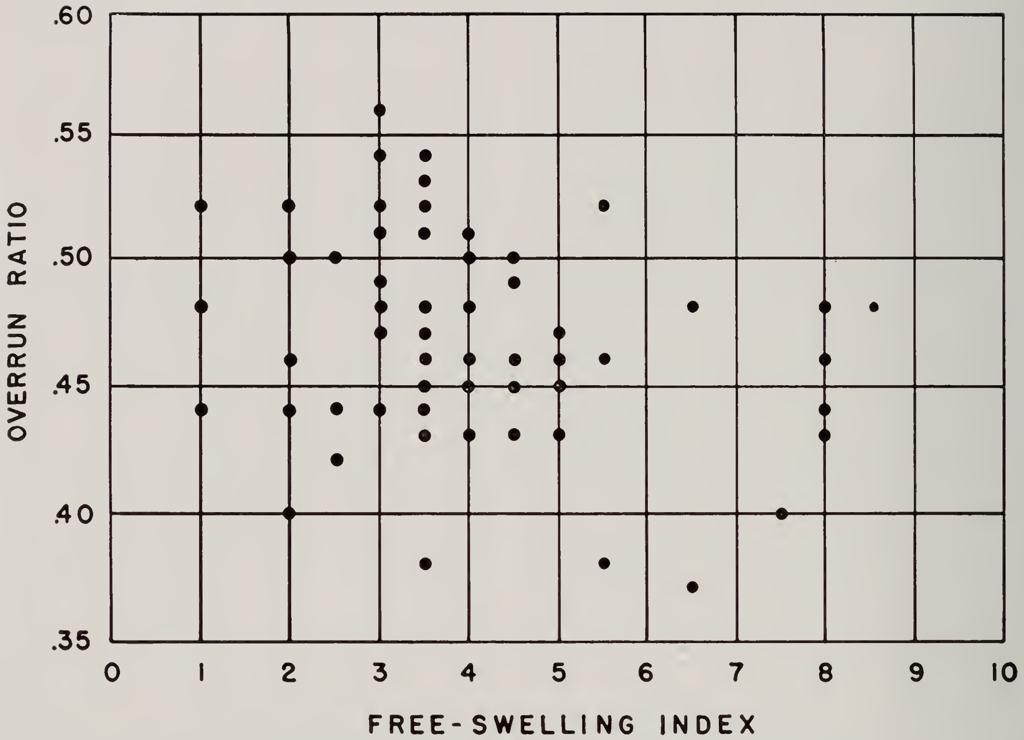

FIG. 23.—Relationship of the overrun ratio to the free-swelling index. Data from R.I. 120 included.

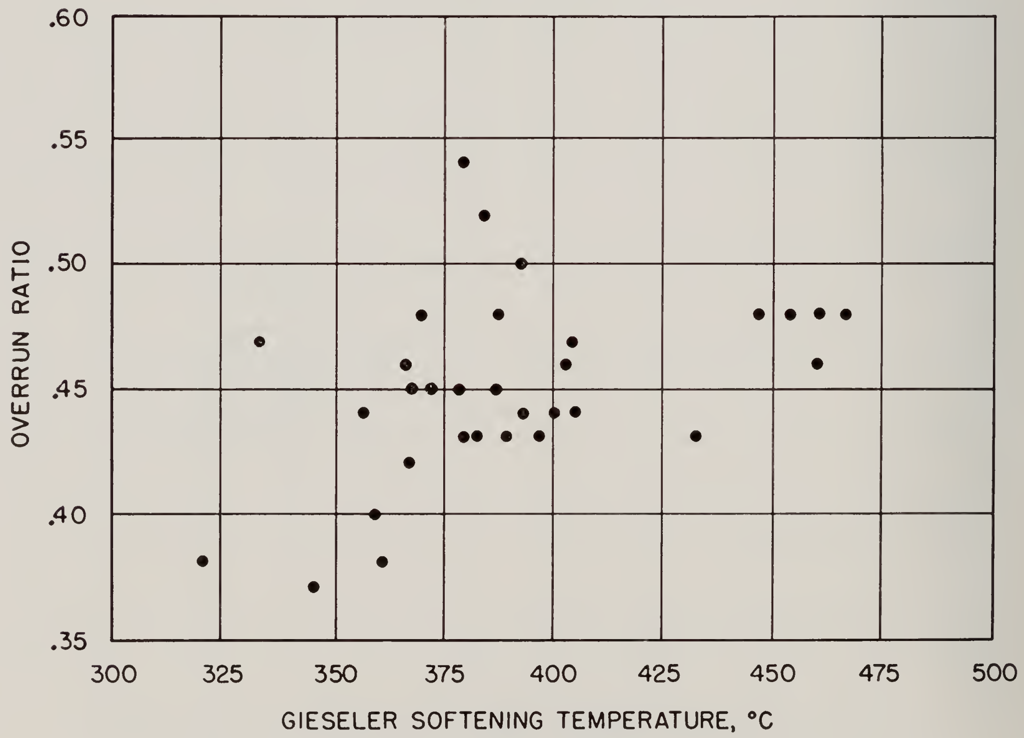

FIG. 24.—Relationship of the overrun ratio to the Gieseler softening temperature.

value for predicting the proportion of ash which can be removed in the form of clinker.

The lack of correlation between ash-softening temperature and amount of clinker formed has also been shown by other investigations. Purdy and Nelson[11] show a graph with the same coordinates as figure 25 which exhibits an equal amount of scatter. Although the exact source of the coals is not disclosed, four of the coals tested at the Survey were from the same state and seam as those included in the report by Purdy and Nelson. There is close agreement of actual values for these four coals even though the testing equipment and procedure differed.

The density of clinker is considered by some to be a valuable index to the ease with which clinkers can be removed. Table 13 (appendix) gives the true specific gravity, the apparent specific gravity, and the porosity of the clinker from the coals tested in this series. A study of numerous graphs (not included in this publication) failed to disclose a useful correlation between any of these three measures of density of the clinker and any of the items given by standard analytical analyses; nor was there any appreciable correlation between the apparent specific gravity of the clinker and the clinker-ash ratio (fig. 26).

No useful correlation was found between any of the small-scale analytical tests and the clinker-shatter index. Figure 27 shows its relationship with the softening temperature of the ash. A fair correlation was found between the clinker-shatter index and the clinker-ash ratio as shown in figure 28. In general, the coals which clinkered most readily were the most resistant to breakage. The major exception to this general tendency was the Pittsburgh seam coal which had a low clinker-shatter index of 47 and a low clinker-ash ratio of 0.26.

The dense clinkers are not always the most resistant to shattering. Figure 29 shows little or no correlation between the clinker-shatter index and the apparent specific gravity of the clinker.

[11] Purdy, J. B., and Nelson, H. W., An evaluation of the performance of thirty-three residential-stoker coals; Transactions of the A.S.M.E., July 1949.

Out-of-State Coals Compared with Illinois Coals

The results which were previously given in Part II (R.I. 120) of this series of reports were based entirely upon tests with the Illinois coals. Although the percentage of ash in these coals varied widely, many other properties (such as volatile matter on a moisture- and ash-free basis) were quite similar. One of the reasons for making tests with out-of-state coals was to learn if the conclusions derived from Illinois coals would hold true for out-of-state coals.

A comparison of test results from Illinois and out-of-state coals indicates that the same conclusions generally apply to both. However, for the coals with high fixed carbon (low volatile matter), the relationship between the heat obtained and the percentage of fixed carbon is not satisfactorily represented by an extension of the straight line shown in figure 9, R.I. 120. The broken line shown in figure 30 is identical with the solid line which was given in R.I. 120 as representative of the Illinois coals tested. An extension of this broken line is obviously unsatisfactory to represent the high fixed-carbon coals. The curved line, which deviates only slightly from the broken line for the lower values of fixed carbon, appears to be more nearly representative of the data included in this report.

The solid line shown in figure 5, which represents the relationship between heat obtained and ash for Midwestern coals, is the same as that shown in figure 10, R.I. 120, as representative of Illinois coals. The line shown in figure 4 as most representative of all coals tested has a greater slope. In all other graphs which show a solid line as most representative of the plotted data, no significant shift in slope of lines resulted from the addition of data from tests of out-of-state coals.

The inclusion of data from the tests of out-of-state coals did not materially improve the degree of correlation for relationships described as "poor" in Part II of this series.

Relative Qualities of Coals Tested

Although the ranking of coals from various sources was not a primary objective of

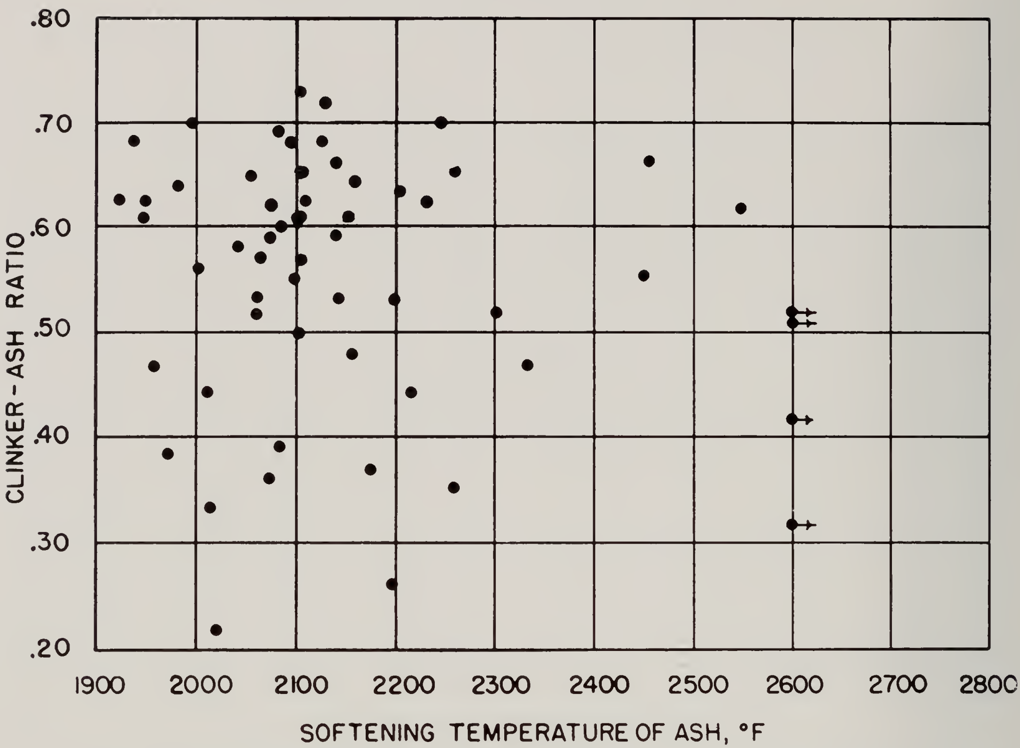

FIG. 25.—Relationship of the clinker-ash ratio to the softening temperature of the ash. Unpublished data included.

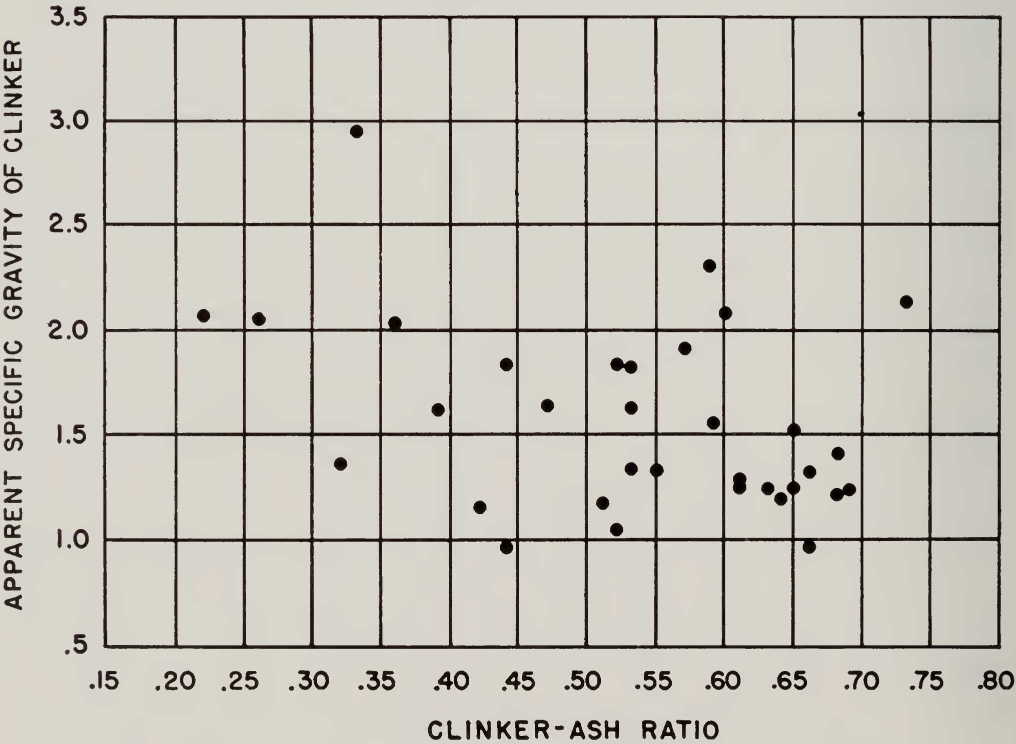

FIG. 26.—Relationship of the apparent specific gravity of the clinker to the clinker-ash ratio.

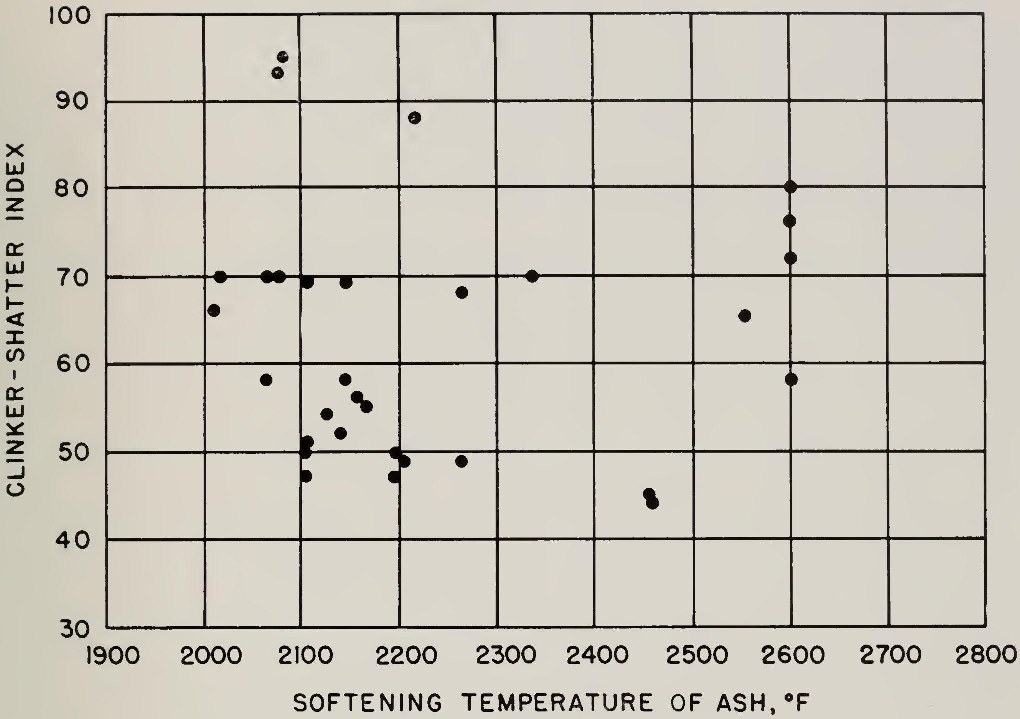

FIG. 27.—Relationship of the clinker-shatter index to the softening temperature of the ash.

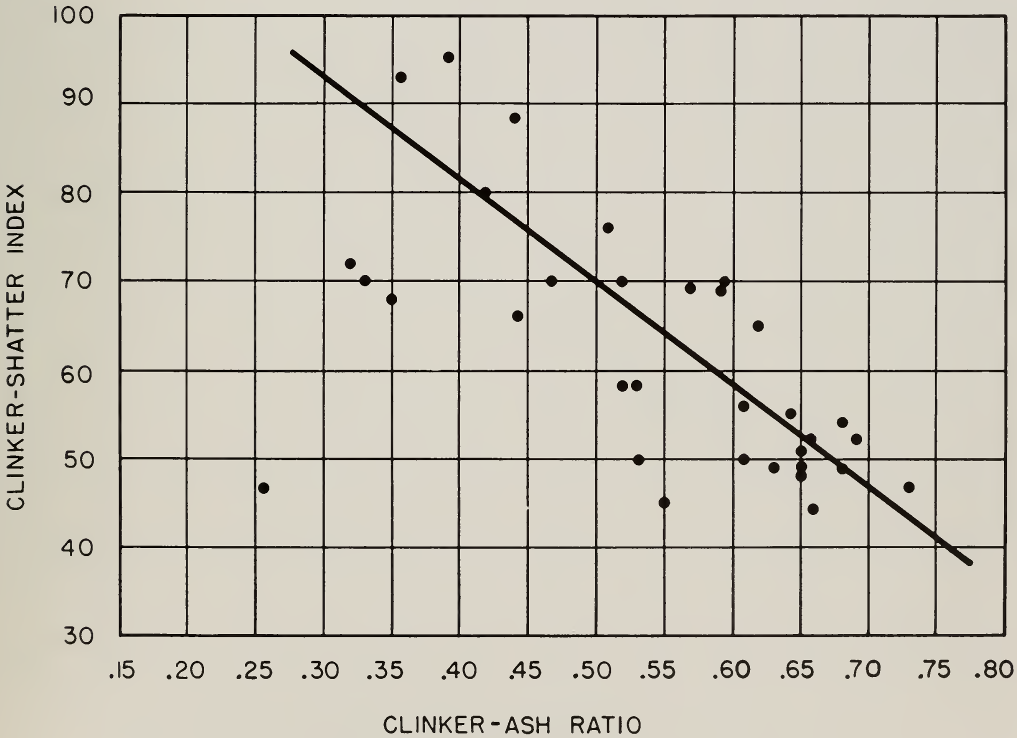

FIG. 28.—Relationship of the clinker-shatter index to the clinker-ash ratio.

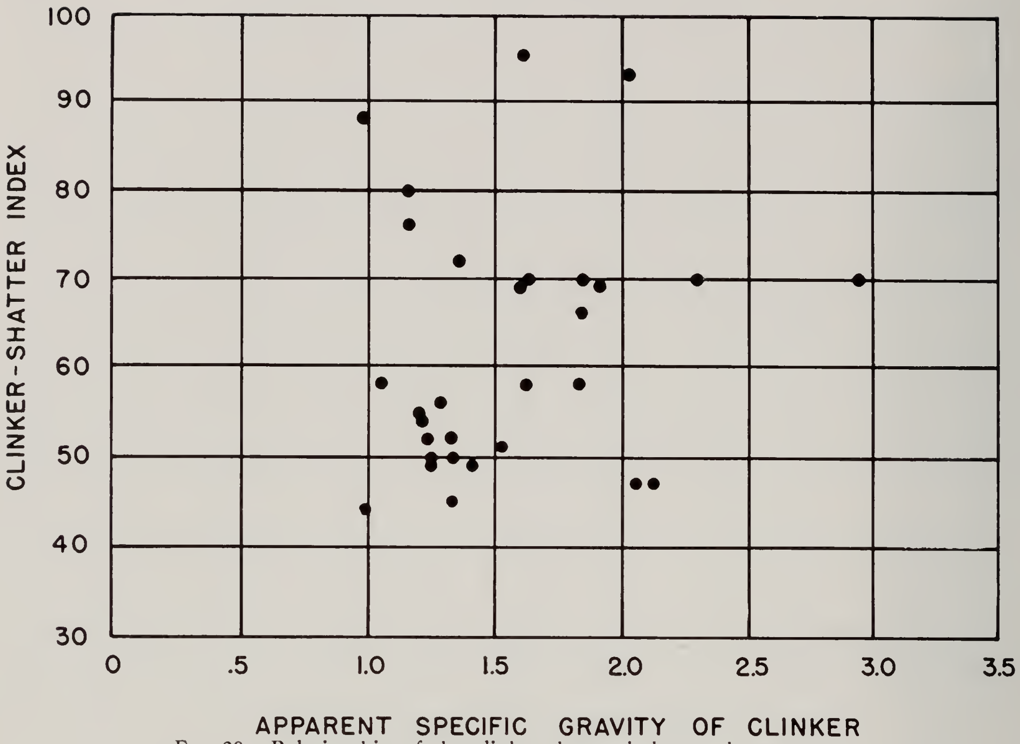

FIG. 29.—Relationship of the clinker-shatter index to the apparent specific gravity of the clinker.

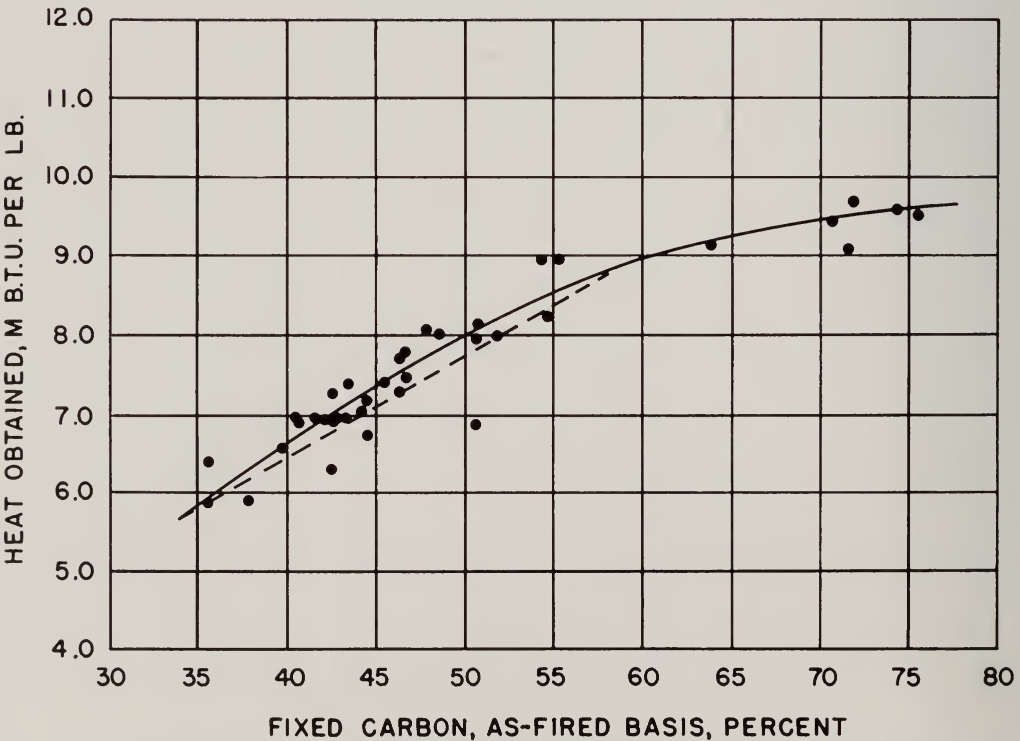

FIG. 30.—Relationship of heat obtained per pound of coal to the percentage of fixed carbon, on the as-fired basis.

this investigation, some of the test results are listed in order of superiority as an aid to those who wish to compare them. It should be remembered that the coals tested are not necessarily typical of those being sold from the indicated source. In fact, a few coals are known to differ considerably from the coal usually marketed from the locality. The Arkansas and Douglas County, Ill., coals received special preparation in the Survey laboratories and are therefore excluded from the tables that follow.

Table 2 lists the stoker coals in order of their uniformity of burning. Inasmuch as the percent variation in tests repeated with the same coal may differ by as much as one percentage figure with the more uniformly burning coals and by five percentage figures with coals of extremely variable performance, the relative positions of the coals tested should be considered only approximate. In other words, the Sheridan County, Wyo., and the Grundy County, Ill., coals should be considered equal in respect to their uniformity of combustion.

The relative amount of heat obtained per pound of coal burned is shown in table 3. Table 4 shows the relative position of the coals with respect to the amount of heat that would be obtained per pound of ash formed. This table gives an approximation of the relative amount of ash that must be removed, presumably in the form of clinker, for the same amount of heat. A difference in heat obtained per pound of coal of less than 0.2 M B.t.u. should not be considered significant.

Although the Eastern coals tested generally supplied more heat per pound of coal, or per pound of ash, their greater cost per ton delivered to Illinois usually more than offsets their higher heating value. As far as nearby coals are concerned, Illinois coals likewise enjoy an excellent competitive position in regard to heat obtained per dollar.

Table 5 gives the relative position of the coals in regard to responsiveness to demand for heat after a prolonged hold-fire period. Inasmuch as the values were obtained from only one cycle of operation, differences of 0.03 or less in the ratio should not be considered significant. Table 6 gives the relative position of the coals in regard to pickup (responsiveness after the stoker had been off for 45 minutes). As the figures are based on 40 cycles of operation, a difference in pickup ratio of 0.02 or more is considered significant. Tables 5 and 6 show that several Illinois coals are very good in respect to their responsiveness to heat demand.

CONCLUSIONS

The useful heat obtained from the coals exhibited a good correlation with the heating value on the as-fired basis. Although a slight increase in efficiency accompanied an increase in heating value, the increase was small, hence the cost of heat will closely approximate the relative cost per B.t.u. as determined by standard analytical methods.

The heat obtained also correlated very well with the percentage of carbon. The correlation with percentage of ash was fair when the comparison was limited to Midwestern coals.

The uniformity of rate of heat release during stoker operation is thought to be a good index of stoker coal performance. The tests indicated that the best correlation with this characteristic was probably the percentage of ash. However, there were numerous exceptions to the general trend of more uniform combustion accompanying a decrease in percentage of ash. The periodic formation of clinkers certainly influenced the rate of combustion. However, the correlation of the uniformity of heat release with the initial deformation, softening, or fluid temperatures of the ash was very poor.

Observation also indicated that the periodic formation and combustion of coke trees had some influence on the uniformity of combustion, although the correlation of free-swelling index with the uniformity of heat release proved to be very poor.

The fluid properties of the coals, as indicated by the Gieseler plastometer, appear to have some correlation with the uniformity of rate of heat release. However, there were many exceptions to the general trend of improved uniformity accompanying a decrease in fluidity.

Little or no correlation was evident between the percentage of volatile matter in coal and the uniformity with which it burned.

None of the items obtained by standard analytical tests gave useful correlations with the responsiveness of the fire after a prolonged hold-fire period.

The responsiveness of the fire to a heat demand after the stoker had been off for a relatively short period (pickup) did not correlate very well with any of the items obtained from standard analytical tests. The correlations with the tendency for the coal to cause overheating (overrun) were likewise poor.

There was little or no correlation between the percentage of ash fused into clinker and the ash-fusion temperatures. Two, and perhaps three, coals with ash-softening temperatures higher than 2600° F. formed a satisfactory proportion of clinker while some in the 2000° F. range did not.

No useful correlation was found between any of the items obtained from standard analytical tests and the shatterability of the clinker.

In general, the coals which clinkered most readily were most resistant to breakage.

The tests disclosed that actual combustion tests are the only satisfactory way to determine the suitability of a coal for use in a domestic stoker. The standard analytical tests are of very limited value in providing indexes to most performance characteristics.

The correlations of standard analytical test results and combustion characteristics of coals in a domestic stoker were essentially the same for out-of-state coals and for Illinois coals.

The tests indicate that many Illinois coals rate high as domestic-stoker coals.

APPENDIX

TABLE 1.—SOURCE AND IDENTIFICATION OF COALS

Sample No.	County	State	Seam
Ill. 1	Douglas	Illinois	No. 7
Ill. 2	Grundy	Illinois	No. 2
Ill. 3	Franklin	Illinois	No. 6
Ill. 4	Fulton	Illinois	No. 5
Ill. 5	Knox	Illinois	No. 6
Ill. 6	Grundy	Illinois	No. 7
Ill. 7	Christian	Illinois	No. 6
Ill. 8	Saline	Illinois	No. 6
Ill. 9	Saline	Illinois	No. 5
Ill. 10	Randolph	Illinois	No. 6
Ill. 11	Jackson	Illinois	No. 6
Ill. 12	Bureau	Illinois	No. 6
Ill. 13	St. Clair	Illinois	No. 6
Ark. 1	Sebastian	Arkansas	Hartshorne
Ark. 2	Johnson	Arkansas	Hartshorne (Spadra)
Ark. 3	Sebastian	Arkansas	Hartshorne
Ark. 4	Logan	Arkansas	Paris
Ind. 1	Vigo	Indiana	IV
Ind. 2	Vigo	Indiana	III
Ind. 3	Gibson	Indiana	V
Ind. 4	Fountain	Indiana	Minshall
Ind. 5	Clay	Indiana	Brazil
Ind. 6	Greene	Indiana	VI
Ind. 7	Greene	Indiana	VII
Ia. 1	Dallas	Iowa	Third seam
Ky. 1	Harlan	Kentucky	No. 5
Ky. 2	Perry	Kentucky	Hazard No. 4
Ky. 3	Hopkins	Kentucky	No. 11
Ky. 4	Hopkins	Kentucky	No. 6
Ky. 5	Letcher	Kentucky	Elkhorn
Mo. 1	Randolph	Missouri	Bevier
Mo. 2	Macon	Missouri	Mulky
Ohio 1	Athens[a]	Ohio	Middle Kittaning[a]
W. Va. 1	Marion	West Virginia	Pittsburgh
W. Va. 2	Wyoming	West Virginia	Beckley
W. Va. 3	McDowell	West Virginia	Pocahontas No. 4
W. Va. 4	Webster	West Virginia	Sewell
Wyo. 1	Sheridan	Wyoming	Monarch

[a] There is some doubt about the true source of this coal.

TABLE 2.—VARIATION IN RATE OF HEAT RELEASE

STATE	COUNTY	SEAM
Wyo.	Sheridan	Monarch
Ill.	Grundy	No. 2
Ind.	Vigo	IV
Ill.	Knox	No.6
W.Va.	McDowell	Poca. 4
W Va.	Wyoming	Beckley
Ind.	Clay	Brazil
Ind.	Greene	VII
Ill.	Franklin	No.6
Ky	Hopkins	No.6
Ky.	Perry	Hazard 4
Iowa	Dallas	Third
W.Va.	Webster	Sewell
Ky.	Harlan	No.5
Ky.	Letcher	Elkhorn
Ill.	Bureau	No.6
Ill.	Saline	No.5
Mo.	Macon	Mulky
Ind.	Fountain	Minshall
Ill.	Grundy	No.7
Ind.	Vigo	III
Ill.	Christian	No.6
Ill.	Jackson	No.6
Ky.	Hopkins	No.11
Ill	Randolph	No 6
Ind.	Gibson	V
Ill.	Saline	No.6
Mo.	Randolph	Bevier
Ind.	Greene	VI
Ill.	St.Clair	No 6
Ill.	Fulton	No.5
W.Va.	Marion	Pittsburgh

TABLE 3.—HEAT OBTAINED PER POUND OF COAL

STATE	COUNTY	SEAM
W. Va.	McDowell	Poca. 4
W. Va.	Webster	Sewell
W. Va.	Wyoming	Beckley
Ky.	Harlan	No. 5
Ky.	Perry	Hazard No. 4
Ky.	Letcher	Elkhorn
W. Va.	Marion	Pittsburgh
Ky.	Hopkins	No. 6
Ill.	Saline	No. 6
Ill.	Saline	No. 5
Ill.	Franklin	No. 6
Ky.	Hopkins	No. 11
Ill.	Jackson	No. 6
Ill.	Grundy	No. 2
Ill.	Knox	No. 6
Ind.	Greene	VII
Mo.	Macon	Mulky
Ill.	Randolph	No. 6
Ill.	St. Clair	No. 6
Ind.	Vigo	III
Ind.	Clay	Brazil
Mo.	Randolph	Bevier
Ind.	Greene	VI
Ill.	Grundy	No. 7
Ind.	Vigo	IV
Ill.	Bureau	No. 6
Ill.	Christian	No. 6
Ill.	Fulton	No. 5
Wyo.	Sheridan	Monarch
Ind.	Gibson	V
Ind.	Fountain	Minshall
Iowa	Dallas	Third

Table 4.—Heat Obtained per Pound of Ash Formed

STATE	COUNTY	SEAM
Ky.	Hopkins	No. 6
Ky.	Perry	Hazard 4
Ky.	Harlan	No. 5
W. Va.	Webster	Sewell
Ky.	Hopkins	No. 11
Ill	Grundy	No. 2
W. Va.	McDowell	Poca. 4
Wyo.	Sheridan	Monarch
Mo.	Macon	Mulky
Ky.	Letcher	Elkhorn
Ind.	Vigo	IV
W. Va.	Marion	Pittsburgh
Ill	Franklin	No. 6
Ill.	Knox	No. 6
W. Va	Wyoming	Beckley
Ind.	Greene	VII
Ill.	Saline	No. 5
Mo.	Randolph	Bevier
Ill.	Saline	No. 6
Ill.	Jackson	No. 6
Ind.	Vigo	III
Ill.	St. Clair	No. 6
Ill.	Grundy	No. 7
Ill.	Randolph	No. 6
Ill.	Bureau	No. 6
Ill.	Fulton	No. 5
Ind.	Clay	Brazil
Ill.	Christian	No. 6
Ind.	Fountain	Minshall
Ind.	Greene	VI
Ind.	Gibson	V
Iowa	Dallas	Third

Table 5.—Responsiveness of Fire to Heat Demand

STATE	COUNTY	SEAM
Ill	Grundy	No. 2
Wyo.	Sheridan	Monarch
Ind.	Greene	VII
Ind.	Greene	VI
Ill	Bureau	No. 6
Iowa	Dallas	Third
Ill.	Fulton	No. 5
Ind.	Vigo	IV
W. Va.	McDowell	Poca. 4
Ill.	Grundy	No. 7
Ind.	Clay	Brazil
Mo.	Randolph	Bevier
Ill.	Randolph	No. 6
Ill.	St. Clair	No. 6
Mo.	Macon	Mulky
Ill.	Franklin	No. 6
Ill.	Christian	No. 6
Ill.	Saline	No. 5
Ill	Knox	No. 6
Ky.	Perry	Hazard 4
W. Va.	Wyoming	Beckley
Ky.	Hopkins	No. 6
Ky.	Harlan	No. 5
Ky.	Hopkins	No. 11
Ill.	Jackson	No. 6
Ind.	Vigo	III
Ind.	Fountain	Minshall
Ky.	Letcher	Elkhorn
Ind.	Gibson	V
W. Va.	Webster	Sewell
Ill.	Saline	No. 6
W. Va.	Marion	Pittsburgh

Table 6.—Pickup Ratios

STATE	COUNTY	SEAM
Wyo.	Sheridan	Monarch
Ill.	Grundy	No. 2
Ill.	St. Clair	No. 6
Ill.	Bureau	No. 6
Ind.	Greene	VII
Ky.	Perry	Hazard 4
Ky.	Hopkins	No. 11
Mo.	Randolph	Bevier
Ind.	Gibson	V
Ind.	Greene	VI
Iowa	Dallas	Third
W. Va.	Webster	Sewell
W. Va.	Wyoming	Beckley
W. Va.	Marion	Pittsburgh
Ill.	Christian	No. 6
Ill.	Jackson	No. 6
Ill.	Randolph	No. 6
Ill.	Saline	No. 6
Ind.	Vigo	IV
Ind.	Vigo	III
Ind.	Clay	Brazil
W. Va.	McDowell	Poca. 4
Ill.	Franklin	No. 6
Ill.	Saline	No. 5
Ill.	Knox	No. 6
Ill.	Grundy	No. 7
Ill.	Fulton	No. 5
Ky.	Hopkins	No. 6
Mo.	Macon	Mulky
Ind.	Fountain	Minshall
Ky.	Letcher	Elkhorn
Ky.	Harlan	No. 5

Table 7.—Size Analyses of Coals

Sample No.	+1[a]	1×3/4[a]	3/4×1/2[a]	1/2×3/8[a]	3/8[a]×3[b]	3×4[b]	4×6[b]	6×8[b]	8×10[b]	10×14[b]	14×20[b]	20×0[b]
Ill. 1			14.9	15.5	21.0	14.7	10.8	9.1	7.4	3.9	1.2	1.5
Ill. 2		4.1	29.1	19.9	24.5	13.4	4.6	1.7	0.8	0.5	0.2	1.2
Ill. 3		3.9	23.4	15.5	17.8	11.1	8.1	8.3	5.6	2.8	1.8	1.7
Ill. 4			27.5	33.1	27.6	5.3	1.8	1.0	0.7	0.5	0.4	2.1
Ill. 5		6.3	51.2	26.9	8.3	1.9	1.0	0.7	0.6	0.4	0.3	2.4
Ill. 6		4.1	33.0	17.9	21.3	14.2	4.4	1.7	0.9	0.5	0.3	1.7
Ill. 7			2.3	12.0	19.4	14.7	11.9	11.8	10.3	7.1	4.3	6.2
Ill. 8		7.0	44.6	13.6	10.8	6.4	4.7	3.9	3.2	1.9	1.2	2.7
Ill. 9			23.2	26.8	23.8	11.1	5.0	3.3	2.4	1.5	0.9	2.0
Ill. 10			25.8	24.8	30.3	11.8	2.7	1.4	0.9	0.5	0.3	1.5
Ill. 11			20.9	33.3	25.7	10.5	3.5	2.1	1.7	1.5	0.7	0.1
Ill. 12		5.6	15.3	11.4	15.3	11.0	9.1	9.4	7.6	4.3	2.6	8.4
Ill. 13			25.5	26.9	29.4	10.5	2.5	1.3	0.9	0.6	0.4	2.0
Ark. 1R				5.1	10.6	11.9	13.7	14.6	15.7	13.6	5.3	9.5
Ark. 1W				2.4	28.9	9.1	11.6	11.6	14.1	10.8	4.4	7.1
Ark. 2R			11.3	10.3	12.4	15.5	11.8	12.2	12.1	8.0	2.0	4.4
Ark. 2W			5.4	8.4	9.1	12.9	13.2	14.1	14.6	11.5	4.3	6.5
Ark. 3R				10.4	14.6	16.3	13.8	13.8	13.8	9.5	2.2	5.6
Ark. 3W				11.1	14.7	15.3	13.0	12.3	11.3	7.9	3.9	10.5
Ark. 4R			12.6	10.9	9.9	10.8	13.9	11.4	13.8	10.0	2.4	4.3
Ark. 4W			17.5	11.8	14.8	13.2	13.6	10.8	9.0	5.0	1.4	2.9
Ind. 1	3.8	23.5	44.5	14.6	8.5	1.7	0.8	0.5	0.4	0.2	0.2	1.3
Ind. 2			27.8	28.4	27.9	7.4	3.1	1.6	1.0	0.6	0.4	1.8
Ind. 3		15.2	24.0	13.7	20.7	14.8	6.0	1.8	0.9	0.5	0.3	2.1
Ind. 4	9.9	17.0	32.9	13.3	16.0	5.4	1.8	0.9	0.6	0.4	0.3	1.5
Ind. 5		14.0	33.9	15.9	16.4	6.9	3.8	2.3	1.6	1.1	0.6	3.5
Ind. 6			8.6	18.2	23.9	15.0	9.7	8.4	6.9	4.4	2.2	2.7
Ind. 7			10.7	20.4	24.5	13.9	10.0	8.4	6.8	3.5	0.9	0.9
Iowa 1	9.9	16.7	26.6	12.1	13.2	7.8	4.4	2.1	1.4	0.9	0.7	4.2
Ky. 1		11.7	25.4	12.6	18.5	13.5	10.0	5.5	1.4	0.5	0.2	0.7
Ky. 2		4.1	26.1	19.9	25.2	15.7	5.7	1.6	0.6	0.3	0.1	0.7
Ky. 3		20.8	37.5	16.1	16.0	6.2	1.3	0.8	0.4	0.3	0.2	0.4
Ky. 4			30.5	21.7	23.4	12.2	5.5	4.5	2.0	0.2	0.0	0.0
Ky. 5		2.0	20.9	15.0	22.0	12.8	5.6	4.4	3.6	2.5	2.0	9.2
Mo. 1		6.6	32.7	16.5	16.5	11.1	7.2	4.5	2.1	0.9	0.5	1.4
Mo. 2		41.2	40.7	8.9	4.1	1.0	0.6	0.5	0.4	0.3	0.3	2.0
Ohio 1	4.0	20.0	34.8	13.7	11.7	4.1	2.3	1.9	1.5	1.1	0.9	4.0
W. Va. 1	5.8	33.2	42.7	7.3	3.0	1.3	0.8	0.7	0.7	0.5	0.5	3.5
W. Va. 2			9.3	18.0	29.5	18.8	9.2	3.6	2.5	1.6	1.2	6.3
W. Va. 3			13.0	29.4	33.1	13.8	3.7	1.4	1.2	0.8	0.6	3.0
W. Va. 4			19.6	24.7	31.4	12.1	3.1	1.9	1.6	1.1	0.8	3.7
Wyo. 1	12.2	50.0	23.1	4.8	3.6	1.6	0.8	0.6	0.5	0.4	0.3	2.1

[a] Square openings in inches. [b] Tyler mesh series.

Table 8.—Proximate Analyses of Coals

Sample No.	Proximate Analysis													
	As Fired				Moisture Free			Moisture and Ash Free		Dry Mineral Matter Free		Moist Mineral Matter Free		
	Moisture, %	Ash, %	Volatile Matter, %	Fixed Carbon, %	Ash, %	Volatile Matter, %	Fixed Carbon, %	Volatile Matter, %	Fixed Carbon, %	Volatile Matter, %	Fixed Carbon, %	Moisture, %	Volatile Matter, %	Fixed Carbon, %
Ill. 1	11.5	6.6	37.8	44.1	7.5	42.7	49.8	46.2	53.8	45.5	54.5	12.5	39.8	47.7
Ill. 2	9.9	5.4	38.0	46.7	6.0	42.2	51.8	44.9	55.1	44.3	55.7	10.6	39.5	49.9
Ill. 3	9.2	7.6	32.7	50.5	8.4	36.0	55.6	39.3	60.7	38.7	61.3	10.1	34.8	55.1
Ill. 4	16.0	9.4	34.8	39.8	11.2	41.4	47.4	46.7	53.3	45.6	54.4	18 1	37.4	44.5
Ill. 5	12.7	7.0	36.9	43.4	8.0	42.3	49.7	46.0	54.0	45.2	54.8	13.9	38.9	47.2
Ill. 6	10.6	9.0	39.6	40.8	10.0	44.3	45.7	49.2	50.8	48.3	51.7	12.0	42.5	45.5
Ill. 7	9.8	12.3	33.3	44.6	13.6	37.0	49.4	42.8	57.2	41.3	58.7	11.6	36.4	52.0
Ill. 8	5.3	9.6	36.7	48.4	10.1	38.8	51.1	43.2	56.8	42.1	57.9	6.0	39.5	54.5
Ill. 9	5.6	9.4	33.4	51.6	9.9	35.4	54.7	39.3	60.7	38.3	61.7	6.3	35.9	57.8
Ill. 10	9.3	9.6	36.6	44.5	10.5	40.4	49.1	45.2	54.8	44.0	56.0	10.6	39.3	50.1
Ill. 11	7.8	9.4	36.7	46.1	10.2	39.8	50.0	44.3	55.7	43.3	56.7	8.8	39.5	51.7
Ill. 12	12.0	9.2	36.2	42.6	10.4	41.1	48.5	45.9	54.1	44.8	55.2	13.6	38.8	47.6
Ill. 13	10.2	9.1	39.0	41.7	10.2	43.4	46.4	48.3	51.7	47.3	52.7	11.5	41.9	46.6
Ark. 1R														
Ark. 1W	1.5	7.0	17.3	74.2	7.1	17.6	75.3	19.0	81.0	18.12	81.88	1.63	17.79	80.58
Ark. 2R	2.5	13.9	12.0	71.6	14.2	12.3	73.5	14.4	85.6	11.9	88.1	3.0	11.6	85.4
Ark. 2W	2.1	6.6			6.8									
Ark. 3R	1.8	8.7			8.8									
Ark. 3W	1.7	6.8	19.7	71.8	7.0	20.1	72.9	21.6	78.4	20.88	79.12	1.84	20.42	77.74
Ark. 4R	1.2	18.1			18.3									
Ark. 4W	1.3	10.5	17.6	70.6	10.7	17.8	71.5	20.0	80.0	18.34	81.66	1.49	18.10	80.41
Ind. 1	13.6	6.2	29.8	50.4	7.2	34.5	58.3	37.2	62.8	36.6	63.4	14.6	31.2	54.2
Ind. 2	7.5	8.6	41.1	42.8	9.3	44.4	46.3	49.0	51.0	47.9	52.1	8.5	43.9	47.6
Ind. 3	10.1	13.7	33.7	42.5	15.2	37.4	47.4	44.2	55.8	42.9	57.1	12.0	37.8	50.2
Ind. 4	11.2	11.0	39.9	37.9	12.4	44.9	42.7	51.3	48.7	50.1	49.9	13.0	43.6	43.4
Ind. 5	13.2	11.7	33.0	42.1	13.5	38.1	48.4	44.0	56.0	43.2	56.8	15.2	36.5	48.3
Ind. 6	7.7	13.2	35.9	43.2	14.2	38.9	46.9	45.4	54.6	44.0	56.0	9.2	40.0	50.8
Ind. 7	9.6	8.0	36.3	46.1	8.9	40.1	51.0	44.0	56.0	43.4	56.6	10.6	38.8	50.6
Iowa 1	14.0	16.4	34.1	35.5	19.0	39.7	41.3	49.0	51.0	47.2	52.8	17.5	38.9	43.6
Ky. 1	2.5	4.6	37.7	55.2	4.8	38.6	56.6	40.6	59.4	40.2	59.8	2.6	39.1	58.3
Ky. 2	3.5	4.1	38.1	54.3	4.3	39.5	56.2	41.2	58.8	40.9	59.1	3.7	39.3	57.0
Ky. 3	7.5	5.4	40.6	46.5	5.8	43.9	50.3	46.6	53.4	45.9	54.1	8.1	42.1	49.8
Ky. 4	9.9	3.6	38.7	47.8	4.0	43.0	53.0	44.8	55.2	44.3	55.7	10.4	39.7	49.9
Ky. 5	3.0	7.3	35.1	54.6	7.5	36.2	56.3	39.1	60.9	38.6	61.4	3.3	37.3	59.4
Mo. 1	13.0	8.2	38.3	40.5	9.4	44.0	46.6	48.6	51.4	47.4	52.6	14.6	40.5	44.9
Mo. 2	9.6	5.8	42.0	42.6	6.4	46.4	47.2	49.6	50.4	48.6	51.4	10.5	43.6	45.9
Ohio 1	7.0	10.9	36.8	45.3	11.7	39.6	48.7	44.8	55.2	43.7	56 3	8.1	40.2	51.7
W. Va. 1	1.5	7.5	40.3	50.7	7.7	40.9	51.4	44.3	55.7	43.4	56.6	1.7	42.7	55.6
W. Va. 2	1.2	8.7	18.6	71.5	8.8	18.9	72.3	20.7	79.3	19.9	80.1	1.3	19.5	79.2
W. Va. 3	2.0	7.5	15.1	75.4	7.6	15.4	77.0	16.7	83.3	15.9	84.1	2.2	15.6	82.2
W. Va. 4	2.0	5.5	28.7	63.8	5.6	29.3	65.1	31.0	69.0	30.5	69.5	2.1	29.9	68.0
Wyo. 1	20.9	5.1	38.4	35.6	6.5	48.5	45.0	51.9	48.1	51.5	48.5	22.2	40.1	37.7

Table 9.—Ultimate Analyses of Coals

Sample No.	Ultimate Analysis																
	As Fired						Moisture Free						Moisture and Ash Free				
	Hydrogen, %	Carbon, %	Nitrogen, %	Oxygen, %	Sulfur, %	Ash, %	Hydrogen, %	Carbon, %	Nitrogen, %	Oxygen, %	Sulfur, %	Ash, %	Hydrogen, %	Carbon, %	Nitrogen, %	Oxygen, %	Sulfur, %
Ill. 1	5.89	65.68	1.60	18.42	1.80	6.61	5.22	74.23	1.80	9.25	2.03	7.47	5.64	80.23	1.95	9.99	2.19
Ill. 2	5.77	68.04	1.30	17.58	1.86	5.45	5.18	75.51	1.45	9.74	2.07	6.05	5.51	80.37	1.54	10.38	2.20
Ill. 3	5.42	67.87	1.61	16.60	0.88	7.62	4.85	74.77	1.78	9.24	0.97	8.39	5.29	81.62	1.94	10.09	1.06
Ill. 4	5.88	59.93	1.17	21.16	2.49	9.37	4.90	71.28	1.39	8.33	2.96	11.14	5.52	80.22	1.57	9.36	3.33
Ill. 5	5.81	64.05	1.32	19.48	2.34	7.00	5.04	73.35	1.51	9.40	2.68	8.02	5.48	79.74	1.64	10.23	2.91
Ill. 6	5.75	63.83	1.33	17.24	2.89	8.96	5.12	71.42	1.49	8.72	3.23	10.02	5.69	79.37	1.65	9.70	3.59
Ill. 7	5.39	61.02	1.22	16.42	3.67	12.28	4.77	67.72	1.35	8.45	4.08	13.63	5.53	78.40	1.57	9.78	4.72
Ill. 8	5.32	69.03	1.59	11.69	2.82	9.55	4.99	72.90	1.67	7.37	2.98	10.09	5.55	81.08	1.86	8.19	3.32
Ill. 9	5.23	69.82	1.78	11.84	2.00	9.33	4.88	74.00	1.88	7.23	2.12	9.89	5.41	82.12	2.09	8.02	2.36
Ill. 10	5.45	63.97	1.32	16.60	3.07	9.59	4.87	70.54	1.46	9.17	3.39	10.57	5.44	78.88	1.63	10.26	3.79
Ill. 11	5.50	67.35	1.39	13.77	2.62	9.37	5.03	72.99	1.50	7.49	2.84	10.15	5.60	81.24	1.67	8.33	3.16
Ill. 12	5.75	61.03	1.04	20.16	2.87	9.15	5.02	69.37	1.18	10.77	3.26	10.40	5.60	77.42	1.32	12.02	3.64
Ill. 13	5.71	63.74	1.26	17.07	3.10	9.12	5.09	71.04	1.40	8.84	3.46	10.17	5.67	79.08	1.56	9.84	3.85
Ark. 1R																	
Ark. 1W	4.51	82.35	2.11	2.98	0.99	7.06	4.41	83.62	2.14	1.66	1.01	7.16	4.75	90.07	2.31	1.79	1.08
Ark. 2R	3.73	74.77	1.48	3.09	3.05	13.88	3.54	76.68	1.51	0.90	3.13	14.24	4.13	89.40	1.76	1.06	3.65
Ark. 2W																	
Ark. 3R																	
Ark. 3W	4.43	83.12	1.89	2.92	0.82	6.82	4.31	84.55	1.93	1.42	0.84	6.95	4.64	90.87	2.07	1.52	0.90
Ark. 4R																	
Ark. 4W	4.27	79.78	1.70	1.37	2.38	10.50	4.18	80.83	1.72	0.23	2.41	10.63	4.67	90.38	1.93	0.33	2.69
Ind. 1	6.01	66.18	1.57	19.45	0.65	6.14	5.20	76.57	1.81	8.56	0.75	7.11	5.60	82.43	1.95	9.22	0.80
Ind. 2	5.71	67.38	1.35	13.31	3.61	8.64	5.28	72.83	1.46	7.19	3.90	9.34	5.82	80.29	1.61	7.98	4.30
Ind 3	5.39	61.81	1.34	15.93	1.87	13.66	4.74	68.76	1.49	7.73	2.08	15.20	5.59	81.08	1.76	9.12	2.45
Ind. 4	5.82	61.52	1.28	16.81	3.57	11.00	5.15	69.28	1.44	7.72	4.02	12.39	5.88	79.08	1.65	8.80	4.59
Ind. 5	5.55	61.01	1.31	19.70	0.78	11.65	4.73	70.00	1.50	9.51	0.90	13.36	5.46	80.80	1.73	10.97	1.04
Ind. 6	5.34	63.53	1.32	13.76	2.89	13.16	4.86	68.80	1.42	7.54	3.13	14.25	5.67	80.24	1.66	8.78	3.65
Ind. 7	5.65	66.56	1.49	17.22	1.09	7.99	5.07	73.61	1.64	9.63	1.21	8.84	5.56	80.74	1.80	10.58	1.32
Iowa 1	5.48	54.36	1.14	18.46	4.21	16.35	4.56	63.18	1.33	7.04	4.89	19.00	5.63	78.00	1.64	8.69	6.04
Ky. 1	5.46	78.21	1.63	9.32	0.70	4.68	5.32	80.24	1.67	7.25	0.72	4.80	5.58	84.28	1.76	7.62	0.76
Ky. 2	5.45	77.09	1.69	10.66	0.96	4.15	5.25	79.85	1.75	7.85	1.00	4.30	5.48	83.44	1.83	8.21	1.04
Ky. 3	5.72	70.00	1.47	14.66	2.84	5.31	5.29	75.62	1.59	8.70	3.07	5.73	5.61	80.21	1.69	9.23	3.26
Ky. 4	5.80	70.13	1.77	17.03	1.65	3.62	5.20	78.04	1.96	8.93	1.84	4.03	5.42	81.32	2.05	9.30	1.91
Ky. 5	5.18	75.78	1.63	9.39	0.76	7.26	5.00	78.07	1.68	6.99	0.78	7.48	5.40	84.39	1.82	7.55	0.84
Mo. 1	5.70	61.97	1.14	19.12	3.91	8.16	4.90	71.10	1.31	8.83	4.50	9.36	5.40	78.45	1.45	9.74	4.96
Mo. 2	5.84	66.14	1.18	16.66	4.39	5.79	5.29	73.12	1.30	9.04	4.85	6.40	5.65	78.12	1.39	9.66	5.18
Ohio 1	5.26	65.50	1.41	14.23	2.69	10.91	4.82	70.43	1.51	8.62	2.89	11.73	5.46	79.79	1.71	9.77	3.27
W. Va. 1	5.50	76.33	1.56	6.14	2.89	7.58	5.41	77.48	1.58	4.91	2.93	7.69	5.86	83.94	1.71	5.32	3.17
W. Va. 2	4.36	81.07	1.56	3.56	0.71	8.74	4.27	82.06	1.58	2.52	0.72	8.85	4.68	90.02	1.73	2.78	0.79
W. Va. 3	4.21	82.61	1.27	3.94	0.50	7.47	4.07	84.29	1.29	2.22	0.51	7.62	4.41	91.25	1.40	2.39	0.55
W. Va. 4	5.11	80.90	1.60	6.05	0.78	5.56	4.98	82.75	1.63	4.16	0.79	5.69	5.28	87.74	1.73	4.41	0.84
Wyo. 1	6.22	55.18	1.33	31.58	0.52	5.17	4.92	69.78	1.68	16.42	0.66	6.54	5.27	74.66	1.80	17.56	0.71

Table 10.—Heating Values and Sulfur Varieties

Sample No.	Heating Value, B.T.U. per lb.					Sulfur Varieties								
						As Fired			Moisture Free			Moisture and Ash Free		
	As Fired	Moist Free	Moist and Ash Free	Unit Coal Dry	Unit Coal Moist	Sulfate	Pyritic	Organic	Sulfate	Pyritic	Organic	Sulfate	Pyritic	Organic
Ill. 1	11901	13444	14530	14698	12855	.11	.82	.87	.12	.92	.99	.13	1.00	1.06
Ill. 2	12210	13546	14415	14551	13008	.05	1.05	.76	.05	1.16	.86	.06	1.24	.90
Ill. 3	11953	13162	14372	14506	13042	.02	.39	.47	.02	.43	.52	.02	.47	.57
Ill. 4	10760	12803	14415	14669	12020	.08	.85	1.56	.09	1.02	1.85	.10	1.14	2.10
Ill. 5	11561	13239	14395	14579	12555	.12	.74	1.48	.14	.85	1.69	.15	.92	1.84
Ill. 6	11515	12881	14315	14550	12820	.07	1.11	1.71	.07	1.24	1.92	.08	1.38	2.13
Ill. 7	11047	12253	14186	14505	12826	.05	1.70	1.92	.05	1.89	2.14	.06	2.19	2.47
Ill. 8	12599	13308	14806	15047	14144	.03	1.47	1.32	.03	1.55	1.40	.03	1.73	1.56
Ill. 9	12420	13159	14611	14809	13882	.05	1.18	.77	.05	1.25	.82	.06	1.39	.91
Ill. 10	11547	12730	14230	14471	12956	.03	1.32	1.72	.03	1.46	1.90	.03	1.63	2.13
Ill. 11	12038	13050	14530	14765	13468	.03	1.08	1.51	.03	1.17	1.64	.03	1.31	1.82
Ill. 12	10971	12470	13924	14149	12237	.20	1.22	1.45	.23	1.39	1.64	.25	1.55	1.84
Ill. 13	11529	12845	14301	14552	12858	.02	1.17	19.91	.02	1.30	2.14	.02	1.45	2.38
Ark. 1R														
Ark. 1W	14149	14364	15469	15596	15343	.02	.29	.68	.02	.29	.69	.03	.31	.74
Ark. 2R	12718	13042	15206	15536	15081	.14	1.99	.92	.14	2.04	.95	.16	2.38	1.11
Ark. 2W														
Ark. 3R														
Ark. 3W	14123	14366	15440	15573	15272	.02	.14	.66	.02	.14	.68	.02	.15	.73
Ark. 4R														
Ark. 4W	13688	13868	15525	15780	15534	.08	1.59	.71	.08	1.61	.72	.09	1.80	.80
Ind. 1	11785	13632	14683	14807	12645	.00	.07	.58	.00	.08	.67	.00	.09	.71
Ind. 2	12260	13252	14610	14270	13615	.05	1.72	1.84	.05	1.86	1.99	.06	2.05	2.19
Ind. 3	11057	12304	14510	14803	13025	.03	1.17	.67	.03	1.31	.74	.04	1.54	.87
Ind. 4	11238	12662	14449	14764	12836	.73	2.10	.74	.82	2.36	.84	.94	2.69	.96
Ind. 5	10936	12606	14567	14792	12535	.04	.43	.31	.04	.50	.36	.05	.58	.41
Ind. 6	11170	12096	14105	14395	13102	.27	1.52	1.10	.29	1.64	1.20	.34	1.91	1.40
Ind. 7	11839	13093	14365	14526	12984	.08	.55	.46	.09	.61	.51	.09	.67	.56
Iowa 1	9864	11467	14161	14615	12071	.21	3.29	.71	.24	3.83	.82	.30	4.72	1.02
Ky. 1	13998	14355	15073	15165	14754	.00	.14	.56	.00	.14	.58	.00	.15	.61
Ky. 2	13872	14370	15012	15104	14545	.01	.34	.61	.01	.36	.63	.01	.37	.66
Ky. 3	12771	13801	14648	14826	13637	.06	1.03	1.75	.06	1.12	1.89	.07	1.18	2.01
Ky. 4	12548	13925	14508	14612	13094	.10	.79	.76	.11	.88	.85	.12	.91	.88
Ky. 5	13465	13878	15004	15130	14642	.01	.17	.58	.01	.17	.60	.01	.19	.64
Mo. 1	11292	12986	14331	14606	12469	.24	2.21	1.46	.28	2.55	1.67	.31	2.81	1.84
Mo. 2	12187	13479	14402	14639	13104	.32	1.70	2.37	.35	1.88	2.62	.38	2.01	2.79
Ohio 1	11739	12619	14292	14544	13377	.07	1.84	.78	.07	1.98	.84	.08	2.24	.95
W. Va. 1	13887	14098	15266	15490	15217	.01	1.11	1.77	.01	1.13	1.79	.01	1.22	1.94
W. Va. 2	14256	14429	15827	15974	15764	.00	.15	.56	.00	.15	.57	.00	.16	.63
W. Va. 3	14224	14514	15711	15833	15498	.00	.05	.45	.00	.05	.46	.00	.05	.50
W. Va. 4	14473	14768	15649	15749	15416	.00	.02	.76	.00	.02	.77	.00	.02	.82
Wyo. 1	9553	12076	12917	13003	10114	.01	.14	.37	.01	.18	.47	.01	.20	.50

Table 11.—Ash Fusion Temperatures, Gieseler Plasticity, Free-Swelling Index and Ash Analyses

Sample No.	Ash Fusion Temperatures			Gieseler Plasticity					Free-Swelling Index	Ash Analysis						
	Initial Deformation °F	Softening, °F	Fluid, °F	Softening Temp. °C	Fusion Temp. °C	Maximum Fluidity °C	Solidification Temp. °C	Max. Fluidity Div. per Minute		SiO_2, %	$Al\ O_3$, %	Fe_2O_3, %	MgO, %	CaO, %	SO_3, %	Ignition Loss %
Ill. 1	1942	2197	2357	362	414	429	460	11.9	4.0							
Ill. 2	2026	2107	2149		NO	PLA	STIC	ITY	3.0	32.73	18.28	28.47	.89	8.46	7.42	.35
Ill. 3	2182	2264	2311	400		416	455	1.5	3.0	49.64	22.75	8.91	1.04	8.17	5.94	.65
Ill. 4	2039	2105	2169	369		409	446	2.4	3.5	48.38	15.62	12.89	.73	10.19	10.74	1.46
Ill. 5	1980	2105	2254	372		403	450	2.5	3.5	48.20	25.33	17.92	1.23	1.74	1.12	.86
Ill. 6	2079	2156	2205	356	418	425	452	6.8	2.5	48.23	20.98	17.33	.58	4.55	4.44	−.02
Ill. 7	2032	2109	2140		NO	PLA	STIC	ITY	3.5	44.25	19.04	19.01	.54	5.19	5.40	2.13
Ill. 8	2064	2265	2304	388	415	436	477	164	5.0	48.14	24.12	21.01	.49	1.22	.87	1.16
Ill. 9	2055	2165	2304	405		445	468	3.8	5.0							
Ill. 10	2070	2140	2181	379		423	447	3.2	4.0							
Ill. 11	2090	2146	2195	380	408	434	466	145	5.0							
Ill. 12	1993	2113	2195		NO	PLA	STIC	ITY	1.0							
Ill. 13	2009	2162	2220	333	401	420	457	54	3.0							
Ark. 1R																
Ark. 1W	1938	2083	2245	454		485	515	3.9	8.5							
Ark. 2R	2082	2284	2380		NO	PLA	STIC	ITY	1 0							
Ark. 2W																
Ark. 3R																
Ark. 3W	1892	1971	1998	461		469	505	1.7	8.0							
Ark. 4R																
Ark. 4W	1933	2021	2156	461		492	516	3.9	8.0							
Ind. 1	2328	2552	2600+		NO	PLA	STIC	ITY	4.5	48.76	33.84	5.40	.80	3.03	1.85	1.68
Ind. 2	2016	2144	2256	321	389	426	463	2143	5.5	40.13	24.05	25.84	.44	3.03	3.07	1.20
Ind. 3	2060	2204	2380	383	415	430	461	9.0	5.0	51.19	23.32	13.66	.95	3.17	3.37	1.69
Ind. 4	1988	2062	2102	358	412	431	462	25.5	2.0	28.43	16.56	35.86	.71	8.93	6.74	1.62
Ind. 5	2220	2456	2546	393		425	459	4.5	2.5	51.96	25.38	18.07	.96	.64	.31	.00
Ind. 6	2030	2126	2341	385		413	457	3.0	3.5	52.59	21.42	20.07	1.25	.52	.45	.76
Ind. 7	2102	2459	2532	380		413	458	3.7	3.5	56.18	25.72	11.62	1.32	.55	.14	.14
Iowa 1	2001	2075	2105	388		412	449	2.1	1.0							
Ky. 1	2103	2215	2351	397	421	444	472	620	3.5	43.34	26.25	12.63	2.01	4.80	5.47	3.47
Ky. 2	2228	2600+	2600+	433	456	462	494	22	4.5							
Ky. 3	1996	2080	2158	360	401	427	462	155	3.5	41.05	22.41	26.69	.67	2.91	2.67	.82
Ky. 4	1952	2074	2248	390		427	457	2.3	5.0	35.97	21.68	35.85	.91	1.78	.35	.72
Ky. 5	2375	2600+	2600+	403	425	447	475	74	5.5							
Mo. 1	1949	2011	2072	365		405	454	3.2	2.0	38.34	16.78	40.11	.87	.75	.75	.81
Mo. 2	1965	2018	2064	366	422	428	456	6.2	2.5	31.86	13.31	42.10	.88	5.14	5.19	−.14
Ohio 1	2039	2144	2238	406		422	455	0.8	2.0							
W. Va. 1	2062	2197	2245	345	388	420	495	6000	6.5	39.22	23.51	17.17	1.49	7.03	9.46	4.49
W. Va. 2	2600+	2600+	2600+	447	468	490	519	23.0	8.0							
W. Va. 3	2286	2338	2399	467		500	523	4.4	6.5							
W. Va. 4	2388	2600+	2600+	394	416	444	499	1957	8.0							
Wyo. 1	1981	2064	2103		NO	PLA	STIC	ITY	0	31.68	18.60	8.64	6.01	13.56	16.52	3.01

TABLE 12.—COMBUSTION DATA

Sample No.	HEAT OBTAINED: M B. T. U. per Hour[a]	HEAT OBTAINED: M B. T. U. per Lb.	UNIFORMITY: Ave. Var. %	UNIFORMITY: Minimum ÷ Average	RESPONSIVENESS: M B. T. U. First 30 Min.	RESPONSIVENESS: Ratio	RESPONSIVENESS: M B. T. U. First Hour	PICKUP: M B. T. U.	PICKUP: Ratio	OVERRUN: M B. T. U.	OVERRUN: Ratio	Heat Obtained ÷ % Ash	Windbox Pressure In. of H_2O	CO_2, %
Ill. 1	163	7.02	5.7	.86	14.9	.18	91.6	37.2	.23	72.8	.45	1.06	0.77	10.7
Ill. 2	164	7.44	3.4	.92	28.4	.35	103.8	43.6	.27	84.1	.51	1.38	0.58	10.0
Ill. 3	188	7.95	6.3	.81	19.5	.21	84.6	38.8	.21	82.5	.44	1.05	0.57	13.0
Ill. 4	150	6.52	13.5	.68	17.6	.24	57.2	31.2	.21	71.3	.48	.69	0.56	9.2
Ill. 5	165	7.37	4.9	.86	14.9	.18	70.8	34.7	.21	74.6	.45	1.05	0.50	10.3
Ill. 6	154	6.90	8.9	.80	17.6	.23	83.4	33.0	.21	67.5	.44	.77	0.74	11.1
Ill. 7	172	6.70	9.8	.77	18.2	.21	74.8	37.6	.22	74.9	.44	.54	0.98	12.7
Ill. 8	186	8.00	11.9	.66	8.4	.09	31.4	40.1	.22	82.9	.45	.83	0.89	13.7
Ill. 9	192	7.97	8.0	.80	19.8	.21	84.6	40.7	.21	89.2	.47	.85	0.86	13.4
Ill. 10	179	7.16	11.8	.78	19.9	.22	83.6	38.8	.22	80.7	.45	.74	0.73	13.0
Ill. 11	188	7.68	10.5	.77	13.2	.14	43.2	41.8	.22	80.3	.43	.82	0.77	13.8
Ill. 12	166	6.83	7.3	.78	23.2	.28	109.5	41.6	.25	86.1	.52	.74	1.02	12.2
Ill. 13	164	6.99	13.0	.63	17.6	.22	75.7	42.2	.26	77.0	.47	.77	0.92	11.5
Ark. 1R	Fire	could	not b	e main	tained	withou	t man	ual at	tentio	n				
Ark. 1W	251	9.57	4.6	.86	[c]	[c]	[c]	60.0	.24	120.5	.48	1.37	0.89	14.1
Ark. 2R	Fire	could	not b	e main	tained	withou	t man	ual at	tentio	n				
Ark. 2W	Fire	could	not b	e main	tained	withou	t man	ual at	tentio	n				
Ark. 3R	243	9.57	4.7	.88	47.6	.39	131.1	59.7	.25	113.2	.47	1.10	0.81	13.7
Ark. 3W	243	9.67	4.1	.90	32.5	.27	120.9	69.4	.29	116.4	.48	1.42	0.82	13.6
Ark. 4R	214	8.69[b]	5.9	.83	27.1	.25	115.4	57.0	.26	111.6	.51	.48	1.07	12.3
Ark. 4W	236	9.41	5.3	.89	32.7	.28	112.9	54.8	.23	109.1	.46	.90	0.97	13.0
Ind. 1	150	6.87	4.6	.89	18.3	.24	78.3	32.9	.22	69.6	.46	1.11	0.60	9.8
Ind. 2	162	6.95	9.4	.76	11.3	.14	40.6	36.1	.22	62.4	.38	.81	0.81	10.1
Ind. 3	147	6.26	11.8	.72	9.3	.13	45.6	34.2	.23	62.8	.43	.46	1.00	9.6
Ind. 4	132	5.89	8.7	.83	9.3	.14	37.0	26.5	.20	52.5	.40	.54	0.74	
Ind. 5	147	6.95	5.7	.84	16.9	.23	76.1	32.8	.22	72.8	.50	.59	0.93	10.5
Ind. 6	162	6.92	12.5	.69	26.2	.32	102.3	37.4	.23	84.7	.52	.52	1.00	
Ind. 7	168	7.25	6.0	.86	28.2	.34	110.0	42.0	.25	91.0	.54	.91	0.81	9.7
Iowa 1	127	5.85	6.9	.85	16.0	.25	64.5	29.3	.23	61.7	.48	.36	0.76	9.9
Ky. 1	208	8.96	7.2	.79	15.2	.15	73.2	40.3	.19	89.5	.43	1.95	0.51	13.4
Ky. 2	206	8.92	6.7	.84	18.4	.18	96.7	49.7	.24	88.4	.43	2.18	0.70	11.5
Ky. 3	165	7.74	10.5	.71	12.1	.15	32.2	39.8	.24	63.2	.38	1.43	0.65	9.5
Ky. 4	174	8.07	6.3	.88	15.0	.17	85.0	37.2	.21	74.6	.43	2.24	0.50	11.0
Ky. 5	202	8.23	7.2	.80	13.8	.14	89.2	41.0	.20	92.9	.46	1.13	1.03	
Mo. 1	154	6.95	12.1	.77	17.9	.23	50.8	37.0	.24	70.8	.46	.85	0.76	9.5
Mo. 2	147	7.25	8.0	.84	15.9	.22	57.6	31.0	.21	62.4	.42	1.25	0.65	8.6
Ohio 1	166	7.39	6.8	.79	14.2	.17	57.7	33.7	.20	72.3	.44	.68	0.72	13.2
W. Va. 1	176	8.12	16.9	.54	[c]	[c]	[c]	40.1	.23	66.0	.37	1.08	1.06	10.7
W. Va. 2	235	9.09	5.6	.84	21.6	.18	114.6	54.9	.23	112.8	.48	1.04	1.13	13.3
W. Va. 3	238	9.50	5.2	.88	28.4	.24	115.7	52.0	.22	113.7	.48	1.27	0.74	13.2
W. Va. 4	223	9.11	7.1	.83	13.9	.13	86.5	51.3	.23	98.5	.44	1.66	0.80	12.6
Wyo. 1	126	6.36	3.1	.93	22.1	.35	86.3	34.7	.28	61.7	.49	1.25	0.49	10.6

[a] With continuous stoker operation. [b] Only two rates of stoker operation. [c] Fire not maintained.

Table 13.—Clinker and Fly-Ash Data, and Coal-Burning Rates

Sample No.	Clinker Rating	Specific Gr. of Clinker		Porosity of Clinker %	Clinker Shatter Index	Clinker Ash Ratio	Fly Ash			Coal Burned, Lb. per Hr.			
		Apparent	True				Lbs.	% of Ash	% of Coal	60[a]	45[a]	30[a]	15[a]
Ill. 1	3	1.33	2.79	52	50	0.53	1.5	1.9	.12	22.4	17.7	11.5	5.6
Ill. 2	3	1.91	3.16	40	69	0.57	1.0	1.6	.08	22.1	16.6	11.0	5.6
Ill. 3	3	1.25	2.72	54	49	0.65	1.0	1.2	.08	23.3	17.1	11.3	5.8
Ill. 4	3	2.13	2.78	23	47	0.73	1.5	1.4	.12	22.6	17.0	11.5	5.9
Ill. 5	4	1.25	2.78	55	50	0.61	1.5	1.8	.12	22.3	16.9	11.3	5.6
Ill. 6	3	1.29	2.78	53	56	0.61	1.5	1.5	.13	21.6	16.5	11.2	5.6
Ill. 7	2	1.52	2.88	47	51	0.65	1.5	1.0	.11	24.7	18.6	12.3	6.5
Ill. 8	2	1.37	2.83	52	68	0.35	2.0	1.7	.15	22.8	16.4	12.2	6.0
Ill. 9	3	1.20	2.79	57	55	0.64	2.0	1.8	.15	23.5	17.8	12.1	6.0
Ill. 10	3−	1.32	2.83	53	52	0.66	1.5	1.2	.11	24.9	18.2	12.3	6.1
Ill. 11	3	1.23	2.80	56	52	0.69	2.0	1.8	.16	23.6	17.5	11.4	5.8
Ill. 12	3	1.41	2.88	51	49	0.68	2.5	2.0	.19	23.6	18.0	12.2	6.2
Ill. 13	3−	1.24	2.68	54	48	0.65	2.0	1.8	.16	22.9	18.1	12.3	6.1
Ark. 1R	0												
Ark. 1W	3	2.09				0.60	4.0	4.6	.29	26.5	19.2	12.8	6.3
Ark. 2R	0												
Ark. 2W	0												
Ark. 3R	2					0.47	2.5	2.5	.19	25.2	18.6	12.7	6.3
Ark. 3W	3					0.38	5.0	7.3	.38	24.8	18.4	12.4	6.2
Ark. 4R	2	1.63								25.1			6.4
Ark. 4W	3	2.07				0.22	5.5	5.1	.42	24.9	18.4	12.4	6.0
Ind. 1	4	0.92	2.62	65	65	0.62	1.0	1.5	.09	21.4	16.4	11.0	5.5
Ind. 2	3	1.56	2.93	47	69	0.59	2.5	2.4	.21	22.4	16.6	11.3	5.5
Ind. 3	3	1.25	2.70	54	49	0.63	2.0	1.3	.16	23.0	17.4	11.7	5.8
Ind. 4	3	1.82	3.37	46	58	0.53	2.5	2.1	.22	20.3	15.7	10.6	5.2
Ind. 5	3	1.32	2.79	53	45	0.55	2.0	1.5	.17	21.2	16.3	10.7	5.3
Ind. 6	2	1.21	2.78	57	54	0.68	2.5	1.5	.19	23.6	18.0	12.1	6.1
Ind. 7	3	.98	2.66	63	44	0.66	2.5	2.5	.20	23.6	17.8	12.0	6.0
Iowa 1	2	2.28	3.34	32	70	0.59	3.0	1.8	.26	21.7	16.8	10.9	5.5
Ky. 1	4+	.98	2.78	65	88	0.44	1.5	3.3	.12	22.7	17.0	11.3	5.6
Ky. 2	4	1.36	2.87	53	72	0.32	2.5	5.0	.20	23.1	17.0	11.5	5.7
Ky. 3	2	1.61	2.83	43	95	0.39	1.5	2.4	.13	20.4	15.9	10.5	5.2
Ky. 4	3	2.03	3.14	35	93	0.36	1.5	3.9	.13	20.9	15.6	10.5	5.1
Ky. 5	2	1.05	2.65	60	58	0.52	3.0	3.4	.23	23.7	18.0	11.5	6.0
Mo. 1	2	1.84	3.23	43	66	0.44	2.5	2.6	.20	21.9	17.2	11.6	5.7
Mo. 2	4	2.94	3.49	16	70	0.33	2.5	4.3	.23	19.6	14.8	10.0	4.9
Ohio 1	3	1.62	3.03	47	58	0.53	2.0	1.6	.17	21.7	16.5	11.0	5.5
W. Va. 1	3	2.06	2.99	31	47	0.26	2.5	2.9	.22	21.1	16.7	11.0	5.3
W. Va. 2	2	1.18	2.68	56	76	0.51	2.5	2.1	.18	25.8	19.4	13.0	6.4
W. Va. 3	4	1.63	2.83	42	70	0.47	3.5	4.0	.15	24.6	18.1	11.7	6.1
W. Va. 4	3	1.16	2.74	58	80	0.42	2.0	2.8	.16	23.8	17.9	11.9	5.9
Wyo. 1	3	1.85	3.04	39	70	0.52	1.0	2.1	.09	19.9	15.1	10.2	5.1

[a] Minutes of stoker operation per hour.

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