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DIVISION OF THE STATE GEOLOGICAL SURVEY M. M. LEIGHTON, Chief URBANA

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

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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

ΒY

ROY J. HELFINSTINE

ARIOUS 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 I1 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.

Acknowledgments

Grateful acknowledgment is made of assistance given by numerous members of the staff, particularly by W. E. Cooper, Technical Assistant in the Coal Division. S. Konzo served as consultant, and his helpful advice is gratefully acknowledged.

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.

EOUIPMENT

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 occa-

 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 com-bustion with laboratory tests and types of fuels. III. Effect of coal size upon combustion characteristics: Illi-nois Geol. Survey Rept. Inv. 133, 47 pp., 1948.

sionally 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 onehalf 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 CO2 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 $2\frac{1}{2}$ 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 stokerboiler 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 onehalf hour at a definite time during each test with a given operation rate.

Th	e chr	onological 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 contin-							
		uous 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.							

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 13/4 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 Ratio= ______ coal fed--- (clinker removed + ash in refuse + fly coal fed into combustion chamber

weighing less than 1/4 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 holdfire period) is the heat output in B.t.u. during the 30 minutes of continuous stoker operation immediately following the holdfire period. The responsiveness ratio is the ratio of heat output during the first 30minute 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 II⁸ 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 \pm 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 ashfree 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 \div (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.

RESULTS



HEATING VALUE, BT.U. PER LB. AS FIRED

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.









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 ashfusion 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 freeswelling 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.

RESULTS



ASH, AS-FIRED BASIS, PERCENT 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.

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FLUID MINUS INITIAL DEFORMATION TEMPERATURE OF ASH 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. 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 30minute 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 ashsoftening 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 smallscale 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 clinkerash 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







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







FREE-SWELLING INDEX 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. 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 Nelson¹¹ 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.

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 outof-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

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.



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

RESULTS



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.

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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, III., 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 ashsoftening 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

DOMESTIC STOKER COMBUSTION

Sample No.		County	State	Seam	
 III.	$ \begin{array}{c} 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 8\\ 9\\ 10\\ 11\\ 12\\ 13\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 6\\ 7\\ 1\\ 2\\ 3\\ 4\\ 5\\ 1\\ 2\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2\\ 1\\ 2.$	Douglas. Grundy. Franklin. Fulton. Knox. Grundy. Christian. Saline. Sa	Illinois Indiana Indiana Indiana Iowa Kentucky Kentucky Kentucky M	No. 7 No. 2 No. 6 No. 5 No. 6 No. 7 No. 6 No. 6 No. 6 No. 6 No. 6 No. 6 Hartshorne Hartshorne Hartshorne Paris IV HII V W Minshall Brazil VI VI VI VI VI VI VI VI VI VI VI VI VI	
W. V W. V Wyo.	a. 3 a. 4 1	McDowell Webster Sheridan	West Virginia. West Virginia. Wyoming	Pocahontas No. 4 Sewell Monarch	

TABLE 1.—Source and Identification of Coals

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

APPENDIX

TABLE 2.—VARIATION IN RATE OF HEAT RELEASE

	COUNTY	CEAN	PERCENT VARIATION				
STATE		SEAM -	0	5	10	15	20
Wyo.	Sheridan	Monarch					
III.	Grundy	No. 2					
Ind.	Vigo	IV					
IH.	Knox	No.6					
₩.Va.	M ^c Dowell	Poca.4					
₩ Va.	Wyoming	Beckley					
Ind.	Clay	Brazil	ala san fisi				
Ind.	Greene	VII					
III.	Franklin	No.6					
Ку	Hopkins	No.6					
Ку.	Perry	Hazard 4					
Iowa	Dallas	Third					
W.Va.	Webster	Sewell					
Ky.	Harlan	No.5					
Ky.	Letcher	Elkhorn	Transfer (* 1990)				
III.	Bureau	No.6					
1 11.	Saline	No.5					
Mo.	Macon	Mulky					
Ind.	Fountain	Minshall		an a			
III. ⁶	Grundy	No.7					
Ind.	Vigo	ш			l		
III.	Christian	No.6					
III.	Jackson	No.6					
Ky.	Hopkins	No.11					
III	Randolph	No 6					
Ind.	Gibson	V			ter and the second		
III.	Saline	No.6					
Mo.	Randolph	Bevier					
Ind.	Greene	VI					
III.	St.Clair	No 6		1			
I II.	Fulton	No.5					
W.Va.	Marion	Pittsburgh			an da Kanta I.a. ana an	and the second	

DOMESTIC STOKER COMBUSTION

			HEAT OBTAINED, M. B.T.U. PER LB.	
STATE	COUNTY	SEAM	2 4 6 8	10
W.Va.	M ^C Dowell	Poca. 4		
W.Va.	Webster	Sewell		
W. Va.	Wyoming	Beckley		
Ку.	Harlan	No. 5		
Ky.	Perry	Hazard No.4		
Ky.	Letcher	Elkhorn		
W.Va.	Marion	Pittsburgh		
Ky.	Hopkins	No.6		
III.	Saline	No.6		
III.	Saline	No. 5		
I II.	Franklin	No.6		
Ky.	Hopkins	No.11		
III.	Jackson	No.6		
III.	Grundy	No.2		
III.	Knox	No.6		
Ind.	Greene	VII		
Mo.	Macon	Mulky		
III.	Randolph	No.6		
I II.	St. Clair	No.6		
Ind.	Vigo	111		
Ind.	Clay	Brazil		
Mo.	Randolph	Bevier		
Ind.	Greene	VI		
III.	Grundy	No.7		
]nd.	Vigo	IV		
111.	Bureau	No.6		
III.	Christian	No.6		
I II.	Fulton	No.5		
Wyo.	Sheridan	Monarch		
Ind.	Gibson	v		
Ind.	Fountain	Minshall		
Iowa	Dallas	Third		

TABLE 3.—HEAT OBTAINED PER POUND OF COAL

APPENDIX

			HEAT OBTAINED MBTU PER LB. OF ASH					
STATE	COUNTY	SEAM	0	50	100	150	200	250
Ky.	Hopkins	No.6						
Ky.	Perry	Hazard 4			888) y Niji 🛄	and a straight of the straight		
Ку.	Harlan	No. 5				ر. مانگری بیانیندی به ایرون ایرون		
W.Va.	Webster	Sewell			a daga sa karang sa			
Ky.	Hopkins	No.11			Station .			
10	Grundy	No. 2						
W.Va.	M ^C Dowell	Poca. 4						
Wyo.	Sheridan	Monarch						
Mo.	Macon	Mulky		a an	all and the second s			
Ку.	Letcher	Elkhorn			i Andrian Andri			
Ind.	Vigo	IV						
W.Va.	Marion	Pittsburgh						
III	Franklin	No.6		Carlos and C				
I H.	Кпох	No 6						
W.Va.	Wyoming	Beckley	and the second					
Ind.	Greene	VII						
m.	Saline	No. 5		katalah (Katalah (Katalah)				
Mo.	Randolph	Bevier						
10.	Saline	No.6	s policita	a para da producera en este de la com				
I 11.	Jackson	No.6		Maria and Star				
Ind.	Vigo	HI	Statile.					
1 11.	St.Clair	No.6						
10.	Grundy	No.7	San Star					
I II.	Randolph	No.6						
III.	Bureau	No. 6	Version of		1			
1 (1,	Fulton	No.5						
Ind.	Clay	Brazil						
1 11.	Christian	No.6				×		
Ind.	Fountain	Minshall						
Ind.	Greene	VI	800					
Ind.	Gibson	v	6223					
lowa	Dallas	Third	30°503	Magazi				

DOMESTIC STOKER COMBUSTION

	COUNTY	SEAM	RESPONSIVENESS RATIO				
STATE			0	0.10	0.20	030	0.40
III	Grundy	No. 2					 I
Wyo.	Sheridan	Monarch					l
Ind.	Greene	VII					
Ind.	Greene	VI	0.46.0.13				
III	Bureau	No.6					
[owa	Dallas	Third	1 -10-55				
III.	Fulton	No.5					
Ind.	Vigo	IV					
W.Va.	M ^C Dowell	Poca.4					
III.	Grundy	No. 7					
Ind.	Clay	Brazil					
Mo.	Randolph	Bevier					
I II.	Randolph	No.6		ur an			
III.	St.Clair	No.6					
Mo.	Macon	Mulky					
III.	Franklin	No. 6		o			
III.	Christian	No.6	The second second				
] 11.	Saline	No. 5					
m	Knox	No.6		ARNEW FRAME			
КУ.	Perry	Hazard 4					
W.Va.	Wyoming	Beckley					
Ky.	Hopkins	No.6					
Ку.	Harlan	No.5					
Ку.	Hopkins	No.11			1		
I(I.	Jackson	No.6					
Ind.	Vigo	111					
Ind.	Fountain	Minshall					
Ky.	Letcher	Elkhorn	E				
Ind.	Gibson	v					
W.Va.	Webster	Sewell					
111.	Saline	No. 6					
W.Va.	Marion	Pittsburgh					

TABLE 5.—RESPONSIVENESS OF FIRE TO HEAT DEMAND

APPENDIX

TABLE 6.—PICKUP RATIOS

			PICKUP RATIO			
STATE	COUNTY	SEAM	0.15	020	0.25	0.30
Wyo.	Sheridan	Monarch				
III.	Grundy	No. 2				
III.	St.Clair	No.6				
III.	Bureau	No.6				
Ind.	Greene	VII		an a		
Ку.	Perry	Hazard 4	a state			
Ку	Hopkins	No.11				
Mo.	Randolph	Bevier				
Ind.	Gibson	v				
Ind.	Greene	VI				
Iowa	Dallas	Third				
W.Va.	Webster	Sewell		Material March 12, 1970		
W.Va.	Wyoming	Beckley				
₩.Va.	Marion	Pittsburgh				
I II.	Christian	No. 6		Brend Balling and States		
III.	Jackson	No.6				
111.	Randolph	No.6		and the state of the		
IH.	Saline	N 0.6				
Ind.	Vigo	IV				
Ind.	Vigo	111				
Ind.	Clay	Brazil				
₩.Va.	M ^C Dowell	Poca.4		alana anina tan' ka Sana amina amina a		
10.	Franklin	No.6				
1 11.	Saline	No. 5				
I II.	Knox	N 0.6				
I II.	Grundy	NO.7				
Ш.	Fulton	No.5				
Ky.	Hopkins	No.6				
Mo.	Macon	Mulky				
Ind.	Fountain	Minshall				
Ky.	Letcher	Elkhorn				
Ky.	Harlan	No. 5				

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DOMESTIC STOKER COMBUSTION

TABLE	7.—Size	ANALYSES	OF	COALS
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	Sample No.	+1ª	1×34	34×1/2ª	½×½*	$\frac{1}{8}$ ^a $\times 3^{b}$	3×4^{b}	4×6 ^b	6×8 ^b	8×10 ^b	10×14 ^b	14×20 ^b	$20 \times 0^{\rm b}$
III. III. III. III. III. III.	1 2 3 4 5		4.1 3.9 6.3	14.9 29.1 23.4 27.5 51.2	15.5 19.9 15.5 33.1 26.9	21.0 24.5 17.8 27.6 8.3	14.7 13.4 11.1 5.3 1.9	10.8 4.6 8.1 1.8 1.0	9.1 1.7 8.3 1.0 0.7	7.4 0.8 5.6 0.7 0.6	3.9 0.5 2.8 0.5 0.4	$ \begin{array}{r} 1.2 \\ 0.2 \\ 1.8 \\ 0.4 \\ 0.3 \end{array} $	1.5 1.2 1.7 2.1 2.4
III. III. III. III. III. III.	6 7 8 9 10		4.1 7.0	33.0 2.3 44.6 23.2 25.8	17.9 12.0 13.6 26.8 24.8	21.3 19.4 10.8 23.8 30.3	$14.2 \\ 14.7 \\ 6.4 \\ 11.1 \\ 11.8$	$\begin{array}{r} 4.4 \\ 11.9 \\ 4.7 \\ 5.0 \\ 2.7 \end{array}$	1.7 11.8 3.9 3.3 1.4	0.9 10.3 3.2 2.4 0.9	0.5 7.1 1.9 1.5 0.5	$\begin{array}{c} 0.3 \\ 4.3 \\ 1.2 \\ 0.9 \\ 0.3 \end{array}$	1.7 6.2 2.7 2.0 1.5
III. III. III. Ark. Ark.	11 12 13 1R 1W		5.6	20.9 15.3 25.5	33.3 11.4 26.9 5.1 2.4	25.7 15.3 29.4 10.6 28.9	10.5 11.0 10.5 11.9 9.1	3.5 9.1 2.5 13.7 11.6	$2.1 \\ 9.4 \\ 1.3 \\ 14.6 \\ 11.6$	$1.7 \\ 7.6 \\ 0.9 \\ 15.7 \\ 14.1$	$ \begin{array}{c} 1.5 \\ 4.3 \\ 0.6 \\ 13.6 \\ 10.8 \end{array} $	$\begin{array}{c} 0.7 \\ 2.6 \\ 0.4 \\ 5.3 \\ 4.4 \end{array}$	$\begin{array}{c} 0.1 \\ 8.4 \\ 2.0 \\ 9.5 \\ 7.1 \end{array}$
Ark. Ark. Ark. Ark. Ark. Ark.	2R 2W 3R 3W 4R			11.3 5.4 12.6	10.3 8.4 10.4 11.1 10.9	$12.4 \\ 9.1 \\ 14.6 \\ 14.7 \\ 9.9$	15.512.916.315.310.8	11.8 13.2 13.8 13.0 13.9	$12.2 \\ 14.1 \\ 13.8 \\ 12.3 \\ 11.4$	$12.1 \\ 14.6 \\ 13.8 \\ 11.3 \\ 13.8 \\ $	8.0 11.5 9.5 7.9 10.0	2.0 4.3 2.2 3.9 2.4	4.4 6.5 5.6 10.5 4.3
Ark. Ind. Ind. Ind. Ind.	4W 1 2 3 4	3.8 9.9	23.5 15.2 17.0	17.5 44.5 27.8 24.0 32.9	11.8 14.6 28.4 13.7 13.3	14.8 8.5 27.9 20.7 16.0	$13.2 \\ 1.7 \\ 7.4 \\ 14.8 \\ 5.4$	$13.6 \\ 0.8 \\ 3.1 \\ 6.0 \\ 1.8$	$10.8 \\ 0.5 \\ 1.6 \\ 1.8 \\ 0.9$	$9.0 \\ 0.4 \\ 1.0 \\ 0.9 \\ 0.6$	5.0 0.2 0.6 0.5 0.4	$ \begin{array}{r} 1.4 \\ 0.2 \\ 0.4 \\ 0.3 \\ 0.3 \\ 0.3 \end{array} $	2.9 1.3 1.8 2.1 1.5
Ind. Ind. Ind. Iowa Ky.	5 6 7 1 1	9.9	14.0 16.7 11.7	33.9 8.6 10.7 26.6 25.4	15.9 18.2 20.4 12.1 12.6	16.4 23.9 24.5 13.2 18.5	6.9 15.0 13.9 7.8 13.5	3.8 9.7 10.0 4.4 10.0	2.3 8.4 8.4 2.1 5.5	$1.6 \\ 6.9 \\ 6.8 \\ 1.4 \\ 1.4$	1.1 4.4 3.5 0.9 0.5	$0.6 \\ 2.2 \\ 0.9 \\ 0.7 \\ 0.2$	3.5 2.7 0.9 4.2 0.7
Ky. Ky. Ky. Ky. Mo.	2 3 4 5 1		4.1 20.8 2.0 6.6	26.1 37.5 30.5 20.9 32.7	19.9 16.1 21.7 15.0 16.5	25.2 16.0 23.4 22.0 16.5	15.7 6.2 12.2 12.8 11.1	5.7 1.3 5.5 5.6 7.2	$1.6 \\ 0.8 \\ 4.5 \\ 4.4 \\ 4.5$	$0.6 \\ 0.4 \\ 2.0 \\ 3.6 \\ 2.1$	$\begin{array}{c} 0.3 \\ 0.3 \\ 0.2 \\ 2.5 \\ 0.9 \end{array}$	$\begin{array}{c} 0.1 \\ 0.2 \\ 0.0 \\ 2.0 \\ 0.5 \end{array}$	$0.7 \\ 0.4 \\ 0.0 \\ 9.2 \\ 1.4$
Mo. Ohio W. Va W. Va W. Va	2 1 1 2 3	4.0 5.8	41.2 20.0 33.2	40.7 34.8 42.7 9.3 13.0	8.9 13.7 7.3 18.0 29.4	4.1 11.7 3.0 29.5 33.1	1.0 4.1 1.3 18.8 13.8	0.6 2.3 0.8 9.2 3.7	$0.5 \\ 1.9 \\ 0.7 \\ 3.6 \\ 1.4$	$\begin{array}{c} 0.4 \\ 1.5 \\ 0.7 \\ 2.5 \\ 1.2 \end{array}$	$\begin{array}{c} 0.3 \\ 1.1 \\ 0.5 \\ 1.6 \\ 0.8 \end{array}$	$\begin{array}{c} 0.3 \\ 0.9 \\ 0.5 \\ 1.2 \\ 0.6 \end{array}$	2.0 4.0 3.5 6.3 3.0
W. Va Wyo.	. 4 1	12.2	50.0	19.6 23.1	24.7 4.8	31.4 3.6	12.1 1.6	3.1 0.8	1.9 0.6	1.6 0.5	1.1 0.4	0.8 0.3	3.7 2.1

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* Square openings in inches.

^b Tyler mesh series.

APPENDIX

TABLE 8.—PROXIMATE ANALYSES OF COALS

						PROXIMATE ANALYSIS										
Sam	ple		As F	IRED		Мо	STURE F	REE	Moistu Ash	ire and Free	Dry M Mattei	ineral r Free	Moi M.	IST MINE ATTER FI	RAL	
N	0.	Mois- ture, %	Ash, %	Vola- tile Matter, %	Fixed Car- bon, %	Ash, %	Vola- tile Matter, %	Fixed Car- bon, %	Vola- tile Matter, %	Fixed Car- bon, %	Vola- tile Matter, %	Fixed Car- bon, %	Mois- ture, %	Vola- tile Matter, %	Fixed Car- bon, %	
III. III. III. III. III. III.	1 2 3 4 5	$11.5 \\ 9.9 \\ 9.2 \\ 16.0 \\ 12.7$	6.6 5.4 7.6 9.4 7.0	37.8 38.0 32.7 34.8 36.9	$\begin{array}{r} 44.1 \\ 46.7 \\ 50.5 \\ 39.8 \\ 43.4 \end{array}$	7.5 6.0 8.4 11.2 8.0	$\begin{array}{r} 42.7 \\ 42.2 \\ 36.0 \\ 41.4 \\ 42.3 \end{array}$	49.8 51.8 55.6 47.4 49.7	46.2 44.9 39.3 46.7 46.0	53.8 55.1 60.7 53.3 54.0	45.5 44.3 38.7 45.6 45.2	54.5 55.7 61.3 54.4 54.8	12.5 10.6 10.1 18 1 13.9	39.8 39.5 34.8 37.4 38.9	47.7 49.9 55.1 44.5 47.2	
111. 111. 111. 111. 111. 111.	6 7 8 9 10	10.6 9.8 5.3 5.6 9.3	9.0 12.3 9.6 9.4 9.6	39.6 33.3 36.7 33.4 36.6	$\begin{array}{r} 40.8 \\ 44.6 \\ 48.4 \\ 51.6 \\ 44.5 \end{array}$	$10.0 \\ 13.6 \\ 10.1 \\ 9.9 \\ 10.5$	44.3 37.0 38.8 35.4 40.4	45.7 49.4 51.1 54.7 49.1	49.2 42.8 43.2 39.3 45.2	50.8 57.2 56.8 60.7 54.8	$\begin{array}{r} 48.3 \\ 41.3 \\ 42.1 \\ 38.3 \\ 44.0 \end{array}$	51.7 58.7 57.9 61.7 56.0	$12.0 \\ 11.6 \\ 6.0 \\ 6.3 \\ 10.6$	$\begin{array}{r} 42.5\\ 36.4\\ 39.5\\ 35.9\\ 39.3 \end{array}$	$\begin{array}{r} 45.5\\52.0\\54.5\\57.8\\50.1 \end{array}$	
III. III. III. Ark.	11 12 13 1R	7.8 12.0 10.2	9.4 9.2 9.1	36.7 36.2 39.0	46.1 42.6 41.7	10.2 10.4 10.2	39.8 41.1 43.4	50.0 48.5 46.4	44.3 45.9 48.3	55.7 54.1 51.7	43.3 44.8 47.3	56.7 55.2 52.7	8.8 13.6 11.5	39.5 38.8 41.9	51.7 47.6 46.6	
Ark. Ark. Ark. Ark. Ark. Ark.	1W 2R 2W 3R 3W 4R	1.5 2.5 2.1 1.8 1.7 1.2	7.0 13.9 6.6 8.7 6.8 18.1	17.3 12.0 19.7	74.2 71.6 71.8	7.1 14.2 6.8 8.8 7.0 18.3	17.6 12.3 20.1	75.3 73.5 72.9	19.0 14.4 21.6	81.0 85.6 78.4	18.12 11.9 20.88	81.88 88.1 79.12	1.63 3.0 1.84	17.79 11.6 20.42	80.58 85.4 77.74	
Ark. Ind. Ind. Ind. Ind.	4W 1 2 3 4	$ \begin{array}{r} 1.3 \\ 13.6 \\ 7.5 \\ 10.1 \\ 11.2 \end{array} $	$ \begin{array}{r} 10.5 \\ 6.2 \\ 8.6 \\ 13.7 \\ 11.0 \end{array} $	$ \begin{array}{c} 17.6\\ 29.8\\ 41.1\\ 33.7\\ 39.9 \end{array} $	70.6 50.4 42.8 42.5 37.9	10.7 7.2 9.3 15.2 12.4	$17.8 \\ 34.5 \\ 44.4 \\ 37.4 \\ 44.9$	71.5 58.3 46.3 47.4 42.7	20.0 37.2 49.0 44.2 51.3	80.0 62.8 51.0 55.8 48.7	18.3436.647.942.950.1	81.66 63.4 52.1 57.1 49.9	1.49 14.6 8.5 12.0 13.0	$18.10 \\ 31.2 \\ 43.9 \\ 37.8 \\ 43.6$	80.41 54.2 47.6 50.2 43.4	
Ind. Ind. Ind. Iowa Ky.	5 6 7 1 1	$ \begin{array}{r} 13.2 \\ 7.7 \\ 9.6 \\ 14.0 \\ 2.5 \\ \end{array} $	$11.7 \\ 13.2 \\ 8.0 \\ 16.4 \\ 4.6$	33.0 35.9 36.3 34.1 37.7	42.1 43.2 46.1 35.5 55.2	13.5 14.2 8.9 19.0 4.8	38.1 38.9 40.1 39.7 38.6	$\begin{array}{r} 48.4 \\ 46.9 \\ 51.0 \\ 41.3 \\ 56.6 \end{array}$	$\begin{array}{r} 44.0\\ 45.4\\ 44.0\\ 49.0\\ 40.6\end{array}$	56.0 54.6 56.0 51.0 59.4	$\begin{array}{r} 43.2 \\ 44.0 \\ 43.4 \\ 47.2 \\ 40.2 \end{array}$	56.8 56.0 56.6 52.8 59.8	15.2 9.2 10.6 17.5 2.6	36.5 40.0 38.8 38.9 39.1	$\begin{array}{r} 48.3 \\ 50.8 \\ 50.6 \\ 43.6 \\ 58.3 \end{array}$	
Ку. Ку. Ку. Ку. Мо.	2 3 4 5 1	3.5 7.5 9.9 3.0 13.0	4.1 5.4 3.6 7.3 8.2	38.1 40.6 38.7 35.1 38.3	54.3 46.5 47.8 54.6 40.5	4.3 5.8 4.0 7. 5 9.4	$\begin{array}{r} 39.5 \\ 43.9 \\ 43.0 \\ 36.2 \\ 44.0 \end{array}$	56.2 50.3 53.0 56.3 46.6	$\begin{array}{c} 41.2 \\ 46.6 \\ 44.8 \\ 39.1 \\ 48.6 \end{array}$	58.8 53.4 55.2 60.9 51.4	$\begin{array}{r} 40.9 \\ 45.9 \\ 44.3 \\ 38.6 \\ 47.4 \end{array}$	59.1 54.1 55.7 61.4 52.6	3.7 8.1 10.4 3.3 14.6	39.3 42.1 39.7 37.3 40.5	57.0 49.8 49.9 59.4 44.9	
Mo. Ohio W. Va W. Va W. Va	2 1 a. 1 a. 2 a. 3	9.6 7.0 1.5 1.2 2.0	5.8 10.9 7.5 8.7 7.5	42.0 36.8 40.3 18.6 15.1	42.6 45.3 50.7 71.5 75.4	6.4 11.7 7.7 8.8 7.6	46.4 39.6 40.9 18.9 15.4	47.2 48.7 51.4 72.3 77.0	49.6 44.8 44.3 20.7 16.7	50.4 55.2 55.7 79.3 83.3	48.6 43.7 43.4 19.9 15.9	51.4 56.3 56.6 80.1 84.1	$10.5 \\ 8.1 \\ 1.7 \\ 1.3 \\ 2.2$	$\begin{array}{r} 43.6 \\ 40.2 \\ 42.7 \\ 19.5 \\ 15.6 \end{array}$	45.9 51.7 55.6 79.2 82.2	
W. Va Wyo.	a. 4 1	2.0 20.9	5.5 5.1	28.7 38.4	63.8 35.6	5.6 6.5	29.3 48.5	65.1 45.0	31.0 51.9	69.0 48.1	30.5 51.5	69.5 48.5	$\begin{array}{c} 2.1\\ 22.2 \end{array}$	29.9 40.1	68.0 37.7	

DOMESTIC STOKER COMBUSTION

											ULTIMATE ANALYSIS																					
Sar	nple				As	Fir	ED								N	Лог	STU	RE	Fre	Е				3	Mo	ISTU	RE	AN	D A	4SH	Fr	EE
N	Io.	Hy- dro- gen, %	Ca bo %	r- n,	Ni- tro- gen, %	C 8	xy- en, %	Si fu	ul- 1r, %	As	sh, %	H di ge	y- o- n, %	C. bo	ar- on, %	N tr ge	Vi- :0- en, %	Oz ge	ky- en, %	St fu	11- 1r, 70	As %	sh, 70	H dr ge	y- .o- .n, %	C	ar- on, %	N ti ge	Vi- :0- :2n, %	Oz ge	ky- en, Z	Sul- fur, %
III. III. III. III. III. III.	1 2 3 4 5	5.89 5.77 5.42 5.88 5.81	65. 68. 67. 59. 64.	68 04 87 93 05	1.61.31.61.61.11.11.11.11.11.11.11.11.11.11.11	$ \begin{array}{c} 0 & 18 \\ 0 & 17 \\ 1 & 16 \\ 7 & 21 \\ 2 & 19 \\ \end{array} $	8.42 7.58 5.60 .16 9.48	$ \begin{array}{c} 1 \\ 1 \\ 0 \\ 2 \\ 2 \end{array} $. 80 . 86 . 88 . 49 . 34	6 5 7 9 7	. 61 . 45 . 62 . 37 . 00	5 5 4 5	. 22 . 18 . 85 . 90 . 04	74 75 74 71 73	. 23 . 51 . 77 . 28 . 35	1 1 1 1	. 80 . 45 . 78 . 39 . 51	9 9 9 8 9	. 25 . 74 . 24 . 33 . 40	2. 2. 0. 2. 2.	03 07 97 96 68	7. 6. 8. 11. 8.	47 05 39 14 02	5 5 5 5	. 64 . 51 . 29 . 52 . 48	80 80 81 80 79	.23 .37 .62 .22 .74	1 1 1 1	.95 .54 .94 .57 .64	9 10 10 9 10	.99 .38 .09 .36 .23	2.19 2.20 1.06 3.33 2.91
III. III. III. III. III. III.	6 7 8 9 10	5.75 5.39 5.32 5.23 5.45	63. 61. 69. 69. 69.	83 02 03 82 97	1.3 1.2 1.5 1.7 1.7	3 17 2 16 9 11 8 11 2 16	24 . 42 . 69 . 84 . 60	2 3 2 2 3	. 89 . 67 . 82 . 00 . 07	8 12 9 9	.96 .28 .55 .33 .59	5 4 4 4	. 12 . 77 . 99 . 88 . 87	71 67 72 74 70	. 42 . 72 . 90 . 00 . 54	1 1 1 1 1	. 49 . 35 . 67 . 88 . 46	8 8 7 7 9	.72 .45 .37 .23 .17	3. 4. 2. 3.	23 08 98 12 39	10. 13. 10. 9. 10.	02 63 09 89 57	5. 5. 5. 5.	. 69 . 53 . 55 . 41 . 44	79 78 81 82 78	. 37 . 40 . 08 . 12 . 88	1 1 2 1	. 65 . 57 . 86 . 09 . 63	9 9 8 10	70 78 19 02 26	3.59 4.72 3.32 2.36 3.79
III. III. III. Ark.	11 12 13 1R	5.50 5.75 5.71	67. 61. 63.	35 03 74	1.3 1.0 1.2	9 13 4 20 5 17	3.77).16 7.07	2 2 3	. 62 . 87 . 10	9. 9. 9.	.37 .15 .12	5 5 5	. 03 . 02 . 09	72 69 71	.99 .37 .04	1 1 1	. 50 . 18 . 40	7 10 8	. 49 . 77 . 84	2. 3. 3.	84 26 46	10. 10. 10.	15 40 17	5. 5. 5.	60 60 67	81 77 79	. 24 . 42 . 08	1 1 1	. 67 . 32 . 56	8 12 9	33 02 84	3.16 3.64 3.85
Ark.	1W	4.51	82.	35	2.1	1 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. Ark.	2R 2W	3.73	74.	77	1.4	8 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. Ark. Ark.	3R 3W 4R	4.43	83.	12	1.89	9 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. Ind. Ind. Ind. Ind.	4W 1 2 3 4	4.27 6.01 5.71 5.39 5.82	79. 66. 67. 61.	78 18 38 81 52	1.70 1.57 1.32 1.34 1.28) 1 7 19 5 13 4 15 8 16	.37 .45 .31 .93 .81	2 0 3 1 3	. 38 . 65 . 61 . 87 . 57	10. 6. 8. 13. 11.	50 14 64 66 00	4 5 4 5	18 20 28 74 15	80 76 72 68 69	. 83 . 57 . 83 . 76 . 28	1 1 1 1	. 72 . 81 . 46 . 49 . 44	0. 8. 7. 7. 7.	23 56 19 73 72	2. 0. 3. 2. 4.	41 75 90 08 02	10. 7. 9. 15. 12.	63 11 34 20 39	4. 5. 5. 5.	67 60 82 59 88	90 82 80 81 79	. 38 . 43 . 29 . 08 . 08	$ \begin{array}{c} 1 \\ $.93 .95 .61 .76 .65	0. 9. 7. 9.	33 22 98 12 80	2.69 0.80 4.30 2.45 4.59
Ind. Ind. Ind. Iowa Ky.	5 6 7 1	5.55 5.34 5.65 5.48 5.46	61. 63. 66. 54. 78.	01 53 56 36 21	1.31 1.32 1.49 1.14 1.63	1 19 2 13 9 17 4 18 3 9	.70 .76 .22 .46 .32	0. 2. 1. 4. 0.	78 89 09 21 70	11. 13. 7. 16. 4.	65 16 99 35 68	4 4 5 4 5	73 86 07 56 32	70 68 73 63 80	.00 .80 .61 .18 .24	$ \begin{array}{c} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{array} $. 50 . 42 . 64 . 33 . 67	9. 7. 9. 7. 7.	51 54 63 04 25	$\begin{array}{c} 0.\\ 3.\\ 1.\\ 4.\\ 0. \end{array}$	90 13 21 89 72	13. 14. 8. 19. 4.	36 25 84 00 80	5. 5. 5. 5. 5.	46 67 56 63 58	80 80 80 78 84	80 24 74 00 28	$ \begin{array}{c} 1 \\ $	73 66 80 64 76	10. 8. 10. 8. 7.	97 78 58 69 62	1.04 3.65 1.32 6.04 0.76
Ky. Ky. Ky. Ky. Mo.	2 3 4 5 1	5.45 5.72 5.80 5.18 5.70	77. 70. 70. 75. 61.	09 00 13 78 97	1.69 1.47 1.77 1.63 1.14	9 10 7 14 7 17 3 9 4 19	. 66 . 66 . 03 . 39 . 12	0. 2. 1. 0. 3.	.96 .84 .65 .76 .91	4. 5. 3. 7. 8.	15 31 62 26 16	5 5 5 5 4	25 29 20 00 90	79 75 78 78 78	.85 .62 .04 .07 .10	1 1 1 1 1	. 75 . 59 . 96 . 68 . 31	7. 8. 8. 6.	.85 .70 .93 .99 .83	1. 3. 1. 0. 4.	00 07 84 78 50	4. 5. 4. 7. 9.	30 73 03 48 36	5. 5. 5. 5.	48 61 42 40 40	83 80 81 84 78	. 44 . 21 . 32 . 39 . 45	1 . 1 . 2 . 1 . 1 .	83 69 05 82 45	8. 9. 9. 7. 9.	21 23 30 55 74	1.04 3.26 1.91 0.84 4.96
Mo. Ohio W. V W. V W. V	2 1 a. 1 a. 2 a. 3	5.84 5.26 5.50 4.36 4.21	66. 65. 76. 81. 82.	14 50 33 07 61	1.18 1.41 1.56 1.56 1.27	8 16 1 14 5 6 5 3 7 3	. 66 . 23 . 14 . 56 . 94	4. 2. 0. 0.	39 69 89 71 50	5. 10. 7. 8. 7.	79 91 58 74 47	5 4 5 4 4	29 82 41 27 07	73 70 77 82 84	12 43 48 06 29	1 . 1 . 1 . 1 .	. 30 . 51 . 58 . 58 . 29	9. 8. 4. 2.	04 62 91 52 22	4. 2. 2. 0. 0.	85 89 93 72 51	6. 11. 7. 8. 7.	40 73 69 85 62	5. 5. 5. 4. 4.	65 46 86 68 41	78 79 83 90 91	12 79 94 02 25	1. 1. 1. 1.	39 71 71 73 40	9. 9. 5. 2.	66 77 32 78 39	5.18 3.27 3.17 0.79 0.55
W. V Wyo.	a. 4 1	5.11 6.22	80. 55.	90 18	1.60 1.33	$\begin{vmatrix} 6\\3\\31 \end{vmatrix}$. 05 . 58	0. 0.	78 52	5. 5.	56 17	4. 4.	98 92	82 69	.75 .78	1 1	. 63 . 68	4. 16.	16 42	0. 0.	79 66	5. 6.	69 54	5. 5.	28 27	87. 74.	.74 .66	1. 1.	73 80	4. 17.	41 56	0.84 0.71

TABLE 9.—ULTIMATE ANALYSES OF COALS

APPENDIX

HEATING VALUE, B.T.U. PER I						R LB.	B. SULFUR VARIETIES										
Sam N	nple	Δc	Moist	Moist and	Unit	Unit		As Firei)	Moi	STURE F	REE	Mo A	ISTURE A	AND E		
1,	0.	Fired	Free	Ash Free	Dry	Moist	Sul- fate	Pyritic	Or- ganic	Sul- fate	Pyritic	Or- ganic	Sul- fate	Pyritic	Or- ganic		
III. III. III. III. III.	1 2 3 4 5	11901 12210 11953 10760 11561	13444 13546 13162 12803 13239	14530 14415 14372 14415 14395	14698 14551 14506 14669 14579	12855 13008 13042 12020 12555	. 11 . 05 . 02 . 08 . 12	.82 1.05 .39 .85 .74	.87 .76 .47 1.56 1.48	.12 .05 .02 .09 .14	$\begin{array}{r} .92 \\ 1.16 \\ .43 \\ 1.02 \\ .85 \end{array}$.99 .86 .52 1.85 1.69	.13 .06 .02 .10 .15	1.00 1.24 .47 1.14 .92	1.06 .90 .57 2.10 1.84		
I11. I11. I11. I11. I11. I11.	6 7 8 9 10	11515 11047 12599 12420 11547	12881 12253 13308 13159 12730	14315 14186 14806 14611 14230	14550 14505 15047 14809 14471	12820 12826 14144 13882 12956	.07 .05 .03 .05 .03	$1.11 \\ 1.70 \\ 1.47 \\ 1.18 \\ 1.32$	$1.71 \\ 1.92 \\ 1.32 \\ .77 \\ 1.72$.07 .05 .03 .05 .03	$1.24 \\ 1.89 \\ 1.55 \\ 1.25 \\ 1.46$	1.922.141.40.821.90	.08 .06 .03 .06 .03	1.38 2.19 1.73 1.39 1.63	2.13 2.47 1.56 .91 2.13		
Ill. Ill. Ill. Ark	11 12 13 1R	12038 10971 11529	13050 12470 12845	14530 13924 14301	14765 14149 14552	13468 12237 12858	.03 .20 .02	1.08 1.22 1.17	1.51 1.45 19.91	.03 .23 .02	1.17 1.39 1.30	$1.64 \\ 1.64 \\ 2.14$.03 .25 .02	$1.31 \\ 1.55 \\ 1.45$	1.82 1.84 2.38		
Ark.	1W	14149	14364	15469	15596	15343	.02	. 29	. 68	.02	. 29	. 69	.03	.31	.74		
Ark. Ark.	2R 2W	12718	13042	15206	15536	15081	.14	1.99	.92	. 14	2.04	.95	.16	2.38	1.11		
Ark. Ark. Ark.	3R 3W 4R	14123	14366	15440	15573	15272	. 02	.14	.66	.02	. 14	.68	.02	.15	.73		
Ark. Ind. Ind. Ind. Ind.	4W 1 2 3 4	13688 11785 12260 11057 11238	13868 13632 13252 12304 12662	$15525 \\ 14683 \\ 14610 \\ 14510 \\ 14449$	15780 14807 14270 14803 14764	15534 12645 13615 13025 12836	.08 .00 .05 .03 .73	1.59 .07 1.72 1.17 2.10	.71 .58 1.84 .67 .74	.08 .00 .05 .03 .82	$1.61 \\ .08 \\ 1.86 \\ 1.31 \\ 2.36$.72 .67 1.99 .74 .84	.09 .00 .06 .04 .94	$ \begin{array}{r} 1.80 \\ .09 \\ 2.05 \\ 1.54 \\ 2.69 \\ \end{array} $.80 .71 2.19 .87 .96		
Ind. Ind. Ind. Iowa Ky.	5 6 7 1	10936 11170 11839 9864 13998	12606 12096 13093 11467 14355	$\begin{array}{c} 14567 \\ 14105 \\ 14365 \\ 14161 \\ 15073 \end{array}$	14792 14395 14526 14615 15165	12535 13102 12984 12071 14754	.04 .27 .08 .21 .00	.43 1.52 .55 3.29 .14	.31 1.10 .46 .71 .56	.04 .29 .09 .24 .00	.50 1.64 .61 3.83 .14	.36 1.20 .51 .82 .58	.05 .34 .09 .30 .00	.58 1.91 .67 4.72 .15	$\begin{array}{r} .41 \\ 1.40 \\ .56 \\ 1.02 \\ .61 \end{array}$		
Ky. Ky. Ky. Ky. Mo.	2 3 4 5 1	13872 12771 12548 13465 11292	14370 13801 13925 13878 12986	$15012 \\ 14648 \\ 14508 \\ 15004 \\ 14331$	15104 14826 14612 15130 14606	14545 13637 13094 14642 12469	.01 .06 .10 .01 .24	.34 1.03 .79 .17 2.21	.61 1.75 .76 .58 1.46	.01 .06 .11 .01 .28	.36 1.12 .88 .17 2.55	.63 1.89 .85 .60 1.67	.01 .07 .12 .01 .31	.37 1.18 .91 .19 2.81	.66 2.01 .88 .64 1.84		
Mo. Ohio W. V W. V W. V	2 1 a. 1 a. 2 a. 3	12187 11739 13887 14256 14224	13479 12619 14098 14429 14514	14402 14292 15266 15827 15711	14639 14544 15490 15974 15833	13104 13377 15217 15764 15498	.32 .07 .01 .00 .00	1.70 1.84 1.11 .15 .05	2.37 .78 1.77 .56 .45	.35 .07 .01 .00 .00	1.88 1.98 1.13 .15 .05	2.62 .84 1.79 .57 .46	.38 .08 .01 .00 .00	2.01 2.24 1.22 .16 .05	2.79 .95 1.94 .63 .50		
W. V Wyo.	a. 4 1	14473 9553	14768 12076	15649 12917	15749 13003	15416 10114	.00 .01	.02 .14	.76 .37	.00 .01	.02 .18	.77 .47	.00 .01	.02 .20	. 82 . 50		

TABLE 10.—HEATING VALUES AND SULFUR VARIETIES

DOMESTIC STOKER COMBUSTION

	ASI TEM	H FUS PERA1	ION URES	GI	ESELE	R PLA	ASTICI		ASH ANALYSIS								
Sample No.	Initial Deforma- tion °F	Softening, °F	Fluid, °F	Softening Temp. °C	Fusion Temp. °C	Maximum Fluidity °C	Solidifi- cation Temp. °C	Max. Fluid- ity Div. per Minute	Free- Swelling Index	SiO2, %	0	AI U3, %	Fe2O3, %	MgO. %	CaO, %	SO3, %	Ignition Loss
Ill. 1 Ill. 2 Ill. 3 Ill. 4 Ill. 5	1942 2026 2182 2039 1980	2197 2107 2264 2105 2105	2357 2149 2311 2169 2254	362 400 369 372	414 NO	429 PLA 416 409 403	460 STIC 455 446 450	11.9 ITY 1.5 2.4 2.5	4.0 3.0 3.0 3.5 3.5	32.7 49.6 48.3 48.2	3 18 . 4 22 . 3 15 .) 25 .	28 75 62 33	28.47 8.91 12.89 17.92	.8 1.0 .7 1.2	9 8.4 4 8.1 3 10.1 3 1.7	6 7.42 7 5.94 9 10.74 4 1.12	2 .35 .65 1.46 .86
Ill. 6 Ill. 7 Ill. 8 Ill. 9 Ill. 10	2079 2032 2064 2055 2070	2156 2109 2265 2165 2140	2205 2140 2304 2304 2181	356 388 405 379	418 NO 415	425 PLA 436 445 423	452 STIC 477 468 447	6.8 ITY 164 3.8 3.2	2.5 3.5 5.0 5.0 4.0	48.2: 44.2. 48.14	3 20 . 5 19 . 4 24 .	98 04 12	17.33 19.01 21.01	. 5 . 5 . 4	8 4.5. 4 5.19 9 1.22	5 4.44 9 5.40 2 .87	02 2.13 1.16
Ill. 11 Ill. 12 Ill. 13 Ark. 1R	2090 1993 2009	2146 2113 2162	2195 2195 2220	380 333	408 NO 401	434 PLA 420	466 STIC 457	145 ITY 54	$\begin{array}{c} 5.0\\ 1.0\\ 3.0 \end{array}$								
Ark. 1W	1938	2083	2245	454		485	515	3.9	8.5								
Ark. 2R Ark. 2W Ark. 3R Ark. 3W Ark. 4R	2082 1892	2284 1971	2380 1998	461	NO	PLA 469	STIC 505	ITY 1.7	1 0 8.0								
Ark. 4W Ind. 1 Ind. 2 Ind. 3 Ind. 4	1933 2328 2016 2060 1988	2021 2552 2144 2204 2062	2156 2600+ 2256 2380 2102	461 321 383 358	NO 389 415 412	492 PLA 426 430 431	516 STIC 463 461 462	3.9 ITY 2143 9.0 25.5	8.0 4.5 5.5 5.0 2.0	48.76 40.13 51.19 28.43	33. 24. 23. 16.	84 05 32 56	5.40 25.84 13.66 35.86	.80 .44 .93) 3.03 4 3.03 5 3.17 8.93	8 1.85 3 3.07 7 3.37 8 6.74	1.68 1.20 1.69 1.62
Ind. 5 Ind. 6 Ind. 7 Iowa 1 Ky. 1	2220 2030 2102 2001 2103	2456 2126 2459 2075 2215	2546 2341 2532 2105 2351	393 385 380 388 397	421	425 413 413 412 444	459 457 458 449 472	4.5 3.0 3.7 2.1 620	2.5 3.5 3.5 1.0 3.5	51.96 52.59 56.18 43.34	25. 21. 25. 26.	38 42 72 25	18.07 20.07 11.62 12.63	.96 1.2 1.3 2.0	64.80 2.55	.31 .45 .14 5.47	.00 .76 .14 3.47
Ky. 2 Ky. 3 Ky. 4 Ky. 5 Mo. 1	2228 1996 1952 2375 1949	2600+ 2080 2074 2600+ 2011	2600+ 2158 2248 2600+ 2072	433 360 390 403 365	456 401 425	462 427 427 447 405	494 462 457 475 454	22 155 2.3 74 3.2	4.5 3.5 5.0 5.5 2.0	41 . 05 35 . 97 38 . 34	22. 21. 16.	41 68 78	26.69 35.85 40.11	. 67 . 91 . 87	2.91	2.67 .35 .75	. 82 . 72 . 81
Mo. 2 Ohio 1 W. Va. 1 W. Va. 2 W. Va. 3	1965 2039 2062 2600+ 2286	2018 2144 2197 2600 ⁺ 2338	2064 2238 2245 2600+ 2399	366 406 345 447 467	422 388 468	428 422 420 490 500	456 455 495 519 523	$6.2 \\ 0.8 \\ 6000 \\ 23.0 \\ 4.4$	2.5 2.0 6.5 8.0 6.5	31.86 39,22	13. 23.	31 51	42.10 17.17	.88 1.49	3 5.14 7.03	5.19 9.46	14 4.49
W. Va. 4 Wyo. 1	2388 1981	2600+ 2064	2600^+ 2103	394	416 NO	444 PLA	499 STIC	1957 ITY	0.8 0	31.68	18.	60	8.64	6.0	13.56	5 16.52	3.01

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

APPENDIX

TABLE 12.—Combustion Data

Sample		HE OBTA	AT INED	UN FORM	NI- MITY	RESP	ENESS	S PICKUP		OVEI	RRUN	Heat	Wind		
Sam No	ple	M B. T. U. per Hour ^a	B. T.U. per Lb.	Ave. Var. %	Min- imum ÷ Aver- age	M B. T. U. First 30 Min.	Ratio	M B. T. U. First Hour	в. Т. U.	Ratio	в. т. u.	Ratio	Db- tained \div % Ash	box Pres- sure In. of H ₂ O	CO2, %
III. III. III. III. III. III.	1 2 3 4 5	163 164 188 150 165	7.02 7.44 7.95 6.52 7.37	5.7 3.4 6.3 13.5 4.9	. 86 . 92 . 81 . 68 . 86	$ \begin{array}{r} 14.9\\28.4\\19.5\\17.6\\14.9\end{array} $.18 .35 .21 .24 .18	91.6 103.8 84.6 57.2 70.8	37.2 43.6 38.8 31.2 34.7	.23 .27 .21 .21 .21	72.8 84.1 82.5 71.3 74.6	.45 .51 .44 .48 .45	1.06 1.38 1.05 .69 1.05	$\begin{array}{c} 0.77 \\ 0.58 \\ 0.57 \\ 0.56 \\ 0.50 \end{array}$	$ \begin{array}{r} 10.7 \\ 10.0 \\ 13.0 \\ 9.2 \\ 10.3 \end{array} $
111. 111. 111. 111. 111. 111.	6 7 8 9 10	154 172 186 192 179	6.90 6.70 8.00 7.97 7.16	8.9 9.8 11.9 8.0 11.8	. 80 . 77 . 66 . 80 . 78	17.6 18.2 8.4 19.8 19.9	. 23 . 21 . 09 . 21 . 22	83.4 74.8 31.4 84.6 83.6	33.0 37.6 40.1 40.7 38.8	. 21 . 22 . 22 . 21 . 22	67.5 74.9 82.9 89.2 80.7	.44 .44 .45 .47 .45	.77 .54 .83 .85 .74	$\begin{array}{c} 0.74 \\ 0.98 \\ 0.89 \\ 0.86 \\ 0.73 \end{array}$	$11.1 \\ 12.7 \\ 13.7 \\ 13.4 \\ 13.0$
Ill. Ill. Ill. Ark. Ark.	11 12 13 1R 1W	188 166 164 Fire 251	7.68 6.83 6.99 could 9.57	10.5 7.3 13.0 not b 4.6	.77 .78 .63 e main .86	13.2 23.2 17.6 tained c	.14 .28 .22 withou	43.2 109.5 75.7 t man °	41.8 41.6 42.2 ual at 60.0	.22 .25 .26 tentio .24	80.3 86.1 77.0 n 120.5	.43 .52 .47 .48	.82 .74 .77 1.37	0.77 1.02 0.92 0.89	13.8 12.2 11.5 14.1
Ark. Ark. Ark. Ark. Ark.	2R 2W 3R 3W 4R	Fire Fire 243 243 214	could could 9.57 9.67 8.69 ^b	not b not b 4.7 4.1 5.9	e main e main . 88 . 90 . 83	tained tained 47.6 32.5 27.1	withou . 39 . 27 . 25	t man t man 131.1 120.9 115.4	ual at ual at 59.7 69.4 57.0	tentio .25 .29 .26	n n 113.2 116.4 111.6	. 47 . 48 . 51	1.10 1.42 .48	0.81 0.82 1.07	13.7 13.6 12.3
Ark. Ind. Ind. Ind. Ind.	4W 1 2 3 4	236 150 162 147 132	9.41 6.87 6.95 6.26 5.89	5.3 4.6 9.4 11.8 8.7	. 89 . 89 . 76 . 72 . 83	32.7 18.3 11.3 9.3 9.3	. 28 . 24 . 14 . 13 . 14	$112.9 \\78.3 \\40.6 \\45.6 \\37.0$	54.8 32.9 36.1 34.2 26.5	.23 .22 .22 .23 .20	109.1 69.6 62.4 62.8 52.5	. 46 . 46 . 38 . 43 . 40	.90 1.11 .81 .46 .54	$\begin{array}{c} 0.97 \\ 0.60 \\ 0.81 \\ 1.00 \\ 0.74 \end{array}$	$13.0 \\ 9.8 \\ 10.1 \\ 9.6$
Ind. Ind. Ind. Iowa Ky.	5 6 7 1 1	147 162 168 127 208	6.95 6.92 7.25 5.85 8.96	5.7 12.5 6.0 6.9 7.2	. 84 . 69 . 86 . 85 . 79	16.9 26.2 28.2 16.0 15.2	. 23 . 32 . 34 . 25 . 15	$76.1 \\ 102.3 \\ 110.0 \\ 64.5 \\ 73.2$	$\begin{array}{r} 32.8\\ 37.4\\ 42.0\\ 29.3\\ 40.3 \end{array}$.22 .23 .25 .23 .19	72.8 84.7 91.0 61.7 89.5	. 50 . 52 . 54 . 48 . 43	.59 .52 .91 .36 1.95	$\begin{array}{c} 0.93 \\ 1.00 \\ 0.81 \\ 0.76 \\ 0.51 \end{array}$	10.5 9.7 9.9 13.4
Ку. Ку. Ку. Ку. Мо.	2 3 4 5 1	206 165 174 202 154	8.92 7.74 8.07 8.23 6.95	$6.7 \\ 10.5 \\ 6.3 \\ 7.2 \\ 12.1$. 84 . 71 . 88 . 80 . 77	18.4 12.1 15.0 13.8 17.9	. 18 . 15 . 17 . 14 . 23	96.7 32.2 85.0 89.2 50.8	49.7 39.8 37.2 41.0 37.0	. 24 . 24 . 21 . 20 . 24	88.4 63.2 74.6 92.9 70.8	. 43 . 38 . 43 . 46 . 46	2.18 1.43 2.24 1.13 .85	$\begin{array}{c} 0.70 \\ 0.65 \\ 0.50 \\ 1.03 \\ 0.76 \end{array}$	$ \begin{array}{r} 11.5 \\ 9.5 \\ 11.0 \\ 9.5 \end{array} $
Mo. Ohio W. Va W. Va W. Va	$2 \\ 1 \\ . 1 \\ . 2 \\ . 3$	147 166 176 235 238	7.25 7.39 8.12 9.09 9.50	8.0 6.8 16.9 5.6 5.2	. 84 . 79 . 54 . 84 . 88	15.9 14.2 c 21.6 28.4	. 22 . 17 . 18 . 24	57.6 57.7 e 114.6 115.7	$31.0 \\ 33.7 \\ 40.1 \\ 54.9 \\ 52.0$. 21 . 20 . 23 . 23 . 22	$\begin{array}{r} 62.4 \\ 72.3 \\ 66.0 \\ 112.8 \\ 113.7 \end{array}$.42 .44 .37 .48 .48	$1.25 \\ .68 \\ 1.08 \\ 1.04 \\ 1.27$	$\begin{array}{c} 0.65 \\ 0.72 \\ 1.06 \\ 1.13 \\ 0.74 \end{array}$	$8.6 \\ 13.2 \\ 10.7 \\ 13.3 \\ 13.2$
W. Va Wyo.	. 4 1	223 126	9.11 6.36	7.1 3.1	. 83 . 93	13.9 22.1	.13 .35	86.5 86.3	51.3 34.7	. 23 . 28	98.5 61.7	.44 .49	1.66 1.25	0.80 0.49	$\begin{array}{c} 12.6 \\ 10.6 \end{array}$

^a With continuous stoker operation.

^b Only two rates of stoker operation.

° Fire not maintained.

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DOMESTIC STOKER COMBUSTION

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

TABLE 13.-CLINKER AND FLY-ASH DATA, AND COAL-BURNING RATES

^a Minutes of stoker operation per hour.

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