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DIVISION OF THE
STATE GEOLOGICAL SURVEY
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URBANA

REPORT OF INVESTIGATIONS—NO. 120

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

II. COMBUSTION TESTS AND PREPARATION STUDIES OF REPRESENTATIVE ILLINOIS COALS

BY

ROY J. HELFINSTINE AND CHARLES C. BOLEY

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Aug. 1, 1946

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INTRODUCTION

IN 1942 the Illinois State Geological Survey issued the first report[1] of a series on stoker combustion studies designed to explore the influence of coal on the performance of typical domestic stokers. The first investigation, which was carried out in cooperation with the University of Illinois Engineering Experiment Station, described the testing of six Illinois and two West Virginia coals. Performance characteristics, as determined primarily from the observed formation of coke in the fuel bed, the smoke emission, and the nature of the clinker, appeared to have some correlation with rank, petrographic constitution, and British swelling index number.

The present report, the second of the series, describes the results of more comprehensive work along the same lines.

Acknowledgments

This investigation was made under the supervision of Gilbert H. Cady, Head of the Coal Division, for whose continuing interest and many helpful suggestions the writers are indebted.

Grateful acknowledgment is extended to O. W. Rees, Geochemical Section, who directed the many routine and specialized chemical tests, to B. C. Parks, Coal Division, who was responsible for the petrographic analyses, and to S. Konzo of the University of Illinois Engineering Experiment Station for assistance and advice throughout the investigation.

Most of the coal samples were contributed by the coal companies whose cooperation at all times is sincerely appreciated.

OBJECTIVES

The primary objective of the tests described in this report was to determine the degree of correlation existing between the combustion characteristics of Illinois coal in domestic stokers and their chemical properties and petrographic composition. An essential preliminary objective was the development of suitable criteria by which the relative combustion behavior of coal could be evaluated.

As a study of the entire range of Illinois coal quality was desired, several methods of cleaning the coal were employed. The action and effectiveness of these methods formed a secondary objective.

SCOPE

There are many factors that govern the suitability of coals for domestic stokers. Included are: 1) cost of heat; 2) attention required by the heating plant, including related cleanliness; 3) the ability to maintain the desired temperature in the home; 4) the smoke emitted during combustion; 5) the ability to maintain fire at low rates of operation; 6) the appearance of the fuel bed and fire; 7) the odors given off by clinkers during their removal; and 8) the quietness of operation. These factors vary in relative importance, depending upon the heating system being used and also upon personal preferences of the operator.

Some indicators of all the factors listed (except the odors given off by the clinker

[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.

and the quietness of operation) were devised and are included in this report. The rating factors are discussed in a separate section (pp. 15-18). As the present project was concerned only with factors influenced by the combustion properties of the fuel, the appearance and cleanliness of the coal before firing were not considered.

Forty-three Illinois coals, prepared from fifteen major samples, were tested. Chemical tests of each coal included the proximate analysis, the ultimate analysis, heating value, ash fusion temperatures, British swelling index, and some measure of plasticity. Additional determinations were made for the varieties of sulfur for 20 of the 43 coals, the chemical constituents of the ash for 22 coals, a measure of ignitibility for 21 coals, and chemical fusain for 16 coals.

Analysis for petrographic constitution involved a determination of the percentages of vitrain, clarain, durain, and fusain,[2] and of non-coal material, defined as material exceeding 1.5 in specific gravity.

Quantitative correlations of combustion characteristics and the data on chemical nature and petrographic composition were sought and are presented, together with an analysis of the effects of the cleaning processes on the quality and quantity of the coals. In addition, a basic fund of information regarding the combustion behavior of a group of Illinois coals has been obtained.

EQUIPMENT

Combustion

All the tests included in this report were made in a stoker-fired cast-iron boiler, rated at 570 sq. ft. of equivalent direct radiation (136,800 B.t.u. per hour). A maximum feeding rate of 28 pounds per hour was also indicated by the boiler manufacturer. The unit was operated as a conventional forced-circulation hot-water boiler. The boiler inlet water was maintained at approximately 160° F. by automatic control of the quantity of cooling water to a heat exchanger in the boiler-water circuit.

The entire stoker-boiler unit, including the heat exchanger, was mounted on a scale with dial graduations of ½ pound. All external connections were made highly flexible; in fact a 2-ounce weight placed on the unit would cause an observable movement of the scale pointer. A photograph of the test unit is shown in figure 1.

A two-pen mercury-actuated recording thermometer provided a continuous record of the temperatures of the water entering and leaving the boiler. This recorder had 12-inch round charts, with a temperature range of 80–220° F. and 1° scale divisions. A check indicated the accuracy of the instrument to be about ± ¼° F. This instrument error would be proportionately large during tests with low rates of operation if the maximum temperature difference between the inlet and outlet water were limited to 20° or 30° F., which is common practice in home installations. Therefore the maximum difference between the inlet and outlet boiler-water temperature was allowed to exceed 20° on many occasions.

The quantity of water flowing in the boiler-water circuit was indicated by a hot-water meter. The meter was checked by occasionally weighing the quantity of water passing through, although no appreciable variation was ever found.

The rate of water flow was kept constant during the tests, irrespective of the operation of the stoker. This is contrary to usual home practice, but seemed to be necessary if the measurements were to be accurate. Intermittent flow would result in increased errors of flow measurement, requiring knowledge of the instantaneous rate of flow and the difference between inlet and outlet boiler-water temperatures at corresponding times. Such coordination would be extremely difficult. Therefore the water was circulated at a constant rate and as the same procedure was used for all tests, comparable results were obtained.

The temperatures of the air entering the stoker fan and of the stack gas were recorded by means of a multipoint potentiometer (0 to 40 millivolt range) and thermocouples.

[2] Cady, Gilbert H., Nomenclature of the megascopic description of Illinois coals: Econ. Geol. vol. 34, No. 5, pp. 475-94, 1939; Illinois Geol. Survey Cir. 46, 20 pp., 1939.

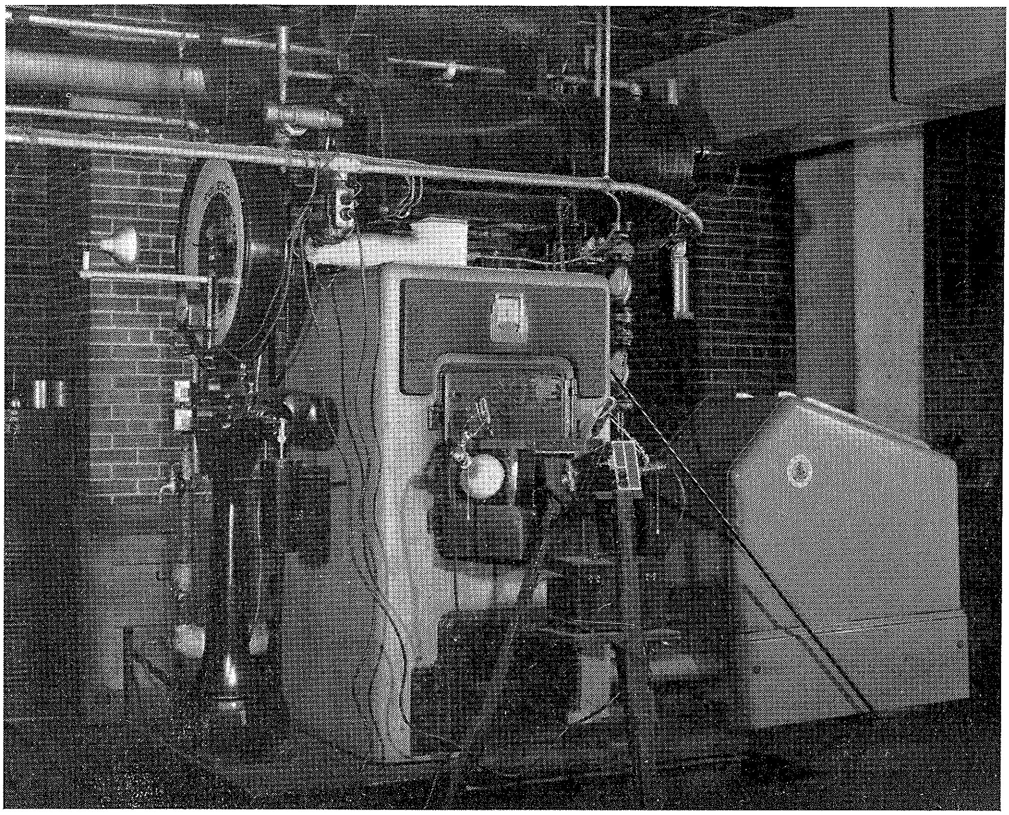

FIG. 1. Stoker-boiler unit.

A chemical-type meter, which was frequently checked with a hand-operated Orsat analyzer, recorded the percentage of CO_2 in the stack gas. The static pressure in the stoker air duct was recorded by a pressure gage. A wattmeter, to show the power required by the stoker, and inclined tube manometers, to show the draft in the stack and combustion chamber, were provided.

The multipoint potentiometer also recorded the opacity of the stack gases. This was done by projecting a beam of light across the smoke pipe upon a photoelectric cell. The current generated, which is approximately proportional to the illumination on the face of the photoelectric cell, was passed through a fixed resistance. The voltage drop across this resistance was recorded by the potentiometer. Since the illumination falling upon the photoelectric cell is governed by the "density" of the smoke in the stack, the desired record was made by the potentiometer.

A 16-mm. motion picture camera was used for taking pictures of the fuel bed by one arrangement and of the scale dial by another. A special timer allowed the pictures of the fuel bed to be taken at any interval from 1/4 to 6 seconds per frame. One frame every 2 1/2 seconds was adopted as standard for the tests to date. When not being used for taking pictures of the fuel bed, the camera was mounted and controlled in such a manner that it automatically took single frame pictures of the scale dial and a clock at appropriate regular intervals, thereby furnishing a record of the loss in weight of the 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.

Preparation

The coal washing unit selected for the investigation was a laboratory-size concentrating table, equipped with a diagonal linoleum-covered deck and wooden riffles. The dimensions of the deck were 8 feet 8 inches by 4 feet 7 inches.

The action of the concentrating table, in common with most coal washing processes, takes advantage of the fact that the specific

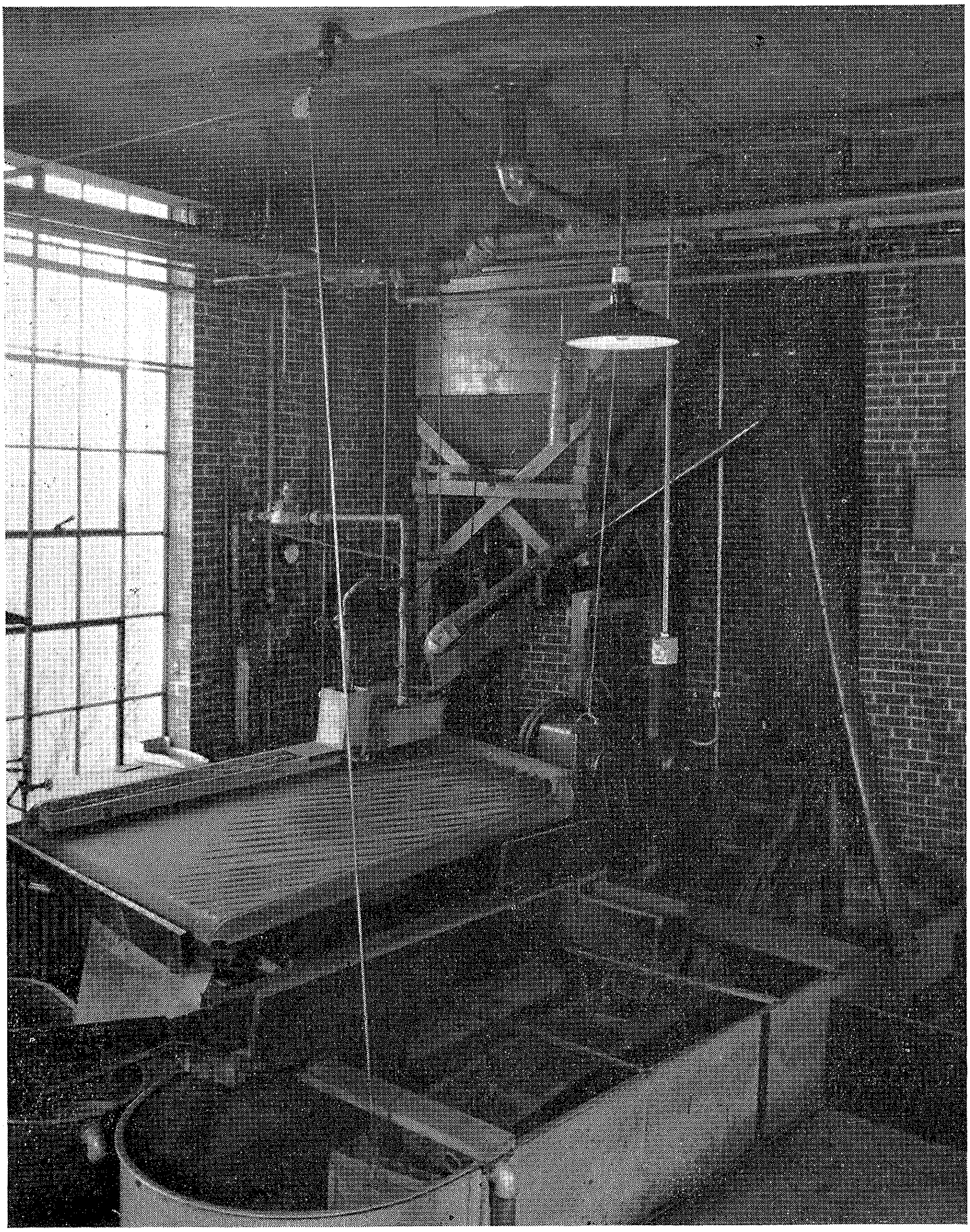

Fig. 2. Concentrating table and auxiliaries.

gravity of clean coal is appreciably less than the specific gravity of any solid inert material associated with the coal. Thus any separation based upon specific gravity will also produce a relatively low-ash fraction and a relatively high-ash fraction.

The concentrating table utilizes specific gravity differences by balancing two tendencies that are simultaneously brought to bear on the coal particles. The head motion imparts a non-symmetric reciprocation of the table along its long axis, in such a way that particles on it tend to move toward one end. At the same time a sheet of water flows across the table, tending to carry particles toward one side. The coal to be cleaned is introduced at one corner, where the separation process begins. Particles of low specific gravity are affected more by the wash of water and less by the reciprocation of the deck and thus tend to be carried to the side, while the net tendency of motion for particles of higher specific gravity is toward the end.

It is evident that the angles of cross-wise and longitudinal slope are important in their effect. The concentrating table is built with provision for adjusting the cross-wise slope during operation; in these tests the table was modified to permit prompt adjustment of longitudinal slope also.

Special provision was also made to change the speed of reciprocation of the table, normally of the order of 270 strokes per minute. Length of stroke could be adjusted during operation up to a maximum of about 1½ inches.

Coal from a bin of about 3500-pound capacity was fed to the table by a vibrating feeder controlled by a variable voltage auto-transformer. Water flow was metered, and a modified type of manometer was provided to indicate rate of flow.

Because relatively small quantities of coal were available for the entire procedure of establishing equilibrium, beginning with an empty table and producing at least 1500 pounds of coal under stable conditions, a recirculating system was developed, which consisted of a flight conveyor, a bucket elevator, and appropriate launders and chutes. It was then possible to draw off a relatively small (200 to 300 pounds) quantity of coal from the feed bin and to experiment at length, without further loss of coal, in order to establish desired washing conditions. During this period, coal particles were separated on the table, recombined by launders, and dropped into relatively quiet water in a large tank where they settled into the trough of the flight conveyor. They were then carried up a de-watering section and dropped into the boot of a bucket elevator, which lifted them to a point that permitted chuting them back to the feedbox of the table. A photograph of the table and auxiliary equipment is shown in figure 2.

When the desired washing conditions were established, a simple redisposition of a launder and a deflector permitted the withdrawal of the separated products. At the same time, of course, the feeder from the main feed bins was cut in, and the recirculation phase of the washing operation gave way to the production phase, which continued steadily as long as necessary.

Sampling boxes were available for snap zone samples of the table products and for rapid estimation of percentage of reject being produced at any time.

Variations of size also affect the direction and rate of travel of particles across the deck of a concentrating table, so that separation is not solely based on differences in specific gravity. For separation on a true specific gravity basis, a bath of high-density liquid in which particles are free to sink or to float may be used. In this investigation, water solutions of zinc chloride were used, contained in 55-gallon barrels. Coal was lowered into the solution in a close-fitting wire-mesh basket, and after stratification had taken place, a "float" basket with a special damper-type bottom was lowered through the floating coal. By closing the bottom and raising the float basket, practically all of the floating coal was removed at once, leaving only scattered particles to remove with a dipper. Sink material was of course left in the larger basket. A small tank filled with water to wash the zinc chloride solution from the coal, and an over-

TABLE 1.—SOURCE AND DESCRIPTION OF SAMPLES

Lab. No.	County	Coal bed	Mining district[a]	County rank index[b]	Rank, High volatile A, B, or C	Description of coal
1	Franklin	Herrin No. 6	Franklin-Williamson	131	B	Washed stoker, 7/16″ by 10 mesh
2	LaSalle	LaSalle No. 2	LaSalle	122	C	Raw 1¼″ stoker
3	Vermilion	Grape Creek	Danville	122	C	1¼″ screenings, dedusted
5	Macoupin	Herrin No. 6	Central Illinois	121	C	1¼″ screenings
6	Peoria	Springfield No. 5	Fulton-Peoria	122	C	1¼″ screenings
7	Gallatin	Harrisburg No. 5	Eagle Valley	145	A	Mine run
8	Wabash	Friendsville	Mt. Carmel	122	C	Largely 2″ or 3″ screenings with some lump
9	St. Clair	Herrin No. 6	Belleville	126	C	Mine run. Considerable fine coal included
10	Saline	Harrisburg No. 5	Saline	137	B	Stoker, 1½″ by 10 mesh
11	Vermilion	Danville No. 7	Danville	125	C	Small stoker, 1″ by 8 mesh
12	Sangamon	Springfield No. 5	Springfield	121	C	Largely stoker, 1″ by 5/16″, with some 5/16″ by 0
13	Randolph	Herrin No. 6	Southwestern Illinois	126	C	Crushed 1½″ by ¾″
14	Christian	Herrin No. 6	Central Illinois	123	C	1½″ screenings
15	Williamson	Herrin No. 6	Franklin-Williamson	133	B	1½″ dedusted screenings
16	Knox	Rock Island No. 1	Northwestern Illinois	123	C	Stoker, 1″ by ¼″

[a] Designation of mining districts approximately as used in: Bement A., Illinois coal: Illinois Geol. Survey Bull. 56, p. 23, 1929.

[b] Average heating value, expressed in hundreds of B.t.u. per pound on a moist mineral-matter-free basis, for face samples reported up to October, 1934. See: Cady, Gilbert H., Classification and selection of Illinois coals: Illinois Geol. Survey Bull. 62, 354 pp., 1935.

head track, trolley, and chain hoist simplified the hoisting and moving operations.

A three-surface vibrating screen, accommodating wire-mesh screens 17 by 32 inches in size, was used for the screening operations, and a small jaw crusher and a 12 by 10-inch smooth surface double-roll crusher were used for crushing.

PROCEDURE

In brief, the flow of work involved obtaining a truck-load of coal from a selected mine, sizing the coal, preparing from it two lots of improved quality (reduced mineral matter content), and testing a lot of sized but otherwise untreated coal and the two improved lots with standardized tests in a stoker-boiler unit. At the same time, samples were obtained for subsequent chemical and petrographic analyses, so that a mass of data relating to the combustion, chemical, and petrographic characteristics of all the test coals was built up.

Salient details of the source of the samples, methods of preparation, and nature of chemical and petrographic analyses are given below.

SOURCE OF COAL SAMPLES

Fifteen shaft mines throughout the State of Illinois, producing coal from all commercially important seams and in all major mining districts (excluding strip mines), were selected (table 1 and fig. 3).

The county average of rank index[3] of the coals tested ranged from 121 to 145, as

[3] Heating value, moist mineral-matter-free basis, expressed in hundreds of B.t.u. per pound.

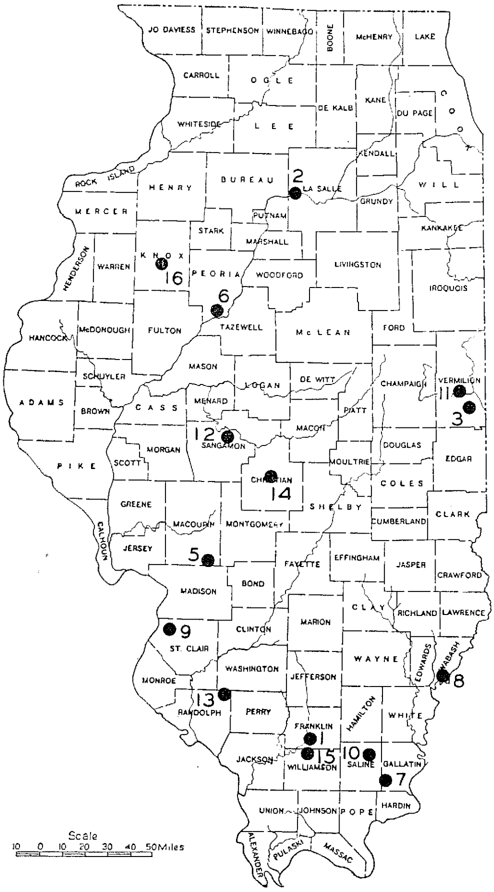

Fig. 3. Location of mines from which samples were obtained.

noted in table 1. This represents nearly the complete range of rank index variation for Illinois coal, extending from 112 to 145. The only coal available with rank index lower than 121 is strip-mine coal, which was avoided throughout because of possible effects due to weathering.

Preparation

A fixed size range of one-half inch square hole by 8 mesh was selected and used throughout the tests. A study of the effect of size on combustion is the objective of a separate investigation. The selected size was well adapted to the concentrating table, and discrepancies due to sampling and segregation in handling were minimized by the small absolute size and the narrow size range.

With the exception of test coal 1A, all sizing was done with the vibrating screen. The nominal size of coal 1A as obtained was 7/16-inch by 10 mesh, and it received no further preparation. The other test coals were passed over a one-half inch screen, and the oversize was crushed and passed over the screen a second time, this being repeated if necessary. Minus 8-mesh particles were sampled, weighed, and discarded.

The concentrating table was used to produce a coal of reduced mineral matter content (identified by the suffix letter B) from the raw coal (identified by the suffix letter A). This operation was carried out in such a way that there was a commercially reasonable recovery, usually of the order of 80 to 90 percent.

The adjustments of the concentrating table were varied during an initial trial period as appeared to be necessary for the coal being prepared. The recirculation equipment (p. 11) permitted experimentation for any desired length of time. When a visually satisfactory separation was obtained, with approximately the desired amount of recovery, preparation of the test coal was begun and carried through without further change in the adjustments.

In most cases a coal of still lower mineral matter content (identified by the suffix letter C) was then prepared, using the table or the zinc chloride solution, or both. This operation was carried out without regard to the maintenance of a commercially reasonable percentage of recovery; the major intent was to produce, from the quantity available, a coal with the greatest possible change in characteristics from the original. The only limitation was the need for approximately 1500 pounds for sampling and combustion testing.

Each washed coal was surface dried, without heat, in an effort to produce a washed coal having a moisture content similar to that of the corresponding raw coal. Coals 5B and $5B^1$ were exceptions; they were dried in a gas-fired oven, with resulting moisture contents less than half of that of coal 5A.

Coals 5B[1] and 6B[1] were substantial duplicates of coals 5B and 6B, respectively, with regard to preparation procedure and to resulting ash content.

Coal 12A[1] was prepared by adding to coal 12C crushed and sized clinker produced in burning coal 12B in an amount calculated to bring the resulting ash content up to that of the raw coal, 12A.

Chemical Analysis

A sample of from 100 to 150 pounds from each of the 43 coals was crushed and riffled to a portion of about two pounds for the chemical tests, which were conducted under the direction of O. W. Rees, Head of the Analytical Chemistry Division of the Illinois Geological Survey. Standard methods of the American Society for Testing Materials[4] were used for the proximate and ultimate analyses, and for the determination of heating values and ash fusion temperatures. Varieties of sulfur were determined according to Powell and Parr.[5] For the property of plasticity, the Gieseler test[6] was used for the majority of the coals. For ignitibility, the procedure developed by the Coal Research Laboratory of Carnegie Institute of Technology[7] was used. Chemical fusain was determined by a method suggested by Fuchs and his associates.[8]

Petrographic Analysis

The petrographic work, in which the percentages of vitrain, clarain, durain, and fusain were estimated, was conducted by B. C. Parks. The method used involved a microscopic examination of each of a number of closely sized fractions prepared from a sample of the coal to be analyzed. A thorough review of the subject and description of the technique has been prepared for separate publication.[9]

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 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, and then 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. Moving 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
10:50 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.

[4] Standard methods of laboratory sampling and analysis of coal and coke: A.S.T.M. Designation D271-44.

[5] Powell, A. R., with Parr, S. W., A study of the forms in which sulfur occurs in coal: Univ. of Ill. Eng. Exp. Sta. Bull. 111, 66 pp., April 1919.

[6] Brewer, R. E., Plastic and swelling properties of bituminous coking coals: U. S. Bur. Mines Bull. 445, pp. 109–111, 1942.

[7] Sebastian, J. J. S., and Mayers, M. A., Coke reactivity determination by a modified ignition point method: Ind. Eng. Chem., vol. 29, p. 1118, October 1937.

[8] Fuchs, Walter, Gauger, A. W., Hsaio, C. C., and Wright, C. C., The chemistry of the petrographic constituents of bituminous coals. Part I, Studies on Fusain: Pa. State College, Min. Ind. Exp. Sta. Bull. 23, 43 pp., 1938.

[9] Parks, Bryan C., Studies in the petrographic analysis of broken coal by the particle count method: Illinois Geol. Surv., Rept. Inv. In preparation.

1:15 p.m.	End of test period with stoker operating 45 min. 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).
	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.

The weights of all coal placed in the hopper, and of the coal, clinker, fly ash, and refuse removed were recorded. The refuse was sampled and analyzed for percentage of ash. This information enabled the calculation of the average relationship between the loss in weight of the stoker-boiler unit and the coal burned.[10]

The average difference between the inlet and outlet boiler-water temperature was determined for 20-minute intervals for the test with continuous stoker operation, and for each hour for the three tests with intermittent stoker operation. Overall averages of these temperature differences for each operation rate were determined. Overall averages for each operation rate were also obtained for "density" of smoke, pressure in the stoker windbox, temperature of the room, temperature of the stack gases during stoker operation, percentage of CO_2 in stack gases during stoker operation, rate of water flow through the boiler, boiler output, and coal burning rate.

COMBUSTION RATING FACTORS

As stated in the discussion of the scope of the investigation, some indicators were devised for all listed performance characteristics (p. 7), except odor given off by the clinker and quietness of operation. These indicators were all based upon objective measurements, with the exception of clinker characteristics. A brief description of these indicators follows.

Cost of Heat

The cost of heat can be readily computed if the amount of heat that can be obtained from a pound of coal and the cost of the coal are known. The former can be determined by fairly standard laboratory procedures, which were followed for all reported tests. With these standard tests, the heat output of the boiler, which is called "heat obtained" in this report, is the product of the difference in temperature between the inlet and outlet water and the quantity of water flowing through the boiler.

It should be recognized that the actual quantity of heat obtained per pound of coal will be dependent upon the heating plant used for the tests. Therefore the values for heat obtained should be considered as relative, and are given in absolute terms only as a convenience. In fact, the figures do not represent the total amount of heat that would be given up to the house with the unit because of radiation from the heating plant, including the chimney. A discussion of these losses is given in University of Illinois Experiment Station Bulletin No. 189.[11]

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

[11] Willard, Arthur C., Kratz, Alonzo P., and Day, Vincent S., Investigation of warm air furnaces and heating systems, Part IV: Univ. Ill. Eng. Exp. Sta. Bull. 189, pp. 46–55, 1929.

Attention Required

The attention required by a stoker-fired heating plant depends upon many things. One major item is the frequency of required cleaning periods, which is generally related to the quantity of ash. Another is the quantity of clinker to be removed, which is equal to the quantity of ash, if it is a good stoker coal. Thus the percentage of ash in a coal is one index of the amount of attention required.

Other factors include the characteristics of the clinker. It is generally considered desirable for clinkers to have a high density (to minimize volume removed) and to be tough (to enable removal without shattering). However, the clinker should not be so hard that it is difficult to break it into pieces that are easy to handle. The clinker should not stick to the hearth or combustion chamber walls, nor tend to form within the stoker retort. A major requirement is that the ash fuse into a clinker so that none must be removed in loose form.

It is evident that judgment concerning clinkering characteristics is largely based upon personal opinions and that such characteristics do not readily lend themselves to objective tests. A subjective ranking varying from 0 (unsatisfactory) to 5 (ideal) was made at the time of clinker removal. In common with all subjective rankings, its value is limited.

Ability to Maintain Desired Temperature in the Home

The ability of a heating plant to maintain the desired temperature within a home is generally thought to be governed by the heating plant and its controls. Nevertheless, the fuel burned may exert a powerful influence. For example, if the coal does not burn uniformly it is possible that too little heat will be supplied during a period of poor combustion to maintain the desired temperature, even though the stoker operates continuously.

The magnitude of the variation of the instantaneous rate of heat release is frequently not realized. Figure 4 shows this variation in rate of heat release with one of the coals tested that did not burn uniformly. The stoker was operating continuously throughout the period illustrated. Even the most uniformly burning coal varied somewhat in rate of heat release, as shown by figure 5.

An indicator of the magnitude of this variation is the ratio of minimum rate of heat release to the average rate of heat release. Therefore the heat release for each 20-minute interval of the test with continuous stoker operation was determined, and the minimum value was divided by the average to give the required ratio. The ratio of the minimum to average rates of heat release was also determined for the tests

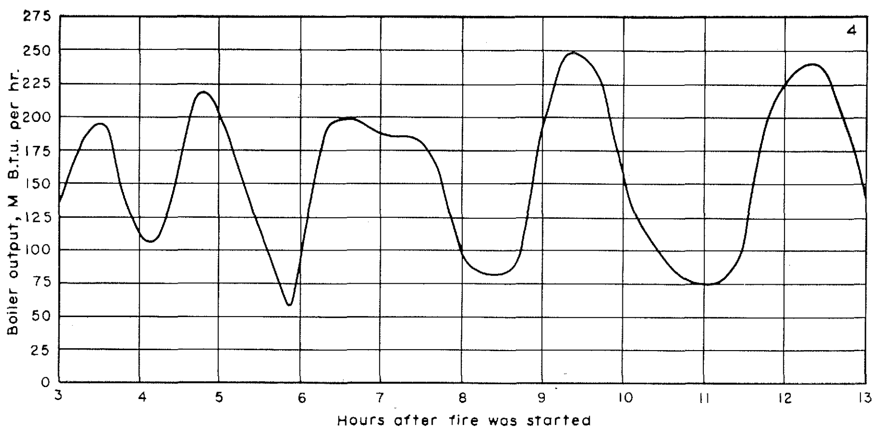


FIG. 4. Variation in heat output during continuous stoker operation with coal 9A, a relatively non-uniformly burning coal.

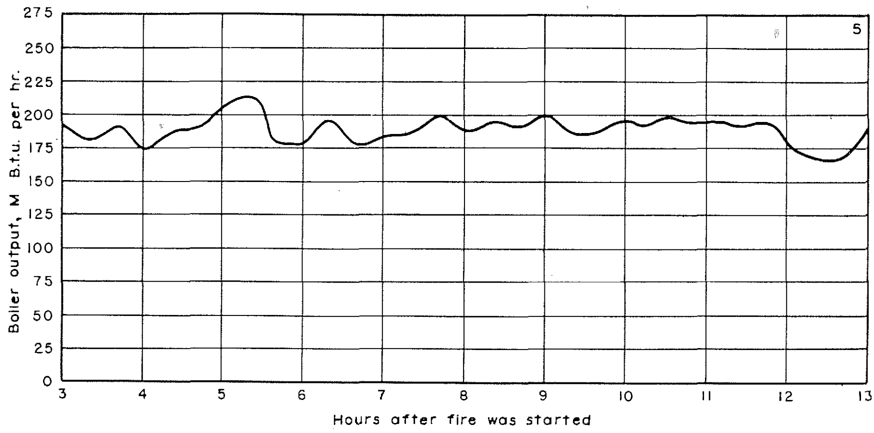


FIG. 5. Variation in heat output during continuous stoker operation with coal 15C, a relatively uniformly burning coal.

with 45, 30, and 15 minutes of stoker operation per hour. The cycle of operation for these tests was considered to be 60 minutes. It is recognized that the determination of absolute minimum value requires tests of infinite length. However, each test had a sufficient number of cycles to furnish a fairly reliable indicator of this combustion characteristic.

The ability of a heating plant to maintain uniform temperatures will probably be influenced by the constancy of the heat release at any one operation rate. This characteristic was expressed as the average percentage variation of the rate of heat release, for relatively short intervals of time, from the average rate of heat release for the test. The intervals arbitrarily selected were 20 minutes for the test with continuous stoker operation, and 60 minutes for the other three rates.

The responsiveness of the fire is an important factor when quick heat is desired after a prolonged hold-fire period, such as occurs when the house temperature is reduced during the night. "Responsiveness" in the present report is the average rate of heat release from the boiler for the first 30 minutes of stoker operation following the 50-hour hold-fire period. Only one test was made for each coal, because the time required for duplicate tests was not thought to be warranted. The values indicated should not be considered as representative, but as single examples. Another factor closely connected with the responsiveness of the fire after a prolonged "off" period is the responsiveness after a shorter "off" period, such as caused by thermostatic control during normal operation. This factor was measured by determining the amount of heat released during the first five minutes of stoker operation following a 45-minute "off" period, and was classified as "pick-up." The values given are averages of 40 cycles.

Some stoker-fired heating systems occasionally release sufficient heat after the stoker is shut off (by thermostatic or other type of control) to cause the temperature to rise above that desired. If so, the home owner would favor a coal furnishing the least amount of heat after the stoker shuts off. A measure of this tendency was made by determining the amount of heat released during the first five minutes after the stoker is shut off during the test period with 15 minutes of stoker operation per hour. The value given is the average for 40 cycles, and is called "overrun." Overrun is also an indicator of the responsiveness of the fire to control.

Smoke Emitted

It is difficult to measure the quantity of smoke that passes out the stack during combustion. However, a record of the opacity of the stack gases can be made fairly conveniently with the apparatus described (p. 9). It should be recognized that the record obtained does not give a quantitative measure of "smoke" for several reasons. Included is the fact that the velocity of the smoke particles through the beam of light is not constant. For example, with other factors constant, a drop in stack temperature from 1000° F. to 635° F. results in a 25-percent decrease in velocity of the stack gas. If the velocity of the smoke particle is considered equal to that of the gas, only three-fourths the amount of smoke would pass out the stack at the lower temperature for the same reading of the smoke density indicator. This range in stack temperature could readily occur when testing poor coals.

With intermittent stoker operation, the possible variation between smoke density and weight of the solid particles can be even greater, for the stack temperature not only drops a greater amount when the stoker shuts off, but the actual flow by weight of stack gas is reduced to a very small amount. Thus the volume of gas passing out the stack is extremely low, and a rather limited amount of "smoke" by weight passing out the stack per unit of time will result in a relatively opaque gas. This fact should always be remembered when records show that with a domestic stoker, the smoke density is greatest just after the stoker stops. This does not necessarily mean that the rate of the "smoke" emission during this off period is greater than during operation.

In any event the smoke produced when using a properly adjusted domestic stoker is not a serious problem, so elaborate equipment and highly accurate measurements were not considered warranted.

Ability to Maintain Fire at Low Rates of Operation

A satisfactory stoker coal must provide a responsive fire without giving off an appreciable quantity of heat. The most desirable coal in this respect would be the one that maintained the most responsive fire with the lowest combustion rate. As the length of time required to determine the lowest operation rate for each coal would be prohibitive, it was arbitrarily decided that any coal that would maintain a responsive fire with the stoker operating approximately 3 minutes out of each 1¾ hours would be considered excellent in this respect. All coals were thus checked.

APPEARANCE OF FUEL BED AND FIRE

Some householders may judge the suitability of a coal for domestic stokers by the appearance of the fuel bed and fire. This is rather unfortunate since the appearance may be very misleading. A level fuel bed, burning uniformly across the hearth, so often pictured, seldom exists in practice.

Although visual inspection alone is not an adequate basis for judging stoker coal performance, it may aid in assigning the cause for non-uniform combustion. Thus, motion pictures of the fuel bed furnish a useful record. Such pictures are not amenable to presentation in a written report except for enlargement of isolated frames.

RESULTS

Correlation of Combustion Results with Chemical and Petrographic Analyses

Before discussing the results of the tests, it seems desirable to point out that the exact duplication of any single test can not be expected for several reasons. Included among these is the fact that coal is not a homogeneous substance, and no two loads, or even pieces of coal, are exactly alike. Consequently different results may be well expected, with the amount of variation dependent upon the uniformity of the coal. Errors of measurement also prevent the exact duplication of results. These errors are quite small with the present equipment, but still exist. The results of a few duplicate tests indicate that 200 or 300 B.t.u. per pound is the least variation in heat obtained that should be considered significant. The least significant variations for the other combustion rating factors are probably two percentage figures for uniformity, 3,000 B.t.u. per hour for responsiveness, 2,000 B.t.u. per hour for pickup, and 3,000 B.t.u. per hour for overrun.

The results discussed are all based upon tests of Illinois coals Although the range in characteristics is quite large, the coals are limited to the high volatile bituminous group. The conclusions reached are meant to apply to Illinois coals, and no extrapolation of results to out-of-state coals has been attempted. The data reported were obtained from the tests on the stoker-boiler unit previously described. However, it is thought that the coals would exhibit the same relative performance characteristics in other domestic heating units of this general type. Several tests on duplicate coals with a stoker-furnace unit that was available supported this conclusion.

Reference in the following discussion to degree of correlation existing between various items is based upon judgment of the usefulness of the graphs from the standpoint of estimation of one item from knowledge of another. The use of statistical methods to evaluate degree of correlation, while possible, did not appear to be warranted. The data are presented in full in the appendix.

1. Heat Obtained

The amount of heat that was obtained from each coal was very nearly directly proportional to the heating value of the fuel, on the as-fired basis, as determined in a cal-

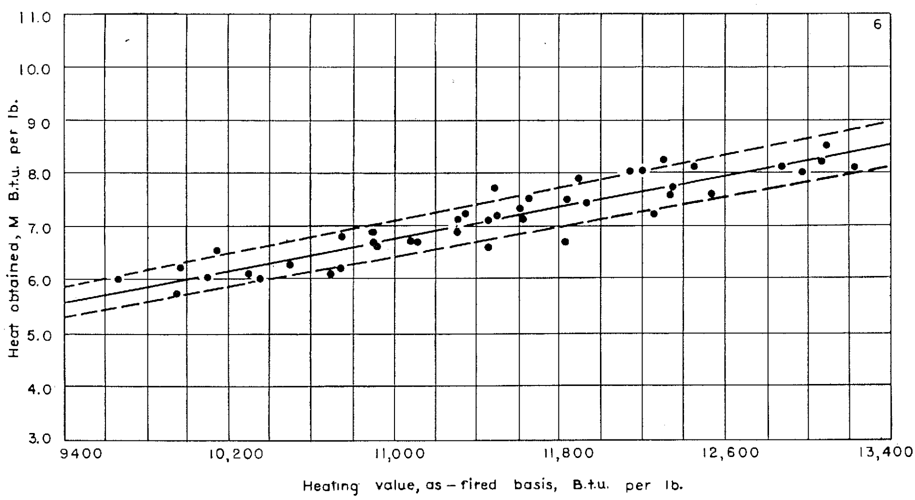


FIG. 6. Relationship of heat obtained per pound of coal to heating value, on the as-fired basis.

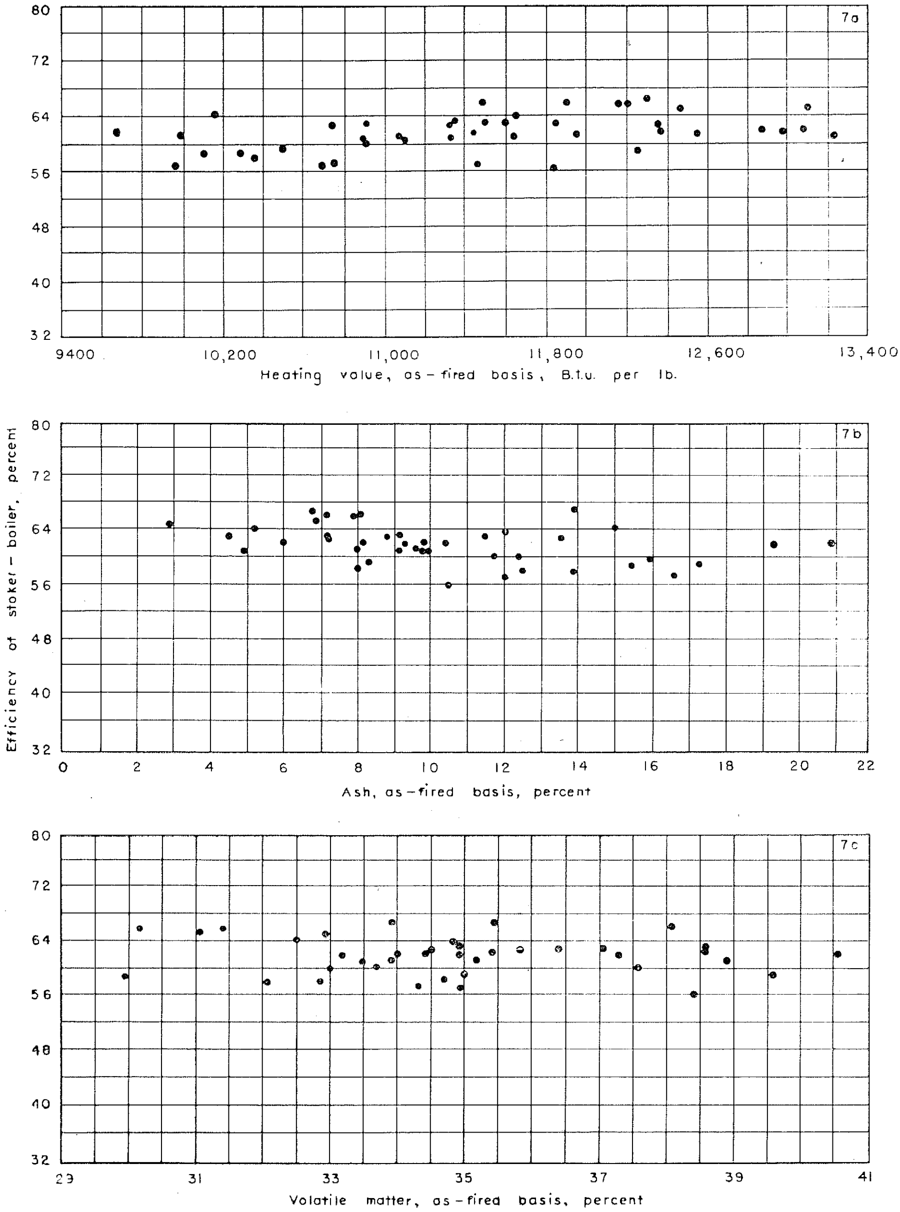


FIG. 7. Relationship of efficiency of stoker-boiler to (*a*) heating value, (*b*) ash, and (*c*) volatile matter, on the as-fired basis.

orimeter (fig. 6). The solid line appears to be the best single line to represent the points shown. All points falling within the dotted lines are within 5 percent of the value indicated by the solid line. It will be observed that most of the points plotted are within the ± 5-percent lines.

No evidence of unusual test or sampling errors could be found that would account for the variations exceeding 5 percent. Thus while the heat that will be obtained from Illinois coals can generally be closely predicted from knowledge of the heating value, exceptions are quite probable.

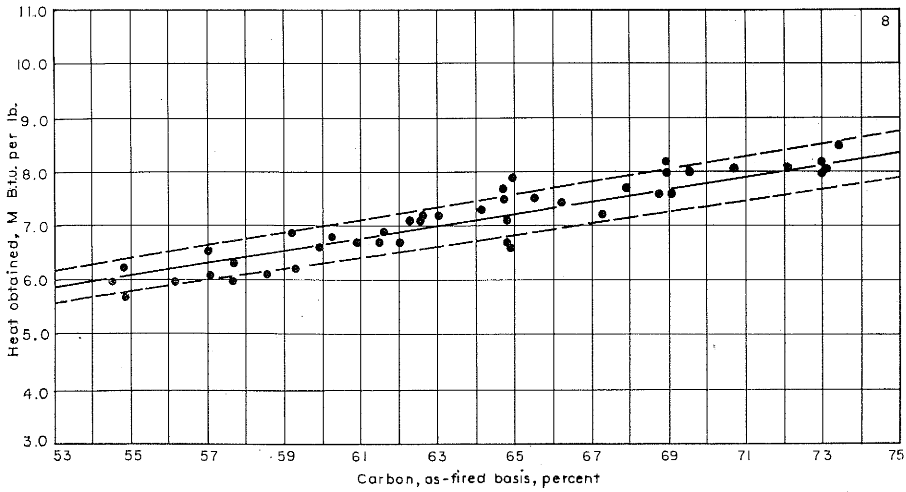


FIG. 8. Relationship of heat obtained per pound of coal to percentage of carbon, on the as-fired basis.

Attention should be directed to the fact that the line indicated as the best for the points plotted is not an exact proportionality, owing to a slight increase in efficiency[12] of the heating plant with an increase in the heating value of the coal, as indicated by figure 7a. The increase in efficiency for the range of heating value represented was about 5 percent, although the coal with the lowest heating value (coal 8A) actually burned with a higher efficiency than did the coal with the greatest heating value (coal 7C). This emphasizes the risk in making all-inclusive generalizations.

Figures 7b and 7c also show the relationships between efficiency and the percentages of ash and volatile matter as determined by chemical analysis. No marked trends are indicated.

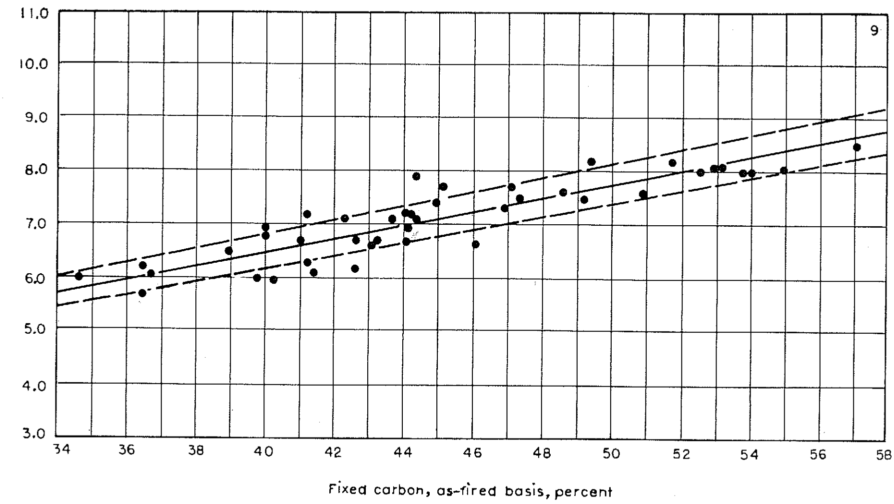
It might be well to emphasize that as far as cost of heating is concerned, the product of efficiency and heating value, which is called "heat obtained" in this report, is the governing factor. In addition, the term efficiency has several meanings, which often lead to misunderstandings, so its use is minimized in this report.

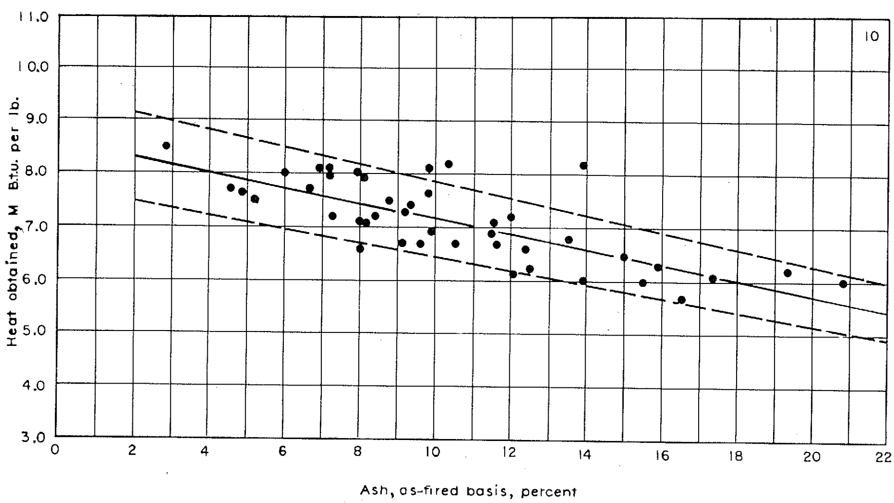
[12] The term efficiency as used in this report is the ratio of the heat absorbed by the boiler water to the heat of complete combustion, per unit weight of fuel burned.

The heat obtained from the coals tested was also nearly directly proportional to the percentage of ultimate carbon, on the as-fired basis (fig. 8). There were actually fewer points outside the ± 5-percent lines with the carbon curve than with the heating value curve. However, this correlation with carbon is not as useful as that with heating value, because the former is more difficult to determine by present methods used in the chemical laboratory.

Heat obtained also exhibited a strong correlation with fixed carbon (fig. 9) although not quite as good as with heating value (fig. 6) or ultimate carbon (fig. 8). The correlation of heat obtained with the percentage of ash should probably be considered as only fair, but it is a useful one because it is easily determined in the laboratory. Figure 10 shows that most of the values obtained fall within the ± 10-percent lines.

Some of the chemical items that furnished relatively poor correlations with heat obtained may be of interest. Although graphs are not shown in this report, little or no useful correlation was found to exist between the heat obtained and the British swelling index, volatile matter, moisture or vitrain.





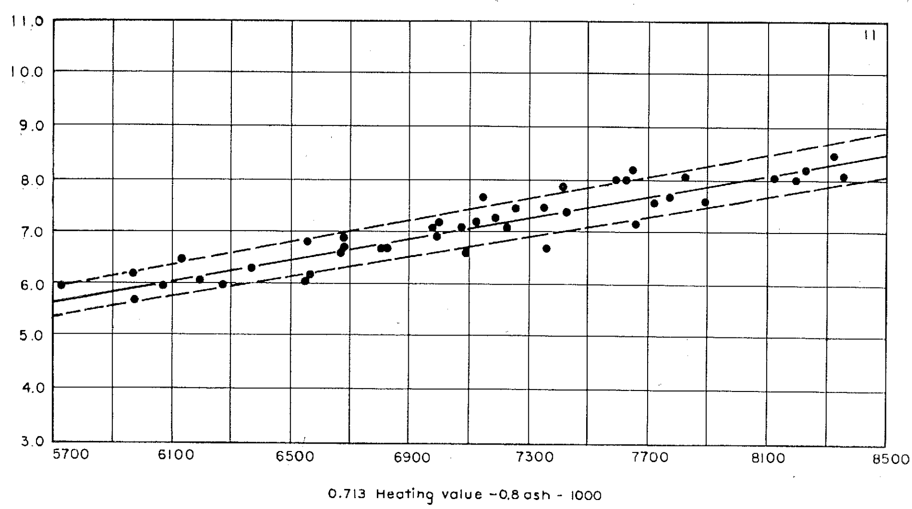


FIG. 9 (Top). Relationship of heat obtained per pound of coal to percentage of fixed carbon, on the as-fired basis.

FIG. 10 (Middle). Relationship of heat obtained per pound of coal to percentage of ash, on the as-fired basis.

FIG. 11 (Bottom). Relationship of heat obtained per pound of coal to the best fitting linear expression involving heating value and ash, on the as-fired basis.

Combinations of a few items given by chemical analysis were selected and the best co-efficients for a linear equation (equated to heat obtained) were calculated. The improvements in correlation over that obtained with heating value alone are very slight. Figure 11 is a graph of one of the combinations calculated. Three other combinations

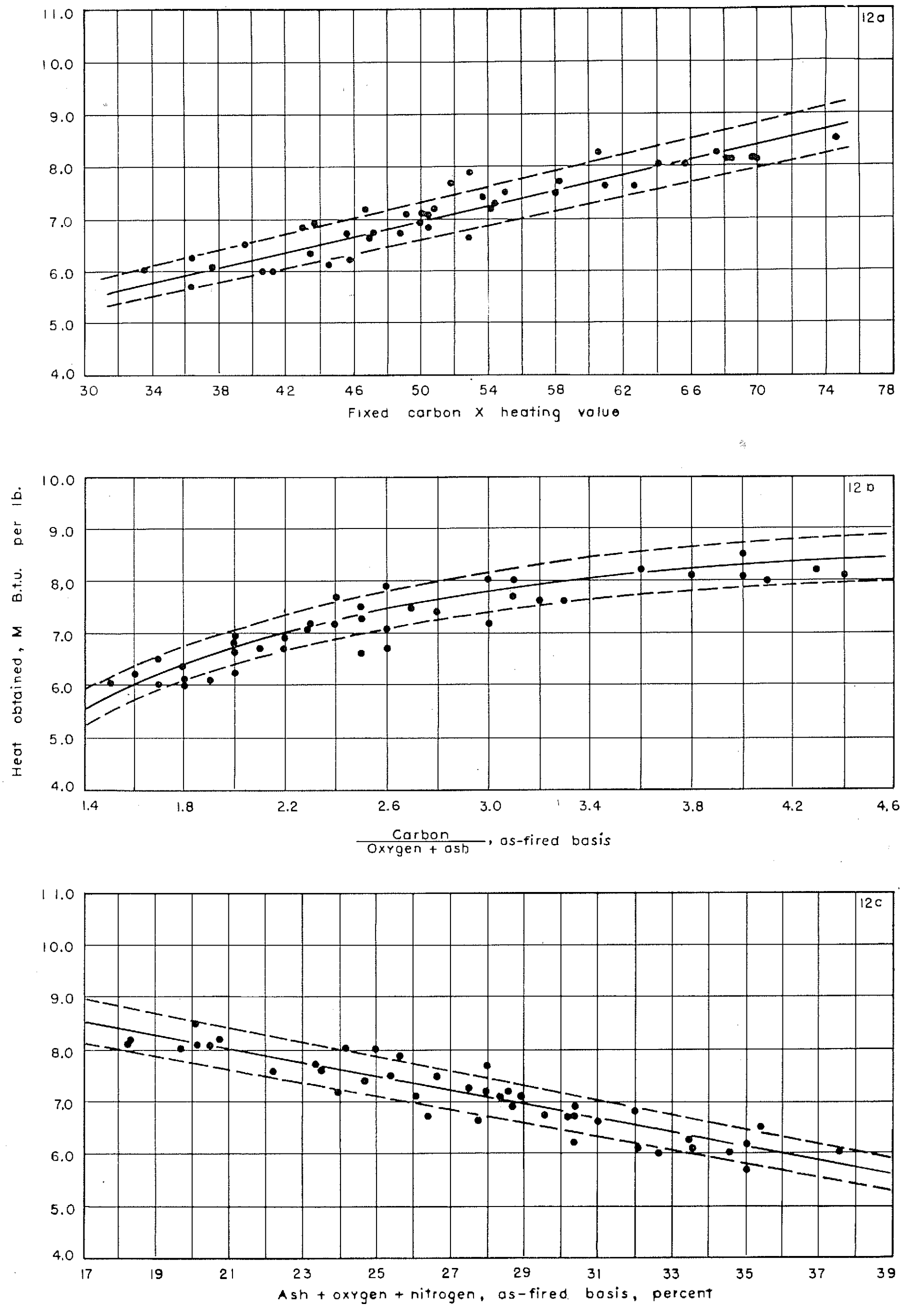


FIG. 12. Relationship of heat obtained per pound of coal to (*a*) fixed carbon × heating value; (*b*) ratio of carbon to oxygen plus ash; (*c*) percentage of ash + oxygen + nitrogen; all on the as-fired basis.

Table 2.—Relationship between Cost of Heat, Heating Value of Coal, and Cost of Coal

Cost of coal, dollars per ton	Heating value of coal, B.t.u. per lb. 9600	10000	10400	10800	11200	11600	12000	12400	12800	13200
	Relative cost of heat obtained									
3.00	27	26	25	24	23	22	21	20	19	19
3.25	30	28	27	26	24	23	23	22	21	20
3.50	32	30	29	28	26	25	24	23	22	22
3.75	34	32	31	29	28	27	26	25	24	23
4.00	36	35	33	31	30	29	28	27	26	25
4.25	39	37	35	33	32	31	29	28	27	26
4.50	41	39	37	35	34	32	31	30	29	28
4.75	43	41	39	37	36	34	33	32	30	29
5.00	45	43	41	39	38	36	35	33	32	31
5.25	48	45	43	41	39	38	36	35	34	32
5.50	50	47	45	43	41	40	38	37	35	34
5.75	52	50	47	45	43	41	40	38	37	36
6.00	55	52	49	47	45	43	42	40	38	37
6.25	57	54	51	49	47	45	43	42	40	39
6.50	59	56	53	51	49	47	45	43	42	40
6.75	61	58	56	53	51	49	47	45	43	42
7.00	63	60	58	55	53	50	49	47	45	43
7.25	66	63	60	57	54	52	50	48	47	45
7.50	68	65	62	59	56	54	52	50	48	46
7.75	70	67	64	61	58	56	54	52	50	48
8.00	73	69	66	63	60	58	55	53	51	50
8.25	75	71	68	65	62	59	57	55	53	51
8.50	77	73	70	67	64	61	59	57	55	53
8.75	79	76	72	69	66	63	61	58	56	54
9.00	82	78	74	71	68	65	62	60	58	56
9.25	84	80	76	73	70	67	64	62	59	57
9.50	86	82	78	75	71	68	66	63	61	59
9.75	88	84	80	77	73	70	68	65	63	60
10.00	91	86	82	79	75	72	69	67	64	62
10.25	93	89	84	81	77	74	71	68	66	64
10.50	95	91	87	83	79	76	73	70	67	65
10.75	98	93	89	85	81	78	75	72	69	67
11.00	100	95	91	87	83	79	76	73	71	68

which also give good correlation with heat obtained are: 1) the product of fixed carbon and of heating value (fig. 12a); 2) the ratio of carbon to oxygen-plus-ash (fig. 12b); and 3) ash plus oxygen plus nitrogen (fig. 12c). The product of fixed carbon and heating value will probably prove to be the most useful of this group.

The home owner is not primarily interested in the actual amount of heat that can be obtained from a pound of coal. His problem is one of relative costs. The relative cost of heat can be fairly readily calculated, if the cost of the coals and the amount of heat that is obtained per pound are known.

As the heat that can be obtained from a pound of coal can be closely predicted as indicated by figure 6, it is possible to approximate the cost of heat directly from knowledge of the heating value. Such calculations are given in table 2. The base cost of heat given in the table is that obtained with coal of 9600 B.t.u. per pound, on the as-received basis, and costing $11.00 per ton, which is assigned a value of 100. The figures for all other heating values and coal cost give the cost of heat relative to this arbitrarily selected base coal. The same general information contained in table 2 is given in figure 13.

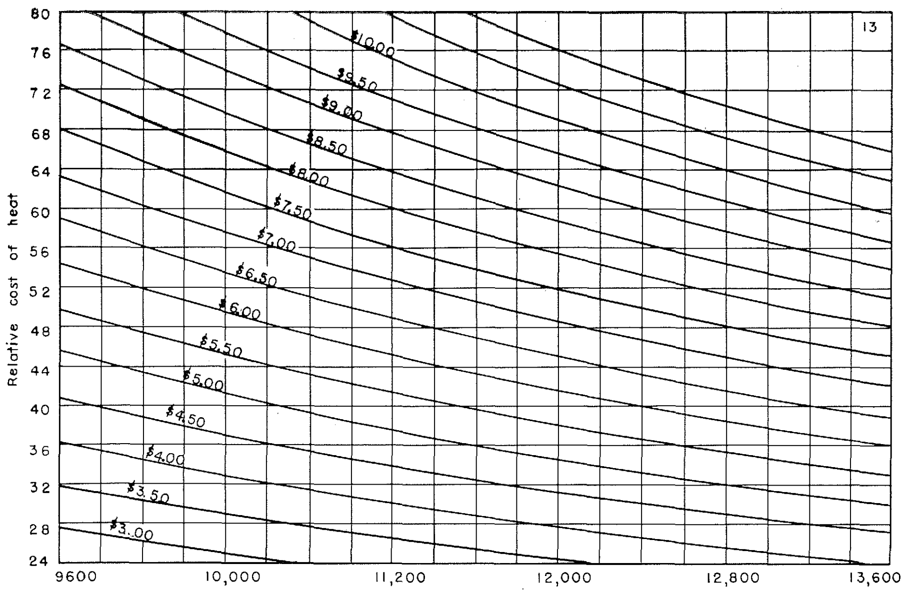


FIG. 13. Relative cost of heat, as affected by heating value and cost of coal.

For an example of the use of table 2, assume that information is desired regarding the relative cost of heating with two coals, called A and B. Coal A has a heating value of 11,600 B.t.u. per pound and costs $8.50 per ton. From the table it is found that its relative cost is 61. Coal B has a heating value of 10,400 B.t.u. per pound and costs $5.75 per ton. The table indicates its relative cost is 47. In other words, the ratio of heating costs would be 61 to 47, or approximately 23 percent less with coal B than with coal A. The same values can be obtained from figure 13.

2. UNIFORMITY OF COMBUSTION

Uniformity of combustion, expressed as the percentage variation from the average rate of heat release, correlated about equally well with chemically determined values for ash, mineral matter,[13] and sulfur on the as-fired basis. The general tendency was for more uniform combustion with a decrease in the percentage of these chemical items. The relationships are shown in figures 14, 15, and 16.

Exceptions to the general trend were numerous. The most notable exception in case of ash vs. uniformity was with coal 8A (20.8 percent ash) from Wabash County which had an average variation of only 8.3 percent.

One possible explanation is that this coal did not exhibit very strong coking tendencies, hence "coke tree" formation did not cause irregular combustion. The motion pictures taken of the fuel bed point to this explanation. Figure 17 is one view of the fire showing the lack of coke. The immense clinker which is shown certainly checked the fire, but did so in a fairly uniform manner as indicated by the relatively low percentage of variation. Coal 9A had approximately the same percentage of ash (19.3 percent) as 8A, but did not burn as uniformly (20.5 percent variation). Although the black and white picture of the fuel bed with coal 9A (fig. 18) does not differentiate coke and clinker, the original colored film makes possible definite identifications

[13] In the present report, mineral matter is assumed to be 1.08 × (Ash) + 0.55 × (Sulfur).

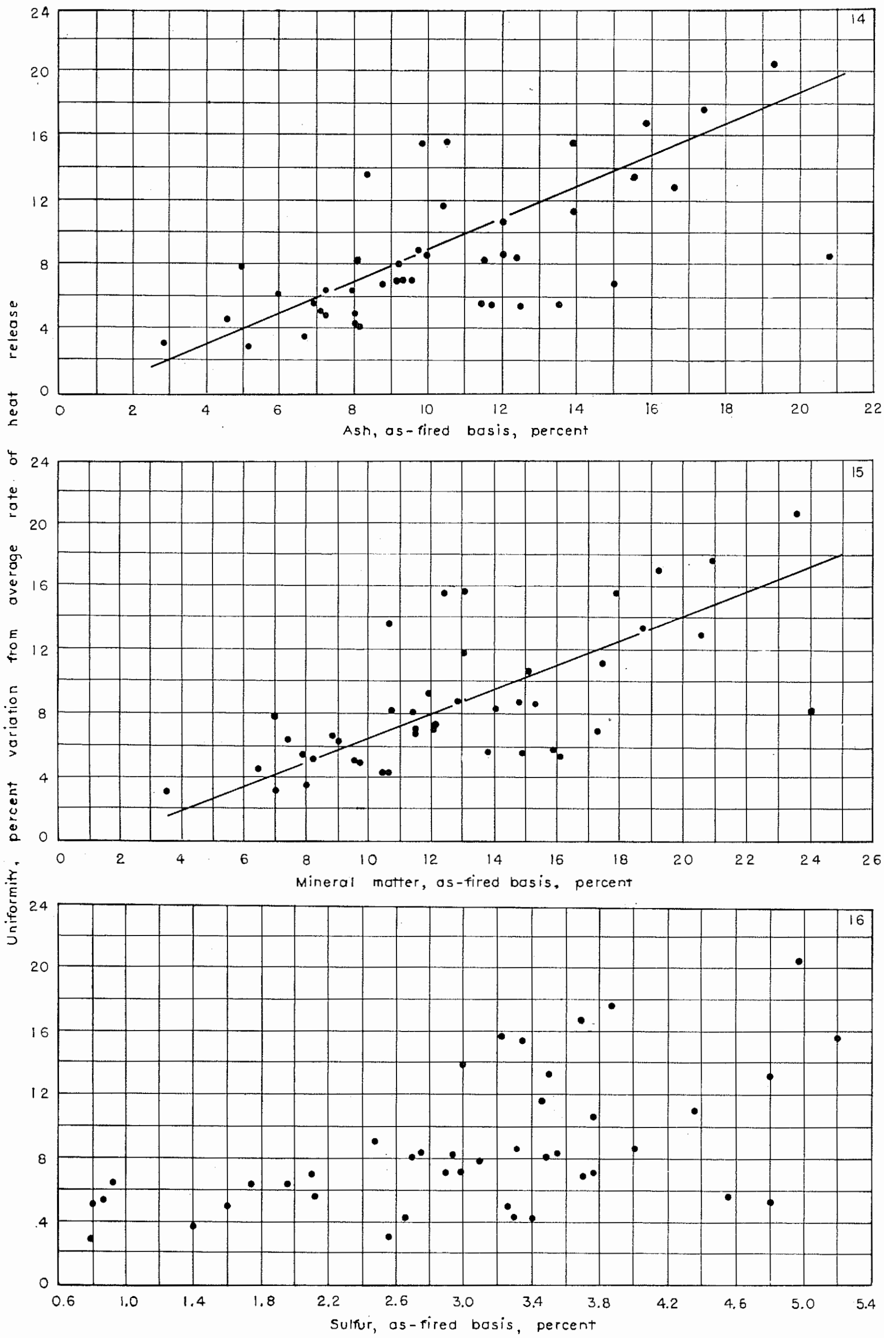


FIG. 14 (Top). Relationship of uniformity of combustion to percentage of ash, on the as-fired basis.

FIG. 15 (Middle). Relationship of uniformity of combustion to percentage of mineral matter, on the as-fired basis.

FIG. 16 (Bottom). Relationship of uniformity of combustion to percentage of sulfur, on the as-fired basis.

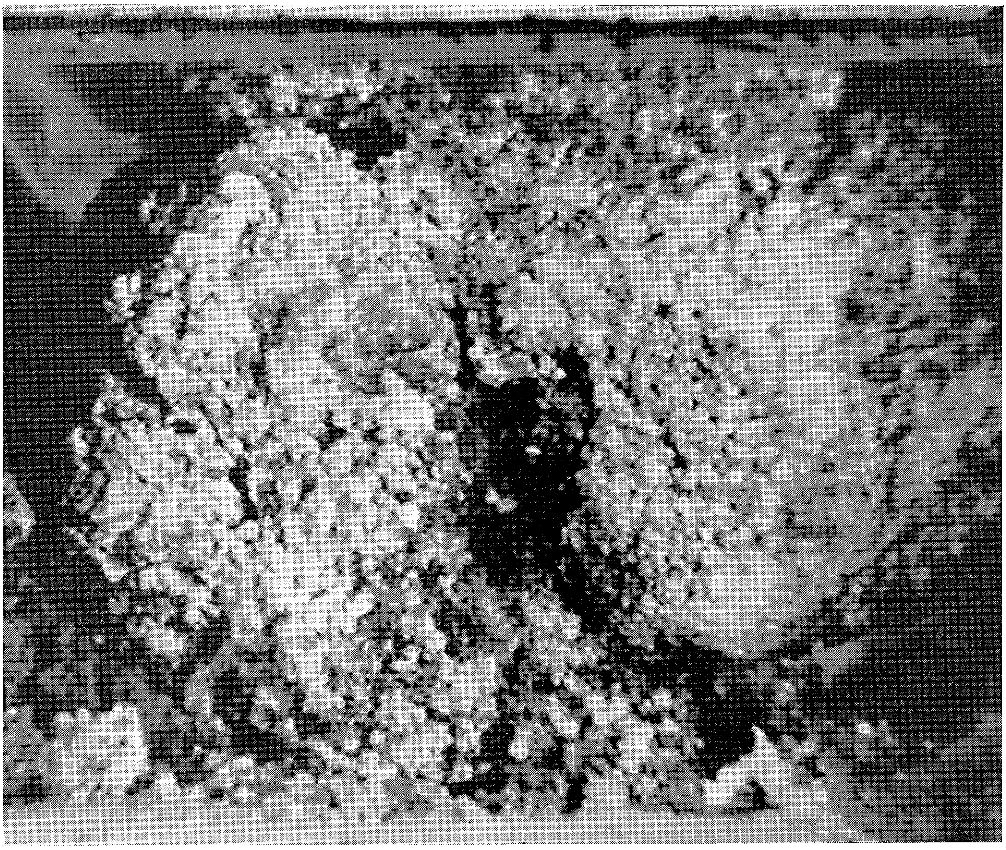


FIG. 17. View of fuel bed with large amount of clinker.

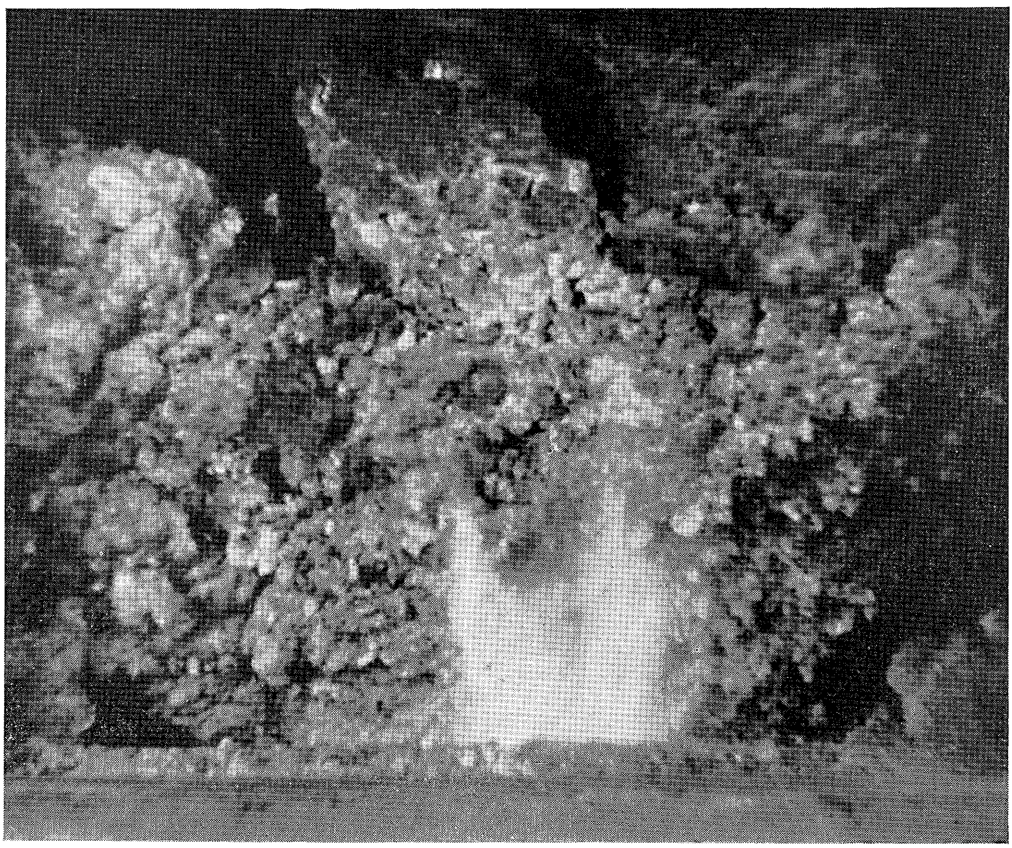


FIG. 18. View of fuel bed with considerable amounts of coke and clinker.

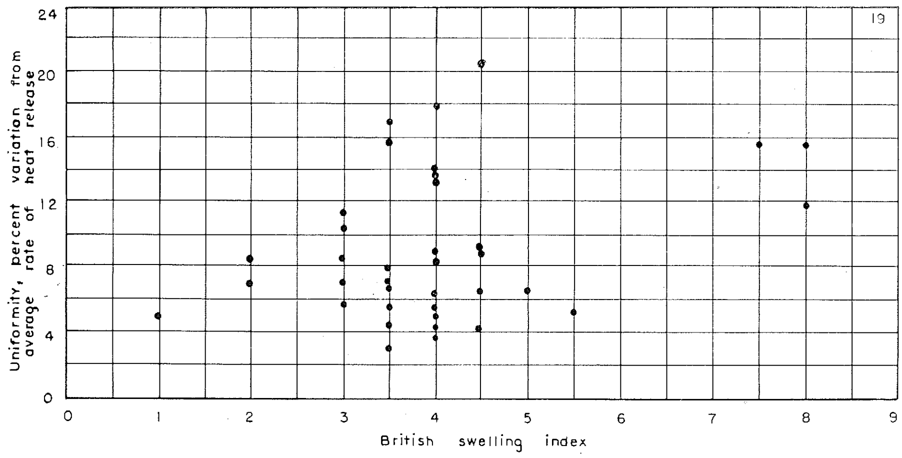


FIG. 19. Relationship of uniformity of combustion to British swelling index.

of the large solid mass in the foreground as clinker, and the two spires at the top of the picture as coke. The lower portions of the pieces of coke are hidden by the clinker. It is obvious that the amounts of both coke and clinker would influence the uniformity of combustion. Hence the more uniform combustion with coal 8A than with coal 9A might be attributed to the difference in coking tendencies, since their percentages of ash are comparable.

The British swelling index is commonly considered to be an indicator of coking tendency, and so an attempt was made to combine the percentage of ash and this swelling index in a manner that would give a useful correlation with uniformity of heat release. However, no systematic relationship could be found.

The correlation of uniformity of combustion and British swelling index alone is very poor, as indicated by figure 19. This figure

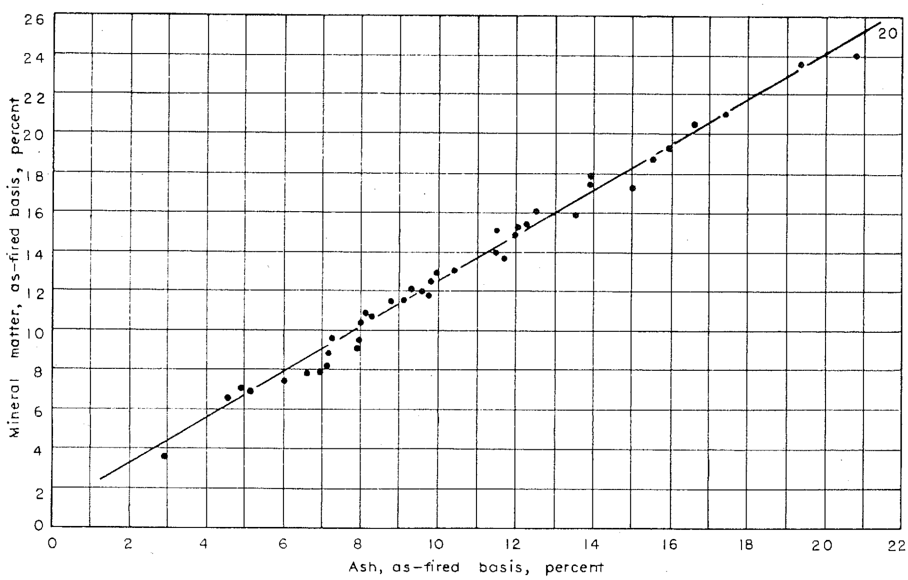


FIG. 20. Relationship of percentage of mineral matter to percentage of ash in coals tested, on the as-fired basis.

also indicates that the great majority of Illinois coals have a British swelling index in the 3 to 5 range, which is indicative of intermediate to weak coking tendency.

The uniformity vs. mineral matter graph (fig. 15) exhibits very nearly the same characteristics as the uniformity vs. ash graph, with coals 8A, 3A, 8B, 2A, 16A, 8C, 11B, 11C, and 7C still exhibiting the greatest variation from the curve drawn. This might be expected, because the percentages of ash and mineral matter in the Illinois coals tested exhibit a strong correlation as shown in figure 20.

When the percentages of sulfur were plotted against uniformity (fig. 16), it was found that the Wabash County coals (8 series) followed the indicated trend quite closely. Coals 2A, 16A, 11C, 11B, and 7C varied considerably from the general trend, as they did on the uniformity vs. ash graph, and also coals 11A and 9A.

The uniformity of combustion correlated fairly well with the percentage of vitrain (fig. 21) with the exception of the Wabash County coals. However, the maximum percentage of vitrain reported for any coal burned was less than 30 percent. Within the range of coals tested, those with the higher percentages of vitrain tended to burn more uniformly.

Numerous other single chemical items were plotted against the uniformity of combustion. Included were ultimate carbon, fixed carbon, moisture, Gieseler plasticity, heating value, oxygen, volatile matter, initial deformation temperature of the ash, softening temperature of the ash, and fluid temperature of the ash. The correlations were considered to be poor or non-existent in every case.

Several combinations including ash and sulfur; ash, sulfur and carbon-hydrogen ratio; and ash and ash-softening temperature were tried. Little or no improvement in correlation over that found with ash alone was evident.

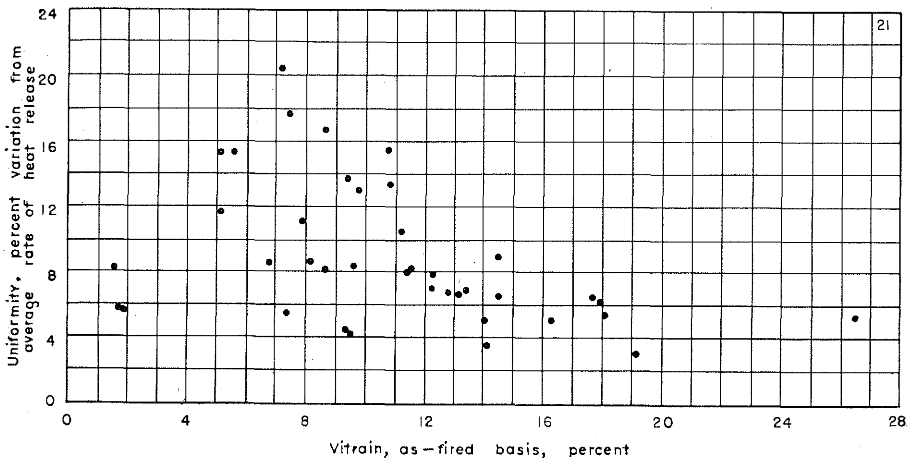


FIG. 21. Relationship of uniformity of combustion to percentage of vitrain.

3. RESPONSIVENESS

The responsiveness of the fire after a prolonged hold-fire period correlated fairly well with the percentage of ash in the coals (fig. 22). No definite reason could be found to explain the wide deviation of the group of six coals with approximately 9 percent ash that released heat to the boiler at a rate well above the apparent trend.

As coal was fed into the combustion chamber faster than it burned during the period when the responsiveness of the coal was measured, it would seem that there might be a useful correlation with some measure of ignitibility. However, the ignition temperatures reported were very nearly constant, and no correlation was evident.

The volatile matter is driven off rapidly after the coal comes into the combustion chamber, so that correlation between responsiveness and volatile matter seemed possible. However, the data (fig. 23) did not reveal such a correlation.

The value given as an index to responsiveness is not a measure of the amount of heat released by the coal, but of the rate of heat absorption by the boiler water. Because the clinker, ash, and fuel in the com-

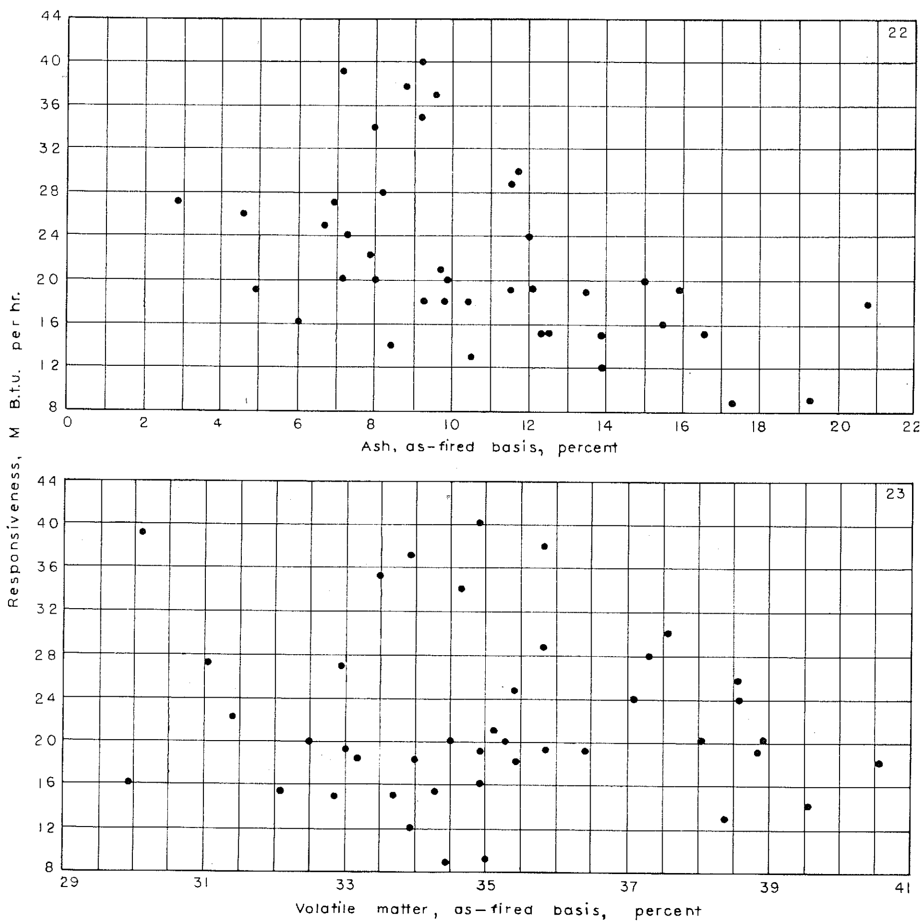


FIG. 22 (Top). Relationship of responsiveness of the fire after a prolonged hold-fire period to percentage of ash, on the as-fired basis.

FIG. 23 (Bottom). Relationship of responsiveness of the fire after a prolonged hold-fire period to percentage of volatile matter, on the as-fired basis.

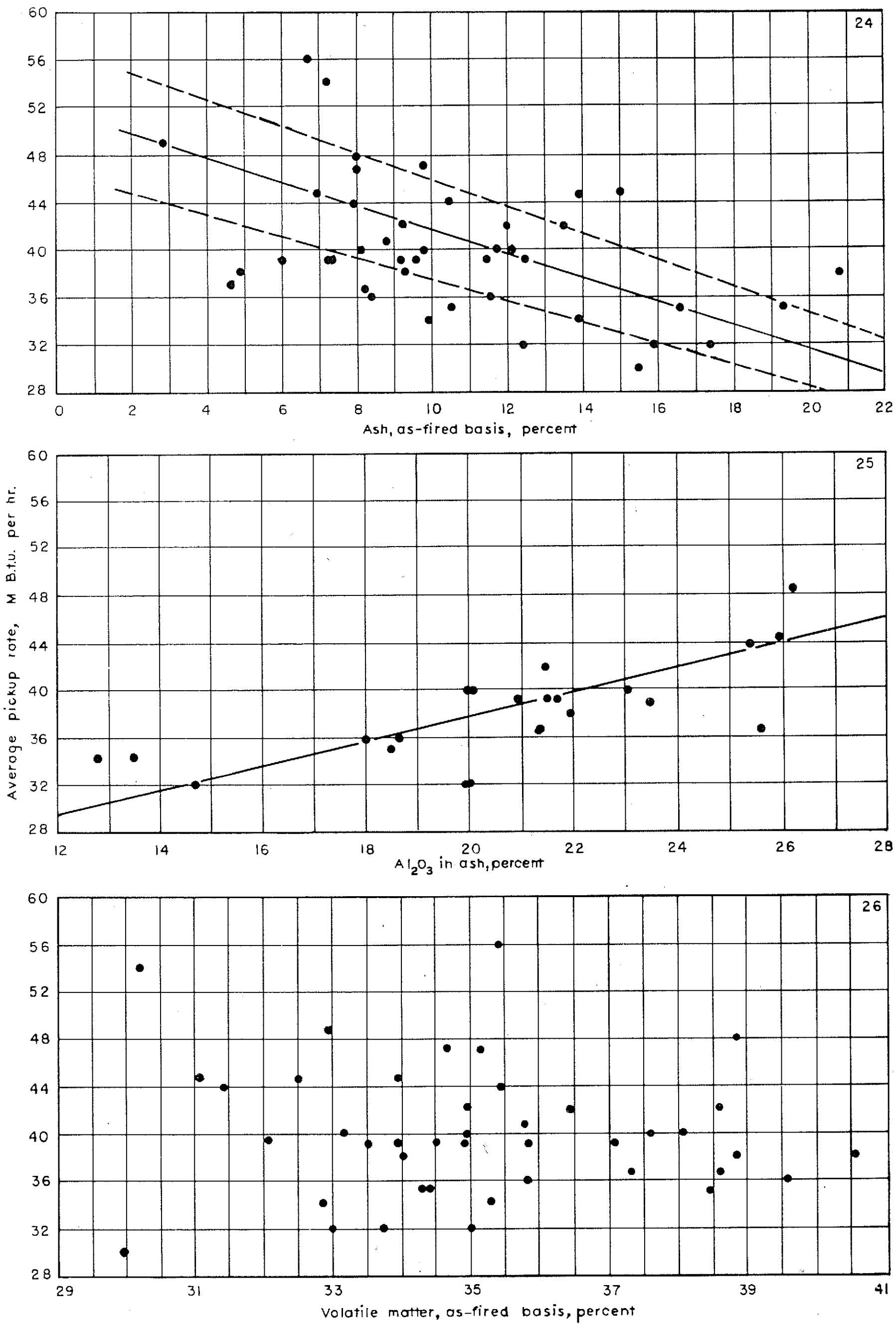


FIG. 24 (Top). Relationship of pickup rate after a 45-minute "off" period to percentage of ash, on the as-fired basis.

FIG. 25 (Middle). Relationship of pickup rate after a 45-minute "off" period to percentage of Al_2O_3 in the ash.

FIG. 26 (Bottom). Relationship of pickup rate after a 45-minute "off" period to percentage of volatile matter, on the as-fired basis.

bustion chamber are relatively cool after a prolonged hold-fire period, they will absorb heat during the early part of the operation period. The quantity of heat absorbed will be partially dependent upon the amount of clinker, ash, and fuel in the combustion chamber. It is therefore obvious that even if the rate of heat release were the same for all coals, the rate of heat absorption by the boiler would be less for the high-ash coals.

With the exception of mineral matter, all the other chemical items tried furnished either poor or no correlation with the responsiveness. Included were British swelling index, ultimate carbon, Gieseler plasticity, heating value, oxygen, sulfur, moisture, initial deformation temperature of the ash, softening temperature of the ash, and fluid temperature of the ash. Little or no correlation was evident between the percentage of vitrain and responsiveness.

4. PICKUP

One of the better indicators of pickup (defined on p. 17) was the percentage of ash on the as-fired basis, shown in figure 24. Numerous points fall outside the ± 10-percent lines. It is evident that the correlation is far from excellent.

Coal 8A again gave better performance than would be expected in view of its high ash content. In fact, its rate of pickup was greater than that of coal 16C which had less than 5 percent ash. Thus, while the pickup rate did generally increase with a decrease in ash, the performance of individual coals can not be predicted.

The heating value, sulfur, mineral matter, and carbon, on the as-fired basis, furnish about the same degree of correlation with pickup as the percentage of ash. A graph of the percentage of aluminum oxide in the ash vs. pickup rate indicates a fair correlation, as shown by figure 25, with a general increase in pickup accompanying an increase in Al_2O_3. Coals 3C and 1A, which furnished the greatest rate of pickup, were not included among the 22 coals for which the composition of the ash was determined. Unless these coals had more than 26 percent Al_2O_3 in their ash, which would not be expected, their high rate of pickup must be assigned to other causes.

Although during the pickup period the coal is fed into the combustion chamber faster than it is burned, the volatile matter is probably released as fast as the coal is fed. Thus, the volatile matter might be expected to serve as an indicator of pickup rate. However, figure 26 indicates that there is little or no correlation.

Other chemical and petrographic items that gave poor or no correlation with pickup rate were British swelling index, fixed carbon, moisture, ash fusion characteristics, Gieseler plasticity, and vitrain.

5. OVERRUN

The percentage of ash and the heating value of the coal, on the as-fired basis, give the best correlations with overrun (defined on p. 17) of those plotted. Neither is very good (figs. 27 and 28). The range in overrun for equal ash or heating value is quite large. The correlation of mineral matter, sulfur, and carbon, on the as-fired basis, with overrun rate was of the same general order as the correlations of overrun with ash and with heating value. The correlations between overrun rate and British swelling index, Gieseler plasticity, oxygen, volatile matter, ash fusion characteristics, and vitrain were either poor or non-existent.

6. CLINKER RATING

It is recognized that the subjective ratings of the clinker may not be strictly comparable because more than two years elapsed between removing the first and last clinker for the series of tests reported, and the successive ratings were probably biased in each case by comparison with the clinker last seen. In other words, the tendency would be to give the clinker a higher rating than proper if the clinkers recently removed had been very poor, and a lower rating if the previous ones had been excellent.

Some correlation is evident between the subjective clinker rating and percentage of ash (fig. 29), but the points are widely scattered from the general trend. One coal

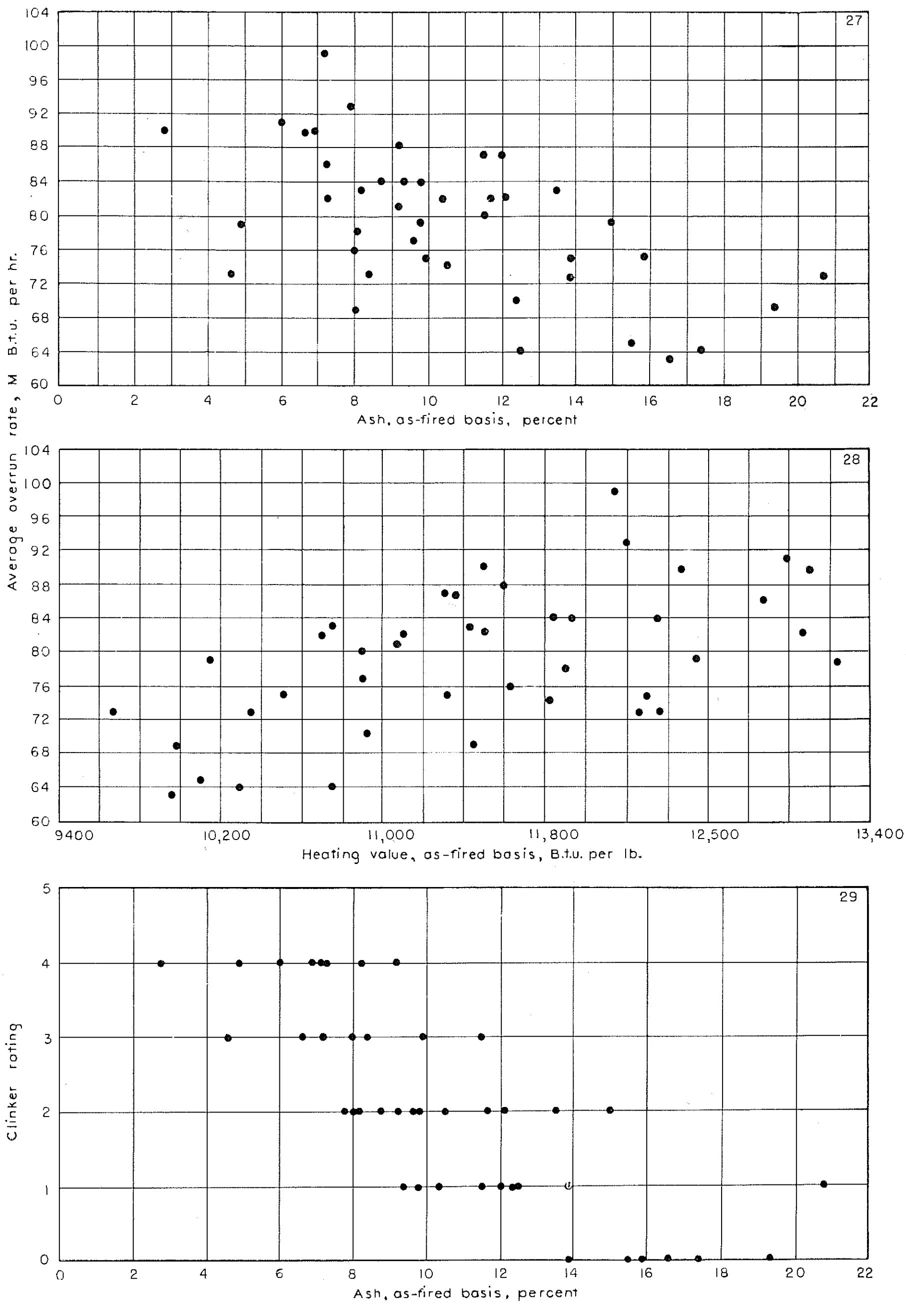
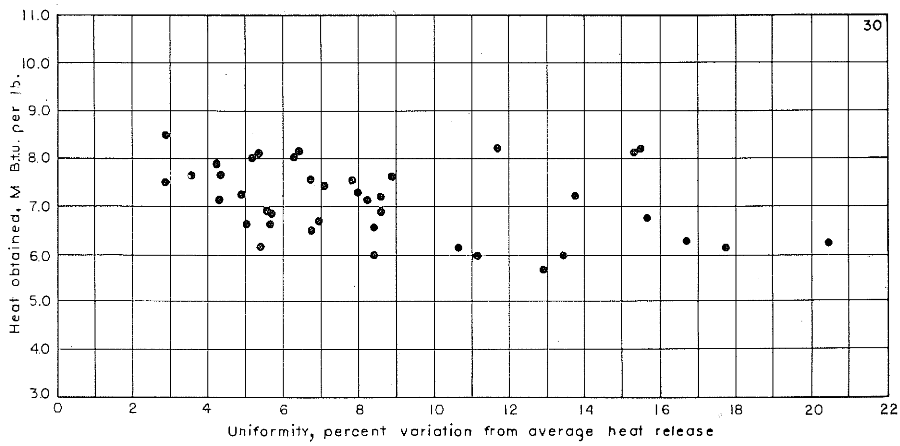
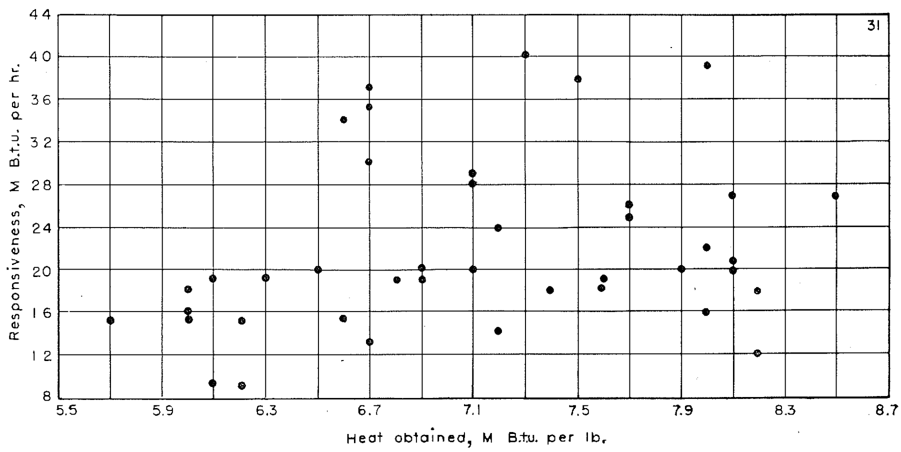


FIG. 27 (Top). Relationship of overrun rate after a 15-minute "on" period to percentage of ash, on the as-fired basis.

FIG. 28 (Middle). Relationship of overrun rate after a 15-minute "on" period to heating value, on the as-fired basis.

FIG. 29 (Bottom). Relationship of subjective clinker rating to percentage of ash, on the as-fired basis.





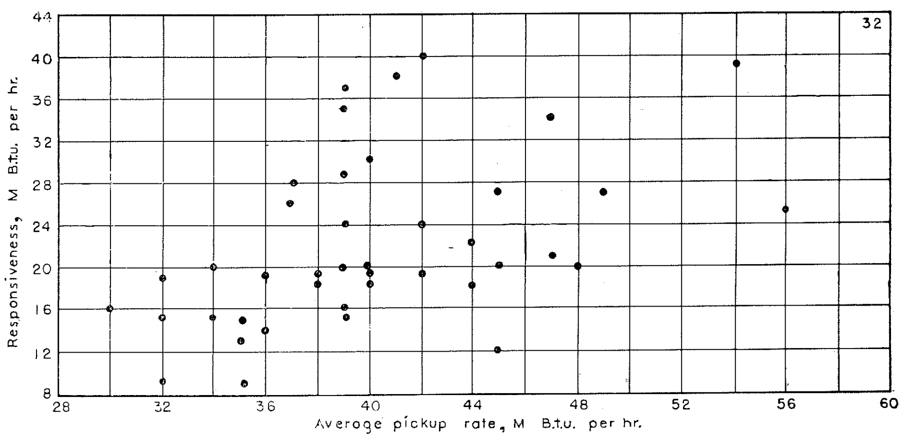


FIG. 30 (Top). Relationship of heat obtained per pound of coal to uniformity of combustion.

FIG. 31 (Middle). Relationship of heat obtained per pound of coal to responsiveness of the fire after a prolonged hold-fire period.

FIG. 32 (Bottom). Relationship of responsiveness of the fire after a prolonged hold-fire period to pickup rate after a 45-minute "off" period.

with a clinker rating of four had an ash content approximately equal to another with a rating of one. This overlapping is even more evident in intervening ratings.

The clinker rating was also plotted against the initial deformation, softening, and fluid temperatures of the ash. Little or no correlation was evident.

Correlations Between Combustion Characteristics

Little if any apparent definite relationship exists between the heat obtained from a coal and the uniformity with which it burns (fig. 30). Only one coal furnished more heat than the Gallatin County coals (7 series), but they were among the poorer coals in respect to uniformity. Several coals that furnished very low quantities of heat burned quite uniformly. However, the Franklin, Saline, and Williamson County coals ranked high in both categories.

The responsiveness of the fire to heat demand after a prolonged hold-fire period appeared to have only a slight correlation with the heat obtained as shown in figure 31. A slightly better correlation is shown in figure 32 between responsiveness and pickup. Figures 33 and 34 show that there is little correlation between uniformity of combustion and pickup or overrun. However, an increase in pickup is generally accompanied by an increase in overrun, as indicated by figure 35. Figure 36 shows that there is a very good correlation between the uniformity of combustion and the minimum rate of heat release divided by the average rate of heat release.

RANKING OF COALS

As has been stated, the coals can be ranked according to individual characteristics, but these individual characteristics can not be combined into a single overall rating, because their relative importance is not constant.

Table 3 lists some of the combustion and chemical properties of the coals tested in numerical order from good to poor. Although the coals from southern Illinois are generally superior in most of the characteristics listed, frequently the prepared coals from other fields, and occasionally a raw coal from the northern districts, are included with the superior coals.

Coal 15C furnished the greatest amount of heat per pound of coal of any tested. This coal was the float coal in a solution of approximately 1.3 specific gravity, and represented the lightest 44 percent of coal 15A. This low recovery, although not commercially practical, was of laboratory interest in an endeavor to secure an extreme improvement. It may be noted that the softening temperature of the ash was 250° F. less than with coal 15B. Nevertheless, some improvement over 15B occurred in nearly all the combustion characteristics.

This was not true with coal from Knox County (16 series). The lightest fraction did not in general perform more satisfactorily than the first upgrade, although its lower ash would be desirable.

The coals from La Salle County (2 series) ranked rather poorly from the standpoint of heat obtained, but remarkably high in uniformity of combustion.

The chief point of interest about the Gallatin County coals (7 series) was the lack of improvement resulting from the cleaning operations. Although all three of the series ranked high as far as heat obtained per pound was concerned, they were in the lower ranks for most of the other combustion characteristics. The moisture content of these coals is quite low in comparison with other Illinois coals.

Care needs to be exercised when using table 3 for a comparison of coals. For example, one of the poorer performing coals (6A) has the lowest percentage of volatile matter. This is a result of a high percentage of inerts, and the relative position of this coal would be shifted considerably if the volatile matter ranking were made on a moisture-and-ash-free basis.

TABLE 3.—COMBUSTION AND CHEMICAL PROPERTIES OF COALS TESTED.

Heat obtained		Uniformity		Responsiveness		Pickup		Overrun		Ash		Volatile matter		Fixed carbon	
Coal No.	M B.t.u. per lb.	Coal No.	Variation per cent	Coal No.	M B.t.u. per hr.	Coal No.	M B.t.u. per hr.	Coal No.	M B.t.u. per hr.	Coal No.	Per cent	Coal No.	Per cent	Coal No.	Per cent
15C	8.48	2C	2.9	13C	39.5	3C	56	5A	63	15C	2.8	6A	29.9	15C	57.1
7A	8.19	15C	2.9	1A	38.5	1A	54	2A	64	16C	4.6	1A	30.2	15B	54.9
15B	8.17	3C	3.6	5B[1]	37.9	15C	49	11A	64	9C	4.9	15B	31.1	1A	54.0
7B	8.16	16B	4.2	6B[1]	37.3	2B	48	6B	65	2C	5.2	15A	31.4	10C	53.8
7C	8.09	2B	4.3	6B	35.3	3B	47	3B	69	10C	6.0	2A	32.1	10B	53.2
10B	8.05	16C	4.4	3B	34.0	7C	47	9A	69	3C	6.7	3A	32.5	7C	52.9
15A	8.03	14C	4.9	8C	29.7	3A	45	12A[1]	70	15B	6.9	12A	32.8	15A	52.5
1A	8.02	3B	5.0	13B	29.4	7A	45	8A	73	1A	7.2	15C	32.9	7B	51.7
10C	8.01	1A	5.2	14B	28.0	15B	45	11C	73	10B	7.2	13A	33.0	10A	50.9
16B	7.86	2A	5.4	15C	27.2	7B	44	12A	73	14C	7.3	10A	33.2	7A	49.4
16C	7.73	15B	5.4	15B	27.1	15A	44	16C	73	15A	7.9	6B[1]	33.5	5B[1]	49.2
3C	7.68	16A	5.6	16C	25.8	8B	42	11B	74	2B	8.0	12A	33.7	9C	48.7
10A	7.63	8C	5.7	3C	25.2	9B	42	7A	75	3B	8.0	6B[1]	33.9	2C	47.3
9C	7.63	8B	5.7	9B	23.7	13C	42	12B	75	16B	8.1	7A	33.9	16C	47.1
2C	7.47	10C	6.3	14C	23.7	5B[1]	41	13A	75	14B	8.2	8A	34.0	13C	46.9
5B[1]	7.45	15A	6.4	15A	21.9	8C	40	2B	76	11C	8.4	5A	34.3	3B	46.1
5B	7.39	10B	6.4	7C	20.6	10A	40	6B[1]	77	5B[1]	8.8	9A	34.4	3C	45.2
13C	7.31	5B[1]	6.7	2B	20.4	14A	40	16B	78	6B	9.2	10B	34.5	5B	44.9
14C	7.22	3A	6.8	16B	20.3	16B	40	3A	79	13C	9.2	3B	34.7	13B	44.4
11C	7.22	6B[1]	6.9	3A	20.2	2A	39	7C	79	5B	9.3	2C	34.8	16B	44.4
9B	7.21	6B	6.9	12B	19.8	6B	39	9C	79	6B[1]	9.6	10C	34.9	11C	44.2
13B	7.12	5B	7.1	10B	19.5	6B[1]	39	16A	80	7C	9.8	13C	34.9	12B	44.2
2B	7.09	9C	7.9	14A	19.3	10B	39	6B	81	10A	9.8	14A	34.9	6B	44.1
14B	7.07	13C	8.0	9C	19.1	10C	39	7B	82	12B	9.9	11A	35.0	14C	44.1
12B	6.90	14B	8.2	16A	19.1	13B	39	8C	82	7B	10.4	7C	35.2	14B	43.7
16A	6.89	13B	8.2	8B	18.8	14C	39	14A	82	11B	10.5	12B	35.3	6B[1]	43.3
8B	6.75	8A	8.3	13A	18.6	5B	38	14C	82	13B	11.5	3C	35.4	12A[1]	43.1
6B	6.74	12A[1]	8.4	5B	18.4	8A	38	8B	83	16A	11.5	7B	35.4	2A	42.9
8C	6.71	12B	8.6	10A	18.2	9C	38	14B	83	8C	11.7	5B[1]	35.8	11B	42.6
11B	6.67	9B	8.6	8A	18.0	14B	37	5B	84	9B	12.0	13B	35.8	2B	42.3
6B[1]	6.65	10A	8.9	7B	17.6	16C	37	5B[1]	84	14A	12.1	16A	35.8	14A	41.4
3B	6.60	14A	10.6	10C	16.2	11C	36	10A	84	12A[1]	12.4	8B	36.4	13A	41.3
12A[1]	6.57	12A	11.1	6A	15.7	16A	36	10B	86	2A	12.5	14C	37.1	9B	41.2
3A	6.53	7B	11.8	12A	15.4	5A	35	9B	87	8B	13.5	14B	37.3	8C	41.1
13A	6.25	5A	12.9	12A[1]	15.0	9A	35	13B	87	7A	13.9	8C	37.6	6A	40.3
2A	6.21	6A	13.4	2A	14.6	11B	35	13C	88	12A	13.9	16B	38.1	8B	40.0
9A	6.18	11C	13.8	5A	14.6	12A	34	3C	90	3A	15.0	11B	38.4	16A	40.0
14A	6.11	7C	15.4	11C	13.7	12B	34	15B	90	6A	15.5	9B	38.6	12A	39.8
11A	6.09	7A	15.5	11B	12.6	11A	32	15C	90	13A	15.9	16C	38.6	3A	38.9
12A	6.04	11B	15.7	7A	11.7	12A[1]	32	10C	91	5A	16.6	9C	38.8	11A	36.6
8A	5.98	13A	16.8	11A	9.3	13A	32	15A	93	11A	17.4	2B	38.9	5A	36.5
6A	5.96	11A	17.8	9A	9.2	6A	30	1A	99	9A	19.3	11C	39.6	9A	36.4
5A	5.71	9A	20.5							8A	20.8	5B	40.6	8A	34.6

EFFECT OF CLEANING UPON QUALITY OF COAL

The production of coals with characteristics appreciably different from those of the raw coals was the primary purpose of the coal cleaning work. The examination of the degree of change in quality resulting from the cleaning operation was an objective of secondary importance.

It was not considered advisable nor within the scope of the investigation to standardize on some one element of the cleaning operation, such as percentage of reject, percentage of reduction in mineral matter, percentage of final mineral matter, or, in the case of the concentrating table, the setting of the various operating variables. Such a selection and its numerical value would have been arbitrary, and no single choice could be expected to be applicable to all Illinois coals.

The criterion for the tabling which produced the "B" coals was the establishment of an optimum degree of separation of coal

Each Property is Listed in Numerical Order from Good to Poor

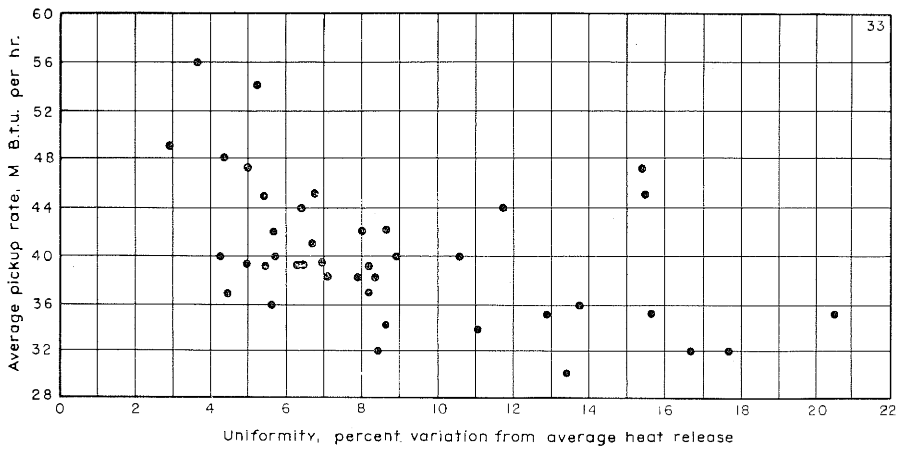
Sulfur		Carbon		Oxygen		I.D. of Ash		S.T. of Ash		F.T. of Ash		Carbon ÷ available Hydrogen		Heating value	
Coal No.	Per cent	Coal No.	Per cent	Coal No.	Per cent	Coal No.	°F	Coal No.	°F	Coal No.	°F	Coal No.	Ratio	Coal No.	B.t.u. per lb.
15C	.79	15C	73.4	7A	5.4	15B	2460	15B	2550	15A	2650	1A	20.2	7C	13220
1A	.80	7C	73.2	7B	6.4	15A	2320	15A	2530	15B	2650	15A	20.1	15C	13100
15B	.85	7B	73.0	7C	7.0	1A	2190	15C	2300	8A	2620	15B	20.0	7B	13080
15A	.91	10C	73.0	10B	11.7	8B	2180	1A	2260	16C	2570	15C	19.2	10C	12990
3C	1.41	10B	72.1	10C	11.7	8C	2180	8C	2250	8B	2530	3A	19.1	10B	12880
3B	1.59	15B	70.7	10A	11.8	15C	2130	8B	2230	15C	2530	14A	19.1	9C	12530
10C	1.74	1A	69.6	5B	14.2	3A	2120	3A	2170	16B	2530	14B	18.9	15B	12460
10B	1.95	9C	69.0	11C	14.2	3B	2110	16C	2170	8C	2510	14C	18.7	16C	12360
3A	2.09	7A	68.9	15B	14.6	8A	2070	3B	2160	1A	2460	3A	18.6	10A	12330
8C	2.10	15A	68.9	11B	14.7	13C	2060	16B	2160	3A	2420	13C	18.6	7A	12300
8B	2.12	10A	68.8	9A	14.8	16B	2060	3C	2140	13C	2400	9C	18.5	11C	12260
10A	2.47	16C	67.9	11A	15.2	14C	2050	13C	2130	13B	2390	3B	18.4	15A	12200
2C	2.56	11C	67.3	1A	15.4	16A	2040	2A	2110	11C	2380	5B[1]	18.4	1A	12160
16C	2.65	5B	66.2	5B[1]	15.4	16C	2040	7B	2110	3C	2370	8C	18.4	5B	11940
13C	2.72	5B[1]	65.5	8A	15.4	3C	2030	8A	2110	3B	2370	12A[1]	18.3	16B	11890
8A	2.77	3B	64.9	15A	15.4	14B	2030	14C	2110	14A	2360	5B	18.2	5B[1]	11830
6B	2.93	16B	64.9	9B	15.5	5B	2020	7C	2100	14B	2360	10B	18.2	11B	11830
13B	2.93	2B	64.8	15C	15.7	14A	2020	16A	2100	5A	2350	13B	18.2	2C	11650
6B[1]	2.98	11B	64.8	9C	16.0	5A	2000	14B	2090	5B	2340	2C	18.1	2B	11630
11C	3.00	2C	64.7	13B	16.2	13B	2000	2B	2080	6B	2340	8B	18.1	13C	11600
9C	3.09	3C	64.7	13A	16.4	5B[1]	1980	5B	2080	11A	2340	9B	18.0	3C	11490
11B	3.28	13C	64.2	16B	16.5	2A	1970	13B	2080	14C	2340	13A	18.0	14C	11490
14C	3.26	14C	63.1	2A	16.9	6B	1970	5B[1]	2060	6B[1]	2330	10C	17.9	3B	11450
2B	3.32	9B	62.7	2B	17.0	7B	1970	5A	2050	12A	2330	12A	17.8	14B	11430
9B	3.32	13B	62.7	13C	17.0	6A	1960	14A	2050	5B[1]	2320	12B	17.8	9B	11360
7C	3.35	14B	62.4	8B	17.1	6B[1]	1960	2C	2040	9B	2320	11C	17.7	13B	11330
16B	3.40	8C	62.0	8C	17.2	7C	1950	6B	2040	10A	2290	2B	17.6	12B	11320
7B	3.46	12B	61.6	5A	17.4	9C	1940	6B[1]	2040	10C	2290	6B[1]	17.6	8C	11110
14B	3.48	6B	61.5	12A[1]	17.5	7A	1930	9C	2010	16A	2290	16C	17.3	6B	11070
6A	3.54	6B[1]	60.9	12B	17.6	2B	1920	6A	2000	10B	2280	2A	17.1	12A[1]	10920
12A[1]	3.55	8B	60.3	16C	17.6	9B	1920	7A	2000	7C	2260	7C	17.1	16A	10920
5B	3.68	12A[1]	59.9	12A	17.7	10A	1920	13A	2000	7B	2250	10A	17.0	6B[1]	10900
13A	3.69	2A	59.3	16A	17.9	2C	1910	11A	1990	9C	2250	6B	16.9	8B	10750
5B	3.76	16A	59.2	6A	18.0	11B	1910	11B	1990	11B	2240	8A	16.9	2A	10740
14B	3.77	14A	58.6	15B	18.3	12A[1]	1910	9B	1980	9A	2230	11B	16.9	14A	10720
11A	3.88	13A	57.7	14A	19.0	11A	1890	10C	1980	6A	2220	6A	16.8	13A	10510
12B	4.01	12A	57.6	14B	19.0	11C	1890	11C	1970	2A	2210	5A	16.6	12A	10350
12A	4.37	11A	57.1	3A	19.2	9A	1880	10B	1960	13A	2210	9A	16.5	11A	10300
16A	4.55	3A	57.0	6B	19.3	13A	1880	9A	1950	2C	2200	16B	16.3	3A	10150
2A	4.77	6A	56.2	14C	19.4	10B	1870	12A[1]	1950	7A	2160	11A	16.1	6A	10100
5A	4.79	5A	54.8	6B[1]	19.5	12A	1870	10A	1940	2B	2130	16A	16.1	9A	9990
9A	4.97	9A	54.8	3C	20.0	12B	1870	12A	1940	12A[1]	2120	7B	16.0	5A	9960
7A	5.21	8A	54.5	2C	20.4	10C	1860	12B	1920	12B	2080	7A	15.7	8A	9660

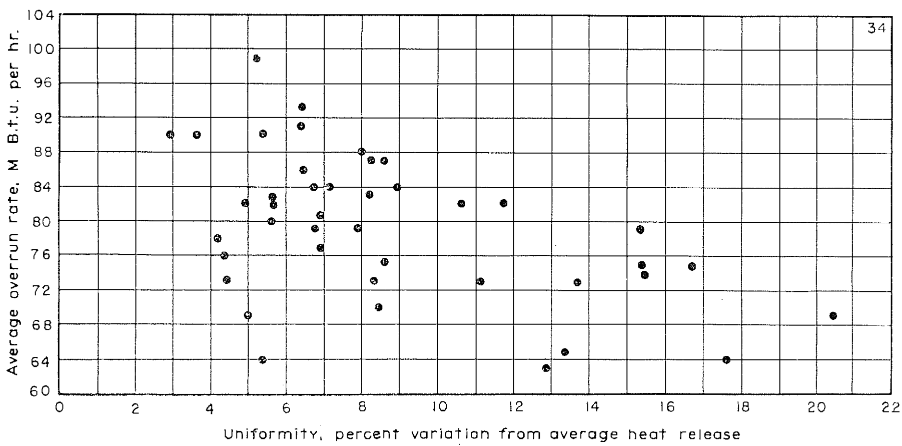
from impurities as judged visually. Different coals produced varying percentages of reject and of improvement, but it is felt that a reasonable simulation of commercial cleaning was achieved. Indeed, it is probable that the results were conservative compared to those obtainable in a commercial installation, using unlimited coal, unlimited time, and larger equipment.

As has been mentioned the "C" coals were produced in an endeavor to achieve an extreme change in characteristics from the "A" coals and a significant change in characteristics from the "B" coals, without regard to the percentage of reject in the process.

In general, the procedure thus provided coals of the same size range at three quality or grade levels.

Percentage of reject was considered to be the ratio of material rejected to the sum of material rejected and cleaned coal, disregarding the substantially constant quantity





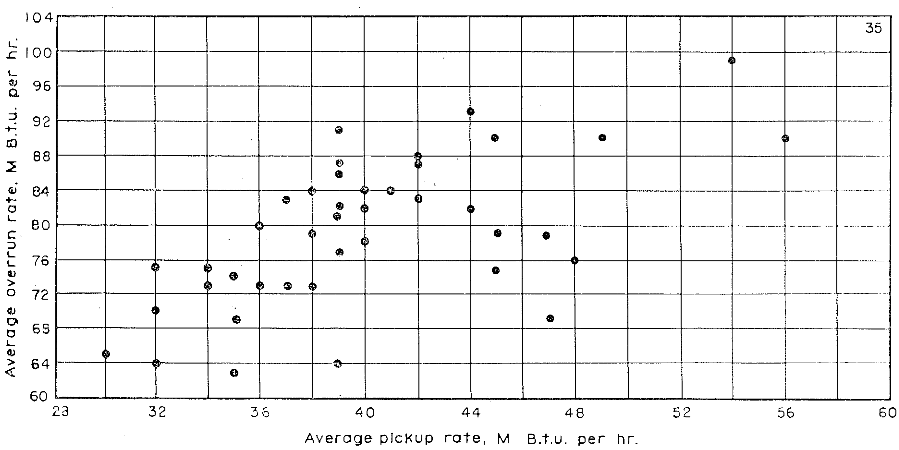


FIG. 33 (Top). Relationship of uniformity of combustion to the pickup rate after a 45-minute "off" period.

FIG. 34 (Middle). Relationship of uniformity of combustion to the overrun rate after a 15-minute "on" period.

FIG. 35 (Bottom). Relationship of overrun rate after a 15-minute "on" period to pickup rate after a 45-minute "off" period.

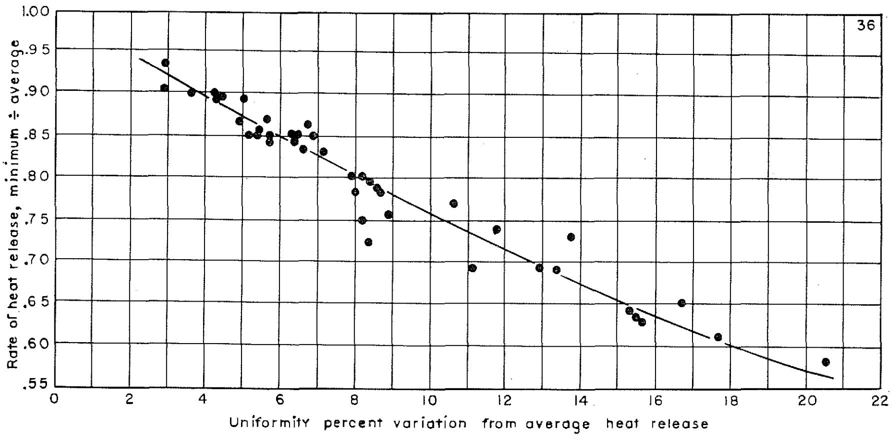


FIG. 36. Relationship of uniformity of combustion to the minimum rate of heat release divided by the average rate of heat release for all stoker operation rates except hold-fire.

of coal remaining on the table and in the conveying equipment at the end of the cleaning run.

The changes in quality characteristics resulting from the coal cleaning work in this investigation are discussed in the following sections. The summaries apply only to the coals actually cleaned and should not be considered as necessarily representative of all cleaned and all raw Illinois coal.

Effect upon Chemical Characteristics

Tables 4 and 5 summarize the data relating to type of cleaning, amount of reject, and extent of improvement in quality in the 28 coals cleaned in the course of the present investigation, as reflected in changes in mineral matter, ash, sulfur, and heating value. Figure 37 illustrates certain of the data shown in table 4. Unless otherwise stated, all data are reported on the dry basis and in terms of raw coal.

a). Mineral matter content. — The major purpose and effect of any coal cleaning process is reduction of mineral matter, defined for the purposes of the present report as $1.08 \times (\text{Ash}) + 0.55 \times (\text{Sulfur})$. In table 5 the changes in mineral matter are summarized and classified by method of cleaning. The majority of coals were prepared by tabling, with the operating adjustments such that no more than a commercially reasonable amount of raw coal was rejected. This was arbitrarily taken as a maximum of 25 percent, although for any given coal and process, the percentage of reject most financially attractive depends upon a variety of market considerations. In Illinois cleaning plants, the proportion of reject averages about 16 percent of raw coal,[14] and in at least one plant it is understood to be about 25 percent.

For the 17 coals cleaned by the use of the table alone, so operated that less than 25 percent of raw coal was rejected, mineral matter was reduced an average of 33.9 percent, varying from 13.5 to 47.7 percent (table 5, column 1). On the basis of percentage points the average reduction was 7.2, varying from 1.3 to 11.7.

Variations in degree of improvement in the up-grading of coals are due primarily to differences in specific gravity distribution. A raw coal containing a relatively large proportion of particles composed of both high- and low-gravity material bound together is much more difficult to separate sharply on the basis of specific gravity than

[14] Young, W. H., Anderson, R. L., and Isaac, L. H., Bituminous coal and lignite; table 52. U. S. Bur. Mines Minerals Yearbook, 1943.

TABLE 4.—CHANGES IN HEATING VALUE, MINERAL MATTER, ASH, TOTAL SULFUR, AND PYRITIC SULFUR CAUSED BY CLEANING[a]

Coal	Type of cleaning	Loss in cleaning, percent	Decrease in mineral matter		Percentage increase in coal substance (100 minus mineral matter)	Increase in heating value		Decrease in ash		Decrease in sulfur		Decrease in pyritic sulfur	
			percentage pts.	percent		B.t.u./lb.	percent	percentage pts.	percent	percentage pts.	percent	percentage pts.	percent
2B	Tabling	8.5	6.79	36.8	8.3	726	5.9	5.4	37.6	1.75	32.0	1.35	36.1
2C	Tabling	40.8	10.47	56.7	12.8	1032	8.4	8.4	58.6	2.54	46.4	2.37	63.4
3B	Tabling	28.6	9.42	46.8	11.8	1138	9.7	8.5	48.7	.63	26.0	.59	43.4
3C	Tabling	40.6	11.03	54.8	13.8	1415	12.0	9.8	56.4	.81	33.5	.55	40.4
5B	Tabling	9.1	10.76	45.7	14.1	1207	10.6	9.2	48.3	1.50	27.4	1.89	57.3
5B[1]	Tabling	11.2	11.22	47.7	14.7	1231	10.8	9.6	50.5	1.55	28.3	1.95	59.1
6B	Tabling	7.4	8.52	39.0	10.9	987	8.4	7.6	41.9	.76	18.4	1.17	49.2
6B[1]	Tabling	4.8	7.94	36.4	10.2	776	6.6	7.0	38.7	.69	16.7	1.24	52.1
7B	Tabling	7.9	4.89	26.6	6.0	759	6.0	3.7	25.9	1.81	33.8	1.68	50.3
7C	Tabling	24.4	5.71	31.0	7.0	856	6.8	4.4	30.5	1.93	36.1	1.76	52.7
8B	Tabling	10.1	9.36	34.8	12.8	1158	10.7	8.3	35.6	.73	23.6	1.04	59.4
8C	Tabling	20.6	11.65	43.4	15.9	1494	13.9	10.4	44.7	.76	24.6	1.14	65.1
9B	Tabling	8.9	10.12	38.5	13.7	1272	11.5	8.4	39.1	1.90	34.4	1.53	45.9
9C	Float and sink	61.3	18.69	71.2	25.4	2466	22.2	16.2	75.3	2.17	39.3		
10B	Tabling	12.6	3.34	26.3	3.8	437	3.3	2.8	26.9	.57	21.7		
10C	Retabling[b]	60.3	4.86	38.3	5.6	589	4.5	4.1	39.4	.79	30.0		
11B	Tabling	14.0	9.21	39.3	12.0	1351	11.7	8.1	41.5	.83	19.0		
11C	Retabling[b]	40.6	11.84	50.5	15.5	1716	14.8	10.4	53.3	1.11	25.5		
12B	Tabling	13.2	5.71	28.3	7.2	689	5.8	5.0	31.1	.57	11.3		
12C	Retabling[b]	38.2	6.97	34.6	8.7	881	7.4	6.0	37.3	.90	17.8		
13B	Tabling	11.7	5.88	27.7	7.5	716	6.1	5.0	28.4	.88	21.6		
13C	Retabling[b]	40.0	8.70	40.9	11.0	1109	9.5	7.5	42.6	1.09	26.7		
14B	Tabling	13.2	5.06	29.5	6.1	684	5.6	4.5	32.8	.36	8.5		
14C	Retabling[b]	40.2	6.26	36.5	7.6	846	7.0	5.5	40.1	.58	13.6		
16B	Tabling	14.3	1.33	13.5	1.5	111	0.8	1.2	14.0	.07	7.1		
15C	Tabling and float and sink	56.0	6.12	62.3	6.8	817	6.1	5.6	65.1	.13	13.1		
16B	Tabling	18.2	5.45	31.8	6.6	627	5.0	4.3	32.6	1.46	28.0		
16C	Tabling and float and sink	53.5	9.99	58.4	12.1	1192	9.5	8.1	61.4	2.27	43.6		

[a] All data are reported on dry basis. Percentages are referred to raw coal.

[b] Second tabling of previously tabled coal.

TABLE 5.—CHANGE IN QUALITY, CLASSIFIED BY METHODS OF CLEANING[a]

	1 Tabling, reject less than 25%	2 Tabling, reject exceeding 25%	3 Tabling followed by a second tabling	4 Float and Sink
Number of tests	17	3	5	3
Percentage of reject—				
Average	12.4	36.7	43.9	56.9
Range	4.8–24.4	28.6–40.8	38.2–60.3	53.5–61.3
Change in quality, absolute basis				
Reduction in mineral matter, percentage figures				
Average	7.2	10.3	7.7	11.6
Range	1.3–11.7	9.4–11.0	4.9–11.8	6.1–18.7
Reduction in ash, percentage figures				
Average	6.2	8.9	6.7	10.0
Range	1.2–10.4	8.4–9.8	4.1–10.4	5.6–16.2
Reduction in sulfur, percentage figures				
Average	1.07	1.33	0.89	1.52
Range	0.07–1.93	0.63–2.54	0.58–1.11	0.13–2.27
Increase in heating value, B.t.u. per lb. of coal				
Average	887	1195	1028	1492
Range	111–1494	1032–1415	589–1716	817–2466
Change in quality, percentage basis				
Reduction in mineral matter, percent of mineral matter in raw coal				
Average	33.9	52.8	40.2	64.0
Range	13.5–47.7	46.8–56.7	34.6–50.5	58.4–71.2
Reduction in ash, percent of ash in raw coal				
Average	35.3	54.6	42.5	67.3
Range	14.0–50.5	48.7–58.6	37.3–53.3	61.4–75.3
Reduction in sulfur, percent of sulfur in raw coal				
Average	23.1	35.3	22.7	32.0
Range	7.1–36.1	26.0–46.4	13.6–30.0	13.1–43.6
Increase in heating value, percent of heating value of raw coal				
Average	7.6	10.0	8.6	12.6
Range	0.8–13.9	8.4–12.0	4.5–14.8	6.1–22.2

[a] All data are reported on dry basis. Percentages of reject are referred to raw coal.

is a raw coal containing relatively small proportions of such mixed material. Hence when the characteristics of any specified coal are being studied preliminary to installing a cleaning plant, float-and-sink work to determine the specific gravity distribution is desirable.[15]

Variations in degree of improvement are also due, of course, to variations in percentage of reject. However, as a rule the reduction in mineral matter is much less than proportional to increase in percentage of reject. This is fairly evident in the cases

[15] Callen, A. C., and Mitchell, D. R., Washability tests of Illinois coals: Univ. Ill. Eng. Exp. Sta. Bull. 217, 114 pp., 1930.

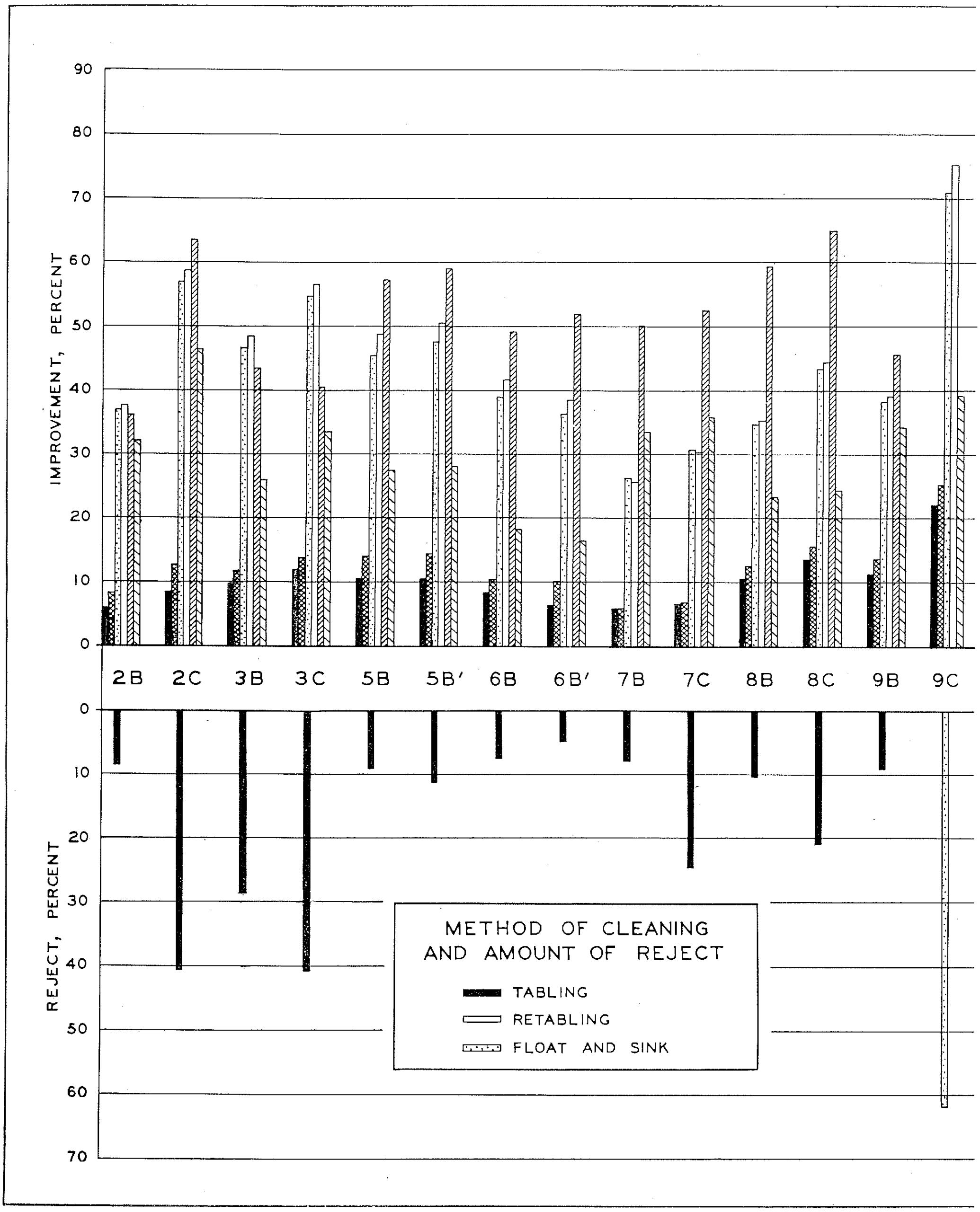


FIG. 37*a*. Changes in heating value, mineral matter, ash, sulfur, and pyritic sulfur, on the dry basis, caused by cleaning.

of coals 2, 3, 7, and 8 (table 4 and fig. 37), the second tabling of which (at substantially larger percentages of reject) produced additional but not proportionately large reductions in mineral matter.

Efforts were made to further increase the quality of coal by: 1) special tabling to insure a percentage of reject exceeding 25 percent (table 5, column 2); 2) retabling the first cleaning products, also with high

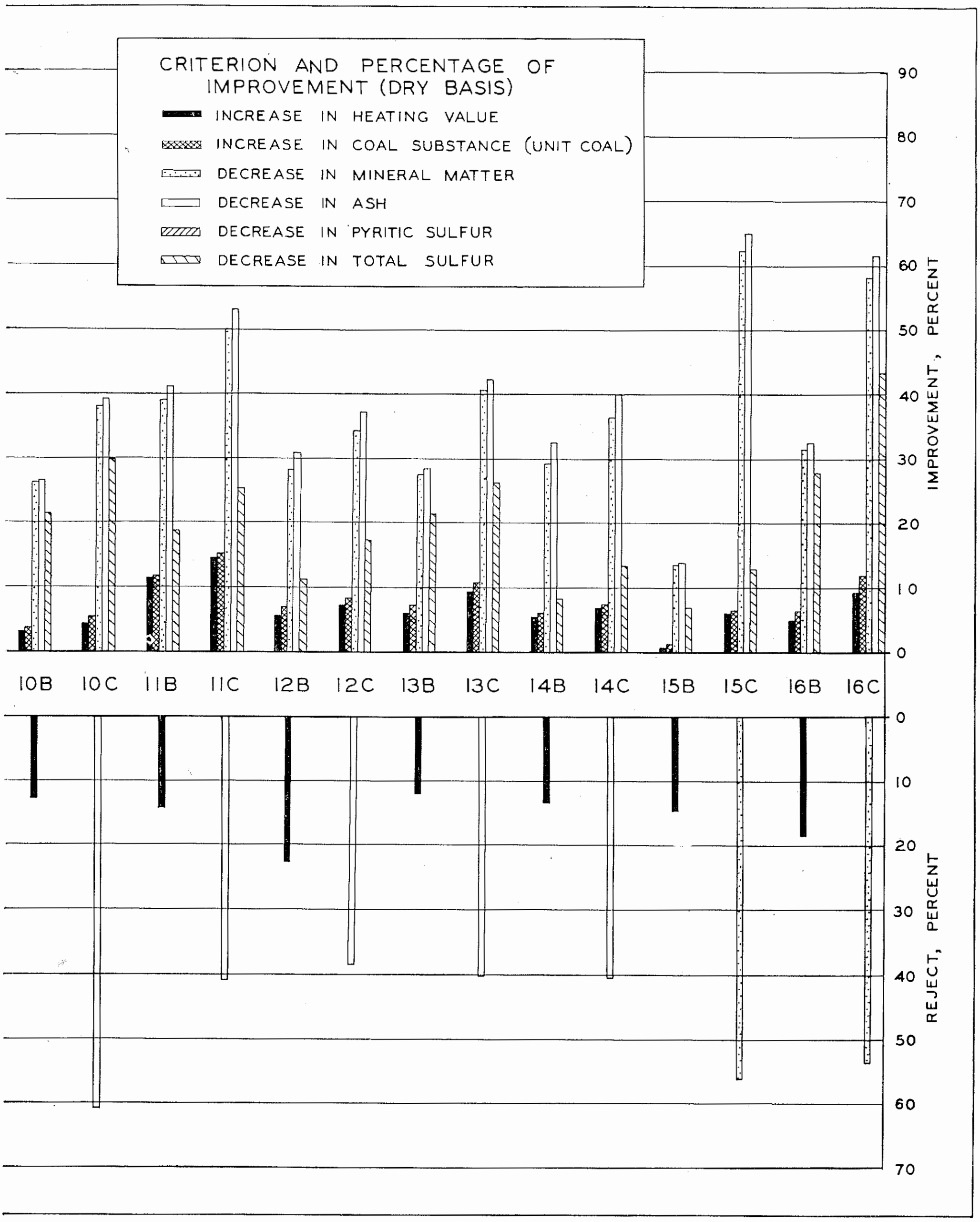


FIG. 37*b*. Changes in heating value, mineral matter, ash, sulfur, and pyritic sulfur, on the dry basis, caused by cleaning.

percentages of reject referred to the raw coal (table 5, column 3); and 3) float-and-sink procedures (table 5, column 4). Three coals were produced by the first method, with an average reduction of mineral matter of 52.8 percent and an average reject of 36.7 percent. For the five coals produced by the second method, the reduction in mineral matter averaged 40.2 percent, with an average reject of 43.9 percent Three coals were produced by the third method, using zinc chloride solutions of such low specific gravities (of the order of 1.30) that rejects of over 50 percent were produced in each case. The average reduction in mineral matter was 64.0 percent. However, no single coal was cleaned by more than one of the three methods, so a direct comparison of the methods is not possible.

b). Ash content.—Quantity of ash is more easily determined and hence more commonly used than quantity of mineral matter in evaluating quality of coal, even though it is less exact theoretically. Ash, or inert material in its burned state, is generally about fifteen percent less than mineral matter, which approximates inert material (dry basis) in its unburned state. However, the relative reductions of ash and of mineral matter from raw to cleaned coal are of similar magnitude, and the foregoing comments on the effect of cleaning on mineral matter apply very closely to the effect of cleaning on ash. Tables 4 and 5 and figure 37 set forth the data.

c). Sulfur content.—Reduction of sulphur on a moisture-free basis is not usually as high, on a percentage basis, as reduction in mineral matter and ash (tables 4 and 5, fig. 37). For the 17 tabled coals prepared at the expense of less than 25 percent reject, the average reduction in sulfur was about 1 percentage point, or 23 percent. For the coals prepared at the expense of higher percentages of reject, the reductions averaged 1.2 percentage points, or 29 percent.

Sulfur occurs in three distinct forms in coal, but only pyrite (iron disulfide), with a specific gravity of about 5.0, is reduced in percentage by a cleaning process that depends upon differences in specific gravity. Neither sulfur organically combined with the coal substance nor that occurring as a sulfate compound is appreciably affected by such a process.

Data on the percentage reduction in pyritic sulfur are presented for thirteen cleaned coals (table 4, fig. 37). They tend to be somewhat higher than the percentage reduction in mineral matter, ranging from 36.1 to 65.1 percent.

d). Heating value.—For the 17 coals cleaned by the use of the table alone, so operated that less than 25 percent of raw coal was rejected (table 5, column 1), heating values were increased an average of 887 B.t.u. per pound, varying from 111 to 1494 B.t.u. per pound. The average percentage increase in heating value was 7.6 with a range from 0.8 to 13.9.

For the eleven coals cleaned by means of the table or float-and-sink methods, or both, with percentages of reject more than 25 percent (table 5, columns 2, 3, 4, and 5), the increases in heating value were somewhat greater. They had an average of 1200 B.t.u. per pound and ranged from 589 to 2466 B.t.u. per pound. On a percentage basis, the average increase in heating value was 10.1, with a range from 4.5 to 22.2.

The heating value of a given coal may be considered approximately proportional to the percentage of heat-producing material, with inert or non-heat-producing material acting as a diluent. For purposes of computation, satisfactory accuracy may usually be obtained by defining inert material (dry basis) simply as ash. This leads to the familiar dry ash-free heating value as a basis for computing heating value for any cleaned product, the ash content of which is known. The heating values of the 28 cleaned coals, so computed, have an average variation from the heating values, as determined in a calorimeter, of 84 B.t.u. per pound.

More complex definitions of inert material have been proposed, one being mineral matter, previously defined as ($1.08 \times$ Ash $+ 0.55 \times$ Sulfur), and another a modification of this ($1.1 \times$ Ash $+ 0.1 \times$ Sulfur). These do not always yield better results in computing heating value. As a matter of fact, for the 28 cleaned coals, the average difference between computed and determined heating values is 147 B.t.u. per pound using ($1.1 \times$ Ash $+ 0.1 \times$ Sulfur) as the diluent, or 204 B.t.u. per pound using ($1.08 \times$ Ash $+ 0.55 \times$ Sulfur) as the diluent. Correcting for the heat of combustion of sulfur, as recommended by

Parr,[16] reduces the latter average difference to 127 B.t.u. per pound.

Dry mineral-matter-free heating value with correction for sulfur (unit heating value) is a concept widely accepted as an estimate of the heating value of the pure coal substance. For the present data, unit heating value averages 153 B.t.u. per pound lower in the cleaned coal than in the raw coal, a value larger than can be accounted for by sampling fluctuations. The cleaning process thus appears to have reduced the heating value of the coal substance, insofar as this is given by unit heating value, by approximately 1.0 percent. Possible explanations are: 1) accelerated oxidation of the coal due to the wetting and drying cycle suffered in the washing process; or 2) a selective action in the washing process whereby particles of a prevailingly lower unit heating value concentrate in the cleaned-coal product.

e). Volatile matter and fixed carbon.— On any comparable moisture basis the reduction of ash in a coal by a known amount obviously increases by an equal amount the percentage of coal material represented by the sum of volatile matter and fixed carbon. Ordinarily, but not always, both volatile matter and fixed carbon share in this increase. For the 27 cleaned coals for which data are available, the average increase in volatile matter was 2.3 percentage figures, and in fixed carbon, 4.7 percentage figures, on the dry basis. In three cases the entire increase due to reduction in ash was absorbed by fixed carbon and in one case by volatile matter.

The possibility of selective action in the cleaning process, whereby particles having prevailingly higher or lower fixed carbon are concentrated in the clean coal, may be investigated by comparing the ratio of fixed carbon to volatile matter before and after cleaning. These ratios are, respectively, 1.25 and 1.30 on the average for the data of this report. In other words, the average raw coal had a fixed carbon content 25 percent greater than volatile matter, while the average cleaned coal had a fixed carbon content 30 percent greater than volatile matter. This difference is greater than could be attributed to sampling fluctuations, and it may be inferred that a slight selective action existed in the cleaning processes, possibly due to low-ash particles having a prevailingly higher ratio of fixed carbon to volatile matter than high-ash particles in most of the coals tested.

f). Items of the ultimate analysis.— Reduction of non-combustible material results in a corresponding increase in the coal substance and hence usually in increases in the percentages of carbon, hydrogen, oxygen, and nitrogen. However, the increases in these elementary components are rarely proportionately alike, the tendency being toward appreciably higher oxygen in the cleaned coals than might be expected. On the moisture-and-ash-free basis, the average cleaned coal has 1.4 percentage figure more oxygen than the average raw coal, a difference greater than may be attributed to sampling fluctuations. On the same basis the differences in carbon, hydrogen, and nitrogen appear to be insignificant. Sulfur, of course, is reduced, as has been discussed previously.

g). Ash fusion temperatures.—The average difference in ash softening temperature between the raw coals and the cleaned coals was an increase of 30° F. Although this is less than the usual laboratory tolerance of 54° F. between duplicate samples, the trend exceeds reasonable sampling fluctuations, and a tendency toward slightly higher ash softening temperature in the washed coals prepared in the present investigation seems evident.

No significant change in either initial deformation temperature or fluid temperature is apparent.

h). Other chemical tests. — Washing appeared to reduce chemical fusain, but changes were small in absolute amount.

No significant effects due to washing on British swelling index, Gieseler plasticity, or ignition temperature appear to be demonstrated.

[16] Parr, S. W., The classification of coal: Univ. Ill. Eng. Exp. Sta. Bull. 180, 59 pp., 1928.

TABLE 6.—CHANGES IN VITRAIN CONTENT CAUSED BY CLEANING

Coal	County and coal bed	Method of cleaning	Loss in cleaning, percent	Ash content (dry), percent	Vitrain, percent	Vitrain, percentage figure change	Vitrain, percentage change in cleaned coal referred to raw coal
1A	Franklin—No. 6			7.9	26.5		
3A	Vermilion—Grape Creek			17.4	12.8		
3B	Vermilion—Grape Creek	Tabling	28.6	9.0	16.3	+3.5	+27
3C	Vermilion—Grape Creek	Tabling	40.6	7.6	14.2	+1.4	+11
5A	Macoupin—No. 6			19.0	9.8		
5B	Macoupin—No. 6	Tabling	9.1	9.8	12.3	+2.5	+26
5B[1]	Macoupin—No. 6	Tabling	11.2	9.4	13.2	−3.4	+35
6A	Peoria—No. 5			18.1	10.8		
6B	Peoria—No. 5	Tabling	7.4	10.6	12.4	+2.6	+15
6B[1]	Peoria—No. 5	Tabling	4.8	11.1	13.4	+2.6	+24
7A	Gallatin—No. 5			14.3	5.7		
7B	Gallatin—No. 5	Tabling	7.9	10.7	5.2	−0.5	− 9
7C	Gallatin—No. 5	Tabling	24.4	10.0	5.1	−0.6	−11
8A	Wabash—Friendsville			23.3	1.50		
8B	Wabash—Friendsville	Tabling	10.1	15.0	1.68	+0.18	+12
8C	Wabash—Friendsville	Tabling	20.6	12.9	1.87	+0.37	+25
9A	St. Clair—No. 6			21.5	7.2		
9B	St. Clair—No. 6	Tabling	8.9	13.1	6.8	−0.4	− 6
9C	St. Clair—No. 6	Float-and-sink	61.3	5.3	12.3	+5.1	+71
10A	Saline—No. 5			10.4	14.5		
10B	Saline—No. 5	Tabling	12.6	7.6	17.7	+3.2	+22
10C	Saline—No. 5	Retabling	60.3	6.3	17.9	+3.4	+24
11A	Vermilion—No. 7			19.5	7.4		
11B	Vermilion—No. 7	Tabling	14.0	11.4	10.7	+3.3	+45
11C	Vermilion—No. 7	Retabling	40.6	9.1	9.4	+2.0	+27
12A	Sangamon—No. 5			16.1	7.9		
12B	Sangamon—No. 5	Tabling	13.2	11.1	8.2	+0.3	+ 4
12C	Sangamon—No. 5	Retabling	38.2	10.1	10.2	+2.3	+29
13A	Randolph—No. 6			17.6	8.6		
13B	Randolph—No. 6	Tabling	11.7	12.6	8.6	—	—
13C	Randolph—No. 6	Retabling	40.0	10.1	11.4	+2.8	+33
14A	Christian—No. 6			13.7	11.2		
14B	Christian—No. 6	Tabling	13.2	9.2	11.5	+0.3	+ 3
14C	Christian—No. 6	Retabling	40.2	8.2	14.1	+2.9	+26
15A	Williamson—No. 6			8.6	14.5		
15B	Williamson—No. 6	Tabling	14.3	7.4	18.1	+3.6	+25
15C	Williamson—No. 6	Float-and-sink	56.0	3.0	19.2	+4.7	+32
16A	Knox—No. 1			13.2	7.4		
16B	Knox—No. 1	Tabling	18.2	8.9	9.5	+2.1	+28
16C	Knox—No. 1	Float-and-sink	53.5	5.1	9.4	+2.0	+27

EFFECT UPON PETROGRAPHIC CONSTITUTION

a). Vitrain content.—Owing to its low ash content and low specific gravity, vitrain is ordinarily considered to concentrate in a washed coal. The data of the present report indicate a minor trend in that direction. Table 6 sets forth the percentages of vitrain and dry ash for 40 test coals, of which 14 were raw and 26 were cleaned coals. The percentage change in vitrain and the percentage of raw coal rejected in the cleaning process are also listed. Petrographic data on the coal from La Salle County (2 series) were not obtained.

It will be observed that of the 16 tabled coals prepared at the expense of less than 25 percent reject, 12 showed an increase, three showed a slight decrease, and one showed no change. The average change was an increase of 1.4 percentage figures or 15 percent (table 7).

TABLE 7.—SUMMARY OF CHANGES IN VITRAIN CONTENT CAUSED BY CLEANING

Percentage of reject	Number of coals	Percentage figures	Percentage
Less than 25 percent.....	16	1.4	15
Exceeding 25 percent.....	10	3.0	33
All coals......	26	2.0	21

In the ten coals cleaned by tabling, retabling, or float-and-sink methods, with percentages of reject exceeding 25 percent, the increases in vitrain were somewhat greater, averaging 3.0 percentage figures or 33 percent.

The average increase in vitrain for the entire 26 cleaned coals was 21 percent or 2.0 percentage figures (table 7). A portion of this increase is attributable, of course, to the upward adjustment of the vitrain percentages of the raw coal due to decrease in 1.5 sink material, considered for petrographic purposes to be non-coal. The effect of washing (exclusive of this effect) is given by a comparison of the percentage of vitrain on a 1.5-float basis, as reported in table 8. From this it will be seen that of the 26 prepared coals for which data are available, 15 show an increase, 4 show a decrease, and 7 show no change, where a change of 1.0 percentage figure is regarded as the minimum for significance. The average change was an increase of 1.0 percentage figure on a 1.5-float basis.

Although tests on coals containing 70 percent or more of vitrain were described both in the first report of this series and in an earlier exploratory study,[17] none of the coals tested during this phase of the general investigation was reported to approach that quantity of vitrain. All but one contained less than 20 percent, despite preparation procedures which were expected to increase vitrain markedly. The coal richest in vitrain was a cleaned 7/16-inch by 10-mesh coal from Franklin County, with a vitrain content of only 26.5 percent. The reason for the wide discrepancy between this figure and the 70-percent figure obtained in a similar coal in the earlier work is not known. Certain possible explanations are being investigated.

b). Clarain content. — Percentage of clarain (table 8) for the coals reported varied between 67 and 89 percent, on the as-fired basis, with a rather distinct trend in the direction of increased clarain content in the cleaned coals. The average increase was 8.3 percentage figures. However, this is primarily due to an adjustment in the percentage figure resulting from a decrease in 1.5-sink material rather than to a selective concentration of clarain. The percentages of clarain on a 1.5-float basis show no consistent trends associated with washing.

c). Durain and fusain content.—The percentages of both durain and fusain (table 8) were uniformly low, ranging from zero to 3.0 percent for the former, and from 0.1 to 1.4 percent for the latter, as-fired basis. In each case the trend was toward reduction with washing, but changes were small in absolute amount.

EFFECT UPON COMBUSTION CHARACTERISTICS

a). Heat obtained per pound of coal— Of the 27 cleaned coals for which comparable data were obtained, 23 showed increases in heat obtained per pound and four showed no change (table 9), where a difference of 200 B.t.u. per pound was established as the minimum to be regarded as significant. The average increase was 810

[17] McCabe, L. C., Illinois coals—constitution important with reference to their utilization: Mech. Eng., vol. 60, No. 3, pp. 217–21, March 1938.

TABLE 8.—PERCENTAGES OF THE BANDED INGREDIENTS IN THE TEST COALS

Coal	Vitrain		Clarain		Durain		Fusain		1.5-sink material, as-fired basis, percent
	as-fired basis, percent	1.5-float basis, percent	as-fired basis, percent	1.5-float basis, percent	as-fired basis, percent	1.5-float basis, percent	as-fired basis, percent	1.5-float basis, percent	
1A	26.5	27.7	66.8	69.7	1.2	1.3	1.3	1.3	4.2
3A	12.8	15.5	66.9	80.8	2.0	2.4	1.1	1.3	17.2
3B	16.3	17.2	75.2	79.5	1.9	2.0	1.2	1.3	5.4
3C	14.2	14.6	81.1	83.1	1.3	1.3	1.0	1.0	2.4
5A	9.8	10.4	80.5	86.2	1.7	1.9	1.4	1.5	6.6
5B	12.3	12.7	81.3	84.3	1.9	2.0	0.9	1.0	3.6
5B[1]	13.2	13.9	79.5	83.7	1.5	1.6	0.7	0.8	5.0
6A	10.8	12.8	71.2	84.4	1.6	1.9	0.7	0.9	15.7
6B	12.4	12.9	82.5	85.7	0.9	1.0	0.4	0.4	3.8
6B[1]	13.4	14.0	80.7	84.4	0.9	1.0	0.6	0.7	4.4
7A	5.7	6.6	79.7	92.3	0.5	0.6	0.5	0.6	13.6
7B	5.2	5.5	87.2	93.0	0.9	0.9	0.5	0.5	6.2
7C	5.1	5.4	89.0	93.7	0.3	0.4	0.6	0.6	5.0
8A	1.5	1.9	75.3	95.7	1.7	2.2	0.2	0.2	21.3
8B	1.7	1.9	84.7	96.8	1.1	1.2	0.1	0.1	12.5
8C	1.9	2.0	87.3	94.9	2.7	2.9	0.1	0.1	8.0
9A	7.2	9.2	69.5	88.8	1.0	1.3	0.5	0.7	21.7
9B	6.8	7.6	82.2	91.2	0.7	0.8	0.4	0.5	9.9
9C	12.3	12.4	86.6	86.9	0.4	0.4	0.3	0.3	0.3
10A	14.5	15.5	74.4	79.8	3.0	3.2	1.4	1.5	6.7
10B	17.7	18.3	76.7	79.5	1.2	1.2	0.9	1.0	3.5
10C	17.9	18.1	78.9	79.6	1.3	1.4	0.9	0.9	1.0
11A	7.4	9.3	70.0	88.9	0.7	0.9	0.7	0.9	21.2
11B	10.7	11.6	80.0	86.5	1.1	1.1	0.7	0.8	7.5
11C	9.4	9.7	86.0	89.0	0.5	0.6	0.7	0.7	3.4
12A	7.9	9.1	76.7	88.9	1.0	1.2	0.7	0.8	13.7
12B	8.2	8.9	83.0	89.3	0.9	1.0	0.7	0.8	7.2
12C	10.2	10.6	84.5	87.7	0.8	0.9	0.8	0.8	3.7
12A[1]	9.6	10.6	79.5	87.7	0.8	0.9	0.7	0.8	9.4
13A	8.6	10.4	72.3	87.5	1.1	1.3	0.6	0.8	17.4
13B	8.6	9.5	80.1	88.2	1.6	1.8	0.4	0.5	9.3
13C	11.4	11.9	81.9	85.9	1.4	1.5	0.7	0.7	4.6

14A.............	11.2	13.2	71.0	83.8	1.5	1.8	1.0	1.2	15.3
14B.............	11.5	12.0	81.9	85.5	1.3	1.3	1.1	1.2	4.2
14C.............	14.1	14.5	80.8	83.1	1.4	1.4	1.0	1.0	2.7
15A.............	14.5	15.3	78.4	82.8	1.2	1.3	0.5	0.6	5.4
15B.............	18.1	18.5	78.3	80.0	0.7	0.8	0.7	0.7	2.2
15C.............	19.2	19.2	80.3	80.5	—	—	0.3	0.3	0.2
16A.............	7.4	8.5	76.9	88.2	2.0	2.3	0.9	1.0	12.8
16B.............	9.5	9.8	84.4	87.9	1.4	1.5	0.8	0.8	3.9
16C.............	9.4	9.5	87.5	88.1	1.6	1.6	0.8	0.8	0.7
Averages (exclusive of Nos. 1A and 12A[1]):									
Raw............	9.2	10.6	74.1	86.8	1.5	1.7	0.8	0.9	14.5
Cleaned.........	11.2	11.6	82.4	86.5	1.1	1.2	0.7	0.7	4.6

TABLE 9.—CHANGES IN COMBUSTION CHARACTERISTICS CAUSED BY CLEANING

Coal No.	Reject, percent	Heat Obtained, M B.t.u./lb.		Uniformity, percentage figures		Responsiveness, M B.t.u./hr.		Pickup, M B.t.u./hr.		Overrun, M B.t.u./hr.	
		Reject <25%	Reject >25%	Reject <25%	Reject >25%	Reject <25%	Reject >25%	Reject <25%	Reject >25%	Reject <25%	Reject >25%
2B.....	8.5	+0.88		− 1.1		+ 5.8		+9		+12	
2C.....	40.8		+1.26		− 2.5		([a])		([a])		([a])
3B.....	28.6		+0.09		− 1.8		+13.8		+ 2		−10
3C.....	40.6		+1.17		− 3.2		+ 5.0		+11		+11
5B.....	9.1	+1.68		− 5.8		+ 3.8		+ 3		+21	
$5B^1$....	11.2	+1.74		− 6.2		+23.3		+ 6		+21	
6B.....	7.4	+0.78		− 6.5		+19.6		+9		+16	
$6B^1$....	4.8	+0.69		− 6.5		+21.6		+9		+12	
7B.....	7.9	−0.03		− 3.7		+ 5.9		−1		+ 7	
7C.....	24.4	−0.10		− 0.1		+ 8.9		+2		+ 4	
8B.....	10.1	+0.77		− 2.6		+ 0.8		+4		+10	
8C.....	20.6	+0.73		− 2.6		+11.7		+2		+ 9	
9B.....	8.9	+1.03		−11.9		+14.5		+7		+18	
9C.....	61.3		+1.45		−12.6		+ 9.9		+ 3		+10
10B.....	12.6	+0.42		− 2.5		+ 1.3		−1		+ 2	
10C.....	60.3		+0.38		− 2.6		− 2.0		− 1		+ 7
11B.....	14.0	+0.58		− 2.1		+ 3.3		+3		+10	
11C.....	40.6		+1.13		− 4.0		+ 4.4		+ 4		+ 9
12B.....	13.2	+0.86		− 2.5		+ 4.4		0		+ 2	
13B.....	11.7	+0.87		− 8.6		+10.8		+7		+12	
13C.....	40.0		+1.06		− 8.8		+20.9		+10		+13
14B.....	13.2	+0.96		− 2.4		+ 8.7		−3		+ 1	
14C.....	40.2		+1.11		− 5.7		+ 4.4		− 1		0
15B.....	14.3	+0.11		− 1.0		+ 5.2		+1		− 3	
15C.....	56.0		+0.45		− 3.5		+ 5.3		+ 5		− 3
16B.....	18.2	+0.97		− 1.4		+ 1.2		+4		− 2	
16C.....	53.5		+0.84		− 1.2		+ 6.7		+ 1		− 7
Averages...............		+0.76	+0.89	− 4.0	− 4.6	+ 8.9	+ 7.6	+ 3.6	+3.8	+ 8.9	+ 3.3
Averages for all cleaned coal..................		+0.81		−4.2		+8.4		+3.7		+7.0	

[a] Not obtained.

B.t.u. per pound on the as-fired basis (table 10). Improvement due to washing is to be expected, inasmuch as washing increased the heating value and carbon and decreased the ash and sulfur, both types of change having been shown to exert a positive influence on the heat obtained.

The decreasing advantage of cleaning with heavy reject losses is illustrated by comparing the results obtained with smaller and with larger reject. For the 17 coals cleaned at the expense of less than 25 percent reject, the average increase in heating value was 760 B.t.u. per pound and the average reject was 12.4 percent (table 10). For the 10 coals cleaned at the expense of reject exceeding 25 percent, the average increase in heating value was 890 B.t.u. per pound and the average reject was 46.2 percent. Hence, a further gain of only 130 B.t.u. per pound

TABLE 10.—SUMMARY OF CHANGES IN COMBUSTION CHARACTERISTICS CAUSED BY CLEANING

Reject loss in cleaning coal	Number of tests	Average loss in cleaning, percent	Heat obtained, M B.t.u./lb.	Uniformity, percentage figures	Responsiveness, M B.t.u./hr.	Pickup, M B.t.u./hr.	Overrun, M B.t.u./hr.
Less than 25%.....	17	12.4	+0.76	−4.0	+8.9	+3.6	+9
More than 25%.....	10	46.2	+0.89	−4.6	+7.6[a]	+3.8[a]	+3[a]
All cleaned coals.....	27	24.9	+0.81	−4.2	+8.4	+3.7	+7

[a] Nine comparisons only.

was obtained at the expense of a reject loss nearly four times as great.

The heat obtained per pound from the stoker combustion tests for a cleaned coal may be fairly closely computed from the heat obtained from the raw coal by correcting for the change in the amount of heat producing material per pound. Values so computed for the cleaned coals, using whole coal minus the moisture and ash as the equivalent of heat producing material, have an average difference from stoker test results of 130 B.t.u. per pound, a difference chargeable to sampling fluctuations.

b). Uniformity. — The cleaned coals tended to burn more uniformly than the raw coals, as measured by the average variation from the mean burning rate of each coal (p. 17). Of the 27 cleaned coals for which comparable data were obtained, 21 showed decreases in average variation and six showed no change (table 9), where a change of at least two percentage figures was arbitrarily selected as the minimum to be considered. The average change was 4.2 (table 10) and the maximum 12.6 percentage figures, the latter representing a reduction in variation of 61 percent referred to the raw coal.

Comparing coals cleaned at the expense of more than and of less than 25 percent reject, the average improvements in uniformity were 4.6 and 4.0 percentage points respectively (table 10), a difference which is not regarded as significant.

c). Responsiveness.—The cleaned coals tended to be more responsive than the raw coals, as measured by the average rate of heat release during the first 30 minutes of operation after a prolonged hold-fire period (p. 17). Of the 26 cleaned coals for which comparable data were obtained, 22 showed increases in responsiveness and four showed no change (table 9), where a change of at least 3000 B.t.u. per hour was arbitrarily selected as the minimum to be considered. The average change was 8400 B.t.u. per hour (table 10) and the maximum 23,300 B.t.u. per hour. Although a trend toward greater responsiveness might be expected, due to the increased heating values of the cleaned coals, the observed increase was generally much more than could be attributed to this factor. Referring to the raw coal in each case, the average percentage increase in responsiveness was 57 percent, while the average increase in heating value, as-fired basis, was only 11 percent for the same 26 cleaned coals.

The coals cleaned at the expense of greater percentages of reject (table 10) had a slightly smaller average increase in responsiveness than coals cleaned at the expense of lesser percentages of reject. The respective figures are 7600 and 8900 B.t.u. per hour.

d). Pickup.—The cleaned coals showed a pronounced trend toward increased pickup over the corresponding raw coals, where pickup is based upon the average rate of heat release during the first five minutes of operation following an "off" period of 45 minutes (p. 17). Of 26 cleaned coals for which comparable data were obtained, 18 showed an increase, one showed a decrease, and seven showed no change (table 9), where a change of at least 2000 B.t.u. per hour was arbitrarily taken as the minimum to be considered. The average increase was 3700 B.t.u. per hour (table 10). The average improvements in pickup for the coals cleaned at the expense of greater and of lesser percentages of reject were practically the same, the respective figures being 3800 and 3600 B.t.u. per hour (table 10).

e). Overrun.—The cleaned coals tended toward increased overrun over the corresponding raw coals, where overrun is based upon the average rate of heat release during the first five minutes of an "off" period following an "on" period of 15 minutes (p. 17). Of 26 cleaned coals for which comparable data were obtained, 17 showed an increase, four showed a decrease, and five showed no change (table 9), where a change of at least 3000 B.t.u. per hour was arbitrarily taken as the minimum to be considered. The average increase was 7000 B.t.u. per hour (table 10). The average change in overrun for the coals cleaned at the expense of greater percentages of reject was considerably less than that for those with smaller percentages of reject, the respective figures being 3000 and 9000 B.t.u. per hour (table 10). However, because of the wide variations in the individual coals, the difference is not regarded as significant.

f). Other criteria.—Both hold-fire ability and smoke-producing tendency were at satisfactory levels for all coals, whether raw or cleaned.

CONCLUSIONS

1). The heat obtained from the coals tested was very nearly directly proportional to the heating value and to percentage of ultimate carbon, on as-fired basis.

2). A slight increase in efficiency of about 1½ percent for each 1000 B.t.u. per pound increase in heating value was obtained from the tests. However, exceptions to this general tendency were numerous.

3). A general improvement in all performance characteristics measured, except overrun, accompanied a reduction in the percentage of ash.

4). An increase in vitrain was generally accompanied by more uniform combustion.

5). None of the following chemical characteristics furnished useful correlations with any of the measured performance characteristics of the coal: British swelling index; Gieseler plasticity; volatile matter; initial deformation, softening, or fluid temperatures of the ash.

6). The southern Illinois coals tested are generally superior in most of the performance characteristics measured. Several of the cleaned coals and a few of the raw coals from the central and northern fields are also included in some of the superior groupings.

7). By the use of the concentrating table so adjusted as to produce a commercially reasonable percentage of reject, not to exceed 25 percent, a reduction of roughly one-third in mineral matter and in ash was obtained for most of the raw coals. Reduction in total sulfur was generally somewhat less, whereas heating value was increased an average of 7.6 percent. The percentages of both vitrain and clarain were increased for most coals. Performance characteristics were generally improved, excepting for overrun.

8). Cleaning by tabling or float-and-sink procedures in such ways that percentages of reject in excess of 25 percent were produced resulted in further reductions in mineral matter, ash, and total sulfur, and slight further increases in heating value. For most coals, the percentages of vitrain and clarain were also slightly increased. Performance characteristics were not appreciably different from those of coals produced at the expense of lower percentages of reject.

9). Quality changes not caused directly by reduction in mineral matter, observed in most of the cleaned coals, were increases in the ratio of fixed carbon to volatile matter, in oxygen (dry ash-free basis), and in vitrain (1.50-float basis); and a decrease in heating value (unit-coal basis). Each of these was minor in magnitude.

APPENDIX

COMPLETE DATA ON ALL TEST COALS

Coal No.	Analysis No.	Source: County	Source: Seam	Proximate Analysis: As-fired: Mosture, %	As-fired: Ash, %	As-fired: Volatile Matter, %	As-fired: Fixed Carbon, %	Moisture-free: Ash, %	Moisture-free: Volatile Matter, %	Moisture-free: Fixed Carbon, %	Moisture and Ash Free: Volatile Matter, %	Moisture and Ash Free: Fixed Carbon, %	Dry Mineral-Matter-Free: Volatile Matter, %	Dry Mineral-Matter-Free: Fixed Carbon. %
1A	C-2507	Franklin.........	6	8.6	7.2	30.2	54.0	7.9	33.0	59.1	35.9	64.1	35.2	64.8
2A	C-2527	LaSalle..........	2	12.7	12.5	32.1	42.7	14.3	36.8	48.9	42.9	57.1	41.0	59.0
2B	C-2529	LaSalle..........	2	10.8	8.0	38.9	42.3	8.9	43.6	47.5	47.9	52.1	46.9	53.1
2C	C-2577	LaSalle..........	2	12.7	5.2	34.8	47.3	5.9	39.9	54.2	42.4	57.6	41.6	58.4
3A	C-2556	Vermilion.......	6	13.6	15.0	32.5	38.9	17.4	37.6	45.0	45.6	54.4	44.1	55.9
3B	C-2617	Vermilion.......	6	11.2	8.0	34.7	46.1	9.0	39.0	52.0	42.9	57.1	42.1	57.9
3C	C-2721	Vermilion.......	6	12.7	6.7	35.4	45.2	7.6	40.5	51.9	43.9	56.1	43.2	56.8
5A	C-2697	Macoupin.......	6	12.6	16.6	34.3	36.5	19.0	39.2	41.8	48.4	51.6	46.4	53.6
5B	C-2768	Macoupin.......	6	5.2	9.3	40.6	44.9	9.8	42.9	47.3	47.5	52.5	46.5	53.5
5B[1]	C-2775	Macoupin.......	6	6.2	8.8	35.8	49.2	9.4	38.2	52.4	42.1	57.9	40.9	59.1
6A	C-2776	Peoria..........	5	14.3	15.5	29.9	40.3	18.1	34.9	47.0	42.7	57.3	40.7	59.3
6B	C-2873	Peoria..........	5	13.2	9.2	33.5	44.1	10.6	38.6	50.8	43.2	56.8	41.9	58.1
6B[1]	C-2895	Peoria..........	5	13.2	9.6	33.9	43.3	11.1	39.1	49.8	43.9	56.1	42.8	57.2
7A	C-2912	Gallatin.........	5	2.8	13.9	33.9	49.4	14.3	34.9	50.8	40.7	59.3	38.7	61.3
7B	C-2920	Gallatin.........	5	2.5	10.4	35.4	51.7	10.7	36.3	53.0	40.7	59.3	39.3	60.7
7C	C-2921	Gallatin.........	5	2.1	9.8	35.2	52.9	10.0	35.9	54.1	39.9	60.1	38.6	61.4
8A	C-2932	Wabash.........	*	10.6	20.8	34.0	34.6	23.3	38.1	38.6	49.6	50.4	47.9	52.1
8B	C-2939	Wabash.........	*	10.1	13.5	36.4	40.0	15.0	40.5	44.5	47.6	52.4	46.5	53.5
8C	C-2943	Wabash.........	*	9.6	11.7	37.6	41.1	12.9	41.6	45.5	47.7	52.3	46.8	53.2
9A	C-2953	St. Clair.........	6	9.9	19.3	34.4	36.4	21.5	38.1	40.4	48.6	51.4	46.4	53.6
9B	C-2998	St. Clair.........	6	8.2	12.0	38.6	41.2	13.1	42.0	44.9	48.3	51.7	47.1	52.9
9C	C-3032	St. Clair.........	6	7.6	4.9	38.8	48.7	5.3	42.0	52.7	44.4	55.6	43.5	56.5
10A	C-3024	Saline...........	5	6.1	9.8	33.2	50.9	10.4	35.4	54.2	39.5	60.5	38.4	61.6
10B	C-3048	Saline...........	5	5.1	7.2	34.5	53.2	7.6	36.3	56.1	39.3	60.7	38.5	61.5
10C	C-3072	Saline...........	5	5.3	6.0	34.9	53.8	6.3	36.8	56.9	39.3	60.7	38.6	61.4
11A	C-3079	Vermilion.......	7	11.0	17.4	35.0	36.6	19.5	39.3	41.2	48.9	51.1	47.1	52.9
11B	C-3088	Vermilion.......	7	8.5	10.5	38.4	42.6	11.4	41.9	46.7	47.4	52.6	46.2	53.8
11C	C-3113	Vermilion.......	7	7.8	8.4	39.6	44.2	9.1	42.9	48.0	47.2	52.8	46.3	53.7
12A	C-3132	Sangamon.......	5	13.5	13.9	32.8	39.8	16.1	38.0	45.9	45.2	54.8	43.4	56.6
12A[1]	C-3183	Sangamon.......	5	10.8	12.4	33.7	43.1	13.9	37.8	48.3	43.9	56.1	42.4	57.6
12B	C-3151	Sangamon.......	5	10.6	9.9	35.3	44.2	11.1	39.4	49.5	44.4	55.6	42.9	57.1
12C	C-3181	Sangamon.......	5	11.8	8.9	—	—	13.9	—	—	—	—	—	—
13A	C-3204	Randolph........	6	9.8	15.9	33.0	41.3	17.6	36.6	45.8	44.4	55.6	42.6	57.4
13B	C-3229	Randolph........	6	8.3	11.5	35.8	44.4	12.6	39.0	48.4	44.6	55.4	43.4	56.6
13C	C-3246	Randolph........	6	9.0	9.2	34.9	46.9	10.1	38.3	51.6	42.6	57.4	41.5	58.5
14A	C-3257	Christian........	6	11.6	12.1	34.9	41.4	13.7	39.5	46.8	45.7	54.3	44.3	55.7
14B	C-3286	Christian........	6	10.8	8.2	37.3	43.7	9.2	41.8	49.0	46.1	53.9	45.0	55.0
14C	C-3304	Christian........	6	11.5	7.3	37.1	44.1	8.2	41.9	49.9	45.7	54.3	44.6	55.4
15A	C-3319	Williamson......	6	8.2	7.9	31.4	52.5	8.6	34.3	57.1	37.5	62.5	36.8	63.2
15B	C-3389	Williamson......	6	7.1	6.9	31.1	54.9	7.4	33.5	59.1	36.2	63.8	35.6	64.4
15C	C-3462	Williamson......	6	7.2	2.8	32.9	57.1	3.0	35.5	61.5	36.6	63.4	36.2	63.8
16A	C-3463	Knox...........	1	12.7	11.5	35.8	40.0	13.2	41.0	45.8	47.3	52.7	45.7	54.3
16B	C-3507	Knox...........	1	9.4	8.1	38.1	44.4	8.9	42.0	49.1	46.1	53.9	45.0	55.0
16C	C-3520	Knox...........	1	9.7	4.6	38.6	47.1	5.1	42.8	52.1	45.1	54.9	44.4	55.6

*Friendsville

Proximate Analysis, Moist, Mineral-Matter-Free			Sulfur			Heating Value					Ash Fusion Characteristics			Coal No.
Moisture, %	Volatile Matter, %	Fixed Carbon, %	As-fired, %	Moisture free, %	Moisture and Ash-free, %	As-fired, B.t.u./lb.	Moisture free B.t.u./lb.	Moisture and Ash-free, B.t.u./lb.	Mineral-matter-free Dry, B.t.u./lb.	Mineral-matter-free Moist, B.t.u./lb.	Initial Deform. °F	Softening, °F	Fluid, °F	
9.4	31.9	58.7	.80	.87	.95	12,160	13,306	14,446	14,576	13,205	2188	2258	2462	1A
15.1	34.8	50.1	4.77	5.47	6.38	10,741	12,309	14,357	14,758	12,521	1969	2105	2209	2B
12 1	41.2	46.7	3.32	3.72	4.09	11,628	13,035	14,315	14,545	12,802	1918	2078	2128	2B
13.7	35.9	50.4	2.56	2.93	3.12	11,650	13,341	14,181	14,339	12,392	1912	2040	2202	2C
16.5	36.9	46.6	2.09	2.42	2.92	10,148	11,748	14,224	14,556	12,151	2115	2167	2415	3A
12.4	36.9	50.7	1.59	1.79	1.97	11,448	12,886	14,154	14,330	12,563	2113	2160	2370	3B
13.8	37.3	48.9	1.41	1.61	1.75	11,490	13,163	14,253	14,391	12,414	2033	2140	2368	3C
15.9	39.1	45.0	4.79	5.47	6.76	9,955	11,387	14,058	14,533	12,230	1996	2048	2346	5A
5.9	43.6	50.5	3.76	3.97	4.40	11,935	12,594	13,957	14,209	13,366	2020	2075	2344	5B
7.0	38.0	55.0	3.68	3.92	4.33	11,833	12,618	13,923	14,165	13,167	1984	2060	2320	5B[1]
17.6	33.5	48.9	3.54	4.13	5.05	10,095	11,776	14,383	14,798	12,197	1960	2002	2215	6A
14.9	35.7	49.4	2.93	3.37	3.77	11,074	12,763	14,275	14,526	12,354	1972	2040	2338	6B
15.0	36.3	48.7	2.98	3.44	3.87	10,895	12,552	14,115	14,375	12,212	1963	2040	2328	6B[1]
3.4	37.4	59.2	5.21	5.35	6.25	12,297	12,649	14,760	15,170	14,657	1927	2002	2155	7A
2.9	38.2	58.9	3.46	3.54	3.97	13,075	13,408	15,008	15,296	14,854	1969	2105	2251	7B
2.4	37.8	59.8	3.35	3.42	3.80	13,223	13,505	15,009	15,270	14,907	1951	2100	2256	7C
13.9	41.1	45.0	2.77	3.09	4.03	9,655	10,794	14,067	14,547	12,518	2065	2113	2618	8A
12.0	40.9	47.1	2.12	2.36	2.78	10,746	11,953	14,065	14,345	12,629	2177	2229	2529	8B
11.1	41.6	47.3	2.10	2.33	2.67	11,108	12,290	14,102	14,357	12,763	2184	2247	2514	8C
13.0	40.4	46.6	4.97	5.52	7.03	9,989	11,090	14,123	14,665	12,744	1883	1948	2231	9A
9.6	42.6	47.8	3.32	3.62	4.16	11,358	12,362	14,225	14,525	13,136	1924	1981	2319	9B
8.2	40.0	51.8	3.09	3.35	3.54	12,531	13,556	14,321	14,483	13,306	1937	2005	2254	9C
6.9	35.7	57.4	2.47	2.63	2.93	12,333	13,136	14,666	14,894	13,865	1920	1940	2287	10A
5.6	36.3	58.1	1.95	2.06	2.23	12,876	13,573	14,685	14,851	14,019	1873	1958	2280	10B
5.7	36.4	57.9	1.74	1.84	1.97	12,993	13,725	14,655	14,786	13,943	1857	1983	2291	10C
13.9	40.5	45.6	3.88	4.36	5.42	10,299	11,574	14,382	14,844	12,775	1892	1985	2338	11A
9.8	41.8	48.4	3.23	3.53	3.98	11,825	12,925	14,596	14,867	13,416	1911	1985	2236	11B
8.7	42.2	49.1	3.00	3.25	3.57	12,259	13,290	14,613	14,852	14,561	1888	1970	2380	11C
16.3	36.2	47.5	4.37	5.06	6.02	10,354	11,970	14,260	14,666	12,269	1873	1935	2327	12A
12.8	37.0	50.2	3.55	3.98	4.63	10,915	12,236	14,216	14,543	12,688	1906	1950	2119	12A[1]
12.2	37.8	50.0	4.01	4.49	5.05	11,317	12,659	14,234	14,538	12,767	1868	1922	2077	12B
—	—	—	3.67	4.16	4.63	11,332	12,851	14,297	14,565	12,616	—	—	—	12C
12.1	37.4	50.5	3.69	4.08	4.96	10,506	11,644	14,128	14,521	12,766	1880	1995	2213	13A
9.7	39.2	51.1	2.93	3.20	3.66	11,332	12,360	14,134	14,404	13,011	2003	2081	2389	13B
10.2	37.3	52.5	2.72	2.99	3.32	11,601	12,753	14,180	14,409	12,940	2058	2131	2396	13C
13.7	38.2	48.1	3.77	4.26	4.94	10,720	12,132	14,064	14,395	12,419	2016	2054	2359	14A
12.1	39.5	48.4	3.48	3.90	4.30	11,430	12,816	14,122	14,363	12,620	2026	2094	2357	14B
12.7	39.0	48.3	3.26	3.68	4.01	11,491	12,978	14,136	14,356	12,541	2048	2106	2339	14C
9.0	33.4	57.6	.91	.99	1.09	12,202	13,296	14,546	14,691	13,363	2321	2530	2653	15A
7.7	32.8	59.5	.85	.92	.99	12,458	13,407	14,484	14,604	13,480	2463	2550	2650	15B
7.5	33.5	59.0	.79	.86	.88	13,101	14,113	14,548	14,612	13,528	2130	2304	2532	15C
14.9	38.9	46.2	4.55	5.21	6.00	10,919	12,501	14,403	14,769	12,566	2044	2099	2289	16A
10.5	40.4	49.1	3.40	3.75	4.12	11,889	13,123	14,409	14,650	13,111	2055	2158	2534	16B
10.4	39.7	49.9	2.65	2.94	3.10	12,362	13,693	14,432	14,586	13,010	2036	2173	2565	16C

Coal No.	Ultimate Analysis											
	As Fired						Moisture Free					
	Hydrogen, %	Carbon, %	Nitrogen, %	Oxygen, %	Sulfur, %	Ash, %	Hydrogen, %	Carbon, %	Nitrogen, %	Oxygen, %	Sulfur, %	Ash, %
1A	5.37	69.64	1.58	15.37	.80	7.24	4.83	76.20	1.72	8.46	.87	7.92
2A	5.56	59.28	1.04	16.87	4.77	12.48	4.75	67.94	1.19	6.35	5.47	14.30
2B	5.82	64.78	1.12	17.01	3.32	7.95	5.18	72.62	1.25	8.31	3.72	8.92
2C	6.13	64.67	1.06	20.41	2.56	5.17	5.40	74.06	1.22	10.47	2.93	5.92
3A	5.46	57.03	1.21	19.17	2.09	15.04	4.57	66.02	1.40	8.18	2.42	17.41
3B	5.81	64.85	1.48	18.34	1.59	7.93	5.15	72.99	1.67	9.47	1.79	8.93
3C	5.89	64.74	1.33	20.00	1.41	6.63	5.12	74.17	1.52	9.99	1.61	7.59
5A	5.48	54.76	.97	17.40	4.79	16.60	4.67	62.64	1.11	7.12	5.47	18.99
5B	5.42	66.17	1.22	14.21	3.76	9.22	5.11	69.83	1.28	10.08	3.97	9.73
5B[1]	5.41	65.47	1.21	15.36	3.68	8.81	5.09	69.82	1.29	10.48	3.92	9.40
6A	5.61	56.20	1.04	18.04	3.54	15.57	4.69	65.55	1.21	6.26	4.13	18.16
6B	6.05	61.50	1.05	19.32	2.93	9.15	5.28	70.88	1.21	8.71	3.37	10.55
6B[1]	5.89	60.86	1.16	19.45	2.98	9.66	5.10	70.11	1.34	8.88	3.44	11.13
7A	5.07	68.85	1.52	5.41	5.21	13.94	4.89	70.82	1.56	3.04	5.35	14.34
7B	5.36	72.96	1.46	6.40	3.46	10.36	5.21	74.82	1.49	4.32	3.54	10.62
7C	5.16	73.23	1.50	7.00	3.35	9.76	5.04	74.80	1.53	5.24	3.42	9.97
8A	5.16	54.45	1.39	15.42	2.77	20.81	4.46	60.87	1.55	6.76	3.09	23.27
8B	5.47	60.31	1.49	17.05	2.12	13.56	4.84	67.08	1.66	8.98	2.36	15.08
8C	5.51	62.02	1.57	17.15	2.10	11.65	4.93	68.62	1.74	9.49	2.33	12.89
9A	5.16	54.75	.99	14.77	4.97	19.36	4.51	60.79	1.10	6.59	5.52	21.49
9B	5.41	62.69	1.04	15.54	3.32	12.00	4.91	68.23	1.13	9.05	3.62	13.06
9C	5.73	69.01	1.32	15.95	3.09	4.90	5.38	74.66	1.43	9.88	3.35	5.30
10A	5.31	68.78	1.91	11.77	2.47	9.76	4.93	73.26	2.03	6.75	2.63	10.40
10B	5.42	72.10	1.62	11.71	1.95	7.20	5.11	76.00	1.71	7.53	2.06	7.59
10C	5.53	72.99	2.01	11.68	1.74	6.05	5.22	77.10	2.12	7.33	1.84	6.39
11A	5.44	57.05	1.06	15.18	3.88	17.39	4.76	64.11	1.19	6.04	4.36	19.54
11B	5.66	64.82	1.18	14.67	3.23	10.44	5.16	70.85	1.29	7.75	3.53	11.42
11C	5.81	67.34	1.22	14.24	3.00	8.39	5.36	73.00	1.33	7.97	3.25	9.09
12A	5.45	57.58	1.07	17.65	4.37	13.88	4.57	66.57	1.24	7.51	5.06	16.05
12A[1]	5.46	59.85	1.18	17.53	3.55	12.43	4.77	67.09	1.32	8.91	3.98	13.93
12B	5.66	61.60	1.22	17.58	4.01	9.93	5.01	68.90	1.36	9.13	4.49	11.11
13A	5.25	57.65	1.14	16.42	3.69	15.85	4.61	63.90	1.26	8.58	4.08	17.57
13B	5.48	62.69	1.17	16.22	2.93	11.50	4.97	68.38	1.28	9.63	3.20	12.54
13C	5.59	64.24	1.25	17.03	2.72	9.17	5.04	70.61	1.37	9.91	2.99	10.08
14A	5.45	58.60	.98	19.04	3.77	12.16	4.70	66.32	1.11	9.85	4.26	13.76
14B	5.69	62.43	1.19	18.97	3.48	8.24	5.02	70.00	1.33	10.51	3.90	9.24
14C	5.81	63.11	1.18	19.40	3.26	7.24	5.13	71.28	1.33	10.40	3.68	8.18
15A	5.34	68.90	1.62	15.36	.91	7.87	4.81	75.08	1.76	8.79	.99	8.57
15B	5.35	70.71	1.63	14.58	.85	6.88	4.91	76.10	1.76	8.90	.92	7.41
15C	5.78	73.38	1.65	15.67	.79	2.73	5.37	79.05	1.77	10.01	.86	2.94
16A	5.90	59.18	.99	17.86	4.55	11.52	5.14	67.76	1.14	7.56	5.21	13.19
16B	6.04	64.89	1.11	16.51	3.40	8.05	5.52	71.66	1.23	8.95	3.75	8.89
16C	6.12	67.85	1.17	17.58	2.65	4.63	5.58	75.16	1.30	9.89	2.94	5.13

ULTIMATE ANALYSIS — Moisture and Ash Free					Ash Analysis							Coal No.
Hydrogen, %	Carbon, %	Nitrogen, %	Oxygen, %	Sulfur, %	SiO_2, %	Al_2O_3, %	Fe_2O_3, %	MgO, %	CaO, %	SO_3, %	Ignition loss, %	
5.24	82.73	1.87	9.21	.95	—	—	—	—	—	—	—	1A
5.54	79.25	1.39	7.44	6.38	—	—	—	—	—	—	—	2A
5.69	79.74	1.37	9.11	4.09	—	—	—	—	—	—	—	2B
5.74	78.73	1.29	11.12	3.12	—	—	—	—	—	—	—	2C
5.53	79.93	1.70	9.92	2.92	—	—	—	—	—	—	—	3A
5.66	80.17	1.83	10.37	1.97	—	—	—	—	—	—	—	3B
5.54	80.31	1.64	10.76	1.75	—	—	—	—	—	—	—	3C
5.76	77.32	1.37	8.79	6.76	—	—	—	—	—	—	—	5A
5.66	77.38	1.42	11.14	4.40	—	—	—	—	—	—	—	5B
5.62	77.03	1.43	11.59	4.33	—	—	—	—	—	—	—	5B[1]
5.73	80.06	1.48	7.68	5.05	—	—	—	—	—	—	—	6A
5.90	79.28	1.36	9.69	3.77	—	—	—	—	—	—	—	6B
5.73	78.85	1.50	10.05	3.87	—	—	—	—	—	—	—	6B[1]
5.70	82.64	1.82	3.59	6.25	—	—	—	—	—	—	—	7A
5.83	83.75	1.67	4.78	3.97	—	—	—	—	—	—	—	7B
5.60	83.13	1.70	5.77	3.80	—	—	—	—	—	—	—	7C
5.81	79.33	2.02	8.81	4.03	—	—	—	—	—	—	—	8A
5.70	78.94	1.95	10.63	2.78	—	—	—	—	—	—	—	8B
5.66	78.74	2.00	10.93	2.67	—	—	—	—	—	—	—	8C
5.74	77.41	1.41	8.41	7.03	—	—	—	—	—	—	—	9A
5.65	78.51	1.31	10.37	4.16	—	—	—	—	—	—	—	9B
5.68	78.87	1.51	10.40	3.54	51.25	21.85	17.20	1.02	3.20	1.08	1.39	9C
5.50	81.79	2.27	7.51	2.93	39.99	20.05	24.35	.98	6.18	5.25	2.40	10A
5.53	82.23	1.85	8.16	2.23	41.57	21.88	23.59	.78	4.85	3.92	2.41	10B
5.57	82.33	2.26	7.87	1.97	44.16	23.49	22.02	.94	3.78	2.42	2.75	10C
5.91	79.66	1.48	7.53	5.42	41.88	19.96	21.62	.79	6.05	5.79	3.28	11A
5.83	80.01	1.46	8.72	3.98	38.59	18.51	24.33	.93	6.62	6.68	2.10	11B
5.89	80.27	1.46	8.81	3.57	38.39	18.01	26.68	1.00	5.62	5.68	2.97	11C
5.44	79.30	1.48	7.76	6.02	41.74	12.84	25.56	.78	5.81	5.45	1.07	12A
5.54	77.95	1.53	10.35	4.63	48.93	14.67	24.58	.74	5.06	3.42	1.10	12A[1]
5.63	77.48	1.53	10.31	5.05	47.00	13.49	25.53	.63	5.55	5.43	.87	12B
5.60	77.53	1.53	10.38	4.96	48.90	19.93	18.83	1.00	4.17	4.10	2.17	13A
5.66	78.20	1.46	11.04	3.66	51.53	20.94	14.12	.97	4.05	4.18	2.75	13B
5.61	78.51	1.52	11.04	3.32	51.78	21.46	13.97	.97	3.62	3.80	3.25	13C
5.45	76.88	1.29	11.44	4.94	43.03	20.04	23.85	1.04	3.54	3.30	3.32	14A
5.53	77.13	1.47	11.57	4.30	45.31	21.42	20.03	1.11	2.86	2.39	1.38	14B
5.59	77.64	1.45	11.31	4.01	46.71	21.69	18.65	1.20	2.70	2.70	1.87	14C
5.27	82.14	1.93	9.57	1.09	58.07	25.37	9.20	.78	1.59	1.18	1.58	15A
5.30	82.21	1.90	9.60	.99	58.84	25.90	8.59	1.04	1.28	.72	.72	15B
5.54	81.49	1.83	10.26	.88	50.52	26.21	13.18	1.00	2.79	1.83	1.95	15C
5.92	78.06	1.31	8.71	6.00	36.40	18.67	34.71	.56	6.23	6.90	.37	16A
6.06	78.65	1.35	9.82	4.12	36.42	23.09	29.82	.63	4.16	3.52	.21	16B
5.88	79.21	1.37	10.44	3.10	34.95	25.56	26.25	.58	4.04	2.95	3.13	16C

Coal No.	Varieties of Sulfur											
	As-Fired				Moisture-Free				Moisture and Ash Free			
	Sulfate, %	Pyritic, %	Organic, %	Total, %	Sulfate, %	Pyritic, %	Organic, %	Total, %	Sulfate, %	Pyritic, %	Organic, %	Total, %
2A	.22	3.26	1.29	4.77	.25	3.74	1.48	5.47	.29	4.36	1.73	6.38
2B	.19	2.13	1.00	3.32	.21	2.39	1.12	3.72	.23	2.62	1.24	4.09
2C	.24	1.20	1.12	2.56	.28	1.37	1.28	2.93	.30	1.45	1.37	3.12
3A	.34	1.18	.57	2.09	.39	1.36	.67	2.42	.47	1.65	.80	2.92
3B	.26	.69	.64	1.59	.29	.77	.73	1.79	.32	.85	.80	1.97
3C	.11	.70	.60	1.41	.13	.81	.67	1.61	.14	.87	.74	1.75
5A	.04	2.88	1.87	4.79	.04	3.30	2.13	5.47	.05	4.07	2.64	6.76
5B	.23	1.33	2.20	3.76	.25	1.41	2.31	3.97	.27	1.56	2.57	4.40
5B[1]	.15	1.27	2.26	3.68	.16	1.35	2.41	3.92	.18	1.49	2.66	4.33
6A	.03	2.04	1.47	3.54	.04	2.38	1.71	4.13	.05	2.91	2.09	5.05
6B	.28	1.05	1.60	2.93	.32	1.21	1.84	3.37	.36	1.36	2.05	3.77
6B[1]	.30	.99	1.69	2.98	.35	1.14	1.95	3.44	.39	1.28	2.20	3.87
7A	.08	3.24	1.89	5.21	.08	3.34	1.93	5.35	.09	3.89	2.27	6.25
7B	.06	1.62	1.78	3.46	.06	1.66	1.82	3.54	.07	1.86	2.04	3.97
7C	.05	1.55	1.75	3.35	.05	1.58	1.79	3.42	.06	1.75	1.99	3.80
8A	.08	1.56	1.13	2.77	.09	1.75	1.25	3.09	.12	2.28	1.63	4.03
8B	.06	.64	1.42	2.12	.07	.71	1.58	2.36	.08	.84	1.86	2.78
8C	.06	.55	1.49	2.10	.06	.61	1.66	2.33	.07	.70	1.90	2.67
9A	.10	3.00	1.87	4.97	.11	3.33	2.08	5.52	.14	4.24	2.65	7.03
9B	.08	1.65	1.59	3.32	.08	1.80	1.74	3.62	.09	2.07	2.00	4.16

Giesler Plasticity				Ignition Temperature		Chemical fusain, moisture and ash free, %	British swelling index	Mineral matter, %	Carbon ÷ avail. H_2	Fixed Carbon ÷ Volatile matter	Fixed Carbon × heating value	Recovery of washed coal, referred to raw coal, %	Coal No.
Fusion, °C	Maximum Fluidity, °C	Solidification, °C	Maximum fluidity, divisions per min.	T_{15} °C	T_{75} °C								
*	*	*	*	175	227	2.4	5.5	8.2	20.2	1.79	6566	—	1A
—	—	457	—	169	189	2.2	4.0	16.0	17.1	1.33	4586	—	2A
—	—	456	—	170	191	1.9	4.0	10.5	17.6	1.09	4919	91.5	2B
*	*	*	*	167	188	1.1	3.5	7.0	18.1	1.36	5510	59.2	2C
—	—	454	—	166	187	4.2	3.5	17.3	18.6	1.20	3948	—	3A
†	†	†	†	169	187	2.1	1.0	9.4	18.4	1.33	5278	71.4	3B
*	*	*	*	167	189	2.1	4.0	7.9	19.1	1.28	5193	59.4	3C
398	408	440	.81	167	191	3.1	4.0	20.6	16.6	1.06	3634	—	5A
—	370	433	3.4	169	189	1.7	3.0	12.1	18.2	1.11	5359	90.9	5B
—	377	433	3.2	165	189	1.9	3.5	11.5	18.4	1.37	5822	88.8	5B[1]
384	408	443	11.0	173	188	2.7	4.0	18.8	16.8	1.35	4068	—	6A
—	392	445	2.9	167	190	1.9	2.0	11.5	16.9	1.32	4884	92.6	6B
387	388	445	5.6	174	191	2.1	2.0	12.0	17.6	1.28	4718	95.2	6B[1]
379	415	467	9000	216	257	3.9	7.5	17.9	15.7	1.46	6075	—	7A
382	421	458	20300	214	261	—	8.0	13.1	16.0	1.46	6760	92.1	7B
380	415	459	12800	213	259	—	8.0	12.4	17.1	1.50	6995	75.6	7C
369	375	435	6.7	168	194	—	2.0	24.0	16.9	1.02	3341	—	8A
—	387	436	4.1	168	196	—	3.0	15.9	18.1	1.10	4298	89.9	8B
—	390	435	4.6	166	189	3.8	3.0	13.8	18.4	1.09	4565	79.4	8C
393	404	434	10.0	183	206	2.7	4.5	23.7	16.5	1.06	3636	—	9A
388	407	434	26.0	167	195	—	4.5	14.8	18.0	1.07	4679	91.1	9B
390	406	431	24.0	—	—	—	3.5	7.0	18.5	1.26	6103	38.7	9C
398	417	447	48	—	—	—	4.5	11.9	17.9	1.53	6277	—	10A
404	422	447	27	—	—	—	5.0	8.8	18.2	1.54	6850	87.4	10B
406	425	453	35.6	—	—	—	4.5	7.4	17.9	1.54	6990	39.7	10C
380	409	447	700	—	—	—	4.0	20.9	16.1	1.05	3769	—	11A
†	†	†	†	—	—	—	3.5	13.1	16.9	1.11	5037	86.0	11B
†	†	†	†	—	—	—	4.0	10.7	16.7	1.12	5428	59.4	11C
†	†	†	†	—	—	—	3.0	17.4	17.8	1.21	4121	—	12A
†	†	†	†	—	—	—	3.0	15.3	18.3	1.28	4704	—	12A[1]
†	†	†	†	—	—	—	4.0	12.9	17.8	1.25	5002	86.8	12B
—	—	—	—	—	—	—	—	—	—	—	—	61.8	12C
†	†	†	†	—	—	—	3.5	19.2	18.0	1.25	4339	—	13A
†	†	†	†	—	—	—	4.0	14.0	18.2	1.24	5031	88.3	13B
—	410	440	4.0	—	—	—	4.0	11.4	18.6	1.34	5441	60.0	13C
†	†	†	†	—	—	—	3.0	15.1	19.1	1.19	4438	—	14A
†	†	†	†	—	—	—	4.0	10.8	18.9	1.17	4995	86.8	14B
†	†	†	†	—	—	—	4.0	9.7	18.7	1.19	5068	59.8	14B
418	425	452	6.0	—	—	—	4.0	9.0	20.1	1.67	6406	—	15A
—	420	450	3.2	—	—	—	4.0	7.9	18.2	1.76	6839	85.7	15B
†	†	†	†	—	—	—	3.5	3.5	19.2	1.73	7481	44.0	15C
†	†	†	†	—	—	—	3.5	14.9	16.1	1.12	4368	—	16A
†	†	†	†	—	—	—	4.5	10.6	16.3	1.16	5279	81.8	16B
†	†	†	†	—	—	—	3.5	6.4	17.3	1.22	5823	46.5	16C

* Plasticity characteristics of this coal were tested by other methods, later concluded to be less useful than the Gieseler method. Data not reported.

† Test inconclusive; rabble arms stirred through powdered coal.

Coal No.	Uniformity: Average Variation, %	Uniformity: Minimum ÷ average *	Responsiveness: First 30 min., M B.t.u./hr.	Responsiveness: First hr., M B.t.u./hr.	Pickup, Average Cycle: M B.t.u./hr.	Pickup, Average Cycle: Ratio†	Pickup, Minimum Cycle: M B.t.u./hr.	Pickup, Minimum Cycle: Ratio†	Overrun, Average Cycle: M B.t.u./hr.	Overrun, Average Cycle: Ratio†	Overrun, Maximum Cycle: M B.t.u./hr.	Overrun, Maximum Cycle: Ratio†
1A	5.2	.85	38.5	114.9	54	.28	46	.24	99	.52	120	.62
2A	5.4	.86	14.6	57.8	39	.28	32	.23	64	.46	77	.55
2B	4.3	.89	20.4	68.1	48	.29	40	.24	76	.46	92	.56
2C	2.9	.91	—	—	—	—	—	—	—	—	—	—
3A	6.8	.87	20.2	92.6	45	.29	33	.21	79	.51	108	.70
3B	5.0	.89	34.0	77.4	47	.30	33	.21	69	.44	88	.56
3C	3.6	.90	25.2	103.2	56	.32	42	.24	90	.51	104	.59
5A	12.9	.69	14.6	63.5	35	.25	18	.13	63	.45	81	.58
5B	7.1	.83	18.4	87.6	38	.23	26	.16	84	.51	115	.70
5B[1]	6.7	.83	37.9	97.3	41	.26	25	.16	84	.53	109	69
6A	13.4	.69	15.7	68.0	30	.22	16	.12	65	.48	90	.66
6B	6.9	.85	35.3	—	39	.25	23	.15	81	.52	109	.70
6B[1]	6.9	.85	37.3	113.2	39	.25	25	.16	77	.50	104	.67
7A	15.5	.63	11.7	34.2	45	.24	23	.12	75	.40	111	.59
7B	11.8	.74	17.6	70.0	44	.23	34	.18	82	.43	124	.65
7C	15.4	.64	20.6	81.7	47	.26	32	.18	79	.44	137	.76
8A	8.3	.72	18.0	78.1	38	.27	28	.20	73	.52	93	.66
8B	5.7	.85	18.8	65.8	42	.27	31	.20	83	.54	100	.65
8C	5.7	.84	29.7	101.0	40	.25	25	.16	82	.52	100	.63
9A	20.5	.58	9.2	32.8	35	.23	23	.15	69	.45	117	.76
9B	8.6	.78	23.7	102.5	42	.24	33	.19	87	.50	106	.61
9C	7.9	.80	19.1	86.4	38	.22	26	.15	79	.46	121	.71
10A	8.9	.76	18.2	80.2	40	.24	30	.18	84	.50	116	.69
10B	6.4	.84	19.5	90.5	39	.21	30	.16	86	.46	109	.58
10C	6.3	.85	16.2	86.6	39	.21	32	.17	91	.49	119	.64
11A	17.8	.62	9.3	23.0	32	.23	25	.18	64	.45	89	.63
11B	15.7	.63	12.6	56.4	35	.23	28	.18	74	.48	105	.68
11C	13.8	.73	13.7	74.9	36	.21	30	.18	73	.43	107	.63
12A	11.1	.69	15.4	62.9	34	.23	27	.18	73	.49	100	.67
12A[1]	8.4	.79	15.0	65.5	32	.22	22	.15	70	.48	96	.66
12B	8.6	.78	19.8	75.9	34	.21	28	.17	75	.46	94	.58
13A	16.8	.65	18.6	83.5	32	.22	24	.16	75	.51	91	.62
13B	8.2	.80	29.4	106.2	39	.23	29	.17	87	.51	113	.66
13C	8.0	.78	39.5	112.6	42	.24	34	.19	88	.50	108	.61
14A	10.6	.77	19.3	61.5	40	.27	31	.21	82	.56	99	.68
14B	8.2	.75	28.0	94.1	37	.22	28	.17	83	.50	106	.64
14C	4.9	.87	23.7	97.5	39	.23	31	.18	82	.48	98	.58
15A	6.4	.85	21.9	100.8	44	.24	31	.17	93	.50	111	.60
15B	5.4	.85	27.1	—	45	.24	34	.18	90	48	105	.56
15C	2.9	.93	27.2	99.5	49	.26	43	.23	90	.48	106	.56
16A	5.6	.87	19.1	59.8	36	.24	32	.21	80	.53	91	.60
16B	4.2	.90	20.3	77.4	40	.26	32	.20	78	.50	96	.61
16C	4.4	.89	25.8	89.2	37	.24	31	.20	73	.47	92	.60

* Average of all operation rates except hold-fire.

† Ratio of rate of heat release during pickup or overrun period to the average rate with continuous stoker operation.

Coal No.	Heat Obtained: 60** M B.t.u./lb.	Heat Obtained: 45** M B.t.u./lb.	Heat Obtained: 30** M B.t.u./lb.	Heat Obtained: 15** M B.t.u./lb.	Heat Obtained: Average M B.t.u./lb.	Average efficiency %	Clinker rating	Windbox pressure in. of H_2O	Coal fed, lb./min.	Boiler Output With Continuous Stoker Operation: Average, M B.t.u./hr.	Boiler Output With Continuous Stoker Operation: Minimum, M B.t.u./hr.	Boiler Output With Continuous Stoker Operation: Minimum ÷ Average
1A	7.81	7.84	8.06	8.38	8.02	66.0	4	.60	.42	192	178	.93
2A	6.27	6.09	6.00	6.48	6.21	57.8	1	.84	.38	139	125	.90
2B	7.04	6.94	6.90	7.48	7.09	61.0	2	.72	.40	165	148	.89
2C	6.92	7.25	7.58	8.12	7.47	64.1	—	.62	.40	172	163	.95
3A	6.22	6.25	6.66	6.98	6.53	64.3	2	.98	.42	155	126	.82
3B	6.70	6.76	6.66	6.28	6.60	57.7	3	—	.39	157	144	.92
3C	7.35	7.46	7.61	8.30	7.68	66.8	3	.65	.40	176	154	.88
5A	5.47	5.85	5.74	5.77	5.71	57.4	0	1.07	.43	140	80	.57
5B	7.31	7.42	7.47	7.35	7.39	61.9	1	.72	.36	165	149	.90
5B[1]	7.58	7.39	7.44	7.40	7.45	63.0	2	.68	.36	158	141	.90
6A	5.99	5.93	6.07	5.87	5.96	59.0	0	1.20	.39	136	116	.85
6B	6.79	6.65	6.76	6.76	6.74	60.9	2	.70	.38	156	145	.93
6B[1]	6.79	6.75	6.63	6.43	6.65	61.0	2	.79	.38	155	145	.94
7A	8.22	7.95	8.16	8.43	8.19	66.6	0	1.15	.40	188	134	.71
7B	8.31	8.22	8.32	7.78	8.16	62.4	1	1.22	.39	191	136	.71
7C	8.09	8.02	8.05	8.21	8.09	61.2	1	1.15	.39	180	138	.76
8A	5.74	5.68	6.05	6.43	5.98	61.9	1	1.20	.42	141	100	.71
8B	6.50	6.60	6.77	7.12	6.75	62.8	2	.86	.41	154	141	.91
8C	6.69	6.61	6.72	6.80	6.71	60.4	2	.68	.40	158	125	.79
9A	6.07	5.91	6.16	6.57	6.18	61.9	0	1.13	.43	154	71	.46
9B	7.17	7.02	7.20	7.45	7.21	63.5	1	.92	.41	174	118	.68
9C	7.83	7.64	7.57	7.48	7.63	60.9	4	.72	.37	171	150	.88
10A	7.64	7.48	7.49	7.93	7.63	61.9	2	.93	.38	169	132	.78
10B	8.20	7.88	8.02	8.08	8.05	62.5	3	.83	.38	188	151	.80
10C	8.18	8.08	7.99	7.81	8.01	61.6	4	.69	.38	186	158	.85
11A	6.16	6.09	6.06	6.06	6.09	59.1	0	1.09	.41	141	63	.45
11B	6.71	6.63	6.54	6.80	6.67	56.4	2	.92	.39	154	78	.51
11C	7.46	7.17	7.15	7.09	7.22	58.9	3	.81	.38	169	113	.67
12A	6.17	5.86	6.02	6.12	6.04	58.3	1	.82	.42	149	97	.65
12A[1]	6.61	6.51	6.49	6.66	6.57	60.2	1	.86	.39	145	120	.83
12B	7.12	6.88	6.82	6.79	6.90	61.0	3	.78	.41	163	118	.73
12C	—	—	—	—	—	—	—	—	—	—	—	—
13A	6.04	6.28	6.35	6.34	6.25	59.5	0	.97	.43	147	56	.38
13B	7.08	7.03	7.13	7.24	7.12	62.8	3	.91	.42	172	130	.76
13C	7.26	7.26	7.39	7.33	7.31	63.0	4	.90	.41	177	127	.72
14A	6.21	6.08	5.65	6.50	6.11	57.0	2	.89	.41	146	69	.47
14B	7.06	6.96	6.98	7.26	7.07	61.9	4	.88	.40	166	102	.61
14C	7.30	7.23	7.18	7.17	7.22	62.8	4	.58	.39	170	148	.87
15A	7.86	7.81	8.01	8.44	8.03	65.8	2	.81	.40	185	163	.88
15B	8.26	8.14	8.00	8.27	8.17	65.6	4	.58	.38	188	170	.90
15C	8.75	8.53	8.39	8.26	8.48	64.7	4	.39	.37	189	175	.93
16A	6.77	6.74	6.73	7.33	6.89	63.1	1	.78	.38	151	127	.84
16B	7.55	7.54	7.84	8.52	7.86	66.1	2	.67	.35	158	139	.88
16C	7.74	7.74	7.54	7.88	7.73	62.5	3	.57	.33	155	143	.92

** Minutes of stoker operation per hour.

Coal No.	CO_2 %	Stack Temperature, °F	Heat Absorbed B.t.u./lb.	Heat Absorbed %	Stack Loss B.t.u./lb.	Stack Loss %	Moisture Loss B.t.u./lb.	Moisture Loss %	Hydrogen Loss B.t.u./lb.	Hydrogen Loss %	Radiation and Unaccounted B.t.u./lb.	Radiation and Unaccounted %
	Results Obtained with Continuous Stoker Operation		Heat Balance									
1A	12.9	980	7810	64.2	3070	25.2	130	1.1	450	3.7	700	5.8
2A	9.6	880	6270	53.3	3080	28.7	180	1.7	440	4.1	770	7.2
2B	10.7	970	7040	60.5	3400	29.2	160	1.4	480	4.1	548	4.8
2C	10.4	930	6920	59.4	3400	29.2	180	1.5	460	4.0	690	5.9
3A	10.7	900	6220	61.2	2760	27.2	190	1.9	390	3.9	588	5.8
3B	10.5	890	6700	58.6	3140	27.4	160	1.4	450	3.9	998	8.7
3C	11.5	935	7350	64.0	3040	26.4	180	1.6	440	3.8	480	4.2
5A	9.5	880	5470	55.0	2870	28.8	180	1.8	420	4.2	1015	10.2
5B	10.6	915	7310	61.2	3280	27.5	75	.6	460	3.9	810	6.8
5B[1]	9.8	915	7580	64.1	3500	29.6	84	.7	456	3.8	213	1.8
6A	9.8	865	5990	59.3	2820	28.0	190	1.9	420	4.2	665	6.6
6B	11.4	900	6790	61.3	2760	24.9	190	1.7	470	4.2	874	7.9
6B[1]	10.0	850	6790	62.3	2890	26.5	185	1.7	435	4.0	595	5.5
7A	11.7	965	8220	66.8	3320	27.0	40	.3	575	4.7	142	1.2
7B	12.0	990	8310	63.6	3500	26.7	40	.3	600	4.6	625	4.8
7C	10.0	945	8090	61.2	3960	29.9	30	.2	570	4.3	573	4.4
8A	8.9	895	5740	59.5	3110	32.2	150	1.5	415	4.3	240	2.5
8B	10.1	965	6500	60.5	3310	30.8	150	1.4	440	4.1	346	3.2
8C	10.3	980	6690	60.2	3400	30.6	140	1.3	440	4.0	438	3.9
9A	10.1	910	6070	60.8	2820	28.2	140	1.4	430	4.3	529	5.3
9B	11.6	1000	7170	63.2	3150	27.7	120	1.1	460	4.0	458	4.0
9C	11.3	910	7830	62.5	3210	25.6	110	.9	480	3.8	901	7.2
10A	11.3	920	7640	61.9	3230	26.2	90	.7	500	4.1	873	7.1
10B	12.6	960	8200	63.7	3190	24.8	70	.5	520	4.0	896	7.0
10C	11.3	—	—	—	—	—	—	—	—	—	—	—
11A	10.1	840	6160	59.8	2670	25.9	155	1.5	450	4.4	864	8.4
11B	9.0	850	6710	56.7	3480	29.4	120	1.0	480	4.1	1035	8.8
11C	10.3	910	7460	60.9	3420	27.9	110	.9	520	4.2	749	6.1
12A	9.9	910	6170	59.5	3040	29.4	190	1.8	420	3.1	534	5.2
12A[1]	9.9	900	6610	60.5	3110	28.5	150	1.4	420	3.9	625	5.7
12B	11.0	920	7120	62.8	2950	26.1	150	1.4	450	4.0	647	5.7
13A	9.8	865	6040	57.5	2890	27.5	140	1.3	405	3.9	1031	9.8
13B	—	975	—	—	—	—	—	—	—	—	—	—
13C	12.0	940	7260	62.6	2890	24.9	130	1.1	450	3.9	871	7.5
14A	9.5	900	6210	57.9	3200	29.9	165	1.5	390	3.6	755	7.1
14B	10.8	900	7060	61.8	2960	25.9	150	1.3	425	3.7	835	7.3
14C	11.0	895	7300	63.5	2900	25.2	160	1.4	430	3.8	701	6.1
15A	11.8	1015	7860	64.4	3400	27.9	120	1.0	450	3.7	372	3.0
15B	12.1	960	8260	66.3	3285	26.4	100	.8	510	4.1	303	2.4
15C	11.4	920	8750	66.8	3370	25.7	100	.8	490	3.7	391	3.0
16A	9.5	900	6770	62.0	3140	28.8	180	1.6	470	4.3	359	3.3
16B	—	885	—	—	—	—	—	—	—	—	—	—
16C	8.9	860	7740	62.7	3690	29.8	140	1.1	500	4.0	292	2.4