Use of Iowa Coals in Domestic Stokers

Enlarged Edition

By

M. P. Cleghorn and R. J. Helfinstine

IOWA ENGINEERING
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LETTER OF TRANSMITTAL

T. R. Agg, *Director*
Iowa Engineering Experiment Station
Iowa State College
Ames, Iowa

Dear Sir:

We are submitting a manuscript entitled "Use of Iowa Coals in Domestic Stokers—*Enlarged Edition*" with the recommendation that it be published as a bulletin of the Iowa Engineering Experiment Station. This manuscript includes most of the material appearing in *Bulletin* 134 plus a considerable amount of additional information obtained from subsequent tests. The investigation was conducted as Project 195 of the Station.

The stoker used in the tests was loaned by Iron Fireman Manufacturing Company and the boiler by United States Radiator Corporation. Acknowledgment is made to these companies for their cooperation.

Respectfully submitted,

M. P. Cleghorn
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Ames, Iowa
August 1, 1939

ABSTRACT

This study was made to determine the suitability of Iowa coals for use in domestic stokers. The tests were made with a typical stoker-fired boiler in the laboratory; the results are directly applicable to the usual household installation. Relative costs of heating with Iowa and competitive out-of-state coals, clinkering tendencies and manual attention required when burning Iowa coals, soot and fly ash formation, and characteristics of mixtures of Iowa and high-grade Eastern coals are reported.

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SUMMARY AND CONCLUSIONS

This investigation has demonstrated that Iowa coals can be burned satisfactorily in a properly designed stoker-fired domestic heating plant. Some of the conclusions indicated by the tests are as follows:

1. Iowa coal will furnish the cheapest source of heat with a domestic stoker in much of the state, although it furnishes only three fourths as much heat per pound of coal as the coals from Illinois, Indiana, and western Kentucky.

2. Clinkering is quite rapid and occasionally troublesome with Iowa coals, often causing nonuniformity of combustion. However, attention need not be given to the stoker more than once a day except in the coldest weather.

3. Clinkering of Iowa coals is much less troublesome and efficiency of combustion is increased when the quantity of air supplied to the fuel bed is limited until a light-gray smoke comes from the stack. With this air supply a deep fuel bed will be maintained.

4. A considerably larger heating plant is required for Iowa coals than for the higher-grade Eastern coals to reduce clinkering troubles and to maintain a uniform temperature in the home during a period of poor fire.

5. The performance characteristics of a mixture of equal parts of an Iowa coal and a high-grade Eastern coal are equal to those of an Indiana or Southern Illinois coal. Such a mixture would be cheaper than the Indiana or Southern Illinois coal in some sections of Iowa.

6. Screenings furnish slightly less heat per pound than the prepared stoker coals, but usually burn fairly satisfactorily. However, the dust created by handling is often objectionable.

7. Iowa coals will satisfactorily maintain a fire at fire-holding stoker operation rates.

8. About 10 lb. of soot and fly ash are formed per ton of Iowa coal burned. The resulting heat loss amounts to less than 0.5 percent of the heating value of the coal fired. The amount of ash leaving the fuel bed per pound of coal burned is only slightly affected by the rate of combustion.

9. Considerable crushing and size segregation occur during the passage of the coal from the stoker hopper to the furnace hearth, although they can be minimized by the use of small, uniformly-sized coal. This size segregation and finer coal does not alter combustion characteristics seriously.

10. It is difficult to make Iowa coals dustless for more than a month by present methods of oil treatment.

11. A small domestic stoker should not ordinarily be purchased as a moneysaving device, but rather for the convenience and healthful benefits of automatic heating.

Use of Iowa Coals in Domestic Stokers

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INTRODUCTION

Although Iowa is predominantly an agricultural state, coal mining is a major industry. More than eight thousand workers were employed by the 419 coal mines operated in Iowa during 1938, mining 3,182,638 tons of coal. At this rate of production several thousand years will be required to deplete Iowa's coal supply, for it is estimated[1] that there are at least twenty-five billion tons of workable coal deposits. These deposits underlie much of central and southern Iowa. The present productive portion lies mainly along the Des Moines River and the southern border of the state as shown in Fig. 1.

With the exception of the Centerville seam, which is estimated to cover 1,500 sq. miles, Iowa coal beds are not consolidated into large fields. Some deposits have a thickness of 8 to 10 ft., but most of those being worked in central Iowa average 4 to 5 ft., the Centerville seam, 2½ ft., and the Nodaway seam, 16 in.

Most Iowa coals are high-volatile, clinkering coals, containing less fixed carbon and more moisture, ash, and sulphur than Eastern bituminous coals. Like other Midwestern coals, they contain layers of bright and dull coal of varying thickness; the dull portion is soft and causes the coals to break easily. Because Eastern mines have relatively higher-quality coal and reduced mining costs, resulting from large-scale production of thick-seamed, consolidated fields, Eastern coals offer serious competition to Iowa coals even after the addition of several dollars per ton for transportation.

Iowa coals have been used in hand-fired domestic heating plants for many years, and their performance in this application is fairly well established. However, previous to this investigation little information was available concerning their performance in stoker-fired domestic heating plants, although a large number of small stokers have been installed in Iowa homes. To supply this information the Iowa Engineering Experiment Station inaugurated a testing project in 1935 and published the results of the first tests in *Bulletin* 134 (1937). Since this publication additional tests have been made and the results incorporated in this bulletin along with much of the material appearing in *Bulletin* 134.

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[1] Lees, James H. "Iowa Coal Areas and Characteristics of Iowa Coal." *Iowa Geological Survey*, XXXII (1927), 65-81.

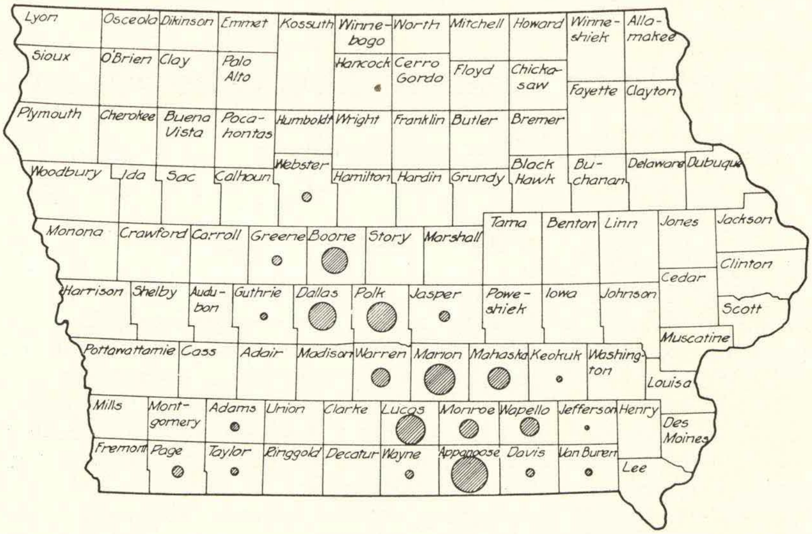

Fig. 1.—The coal-producing areas of Iowa in 1937, based on the biennial report of the state mine inspector. The area of each circle is proportional to the coal production of that county.

OBJECT OF TESTS

The object of this study was to determine the suitability of Iowa coals and coal mixtures for use in domestic stokers and to compare them with selected out-of-state coals. Of the various pertinent factors in this problem the following were investigated:

1. Heat obtained from the coal[2]
2. Manual attention required
3. Clinkering tendencies
4. Uniformity of burning
5. Fire-holding ability
6. Cleanliness
7. Soot and fly ash formation
8. Coal segregation in the retort
9. Crushing of coal by the stoker

Many of these factors are closely related; some are important only because of their effect on the others. The facts concerning all are needed to enable intelligent selection and use of stoker coal.

[2] The heat obtained from the coal will be given in this bulletin in "pounds of equivalent evaporation per pound of coal burned." One pound of equivalent evaporation is the amount of heat required to change 1.0 lb. of boiling water to steam at an absolute pressure of 14.7 lb. per sq. in.

APPARATUS

The tests were made with a stoker-fired heating boiler such as might be found in a home (Figs. 2 and 3). The added test equipment did not affect the operation of the heating plant and was used only to obtain data.

A rectangular, Model B-8, "Capitol" boiler, rated at 920 sq. ft. of direct radiation with 13,000-B.t.u. coal, was used. The first 82 tests were conducted with an uncovered boiler, and an allowance made for the extra heat loss, in pounds of equivalent evaporation, by means of the formula:

$$\left(\begin{array}{c}\text{Heat lost}\\ \text{from uncovered}\\ \text{boiler}\end{array}\right) = \frac{1.8}{971.7}\left(\begin{array}{c}\text{External boiler}\\ \text{surface in}\\ \text{sq. ft.}\end{array}\right)\left(\begin{array}{c}\text{Elapsed}\\ \text{time}\\ \text{in hr.}\end{array}\right)\left(\begin{array}{c}\text{Difference between boiler}\\ \text{steam temperature and}\\ \text{room temperature in °F.}\end{array}\right).$$ [3]

For the remainder of the tests a 2-in. covering of 85 percent magnesia was placed on the boiler, thus eliminating need for a correction for heat loss.

A 1936, Model R-30, "Iron Fireman" stoker, with a 350-lb. cylin-

[3] The coefficients in the formula are those recommended by the American Society of Heating and Ventilating Engineers.

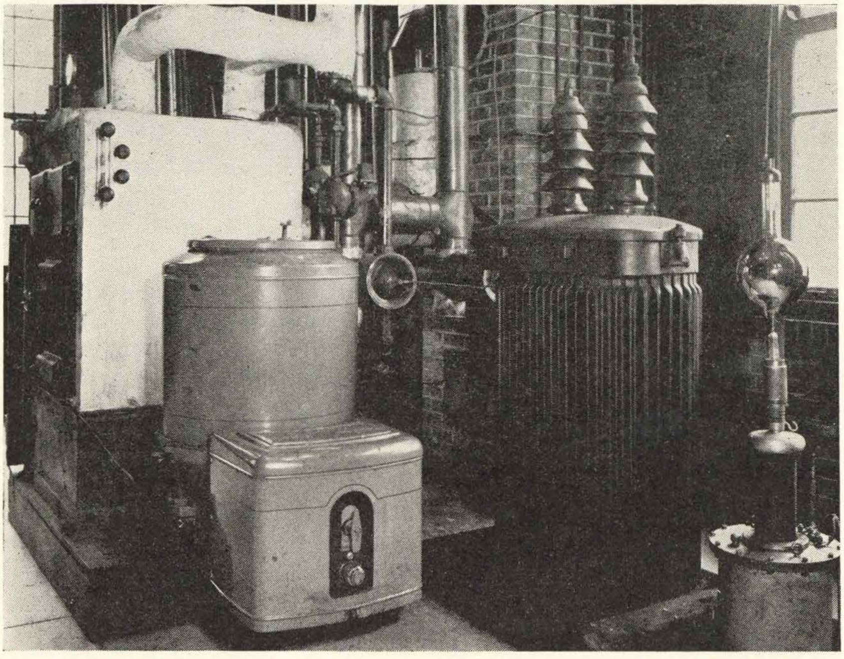

Fig. 2.—Boiler, stoker, and electrical precipitator used in the tests.

drical storage hopper, was installed in the boiler. This stoker had three coal-feeding rates, obtained by varying the speed of the screw conveyor used to move the coal from the hopper to the retort. The maximum coal feed was about 30 lb. per hr.

The top of the stoker retort was set 3 in. below the nominal grate level, or about 25 in. from the lowest part of the boiler arch. This location of the retort created a fairly large combustion chamber, which is desirable when burning a coal high in ash and volatile matter.

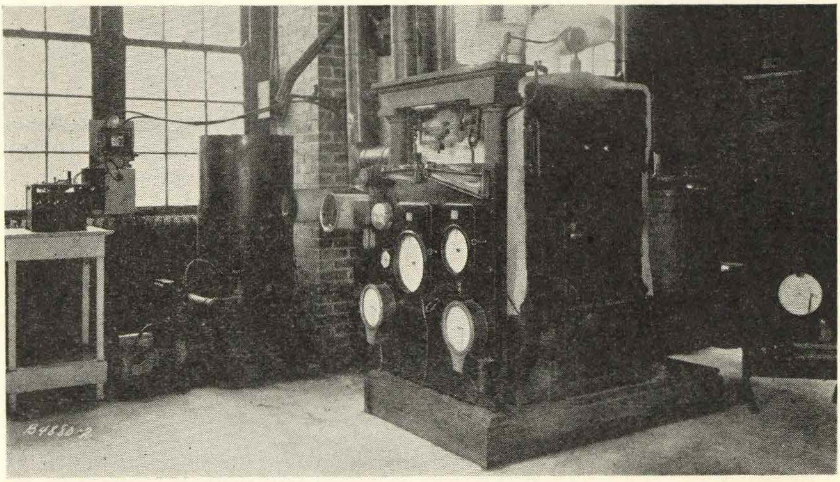

Fig. 3.—Testing apparatus, showing the instruments and feed-water pump.

The steam generated was piped to a condenser on a balcony above the boiler, and the condensate drained into a tank set on a platform scale. This weighing tank could be emptied into the feed-water supply tank. A motor-driven centrifugal water pump automatically maintained a nearly constant water level in the boiler. The pump was also equipped with a manual control to allow accurate water-level regulation when readings were being taken. If the water level in the boiler approached a dangerously low point an automatic cut-off stopped the stoker.

The boiler and stoker were mounted on scales to permit an accurate determination of the amount of combustible burned, which formed a basis for the calculation of the amount of coal burned. Flexible hose connections were made with the condenser and feed-water pump. Flexibility of the smoke pipe was obtained by the use of elbows.

During several of the tests an electrical precipitator was used to collect soot and fly ash. It consisted of four, vertical, 6-in. smoke pipes, each 15 ft. in length, with a 24-gage steel wire stretched through the center of, and electrically insulated from, each grounded pipe. The wires were charged with a unidirectional voltage of 33,000 volts, obtained from the 220-volt alternating-current power line by means of a transformer and a "Kenetron" high-vacuum rectifier tube. The pipes were so arranged that the stack gases could be passed either directly into the chimney, or divided equally among the precipitator pipes and then passed into the chimney. A 7-in., circular, hair brush was used to clean the soot and fly ash from the pipes.

During the earlier tests an electric calorimeter was used to determine the quality of the steam (a measure of the water in the steam). As the quality remained nearly constant at 0.98, and as the apparatus was difficult to operate, the use of the calorimeter was discontinued and a quality of 0.98 assumed for all tests.

Continuous records of the boiler pressure and the temperatures of the feed water, the stack gases, and the air in the room were obtained by recording instruments. Indicating draft gages were connected to the combustion chamber, the stoker wind box, and the stack at the boiler outlet. An Orsat gas analyzer was used for flue-gas determinations. A self-starting electric clock was wired in the stoker motor circuit to indicate the minutes of stoker operation, while a watt-hour meter measured the power consumption of the stoker.

TESTING PROCEDURE

A preliminary investigation was made to determine the length and type of tests best suited to the purposes of the study. It was found that, after the fuel bed had reached a fairly stable condition, an 8-hr. operating period gave practically the same equivalent evaporation per pound of coal as a 24-hr. test, although the shorter test was of insufficient duration to indicate necessary clinker removal periods. Therefore, four tests were selected for the first series (group A) of tests: a 20-hr. test with high-speed, intermittent coal feed (to determine clinkering tendencies); an 8-hr. test with high-speed, continuous coal feed; an 8-hr. test with medium-speed, continuous coal feed; and an 8-hr. test with medium-speed, intermittent coal feed.

The Iowa coals tested were obtained from mines located in various parts of the state and were trucked directly from the mines to the Station. As prepared Iowa stoker coals were not generally available when these tests were started, screenings were used for the group A tests, except in two cases, when it was necessary to substitute crushed mine-run.

Smoky Hollow and Scandia coals were found to be fairly representative of all Iowa coals, so they were selected for additional tests to determine the characteristics of Iowa coals more completely. Throughout each of these tests (group B) the fire was allowed to burn continuously and not attended except to remove the clinker after each hopper of coal had been burned. The stoker was operated at constant rates from 3 to 60 min. per hr. to represent operation under various weather conditions in a home installation. Several other Iowa and out-of-state stoker coals were tested in the same manner, but with fewer stoker operation rates.

Two Iowa coals, a petroleum coke, and five out-of-state coals, varying from high-volatile, clinkering, Midwestern coals to high-grade, low-volatile, coking, Eastern coals, were selected for coal mixture tests (group C). The Sunshine (Iowa) coal was tested by itself and when mixed with one fourth, one half, and three fourths parts of each out-of-state coal. Tests also were made with mixtures of Dallas (Iowa) coal and Pocahontas coal, and of Sunshine coal and petroleum coke. In addition each out-of-state coal was tested individually.

The primary information desired for each mixture was its combustion characteristics at the higher burning rates. Therefore, every test was conducted with a heating load representing the maximum rate of combustion with the Iowa coal.

The fire with each fuel was started on a clean hearth and a fuel bed allowed to build up for about 23 hr. If any clinker had formed it was removed. After another hour to allow the fire to become normal an 8-hr. test was made. The uniformity of combustion was so similar for certain coal mixtures that longer tests were made to indicate the relative rankings.

The amount of soot and fly ash from each coal was determined in a separate series of tests. To insure stable operating conditions the stoker was allowed to operate at a low rate for several hours with the stack gases passing directly into the chimney. Before starting each test the soot and fly ash were removed from the boiler passages with brushes and a vacuum cleaner, and the stoker controls set for the desired rate. Then the voltage was applied to the precipitator, the gases routed through it, and the test started. The gases coming from the stack were watched carefully, and the test was terminated if a discharge of any solid particles (indicating that the precipitator was not retaining all the soot and fly ash) was noted; otherwise the test proceeded until darkness prevented proper observation of the stack gases or until 100 lb. of coal had been burned. At the completion of each of these tests the gases were rerouted directly to the chimney, and the soot and fly ash were cleaned from the precipitator and the boiler passages, weighed, and sampled for chemical analysis.

The tests to determine the size distribution of the coal as it emerged from the retort and the amount of crushing of the coal by the screw conveyor, were made with the stoker out of the boiler. Coal of a known sieve analysis was placed in the hopper and fed to the retort; then the coal emerging from each quarter of the retort was sized by screening. Strips of sheet iron were used to divide the retort into quadrants for these tests.

To determine the effectiveness of their dust treatments about 1,200 lb. each of two oil-treated Iowa stoker coals were placed in storage in adjoining bins in a basement. Their dust-producing properties were checked when received and every week for two months, by which time all apparent effect of the treatment had disappeared.

RESULTS

Heat Obtained from the Coals

The heat obtained from the coals varied considerably (Table 6, Appendix) because of differences in quality of coal, method of stoker operation, and rate of firing. Therefore, considerable care must be used in a comparison of the results obtained from different tests.

To facilitate comparison of the heat secured from the various coals, the results have been arranged in three groups in Table 1, average

TABLE 1.—AVERAGE HEAT OBTAINED FROM VARIOUS COALS

Coal*	Equivalent evaporation,† lb. per lb. of coal		Tests used
	Coal as fired	Dry basis	
Group A tests			
McConville crushed mine-run	6.0	7.2	Four 8-hr. tests with continuous and intermittent operation of stoker at medium and high speeds
Norwood-White screenings	5.9	6.8	
Smoky Hollow screenings	5.7	6.6	
Pershing screenings	5.6	6.6	
Shuler screenings	5.5	6.4	
New Market crushed mine-run	5.3	6.4	
Boone screenings (3 tests only)	4.2	5.1	
Group B tests			
Hopkins County (Kentucky) stoker	8.3	8.9	Tests with varying rates of stoker operation to simulate a home installation
Franklin County (Illinois) stoker	8.1	8.6	
Saline County (Illinois) stoker	8.1	8.5	
Sullivan County (Indiana) stoker	7.9	8.9	
Smoky Hollow stoker	6.7	7.6	
Ellis stoker	6.1	6.8	
Helsing crushed mine-run	6.0	7.1	
Des Moines Ice and Fuel stoker	5.7	6.6	
Scandia ¾- to 1¼-in. nut	5.6	6.4	
Group C tests			
Pocahontas (West Virginia) stoker	9.9	10.0	One 8-hr. test with high-speed, intermittent stoker operation
Floyd County (Kentucky) stoker	8.9	9.2	
Gibson County (Indiana) stoker	7.5	8.0	
Franklin County (Illinois) stoker	7.2	7.9	
Perry County (Illinois) stoker	6.9	7.6	
Sunshine stoker	6.1	6.9	
Dallas stoker	5.6	6.3	

*Unless otherwise stated the coals are from Iowa mines.

†Equivalent evaporation is a measure of the heat obtained from burning the coal in a boiler. One pound of equivalent evaporation is equal to 970 B.t.u. of heat.

TABLE 2.—ANALYSES OF VARIOUS COALS

Coal No.	Coal*	Mine location, county	Proximate analysis of coal as fired† Moisture, per cent	Ash, per cent	Volatile matter, per cent	Fixed carbon, per cent	Sulphur, per cent	Heating value,‡ B.t.u. per lb.	Fusion temperature of ash,ϕ °F.
1	Scandia screenings	Boone	14.66	15.77	35.68	33.89	4.34	9,722	1940
2	Smoky Hollow screenings	Monroe	14.73	12.90	36.32	36.05	2.83	10,037	1965
3	Boone screenings	Boone	16.24	24.18	29.35	30.23	6.15	8,040	1840
4	Pershing screenings	Marion	14.74	17.79	34.04	33.43	4.89	9,778	1945
5	Shuler screenings	Dallas	13.60	17.81	35.40	33.19	6.22	10,083	1970
6	Norwood-White screenings	Polk	13.27	15.80	37.10	33.82	4.60	10,280	2005
7	McConville crushed mine-run	Appanoose	15.80	11.28	35.02	37.90	4.43	10,440	1940
8	New Market crushed mine-run	Taylor	18.04	13.12	34.36	34.48	4.80	9,352	2135
9	Scandia ¾- to 1¼-in. nut	Boone	14.08	17.77	35.67	32.48	4.55	9,863	2025
10	Scandia screenings	Boone	15.82	19.60	32.22	32.36	4.51	9,380	1975
11	Smoky Hollow nut	Monroe	13.55	11.35	38.65	36.45	4.19	10,300	1920
12	Smoky Hollow nut	Monroe	9.34	11.64	38.50	40.52	4.96	11,169	1940
13	Smoky Hollow screenings	Monroe	10.13	13.05	38.10	38.72	4.72	10,703	1930
14	Southern Illinois stoker	Franklin	5.30	10.38	33.55	50.77	1.20	12,100	2250
15	Glendora (Indiana) stoker	Sullivan	10.25	6.34	33.75	49.66	0.81	11,880	2215
16	Western Kentucky stoker	Hopkins	6.03	6.24	37.08	50.65	2.64	12,669	1925
17	Southern Illinois stoker	Saline	5.70	9.43	34.10	50.77	1.37	11,950	1935
18	Des Moines Ice & Fuel oiled stoker	Polk	13.90	16.67	37.33	32.10	5.31	9,932	1955
19	Helsing Strip crushed mine-run	Marion	14.91	12.42	35.18	37.49	6.71	10,403	1920
20	Ellis stoker	Mahaska	10.13	19.91	39.48	30.48	5.60	9,993	2100
21	Smoky Hollow stoker	Monroe	14.58	11.94	34.38	39.10	3.43	10,482	1970
22	Dallas stoker	Dallas	11.06	15.66	33.27	40.01	2.03	10,498	1950
23	Pocahontas (West Virginia)	——	1.38	3.45	17.08	78.09	0.80	14,804	2530
24	Dallas stoker	Dallas	13.84	17.04	32.44	36.68	——	9,590	1980
25	Sunshine stoker	Appanoose	12.37	12.00	35.50	40.13	2.34	11,552	1960
26	Southern Illinois stoker	Perry	8.22	9.40	37.21	45.17	3.38	12,419	2065
27	Sunshine stoker	Appanoose	11.11	14.84	35.37	38.68	1.87	10,607	1960
28	Sunshine stoker	Appanoose	12.17	11.86	34.91	41.06	——	11,663	1960
29	Eastern Kentucky stoker	Floyd	2.66	3.36	37.58	56.38	0.81	15,059	2375
30	Indiana stoker	Gibson	5.98	7.53	36.06	50.43	1.77	12,603	1995
31	Pocahontas (West Virginia)	——	2.16	5.05	16.91	75.88	——	15,115	——
32	Dallas stoker	Dallas	12.56	23.90	37.91	31.63	——	9,140	——
33	Southern Illinois stoker	Franklin	——#	11.64#	37.69#	50.67#	1.74#	13,321#	2345
34	Sunshine stoker	Appanoose	12.81	14.21	35.23	37.75	5.46	11,202	——
35	Petroleum coke	——	8.95	1.37	13.87	75.81	2.75	15,213	——

*Unless otherwise stated the coals are from Iowa mines.

†Proximate analysis is the analysis of a substance into its compounds by a standardized analytical procedure.

‡Heat generated with perfect combustion.

ϕTemperature at which ash softens.

#Analysis of this coal is on a dry basis only.

results from tests performed under similar conditions being grouped together. Comparisons should be made only within each group. The groupings correspond to those listed in the explanation of testing procedure on pages 11 and 12.

The arrangement of the coals in each group in the order of equivalent evaporation should not be considered an absolute ranking of the coals tested. Many of the tests were conducted with coal from but one load which may not have been fully representative of the coal from that mine. The amount of variation from load to load was considerable, as shown by the analyses of different loads from the same mine (Table 2). In the coal received from one mine the ash content varied from 16 to 24 percent and the heating value from 9,100 to 10,500 B.t.u. per lb.

As the tests included in group B were conducted under conditions such as might be found in a home, they are probably the most valuable for comparison of the heat which can be obtained from the various coals. The four out-of-state coals tested in this group sell at about the same price in much of Iowa and furnish the main source of competition for Iowa stoker coal. An average equivalent evaporation of 8.1 lb. per lb. of coal was obtained from these out-of-state coals, while an average value of 6.0 lb. was secured from the Iowa coals. These values are probably fairly representative of the two groups. Thus, the average Iowa coal furnished only three fourths as much heat per pound of coal as the coals from Illinois, Indiana, and western Kentucky.

This difference in heat obtained seems a serious handicap for Iowa coals to overcome, but a comparison of delivered prices shows that Iowa coal furnishes the cheapest source of heat with a domestic stoker in a considerable portion of the state. For an average coal the exact comparison can be determined from Fig. 4, in which the cost of coal is plotted against the cost of heat obtained. The dotted line on this figure indicates the method of finding the value (based only upon heat obtained) of an average Iowa coal compared with an average competitive out-of-state coal. The example shown indicates that \$5.60 per ton could be paid for Iowa coal to obtain the same heat per dollar as would be obtained from an Illinois, Indiana, or Western Kentucky coal priced at \$7.50 per ton. The actual cost may be somewhat lower. The out-of-state coals for these tests were obtained during a hot, dry summer and had a lower moisture content than usual; thus the data probably penalize Iowa coals slightly.

Because of the possible decrease in moisture content of the Midwestern coals in storage, direct comparisons of equivalent evaporations obtained from coals as received may be misleading. A coal containing 20 percent moisture when mined can be dried to 10 percent by storing it a short time in a warm, dry room, thereby increasing its *heating value per pound* by 12½ percent although the *total* *heat available* will remain practically constant. However, as Iowa coals usually have a higher moisture content than Eastern coals, the heating values of the coals can be compared more accurately on the basis of the coal as received. Table 1 and Fig. 4 were prepared on this basis. The data for Table 2 were obtained from chemical analyses of the fuels.

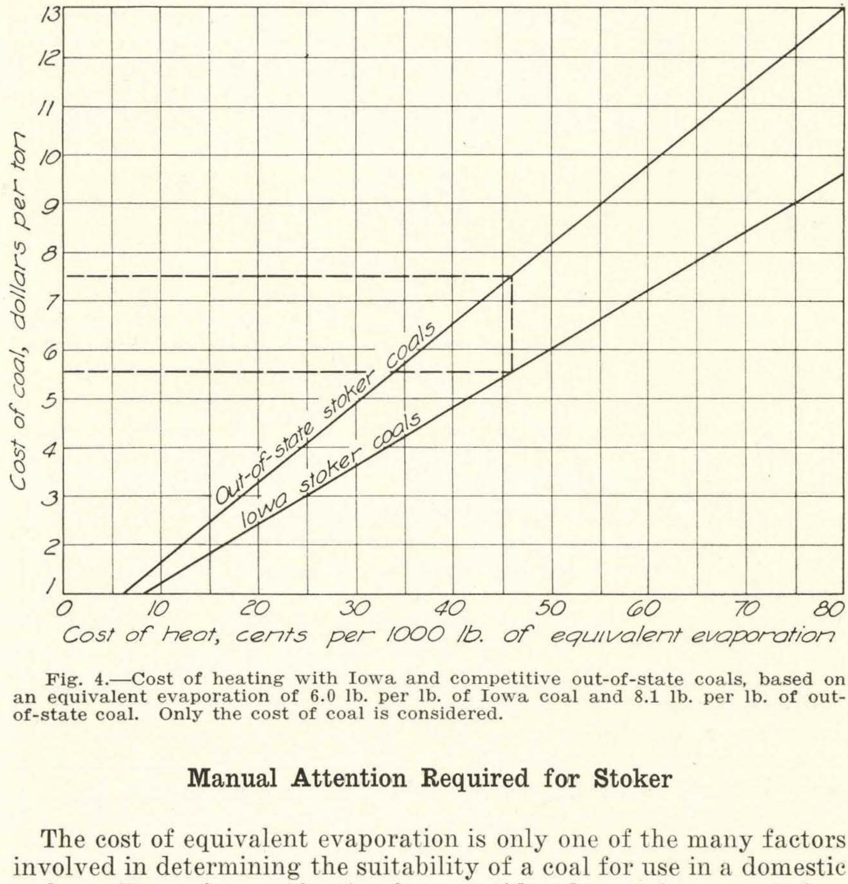

Fig. 4.—Cost of heating with Iowa and competitive out-of-state coals, based on an equivalent evaporation of 6.0 lb. per lb. of Iowa coal and 8.1 lb. per lb. of out-of-state coal. Only the cost of coal is considered.

Manual Attention Required for Stoker

The cost of equivalent evaporation is only one of the many factors involved in determining the suitability of a coal for use in a domestic stoker. Ease of operation is often considered more important than cost. However, the length of time the stoker will operate satisfactorily between clinker-removal periods cannot be determined definitely for any coal, as it will vary not only with the type of coal, but also with the rate of burning and the characteristics of the combustion chamber. The tests indicated that a change from a lower to a higher rate of combustion usually hastens clinker formation, for ash will accumulate on the hearth without clinkering during the low rate of combustion of mild weather periods, then rapidly fuse into clinker when a sudden cold wave causes an increased heat demand and a hotter fire. It is possible that the clinker will have to be removed within a very short time after such a rapid increase in combustion rate. The clinker also will have to be removed more frequently if the combustion chamber is small. For satisfactory automatic operation with a high-ash Iowa coal the combustion chamber should be large enough to store from 50 to 75 lb. of ash and clinker and still leave sufficient space for combustion.

A series of tests on Scandia (Iowa) coal indicated that a hopper of coal (about 350 lb.) can usually be burned without attention. Although the fire performed satisfactorily, better combustion would have resulted with more frequent cleanings. It is seldom that a hopper of coal will be burned in one day; therefore, the practice of filling the hopper and cleaning the fire daily can be followed with most Iowa coals, except in the coldest weather, when more frequent servicings may be necessary.

It is not advisable to disturb the fire frequently since this apparently does not increase the efficiency of combustion and may result in increased clinker formation. However, if insufficient heat is being secured any clinker formed should be removed.

Air Supply

Proper air adjustment is essential for an efficient fire. White-hot, roaring flames result from an oversupply of air and cause a consequent excessive loss of heat in the flue gases. In addition too much air may cause the fire to burn down into the retort and damage it. The flames within the combustion chamber should be rather "lazy" and of dull-red color, with the top of the fuel bed at least 4 in. above the hearth.

The tests not only indicated that efficiency is increased, but also that clinkering of Iowa coals is much less troublesome when the quantity of air supplied is restricted sufficiently to cause a light-gray smoke. The soot passing out the chimney (indicated by the smoke) can be reduced by increasing the air supply, but the amount of fly ash will be increased. This relationship of soot and fly ash to air supply is discussed on pages 23 to 25.

Clinkering Characteristics

The most satisfactory laboratory method of determining the clinkering characteristics of a coal is the determination of the fusion temperature of its ash.[4] The fusion temperatures for the ash of each of

[4] The method used to determine fusion temperature is given in the American Society of Testing Materials Designation D 271-37.

the coals tested are given in Table 2. For domestic stoker coals the fusion temperature should be low enough to allow the ash to fuse into clinker for convenient removal, yet high enough to prevent the clinker from melting and running into the retort. Unfortunately, no definite range of fusion temperatures can be given as ideal, for the clinker formation in the combustion chamber does not always take place under the same conditions or at the fusion temperatures

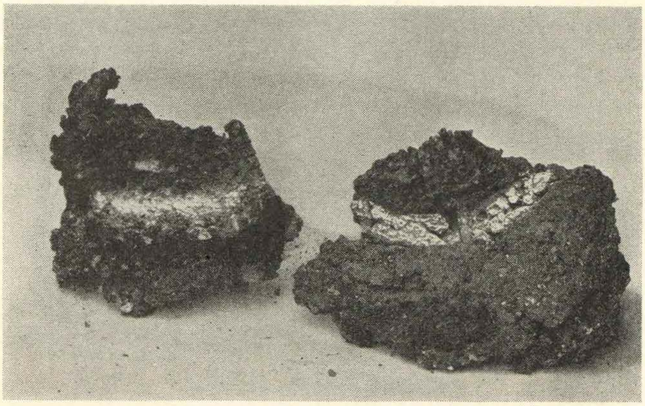

Fig. 5.—Undesirable clinkers from Iowa coals.

determined by laboratory analysis. The size and shape of the combustion chamber, as well as the rate of combustion, have considerable effect on the formation of clinker. In heating plants operated considerably under their maximum capacity a coal with a very low ash-fusion temperature may be necessary if the ash is to be removed as clinker. However, in plants operated at nearly maximum capacity the ash from the same coal may melt and run into the retort, in which case a coal with a higher ash-fusion temperature should be used.

The ash-fusion temperatures of most of the Iowa coals tested ranged from 1,900 to 2,000° F. The clinkers formed were generally hard and glassy, with greater density than those obtained from out-of-state coals. Although clinkers formed rapidly with most Iowa coals at the higher rates of combustion, some failed to clinker at mild-weather rates. In a home, however, it would be necessary to contend with loose ash only when long periods of uniformly mild temperatures occurred during the heating season. Clinkers would form during the colder periods, even though these periods were of short duration. The loose ash present during mild weather usually could be formed into a clinker, permitting more convenient removal, if it were raked to the center of the retort where it probably would be fused by the high temperature.

Figure 5 shows some undesirable clinkers formed with Iowa coals. Notice the imprint of the stoker retort, which was whitened before the photograph was taken to make it plainly visible. The portion of clinker above this whitened ring was hanging over the edge of the stoker retort and preventing proper air distribution. When such clinker forms, and is not removed, the combusion rate gradually decreases until the incoming coal forces the clinker out of the retort, an hour or two usually being required to do this.

Of the Iowa coals tested, only one appeared entirely unsuitable for use in a domestic stoker because of excessive clinkering. This was a high-ash-content screening which had not been prepared nor recommended for use in a domestic stoker. Several other loads of screenings from different Iowa mines were burned, but did not form clinkers that hampered the fire materially at normal rates of combustion, although some undesirable clinkers were formed.

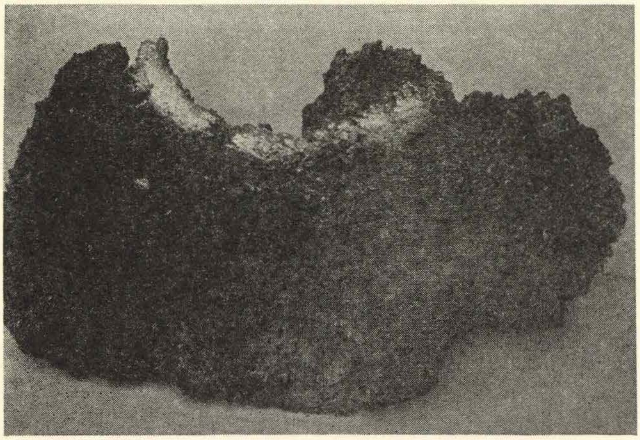

Fig. 6.—Undesirable clinker from an Illinois coal.

Troublesome clinkering in a domestic stoker is not confined to Iowa coals. Figure 6 shows a clinker formed while burning an Illinois coal. The imprint of the stoker retort has again been whitened to make it plainly visible. This clinker measured about 22 in. across, with a maximum thickness of about 9 in., and seriously interfered with air distribution. Although clinkers of this size were not formed frequently when burning the out-of-state coals tested, their formation was not unusual during the tests on some Iowa coals at high combustion rates.

Uniformity of Burning

When a domestic heating plant is required to operate at its peak rating for several hours it is essential that the fire burn uniformly to maintain an even flow of heat to the rooms. Unfortunately, it is difficult to compare the uniformity of combustion of various coals exactly because of the irregularity of clinker formation. However, the tests indicated that the out-of-state coals usually burned more evenly. The difference between the uniformity of combustion of Iowa and out-of-state coals is shown in Fig. 7, where typical rates of

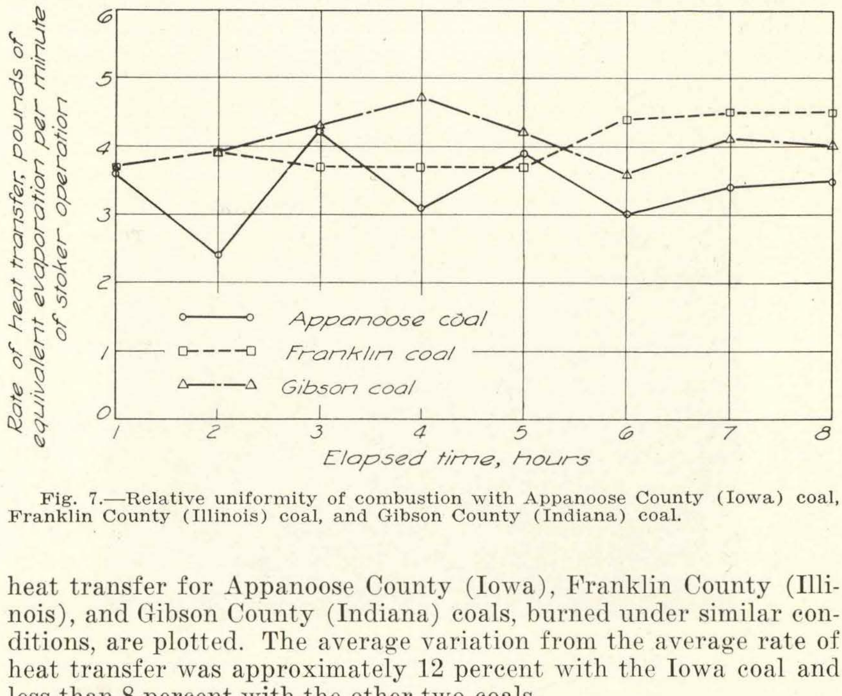

Fig. 7.—Relative uniformity of combustion with Appanoose County (Iowa) coal, Franklin County (Illinois) coal, and Gibson County (Indiana) coal.

heat transfer for Appanoose County (Iowa), Franklin County (Illinois), and Gibson County (Indiana) coals, burned under similar conditions, are plotted. The average variation from the average rate of heat transfer was approximately 12 percent with the Iowa coal and less than 8 percent with the other two coals.

If a stoker using one of the out-of-state coals tested operates nearly continuously in cold weather to supply the necessary heat no attempt should be made to use Iowa coals exclusively. Satisfactory automatic operation with Iowa coals can be obtained only by having a heating plant large enough to furnish adequate heat during a period of poor fire like that indicated by the low point of the curve in Fig. 7. If a heating plant is of sufficient size the irregularity of combustion has little effect upon the comfort conditions in the residence because the thermostatic control compensates for any variation in the uniformity of burning.

Ability of Iowa Coals to Hold Fire

There are many periods during the heating season when the outside temperature is sufficient to maintain comfortable conditions within the house without aid from the heating plant. However, if the plant is to furnish heat automatically a fire must be maintained which will not release any appreciable quantity of heat, yet will respond readily to a heat demand. This is accomplished by fire-holding controls that automatically operate the stoker for a fixed minimum number of minutes per hour, irrespective of the heat demand. Obviously the most suitable coal for such operation is one that requires the least number of minutes of stoker operation per hour to maintain a satisfactory fire.

The condition of the fire during a fire-holding period is indicated by the temperature of the flue gas. If the fire dies the flue-gas temperature drops to the temperature of the room. A good bed of live coals is indicated by a sharp rise in the flue-gas temperature when the stoker is started. The variation in temperature increase during each cycle of stoker operation indicates the irregularity of fire conditions. Thus, a flue-gas temperature chart furnishes a record of fire performance during a fire-holding test.

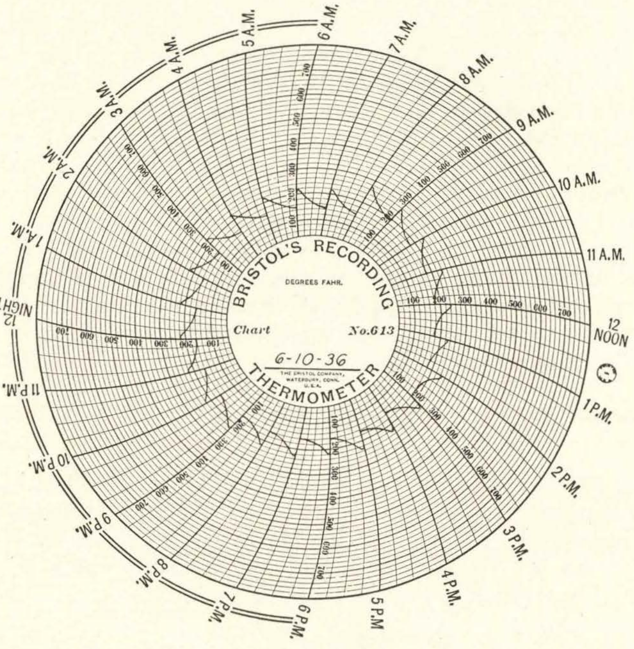

Fig. 8.—Flue-gas temperature chart during a fire-holding test.

Figure 8 shows the first of five flue-gas temperature charts obtained during a 120-hr. fire-holding test on a typical Iowa coal. In this test the stoker operated 3 min. once each hour, and the fire was not disturbed or tended in any way during the 5 days. The chart (Fig. 8) indicates that the fire reached a stable condition at about 6:00 p.m., after which the flue-gas temperature rose sharply from 160 to 220° F. each time the stoker started. This same uniform response was recorded by the four succeeding charts, definitely proving the ability of this coal to maintain a satisfactory fire at a stoker operation rate of 3 min. per hr.

Cleanliness

To meet the demand for clean fuel Eastern coal producers have been carefully preparing their stoker coals for several years. A common process is to remove the dust from the sized coal by washing with water or air, and then to spray oil or paraffin on the clean coal to retain any dust formed during subsequent handling. This oil treatment has proved successful with the Eastern coals, and several Iowa producers have adopted it. However, while sample loads of treated coals obtained from two Iowa mines did not create dust when unloaded into the bins, they did not remain entirely dustless for more than 2 to 3 weeks after treatment, and the effect of the treatment had entirely disappeared after 6 to 8 weeks. The Iowa coals evidently absorb the oil quite rapidly while the harder Eastern coals retain it on the surface where it holds any dust which is formed. Even though the treated Iowa coals were not dustless for as long a period as most Eastern coals, they were cleaner than untreated coals.

The removal of a clinker does not create much dust, but when one is removed from a hot fuel bed a disagreeable gas is given off. It is advisable, therefore, to place the clinkers in an enclosed container near the furnace, with an outlet connection to the chimney. Some heating plants come equipped with such a receptacle, but in most cases one has to be constructed by the householder if this improvement is desired.

Soot and Fly Ash

During several tests the soot and fly ash were collected by an electrical precipitator in order to determine the heat loss in the soot and tar passing out the chimney. This loss was very small in every case, varying from 0.2 to 0.5 percent of the heating value of the coal (Table 9, Appendix).

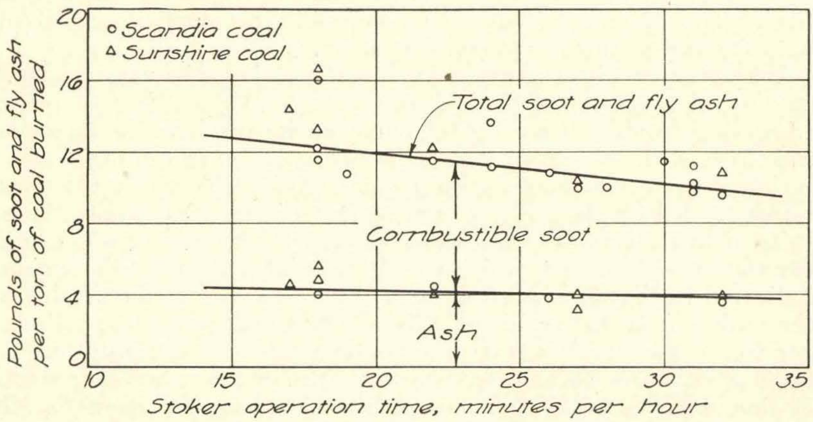

Fig. 9.—Soot and fly ash collected while stoker was operated with an air supply recommended to decrease clinkering troubles.

Table 9 and Fig. 9 indicate that about 4 lb. of ash left the fuel bed per ton of coal burned, and that this amount was nearly independent of the rate of operation of the stoker or the number of starts and stops per hour. However, the total amount of soot and fly ash leaving the fuel bed decreased at higher rates of operation (Fig. 9). Approximately 13 lb. of soot and fly ash were collected per ton of coal burned when the stoker operated one fourth of the time; this amount de-

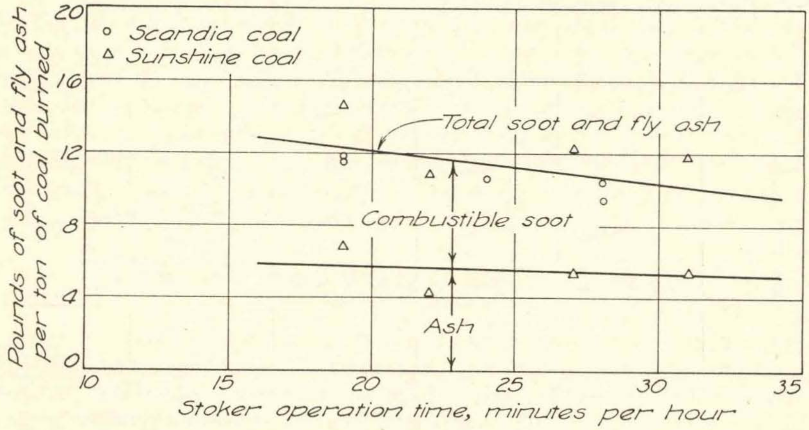

Fig. 10.—Soot and fly ash collected while stoker was operated with a more liberal air supply to decrease smoke.

creased nearly 20 percent when the stoker operated one half of the time. The precipitator did not have sufficient capacity to obtain data for higher rates of stoker operation.

When Iowa coals are burned in domestic stokers the very minimum amount of excess air should be admitted to the fuel bed to reduce clinkering troubles, even though some smoke results. To determine the effect of the air supply upon the formation of soot and fly ash, a series of tests were made with a more liberal air supply than that recommended by the authors (page 17). Figure 10 presents the results of these tests. Fly ash was collected at the rate of about 6 lb. per ton of coal burned, which was 50 percent more than the amount indicated in Fig. 9, where the air setting was that recommended by the authors. However, about 2 lb. of additional soot were collected per ton of coal burned with the recommended air supply, thus the total of soot and fly ash was about the same for either air setting. It should be noted that the more liberal air supply is within the range considered to be good practice; in fact, the stack gases were not entirely colorless.

The heat loss in solids passing out the chimney was greater with the restricted air supply (Fig. 11). Although the percentage change in heat loss caused by restricting the air supply is considerable, the actual difference is only about 0.1 percent of the heating value of the coal. The decrease in the heat loss in the dry stack gases more than compensates for the increase in heat loss in the soot.

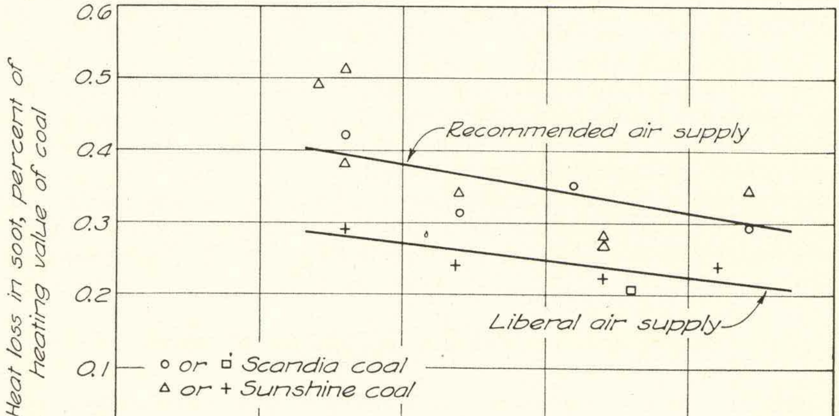

Fig. 11.—Approximate heat loss in the soot.

Although the weight of the soot and fly ash leaving the fuel bed was rather small, the volume was quite large, since 1 gal. of the soot and fly ash precipitated in the stacks weighed only about ¼ lb. The soot and fly ash that settled in the boiler passages were considerably heavier, weighing about 1½ lb. per gal. These approximations indicate that 20 to 40 gal. of soot and fly ash left the fuel bed per ton of Iowa coal burned.

About 6 lb. of soot and fly ash were collected per ton of Franklin County (Illinois) coal burned with the stoker operating one third of the time. This was about one half of the amount collected during tests at a corresponding rate with Iowa coals.

TABLE 3.—ANALYSES OF SOOT AND FLY ASH COLLECTED

Coal burned	Constituents of soot and fly ash, percent				
	Moisture	Carbon	Hydrogen	Nitrogen	Sulphur
Scandia (Iowa)					
In stacks	1.61	50.63	1.97	1.49	5.72
In boiler passages	0.97	31.15	0.85	0.98	4.96
Weighted average	1.37	43.19	1.54	1.30	5.43
Sunshine (Iowa)					
In stacks	3.20	47.74	1.54	0.89	6.25
In boiler passages	1.43	30.61	1.56	2.04	5.71
Weighted average	2.59	41.83	1.55	1.28	6.06
Franklin County (Illinois)					
In stacks	1.90	47.91	1.33	0.91	1.14
In boiler passages	0.95	37.49	1.22	1.56	1.54
Weighted average	1.56	44.21	1.29	1.14	1.28

The Iowa coal soots adhered more readily to the stacks, probably because they contained more tars. This is indicated in Table 3 by the greater percentage of hydrogen in the soot and fly ash collected in the stacks when Scandia (Iowa) coal was burned, the hydrogen probably being combined with carbon in the form of tar. The hydrogen content of the soot and fly ash from Sunshine (Iowa) coal was midway between that from the Scandia (Iowa) coal and the Franklin County (Illinois) coal, as was its tendency to adhere to the smoke pipe.

Segregation and Crushing of Coal by the Stoker

As yet no size range has been agreed upon as best for stoker coal, probably because most stokers satisfactorily handle a wide variation of sizes. However, enough fines are needed to form an effective seal against smoke coming back through an unsealed hopper or bin.

The crushing and segregation of Iowa coal as it passes to the retort are of greater significance than the exact size of the coal fed

TABLE 4.—SEGREGATION AND CRUSHING OF SCANDIA COAL BY THE STOKER FEED

Test No.	Coal size, in.	Percentage of total weight					
		As placed in hopper	As delivered to retort				
			Entire retort	Right front quarter	Left front quarter	Right rear quarter	Left rear quarter
1	under ¼	0	28	1	3	10	14
	¼ to ½	100	72	7	12	29	24
2	under ¼	0	27	1	3	9	14
	¼ to ½	100	73	7	14	27	25
3	under ¼	0	19	0	2	4	13
	¼ to ½	0	25	1	3	11	10
	½ to 1	100	56	7	11	21	17
4	under ¼	0	20	0	2	5	13
	¼ to ½	0	29	3	3	13	10
	½ to 1	100	51	8	13	16	14
5	under ¼	0	26	0	3	5	18
	¼ to ½	0	17	1	2	6	8
	½ to 1	0	42	4	10	14	14
	1 to 1½	100	15	3	5	3	4
6	under ¼	0	21	0	2	3	16
	¼ to ½	0	17	1	2	7	7
	½ to 1	0	42	5	9	15	13
	1 to 1½	100	20	3	6	6	5
				Front half		Rear half	
7	under ¼	1	17	2		15	
	¼ to ½	18	28	4		24	
	½ to 1	59	49	17		32	
	1 to 1½	22	6	4		2	

to the hopper. The feeding screw not only crushes the coal, but also allows it to segregate by sizes and forces a greater amount to the rear of the retort.

Table 4 indicates the extent of the crushing action of the feeding mechanism of the stoker on Scandia (Iowa) coal. About 20 to 25 percent of the coal entering the retort passed through a ¼-in. screen, irrespective of the size of coal placed in the hopper. About 80 to 85 percent of 1- to 1½-in. coal, nearly 50 percent of ½- to 1-in. coal, and more than 25 percent of ¼- to ½-in. coal were crushed to smaller sizes during passage through the screw conveyor.

The extensive crushing action with the larger coal required some additional power and the coal did not feed as rapidly, so that 1- to 1½-in. coal required 13 percent more power per ton of coal fed than ¼- to ½-in. coal.

A considerable amount of segregation accompanied the crushing action (Table 4). In every test more than one half of the coal under ¼ in. came from the left rear quarter of the retort, while practically none came from the front half. (The worm feed is considered as entering at the front of the retort.) Thus an excess of air was supplied to the front portion of the retort because of the larger air passages through the larger coal as compared to the passages through the finer coal at the rear of the retort. However, more air should have been supplied to the rear half of the retort for about 75 percent of the coal came through this half.

Although the fuel had a tendency to burn more rapidly over the front half of the retort, the harmful effects were minimized by a deep fuel bed, in which the resulting coking action of the coal tended to distribute the air more equally and good combustion usually was secured. Therefore, the exact size of the stoker coal should not be of major importance to a domestic stoker owner.

Mixtures of Iowa and Out-of-State Coals

There are a large number of domestic heating plants in Iowa that do not have sufficient capacity to furnish the heat required when burning Iowa coals, even though the operators may wish to use local coals. Other householders may wish a better grade of coal, preferring to pay more for their heat in order to minimize the attention required. Consequently, a large tonnage of Southern Illinois and Indiana coals is sold in Iowa. To serve this market Iowa coals can be mixed with high-grade Eastern coals to increase the heating value and reduce the ash of the mixtures to those of Southern Illinois and Indiana coals. Because of the wide variation in boiler and stoker efficiency secured in the tests with individual coals (Table 6, Ap-

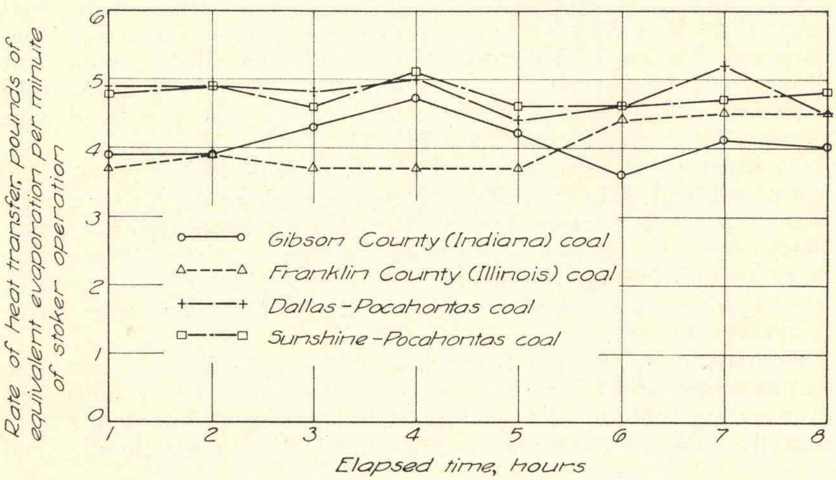

Fig. 12.—Comparison of uniformity of combustion with Iowa coal mixtures and with Illinois and Indiana coals.

pendix) actual combustion tests were required to determine the suitability of coal mixtures. The results of these tests are presented in Table 5.

Two fuels may be capable of supplying an equal amount of heat over an extended period, yet one may not furnish equal comfort in a residence because it fails to supply sufficient heat during a period of poor fire. To reveal this characteristic Table 5 lists the average equivalent evaporation per minute of operation and also the average secured during the hour of lowest heat release. Because of the irregularity of clinker formation, the relative shortness of the test periods, and the very slight variation in the rate of coal feed, the minimum values should be considered only as indicators of probable minimum heat release.

It was found (Table 5) that a pound of Franklin County (Illinois) coal furnished 7.2 lb. of equivalent evaporation, while a fifty-fifty mixture of Sunshine (Iowa) and Pocahontas (West Virginia) coals furnished 7.5 lb. per lb. of coal. In addition the mixture exceeded the Illinois coal in both the average and minimum amount of heat secured per minute of stoker operation; therefore, the mixture had a heating ability at least equal to that of the Illinois coal. Moreover, the mixture had only 8 percent ash, compared with 10 percent for the Franklin County coal.

This and similar comparisons, such as that of Fig. 12, indicated that the combustion characteristics of a mixture of equal parts of a high-grade Eastern coal and an Iowa coal were equal to those of the Indiana and Southern Illinois coals. Local coal prices will determine the advisability of mixing coals; because of wide variations in coal costs, Figs. 13 and 14 have been prepared to enable rapid cost comparisons. Figure 13 indicates the cost of 1,000 lb. of equivalent evaporation from a fifty-fifty mixture of Sunshine and Pocahontas coals, or coals of similar quality; this cost may be compared with the cost for unmixed coals from Fig. 14.

To illustrate the use of Fig. 13, assume $3.00 as the price of an Iowa coal and $11.00 as the price of a high-grade Eastern coal. Draw dotted lines from each of these prices until they intersect. The point of intersection indicates the cost of heat, in cents per 1,000 lb. of equivalent evaporation, for a fifty-fifty mixture of these coals, when read on the scale of the diagonal lines. In the example chosen the cost is 45 cents.

For comparison assume that a Franklin County (Illinois) coal can be purchased for $7.00 per ton. The cost per 1,000 lb. of equivalent evaporation is obtained from Fig. 14 by drawing a dotted line horizontally from the $7.00-per-ton price until it intersects the diagonal

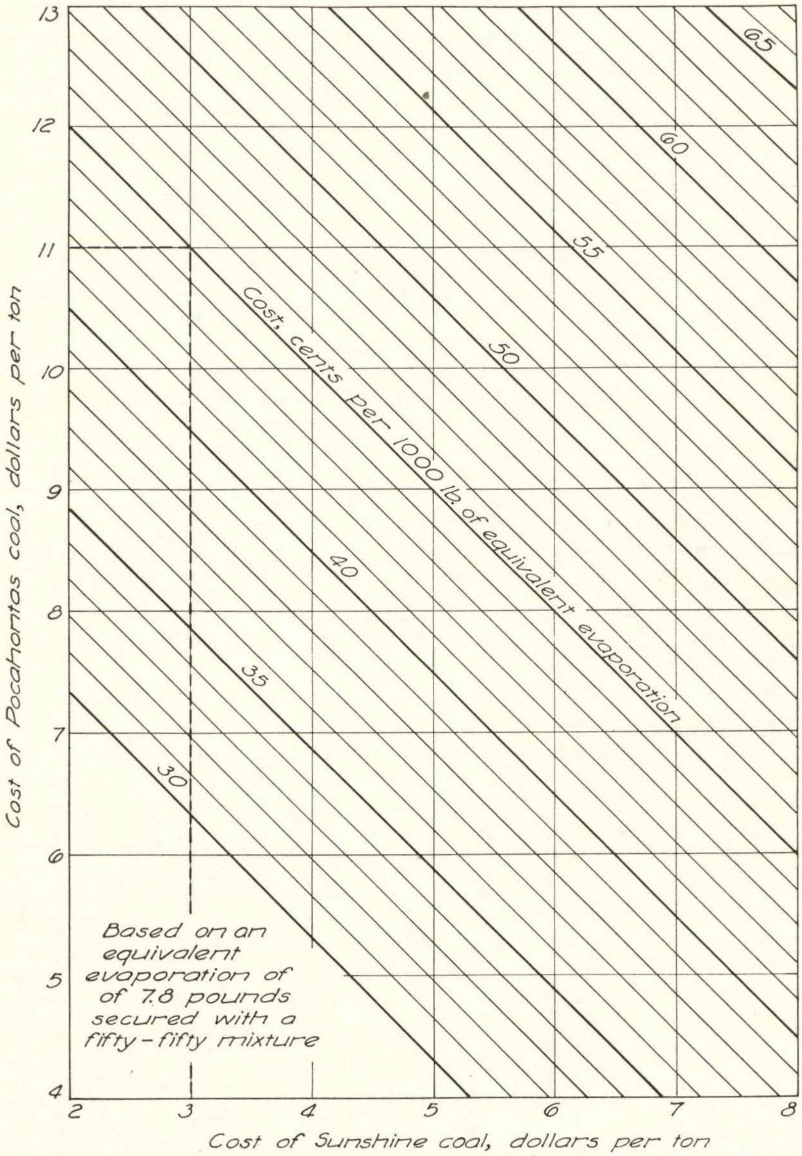

Fig. 13.—Cost of heating with a fifty-fifty Sunshine-Pocahontas coal mixture. Only the cost of coal is considered.

TABLE 5.—SUMMARY OF RESULTS FROM TESTS OF COAL MIXTURES

Coal*	Heat obtained			Efficiency of boiler and stoker, percent	Heating value, B.t.u. per lb.	Ash,‡ percent of coal as fired	Fusion temperature o ash, °F.
	Equiv. evap., lb. per lb. of coal	Av. equiv. evap., lb. per min. of stoker operation	Min. equiv. evap.,† lb. per min. of stoker operation				
Dallas	5.2	2.9	2.0	55	9,140	16	1980
Sunshine	6.1	3.1	2.1	51	11,552	12	1960
3 parts Sunshine, 1 part Perry Co. (Ill.)	6.2	3.3	2.7	52	11,745	12	1970
3 parts Sunshine, 1 part Franklin Co. (Ill.)	6.3	3.5	2.7	54	11,200	12	1960
3 parts Dallas, 1 part Pocahontas (W. Va.)	6.4	4.0	3.1	59	10,468	14	2060
3 parts Sunshine, 1 part Gibson Co. (Ind.)	6.1	3.5	2.8	53	11,213	13	1970
1 part Sunshine, 1 part Gibson Co. (Ind.)	6.4	3.8	3.3	53	11,677	11	1975
1 part Sunshine, 1 part Perry Co. (Ill.)	6.5	3.6	2.9	53	11,970	10	1980
1 part Sunshine, 3 parts Perry Co. (Ill.)	6.5	3.7	3.2	52	12,194	10	2015
3 parts Sunshine, 1 part petroleum coke	6.6	3.9	3.5	52	12,350	11	——
1 part Sunshine, 1 part Franklin Co. (Ill.)	6.9	3.9	2.9	58	11,450	11	2015
Perry Co. (Ill.)	6.9	3.8	3.1	54	12,419	9	2065
3 parts Sunshine, 2 parts petroleum coke	7.0	4.1	3.7	53	12,600	8	——
3 parts Sunshine, 1 part Floyd Co. (Ky.)	7.0	3.6	3.4	54	12,512	10	1945
1 part Sunshine, 3 parts Gibson Co. (Ind.)	7.0	3.8	3.2	56	12.140	9	1975
Franklin Co. (Ill.)	7.2	4.0	3.7	58	11,900	10	2345
3 parts Sunshine, 1 part Pocahontas (W. Va.)	7.2	4.0	3.1	56	12,500	10	1975
1 part Sunshine, 3 parts Franklin Co. (Ill.)	7.4	4.1	3.5	60	11,700	11	2100
1 part Sunshine, 1 part Floyd Co. (Ky.)	7.4	3.8	3.4	54	13,361	8	1990
Gibson Co. (Ind.)	7.5	4.1	3.6	58	12,603	8	1995
1 part Sunshine, 1 part Pocahontas (W. Va.)	7.5	4.6	4.0	57	13,300	8	——
1 part Dallas, 1 part Pocahontas (W. Va.)	7.8	4.9	4.5	60	12,763	10	2050
1 part Sunshine, 3 parts Floyd Co. (Ky.)	7.9	4.3	4.0	54	14,210	6	2085
1 part Sunshine, 3 parts Pocahontas (W. Va.)	8.5	5.1	4.6	60	13,642	7	2155
Floyd Co. (Ky.)	8.9	4.6	4.1	57	15,059	3	2375
1 part Dallas, 3 parts Pocahontas (W. Va.)	8.9	5.5	5.1	61	13,960	7	2100
Pocahontas (W. Va.)	9.5	5.3	5.0	61	15,115	5	2530

*Unless otherwise indicated all coals are Iowa coals.

†For hour of lowest heat release.

‡Weighted average values from all loads of each coal.

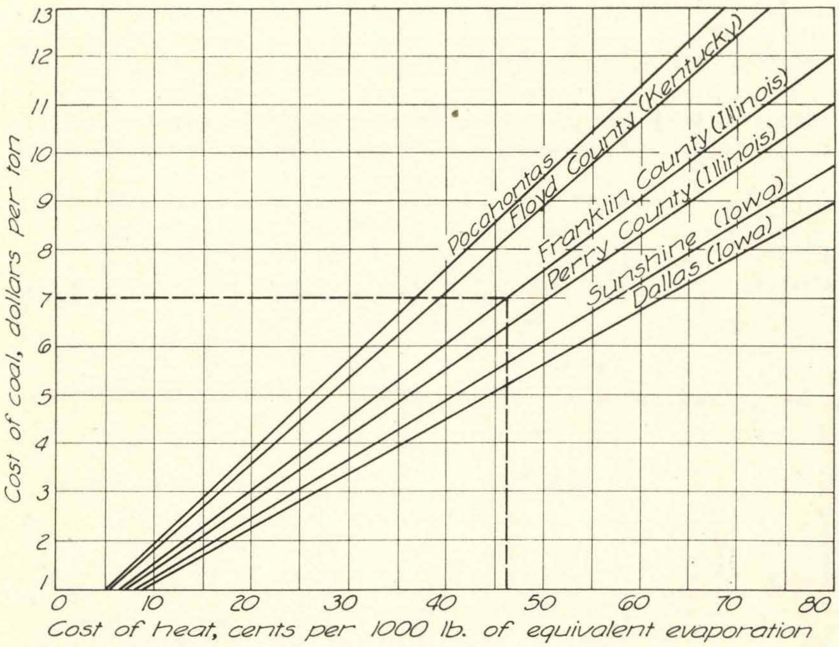

Fig. 14.—Cost of heating with various coals considering only the fuel cost.

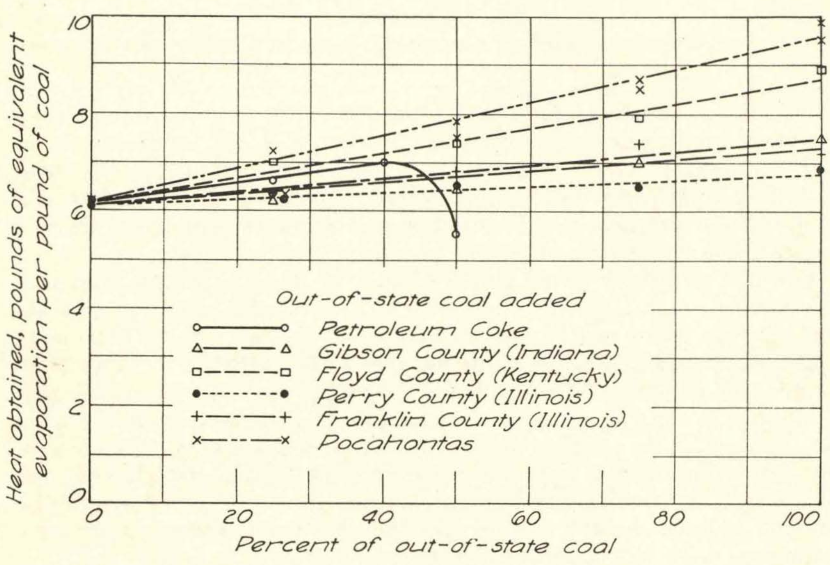

Fig. 15.—Heat obtained from mixtures of Sunshine coal with out-of-state coals.

line labeled "Franklin County (Illinois)," then extending it vertically downward to the horizontal axis, where a cost of 46½ cents is indicated. The mixture would furnish heat at slightly less cost with the assumed tonnage prices.

When determining these evaporation costs, the price of mixing must be included in the cost of the coals. Although it is feasible for

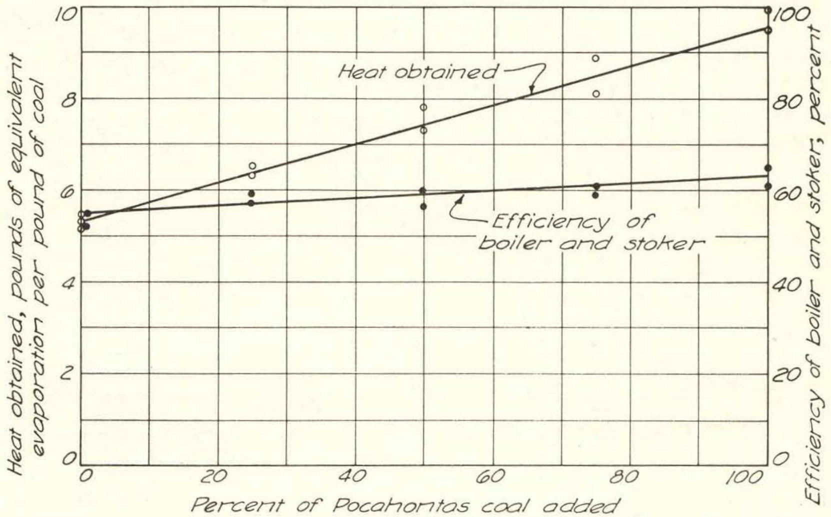

Fig. 16.—Performance of a domestic heating plant with a Dallas-Pocahontas coal mixture.

householders to mix their own coal, few will do so even though they might reduce their heating costs. However, Iowa mine operators and distributors might find such a mixing plan profitable. Instead of failing to sell any Iowa coal to those who demand the quality and evaporation rate of a Southern Illinois or Indiana coal, these dealers might sell Iowa coal in the form of a fifty-fifty mixture.

For most of the coal mixtures tested the heat obtained increased fairly uniformly with the increase in the proportion of out-of-state coal, as shown in Figs. 15 and 16. However, the mixture of petroleum coke and Sunshine coal did not burn satisfactorily with more than 40 percent coke, for when burning a mixture having a greater percentage of coke the clinker froze to the retort, thereby preventing air passage. This clinker was very thin and clung to the sides of the retort so tightly that the incoming fuel could not dislodge it. The resulting restriction of the air supply caused a large accumulation of unburned fuel on the hearth. No such difficulty was encountered with the other mixtures tested.

In the tests of coal mixtures the efficiency[5] of the heating plant increased as greater proportions of an out-of-state coal were added to an Iowa coal (Figs. 16 and 17). While the increase in efficiency was very slight with increasing proportions of Perry County (Illinois) coal, each 10-percent addition of Pocahontas (West Virginia) coal to Iowa coal caused an increase of about one percent in efficiency.

The values for efficiency in Figs. 16 and 17 do not include any allowance for the heat loss through the hearth or the insulated boiler. Moreover, this loss will vary with each installation, so an exact comparison of the efficiencies obtained from different heating plants is quite difficult. In a home installation the heat would be utilized to warm the basement, and thus it actually would not be lost.

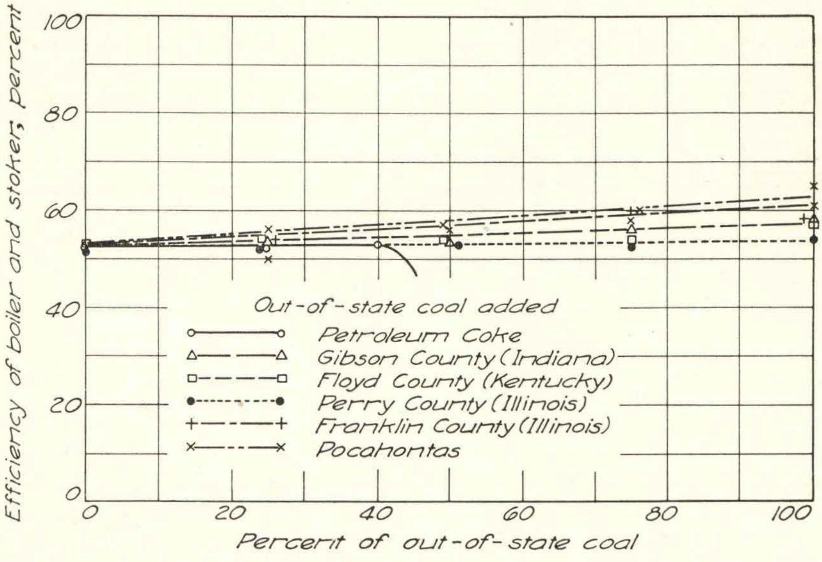

Fig. 17.—Efficiency of the boiler and stoker using various mixtures of Sunshine coal with out-of-state coals.

STOKER-FIRING AND HAND-FIRING

Although it is generally recognized that stoker-firing is more efficient than hand-firing, the exact increase in efficiency cannot be predicted because of variations in heating plants, fuels, and methods of

[5] Efficiency $= \frac{\text{Heat absorbed by boiler per pound of fuel fired}}{\text{Heating value per pound of fuel}}$.

hand-firing. In addition, when coal is fired by hand, the residence is frequently overheated for short periods, thereby producing another variable loss, which may be considerable if the windows are opened to let the excess heat escape. This loss is not experienced with a properly adjusted, automatic heating system.

To obtain a general idea of the fuel saving resulting from the increased efficiency of combustion with a stoker, data obtained by Meeker and Wagner[6] were taken as representative of hand-firing and a comparison was made at about 60 percent of the rated heating capacity of the heating plants. The average amount of heat obtained was found to be 5.2 lb. of equivalent evaporation per lb. of coal when hand-fired and 6.1 lb. when stoker-fired—about 15 percent greater efficiency with the stoker. However, this increased efficiency is not net gain as there are extra costs for the stoker, such as interest on the investment, depreciation, repairs, and cost of electric power. (The power required by the stoker tested was found to be about 12 kw-hr. per ton of coal.) From this examination it would appear that a small domestic stoker ordinarily should not be purchased as a moneysaving device, but rather for the convenience and healthful benefits of automatic heating.

[6] Meeker, W. H., and H. W. Wagner. "House Heating Fuel Tests." *Iowa Engineering Experiment Station*, Bulletin 33 (1913).

APPENDIX

TABLE 6.—DATA FROM TESTS OF VARIOUS COALS

Test No.	Coal No.*	Fuel bed condition†	Stoker feeding rate‡	Length of test, hr.	Coal burned, lb. per hr.	Stoker operation, min. per hr.	Pressure drop through fuel bed, in. of water	Temperature of flue gas,φ °F.	Average CO_2,# per-cent	Heat obtained, lb. of equiv. evap. per lb. of coal		Efficiency of boiler and stoker, per-cent
										As fired	Dry basis	
PRELIMINARY TESTS												
1	1	C	HI	25	36.9	60	1.76	710	10.1	5.6	6.5	56
2	1	C	HI	24	14.5	16	1.31	490	6.9	5.4	6.4	54
3	1	C	HI	8	23.0	34	1.00	650	9.7	6.1	7.0	58
4	1	C	HI	8	21.5	35	0.84	590	9.5	6.2	7.2	60
5	1	C	MI	8	17.7	37	0.82	550	8.0	5.1	5.9	49
GROUP A TESTS												
6	2	C	HI	8	23.4	41	1.15	620	9.0	5.8	6.8	55
7	2	C	HC	8	36.5	60	1.09	730	10.8	6.0	6.9	58
8	2	C	MC	9	26.0	60	0.92	630	8.3	5.7	6.5	55
9	2	C	MI	8	18.1	37	0.78	530	6.8	5.3	6.1	52
10	3	C	MC	8	27.5	60	0.84	600	6.8	4.2	5.1	51
11	3	C	HC	7	37.4	60	1.17	655	8.2	4.5	5.3	54
12	3	C	MI	8	23.0	51	0.93	514	6.4	4.0	4.8	48
13	4	C	HI	8	27.1	43	1.23	619	8.7	5.4	6.4	54
14	4	C	MC	8	26.8	60	1.05	635	8.8	5.6	6.6	56
15	4	C	HC	8	37.6	60	1.39	790	10.3	5.9	7.0	59
16	4	C	MI	8	17.2	39	0.85	520	——	5.3	6.2	53
17	5	C	MI	7	18.9	46	1.27	530	6.3	4.9	5.8	48
18	5	C	HC	8	35.9	60	1.41	780	11.8	5.9	6.8	56
19	5	C	MC	8	26.5	60	0.88	630	7.6	5.5	6.3	52
20	5	C	HI	8	24.9	38	1.20	630	9.3	5.7	6.6	55
21	6	C	MI	8	15.7	41	0.67	515	8.0	5.9	6.0	57
22	6	C	HC	8	32.4	60	0.97	770	10.7	6.4	7.3	60
23	6	C	MC	8	19.7	60	0.62	610	7.9	5.8	6.6	54
24	6	C	HI	8	24.0	44	0.97	610	9.5	5.5	6.4	52
25	7	C	MI	8	16.8	35	0.84	540	7.3	5.9	7.1	56
26	7	C	HC	8	35.1	60	1.09	790	9.9	6.0	7.1	56
27	7	C	MC	8	25.7	60	0.74	650	8.4	5.9	6.9	54
28	7	C	HI	8	23.4	38	0.94	610	10.4	6.3	7.5	59
29	8	C	MC	8	24.4	60	0.66	620	6.8	5.0	6.0	51
30	8	C	HC	8	34.6	60	1.03	750	9.0	5.5	6.6	56
31	8	C	MI	8	19.8	46	0.70	550	7.3	5.0	6.1	52
32	8	C	HI	8	26.2	42	0.94	640	9.0	5.5	6.7	57
GROUP B TESTS												
33	9	C	HI	8	26.0	48	0.68	675	8.0	5.6	6.4	54
34	9	LA	HI	13	23.9	42	0.88	625	10.8	5.7	6.5	55
35	9	LA	HI	17	17.1	29	0.88	575	10.8	5.2	6.0	51

(Continued)

*Table 2 indentifies the coals by number.

†*C* indicates the ash and clinker had all been cleaned from hearth proir to start of test. *LA* indicates that only the clinker had been removed, the loose ash remaining on the hearth at start of test.

‡*HI* indicates high-speed, intermittent operation; *HC* indicates high-speed, continous operation; *MI* indicates medium-speed, intermittent operation; *MC* indicates medium-speed, continous operation.

φTemperature of gas at boiler exit.

#Gas samples were taken only while stoker was operating.

TABLE 6.—DATA FROM TESTS OF VARIOUS COALS—Continued

Test No.	Coal No.*	Fuel bed condition†	Stoker feeding rate‡	Length of test, hr.	Coal burned, lb. per hr.	Stoker operation, min. per hr.	Pressure drop through fuel bed, in. of water	Temperature of flue gas,ϕ °F.	Average CO_2,# per-cent	Heat obtained, lb. of equiv. evap. per lb. of coal		Efficiency of boiler and stoker, per-cent
										As fired	Dry basis	
36	9	LA	HI	26	11.1	20	0.88	550	7.9	5.7	6.5	55
37	9	LA	HI	7	16.0	30	0.74	520	12.2	5.5	6.3	53
38	9	LA	HC	7	33.1	60	1.22	780	10.9	5.2	5.9	50
39	10	LA	HI	8	18.7	30	1.70	550	11.1	5.1	6.1	53
40	11	C	HI	7	22.3	40	0.48	670	11.4	6.8	7.9	64
41	11	C	HI	7	21.9	40	0.49	670	11.8	6.7	7.7	63
42	12	LA	HI	130	4.1	9	——	——	——	5.6	6.5	53
43	12	LA	HI	11	15.5	30	0.84	645	10.0	6.8	7.6	60
44	12	LA	HI	23	10.6	19	0.65	520	9.0	6.5	7.1	56
45	12	LA	HI	7	24.4	44	0.99	700	10.0	6.2	6.9	54
46	12	LA	HC	5	30.4	60	0.62	790	13.0	6.7	7.3	58
47	13	C	HI	7	20.7	41	0.57	720	11.0	7.2	8.0	65
48	14	C	HI	7	17.7	30	0.53	670	12.4	8.4	8.9	67
49	14	LA	HI	7	26.0	44	0.82	825	14.2	8.1	8.5	65
50	14	LA	HI	12	10.5	19	0.60	520	11.3	7.9	8.4	63
51	14	LA	HC	5	30.0	60	0.83	875	13.7	8.2	8.7	66
52	15	C	HI	8	18.8	34	0.47	690	12.6	7.8	8.7	64
53	15	LA	HI	7	26.0	46	0.58	795	14.0	7.9	8.8	65
54	15	LA	HC	5.5	33.1	60	0.69	900	14.8	8.0	9.0	66
55	15	LA	HI	12	11.4	19	0.52	500	13.7	8.1	9.0	66
56	15	LA	HI	24	4.9	8	——	375	——	7.5	8.4	61
57	15	LA	HI	10	18.4	30	0.47	660	14.9	7.9	8.8	65
58	16	C	HI	8	16.5	30	0.38	625	13.8	9.3	9.8	71
59	16	LA	HI	6	26.1	46	0.58	785	14.9	8.3	8.8	63
60	16	LA	HC	5	37.0	60	0.81	800	14.0	7.4	7.9	57
61	16	LA	HI	13	10.6	19	0.46	525	13.1	8.5	9.1	65
62	16	LA	HI	33	5.7	8	——	390	——	7.6	8.0	58
63	16	LA	HI	10	17.4	30	0.70	610	15.0	8.2	8.6	62
64	17	C	HI	9	17.7	34	0.42	690	13.5	8.4	9.0	69
65	17	LA	HI	7	25.4	46	0.79	725	15.0	7.7	8.1	62
66	17	LA	HC	5	30.7	60	0.94	800	14.6	7.8	8.2	63
67	17	LA	HI	12	11.0	19	0.52	520	11.8	8.2	8.6	66
68	17	LA	HI	24	4.9	8	——	350	——	6.7	7.1	54
69	17	LA	HI	9.5	17.7	30	0.79	650	14.7	8.2	8.7	67
70	18	C	HI	8	26.7	52	0.49	730	9.2	5.5	6.5	55
71	18	LA	HI	11	26.1	48	0.68	700	11.1	5.8	6.6	56
72	19	C	HI	8	26.4	45	0.69	710	12.5	5.8	6.8	54
73	19	LA	HI	8	23.0	40	——	——	——	6.2	7.3	58
74	19	LA	HI	8	23.3	45	0.71	620	13.7	6.1	7.1	56
75	20	C	HI	8	22.7	44	0.76	635	11.0	6.3	7.1	62
76	20	LA	HI	6	23.5	44	0.81	700	10.8	6.5	7.2	63
77	20	LA	HI	10	14.4	29	0.80	530	9.2	5.8	6.4	56
78	20	LA	HI	7	14.6	30	0.82	525	6.7	5.9	6.6	57
79	21	C	HI	7	25.6	46	0.63	680	13.4	6.4	7.5	59
80	21	LA	HI	6	23.9	44	0.47	660	12.9	7.1	8.2	65
81	21	LA	HI	6	23.2	44	0.53	640	12.7	6.8	8.1	64
82	21	C	MC	11	24.8	60	0.45	710	10.8	6.6	7.7	59

*Table 2 indentifies the coals by number.

†*C* indicates the ash and clinker had all been cleaned from hearth proir to start of test. *LA* indicates that only the clinker had been removed, the loose ash remaining on the hearth at start of test.

‡*HI* indicates high-speed, intermittent operation; *HC* indicates high-speed, continous operation; *MI* indicates medium-speed, intermittent operation; *MC* indicates medium-speed, continous operation.

ϕTemperature of gas at boiler exit.

#Gas samples were taken only while stoker was operating.

TABLE 7.—DATA FROM TESTS OF COAL MIXTURES

Test No.	Coal number or mixture*	Length of test, hr.	Coal burned, lb. per hr.	Stoker operation, min. per hr.	Pressure drop through fuel bed, in. of water	Temperature of flue gas,† °F.	Average CO_2,‡ percent	Heat obtained, lb. of equiv. evap. per lb. of coal		Efficiency of stoker and boiler, percent
								Coal as fired	Dry basis	
83	22	8	23.1	40	0.68	640	11.4	6.0	6.7	55
84	22	8	28.8	59	0.97	760	11.0	5.6	6.3	52
85	1 part 22, 1 part 23	8	20.0	37	0.43	690	15.0	7.8	8.3	60
86	1 part 22, 1 part 23	8	28.8	56	0.65	900	15.8	7.3	7.8	56
87	23	8	20.2	41	0.34	770	16.5	9.9	10.0	65
88	3 parts 22, 1 part 23	8	29.5	53	0.47	850	14.7	6.3	7.2	57
89	1 part 24, 3 parts 23	7	25.6	47	0.47	900	15.7	8.1	8.5	59
90	25	8	28.7	57	0.47	800	13.7	6.1	6.9	51
91	3 parts 25, 1 part 23	8	31.0	60	0.53	790	13.9	6.3	7.0	50
92	1 part 25, 1 part 23	8	25.7	53	0.46	825	15.0	7.7	8.2	56
93	1 part 25, 3 parts 23	8	23.7	45	0.52	900	16.3	8.6	8.8	58
94	33	8	28.4	51	0.54	900	14.7	7.2	7.9	58
95	1 part 27, 3 parts 33	8	27.6	49	0.63	900	13.2	7.4	8.2	60
96	1 part 27, 1 part 33	8	27.9	49	0.54	875	14.3	6.9	7.7	58
97	3 parts 27, 1 part 33	8	31.3	56	0.53	910	14.6	6.3	7.1	54
98	26	8	28.7	52	0.42	900	14.1	6.9	7.6	54
99	1 part 27, 3 parts 26	8	31.1	55	0.54	900	14.8	6.5	7.2	52
100	1 part 27, 1 part 26	8	30.2	55	0.48	900	13.3	6.5	7.3	53
101	3 parts 27, 1 part 26	8	29.6	55	0.43	900	12.5	6.2	7.1	52
102	3 parts 27, 1 part 29	8	27.2	52	0.50	825	13.3	7.0	7.7	54
103	29	8	21.7	42	0.19	825	15.2	8.9	9.2	57
104	1 part 27, 3 parts 29	8	24.4	45	0.31	875	14.9	7.9	8.4	54
105	1 part 27, 1 part 29	8	24.6	48	0.39	875	12.7	7.4	8.0	54
106	30	8	24.9	46	0.61	850	14.7	7.5	8.0	58
107	1 part 27, 3 parts 30	8	28.7	53	0.60	900	15.0	7.0	7.6	56
108	1 part 27, 1 part 30	8	32.9	56	0.62	900	14.8	6.4	6.9	53
109	3 parts 27, 1 part 30	8	32.5	57	0.52	900	13.6	6.1	6.7	53
110	31	20	21.4	36	0.56	850	15.0	9.5	9.7	61
111	1 part 32, 3 parts 31	30	24.0	39	0.79	850	16.0	8.9	9.3	61
112	1 part 32, 1 part 31	30	27.2	43	0.80	900	15.6	7.8	8.4	60
113	32	20	32.5	59	1.23	800	13.2	5.2	6.0	55
114	3 parts 32, 1 part 31	17	29.6	47	0.94	825	13.6	6.4	7.1	59
115	1 part 27, 3 parts 31	48	24.2	40	0.69	875	15.9	8.5	9.1	60
116	1 part 28, 1 part 31	20	26.2	42	0.65	850	13.8	7.5	8.1	57
117	3 parts 28, 1 part 31	24	23.8	43	0.57	775	12.5	7.2	8.0	56
118	28	24	28.5	53	0.50	800	11.7	6.2	7.2	52
119	3 parts 34, 1 part 35	8	29.6	51	0.71	710	14.3	6.6	7.4	52
120	3 parts 34, 2 parts 35	8	28.5	48	0.69	750	15.9	7.0	7.9	53
121	1 part 34, 1 part 35	4	29.8	58	1.31	—	10.1	5.4	6.1	40

*Table 2 identifies the coals by number.

†Temperature of gas at boiler exit.

‡Gas samples were taken only while stoker was operating.

TABLE 8.—DATA FROM SOOT AND FLY ASH TESTS

Test No.*	Stoker operation, min. per hr.	No. of stoker starts per hr.	Coal burned during test, lb.	Soot and fly ash collected, lb. per ton of coal burned			Air setting†	Pressure drop through fuel bed, in. of water	Average CO_2,‡ percent	Temperature of stack gases, °F.	Heat obtained, lb. of equivalent evaporation per lb. of coal	Efficiency of boiler and stoker, percent
				In precipitator	In boiler passages	Total						
1	18	5	74	7.0	5.4	12.4	2.0	0.56	13.4	425	——	——
2	22	5	110	7.0	4.6	11.6	2.0	0.60	10.3	475	——	——
3	26	5	120	7.2	3.6	10.8	2.0	0.68	11.9	500	——	——
4	32	5	130	6.4	3.2	9.6	2.0	0.70	13.1	575	——	——
5	31	5	121	7.0	3.2	10.2	2.0	0.76	13.2	550	——	——
6	27	3	116	6.8	3.2	10.0	2.0	0.85	13.4	510	——	——
7	19	5	102	7.0	3.8	10.8	2.0	0.72	10.0	440	——	——
8	28	5	136	6.2	4.2	10.4	2.6	1.15	10.1	560	6.05	49.3
9	28	5	123	6.6	3.4	10.0	2.0	0.96	13.6	510	6.12	50.0
10	28	5	140	5.4	4.0	9.4	2.6	1.08	10.8	590	6.06	49.5
11	18	5	97	5.8	6.0	11.8	2.6	——	——	470	5.52	45.0
12	18	5	80	7.6	4.0	11.6	2.0	——	——	425	5.67	46.2
13	18	5	69	11.0	5.0	16.0	2.0	——	——	390	5.32	43.3
14	18	5	84	6.2	5.2	11.4	2.6	——	——	450	5.43	44.3
15	24	5	102	5.0	5.6	10.6	2.6	——	——	535	5.94	48.5
16	31	5	124	5.6	5.8	11.4	2.6	1.03	9.7	580	5.80	47.3
17	31	5	125	6.8	4.4	11.2	2.0	0.85	11.1	525	5.64	46.0
18	31	5	118	5.4	4.4	9.8	2.0	0.80	10.9	535	5.67	46.3
19	22	5	103	8.2	4.2	12.4	2.0	0.70	11.1	510	6.38	53.8
20	18	5	92	12.6	4.0	16.6	2.0	0.66	10.2	460	6.07	51.2
21	17	5	74	10.6	4.0	14.6	2.0	——	——	410	5.98	50.5
22	32	5	87	7.0	4.0	11.0	2.0	0.77	12.7	525	6.33	53.5
23	22	5	99	7.2	3.6	10.8	2.6	0.86	10.4	490	6.23	52.6
24	18	5	63	8.2	4.8	13.0	2.0	——	——	410	6.56	55.3
25	27	5	119	8.0	4.2	12.2	2.6	1.01	9.4	550	6.52	55.0
26	27	5	76	5.8	3.0	8.8	2.0	0.83	11.3	510	6.50	54.8
27	31	5	84	7.2	4.6	11.8	2.6	1.17	10.2	575	6.42	54.2
28	18	5	76	8.0	6.6	14.6	2.6	——	——	450	5.85	49.3
29	27	5	92	6.8	3.4	10.2	2.0	0.86	11.4	490	6.53	55.2
30	24	3	101	6.2	5.0	11.2	2.0	——	——	——	——	——
31	24	3	83	7.2	6.4	13.6	2.0	——	——	——	——	——
32	30	3	122	7.6	5.8	13.4	2.0	——	——	——	——	——
33	25	5	90	3.4	5.0	8.4	2.0	——	——	——	——	——
34	21	5	84	4.0	2.2	6.2	2.0	——	——	——	——	——
35	21	5	96	3.2	2.6	5.8	2.0	——	——	——	——	——
36	21	5	78	3.0	3.0	6.0	2.0	——	——	——	——	——

*Tests 1 to 19 were made with Scandia oil-treated stoker coal, 19 to 30 with Sunshine oil-treated stoker coal, 30 to 33 with Scandia ¾– to 1¼–in. nut coal, and 33 through 36 with Franklin County (Illinois) stoker coal.

†The values given are arbitrary numbers; 2.0 is the damper setting for the air supply recommended by the authors; 2.6 is for a more liberal air supply.

‡Gas samples were taken only while stoker was operating.

PROXIMATE ANALYSES OF COALS USED IN SOOT AND FLY ASH TESTS

Coal*	Constituents of coal as fired, percent					Heating value,† B.t.u. per lb.
	Moisture	Ash	Volatile matter	Fixed carbon	Sulphur	
Scandia stoker	5.23	13.29	43.02	38.46	4.44	11,948
Sunshine stoker	4.78	9.26	42.45	39.40	4.10	12,318
Franklin Co. (Ill.) stoker	4.05	7.43	36.16	52.36	0.62	13,133

*No analysis was made of the Scandia nut coal used in these tests.

†Heat generated with perfect combustion.

Table 9.—Evaluation of Soot and Fly Ash Data

Test No.	Soot and fly ash collected in precipitator				Soot and fly ash collected in boiler				Heat loss in soot		Ash leaving fuel bed, lb. per ton of coal burned
	Lb. per ton of coal burned	Analysis		Heating value, B.t.u. per lb.	Lb. per ton of coal burned	Analysis		Heating value, B.t.u. per lb.	B.t.u. per lb. of coal burned	Percent of heating value of coal fired	
		Moisture, percent	Ash, percent			Moisture, percent	Ash, percent				
1	7.0	1.58	17.86	9,876	5.4	0.75	48.37	5,370	49	0.41	4.0
2	7.0	1.74	24.17	7,670	4.6	0.84	59.44	4,360	37	0.31	4.4
3	7.2	1.92	26.37	9,040	10.8	0.85	53.12	5,108	42	0.35	3.8
4	6.4	2.33	30.13	8,300	9.6	0.72	52.39	5,356	35	0.29	3.6
8	6.2	3.09	45.52	5,514	4.2	0.63	59.15	3,751	25	0.21	5.4
19	8.2	2.27	27.98	7,536	4.2	1.00	45.66	4,460	40	0.35	4.2
20	12.6	1.97	33.00	7,435	4.0	0.90	42.47	6,057	59	0.51	5.8
21	10.6	2.47	26.48	8,484	4.0	1.21	40.30	5,899	57	0.49	4.4
22	7.0	2.11	27.91	8,159	4.0	0.65	45.53	6,418	41	0.35	3.8
23	7.2	3.40	33.88	5,747	3.6	1.21	50.27	4,280	28	0.24	4.2
24	8.2	3.98	26.53	7,729	4.8	1.73	45.18	5,017	44	0.38	4.4
25	8.0	1.85	36.52	4,746	4.2	0.44	57.61	3,706	27	0.24	5.4
26	5.8	2.42	28.86	7,526	3.0	0.79	45.47	5,559	30	0.26	3.0
27	7.2	1.10	40.90	5,039	4.6	0.68	55.71	4,407	28	0.24	5.4
28	8.0	3.08	36.19	5,220	6.6	0.49	58.94	3,842	33	0.29	6.8
29	6.8	1.42	32.80	6,670	3.4	0.31	48.41	5,288	32	0.28	3.8
30	6.2	2.26	22.08	8,754	5.0	1.21	48.87	3,602	36	——	3.8
32	7.6	1.59	19.53	6,480	5.8	1.12	49.71	5,878	43	——	4.4
34	4.0	1.85	20.33	9,005	2.2	0.93	49.98	5,313	24	0.18	2.0

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