P. J. Houser

# The Use of Iowa Coal in Domestic Stokers


By

M. P. Cleghorn and R. J. Helfinstine



IOWA ENGINEERING EXPERIMENT STATION

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By

M. P. Cleghorn, M.E.
*Mechanical Engineer*

and

R. J. Helfinstine, B.S. in M.E.
*Junior Mechanical Engineer*

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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 herewith a manuscript entitled "The Use of Iowa Coal in Domestic Stokers" and recommend that it be published as a bulletin of this Station. This manuscript presents the results of the work done to date on Project 195.

Special acknowledgment should be made to the staff members in the Mechanical Engineering Department of Iowa State College who gave valuable assistance at various times. Their cooperation was deeply appreciated.

Respectfully submitted,

M. P. Cleghorn
*Mechanical Engineer*

R. J. Helfinstine
*Junior Mechanical Engineer*

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## FOREWORD

It is practically impossible for the home owner to determine accurately the performance characteristics of a heating plant in his own home. If, for example, the cost of heating with two coals is desired, only a rough estimation can be made after a year's trial of each; the actual cost per season will not give a true picture.

Fortunately, however, adequate cost information and other pertinent data can be readily and accurately obtained in a laboratory and may be applied to actual home conditions.

The large number of inquiries concerning the use of Iowa coal in domestic stokers indicated the need of such information obtained from tests of this modern type of heating plant.

The test results given in the present bulletin were obtained from a domestic stoker and boiler set up in the laboratory. The discussion includes the following—a comparison of the cost of heating with Iowa and out-of-state coal; the probable fuel savings to be attributed to a stoker; suggestions for burning Iowa coals in the most satisfactory manner; and the amount of attention required with a stoker. Results of tests with different Iowa coals are given in tabular form.

It was found that Iowa coals could be burned satisfactorily in domestic stokers.

# The Use of Iowa Coal in Domestic Stokers

## INTRODUCTION

Coal is the most valuable of the natural resources of Iowa, and if used to the fullest possible extent would lead to increased employment and a greater prosperity. Every ton of coal mined in Iowa puts money in the miners' pockets to be spent locally. If there is sufficient demand for the coal, the mine operators profit as well. Such a profitable demand must come from the people of Iowa or from those close to Iowa on the north and west.

In 1935, 3,787,605 tons of coal valued at $11,362,815 were mined in Iowa. This coal came from deposits which underlie most of the surface of those counties located along the Des Moines River from Boone to the southern boundary of the state and those along the southern border.

Those familiar with the fuel problem in Iowa have recognized the importance of coal and have urged its more general use. The coal operators, slow at first to satisfactorily prepare the coal for market, have awakened to the need of cleaner, better prepared, more suitably sized coal, and are in most cases able to supply it.

Large power-plant stokers have been in use for many years and, when carefully selected, will burn Iowa coal satisfactorily and profitably.

Within the last few years the small domestic coal stoker has been developed and offered to the public. More than 100,000 were sold in the United States in 1936, and the sales are still increasing. Herein lies the possibility of increased demand for Iowa coal if it can be burned satisfactorily in domestic stokers.

Some of the stokers have not entirely substantiated the claims made for them, and some doubt has been expressed as to their ability to burn Iowa coal satisfactorily. In order to determine the facts in the case for the people of Iowa, an investigation was started by the Iowa Engineering Experiment Station. The results of the work so far completed are discussed in the present bulletin.

## OBJECT OF TESTS

The primary object of the tests was to study the use of Iowa coals in domestic stokers. There are many pertinent factors in this problem, of which the following were considered of major importance.

1. Equivalent evaporation per pound of coal.
2. Manual attention required.
3. Clinkering tendencies.
4. Uniformity of burning.
5. Fire-holding ability.
6. Cleanliness.

The relative importance of the above factors is a matter of personal opinion, and justly so. When the first factor—equivalent evaporation per pound of coal—and the cost of the coal are known, the cost of heat can be computed. This cost is usually taken into consideration in ranking coals, although it is not so important to the domestic consumer as to the commercial buyer.

The next three factors—manual attention required, clinkering tendencies, and uniformity of burning—are all closely connected. These, coupled with fire-holding ability, indicate how nearly the stoker operation will be automatic with a given coal. Cleanliness is often the deciding factor in coal selection for the domestic stoker. Although some coals are inherently dirtier than others, all can be made relatively clean by proper treatment.

## APPARATUS USED

Through the courtesy of the Iron Fireman Manufacturing Company, their 1936, Model R-30 stoker was used for all tests. This stoker had a maximum coal feed of about 30 lb. per hr.

The stoker retort was set about 3 in. below the nominal grate level, the top of the retort being about 25 in. from the lowest part of the boiler arch. The hearth was approximately 26 in. wide and 30 in. long.

The boiler used, a "Capitol" Model B-8 loaned by the United States Radiator Corporation, was rated at 920 sq.ft. of direct cast-iron radiation with 13,000-B.t.u. coal. It was of rectangular construction, composed of four cast-iron sections. Figure 1 shows the stoker and boiler as set up for the tests.

The boiler was uncovered and an allowance was made for the resulting heat loss by means of the formula given by the American Society of Heating and Ventilating Engineers (page 24). The steam generated was piped to a condenser on the balcony above the boiler, where it was condensed and discharged into a tank set upon a platform scale. This weighing tank could be emptied into the pump supply tank below. An electrically driven centrifugal water pump automatically kept the boiler water-level nearly constant. The pump also had a manual control, allowing accurate water-level regulation when readings were being taken. The boiler was equipped with a low-water-level cutoff. A pressure control, which could be adjusted

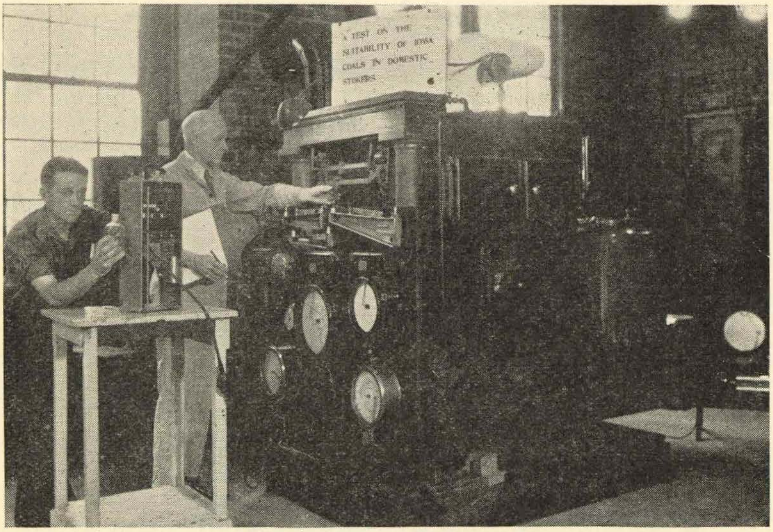

Fig. 1.—View of the boiler and stoker as tested.

to start and stop the stoker at any desired boiler pressures, displaced the usual boiler gage.

## Instruments

During the earlier tests an electric calorimeter was used to determine the quality of the steam. As this quality remained nearly constant at about 0.98, and as the apparatus was rather complicated and difficult to operate, the use of the calorimeter was discontinued and a quality of 0.98 used in all subsequent calculations.

Permanent records of the boiler pressure and the temperatures of the feed water, the stack gases, and the room were obtained by recording instruments. Indicating draft gages were connected to the combustion chamber, the stoker wind box, and the chimney at the boiler outlet. An Orsat gas analyzing set was used for flue-gas determinations. An electric clock gave the number of minutes of stoker operation, and a watthour meter the power required to operate the stoker.

## Stoker and Boiler Mounting

The boiler and stoker were mounted upon scales, which eliminated the necessity of estimating the amount of unburned fuel on the hearth at the start and stop of a test. Accurate tests could be made in a relatively short time.

Flexible connections were made to the condenser and feed-water pump by means of rubber hoses. Flexibility in the smoke pipe was secured by the use of elbows.

## TESTING PROCEDURE

Before starting actual test work, several preliminary tests were made to determine the best air setting and the kind and length of tests needed to gain the desired information. Scandia 1¼-in. screenings, taken from cars at the college heating plant, were used for these tests.

Because analyses of the coals from the various mines of Iowa indicated a considerable variation in composition, actual firing tests on

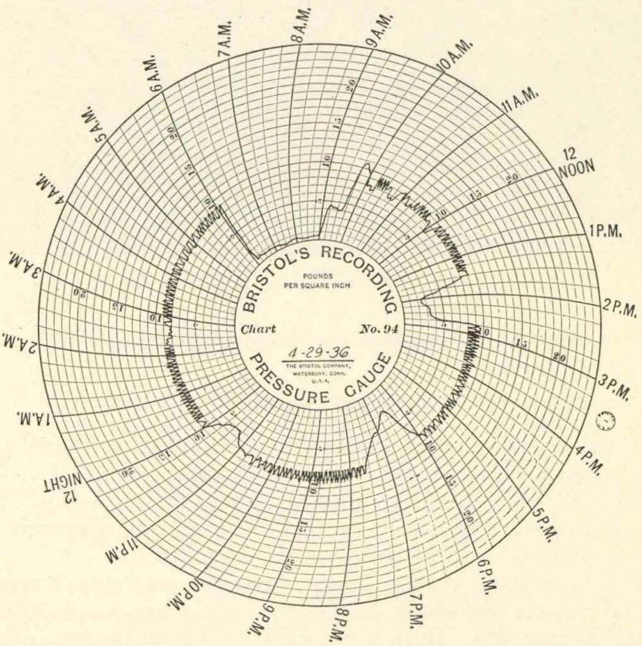


Fig. 2.—Recording pressure chart, showing pressure drops caused by clinker formation with a poor Iowa coal.

coal from a number of mines were needed to determine the effect of these differences when burning the coal with a stoker. The four tests chosen to furnish this information were designated as: (1) high speed, intermittent; (2) high speed, continuous; (3) middle speed, intermittent; and (4) middle speed, continuous. The speed refers to the rate at which the stoker feeding worm revolves during operation, three speeds being possible with the stoker tested. Operation was called continuous when the stoker was not allowed to stop.

Prepared stoker coals were not generally available at the Iowa mines when the tests were started. For comparative purposes, therefore, screenings were chosen for this first series of tests. In two cases, crushed mine run had to be substituted because screenings were not available in those districts. A small truck was used to haul the coal directly from the mines.

In each of these tests, the fire was started upon a clean hearth and the fuel bed allowed to build up for about 4 hr. before actual data were taken. With the exception of the high-speed, intermittent test, which lasted about 20 hr., data were taken for 8 hr. The longer test was needed to furnish information concerning clinker formation.

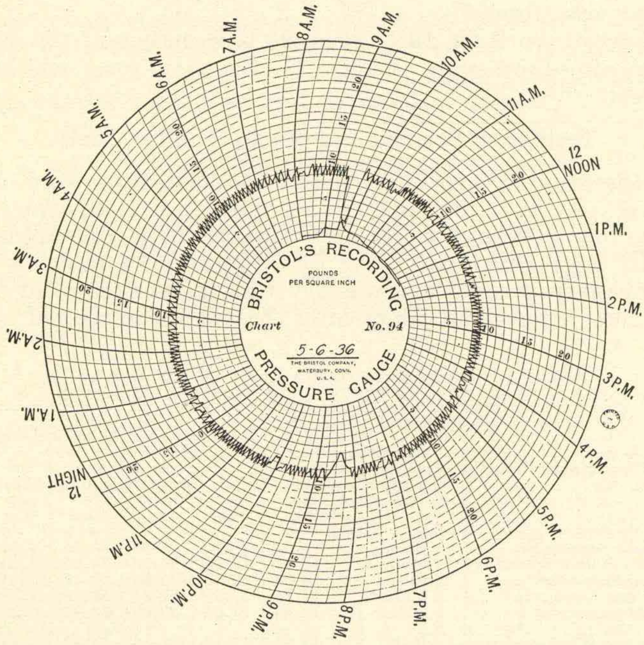


Fig. 3.—Recording pressure chart, showing pressure drops caused by clinker formation with a good Iowa coal.

The pressure chart proved to be of great value for recording the changing conditions of the fire in this longer test. Figure 2 is the pressure chart for April 29, 1936, on which date the fire was started at about 9:00 a. m. It can be noticed that the pressure control stopped the stoker when the upper limit of 10 lb. was reached at 9:50 a.m., as shown by the sharp drop in pressure. The pressure limit was then lowered to 9 lb. and the steam discharge valve set to allow about 130 lb. of steam to pass through per hour at this pressure.

The chart indicates that the fire continued to burn unevenly until a good fuel bed had been built up shortly after noon. The fire then burned briskly, as shown by the frequent cycles of stoker operation, until 1:30 p.m. At that time, the pressure continued to drop, even though the stoker was operating continuously, which indicated that a clinker had formed over the retort and was shutting off the normal air supply.

By 2:35 p.m., the clinker had been raised from the retort by the incoming coal, and soon a good fire was in progress. The gradually decreasing cycle rates after 2:50 p.m. show that clinker was once again being formed, causing a pressure drop at 6:00 p.m. In this manner, the condition of the fire can be traced until 6:00 a.m. when the stoker was stopped.

The chart of April 29, 1936, (Fig. 2) is from one of the more unevenly burning Iowa coals. Figure 3 is the chart for a coal better in this respect.

## Tests with Scandia and Smoky Hollow Coals

After the tests on screenings were concluded, tests were made on Scandia 1¼- by ¾-in. nut coal, which was the size recommended by that mine for household stoker use. During these tests actual home conditions were simulated. The fire was allowed to burn continuously for several weeks, and was never attended except for removal of the clinker after about a hopper of coal had been burned. During

TABLE 1.—PROXIMATE ANALYSIS OF COALS TESTED

| Coal No. | Popular name of coal | Location of mine, county | Proximate analysis, as-fired basis | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Moisture, per cent | Ash, per cent | Volatile matter, per cent | Fixed carbon, per cent | Sulphur, per cent | Thermal value, B.t.u. per lb. |
| 1 | Scandia Screenings | Boone | 14.66 | 15.77 | 35.68 | 33.89 | 4.34 | 9,722 |
| 2 | Smoky Hollow Screenings | Monroe | 14.73 | 12.90 | 36.32 | 36.05 | 2.83 | 10,037 |
| 3 | Boone Screenings | Boone | 16.24 | 24.18 | 29.35 | 30.23 | 6.15 | 8,040 |
| 4 | Pershing Screenings | Marion | 14.74 | 17.79 | 34.04 | 33.43 | 4.89 | 9,778 |
| 5 | Shuler Screenings | Dallas | 13.60 | 17.81 | 35.40 | 33.19 | 6.22 | 10,083 |
| 6 | Norwood White Screenings | Polk | 13.27 | 15.80 | 37.10 | 33.82 | 4.60 | 10,280 |
| 7 | McConville Crushed Mine Run | Appanoose | 15.80 | 11.28 | 35.02 | 37.90 | 4.43 | 10,440 |
| 8 | New Market Crushed Mine Run | Taylor | 18.04 | 13.12 | 34.36 | 34.48 | 4.80 | 9,352 |
| 9 | Scandia 1¼- by ¾-in. Nut | Boone | 14.08 | 17.77 | 35.67 | 32.48 | 4.55 | 9,863 |
| 10 | Scandia Screenings | Boone | 15.82 | 19.60 | 32.22 | 32.36 | 4.51 | 9,380 |
| 11 | Smoky Hollow Nut | Monroe | 13.55 | 11.35 | 38.65 | 36.45 | 4.19 | 10,300 |
| 12 | Smoky Hollow Nut | Monroe | 9.34 | 11.64 | 38.50 | 40.52 | 4.96 | 11,169 |
| 13 | Smoky Hollow Screenings | Monroe | 10.13 | 13.05 | 38.10 | 38.72 | 4.72 | 10,703 |
| 14 | Southern Illinois Stoker | Franklin | 5.30 | 10.38 | 33.55 | 50.77 | 1.20 | 12,100 |
| 15 | Glendora Indiana Stoker | Sullivan | 10.25 | 6.34 | 33.75 | 49.66 | 0.81 | 11,880 |
| 16 | Dawson Daylight Kentucky Stoker | Hopkins | 6.03 | 6.24 | 37.08 | 50.65 | 2.64 | 12,669 |
| 17 | Southern Illinois Stoker | Saline | 5.70 | 9.43 | 34.10 | 50.77 | 1.37 | 11,950 |
| 18 | Des Moines Ice & Fuel Oiled Stoker | Polk | 13.90 | 16.67 | 37.33 | 32.10 | 5.31 | 9,932 |
| 19 | Helsing Strip Crushed Mine Run | Marion | 14.91 | 12.42 | 35.18 | 37.49 | 6.71 | 10,403 |
| 20 | Ellis Stoker | Mahaska | 10.13 | 19.91 | 39.48 | 30.48 | 5.60 | 9,993 |
| 21 | Smoky Hollow Stoker | Monroe | 14.58 | 11.94 | 34.38 | 39.10 | 3.43 | 10,482 |

this long period the stoker was operated at rates varying from "hold fire" (3 min. per hr.) to "continuous," representing a large number of weather conditions.

Practically the same procedure was followed with Smoky Hollow coal. At first, this mine was unable to furnish a household stoker coal, so its screenings were "sized" at the laboratory, a 1¼- by ¼-in. size being used for most tests. Later the mine was able to furnish a prepared stoker coal of about 10 mesh by 1 in.

### Tests with Other Stoker Coals

The out-of-state stoker coals available in Ames were tested next, followed by several other Iowa stoker coals. These coals were tested in the same manner as the Smoky Hollow and Scandia coals, but with a fewer number of stoker operation rates.

## DISCUSSION OF RESULTS

The average proximate analysis for each coal tested is given in Table 1. Results of tests conducted in a similar manner were averaged to give the values shown in Table 2. The individual results, from which Table 2 was prepared, are given in Table 3 (Appendix, page 26).

TABLE 2.—AVERAGE VALUES OF EQUIVALENT EVAPORATION, AND OTHER DATA

| Popular name of coal | Equivalent evaporation per lb. of coal* | | Stoker and boiler efficiency,† percent | Thermal value of coal, B.t.u. per lb., as fired | Fusion temperature of ash,‡ deg. F. |
|---|---|---|---|---|---|
| | as-fired basis | dry basis | | | |
| *Out-of-state coals* | | | | | |
| Dawson Daylight Kentucky Stoker | 8.3 | 8.9 | 64 | 12,669 | 1,785 |
| Franklin County Illinois Stoker | 8.1 | 8.6 | 65 | 12,100 | 2,140 |
| Saline County Illinois Stoker | 8.1 | 8.5 | 66 | 11,950 | 1,800 |
| Glendora Indiana Stoker | 7.9 | 8.9 | 65 | 11,880 | 2,100 |
| Average of out-of-state coals | 8.1 | 8.7 | | | |
| *Iowa coals* | | | | | |
| Prepared stoker coals | | | | | |
| Smoky Hollow Stoker | 6.7 | 7.6 | 60 | 10,726 | 1,780 |
| Ellis Stoker | 6.1 | 6.8 | 59 | 9,993 | 1,980 |
| Helsing Strip | 6.0 | 7.1 | 56 | 10,403 | 1,780 |
| Des Moines Ice & Fuel, Oiled Stoker | 5.7 | 6.6 | 56 | 9,932 | 1,820 |
| Scandia 1¼- by ¾-in. Nut | 5.6 | 6.4 | 55 | 9,863 | 1,895 |
| Average of stoker coals | 6.0 | 6.9 | | | |
| Screenings and crushed mine run | | | | | |
| McConville Crushed Mine Run | 6.0 | 7.2 | 56 | 10,440 | 1,800 |
| Norwood White Screenings | 5.9 | 6.8 | 56 | 10,280 | 1,875 |
| Smoky Hollow Screenings | 5.7 | 6.6 | 55 | 10,037 | 1,830 |
| Pershing Screenings | 5.6 | 6.6 | 56 | 9,778 | 1,810 |
| Shuler Screenings | 5.5 | 6.4 | 53 | 10,083 | 1,835 |
| New Market Crushed Mine Run | 5.3 | 6.4 | 55 | 9,352 | 2,015 |
| Boone Screenings | 4.2 | 5.1 | 51 | 8,040 | 1,690 |
| Average of screenings and crushed mine run | 5.5 | 6.4 | | | |

*One pound of equivalent evaporation represents 970 B.t.u.

†Boiler efficiency is the ratio of the heat transferred to the water in the boiler to the thermal value of the fuel fired.

‡Temperature at which ash softens.

## Equivalent Evaporation from Coals

Feed-water temperature and steam pressure in boiler tests vary, and in order to compare different tests it is necessary to reduce all results to a common basis. The usual method is to change the actual conditions to an arbitrary standard which presumes a feed-water temperature of 212° F. and a steam pressure of 14.7 lb. absolute. In other words, "equivalent evaporation from and at 212° F." is the amount of water which would have been evaporated if these standard conditions had existed during the test. One pound of equivalent evaporation represents 970 B.t.u.

Efficiency has been defined in Table 2 as the ratio of the heat transferred to the water in the boiler to the thermal value of the fuel burned. The meaning of this should be thoroughly understood. Efficiency is a measure of stoker and boiler performance and does not necessarily indicate the value of the coal fired. For example, Table 2 shows that the efficiency of the stoker and boiler while burning Kentucky coal was 2 percent less than with Saline County, Illinois coal; yet the Kentucky coal evaporated 2½ percent more water per pound.

The arrangement in order of pounds of equivalent evaporation in Table 2 is not meant to be an absolute ranking for the coals tested.

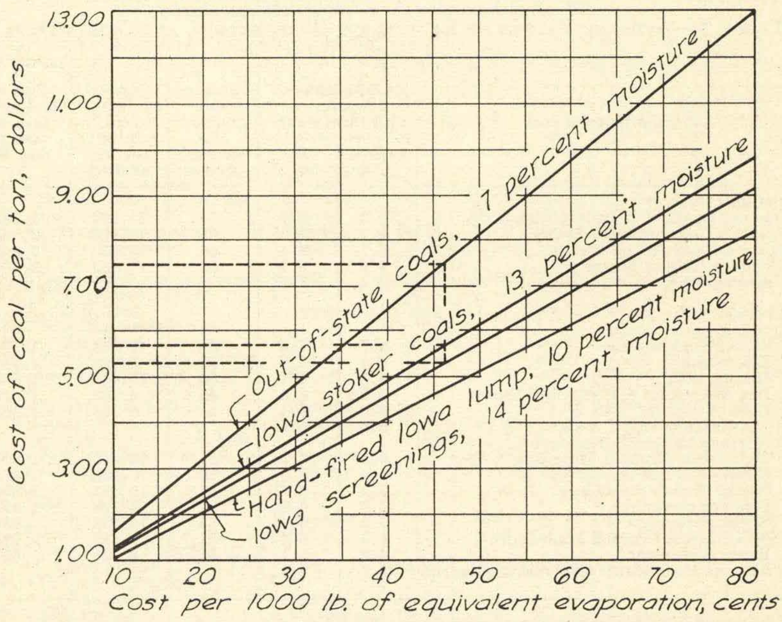


Fig. 4.—The relative costs of equivalent evaporation for various coals and conditions. The percent moisture indicated is the average for the coals "as fired."

Sometimes a coal giving a high evaporation rate may be poorer in other respects. The tests were not conducted with a view to ranking Iowa coals. With the exception of Smoky Hollow, Boone, and Scandia coals, the tests were made upon one load of coal from each mine, which may or may not be representative of that mine.

The most striking fact brought out by the figures given is the difference in equivalent evaporation between the out-of-state and the Iowa coals. It will be noticed that the average Iowa coal evaporated about three-fourths as much water per pound as the out-of-state coals tested. On first thought, this may seem to be a pretty stiff handicap for Iowa coal to overcome, but when the cost of transportation is considered, the comparison is more favorable.

Examination of prices shows that Iowa coal will furnish the cheapest source of heat for domestic stokers in a considerable portion of the state. This is shown in Fig. 4 in which cost of coal per ton is plotted against the cost per 1,000 lb. of equivalent evaporation. The dotted line indicates the method of finding the value of average Iowa coal when one of the out-of-state coals tested can be purchased for $7.50 per ton. It is found that about $5.70 can be paid for Iowa stoker coal and $5.30 for Iowa screenings. In fairness to Iowa coal, it should be stated that the out-of-state coals were purchased during a hot dry summer, and probably had a lower moisture content than normal. No attempt has been made to evaluate this difference.

## Importance of Moisture in Coal

The importance of the amount of moisture in a coal is frequently not realized. Often it represents a greater loss than ash; yet it disappears out the chimney and therefore escapes notice. Figure 5 has been prepared to show the importance of the moisture content of the coal. The curves shown represent the same data as given in Fig. 4, calculated for the varying moisture contents indicated instead of on the "as-fired" basis.

The variations shown in Fig. 5 are not uncommon. The Iowa coals tested ranged from 8.69 to 19.00 percent moisture, and the out-of-state from 4.68 to 16.26 percent. Coal from the same Iowa mine varied from 8.69 to 15.26 percent. These variations indicate another reason for not placing too much weight on the rank according to equivalent evaporation as determined by tests made on only one load of coal.

## Manual Attention Required with Stoker

The cost of evaporation is not the only factor involved in determining the suitability of a coal for a domestic stoker. In fact, the householder often places cleanliness and freedom from attention above cost. The maximum length of time between cleaning periods cannot be definitely stated. This will vary with the coal, the rate

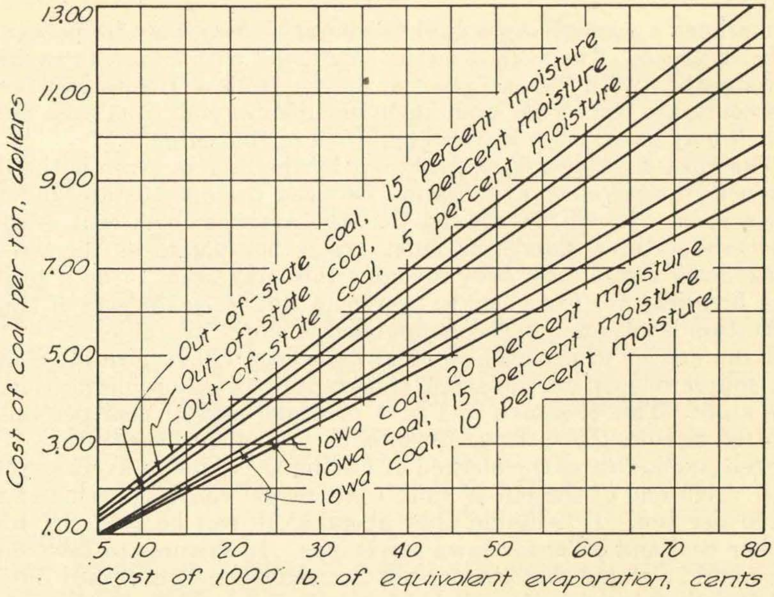


Fig. 5.—The effect of moisture content of coals upon the cost of equivalent evaporation.

of burning, and the combustion chamber within which it is burned.

The series of tests on Scandia coal indicated that a hopper of coal, about 350 lb., can usually be burned without attention. The change from a lower to a higher rate is the critical one. During the slow period, the ash will accumulate on the hearth without clinkering. After a sudden increase in rate, the fire will soon require cleaning.

Perhaps the fire would have required cleaning before a hopper of coal was burned, had the combustion chamber been smaller. With a high-ash 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.

Although the fire performed satisfactorily when cleaned only after 350 lb. of coal had been burned, indications were that better combustion would have resulted with more frequent cleanings. It is seldom that a hopper of coal will be burned in one day, and the custom of filling the hopper and cleaning the fire daily can be followed with Iowa coal, except in the coldest weather.

## Proper Air Supply

The practice of having white-hot, roaring flames, so frequently observed, cannot be too strongly discouraged. The flames within the combustion chamber should be rather "lazy" and of a dull red color The fuel bed should be at least 4 in. deep.

Tests indicate that clinkering is much less troublesome and efficiency is increased when the proper amount of air is supplied. A light-gray smoke coming from the chimney, which indicates that the proper amount of air is being used, is actually desirable.

It is not advisable to disturb the fire too often since indications are that this does not increase efficiency. The practice of leveling the fuel bed, to make it neat in appearance, may even result in increased clinker formation. Of course, if insufficient heat is being secured the clinker should be removed.

### Clinkering Tendencies

As previously mentioned, the firing attention required depends considerably upon the fusion characteristics of the ash. The fusion

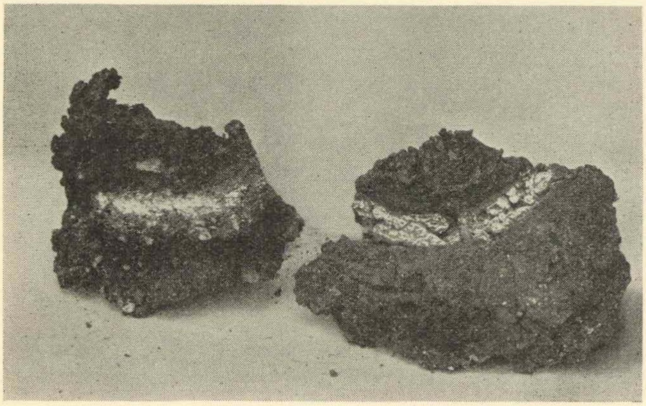

Fig. 6.—Undesirable clinkers formed from an Iowa coal.

temperatures, as determined by laboratory analyses, are valuable indicators of fusion characteristics, but they do not tell the whole story.

The fusion temperatures given in Table 2 were obtained in a Barrett Fusion Furnace in accordance with the directions given by the American Society of Testing Materials Designation D 271-30. This publication may be consulted for details.

It was difficult to determine which of the coals tested had the most desirable clinkering characteristics. Probably the Indiana coal was slightly superior. Although it had a slight tendency to run over into the retort, the Indiana coal was light and porous and allowed the air to pass through.

The clinkers from the Iowa coals were generally hard and glassy when taken from an intense fire. Their density was considerably greater than the clinkers from the out-of-state coals tested. As a person often estimates the amount of clinker removed in terms of volume and not weight, this increased density may be considered an advantage by some. Although clinkers formed much more rapidly with Iowa coals at the higher rates of combustion, some Iowa coals failed to clinker enough at the milder-weather rates. However, it would not be necessary to remove loose ash very often, for seldom does Iowa enjoy long periods of uniformly mild temperatures. Clinkers would be formed during the colder periods, even though these periods were of short duration.

Figure 6 shows some undesirable clinkers formed with Iowa coals. Notice the imprint of the stoker retort which had been whitened to make it plainly visible. The portion of clinker above this whitened

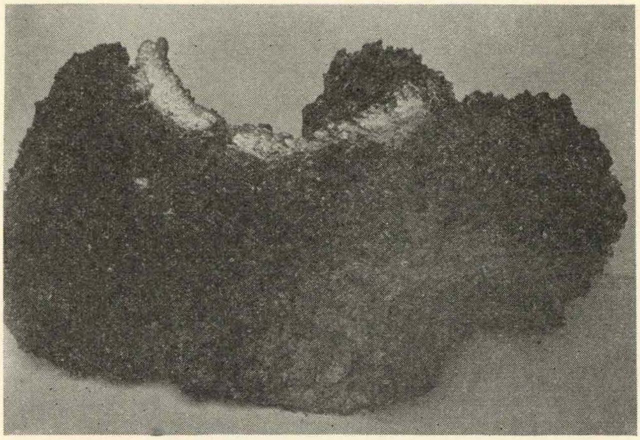

Fig. 7.—Undesirable clinkers formed from an Illinois coal.

ring in the picture was hanging over the edge of the stoker retort before removal, thereby shutting off the normal air supply. When such clinker forms, the combustion rate will gradually decrease until the incoming coal forces the clinker out of the retort. This often takes an hour or two, but usually will occur. The ability of the stoker to overcome such a condition is quite remarkable.

Of the coals tested, only one Iowa coal appeared unsuitable for domestic stoker use because of clinkering. Unless the clinkers were removed quite frequently, little heat was given off with this coal.

It must not be concluded that troublesome clinkering is a characteristic common only to Iowa coals. Figure 7 shows a clinker from an Illinois coal, on which the imprint of the stoker retort has again been whitened to make it plainly visible. Since the other half of this clinker broke into several pieces during removal, it was not photographed. The clinker measured about 22 in. across, with a maximum thickness of about 9 in. Although clinkers of this size were uncommon with the out-of-state coals tested, they were not unusual with some of the Iowa coals.

## Uniformity of Burning

The uniformity with which combustion progresses is a question of considerable importance when the heating plant is required to operate at its peak rating a large share of the time. Unfortunately, it is difficult to compare the various Iowa coals from this angle because of the important part that chance plays in clinker formation.

There is no question but what the out-of-state coals tested usually burned more evenly than Iowa coals (Fig. 8). The amount of evaporation secured per minute of stoker operation was very nearly constant, which was not true with most Iowa coals.

If a stoker is required to operate nearly continuously in cold weather to supply the necessary heat with one of the out-of-state coals tested, it would be useless to expect Iowa coals to maintain a uniform temperature in the house with the same heating plant. It might be advisable to have Iowa coal in another bin to burn in milder weather if cost were a primary factor. Of course, Iowa coal

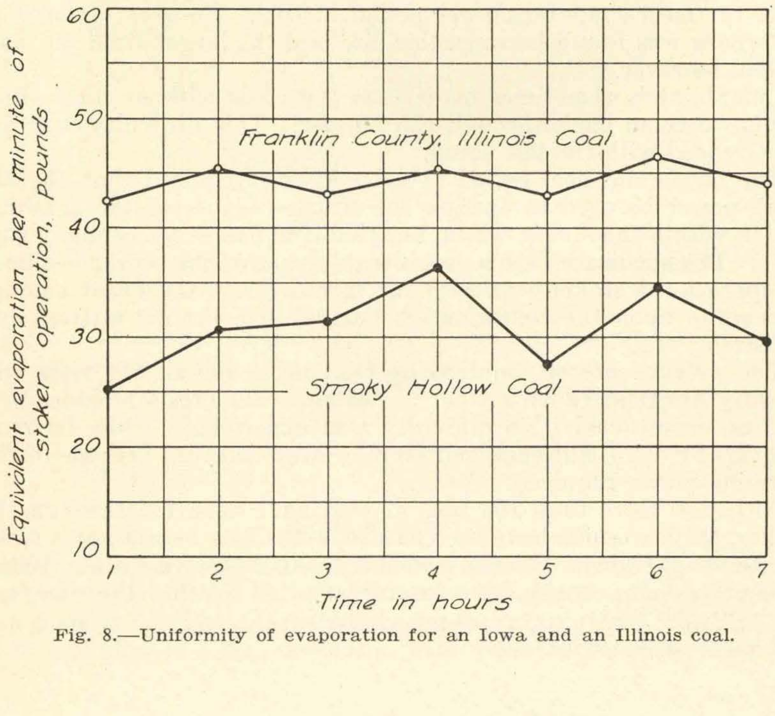


Fig. 8.—Uniformity of evaporation for an Iowa and an Illinois coal.

could be burned all the time if a heating plant of sufficient capacity were installed to furnish the necessary heat during one of the poor-fire periods, such as the one indicated in Fig. 2 between 1:30 and 2:30 p.m.

Ordinarily, this uneven burning with Iowa coal is caused by clinker formation. However, one of the Iowa coals tested formed coke which rose from the retort without being burned. Unless this coke was frequently broken and scattered over the hearth, very uneven evaporation resulted. It is possible that a different-sized combustion chamber would have been better for this coal.

### Effect of Size of Coal

The size of coal to burn in the domestic stoker has been given some study, although further work should be done. As far as cost is concerned, those living near mines will undoubtedly find Iowa screenings to be the cheapest source of heat. Slightly less heat is secured per pound of screenings, as shown in Fig. 4, but the difference in cost between the prepared stoker coal and screenings is often considerable. However, screenings are objectionable to some people unless properly dust-treated. Also, storage of the screenings must often be limited because of the danger of spontaneous combustion.

In the few tests conducted, the smaller sizes (3/4 by 5/16 in.) gave the most evaporation per pound of coal. No great amount of difference was found between this size and the larger-sized nut coal tested, however.

Complaint is sometimes made that the coals without fines allow smoke to come back through the hopper. This difficulty was not experienced with the test setup.

The larger nut coal tested (1¼ by ¾ in.) required that slightly more power be used to operate the stoker because of the crushing action within the stoker worm, but this is not as great as many suppose. Tests indicate that a considerable part of the power required to operate the stoker was used for forced draft, the exact amount depending upon the condition of the fuel bed, the air setting, and the size of coal.

The average power required by the stoker for all the tests was slightly less than 12 kw-hr. per ton of coal. The tests included several on coarse coal. No difficulty was experienced when burning the 1¼- by ¾-in. nut coal, and no pins[1] were sheared because of the crushing power required.

Although more than 100 tons of coal have been fed through the stoker, only two pins have been sheared—the first because of a spike lodging in the worm, and the second from an unknown cause. Whatever the reason, considerable trouble resulted because the coal-feed

[1] The stoker tested had a soft steel shear pin to prevent damage caused by foreign matter lodging in the worm.

failure was not observed immediately. The clinker not only ran over into the retort, but froze to the hearth. If pins sheared frequently it would be highly advisable to arrange the stoker mechanism in such a way that the fan would also stop when the pin sheared.

### Ability of Iowa Coals to Hold Fire

Tests indicated that with Iowa coals the fire remained in good condition and picked up readily upon demand when the stoker was

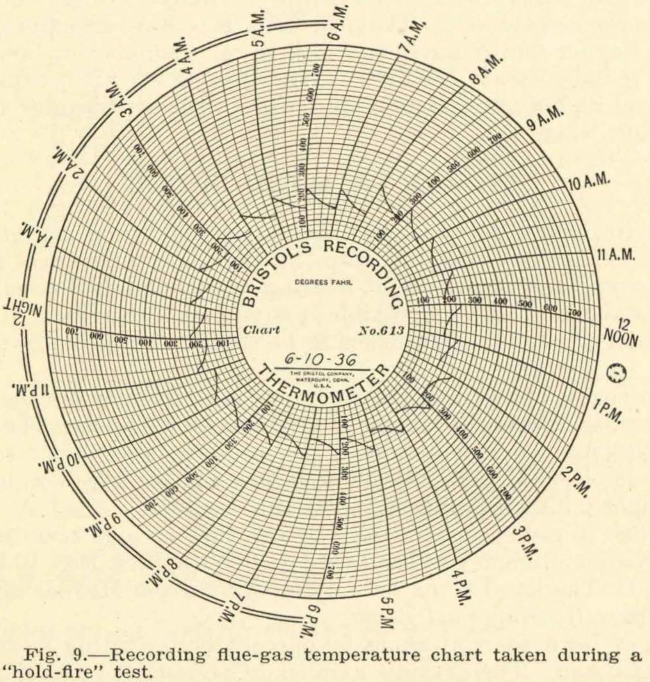


Fig. 9.—Recording flue-gas temperature chart taken during a "hold-fire" test.

operated 3 min. per hr. on high coal feed (Fig. 9). It can be noted that the temperature rose rapidly when the stoker started on the hour. Five successive 24-hr. charts had this same appearance.

About 20 lb. of coal were burned per day with the above rate of operation, and very little heat was given off. It is probable that the fire could have been held with even less coal if it had been desirable.

### Clinker Removal

At the present time, the removal of clinker is all that the bituminous coal stoker lacks of being entirely automatic, bin-feed models now being offered by a large number of manufacturers. The removal of this clinker is a task involving only a few minutes per day, but must be done with regularity. To some it will be a source of annoyance; to others a negligible item.

When the clinker is removed, it must be taken outdoors immediately or placed in a special container so that the evolving gases will not escape into the house. Some furnace companies have solved the problem by providing a special ash compartment beneath the hearth, where the clinker may be dropped. This eliminates all objectionable gases and lessens the dust caused by clinker removal.

Some progressive coal dealers are actually selling "automatic heat" to their customers. The procedure is to have an employee who fills the hopper and removes the clinker for a number of households, making it unnecessary for the customer to go near his heating plant. Such a sales plan appears to offer a wonderful opportunity for dealers in Iowa coal.

## STOKER VS. HAND FIRING

There are many reasons why the fuel savings to be expected from a stoker cannot be predicted. Among them are differences in firing method, type and condition of heating plant, and fuel used. From the facts available, it is impossible to give average savings. Opinions vary widely as to the efficiencies to be expected, especially for hand firing.

When coal is hand-fired, the residence is frequently overheated for short periods, thereby bringing in another variable loss. The amount of this loss may be considerable if the windows are opened to let the excess heat escape. Such a loss can be eliminated, however, by means of a properly installed automatic heating system.

In order to give a general idea of the fuel savings resulting from the increased efficiency of combustion with a stoker, Fig. 10 has been prepared. The hand-firing data were taken from Meeker and Wagner's *House Heating Fuel Tests.*[2]

Tests of Iowa coals at about 60 percent boiler rating were chosen for comparison. The average number of pounds of equivalent evaporation per pound of coal was found to be 5.2 with hand firing and 6.1 with the stoker. This difference has been plotted in Fig. 10 with season fuel cost as ordinate or vertical scale. There is no abscissa, or horizontal scale. The dotted line indicates the method of using this diagram.

In the case shown in Fig. 10, the cost of coal per season was assumed as $100 when firing by hand. This means that about $84 would purchase the coal required, for the same quantity of heat, when stoker-fired. This figure is based upon equally priced coal.

It should be remembered that these figures represent fuel savings for the same quantity of heat as shown by the tests mentioned. They do not include the loss caused by uneven heating with hand firing.

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[2] MEEKER, W. H., and H. W. WAGNER. "House Heating Fuel Tests." *Iowa State College, Engr. Exp. Sta. Bul.* 33. 1913.

However, the fuel savings are not net gain since an appreciable quantity of power is required to operate the stoker. As previously mentioned, this amounted to about 12 kw-hr. per ton of coal for the stoker used. With coal at $5.00 per ton and power at 3½ cents per kw-hr., the power cost would be about one-half the savings shown in Fig. 10. Interest on the investment of approximately $275 at 4 percent would amount to $11.00 per year. In addition, there are other cost items such as depreciation and repairs.

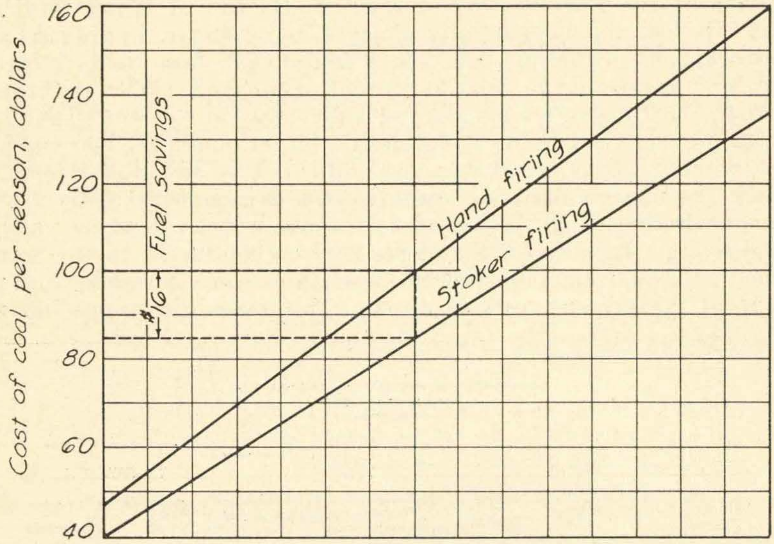


Fig. 10.—Fuel savings shown with stoker over hand firing (Meeker and Wagner tests), using equally priced coal.

It would appear that the smaller stokers should not ordinarily be purchased as money-saving devices. Rather, the satisfaction and convenience of automatic heat, plus the healthful benefits derived, should form the basis for stoker purchase.

## HEAT BALANCE FOR A TYPICAL TEST

Enough data were taken during the tests with continuous stoker operation to enable the calculation of a heat balance. The test of Nov. 24, 1936, has been selected as typical (Fig. 11). The heat balance, calculated upon a covered-boiler basis, follows:

| | |
|---|---|
| Heat absorbed by a covered boiler | 59% |
| Loss due to moisture in coal | 1% |
| Loss due to hydrogen in coal | 4% |
| Loss due to heat in flue gases | 20% |
| Unaccounted-for and radiation losses from covered boiler | 16% |
| | 100% |

The formula[3] given by the American Society of Heating and Ventilating Engineers has been used to convert the results from the uncovered-boiler test to the covered-boiler basis. The radiation loss from a covered boiler has been included in the unaccounted-for losses.

Although no accurate checks were made, about a 4-percent radiation loss could be expected from a covered boiler under these conditions. This leaves a 12-percent unaccounted-for loss.

Tests by the Fuel Section of the U.S. Bureau of Mines[4] indicate that this loss can be partially charged to soot, tar, hydrogen, and hydrocarbons in the flue gas. They found that these losses increase with an increase in the volatile content of the coal. With anthracite as fuel, the Bureau's tests showed an average unaccounted-for loss of 5.5 percent, which for a high-grade bituminous coal increased to 24.5 percent. This trend was also indicated by the stoker tests, in which the unaccounted-for losses were a few percent greater with Iowa coals than with the out-of-state coals, but not as great as with hand firing. It is hoped that tests may be conducted in the future which will determine and isolate these losses since it was beyond the scope of the present tests to do so. The losses did occur, but the

DEPARTMENT OF MECHANICAL ENGINEERING
IOWA STATE COLLEGE
AMES, IOWA

TEST OF SMOKY HOLLOW COAL DATE 11-24-36 OBSERVERS

Intermediate coal feed: Continuous operation. Air setting 1.2:

| Time | Total Weight lb. | Condensate Scale | Condensate Reading | Condensate From Trap | Draft, Inches of water, Stack | Draft, Inches of water, Comb.C | Pressure Windbox In. of $H_2O$ | Continuous Sampling $CO_2$ | Continuous Sampling $CO_2+O_2$ | Continuous Sampling $CO_2+O_2+CO$ | Grab Sample $CO_2$ | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7:30 | 3672 | | | | | | | | | | | |
| 10:30 | 3605 | 201 | | 4.0 | 0.11 | 0.11 | 0.35 | | | | 10.5 | Watthour - 244.0 |
| 11:00 | 3593 | 258 | | | 0.11 | 0.11 | 0.33 | | | | 9.4 | Barometer - 22.88 |
| 11:30 | 3580 | 316 | | | 0.11 | 0.11 | 0.37 | 9.0 | 19.3 | 19.3 | 10.2 | @ 75° |
| 12:00 | 3570 | 385 | | | 0.11 | 0.11 | 0.38 | | | | 12.8 | |
| 12:30 | 3568 | 464 | | | 0.11 | 0.11 | 0.39 | 11.0 | 19.1 | 19.1 | 13.6 | |
| 1:30 | 3550 | 597 | | | 0.11 | 0.11 | 0.35 | 9.5 | 19.6 | 19.6 | 10.4 | |
| 2:30 | 3536 | 721 | | | 0.11 | 0.11 | 0.40 | 9.4 | 19.1 | 19.1 | 15.6 | |
| 3:30 | 3494 | 872 | 222 | | 0.11 | 0.11 | 0.35 | 11.1 | 19.2 | 19.2 | 11.3 | |
| 4:30 | 3479 | | 355 | | 0.11 | 0.11 | 0.31 | 10.4 | 18.8 | 18.8 | 11.7 | |
| 5:30 | 3451 | | 493 | | 0.11 | 0.11 | 0.25 | 12.0 | 19.2 | 19.2 | 9.2 | |
| 6:30 | 3438 | | 635 | | 0.11 | 0.11 | 0.33 | 12.4 | 19.6 | 19.6 | 12.8 | |
| 7:30 | 3400 | 197 | 767 | | 0.11 | 0.11 | 0.29 | 11.7 | 19.2 | 19.2 | 10.0 | |
| 8:00 | 3398 | 265 | | | | | | | | | | |
| 8:30 | 3390 | 310 | | | 0.11 | 0.11 | 0.27 | 11.2 | 19.8 | 19.8 | 9.0 | |
| 9:00 | 3380 | 370 | | | 0.11 | 0.11 | 0.30 | | | | | |
| 9:30 | 3363 | 425 | | 43.0 | 0.11 | 0.11 | 0.38 | 11.8 | 19.0 | 19.0 | 6.5 | Watthour - 245.8 |
| | | | | | 0.11 | 0.11 | 0.34 | 10.8 | 19.2 | 19.2 | 10.8 | |

Fig. 11.—Copy of an original data sheet.

[3] $\left(\text{Allowance for uncovered boiler}\right) = \left(\text{External boiler surface}\right)(1.8)(T_s - T_r)\left(\text{Time in hours}\right)\left(1/971.7\right)$ in which $T_s$ is the temperature of the steam within the boiler in deg. F., and $T_r$ is the room temperature.

[4] *Journal of American Society of Heating and Ventilating Engineers,* 31:89-128. February, 1925.

present test results are in no way affected by what these losses were or where they occurred.

While the tests upon which this bulletin is based were conducted with extreme care and there is no question but that the results represent what actually occurred, this does not mean that any one test could be exactly duplicated. Differences in combustion, caused by clinker formation, will bring in an unavoidable variable which is especially noticeable with Iowa coals.

## SUMMARY OF CONCLUSIONS

It is suggested that the entire discussion of results be read in order to minimize the possibility of misunderstandings, and not just the summary which follows:

1. Iowa coal will furnish the cheapest source of heat with a domestic stoker in most of the state, although in the tests it evaporated only about three-fourths as much water per pound as the out-of-state coals tested.
2. Except in the coldest weather, attention need not be given to the stoker oftener than once a day while burning most Iowa coals.
3. Satisfactory automatic operation was secured from most of the Iowa coals tested although clinkering was troublesome.
4. A larger heating plant is required for Iowa coals than for many others because of lower heating value per pound and the unevenness of combustion.
5. Tests indicated that Iowa coals were very satisfactory for holding fire.
6. Screenings furnished slightly less heat per pound than the prepared stoker coals tested, but usually burned quite satisfactorily. However, the dust in handling is usually objectionable.
7. The small stoker should not be purchased as a money-saving device, but for the satisfaction and convenience it affords.
8. The following practices will aid efficiency while burning coal in domestic stokers:
   (*a*). The air supplied should be limited until a light-gray smoke can be observed coming from the chimney.
   (*b*). The fuel bed should be at least 4 in. deep.
   (*c*). Soot, which forms readily with Iowa coal, should be removed from the heating surfaces frequently.

# APPENDIX

TABLE 3.—INDIVIDUAL TEST RESULTS FOR VARYING CONDITIONS

| Test No. | Coal No. | Fuel bed condition* | Stoker feeding rate† | Length of test, hr. | Coal burned per hr., lb. | Stoker operation, min. per hr. | Pressure drop through fuel bed, in. of $H_2O$ | Flue gas temperature,‡ deg. F. | Average $CO_2$ per cent | Equivalent evaporation per lb. of coal# | | Efficiency of stoker and boiler,° per cent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | as-fired basis, lb. | dry basis, lb. | |
| 1 | 1 | Cl. | H.S.I. | 25 | 36.9 | 60 | 1.76 | 710 | 10.1 | 5.6 | 6.5 | 56 |
| 2 | 1 | Cl. | H.S.I. | 24 | 14.5 | 16 | 1.31 | 490 | 6.9 | 5.4 | 6.4 | 54 |
| 3 | 1 | Cl. | H.S.I. | 8 | 23.0 | 34 | 1.00 | 650 | 9.7 | 6.1 | 7.0 | 58 |
| 4 | 1 | Cl. | H.S.I. | 8 | 21.5 | 35 | 0.84 | 590 | 9.5 | 6.2 | 7.2 | 60 |
| 5 | 1 | Cl. | M.S.I. | 8 | 17.7 | 37 | 0.82 | 550 | 8.0 | 5.1 | 5.9 | 49 |
| 6 | 2 | Cl. | H.S.I. | 8 | 23.4 | 41 | 1.15 | 620 | 9.0 | 5.8 | 6.8 | 55 |
| 7 | 2 | Cl. | H.S.C. | 8 | 36.5 | 60 | 1.09 | 730 | 10.8 | 6.0 | 6.9 | 58 |
| 8 | 2 | Cl. | M.S.C. | 9 | 26.0 | 60 | 0.92 | 630 | 8.3 | 5.7 | 6.5 | 55 |
| 9 | 2 | Cl. | M.S.I. | 8 | 18.1 | 37 | 0.78 | 530 | 6.8 | 5.3 | 6.1 | 52 |
| 10 | 3 | Cl. | M.S.C. | 8 | 27.5 | 60 | 0.84 | 600 | 6.8 | 4.2 | 5.1 | 51 |
| 11 | 3 | Cl. | H.S.C. | 7 | 37.4 | 60 | 1.17 | 655 | 8.2 | 4.5 | 5.3 | 54 |
| 12 | 3 | Cl. | M.S.I. | 8 | 23.0 | 51 | 0.93 | 514 | 6.4 | 4.0 | 4.8 | 48 |
| 13 | 4 | Cl. | H.S.I. | 8 | 27.1 | 43 | 1.23 | 619 | 8.7 | 5.4 | 6.4 | 54 |
| 14 | 4 | Cl. | M.S.C. | 8 | 26.8 | 60 | 1.05 | 635 | 8.8 | 5.6 | 6.6 | 56 |
| 15 | 4 | Cl. | H.S.C. | 8 | 37.6 | 60 | 1.39 | 790 | 10.3 | 5.9 | 7.0 | 59 |
| 16 | 4 | Cl. | M.S.I. | 8 | 17.2 | 39 | 0.85 | 520 | | 5.3 | 6.2 | 53 |
| 17 | 5 | Cl. | M.S.I. | 7 | 18.9 | 46 | 1.27 | 530 | 6.3 | 4.9 | 5.8 | 48 |
| 18 | 5 | Cl. | H.S.C. | 8 | 35.9 | 60 | 1.41 | 780 | 11.8 | 5.9 | 6.8 | 56 |
| 19 | 5 | Cl. | M.S.C. | 8 | 26.5 | 60 | 0.88 | 630 | 7.6 | 5.5 | 6.3 | 52 |
| 20 | 5 | Cl. | H.S.I. | 8 | 24.9 | 38 | 1.20 | 630 | 9.3 | 5.7 | 6.6 | 55 |
| 21 | 6 | Cl. | M.S.I. | 8 | 15.7 | 41 | 0.67 | 515 | 8.0 | 5.9 | 6.9 | 57 |
| 22 | 6 | Cl. | H.S.C. | 8 | 32.4 | 60 | 0.97 | 770 | 10.7 | 6.4 | 7.3 | 60 |
| 23 | 6 | Cl. | M.S.C. | 8 | 19.7 | 60 | 0.62 | 610 | 7.9 | 5.8 | 6.6 | 54 |
| 24 | 6 | Cl. | H.S.I. | 8 | 24.0 | 44 | 0.97 | 610 | 9.5 | 5.5 | 6.4 | 52 |
| 25 | 7 | Cl. | M.S.I. | 8 | 16.8 | 35 | 0.84 | 540 | 7.3 | 5.9 | 7.1 | 56 |
| 26 | 7 | Cl. | H.S.C. | 8 | 35.1 | 60 | 1.09 | 790 | 9.9 | 6.0 | 7.1 | 56 |
| 27 | 7 | Cl. | M.S.C. | 8 | 25.7 | 60 | 0.74 | 650 | 8.4 | 5.9 | 6.9 | 54 |
| 28 | 7 | Cl. | H.S.I. | 8 | 23.4 | 38 | 0.94 | 610 | 10.4 | 6.3 | 7.5 | 59 |
| 29 | 8 | Cl. | M.S.C. | 8 | 24.4 | 60 | 0.66 | 620 | 6.8 | 5.0 | 6.0 | 51 |
| 30 | 8 | Cl. | H.S.C. | 8 | 34.6 | 60 | 1.03 | 750 | 9.0 | 5.5 | 6.6 | 56 |
| 31 | 8 | Cl. | M.S.I. | 8 | 19.8 | 46 | 0.70 | 550 | 7.3 | 5.0 | 6.1 | 52 |
| 32 | 8 | Cl. | H.S.I. | 8 | 26.2 | 42 | 0.94 | 640 | 9.0 | 5.5 | 6.7 | 57 |
| 33 | 9 | Cl. | H.S.I. | 8 | 26.0 | 48 | 0.68 | 675 | 8.0 | 5.6 | 6.4 | 54 |
| 34 | 9 | L.A. | H.S.I. | 13 | 23.9 | 42 | 0.88 | 625 | 10.8 | 5.7 | 6.5 | 55 |
| 35 | 9 | L.A. | H.S.I. | 17 | 17.1 | 29 | 0.88 | 575 | 10.8 | 5.2 | 6.0 | 51 |
| 36 | 9 | L.A. | H.S.I. | 26 | 11.1 | 20 | 0.88 | 550 | 7.9 | 5.7 | 6.5 | 55 |
| 37 | 9 | L.A. | H.S.I. | 7 | 16.0 | 30 | 0.74 | 520 | 12.2 | 5.5 | 6.3 | 53 |
| 38 | 9 | L.A. | H.S.C. | 7 | 33.1 | 60 | 1.22 | 780 | 10.9 | 5.2 | 5.9 | 50 |
| 39 | 10 | L.A. | H.S.I. | 8 | 18.7 | 30 | 1.70 | 550 | 11.1 | 5.1 | 6.1 | 53 |
| 40 | 11 | Cl. | H.S.I. | 7 | 22.3 | 40 | 0.48 | 670 | 11.4 | 6.8 | 7.9 | 64 |

**Cl.*—Indicates the ash and clinker had all been cleaned from hearth prior to start of test.

*L.A.*—Indicates that only the clinker had been removed, the loose ash remaining on the hearth at start of test.

†*H.*—high; *S.*—speed; *M.*—middle; *C.*—continuous; *I.*—intermittent.

‡Temperature of gas at boiler exit.

#One pound of equivalent evaporation represents 970 B.t.u.

°Boiler and stoker efficiency is the ratio of the heat transferred to the water in the boiler to the thermal value of the fuel fired.

TABLE 3 (*Continued*).—INDIVIDUAL TEST RESULTS FOR VARYING CONDITIONS

| Test No. | Coal No. | Fuel bed condition* | Stoker feeding rate† | Length of test, hr. | Coal burned per hr., lb. | Stoker operation, min. per hr. | *Pressure drop through fuel bed, in. of $H_2O$ | Flue gas temperature,‡ deg. F. | Average $CO_2$ percent | Equivalent evaporation per lb. of coal# as-fired basis, lb. | dry basis, lb. | Efficiency of stoker and boiler,° percent |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 41 | 11 | Cl. | H.S.I. | 7 | 21.9 | 40 | 0.49 | 670 | 11.8 | 6.7 | 7.7 | 63 |
| 42 | 12 | L.A. | H.S.I. | 130 | 4.1 | 9 | | | | 5.6 | 6.5 | 53 |
| 43 | 12 | L.A. | H.S.I. | 11 | 15.5 | 30 | 0.84 | 645 | 10.0 | 6.8 | 7.6 | 60 |
| 44 | 12 | L.A. | H.S.I. | 23 | 10.6 | 19 | 0.65 | 520 | 9.0 | 6.5 | 7.1 | 56 |
| 45 | 12 | L.A. | H.S.I. | 7 | 24.4 | 44 | 0.99 | 700 | 10.0 | 6.2 | 6.9 | 54 |
| 46 | 12 | L.A. | H.S.C. | 5 | 30.4 | 60 | 0.62 | 790 | 13.0 | 6.7 | 7.3 | 58 |
| 47 | 13 | Cl. | H.S.I. | 7 | 20.7 | 41 | 0.57 | 720 | 11.0 | 7.2 | 8.0 | 65 |
| 48 | 14 | Cl. | H.S.I. | 7 | 17.7 | 30 | 0.53 | 670 | 12.4 | 8.4 | 8.9 | 67 |
| 49 | 14 | L.A. | H.S.I. | 7 | 26.0 | 44 | 0.82 | 825 | 14.2 | 8.1 | 8.5 | 65 |
| 50 | 14 | L.A. | H.S.I. | 12 | 10.5 | 19 | 0.60 | 520 | 11.3 | 7.9 | 8.4 | 63 |
| 51 | 14 | L.A. | H.S.C. | 5 | 30.0 | 60 | 0.83 | 875 | 13.7 | 8.2 | 8.7 | 66 |
| 52 | 15 | Cl. | H.S.I. | 8 | 18.8 | 34 | 0.47 | 690 | 12.6 | 7.8 | 8.7 | 64 |
| 53 | 15 | L.A. | H.S.I. | 7 | 26.0 | 46 | 0.58 | 795 | 14.0 | 7.9 | 8.8 | 65 |
| 54 | 15 | L.A. | H.S.C. | 5.5 | 33.1 | 60 | 0.69 | 900 | 14.8 | 8.0 | 9.0 | 66 |
| 55 | 15 | L.A. | H.S.I. | 12 | 11.4 | 19 | 0.52 | 500 | 13.7 | 8.1 | 9.0 | 66 |
| 56 | 15 | L.A. | H.S.I. | 24 | 4.9 | 8 | | 375 | | 7.5 | 8.4 | 61 |
| 57 | 15 | L.A. | H.S.I. | 10 | 18.4 | 30 | 0.47 | 660 | 14.9 | 7.9 | 8.8 | 65 |
| 58 | 16 | Cl. | H.S.I. | 8 | 16.5 | 30 | 0.38 | 625 | 13.8 | 9.3 | 9.8 | 71 |
| 59 | 16 | L.A. | H.S.I. | 6 | 26.1 | 46 | 0.58 | 785 | 14.9 | 8.3 | 8.8 | 63 |
| 60 | 16 | L.A. | H.S.C. | 5 | 37.0 | 60 | 0.81 | 800 | 14.0 | 7.4 | 7.9 | 57 |
| 61 | 16 | L.A. | H.S.I. | 13 | 10.6 | 19 | 0.46 | 525 | 13.1 | 8.5 | 9.1 | 65 |
| 62 | 16 | L.A. | H.S.I. | 33 | 5.7 | 8 | | 390 | | 7.6 | 8.0 | 58 |
| 63 | 16 | L.A. | H.S.I. | 10 | 17.4 | 30 | 0.70 | 610 | 15.0 | 8.2 | 8.6 | 62 |
| 64 | 17 | Cl. | H.S.I. | 9 | 17.7 | 34 | 0.42 | 690 | 13.5 | 8.4 | 9.0 | 69 |
| 65 | 17 | L.A. | H.S.I. | 7 | 25.4 | 46 | 0.79 | 725 | 15.0 | 7.7 | 8.1 | 62 |
| 66 | 17 | L.A. | H.S.C. | 5 | 30.7 | 60 | 0.94 | 800 | 14.6 | 7.8 | 8.2 | 63 |
| 67 | 17 | L.A. | H.S.I. | 12 | 11.0 | 19 | 0.52 | 520 | 11.8 | 8.2 | 8.6 | 66 |
| 68 | 17 | L.A. | H.S.I. | 24 | 4.9 | 8 | | 350 | | 6.7 | 7.1 | 54 |
| 69 | 17 | L.A. | H.S.I. | 9.5 | 17.7 | 30 | 0.79 | 650 | 14.7 | 8.2 | 8.7 | 67 |
| 70 | 18 | Cl. | H.S.I. | 8 | 26.7 | 52 | 0.49 | 730 | 9.2 | 5.5 | 6.5 | 55 |
| 71 | 18 | L.A. | H.S.I. | 11 | 26.1 | 48 | 0.68 | 700 | 11.1 | 5.8 | 6.6 | 56 |
| 72 | 19 | Cl. | H.S.I. | 8 | 26.4 | 45 | 0.69 | 710 | 12.5 | 5.8 | 6.8 | 54 |
| 73 | 19 | L.A. | H.S.I. | 8 | 23.0 | 40 | | | | 6.2 | 7.3 | 58 |
| 74 | 19 | L.A. | H.S.I. | 8 | 23.3 | 45 | 0.71 | 620 | 13.7 | 6.1 | 7.1 | 56 |
| 75 | 20 | Cl. | H.S.I. | 8 | 22.7 | 44 | 0.76 | 635 | 11.0 | 6.3 | 7.1 | 62 |
| 76 | 20 | L.A. | H.S.I. | 6 | 23.5 | 44 | 0.81 | 700 | 10.8 | 6.5 | 7.2 | 63 |
| 77 | 20 | L.A. | H.S.I. | 10 | 14.4 | 29 | 0.80 | 530 | 9.2 | 5.8 | 6.4 | 56 |
| 78 | 20 | L.A. | H.S.I. | 7 | 14.6 | 30 | 0.82 | 525 | 6.7 | 5.9 | 6.6 | 57 |
| 79 | 21 | Cl. | H.S.I. | 7 | 25.6 | 46 | 0.63 | 680 | 13.4 | 6.4 | 7.5 | 59 |
| 80 | 21 | L.A. | H.S.I. | 6 | 23.9 | 44 | 0.47 | 660 | 12.9 | 7.1 | 8.2 | 65 |
| 81 | 21 | L.A. | H.S.I. | 6 | 23.2 | 44 | 0.53 | 640 | 12.7 | 6.8 | 8.1 | 64 |
| 82 | 21 | Cl. | M.S.C. | 11 | 24.8 | 60 | 0.45 | 710 | 10.8 | 6.6 | 7.7 | 59 |

**Cl.*—Indicates the ash and clinker had all been cleaned from hearth prior to start of test.

*L.A.*—Indicates that only the clinker had been removed, the loose ash remaining on the hearth at start of test.

†*H.*—high; *S.*—speed; *M.*—middle; *C.*—continuous; *I.*—intermittent.

‡Temperature of gas at boiler exit.

#One pound of equivalent evaporation represents 970 B.t.u.

°Boiler and stoker efficiency is the ratio of the heat transferred to the water in the boiler to the thermal value of the fuel fired.

TABLE 4.—SIZE OF COAL AS FIRED

| Test No. | Popular name of coal | Percent of total weight | | | |
|---|---|---|---|---|---|
| | | 0 to ¼ in. | ¼ to ½ in. | ½ to 1 in. | 1 to 1½ in. |
| 1 | Scandia Screenings | 41 | 33 | 26 | 0 |
| 2 | Scandia Screenings | 13 | 11 | 41 | 35 |
| 3–5 | Scandia Screenings | 34 | 28 | 38 | 0 |
| 6–9 | Smoky Hollow Screenings | 35 | 27 | 33 | 5 |
| 10–12 | Boone Screenings | 18 | 21 | 44 | 17 |
| 13–16 | Pershing Screenings | 23 | 16 | 33 | 28 |
| 17–20 | Shuler Screenings | 21 | 14 | 33 | 32 |
| 21–24 | Norwood White Screenings | 19 | 15 | 34 | 32 |
| 25–28 | McConville Crushed Mine Run | 15 | 25 | 35 | 25 |
| 29–32 | New Market Crushed Mine Run | 15 | 13 | 27 | 45 |
| 33–38 | Scandia Nut | 0 | 17 | 82 | 1 |
| 39 | Scandia Screenings | 57 | 21 | 21 | 1 |
| 40 | Smoky Hollow Special Nut | 1 | 11 | 88 | 0 |
| 41 | Smoky Hollow Special Nut | 9 | 25 | 56 | 10 |
| 42–46 | Smoky Hollow Special Nut | 1 | 12 | 65 | 22 |
| 47 | Smoky Hollow Screenings | 20 | 18 | 41 | 21 |
| 48–51 | Southern Illinois Stoker | 7 | 9 | 47 | 37 |
| 52–57 | Glendora Indiana Stoker | 18 | 20 | 35 | 27 |
| 58–63 | Dawson Daylight Kentucky Stoker | 27 | 16 | 41 | 16 |
| 64–69 | Southern Illinois Stoker | 32 | 34 | 34 | 0 |
| 70–71 | Des Moines Ice & Fuel Oiled Stoker | 9 | 28 | 51 | 12 |
| 72–74 | Helsing Strip Crushed Mine Run | 29 | 19 | 33 | 19 |
| 75–78 | Ellis Stoker | 10 | 23 | 58 | 9 |
| 79–81 | Smoky Hollow Stoker | 22 | 30 | 48 | 0 |
| 82 | Smoky Hollow Screenings | 14 | 11 | 32 | 43 |

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