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BULLETIN NO. 39

TESTS OF WASHED GRADES OF ILLINOIS COAL

BY

C. S. McGOVNEY

UNIVERSITY OF ILLINOIS
ENGINEERING EXPERIMENT STATION

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ENGINEERING EXPERIMENT STATION

BULLETIN NO. 39 AUGUST 1909

TESTS OF WASHED GRADES OF ILLINOIS COAL

BY C. S. MCGOVNEY, FORMERLY ASSISTANT IN THE ENGINEERING EXPERIMENT STATION, IN CHARGE OF FUEL TESTS

CONTENTS

A NOTE OF ACKNOWLEDGMENT

A few years ago, Professor L. P. Breckenridge, while Director of the Engineering Experiment Station, outlined an elaborate series of fuel tests to be undertaken by the Station. In the development of his plans, he invited the cooperation of several distinguished engineers, and to them special acknowledgment is made for many helpful suggestions and criticisms. Those who contributed to the work constituted a Fuel Test Conference Committee, the members of which were Messrs. W. L. Abbott, representing the Board of Trustees, University of Illinois; H. Foster Bain, representing the State Geological Survey; A. Bement, representing the Western Society of Engineers; E. H. Cheney, representing the Building Managers' Association of Chicago; F. H. Clark, representing the Western Railway Club; A Mueller, representing the Illinois Manufacturers' Association; Carl Scholz, representing the Illinois Coal Operators' Association; and A. V. Schroeder, representing the State Electric Light Association. Dr. Bain also gave attention to the selection of the various samples of coal tested. The necessary chemical work was carried on under the direction of Professor S. W. Parr. Material assistance was also rendered by the Technologic Branch of the United States Geological Survey, as represented by its chief, Mr. J. A. Holmes. The author, Mr. C. S. McGovney, acting under the general direction of Professor Breckenridge, has been responsible for the immediate charge and direct supervision of the work.

The work of testing, which proceeded under these plans, has been advanced by methods involving the utmost care, and with results, which, in part, are presented by this bulletin. While the present publication is complete in the sense that it constitutes a final presentation of data covering a definite field, it is to be accepted as a report of a particular phase of the work, rather than as a complete definition of the plans of the Fuel Test Committee.

W. F. M. G.

Engineering Experiment Station
University of Illinois
February, 1910

I. Introduction

1. During the years 1906 and 1907, the Engineering Experiment Station conducted a series of steam boiler trials as part of an investigation of the fuel value of certain Illinois coals. The results of these tests and a discussion of their significance will be found in the following pages. The data apply specifically to a Heine 210 horse-power water-tube boiler, set singly, and served with a 54-in. Green traveling link grate operated under induced draft pressure. A description of this plant will be found in Appendix I.

2. *Object of the Tests.*—This study has for its primary object the comparison of various grades of Illinois washed coal. With this in view, the tests were planned to facilitate comparisons with respect to the following points:

(*a*) Determination of the relation of grade of coal to the economy of evaporation and horse-power obtainable.

(*b*) Determination of the effect of varying rates of combustion upon the economy with various grades.

(*c*) Effect of different depths of fuel beds.

(*d*) Study of the fuel bed, draft and draft pressure requirements for each grade.

3. *Development of Methods.*—In experimental furnace work, the difficulty of controlling variables and measuring quantities depends in some degree upon the peculiarities of the furnace and the object of the experimental work. In the present work it has been the aim to pursue such methods and to keep such records of furnace events as will permit comparisons with future experimental work with the particular plant used. Details of these methods and records have been described at proper places in the report and care has been taken to point out irregularities that have occurred. Those methods toward which special study has been directed and which are perhaps of interest aside from their bearing upon the general results contained herein are:

(*a*) Method of sampling flue gases, see page 88.

(*b*) System for recording furnace observations and the details of furnace control in fuel tests with the chain grate stoker, see page 92.

II. The Coal Used

4. *The Coal* used was selected wholly on account of the sizes represented and not for the purpose of comparing coals from various seams or mines in the State. Direct transportation facilities also influenced the selection because of limited storage capacity at the University.

Coal from washing plants in two districts was selected. That from Vermilion county is believed to be characteristic of the washed coal from the seam mined. Coal from this locality has been widely known as "Grape Creek" coal. The coal from Williamson county, including both washed and unwashed coal, is representative of the coal mined from Seam No. 7 in that and adjoining counties.

The stratigraphy of the seam mined in Vermilion county has been questioned for various technical reasons. The same seam characteristics as are found in Seam No. 7 mined in Williamson, Franklin and Jackson counties are, however, present, although the chemical properties of coals from the two seams show sharp differentiations.

5. *The Washing* plants now in operation in the State number about forty. With few exceptions round-hole revolving screens are used, but the size of coal prepared by these varies. By agreement, in 1903, the operators in Williamson county adopted the following standard of sizes for washed coal. The numbers used refer to screens with round perforations.

Designation	Through	Over
No. 1	3 in.	1¾ in.
No. 2	1¾ in.	1 in.
No. 3	1 in.	¾ in.
No. 4	¾ in.	¼ in.
No. 5	¼ in.	....

This gradation has been, in the main, adopted, although several of the mines in that county are also supplying intermediate sizes to meet special market demands. Of the total number of washeries in the State, fifteen are supplying these sizes. Other grades of washed coal prepared by one or more plants are between screens of the following perforations:

Perforations inches						Screens
2	1	½	0	....	....	Round hole
1¼	¾	0	...	....	....	Round hole
3	1½	⅞	⅜	0	....	Round hole
3	1⅛	¾	0	....	....	Square hole
3	1¾	1¼	¼	0	....	Round hole
2½	1½	¼	...	....	....	Round hole. Size below ¼ discarded.
1¼	0	...	...	....	....	Washed screenings
3	1¾	1	½	¼	0	Round hole
3	1¾	1	¾	5-16	⅛	Round hole
3	1¾	1	¾	5-16	0	Round hole
1¼	¾	0	...	....	....	Bar screen

6. The tables given below show the character and grade of the coal selected for the experiments.

Table 1 gives the size and description of the coal. The screens in use at each of the mines are rotary screens with round perforations. The fuel symbol, column 2, in this and the tables following, is a convenient index number, adopted to facilitate the keeping of records at the testing plant. The integral number is the mine index while the remainder of the symbol refers to the size and condition of the coal. For example in the number 4.0703, 4 is the mine number. The remainder of the number gives the

TABLE 1 DESCRIPTION OF COAL

No.	Fuel Symbol	Commercial Name	Size of Screen	Condition	Kind of Washer	Location of Mine: Town	Location of Mine: County	Coal Seam
1	2	3	4	5	6	7	8	9
1	4.0703W	Washed Pea.	⅞-⅜	Washed	New Century	Westville	Vermilion	6
2	4.0703W	"	"	"	"	"	"	6
3	4.0700W	W.Pea & Duff	⅞-0	"	"	"	"	6
4	4.0300W	Washed Duff.	⅜-0	"	"	"	"	6
5	5.1610W	No. 2 washed	1¾-1	"	Stewart	Herrin	Williamson	7
6	5.1006W	No. 3 "	1-¾	"	"	"	"	7
7	5.0602W	No. 4 "	¾-¼	"	"	"	"	7
8	5.0200W	No. 5 "	¼-0	"	"	"	"	7
9	6.0402W	No. 4 "	½-¼	"	Stewart	Marion	"	7
10	6.0200W	No. 5 "	¼-0	"	"	"	"	7
11	7.1610—	No. 2 Nut....	1¾-1	Unwashed	....	Herrin	"	7

size of the screens used in preparing the coal. The number is given in the octonal system, e. g., 1.6 to 1.0, written for convenience .1610, indicates that the size is between 1$\frac{6}{8}$ in. and 1 in; .0703 indicates that the size is between $\frac{7}{8}$ in. and $\frac{3}{8}$ in.; .1006 that the size is between 1 in. and $\frac{6}{8}$ in., etc. Suffixed to these numbers W indicates washed coal and the dash —, unwashed coal. In Table 1, columns 4, 5, 7 and 8 define the meaning of the fuel symbols for every coal tested.

Table 2 gives the results of analyses of composite samples made up from the samples taken during the progress of the tests. The method of preparing these composite samples is explained on page 119. Sampling at the mine in view of the nature of the experiments was not considered necessary. None of the coal was stored for a greater period than six weeks after receipt so that except for changes in moisture content the analyses of the compos-

TABLE 2 AVERAGE COMPOSITION AND CALORIFIC VALUE OF THE COAL AS FIRED

Analyses of Composite Samples														
				Coal as Fired										
				Proximate Analyses										
						Ultimate Analyses								
No.	Coal Symbol	Chem. Lab. No.	Moisture on Air Drying	Fixed Carbon	Volatile Matter	Total Moisture	Ash	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Calorific Value per pound
1	2	3	4	32.2	33.2	34.2	35.2	37.2	38.2	39.2	40.2	41.2	
			%	%	%	%	%	%	%	%	%	%	B.t.u.
1	4.0703W	608	14.46	41.45	32.10	18.97	7.48	58.72	3.90	8.36	0.98	1.59	10385
2	4.0703W	253	13.10	41.35	32.36	18.03	8.26	59.28	3.82	7.85	1.00	1.76	10534
3	4.0700W	302	14.55	39.30	32.90	18.78	9.02	57.22	3.75	8.55	0.98	1 70	10381
4	4.0300W	600	17.43	36.49	28.73	22.00	12.78	52.05	3.42	6.60	1.11	2.04	9154
5	5.1610W	502	6.04	50.44	31.72	9.60	8.24	66.62	4.53	8.57	1.17	1.27	11843
6	5.1006W	571	4.74	51.18	30.76	9.27	8.79	66.49	4.19	8.86	1.24	1.16	11795
7	5.0602W	273	7.77	48.50	30.18	12.14	9.18	64.62	4.11	7.54	1.16	1.25	11432
8	5.0200W	303	11.62	43.26	28.89	15.69	12.16	58.81	3.66	7.42	1.08	1.18	10398
9	6.0402W	304	7.16	49.50	32.44	10.69	7.37	66.97	4.28	8.13	1.20	1.36	11983
10	6.0200W	587	13.89	44.20	26.62	18.17	11.01	57.00	3.56	7.58	1.23	1.45	10010
11	7.1610—	519	2.83	50.82	32.24	7.45	9.49	66.78	4.30	8.59	1.25	2.14	12012

ite samples fairly represent the coal as delivered. Comparison of the amount of adhering moisture carried by washed coal can be justly made only by taking into account the lengths of haul in transportation, conditions of weather and the time since loading; so in this respect, only qualitative deductions should be drawn from the figures given for total moistures. Coal from the mine, Index No. 4, was usually delivered on the following day after washing and was loaded directly from the car into the boiler room. The coal from each of the other mines was several days in transit and was unloaded into roofed storage sheds. Test samples only were taken. The coal, 5.1006W remained in storage about six weeks before it was sampled.

Table 3 gives the results of analyses for the air-dry sample. These are original figures reported by the chemical laboratory. It is interesting to note that there is but small dif-

TABLE 3 Average Composition and Calorific Value of the Air-Dry Coal

Analyses of Composite Samples												
			Air-Dry Samples									
			Proximate Analyses									
					Ultimate Analyses							
No.	Coal Symbol	Chem. Lab. No.	Fixed Carbon	Volatile Matter	Moisture	Ash	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Calorific Value per pound
1	2	3	4	5	6	7	8	9	10	11	12	13
			%	%	%	%	%	%	%	%	%	B.t.u.
1	4.0703W	608	48.45	37.53	5.27	8.75	68.65	4.56	9.77	1.14	1.86	12141
2	4.0703W	253	47.58	37.24	5.67	9.51	68.22	4.40	9.03	1.15	2.02	12122
3	4.0700W	302	45.99	38.50	4.95	10.56	66.95	4.39	10.01	1.15	1.99	12149
4	4.0300W	600	44.19	34.80	5.53	15.48	63.05	4.14	7.99	1.34	2.47	11086
5	5.1610W	502	53.68	33.76	3.79	8.77	70.90	4.82	9.12	1.25	1.35	12604
6	5.1006W	571	53.72	32.29	4.76	9 23	69.79	4.40	9.30	1.30	1.22	12381
7	5.0602W	273	52.59	32.72	4.74	9.95	70.06	4.46	8.18	1.26	1.35	12395
8	5.0200W	303	48.94	32.69	4.61	13.76	66.55	4.14	8.39	1.22	1.33	11765
9	6.0402W	304	53.32	34.94	3.80	7.94	72.13	4.61	8.76	1.29	1.47	12907
10	6.0200W	587	51.83	30.91	4.97	12.79	66.20	4.13	8.80	1.43	1.68	11625
11	7.1610—	519	52.30	33.18	4.75	9.77	68.72	4.43	8.84	1.29	2.20	12362

ference in the amount of absorbed moisture in the different coals after air drying. The method of air drying is explained on page 101.

Table 4 gives a better comparison of the characteristic differences in composition of the fuel from the two localities represented. For analyses and heating values used in the calculation of the test results, see Tables 37 and 38, Appendix III.

TABLE 4 AVERAGE COMPOSITION AND CALORIFIC VALUE OF THE ASH AND MOISTURE-FREE COAL

			Analyses of Composite Samples							
			Pure Coal (Ash and Moisture-Free Coal)							
			Prox. Analyses		Ultimate Analyses					
No.	Coal Symbol	Chem. Lab. No.	Fixed Carbon	Volatile Matter	Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Calorific Value per pound
			%	%	%	%	%	%	%	B.t.u.
1	4.0703W	608	56.35	43.65	79.85	5.30	11.36	1.33	2.16	14121
2	4.0703W	253	56.10	43.90	80.42	5.19	10.65	1.36	2.38	14291
3	4.0700W	302	54.43	45.57	79.24	5.20	11.85	1.36	2.35	14380
4	4.0300W	600	55.94	44.46	79.81	5.24	10.12	1.70	3.13	14035
5	5.1610W	502	61.39	38.61	81.09	5.51	10.43	1.43	1.54	14416
6	5.1006W	571	62.46	37.54	81.14	5.12	10.81	1.51	1.42	14395
7	5.0602W	273	61.65	38.35	82.12	5.23	9.59	1.48	1.58	14529
8	5.0200W	303	59.95	40.05	81.53	5.07	10.28	1.50	1.62	14412
9	6.0402W	304	60.41	39.59	81.72	5.22	9.93	1.46	1.67	14622
10	6.0200W	587	62.41	37.59	80.50	5.02	10.70	1.74	2.04	14135
11	7.1610—	519	61.18	38.82	80.40	5.18	10.34	1.51	2.57	14462

III. SUMMARY OF RESULTS AND CONCLUSIONS

7. *The conclusions* herewith presented are based on 58 trials with washed coal and 6 trials of No. 2 unwashed coal.

The grades tested were regular commercial grades purchased at the mine, and with one exception, in which a mixture of two grades was tested, were of sizes representing common standards. Tests of eight standard grades covering a full range of sizes suitable for burning upon the chain grate are included.

Much of the work has necessarily been of preliminary character, but an endeavor has been made to obtain as general a survey of the facts relating to the use of washed grades in connection with the chain grate stoker as was possible with the time and funds available. In making an analysis of the work, particular emphasis has been placed upon the modifying influence of methods of furnace control, the variations in the results due to radiation and conduction losses from the furnace and boiler, and the factors that influence the relative values of the fuels. Data not directly applied to the analyses made are presented in Appendix III.

It is shown in the analysis that results of tests direct with steam boilers may be only roughly compared, and that if close comparison of evaporative results is to be made, the amount of radiation and conduction losses must be known and corresponding corrections applied.

8. Concerning the principal points investigated, the following general conclusions may be drawn:

1. A comparison of fuels burned upon the chain grate is possible only when the fuel beds are kept in uniform condition. Irregularities that may occur in the fuel bed, whether induced by characteristics of the fuel or otherwise, may cause variations in the evaporative results for the same grade, which are wider than occur between any grades above the size ⅜ in. to 0, when those grades are burned with the best care and attention.

2. Under the best care of the fuel bed (horse-power, depth of fuel bed, and other imposed conditions being equal), representative grades show the following relative economic values, based upon ash and moisture free coal:

Laboratory File No.	Size inches	Relative Total Heat Values	Relative Practical Heat Values	Relative Economy
5.1610 W	1¾ to 1	1.021	1.036	0.981
7.1610 —	1¾ to 1	1.020	1.038	0.994
5.1006 W	1 to ¾	1.022	1.036	1.039
4.0703 W	⅞ to ⅜	1.000	1 000	1.000
4.0300 W	⅜ to 0	0.984	.983	0.778
6.0200 W	¼ to 0	1.000	1,004	0.813

The ratios shown are taken with respect to the results for fuel 4.0703 W, and economy values are compensated for radiation and conduction losses from the furnace and boiler.

The ratios for the economy include the variations due to size, unequal practical heat value, and ash-pit loss.

The sizes used represent the range of sizes that are practicable for the chain grate stoker. The widest variation in economy shown is that between fuel 5.1006W and fuel 4.0300W, approximately 26 per cent with a variation of 3.8 per cent in the total heat values, and a variation of 5.3 per cent in the practical heat values.

It should be noted that the ratios for relative economy represent only one factor in the money value of the grades. Large sizes, it is known, have better shipping and storing qualities and are suitable for a wide variety of uses. Very fine sizes, on the other hand, require greatest attention in burning and increase the stand-by losses and fixed charges of the plant.

3. The effect of size, *per se*, upon resulting economy and thermal efficiency, i. e., apart from variation induced by differences in initial heat values and losses of heat, is characteristically shown by the quantities of air accompanying combustion. The weight of air per pound of combustible consumed and the percentage of excess air for the several fuels, taking for comparison the same conditions and tests as are used in the comparison (2) above, are as follows:

Index No.	Size inches	Pounds of Air per pound of Combustible Consumed	Excess Air percent
5.1610 W	1¾ to 1	21.05	81.76
7.1610 —	1¾ to 1	21.18	79.29
5.1006 W	1 to ¾	17.93	51.81
4.0703 W	⅞ to ⅜	17.30	54.34
4.0300 W	⅜ to 0	28.05	135.87
6.0200 W	¼ to 0	31.56	169.47

The fact that the order of the values for "Excess air, per cent" is slightly different from the order of the quantities in column 3, is due to a slight difference in the chemical compositions and theoretical air requirements of the combustibles consumed.

These values represent a combined characteristic of the size and grade under conditions of operation that maintained the fuel beds of the same area and gave to each fuel the attention that seemed necessary to produce best economic results. The excess air for all grades may be further reduced by banking the fuel at the back of the grate, but as that condition jeopardizes economy through increased loss of fuel in the ash and refuse, it was not attempted.

4. Any rate of combustion or horse-power desirable for stationary practice may be obtained with any of the standard grades tested above the sizes $\frac{3}{8}$ in. to 0.

With the sizes $\frac{3}{8}$ in. to 0 and $\frac{1}{4}$ in to 0, the boiler rating was obtained approximately, as a maximum result. With one shipment of the grade $\frac{1}{4}$ in. to 0, 175 H. P. was obtained as a maximum. For these small sizes increasing the draft would not further increase capacity. Careful attendance in burning fine sizes pays a big premium.

5. Comparisons of rates of combustion or horse-power for different fuels should be made on the basis of equal rates of air supply. Comparisons in that manner are shown on page 65.

6. For sizes above $\frac{3}{8}$ in. to 0, a slight tendency toward increased excess of air with increased rate of combustion is indicated, though no systematic relation is shown.

The thermal efficiency decreases slightly with increased rate and apparently in a linear relation. The horse-power is approximately proportional to the rate of combustion. Various grades differ in this respect, according to the proportion of excess air accompanying combustion.

The fine sizes produce their best results generally at their maximum rate of combustion. The size $\frac{3}{8}$ to 0 (fuel 4.0300W) is superior in this respect to the size $\frac{1}{4}$ to 0 (fuels 5.0200W and 6.0200W).

7. Increasing the thickness of the fuel bed results in a decrease in the loss of fuel in the ash and refuse. In some cases there results also a slight decrease in excess air, but in other cases a slight increase results. No definite relation depending upon the size of the grade is shown in the latter respect.

The maximum difference shown in over-all efficiencies due to carrying different thicknesses of fuel bed is approximately 2 per cent for gate openings varying from 4 to 7 in.

IV. General Considerations and Definitions

9. In the analysis of the performance of steam generators it is sometimes thought to be useful to define in some detail, the functions of the separate parts of the generator, such as the grate, the combustion space, the boiler, etc. The boiler is easily differentiated from the other parts of the steam generator, but to ascribe a definite division of duties to the furnace parts involves arbitrary assumptions and definitions. Consequently, terms vary in meaning in the literature of the subject and depend upon the view point of the writer. For the purposes of the present work, it will be necessary to make only one division, i. e., the boiler and the furnace and to define them as follows:

10. The *Boiler* is a definite arrangement of heating surfaces including any fixed arrangement of gas baffles that may be used for the purpose of directing the course of the heated gases over the heating surfaces.

The *Furnace* includes the combustion space, the grate or mechanical stoker, incidental brick work and enclosing walls.

Certain parts of the furnace, arches in particular, are essential for the ignition and proper combustion of the fuel in mechanical stokers and, in general, the form of the brick parts is determined by the stoker or the grate. The tile roof of the Heine combustion chamber is a feature of the boiler and also a feature of the furnace.

11. A division according to function is not so simple. The sole function of the boiler is to absorb heat, and with clean heating surfaces its characteristics are definite. In order that the heat in the coal may be actually available for transmission to the boiler, it must be developed and transferred in gases, or by radiation from the fuel bed and flames, at temperatures above that of the heating surfaces. Since a considerable part of the heat is always contained in the gases below the temperature of the heating surface, the economy of the process increases as the heat contained in the gases above the temperature of the heating surface increases. The available heat in the gases at any given temperature is, of course, only the heat that is used to increase the temperature of the gases, i. e., the so-called sensible

heat. However as the gases are cooled in their passage over the boiler surfaces, the part of the heat that was used in doing the work of expanding the gases in the furnace is directly used by the boiler. For lack of a more definite term, the term heat content used in the following discussion is taken to include both the sensible heat and the heat required for the work of expansion. The heat content is proportional to the temperature of the gases and the mean specific heat at constant pressure. Denoting by Q the heat content of one pound of the gases we have, therefore,

$$Q = CpT.$$

The gases are the principal means of conveying heat to the boiler, when the furnace is of the kind used in this work, but where much heat reaches the surfaces by direct radiation, as in plain tubular, locomotive, and internally fired boilers, the problem is much complicated. It is intended, however, to deal here with a single type of plant in which there is reason to believe that but a small proportion of the total heat reaches the heating surface by direct radiation, i. e., by transmission through the tile roof. However, whether the process of heat transfer from the fuel to the boiler is by conduction from gases alone or is a mixed process, it is nevertheless true that economy in the utilization of the heat from the coal increases as the sensible heat content of one pound of gas increases.

12. *Furnace Effect.*—For brevity, and significance as well, the "heat content of one pound of the gases" delivered to the boiler will be termed the *furnace effect.* The factors that operate to modify the furnace effect are:

1. Total heat value of the coal.
2. Latent heat in the moisture formed by the burning of the hydrogen in the coal.
3. Latent heat in the moisture evaporated from the coal.
4. Undeveloped heat in smoke and incompletely burned furnace gases.
5. Proportion of air supplied to fuel consumed.
6. Radiation and conduction from the furnace parts.
7. Loss of heat in hot ash and refuse.

The first, second, and third factors determine the quantity of heat from the coal that will be available for producing rise of temperature. The total heat value of a coal as determined by means of the combustion bomb calorimeter is the heat that would be available by cooling the combustion gases to the temperature at which the combustion was initiated, i. e., room temperature—usually about 70° F. Thus the heat that becomes latent in furnace processes is included in the reported total heat value of the coal.

The total heat minus the latent heat of the moisture is usually termed the *practical heat value* of the coal. It may be calculated as follows:

Let H = the total heat value, B. t. u. per lb.

m_1 = the moisture in the coal by weight per lb. of coal.

m_2 = the moisture formed in the burning of the hydrogen by weight per lb. of coal.

Then Practical heat value $= H - 966\ (m_1 - m_2)$

Ash and moisture in coal are extremely variable and may be considered extraneous and as adding nothing of value. They are properly considered as diluents in considering heat values and may thus readily be taken account of in the purchase of coal. Because of the variability of ash and moisture content and the ready manner in which they may be accounted for by simple analysis, comparison of the practical effects of different types of coals is most satisfactorily based upon the unit of "combustible", i. e., ash and moisture free coal. This unit is termed by some writers "pure coal"; the usual designation combustible as used in the A. S. M. E. code is adhered to herein.

To give a rough idea of the variation in the furnace effect due to differences in practical heat values per unit of combustible, consider two Illinois coals having heat values of 13950 and 13500 B. t. u. respectively, and assume an air supply of 14 pounds per pound of combustible. Thus approximately 15 pounds of gas is formed and neglecting radiation and conduction losses, etc., the furnace effects are 930 and 901 B. t. u., respectively.

The quantity of air used, however, may vary between 14 lb. and 40 lb., giving with the latter quantity furnace effects of 340 and 330 respectively, for the two combustibles. In bad furnace operation as much as 50 pounds or more of air used per unit of combustible is not infrequently found. This illustration has been given to show the relative influences of the fifth factor given above and of the heat values of coals.

The effect of a higher heat value in coal must, of course, be a beneficial one, but the evaporative effect obtained in actual operation at times due to conditions that cause disproportion of the air supply may indicate even the reverse. The decrease in the furnace effect due to radiation and conduction from the furnace varies with the area of the exposed wall surface of the setting, the temperature within the furnace, specific conductivity of the walls, temperature of the surroundings, and drafts of air through the boiler room. Its real value in any instance has never been directly determined.

The fourth and fifth factors, it is well understood, can be modified either in the direction of good effect or of bad effect by the features of the furnace, the fuel, and the manner of operating the furnace. The importance of the proper proportion of the air supply has been indicated. The proportion of air to fuel consumed is affected by care or indifference in operating, mechanical conditions of the fuel, and leakage around the edges of the grate. These same conditions play an important part in determining the amount of smoke and incompletely burned furnace gases. The construction of the grate or mechanical stoker and the combustion space are important elements in determining the latter factor. Conditions affecting air proportion, smoke and incomplete combustion vary from those of poorly constructed and poorly operated hand-stoked furnaces and mechanically-stoked furnaces to excellent construction and operation in both, but whether a hand-stoked furnace or a mechanically-stoked one, the personal factor of the operation does not lose its importance.

The seventh factor may be disposed of as negligible for practical purposes.

This involved condition of affairs makes it impossible to assign the function of producing good furnace effect to any one element alone, or, on the other hand, to assign to any single element a function not involved in the function of other elements.

13. *Service Value of a Fuel.*—In view of the involved nature of the influences just noted, it will easily be understood why the application of the results obtained in evaporative tests of fuels is restricted in application to the particular types and combination of boiler and furnace in connection with which the tests were made, and further are especially restricted by the particular conditions of the furnace control.

For the purpose of comparing the economy of fuels, the heat absorbed by the boiler per pound of fuel should be based upon the fuel fed to the furnace. The results then take into account the loss of fuel from the grate. Conditions of the furnace operation in comparative tests are usually either very carefully controlled or they are the usual operating conditions in the plant where the tests are made. In either case loss of fuel in the ash and refuse is chargeable to the character of the fuel, the characteristics of the grate in that respect, and the conditions of operation. In a summary of experimental results, page 50, the term "service heat value" is used to designate the value of the fuel as found under test with a particular combination of boiler and furnace, operated under specifically controlled conditions.

By the term "service heat value" is meant the quantity of heat (B. t. u.) absorbed by the boiler and delivered to the steam per pound of fuel fed to the furnace. The expression of the economic result in B. t. u. is more convenient for comparison with the total heat value of the fuel than if expressed in pounds of water evaporated per pound of fuel. Otherwise, either manner of expressing the economic result is equally useful.

The heat absorbed by the boiler depends mainly upon the furnace effect and whatever modifications of results are due to the characteristics of the boiler. When, however, the resulting absorption is expressed on the basis of one pound of fuel, the heat delivered to the boiler per pound of fuel is a measurable factor. It is the difference between the total heat value of the fuel and the sum of the losses due to incomplete combustion, latent heat in moisture, loss of fuel from the grate and radiation and conduction losses from the furnace. The furnace effect is equal to this difference divided by the number of pounds of moist combustion gases resulting per pound of fuel. Evidently it is possible in two different operations to have equal furnace effects with unequal quantities of heat delivered per pound of fuel. This condition may result from a difference in the initial heat value of the fuel or a difference in the sum of the losses. Necessarily different weights of gas per pound of fuel will be required in two cases: and since the rate of heat transmission depends upon the temperature of the gases above the temperature of the heating surface a different heat absorption per pound of fuel must result.

14. *Efficiencies*—Two expressions for efficiency are used in this report. They are termed respectively:*

Over-all efficiency, E_1.

Efficiency of the boiler and furnace, E_2.

The reason for adopting these terms in place of the usual ones which are given in the code of the A. S. M. E. for boiler testing, should be evident from the preceding remarks. The A. S. M. E. code expressions are:—

> "*Item 72. Efficiency of boiler:* heat absorbed by the boiler per pound of combustible consumed divided by the heat value of one pound of combustible =Item (71 x 965.8)—Item 51."
>
> "*Item 73. Efficiency of boiler, including the grate:* heat absorbed by the boiler per pound of dry coal fired, divided by the heat value of one pound of dry coal
>
> = Item (70 x 965.8)—Item 50."

Item 72, as it is now defined in the A. S. M. E. code, is not the efficiency of the boiler alone, but includes also the furnace, the influence of the fuel characteristics, and the variation and faults ot operation; in fact, all of the factors that cause variation in the value found for Item 73 with the exception of the ash-pit loss. That is, Item 72 and Item 73 are identical in their main import; they are both measures of composite effects, the only difference being that in Item 73 a charge is made against the plant for the heat of the total weight of fuel fired while in Item 72 the charge against the plant excludes one variable.

E_1 is calculated herein in the same manner as in the A. S. M. E. code Item 73, and E_2 is calculated in the same manner as the A. S. M. E. code Item 72, and in the report these item numbers are used to designate them. The only difference is in the less ambiguity of the terminology. As a matter of fact, the term "boiler and furnace" efficiency is ambiguous unless it is kept in mind that it is merely the over-all efficiency compensated for the ash-pit loss.

In the discussion of results and in Tables 5 to 14 these efficiencies have been compensated for the heat lost in the water-back,† the corrected items being designated by "Item 72.1" and "Item 73.1."

*These terms were suggested by L. P. Breckenridge, Jour. W. Soc. of Engrs. XXII. 3,288.

†See pages 115 and 116.

15. *Rate of Combustion.*—From the standpoint of theoretical chemistry, each constituent in the heterogeneous mixture of carbon and hydrocarbons which make up coal substance should, under isothermal conditions, have a definite velocity with which it will react with oxygen. And, in general, the different components have different rates of reaction, the more so because many of the hydrocarbons wholly oxidize only after volatilization and subsequent successive changes in chemical structure.

Oxidation of these compounds takes place slowly at ordinary temperatures, but at temperatures approaching those of industrial furnaces, the velocity of oxidation is so enormously accelerated that we never note any practical difference in the rate of combustion chargeable purely to differences in the velocity of oxidation of different fuels.

Experience shows that as rapidly as we can supply air to the fuel it will be burned. Differences in rate of combustion in a practical sense are wholly due to conditions that prevent the air from coming in contact with the fuel, and to the amount of air supplied.

With fine sizes of coal the rate of combustion is limited by the rate of air supply that disrupts the fuel bed and permits air to pass through without coming into contact with the fuels. This limit is reached with very fine-sized coals and with screenings containing much dust, and is a serious circumstance in steam generation because of a natural tendency of the fireman to increase the draft when there is demand for more steam. This maximum limit in the rate of combustion is one of the important factors which determine the selection of fuel for a particular condition of service. To discover just what this maximum limit is and to determine its relation to the draft pressure is an essential item to be observed in experimental testing.

For those grades of fuel that do not exhibit a maximum rate of combustion within the limits of practical demands, and below that limit for those that do, it is important to know the relation between characteristics of the grade, the draft conditions, and air supply. For a useful and practical consideration of these features, it is imperative that the following points should be recognized.

In a practical sense the weight of fuel that can be burned in a given time is determined by two principal factors.

(*a*) The rate at which air is supplied to the fuel.

(*b*) The efficiency with which the air is utilized.

The relation of these two factors is apparent at once, for if we consider two equal fuel bed areas to be supplied with the same volume of air per unit time, that one will be most rapidly consumed which utilizes the air most completely. On the other hand if the air in both cases is utilized to the same extent, the relative rates of combustion will be directly proportional to the rate of air supply.

The first factor (*a*) is the one most usually considered as determining the rate of combustion. The second factor (*b*) is rarely given proper consideration. Its significance will be seen when it is recalled that for a given rate of air supply, the rate of combustion will be approximately twice as great with 12 per cent of carbon dioxide in the flue gases as with but 6 per cent.

The second factor (*b*) is that to which we have charged the variations in the furnace effect, and the same causes, viz., character of the fuel, leakage, degree of care in attendance, which affect the furnace effect by dilution of the combustion gases, act under fixed draft capacity to modify the rate of combustion.

The first factor depends upon the resistance of the fuel bed and grate, and the available draft pressure and draft capacity. The resistance of the fuel bed varies with the size of the fuel, the thickness of the fuel bed and the amount and character of caking and clinkering.

V. Test Results

16. As stated elsewhere in the discussion of results, the present report is concerned with that part of the data most directly related to the fuel. In Appendix III many data are presented which, it is hoped, aside from the intrinsic value, may be found useful to those who may wish to review the work critically.

Limitations of results. In comparing the characteristics of the different grades of coal, it has been a problem of serious concern as to how much attention should be given to the fuel beds.

Some fuels require little attention, while others have a characteristic tendency to burn out in spots or clinker more or less seriously. The furnace attendant naturally judges the quality of the coal by the amount of attention required to keep up steam. Thus, since this feeling is a general one, it would be of interest to compare fuels under equal attention all around for certain special plant conditions. To adopt such methods for test purposes, however, would be to place upon large grades of coal a premium which they do not deserve, when market prices are considered. Moreover, a hesitating demand for certain of those grades which require much attention has been a factor in maintaining them as cheap fuels, although more than sufficient pecuniary advantage to offset the extra care required may be obtained from their use.

17. Mechanical stokers, which feed by continuous progression of the fuel over the surface of the grate, or in which the grate itself progresses through the furnace, and which are therefore continuously self-cleaning, are adapted to a wide range of fuels. A feature of these self-cleaning types is the difficulty of proportioning the air supplied to the furnace, especially when the fuel is not uniform or is of very fine size. The nature and depth of the fuel bed changes gradually from the feed gate to the end of the grate, and an excess of air is admitted where least needed by the fuel. The stirring action of inclined stokers, though an advantage with mildly coking coals, is unnecessary with moderately free-burning coal and tends to distribute the air unevenly. Combustion upon the chain grate is free from this particular source of dilution since the fuel bed may remain undisturbed during combustion. Excess air through the thin fuel bed at the rear of the grate, and leakage into the furnace between the bridge wall and the end of the grate, or through the dump grate of the inclined stoker can not be readily controlled. Devices applied to the chain grate for preventing undue leakage, such as over-hanging bridge walls with or without water-backs, designed to permit just sufficient room for the passage of the ash, and the various forms of dampers under the grate and in the ash-pit, are only moderately successful.

A feature of such mechanical stokers, which largely operates to offset the disadvantages just noted and which make them particularly adapted for efficient combustion of high volatile coals, is the ignition arch under which the fuel passes as it enters the furnace. On account of the depth of the fuel bed under the arch, the air supply there is retarded and is insufficient for the complete combustion of the volatile matter distilled off in large amount at that place. If the combustion space is properly constructed, this volatile matter can mix with the diluted gases from the thinner portion of the fuel bed and be burned. Thus a proper proportion of excess air through the rear portion of the fuel bed is an advantage.

In the case of the traveling grate, the importance of carefully standardizing the furnace control in practical testing is emphasized by the following fact. By driving the grate faster than the fuel is consumed and thus passing burning fuel over the rear end into the ash-pit, the excess air at the rear end may be largely utilized, and the result is, of course, a higher furnace effect and consequently higher "boiler and furnace" efficiency, but because of loss of fuel the over-all economy is decreased. This possibility is sometimes taken advantage of in tests in which it is desired to show a high "boiler and furnace" efficiency with a given coal, and in practical operation under conditions where the demand for high boiler horse-power temporarily sets aside considerations of economy.

18. *Control of the Furnace.*—In outlining the tests of these experiments an effort was made to so standardize the operating of the furnace that the details of the control during each test might be made a matter of record. General features of the furnace control, which should be noted because of their bearing upon the test results, are set forth in the following paragraphs.

19. *Depth of the Fuel Bed.*—This was taken as the depth of the gate opening since an accurate estimate of the average depth of the grate could not be made.

20. *Area of the Fuel Bed.*—The area of the fuel bed was maintained as nearly as possible the same for all fuels, regardless of the frequency of adjustment required by the stoker-driving engine. Throughout all the tests, it was specifically understood that the fuel should not be allowed to bank against the water-back nor the live fuel line recede from the water-back a greater distance than was absolutely necessary. An attempt was made to hold the live fuel about 4 inches short of the water-back; the regulation of the small stoker engine, however, could not be depended upon so that this condition could not be exactly met. The difficulty was augmented in the early tests by trouble with the draft engine and by the conditions under which those tests were made.

21. *Attention Given to the Fuel Bed during Operation.*—During the tests No. 1 to 20 attention to the fuel bed was confined to occasional leveling. The object was to observe the performance with minimum attention to the fuel beds. At no time, however, were irregularities in the fuel bed allowed to become serious. During tests No. 20 to 64, it was sought to bring out the best possibilities with each fuel. In these tests, thin spots and humps at the rear edge of the bed were leveled and fuel was frequently pushed against the ledge plates to regulate leakage of air.

22. *Regulation of Draft Pressure.*—The following convention was adopted to define the draft pressure of the furnace. The *normal draft pressure* is that pressure upon the fuel bed which exists when the fuel bed is of the regular area assigned for all tests, when the fuel bed is without thin spots, and when the leakage along the ledge plates is not greater than normal. A normal draft pressure was assigned for each test on the day previous to the date of the test. This made it possible for the firemen to regulate the conditions some time before the start.

23. *Rate of Combustion.*—As closely as possible an even rate of combustion was maintained throughout each test.

24. *Fine Coal From the Drip Plate.*—The fine coal which fell through the grate was returned to the feed hopper and again fed to the furnace. This was done more frequently than usual under ordinary plant operation, the attempt being to distribute the fine coal uniformly.

25. *Leakage at the Rear of the Grate.*—The automatic water-back in all tests except one was allowed to ride upon the ash and clinker, so that the leakage of air passing to the furnace over the rear of the grate was as nearly as possible independent of the character of the fuel and other conditions save the draft pressure.

26. The record of the furnace conditions was carefully kept during each test. An explanation of the furnace record is given on page 92, and Table 40, Appendix III, comprises a summary of as much of the data contained in those records as is possible to represent in tabular form. Essential parts of the record which could not be so summarized have been kept in mind in modifying conclusions concerning the fuels.

VI. Analysis of Results

27. For purpose of more ready comparison, important items from Tables 28 to 40, Appendix III, together with items not elsewhere presented, are set forth in this chapter, and certain of the relations shown graphically by means of charts. General explanations of the tables and charts follow.

28. *Tables.*—At the head of each table is given the fuel index number. The commercial sizes in fractions of inches are given in Table 1, page 4.

Column 1, series test number.

Column 2, depth of fuel bed in inches.

Column 3, draft pressure on the fuel bed in inches of water. This is the drop in pressure through the fuel bed. See page 116.

Column 4, pounds of combustible consumed per square foot of grate surface per hour=code item 30 ÷ 38.2.

This item represents the actual combustion. For the purpose here intended it is a better expression for the rate of combustion than "pound of dry coal per square foot of grate surface" since it removes non-essential variations due to differences in the percentage of ash and in the loss of fuel to the ash-pit.

Column 5, Horse-power developed, Item 65.1. In this column the actual horse-power developed is compensated for the heat lost to the water-back as explained on page 106. Its use removes a minor variation of from 1 to 3 per cent due to that loss. The items are derived from Item 65, Table 34.

Column 6, Horse-power developed per square foot of grate surface = Item 65.1 ÷ 38.2.

Column 7, Per cent of builders' rating developed = Column 5 ÷ 210.

Column 8, Efficiency of "boiler and furnace". See Item 72.1 page 115 and Table 35.

Column 9, Over-all efficiency. See Item 73.1 page 116 and Table 35.

Column 10, Per cent of total combustible lost in the "ash and refuse" = (Item 31 x Item 44) ÷ (100 — Item 42). See Tables 29 and 38 for Items 31, 42, and 44.

Column 11, per cent of CO_2 in dry flue gases. See Table 36 and page 117.

29. The graphical representation of data presented in these tables is shown in Fig. 1 to 9.

These curves are not to be taken as representing mathematically definable relationships, and for this reason it may not be without value to call attention to the following considerations. For the most part the curves represent functions of two or several variables. For example, plotted points for the amount of air used per pound of combustible consumed and the resulting gas composition, should be expected to show only whether the excess of air varies with the rate of combustion and draft pressure. Since the drop in draft pressure is largely affected by the velocity or volume of gas flowing and its temperature, plotting points for this drop against rate of combustion is not wholly illogical, and reference to the points on the carbon dioxide curve or air supply curve will generally indicate the principal cause of variation. The carbon dioxide resulting from the combustion of a uniform coal composition is a function practically of the weight of air used per pound of combustible consumed, and with a constant per cent of CO_2 the volume of air flowing gives a directly proportional rate of combustion.

The general relation of these various factors, one to the other, is not difficult to understand, though the practical mathematics of the relations is somewhat tedious and will not in general permit of exact or in some cases even approximate interpolation between plotted points affected by a third variable; yet with proper consideration, the curves illustrate sufficiently well the relations under the conditions of the experiments. The resulting carbon dioxide percentages have been plotted in each of the charts as a datum of reference. The relation between the per cent of carbon dioxide and the furnace effect and temperature of combustion is very nearly a direct proportion, so that it will be apparent at once that the possibility of representing the data for certain fuels in the form of smooth curves has depended largely upon slight variation in the carbon dioxide conditions. In the charts showing air supply and draft pressures, uniformity of the fuel and furnace operation adds to the uniformity of the curves. The values for air supply data are given in Table 24, page 72. Graphical representation is made only for those fuels that were tested at various rates of combustion.

30. *Fuel 5.0602 W*, Table 5.—Fuel of this grade, commercially known as No. 4 washed coal, is very uniform, and when it is burned upon the chain grate, the fuel bed usually requires little attention beyond care in the regulation of the grate and the occasional removal of clinker accumulating along the ledges. The tests of this fuel included in Table 5 were conducted under conditions of ordinary careful furnace control. Table 34 should be referred to.

TABLE 5 FUEL 5.0602W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
6	4	0.102	19.74	218.4	5.71	104.0	66.66	64.72	2.91	* 7.04
7	4	0.104	20.89	232.5	6.09	110.7	67.12	63.60	5.32	*10.10
8	5	0.090	19.71	216.3	5.66	103.0	66.16	64.42	2.63	* 9.54
9	6	0.134	20.65	215.8	5.64	102.8	62.93	61.87	1.74	* 9.47
10	7	0.162	20.13	210.5	5.51	100.2	63.09	62.00	1.73	* 6.22
11	6	0.150	20.16	216.3	5.66	103.1	64.38	62.91	2.20	* 8.05

*See page 117.

Four thicknesses of fuel bed were tried. The resulting efficiencies are in favor of the 4- and 5-in. beds. The smaller values for the 6- and 7-in. beds are due in part to irregularity of grate performance. On the whole, the furnace control for tests 9, 10 and 11 was less favorable to the fuel than that for tests 6, 7 and 8.

In all these tests, as will be noted generally, the greater ash-pit losses occur with the thinner fuel beds. The flame from this fuel was practically burned out at the rear of the combustion chamber, and no smoke was observed save in tests 10 and 11 at times when the fuel was banked against the water-back. See definition of "banked", page 94. The smoke for those periods was less than the shade represented by Ringelmann chart No. 2, the average for each test being 0.08. See Column 12, Table 36. No trouble of any sort was experienced from clinker.

From the test results, it must be concluded that this fuel may be burned with no attention to the fuel bed, with resulting "boiler and furnace" efficiencies from 64 to 67 per cent, and over-all efficiencies from 62 to 65 per cent. With better attention to the fuel bed and more uniform regulation of the grate travel, this fuel would give as good results as those of Tables 8 and 14.

31. *Fuel 5.0200 W*, Table 6.—Washed coal of this grade passing a ¼-in. round hole screen is generally known as No. 5 washed coal. Though made up of a narrow range in sizes, the proportion of intermediate sizes and especially the amount of dust contained may vary considerably in the washing process, and for this reason considerable variation in results must be expected even with coal from the same washery. The coal forms a very compact fuel bed, so that these slight changes in the proportion of intermediate sizes may produce a very considerable variation in the draft requirements. Six tests were made on this coal to determine the conditions favorable to maximum rate of combustion and evaporation. As in the preceding tests, the furnace control was that of good plant practice.

TABLE 6 FUEL 5.0200W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
12	5	0.270	20.18	179.5	4.70	85.5	54.08	49.76	7.98	*7.10
13	6	0.380	21.54	193.6	5.07	92.2	54.47	51.14	6.12	*6.40
14	6	0.430	21.65	195.5	5.12	93.0	54.84	51.96	5.11	*5.84
15	4	0.290	24.01	216.8	5.67	103.2	54.88	49.17	10.32	*7.02
16	4	0.270	22.62	207.3	5.43	98.7	55.76	49.95	10.27	*5.95

*See page 117.

On account of the fineness of the coal and because of the closeness of the fuel bed, fuel of this size burns best when the force of the air passing through the fuel is sufficiently great to keep the finer particles continually agitated. To carry the draft much beyond this results in trouble. Holes develop rapidly, the increasing rush of air through such spaces reduces the draft pressure, and the rate of combustion is retarded over the entire bed. Reducing the draft much below the best condition not only retards the combustion, but gives the leakage of free air along the ledge plates and at the back of the grate an increasing weight in the total.

The proper draft pressure for the 6-in. bed was between those used. Practically the same rate of combustion was obtained with draft pressures of 0.38 and 0.43 respectively. In test 13 the fuel bed was dead and without serious tendency to form holes, as shown by the data in columns 9, 10 and 11, Table 40, while in test 14 considerable trouble resulted from the formation of holes over the back half of the grate, and the draft pressure varied widely at times. Tests 15 and 16 with a 4-in. gate opening gave most uniform results throughout, but required a high speed of grate travel. See Table 40. The chief trouble with a 4-in. bed was the tendency to burn out at the back end, requiring very careful regulation of the grate travel. For practical purposes a 4-in. fuel bed is too thin for this grade. With the 5-in. gate opening, test 12 gave very satisfactory results in every way except that the draft pressure was too low for maximum results. This was shown by the dull flat appearance of the fuel bed.

From these tests, the general conclusion can be drawn that under good plant practice there may be developed with this fuel for each square foot of grate surface, from 4.5 to 5.5 horse-power at "boiler and furnace" efficiencies from 54 to 56 per cent, and over-all efficiencies from 49 to 52 per cent.

32. *Fuel 4.0700 W*, Table 7.—This fuel is a combination of the two grades, 4.0703W, Table 14, and 4.0300W, Table 13, the mixture containing about 30 per cent of the latter. At the washery, the component grades are washed separately and upon special order combined in varying proportions by running the products into the same bin. Subsequent handling in loading and unloading is depended upon to give a uniform mixture. On account of a fairly even gradation of sizes and the wet condition of the coal, this is ordinarily sufficient.

It was not intended at the time these tests were made, to extend the work to include mixtures of the standard commercial grades, but this car having been received by a mistake in billing, the four tests were made in view of the indications they might give as to the advisability of taking up such a series, and in that connection the results are interesting.

The tests were made under essentially the same conditions as those of Table 5, but the control of the fuel bed area, affected by more uniform regulation of the grate travel, was superior.

TABLE 7 FUEL 4.0700W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
17	5	0.130	19.92	213.3	5.58	101.6	65.31	62.23	4.71	*10.50
18	5	0.130	20.18	225.1	5.89	107.2	67.79	65.42	3.56	*10.60
19	4	0.106	20.39	224.9	5.89	107.0	67.04	64.69	6.66	*11.20
20	6	0.145	20.73	228.6	5.98	108.8	66.80	64.68	3.33	* 9.94

*See page 117.

This fuel burned with as great uniformity as fuel 4.0703W or 5.0602W, but required slightly higher draft pressure. The fuel bed remained in good condition, though burning more rapidly along the ledge plates. It will be noted that the ash in this coal was greater and more irregular, due, no doubt, to the admixture of the finer size, but it appears to have had no effect on the economy or to have caused trouble from clinker. Combustion was complete and without smoke, and in every respect the tests of this fuel indicate that it is as suitable for use with the chain grate as either the fuel 4.0703W or the fuel 5.0602W. How much the rate of combustion may be increased over that shown by the tests can not be exactly stated. Nevertheless, close observation of furnace conditions leads to the conclusion that at least 25 pounds per square foot is possible, a value which represents approximately seven boiler horse-power per square foot of grate surface. There is also no apparent reason why the economy obtainable with this mixture may not be increased by increased attention to the fuel bed.

33. *Fuel 6.0402W*, Table 8.—The tests here included are the first of the series in which the fuel bed was given the attention

TABLE 8 FUEL 6.0402W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
21	6	0.127	19.74	233.0	6.10	111.0	70.92	67.84	4.35	*12.40
22	7	0.138	19.03	218.4	5.72	104.0	68.46	66.98	3.01	*11.01
23	5	0.105	17.28	207.6	5.43	98.9	72.24	68.90	4.63	*11.79
24	4	0.085	19.55	232.3	6.08	110.6	71.65	68.56	4.31	*12.08
27	6	0.122	20.24	226.2	5.92	107.7	67.25	65.84	2.11	* 9.60

*See page 117.

that seemed necessary to keep it in uniform condition. Reference to Table 40 will show that undoubtedly more leveling was done than necessary. This fuel is similar in all respects, as to composition and grade, to the fuel 5.0602W of Table 5; both are from the same seam in Williamson county.

As with the fuel of Table 5, all of these tests were run at about the rated capacity of the boiler. There can be no question, however, that any capacity desirable can be obtained with this grade.

In test 27 of this group, the water-back worked stiffly and had to be supported free from the fuel bed. The test should be excluded for that reason. The remaining tests show but small differences in efficiencies with reference to the thickness of the fuel bed, what advantage there is being with the thinner fuel beds, though the tendency toward increased ash-pit loss with the thinner beds is again indicated. No trouble was experienced with clinker, and though the flame extended through the combustion chamber, the fuel was burned without smoke.

34. *Fuel 5.1610 W*, Table 9.—This fuel is a larger grade of washed coal than is usually burned upon the chain grate. That it

TABLE 9.—FUEL 5.1610W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per. hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
25	6	0.122	17.88	204.7	5.36	97.4	68.16	64.47	5.43	*10.30
26	6	0.122	20.10	227.1	5.95	108.2	67.97	65.35	3.85	*10.00
28	7	0.145	19.35	213.7	5.59	101.8	66.38	65.19	1.82	** 8.88
29	6	0.124	19.06	209.6	5.48	99.8	66.28	64.52	2.69	** 8.88
30	5	0.103	19,61	215.3	5.64	102.5	66.14	64.18	2.96	9.38

is not commonly burned is due, however, to a relatively higher market price and not to any difficulties arising from its use. Except for minor variations in the area of the fuel bed for tests 25 and 26, the conditions under which these tests were run were exceptionally uniform.

Attention should be directed here to the change in the methods of taking gas samples in the interval between tests 27 and 28. A source of leakage in the gas samples was detected and remedied during test 29.

The results of tests 28, 29 and 30 are accepted as representing the comparative economy obtainable with this grade of fuel under the conditions of these tests.

But five tests could be made with this fuel and these were given over to the determination of the effect of thickness of the fuel bed. It is well known that rates of combustion may be obtained with this fuel far beyond any present practical requirements. Referring to the three directly comparable tests 28, 29 and 30, a tendency toward increased ash-pit loss and decreased over-all efficiency with decreasing thickness of fuel bed will be noted. No variation in the boiler and furnace efficiency is shown. See effect of radiation and conduction losses, page 52.

*See page 117.
**Leak in gas sampler.

This fuel ignites readily under the arch. A long flame results but with combustion completed within the combustion chamber. The percentage of clinker was very small and after experience in the first two tests, the regulation of the grate and fuel bed was easily maintained

35. *Fuel 7.1610 Unwashed,* Table 10.—This coal and the washed coal of Table 9 were obtained from mines located about two miles apart at Herrin, Illinois. Both belong to No. 7 seam and are of the

TABLE 10 FUEL 7.1610—

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
31	5	0.093	19.32	216.2	5.66	103.0	65.90	64.40	2.45	9.32
32	6	0,124	18.90	212.0	5.55	101.0	67.82	66.35	2.30	*9.00
33	7	0.143	20.44	223.7	5.86	106,6	65.97	64.56	2.15	9.40
34	6	0.116	21.02	231,9	6.07	110.4	66.13	64.58	2.31	9.47
35	6	0.157	23.40	253.0	6.62	120.4	64.48	63.12	2.14	9.62
36	6	0.188	26.05	275.0	7.20	131.0	63.81	62 35	2.25	9.02

same ultimate chemical composition and heating value and in every respect similar, with the exception of a slightly greater ash and sulphur content in the unwashed coal.

The small difference in ash content did not warrant any expectation of different results in the combustion tests, yet to satisfy any doubt, tests 31, 32 and 33 were made under conditions similar to those of tests 28, 29 and 30.

The occurrence of clinker, though not serious with either fuel, called for some extra attention in burning the unwashed fuel, as shown in column 7, Table 40; otherwise the results are similar.

The remaining tests of this coal were run at increased rates of combustion. Comparison of the six tests in that respect show no positive change in the results charged to the fuel and stoker.

*Slight dilution of sample due to leak.

Both ash-pit loss and the excess air in the combustion gases remain practically constant.

Since the coal of Table 9 and that of Table 10 practically represent the same grade, the results obtained are plotted together in Fig. 1 and 2.

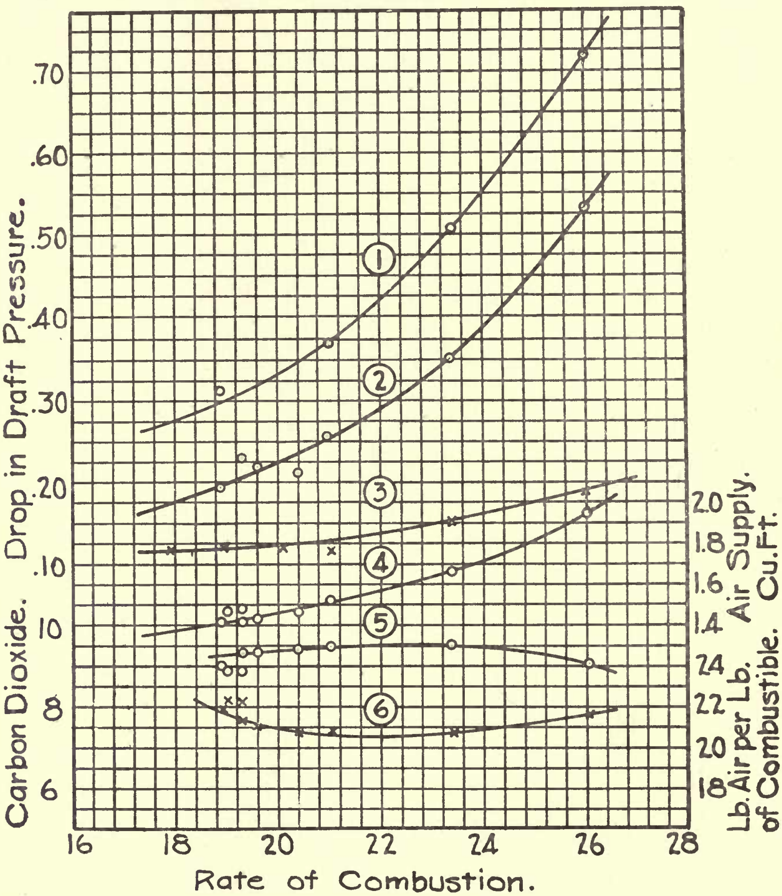

FIG. 1 TESTS OF FUELS 5.1610W AND 7.1610 —

1. Drop in draft pressure through the boiler and fuel bed, inches of water.
2. Drop in draft pressure through boiler, inches of water.
3. Drop in draft pressure through the fuel bed, inches of water. 6 inch fuel bed.
4. Cu. ft. of air supplied per sq. ft. of grate surface per sec.
5. Per cent of carbon dioxide in the flue gases.
6. Pounds of air supplied per pound of combustible consumed.

In Fig. 1, the difference of draft pressure between the furnace and damper, designated curve 2, is plotted for tests succeeding test 30. See page 32. The points are obtained by taking the difference between columns 3 and 4, Table 36.

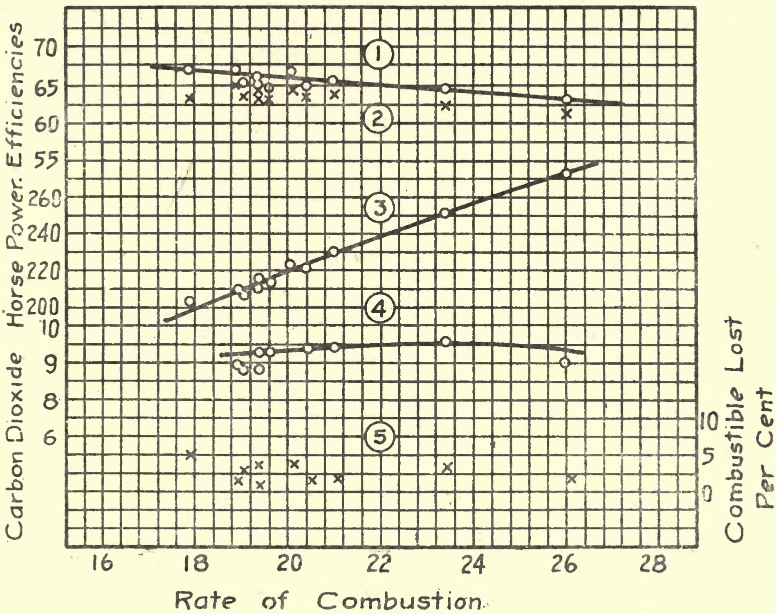

FIG. 2. TESTS OF FUELS 5.1610W AND 7.1610—

1. "Boiler and furnace" efficiency, E_2, per cent.
2. Over-all efficiency, E_1, per cent.
3. Horse-power developed.
4. Per cent of carbon dioxide in the flue gases.
5. Per cent of combustible lost in the "ash and refuse".

In Fig. 2, results for all tests of fuel 5.1610W and fuel 7.1610 — are plotted. It shows that the rate of evaporation or horse-power developed is directly proportional to the rate of combustion. The variation of points from the mean curves for horse-power and efficiencies shows a general relation to the variation in the per cent of carbon dioxide.

A long flame results with this fuel, but even at the higher rates there was no smoke or other evidence of incomplete combustion.

From the standpoint of uniform operation, the most satisfactory rate of combustion is in the range above 21 lb. Below this point the combustion responded too readily to slight changes in draft pressure. Clinker adhering to the ledges accumulated in smaller amounts at the higher rates.

36. *Fuel 5.1006 W*, Table 11. Normally, this fuel contains a very narrow range of intermediate sizes, although as in other well-sized coals, there is always present a proportion of sizes smaller than that of the lower screen. This is caused by the handling during shipping. Usually, this proportion of smaller sizes does not exceed 10 per cent for washed coal similar to that from seam 7, when handled directly from the mines, though long storage may increase the amount considerably. This shipment of coal, after about six weeks' storage, was not as uniform as it was desired to have it. On the average, about 15 per cent passed through a ½-in. sieve, of which amount a little more than one-half was below ⅛ in. The coal used in tests 42, 43 and 45, taken from the bottom of the bin, showed about 25 per cent through the ½-in. sieve with 10 to 12 per cent below ⅛ in.

TABLE 11 FUEL 5.1006W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
37	5	0.097	19.55	231.5	6.68	110.2	71.58	70.55	1.47	10.56
38	5	0.088	17.85	211.5	5.54	100.8	71.37	70.10	1.79	11.09
39	6	0.113	18.32	211.5	5.54	100.8	69.64	68.42	1.73	10.79
40	7	0.144	19.03	213.9	5.60	101.9	67.69	66.49	1.78	10.56
41	6	0.146	23.51	270.3	7.08	128.7	69.25	68.08	1.68	11.48
42	5	0.091	15.92	184.6	4.83	88.0	70.13	67.69	2.02	11.27
43	6	0.174	24.45	271.5	7.11	129.3	68.47	67.19	1.82	11.12
44	6	0.230	30.10	321.8	8.42	153.2	65.51	64.24	1.89	10.27

The first four tests were run at a rate of combustion giving about normal boiler rating. Three thicknesses of fuel bed were used, the resulting efficiencies being apparently in favor of the 5 - in. fuel bed. Tests 37, 38, 39 and 40 should be compared in that respect, though because of the inequalities of size they are not entirely satisfactory. The results for test 37 do not seem to be normal with respect to the carbon dioxide per cent, but the reason is not shown in the records.

The fuel was of such a nature that the fuel bed was compact and dense in all tests; at times, especially with the 6- and 7-in. thickness, the bed became viscous, and the first serious trouble from clinkering experienced with any of the fuels tested occurred. During a period of two hours in test 40, fluxing of the ash persisted to such an extent that the fuel bed had to be broken up with the slice bar three times.

Test 42 was intended as a check on tests 37 and 38. A normal draft pressure of 0.10 in. was assigned for the test, but for the reason stated above, the resulting rate of combustion was low. Test 41 with a 6-in. fuel bed, but with higher rate of combustion, gave similar though slightly less trouble of the nature experienced during test 40.

A normal draft pressure of 0.18 in. was assigned for test 43. This was increased to 0.20 during the test with an average of 0.194 for the test. A greater increase in the rate of combustion than that obtained for test 41 was expected, but the actual increase was only 4.1 per cent with an increase in the air supply of 7.1 per cent. Thus it appears that the resistance factor for the fuel bed was increased and that the leakage of free air around the grate was greater. Less trouble was experienced in this test from clinkering than in test 41.

In test 44 under a normal draft pressure of 0.26 in., the trouble from incipient clinkering entirely disappeared. The marked drop in the boiler and furnace, and the over-all efficiency in that test is chargeable partly to excess air and low furnace effect and partly to characteristics of the boiler.

Aside from the various occurrences just stated, the furnace observers' report showed that the fuel, except at times of overhot fuel beds, burned uniformly and required not more than average attention. As tests of the grade of coal, however, the tests are unsatisfactory. The coal of tests 37 and 38 more nearly represents the grade.

The coal burned with a long bright flame, and except in tests 43 and 44, there was no smoke. It is worthy of note that there was no indication of smoke in test 41 although there was less excess air than for test 43, a fact which indicates a more uniform distribution of the air. In test 43, Ringlemann shade No. 1 was approximated three times. In test 44, there was a faint haze of smoke throughout the test and twice for very short periods a shade corresponding to chart No. 2 was reached. For smoke averages for the tests, see Table 36.

In Fig. 3 and 4, points have been plotted from the results of this set of tests. Smooth curves have been drawn to represent the average course of results, air supply, etc., at different rates

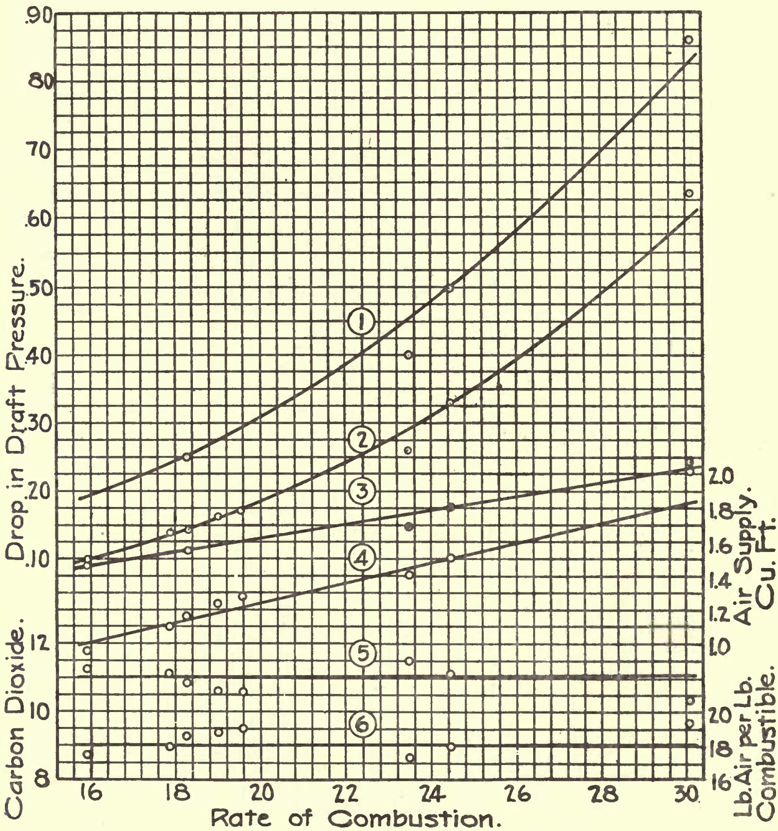

FIG. 3 TESTS OF FUEL 5. 1006 W.

1. Drop in draft pressure through the boiler and fuel bed, inches of water.
2. Drop in draft pressure through boiler, inches of water.
3. Drop in draft pressure through fuel bed, inches of water. 6 in. fuel bed.
4. Cu. ft. of air supplied per sq. ft. of grate surface per sec.
5. Per cent of carbon dioxide in the flue gases.
6. Pounds of air supplied per pound of combustible consumed.

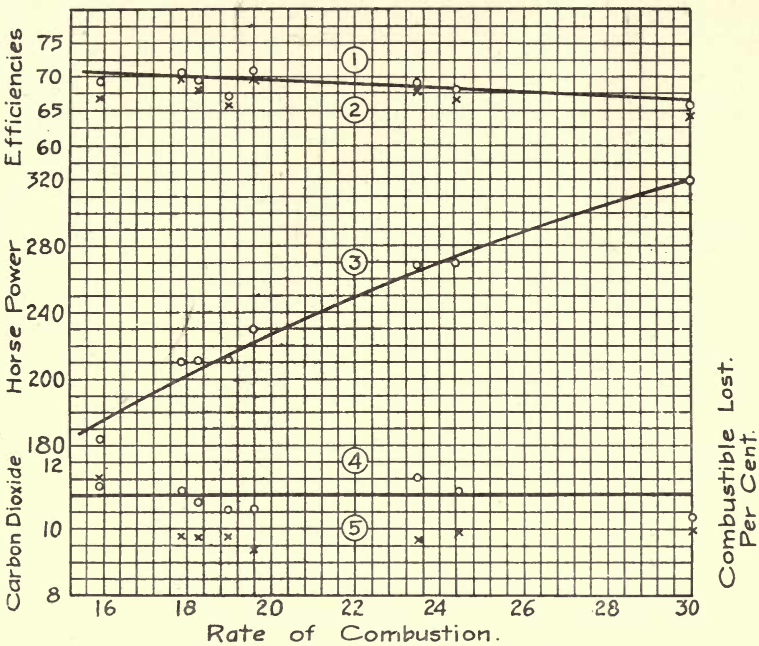

FIG. 4. TESTS OF FUEL 5.1006W

1. Over-all efficiency, E_2 per cent.
2. Over-all efficiency E_1 per cent.
3. Horse-power developed.
4. Per cent of carbon dioxide in the flue gases.
5. Per cent of combustible lost in the "ash and refuse".

of combustion. They are not strictly characteristics of a definite grade, but if each set of points for the individual tests be considered in their variation from the mean curves, much of interest will be found in their general relation to the air supply data and per cent of carbon dioxide.

37. *Fuel 6.0200 W*, Table 12.—Both as to chemical composition and commercial grade, this fuel is similar to the fuel 5.0200W used in the tests of Table 6. At the time of testing, it had been in storage for about 30 days and had dried out somewhat.

Tests 45 and 46 were made with the coal in that condition, the water content being approximately 14 per cent. The tests offer an opportunity of observing the effect of the absence of wetness. In order to take account of the dry condition, the normal draft pressure assigned for the 4-in. bed, test 45, was 0.23 in., 0.29 in. pressure having proved best for the wet coal in test 17. As a result of the dryness, about 40 per cent of the fuel fell through the grate. This was shovelled back into the hopper without wetting. The result was a thin and continually broken fuel bed,

TABLE 12 FUEL 6.0200W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combu-tible Consumed per sq. ft of Grate Sur-face per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
45	4	0.165	13.35	115.5	3.02	55.0	53.36	48.86	8.39	4.62
46	6	0.313	15.71	131.9	3.45	63.1	52.83	50.44	4.53	4.88
47	6	0.414	16.62	151.4	3.96	72.1	55.86	54.80	1.90	5.53
48	6	0.363	16.81	165.5	4.33	78.8	60.41	58.10	3.78	5.98
49	6	0.303	13.27	121.1	3.17	57.7	55.92	53.02	5.16	5.11
50	5	0.305	15.86	155.2	4.06	73.9	60.56	57.29	5.36	6.04
51	5	0.346	16.28	159.1	4.16	75.8	60.30	57.86	4.02	5.87
52	5	0.364	17.80	175.5	4.59	83.6	60.70	58.60	3.44	6.20

requiring an excessive amount of attention. Poor results generally were shown, and it was with very great difficulty that even fairly good starting and closing conditions for the test were obtained.

Test 46 gave but slightly less trouble. An increased rate of combustion was obtained, but the fuel bed was continually broken and the furnace temperature reduced. These tests are sufficient to show that dryness is not one of the best conditions for fine coal in connection with the chain grate. This is well understood in practice, but perhaps the effect on the efficiency is not so well understood.

During the remainder of the tests of this grade, the coal was sprayed and mixed, the weight of the coal being taken after spraying. The drippings were also sprayed before refiring. Spraying the coal reduced the drippings to about 20 per cent of the coal fired.

The results for tests 47 to 52 with some allowance, perhaps 1.5 per cent variation in efficiency, Item 72.1, due to the difficulty of obtaining agreement in starting and closing conditions for the fuel bed, may fairly be considered as characteristic of the fuel and the grate, when given the best possible attention. Reference to Table 40 will show how uniform the conditions of attendance were. In all of these tests, holes in the fire were checked at their incipiency, and the fuel was frequently pushed against the ledge plates.

The furnace observers' report showed the conditions of test 48 to be the most satisfactory for the 6-in. gate opening from the standpoint of operation. For the 5-in. gate opening, the conditions of test 50 gave the least trouble in operation and those of test 52 the most. The rate of combustion and horse-power obtained in test 52 are believed, beyond doubt, to have been the maximum ones obtainable with this particular shipment of coal; the fuel bed was constantly on the point of breaking and considerable care had to be exercised to keep it in good condition.

The dependence of the "boiler and furnace" efficiency upon the temperature of combustion as indicated by the relative percentage of carbon dioxide in the flue gases and the amount of excess air, is plainly shown in these tests. If one will compare the rate of combustion and the quantity of air used in these eight tests, see page 72, an idea will be gained of the uncertainty of the amount of excess air with these fine-sized coals.

Fig. 5 shows the peculiarities of this grade of coal. The maximum rate of combustion, which is between 17 and 18 pounds of combustible per square foot of grate surface per hour, is reached when the volume of air supply is about 1.9 to 2.0 cu. ft. per sq. ft. of grate surface per second. The maximum rate for the 5-in. depth of fuel bed is not shown by the curve, though as stated above, the fuel bed in test 52 in which highest rate was obtained, was continually on the point of breaking even under great care in manipulation. In this test the air was more evenly distributed than in any of the eight tests made. In fact, better distribution of the air supply through the fuel bed and less leakage around the grate seems to be a characteristic of the 5-in. fuel bed for fine sizes. The comparison is shown in the set of curves numbered 2. The relation of the rate of combustion to the draft pressure on the fuel bed, third set of curves, is shown to be linear as long as the fuel bed can be kept in good condition.

In general, it may be said that with especial attention to the operation of the grate and the care of the fuel bed, "boiler and furnace" efficiencies of 56 to 61 per cent and over-all efficiencies from 53 to 59 per cent may be obtained, coincident with 3.2 to

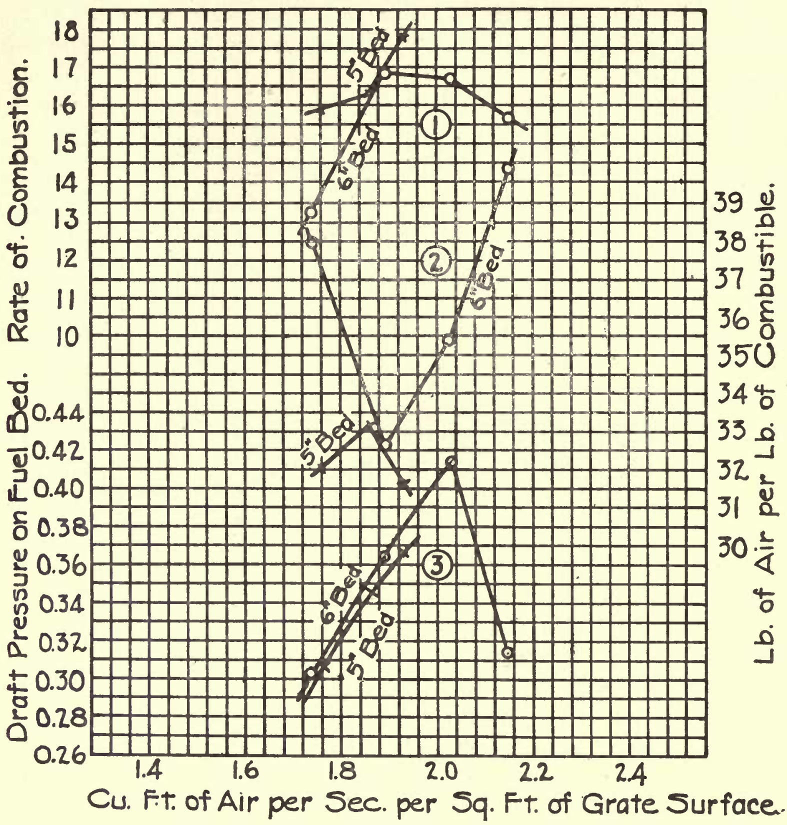

FIG. 5. TESTS OF FUEL 6.0200

1. Rate of combustion, (pounds of combustion consumed per sq. ft. of grate surface per hr).
2. Pounds of air supplied per pound of combustible consumed.
3. Drop in draft pressure through the fuel bed, inches of water.

4.6 horse-power developed per sq. ft. of grate surface per hour.

38. *Fuel 4.0300W*, Table 13—Coal of this grade, passing a ⅜-in. screen, is known as washed "duff" at the washery where it is prepared. It is sometimes marketed under that name though it is of larger size than the No. 5 coals of Tables 6 and 12.

Both the sulphur and ash content in this coal were higher than in the No. 5 coal tested. The volatile matter was about 6 per cent greater. One carload of about 24 tons was available, so that in addition to a preliminary test, not reported, but four tests were obtained.

For test 53 a normal draft pressure of 0.34 in. was assigned. The average of the draft pressure reading for the test was 0.336 as shown, and 194.8 H. P.

TABLE 13 FUEL 4.0300W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
53	5	0.339	20.45	196.5	5.15	93.6	59.73	55.88	6.51	6.56
54	5	0.298	16.81	163.8	4.29	78.0	60.98	57.30	6.05	6.16
55	5	0.367	20.71	200.1	5.14	95.3	60.15	56.68	5.79	6.58
56	5	0.381	21.70	210.4	5.51	100.2	60.73	56.76	6.50	6.90

A lower draft pressure was tried for test 54, and resulted in evaporation with no change in efficiency. A normal draft pressure of 0.38 in. was assigned for test No. 55 and 0.40 in. for test No. 56. Considerable trouble was experienced in all of the tests from coal falling through the grate, but less attention was required in keeping the fuel in good condition, than for the No. 5 coal.

In all of the tests, the coal ignited well under the arch and burned more freely and evenly over the grate than the No. 5 coal. The flame was short on account of the large excess of air and no smoke could possibly result. For the same reason no clinker was formed. Test No. 53 required the least attention to the operation of the grate while test No. 56 required the most attention.

It is possible that slightly increased rate of combustion could have been obtained, but at 0.42 inches normal draft pressure there was a serious tendency for holes to form, due to the lifting force of the draft, the light fuel particles dancing about in the same manner as in the case of the No. 5 coal.

The 5-in gate opening was used for this fuel, to agree with the best conditions found for the No. 5 coal.

For the four tests, an average of about 20 per cent of fine coal fell through the grate to the drip plate, and the fuel bed was probably more nearly of a depth represented by a 4-in. fuel bed of larger-sized coal. Some of the characteristics noted in connection with the fuels of Tables 6 and 12 are noticeable, but the fuel is more even and responds to the draft better. There is at the same time greater uniformity in the relation of the rate of combustion to the horse-power developed. As with the No. 5 coal, the tendency here is toward less excess of air at the maximum rate of combustion, though the fuel bed showed an increased tendency to cake as the excess air was reduced. The results with this fuel are shown graphically in Fig. 6 and 7.

Fig. 6 shows the draft pressure and air supply, plotted against

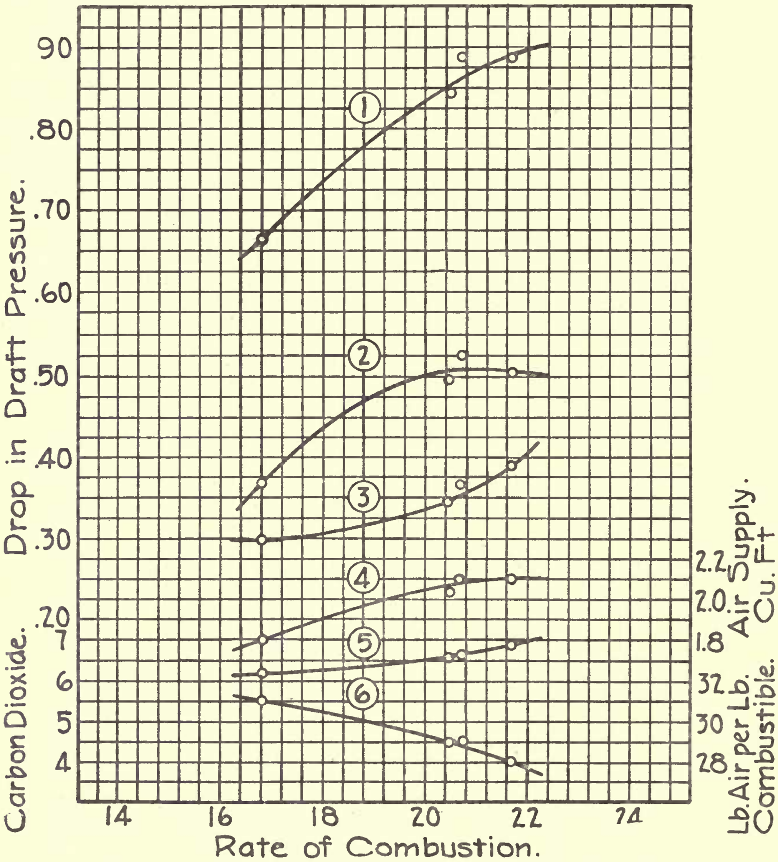

FIG. 6 TESTS OF FUEL 4.0300 W.

1. Drop in draft pressure through the boiler and fuel bed, inches of water
2. Drop in draft pressure through boiler, inches of water.
3. Drop in draft pressure through the fuel bed, inches of water. 5 in. fuel bed.
4. Cu. ft. of air supplied per sq. ft. of grate surface per sec.
5. Per cent of carbon dioxide in the flue gases.
6. Pounds of air supplied per pound of combustible consumed.

the rate of combustion. The curves are characteristic of what may be expected of this fuel. They are not to be considered, however, as showing fixed relations, for, at rates of combustion between 20 to 22, the latter being about the maximum possible rate for the grade experimented with, considerable variation occurs if the fuel bed is not kept in good condition. It will be observed that the rate of combustion does not have the same apparent proportionality to the draft pressure on the fuel bed as in preceding fuels, even under the advantage of increased utilization of the air at the higher rates. Comparing curves 3 and 6, the drop in resistance or friction within the boiler passes (upper portion of curve 2) is due, of course, to the drop in the air supply curve. The deviations of the points for test No. 56 from the mean curves are due to greater leakage.

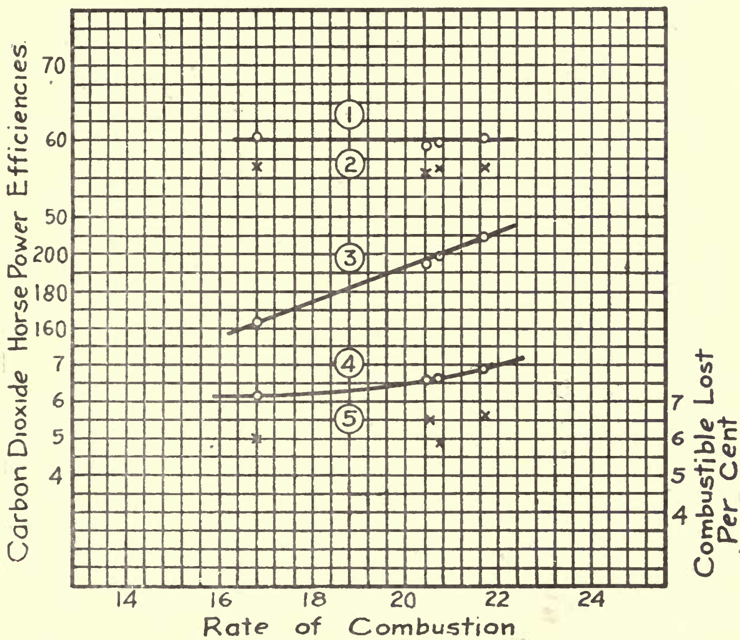

FIG. 7. TESTS OF FUEL 4.0300W

1. "Boiler and furnace" efficiency, E_2, per cent.
2. Over-all efficiency, E_1 per cent.
3. Horse-power developed.
4. Per cent of carbon dioxide in the flue gases.
5. Per cent of combustible lost in the "ash and refuse".

Fig. 7 shows a slight improvement in evaporation for increasing rates of combustion.

39. *Fuel 4.0703 W*, Table 14.—The two series of tests made with this coal, it is believed, give a means of directly comparing the effect of differences in the furnace control. How closely, how-

TABLE 14 FUEL 4.0703W

Test No.	Depth of Fuel Bed Inches	Draft Pressure on Fuel Bed Inches of Water	Lb. of Combustible Consumed per sq. ft. of Grate Surface per hr.	Horse Power Developed Item 65.1	Horse Power Developed per sq. ft. of Grate Surface	Per cent of Builders Rating Developed Item 67.1	Efficiency of "Boiler and Furnace" Item 72.1	Over-all Efficiency Item 73.1	Per cent of Total Combustible Lost in "Ash and Refuse"	Carbon Dioxide in Flue Gases Per cent
1	2	3	4	5	6	7	8	9	10	11
1	6	0.195	25.24	258.9	6.78	123.3	62.78	58.19	7.38	*10.36
2	5	0.157	24.53	264.6	6.93	126.0	65.96	63.96	3.03	* 8.77
3	4	0.116	20.52	214.3	5.61	102.0	63.94	61.34	4.05	*10.26
4	7	0.213	25.79	270.1	7.07	128.6	63.90	61.94	3.02	* 8.86
5	4	0.115	23.90	260.7	6.82	124.2	66.79	64.98	3.78	* 7.82
57	5	0.132	20.71	240.7	6.30	114.6	71.88	69.85	2.90	11.08
58	5	0.118	20.68	241.2	6.31	114.9	70.13	70.40	1.53	11.03
59	5	0.096	15.73	182.9	4.79	87.1	71.43	69.23	3.05	12.50
60	5	0.111	18.27	214.8	5.62	102.3	72.36	70.98	1.94	11.26
61	5	0.137	20,10	230.8	6.04	110.0	70,71	69.21	2.14	10.98
62	5	0.174	25.79	295.2	7.73	140.5	71.14	69.68	2.00	10.93
63	5	0.161	24.55	283.1	7.41	134.8	71.14	69.66	2.07	11.18
64	5	0.058	12.33	146.8	3.84	69.9	72.95	71.65	1.80	12.55

*See page 117.

ever, the two series may be compared in this respect can not be stated. The two sets were made some months apart and no figures are available for the radiation and conduction losses for the earlier tests. See page 53.

In tests 1 to 5, the fuel was not manipulated in any manner and irregularities consequently developed. In the first series, considerable effort was made to keep the fuel bed of standard lengths, but in all of the tests previous to test 26 it was not wholly successful. Otherwise all of the tests were conducted with the same care. Though the unreliability of the gas samples for tests 1 to 5 do not permit an estimation of the amount of excess air nor permit of the estimation of radiation and conduction losses, it is still apparent, from the percentage obtained that the difference in efficiency for the two series was due largely to èxcess of free air entering the furnace along the ledges and through thin parts of the fuel bed.

The control conditions for tests 57 to 64 differed in no particular from the standard conditions adopted for tests 21 to 64. As might be expected, this size of fuel from the standpoint of operation is an exceptionally favorable fuel for the chain grate, and with a little care there is no reason why equally good results may not be obtained in regular practice. Some trouble from adhering clinker along the ledges was experienced in each of the tests, due to a high fuel temperature and diminished leakage of cold air. In tests 1 to 5, no clinker was formed along the ledges since the fuel bed was not so hot and the continual stream of cold air between the grate and ledge prevented its formation. This

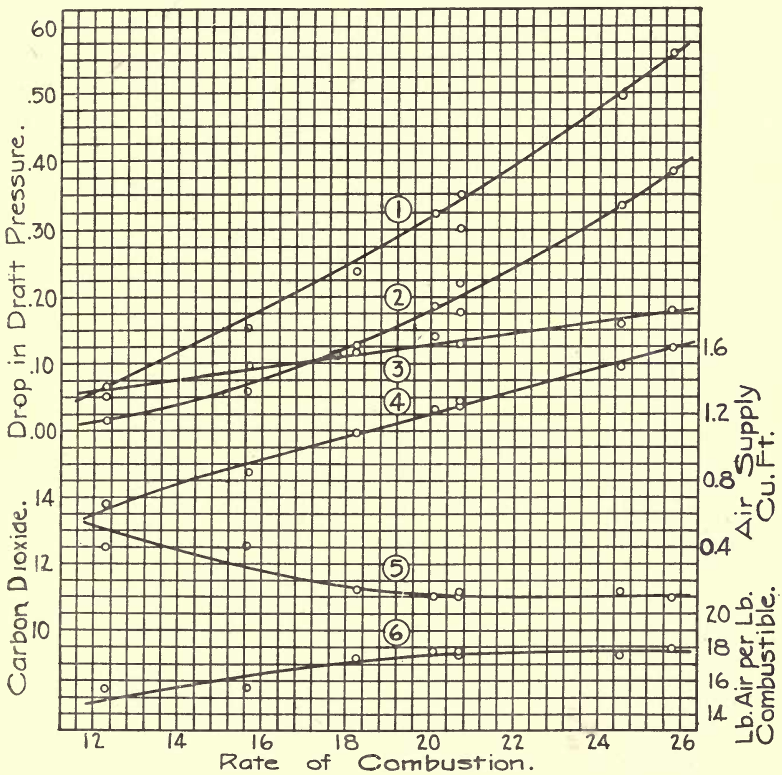

FIG. 8 TESTS OF FUEL 4.0703 W.

1. Drop in draft pressure through the boiler and fuel bed, inches of water.
2. Drop in draft pressure through boiler, inches of water.
3. Drop in draft pressure through the fuel bed, inches of water. 5 in. fuel bed.
4. Cu. ft. of air supplied per sq. ft. of grate surface per sec.
5. Per cent of carbon dioxide in the flue gases.
6. Pounds of air supplied per pound of combustible consumed.

fuel tested the combustion chamber "capacity to consume volatile matter". The flame extended through the combustion chamber and among the tubes in all the tests. Comparing the shade of smoke produced, column 12, Table 36, with the rate of combustion and the amount of air supply, columns 5 and 12, Table 14, it will be seen that the conditions tending to produce smoke depend more upon the proportion of air supplied than upon the rate of combustion. The introduction of a few mixing piers either upon the bridge wall or in the combustion chamber would, of course, result in complete combustion even with considerably reduced excess of air. With the combustion chamber and furnace as they are now, a slightly greater proportion of air is necessary to entirely prevent smoke with this fuel than is needed for the fuel from seam 7 in Williamson county. See Table 11. However, it is not possible to conclude from the evidence of the few tests of these coals available, whether any fundamental difference exists in this respect. The principal point to be noted is the absence

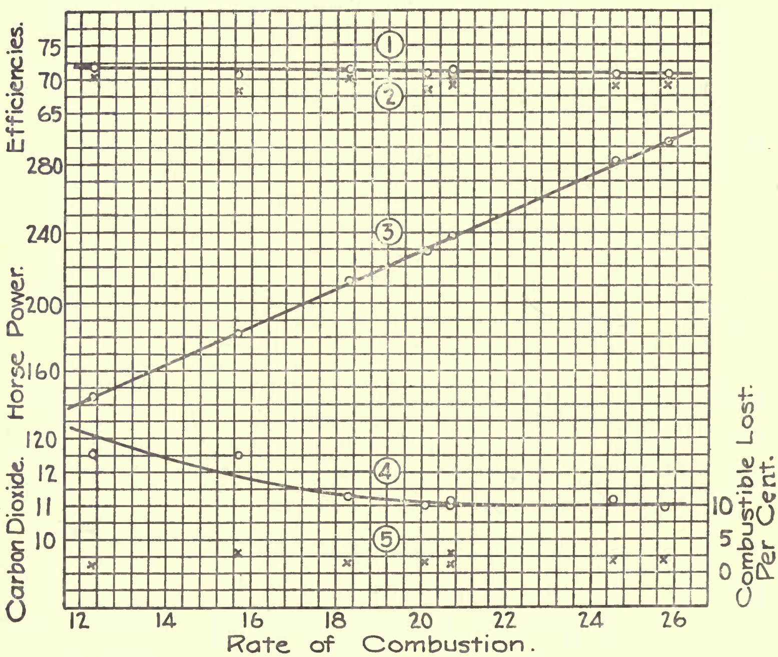

FIG. 9. TEST OF FUEL 4.0703

1. "Boiler and furnace" efficiency, E_2, per cent.
2. Over-all efficiency, E_1, per cent.
3. Horse-power developed.
4. Per cent of carbon dioxide in the flue gases.
5. Per cent of combustible lost in the "ash and refuse".

of any pronounced effect of high rates of combustion in producing smoke with a high volatile coal even though the excess air is extremely low.

In Fig. 8, the mean curves show the general relation of the air supply and draft for this fuel (tests 57 to 64) and in Fig. 9 is shown the corresponding evaporative performance.

Aside from the relation shown for this fuel, the curves are of interest from the fact that a wide range of combustion under uniform conditions is shown. The general remarks made in connection with the curves previously noted, apply to these curves as well and much is to be derived from a general study of the relative deviation of the plotted points from the mean curves drawn.

The nearly constant efficiency shown by the curves is of interest. At the low rates of combustion, the excess air was relatively small, as is indicated by the carbon dioxide points and the calculated points of curve 6. Consequently the furnace effect was proportionately higher. That this does not result in an upward flexure of the efficiency curves, is due to increased proportion of the radiation and conduction losses, as will be seen by referring to the values for those losses, Table 16.

VII. Comparison of Heat Values and Economy

40. Various factors affecting the economic results obtainable with a given coal have been outlined on page 22. The tabulated quantities of Table 16 embrace such of those values as are accessible in the data. For the purpose of uniformity in the fuel unit, the items are based upon the combustible. The derivation of the items is as follows:

Column 3. *Total heat of 1 lb. of combustible, B. t. u.* = Item 51.

Column 4. *Practical heat value, B. t. u.* = Column 3 less latent heat of moisture.

Column 5. *Heat delivered, B. t. u.* = Column 4 less heat lost in carbon of the "ash and refuse."

Column 6. *Furnace effect B. t. u.* = Column 5 ÷ lb. moist gases per pound of combustible fed = Column 5 ÷ (Column 7, Table 24 + Column 3, Table 15)

Column 7. *Equivalent evaporation from and at 212° per lb. of combustible fed, pounds*, compensated for water-back loss = Item 70.1, referred to combustible fed.

Column 8. *Service heat value, B. t. u.*, compensated for water-back loss = Column 7 x 966.

Column 9. *Radiation and conduction loss, B. t. u.* See p. 56.

Column 10. *Service heat value, compensated for radiation and conduction loss.* See page 52.

The heat losses due to latent heat in the moisture from the coal and to the loss of carbon in the ash are shown in Table 15. The items of this table were computed as follows:

Column 3. Weight of water per lb. of combustible, pounds = (per cent of moisture referred to combustible ÷ 100) + (per cent of hydrogen in combustible ÷ 100) x 9.

Column 4. *Latent heat* = Column 3 x 965.8.

Column 5. *Per cent of carbon in ash to combustible* = (Item 31 x item 44) ÷ (100 — Item 42) See tables 29 and 38 for Item 31, 42 and 44.

Column 6. Heat in carbon lost = Column 5 x 14600.

41. Reviewing the values set forth in Table 16, it cannot be doubted that the comparative values of two grades of fuels can be apparent only from an actual service test. It will be seen, however, that over-all test results in themselves do not lend themselves to close comparison. In the table are shown approximate values for the furnace effect and the sensible heat delivered per pound of combustible. In the definitions of those quantities, page 18, the radiation and conduction losses from the furnace have been given proper importance. It would likewise be consistent with a possible working hypothesis of steam boiler performance to base such definitions upon quantities of heat only that are delivered to the boiler at temperatures above that of the heating surfaces. However, to give such factors proper weight in the derivation of numerical values more elaboration is required than seems necessary, especially since the cause for variation in the evaporative results may be shown by simpler means. It is believed that this purpose has been sufficiently shown by the two heat quantities in the calculation of which no account has been taken of the radiation and conduction losses, and by way of supplement introducing as a separate item the values for the total radiation and conduction losses, furnace and boiler combined.

TABLE 15 HEAT LOSS DUE TO WATER FROM COAL AND TO CARBON IN ASH.

No.	Laboratory File No.	Water from Coal		Carbon Lost in Ash-pit		No.	Laboratory File No.	Water from Coal		Carbon Lost in Ash-pit	
		Weight per pound	Latent Heat in	Per cent of Combustible	B. t. u in Carbon Lost			Weight per pound	Latent Heat in	Per cent of Combustible	B. t. u. in Carbon Lost
1	2	3	4	5	6	1	2	3	4	5	6
		Lb.	B. t. u.	P. ct	B. t. u.			Lb.	B. t. u.	P. ct	B. t. u.
1	21—4.0703 W	.716	691	7.38	1077	33	98—7.1610 —	.545	526	2.15	314
2	23— "	.720	695	3.03	442	34	99— "	.560	541	2.31	337
3	24— "	.730	705	4.05	591	35	100— "	.616	595	2.14	312
4	25— "	.729	704	3.02	441	36	101— "	.553	534	2.25	329
5	26— "	.725	700	3.78	552	37	102—5.1006 W	.601	581	1.47	215
6	30—5.0602 W	.628	606	2.91	425	38	104— "	.621	600	1.79	261
7	31— "	.634	612	2.32	339	39	107— "	.611	590	1.73	253
8	32— "	.630	609	2.60	379	40	109— "	.607	586	1.78	264
9	34— "	.639	617	1.74	257	41	110— "	.613	592	1.68	245
10	35— "	.612	591	1.73	252	42	112— "	.607	586	2.02	295
11	36— "	.596	576	2.20	322	43	113— "	.580	560	1.82	266
12	37—5.0200 W	.675	652	7.98	1165	44	114— "	.576	556	1.89	276
13	39— "	.655	632	6.12	890	45	115—6.0200 W	.655	633	8.39	1225
14	40— "	.683	660	5.11	746	46	116— "	.639	617	4.53	661
15	41— "	.653	631	10.32	1507	47	117— "	.765	739	1.90	277
16	42— "	.709	685	10.27	1500	48	118— "	.714	690	3.78	552
17	43—4.0700 W	.723	698	4.71	687	49	119— "	.694	671	5.16	753
18	44— "	.736	711	3.56	519	50	120— "	.728	704	5.36	783
19	45— "	.712	687	6.66	972	51	121— "	.736	711	4.02	587
20	46— "	.727	703	3.33	486	52	122— "	.732	708	3.44	502
21	47—6.0402 W	.599	578	4.35	636	53	124—4.0300 W	.809	782	6.51	950
22	48— "	.594	574	2.11	307	54	125— "	.785	758	6.05	883
23	49— "	.607	587	4.63	675	55	126— "	.795	768	5.79	845
24	50— "	.607	587	4.31	630	56	127— "	.793	766	6.50	949
25	51—5.1610 W	.588	568	5.43	793	57	128—4.0703 W	.697	673	2.90	423
26	52— "	.628	607	3.85	561	58	129— "	.799	772	1.53	223
27	53—6.0402 W	.592	572	2.11	308	59	130— "	.717	693	3.05	445
28	93—5.1610 W	.604	583	1.82	266	60	131— "	.783	757	1.94	283
29	94— "	.593	573	2.69	393	61	132— "	.714	690	2.14	312
30	95— "	.598	578	2.96	432	62	133— "	.707	683	2.00	292
31	96—7.1610 —	.613	592	2.45	358	63	134— "	.739	714	2.07	302
32	97— "	.555	536	2.30	336	64	135— "	.740	715	1.80	263

TABLE 16 COMPARISON OF HEAT VALUES AND ECONOMY, BASED ON 1 LB. OF COMBUSTIBLE AS FED.

No.	Laboratory File No.	Total Heat Value	Practical Heat Value	Sensible Heat Delivered	Furnace Effect	Equivalent Evaporation	Service Heat Value	Radiation and Conduction Loss	Service Heat Value, Compensated for Radiation and Conduction Loss
1	2	3	4	5	6	7	8	9	10
		B. t. u.	B. t. u.	B. t. u.	B. t. u.	Lb.	B. t. u.	B. t. u.	B. t. u.
1	21—4.0703 W	14247	13556	12479	....	8.59	8298	....	....
2	23— "	14273	13578	13136	....	9.45	9130	....	....
3	24— "	14239	13534	12943	....	9.04	9732	....	....
4	25— "	14295	13591	12180	....	9.16	9848	....	....
5	26— "	14241	13541	12989	....	9.48	9157	....	....
	Average—	14259	13560	12945	....	9.14	8833	....	....
6	30—5.0602 W	14483	13877	13352	....	9.70	9369	....	....
7	31— "	14467	13855	13516	....	9.52	9196	....	....
8	32— "	14468	13859	13480	....	9.65	9322	....	....
9	34— "	14477	13860	13603	....	9.28	9965	....	....
10	35— "	14465	13874	13622	....	9.28	8965	....	....
11	36— "	14549	13973	13651	....	9.47	9148	....	....
	Average—	14468	13866	13537	....	9.48	9161	....	....
12	37—5.0200 W	14348	13690	12525	....	7.39	7139	....	....
13	39— "	14391	13759	12867	....	7,53	7274	....	....
14	40— "	14368	13708	12962	....	7.64	7380	....	....
15	41— "	14353	13722	12215	....	7.23	6984	....	....
16	42— "	14341	13656	12156	....	7.33	7080	....	....
	Average—	14371	13663	12535	....	7.52	7266	....	....
17	43—4.0700 W	14295	13597	12910	....	9.18	8868	....	....
18	44— "	14340	13629	13110	....	9.72	9389	....	....
19	45— "	14340	13653	12681	....	9.29	8974	....	....
20	46— "	14384	13645	13159	....	9.63	9302	....	....
	Average—	14839	13631	12965	....	9.46	8883	....	....
21	47—6.0402 W	14516	13938	13303	....	10.19	9843	....	....
22	48— "	14630	14056	13749	....	10.15	9708	....	....
23	49— "	14516	13929	13254	....	10.36	10007	....	....
24	50— "	14469	13882	13252	....	10.27	9920	....	....
27	53— "	14503	13931	13623	....	9.89	9554	....	....
	Average—	14527	13947	13436	....	10.17	9806	....	....
25	51—5.1610 W	14653	14085	13292	....	9.78	9447	....	....
26	52— "	14499	13892	13331	....	9.93	9593	....	....
28	93— "	14509	13926	13660	599*	9.79	9458	1151*	10609*
29	94— "	14472	13899	13506	602*	9.67	9338	1155*	10493*
30	95— "	14471	13893	13461	631	9.62	9287	1315	10602
	Average—	14521	13939	13450	631	9.76	9425	....	10602

*Not included in average.

TABLE 16 COMPARISON OF HEAT VALUES AND ECONOMY BASED ON 1 LB. OF COMBUSTIBLE AS FED

No.	Laboratory File No.	Total Heat Value	Practical Heat Value	Sensible Heat Delivered	Furnace Effect	Equivalent Evaporation	Service Heat Value	Radiation and Conduction Loss	Service Heat Value Compensated for Radiation and Conduction Loss
1	2	3	4	5	6	7	8	9	10
		B. t. u.	B. t. u.	B. t. u	B. t. u.	Lb.	B. t. u.	B. t. u.	B. t. u.
31	96—7.1610 —	14573	13981	13623	618	9.71	9384	1355	10739
32	97— "	14456	13920	13584	613*	9.93	9592	1076*	10668*
33	98— "	14470	13944	13630	644	9.67	9343	1434	10777
34	99— "	14548	14007	13670	646	9.72	9394	1347	10741
35	100— "	14395	13800	13488	629*	9.40*	9086*	1317	10403*
36	101— "	14436	13902	13573	617*	9.32*	9001*	1224	10225*
	Average—	14480	13792	13594	628	9.76	9428	1335	10752
37	102—5.1006 W	14427	13846	13631	696*	10,54	10179	766	10945*
38	104— "	14487	13887	13626	738	10.51	10156	743	11099
39	107— "	14470	13880	13627	718	10.25	9900	1202	11102
40	109— "	14477	13891	13631	705	9.96	9625	1404	11029
41	110— "	14487	13895	13650	761	10.21	9863	1084	10947
42	112— "	14425	13839	13545	730	10.11	9764	1534	11298
43	113— "	14145	13585	13319	722	9.81	9503*	1023	10526*
44	114— "	14240	13684	13408	675*	9.47*	9148*	849	9997*
	Average—	14395	13813	13555	729	10.20	9915	1076	11095
45	115—6.0200 W	14145	13512	12287	314*	7.15*	6911*	652	7563*
46	116— "	13920	13303	12642	324*	7.27*	7021*	903	7924*
47	117— "	14233	13494	13217	366	8.07	7800	924	8724
48	118— "	14229	13539	12987	401	8.56	8267	536	8803
49	119— "	14229	13558	12805	346	7.81	7545	831	8276
50	120— "	14087	13383	12600	400	7.32	7072	656	7728
51	121— "	14133	13422	12835	390	7.47	8180	595	8775
52	122— "	14166	13458	12956	411	8.59	8302	480	8782
	Average—	14143	13458	12791	386	7.97	7861	697	8515
53	124—4.0300 W	14031	13249	12299	438	8.12	7841	605	8446
54	125— "	13948	13190	12307	405	8.27	7992	442	8434
55	126— "	14005	13237	12392	431	8.22	7939	595	8534
56	127— "	13954	13188	12239	450	8.09	7819	586	8405
	Average—	13984	13216	12309	431	8.23	7898	557	8455
57	128—4.0703 W	14090	13417	12994	722	10.19	9843	637	10480
58	129— "	14210	13438	13215	710	10.36	10003	524	10527
59	130— "	14212	13519	13074	805*	10.19*	9839*	1296	11135*
60	131— "	14171	13414	13131	725	10.41	10058	750	10808
61	132— "	14161	13471	13159	714	10.15	9805	867	10672
62	133— "	14045	13362	13070	705	10.13*	9768*	485	10253*
63	134— "	14133	13419	13117	721	10.19*	9846*	504	10350*
64	135— "	14229	13514	13251	817*	10.55*	10193*	1303	11496*
	Average—	14156	13444	13126	716	10.28	9927	796	10622

*Not included in average.

42. Over-all evaporative results in tests of fuels may be compared quantitatively only when the imposed operating conditions of the experiment are carefully taken into account, but the comparison will hold only when the experiments themselves have been made without variation due to losses from radiation and conduction. The present studies clearly show that it is impossible to eliminate such variations, and that some means of correction for the radiation and conduction losses must always be applied. In general, it may be stated that the evaporation depends upon

(1) the heat content of the gas;
(2) the heat delivered per pound of fuel;
(3) the boiler characteristics;
(4) radiation and conduction losses.

43. The values for the radiation and conduction losses for those tests (tests 30 to 64) for which there are data suitable for calculating a satisfactory heat balance, are given in column 9, Table 16. These values are the "unaccounted-for loss" items obtained in heat balances as usually computed. This item, which is obtained by subtracting the total heat measured from the total heat supplied, also represents the variations due to the balance between positive and negative errors of experiment. What weight the latter represents in the figures, cannot be ascertained. It seems reasonable to believe, however, that with the exception of those tests that have been questioned in the table, the sum of these errors does not exceed 1 per cent.

44. Comparison of the variation between the radiation and conduction losses shows the extent to which the service heat values have been affected. It should be especially noted that those tests conducted in the early spring are placed at the greatest disadvantage, e. g., fuels 7.1610—and 5.1610 W. In fixing upon a method of correction for these losses, an endeavor was made to arrive at some satisfactory means of correction for the variations only, such that the resulting corrected values would represent magnitudes obtainable by direct experiment under uniform conditions, but the possibility of such a course has been precluded for the want of a satisfactory datum of reference. The involved nature of the problem will be apparent if one reviews the various

factors that contribute to the magnitude of such losses.

However, for purposes of comparison, it is not essential that the values should numerically represent obtainable ones, and a compensation has been made in column 10 by adding the heat loss of column 9 directly to the obtained figures for the service heat value. This procedure, though somewhat arbitrary, represents the best possible information, since the values approximate those that would have obtained had the heat lost by radiation and conduction from the furnace remained in the gases; further, they eliminate any variations due to radiation and conduction from the boiler, and at the same time those that may have been introduced by errors in the coal or in the water items. This method of compensation is adopted on the theory that heat imparted to the gases above the temperature of the boiler heating surface is absorbed at very high efficiency.*

Since this efficiency, it is known, is not perfect, the figures thus obtained do not strictly represent a function embracing the heat quantities tabulated. Considering these as relative figures only, there appears no reason why, imposed conditions of operation being equal, they should not be comparable within 1 per cent total variation, whereas the over-all results, as is usual with such values, call for considerable latitude of judgment.

45. In bringing results for all of the tests together in Table 16, it is not intended to imply that the results for all tests are strictly comparable. They are brought together to give a survey of the results not afforded by other tables. Tests 1 to 20, as elsewhere pointed out, were made under different conditions of furnace control than were those of succeeding tests.

Values for the radiation and conduction losses were not obtained for tests 1 to 27, and hence a proper presentation of those tests is difficult. At the outset of the tests, it was expected that inasmuch as the boiler was housed in an independently heated building, variations from that source would be small. That between tests run some weeks apart the variation would be as shown was, however, not expected. Upon the disclosure of the conditions, it was at first thought that the results of tests 1 to 27 should be rejected. Careful analysis of those results, however, does not disclose marked variations within any one fuel series which can

*For the major number of tests made at St. Louis by the U. S. Geol. Survey. it was shown that between 80 and 87 per cent of the heat in the gases above steam temperature was absorbed. "A Study of Four Hundred Steaming tests" Bul. 325, U. S. G. S., p. 147.

not be approximately accounted for by other occurrences on record. For this reason and because their value for the other objects of the investigation has not been affected, they have been included in the report. Equal reliability of the results of tests 1 to 27 as representing the conditions that existed is not questioned. The value of these tests as a basis for comparison of the relation of grade to economy is affected, however, for the reasons given. If the tests serve no further purpose in the present connection than to emphasize the importance of reliable flue gas data in experimental boiler and furnace work, the prominence given them will not be without value.

46. The averages shown for the results of each fuel series give a hasty review of the results. In making them, values for tests run at relatively high or low horse-power or rates of combustion have been excluded, as have likewise certain other values which preceding analyses have shown to be in question.

For purposes of more accurate comparison, these averages are supplemented by Table 17. The tests compared therein with one exception, test 52, fuel 6.0200W, represent tests at approximately 210 H. P., and are tests selected especially because of their uniform furnace operation and conditions. For fuel 6.0200 W, 210 H. P., was not obtainable. The items of the table are compiled from Table 16. The ratios at the lower part of the table are taken with respect to the items for test 60, fuel 4.0703 W.

47. *Size of grade and air proportion.*—The relation of the comparable values of column 8, Table 17, to the various heat quantities has been discussed at length. It is also important to look upon the variation of value from the relationship of size and air proportion. Keeping in mind the minor modifications introduced by variations in the heat delivered per pound of fuel, the following is of interest.

48. Air enters the furnace through the active fuel bed and through leakage points outside of the fuel bed. With any constant draft pressure, the relative proportion of the total air supply entering through each source of entrance is proportional to the separate resistances of these sources. The resistance at entrance points outside the fuel bed is practically constant, but the resistance of the fuel bed (neglecting other modifying factors for the present) depends upon the sizes of the interstices between the coal particles. Thus the leakage relative to the total air

TABLE 17 HEAT VALUES AND ECONOMY—BASED ON COMBUSTIBLE AS FED (SELECTED TESTS)

	No.	Fuel	Total Heat Value	Practical Heat Value	Sensible Heat Delivered	Furnace Effect	Service Heat Value, Compensated for Radiation and Conduction Losses
1	2	3	4	5	6	7	8
Heat Quantities	30	5.1610 W	14471	13893	13461	631	10602
	31	7.1610 —	14456	13920	13584	613	10739
	38	5.1006 W	14487	13887	13626	738	11099
	52	6.0200 W	14166	13458	12956	411	8782
	56	4.0300 W	13954	13188	12239	450	8405
	60	4.0703 W	14171	13414	13131	725	10808
Ratios	30	5.1610 W	1.021	1.036	1.035	0.870	0.981
	31	7.1610 —	1.020	1.038	1.035	0.846	0.994
	38	5.1006 W	1.022	1.036	1.038	1.018	1.039
	52	6.0200 W	1,000	1.004	0.987	0.567	0.813
	56	4.0300 W	0.984	0.983	0.932	0.621	0.778
	60	4.0703 W	1.000	1.000	1.000	1.000	1.000

increases as the compactness of the fuel bed increases, and in increasing proportion as it becomes necessary to increase further the draft pressure to give the same rate of combustion or horse-power.

49. The size of the interstices between the coal particles increases with the size of the coal particles, consequently with large grades of uniform coal a large proportion of the total air passes through the fuel bed. As the interstices are further increased, however, a condition is reached where a part of the air may pass through the fuel bed without coming into contact with either gaseous or solid combustible. Thus the fuel bed itself becomes an entrance for excess air. Between the large size, therefore, with excess air entering the furnace through the fuel bed, and perhaps by leakage as well, (some excess is needed with volatile coals for the combustion of the gasified hydrocarbons), and fine sizes with a large proportion of leakage, a size will be found for which a minimum excess occurs. This general consideration would apply more strictly to a non-clinkering and free-burning

coal, except for very fine sizes. Clinkering, caking, and with fine sizes, the formation of craters in the fuel bed, modify the conditions.

50. Ash—It is held, hypothetically, that the presence of ash particles in the fuel bed decreases the chance of the air coming in contact with the solid coal substance, and, depth of fuel bed constant, that the proportion of excess air should increase with increased percentage of ash. Analyses of 286 tests at St. Louis*, however, do not show that this is true in connection with the *plain* grate for ash percentages below 16 per cent, but it was shown that clinkering of the ash is of more serious consequence because of obstruction of the grate. The extent and seriousness of clinkering depend upon the fluxing properties of the ash, the temperature of the fuel bed and the quantity of ash present. Parenthetically, it should be said that the mere presence of ash in quantity does not induce clinkering; in fact, ash which fuses in a hot fuel bed may, by its presence in large amounts, operate to prevent clinkering by inducing excess air cooling of the fuel bed and furnace.

51. Tests with the chain grate stoker, by Mr. W. L. Abbott†, to determine the effect of varying percentages of ashpit refuse added to No. 4 washed coal, show the following results for percentages of ash below 25 per cent.

TABLE 18

Per cent of Ash in Dry Coal	Efficiency
9	59.0
16	57.0
20	61.5
24	56.0
24	57.0

For percentages of ash above 30 per cent, Mr. Abbott's results varied widely, as might be expected. Results for the lower percentages show no greater variations than are usual to over-all results.

52. The percentage of ash for the tests of Table 17 range from 9 to 16 per cent, dry coal basis, and it appears from the results just quoted that except for tests of fuel 5.1006 W, in which serious clinkering occurred, no important variations are to be ascribed to ash, but that the excess air quantities, (see p. 80), under the test conditions, are to be considered as characteristics of the grade

*Bul. U. S. G. S. 190. p. 39.
†Jour. Wester Soc. Engrs. Vol. 11, p. 529.

sizes. This would in fact be true under any consideration since the percentages of ash in washed grades have a close relation to the grade size.

In the paper quoted above, Mr. Abbott has shown a similar and remarkable relationship for specially prepared *unwashed* sizes based, however, upon size and *efficiency*.

VIII. Effect of Different Thicknesses of Fuel Bed

53. In connection with the detailed statement concerning results set forth in Tables 5 to 14, a cursory examination of the effect of different thicknesses of fuel bed has been made. It is intended here to summarize the general conclusions in that respect presented by the data. Aside from a general contribution to the data on each grade, two points of interest in respect to the thickness of fuel bed have been under investigation.

(*a*) The first of these was to determine whether any difference in the amount of combustible matter in the ash-pit refuse would result for different thicknesses of fuel bed.

(*b*) The second point of interest relates to the determination of whether or not a different economy would result for different thicknesses.

54. *Loss of Fuel in the "Ash and Refuse"*.—Relative to the first question, it was thought that thick fuel beds, with their higher interior temperature and consequent higher temperature of the layer of ash beneath, together with the proportionately greater quantity of air which must necessarily pass through each unit area of the ash bed, would result in smaller ashpit loss; that is, according to the accepted notion of combustion and of the protecting effect of ash in quantity, the chances of air coming into contact with the imbedded fuel particles are in proportion to the product of the rate of air flow and the time that the ash remains upon the grate.

55. In Table 19, the averages of the available data for each thickness of fuel bed are given for the several grades. Compar-

TABLE 19 RELATION OF LOSS OF FUEL IN THE "ASH AND REFUSE" TO THE THICKNESS OF THE FUEL BED

Thickness of the Fuel Bed, Inches	Loss of Fuel, per cent of Total Combustible									
	Fuel 5.0602 W	Fuel 5.0200 W	Fuel 4.0700 W	Fuel 6.0402 W	Fuel 5.1610 W	Fuel 7.1610 —	Fuel 5.1006 W	Fuel 6.0200 W	Fuel 4.0300 W	Fuel 4.0703 W
1	2	3	4	5	6	7	8	9	10	11
4	2.91	10.29	6.66	4.31	....	....	....	8.39	....	....
5	2.60	7.98	4.13	4.63	2.96	2.45	1.76	4.27	6.21	2.18
6	2.20	5.61	3.33	3.26	2.69b	2.25	1.78	3.84	....	....
7	1.73	....	....	3.01	1.82	2.15	1.78	....	....	....

ing these results with the conditions of fuel bed area, (columns 3, 4, 5 and 6, Table 40), it will be seen that the variations in the latter had a minor effect upon the ash-pit loss. Comparing the ash-pit loss with the grate travel (column 12, Table 40), it appears that the latter *per se*, is not the factor in determining the percentage of loss. This is verified by the fact that the slight variations in the loss for the same grade and the same thickness of fuel bed show no relation to the difference in rates of combustion.

56. The explanation of the variation of loss due to difference in thickness for one grade, it is believed, agrees with the premise which led to the carrying out of the experiments.

Inspection of the difference in loss with different grades for the same thickness of fuel bed shows that there is a general coincidence between increased loss and the increased ash in the coal, and likewise the amount of excess air used in burning the coal, factors which affect the depth and the temperature of the ash layer. That these two factors determine the difference between losses for different grades, when the variations due to irregularities of operation are minimized, seems reasonable, but the effects can not be shown separately in the data available.

57. *Effect of Thickness of Fuel Bed upon Economy.*—Coke, just as anthracite coal, requires a moderately thick fuel bed in order

b. Tests 25 and 26 not included.

that the air supplied through the bed may be satisfactorily utilized. For bituminous coal, on the other hand, because of the volatile matter gasified in the voids between the coal particles, a much thinner fuel bed suffices. In the combustion process upon mechanical stoker grates, conditions are peculiar; at the feed end of the grate bituminous coal is under combustion with a deficiency of air, while over a greater or less portion of the grate, coke is under combustion with a thin fuel bed, and therefore with the possibility (depending upon the size of the fuel and the degree of caking which has occurred) of a greater or less excess of air. Thus the relative depths of fuel along the grate from the feed gate to the ashpit are the reverse of what would be considered good practice in hand firing. It has usually been assumed that thicker fuel beds for the chain grate stoker result in less excess of air and better economy. To what extent this would affect the choice of thickness of fuel bed in the comparison to be made of grades, became naturally a question for investigation.

58. Two series of experiments with the chain grate by W. L. Abbott*, one with No. 5 washed coal at a depth of fuel bed from 4.5 to 8.5 inches, and one with washed screenings at depths from 4 to 12 inches, resulted in minor variations only in the efficiency E_2. In explaining his results, Mr. Abbott concluded that "under these conditions, a thin fire increases the loss due to excess of air, but decreases that due to smoke and incomplete combustion. On the other hand, a thick fire reduces the excess of air, but increases the smoke and escaping combustible gas." The experiments were made in connection with a Babcock and Wilcox boiler; and to the length of the vertical pass, 14 tubes high, Mr. Abbott speculatively attributed some of the influence toward constancy of results.

59. With the equipment used in the experiments of the present paper, no smoke results under proper operation at any thickness of fuel bed, so that previous opinion seemed to confirm the expectation of a difference in results under such conditions. In outlining the experiments, thicknesses of fuel bed to be used were confined to those usual in practice. In the first few experiments, it became apparent that any differences in results due to different thicknesses of fuel bed were small, and it appeared extremely doubtful whether they could be shown upon the basis of over-all

* Jour. Western Soc. of Engineers, Vol. 11 p. 529.

results. The results up to test 27, due to the failure to obtain satisfactory flue gas samples, gave no indication as to how much the resulting efficiencies might be affected by radiation losses; consequently, tests 28 to 34, 37 to 40 and 45 to 52, were intended to be suitable for closer comparison.

60. All tests intended for comparison in this respect were to be run with a developed horse-power of as nearly boiler rating as possible; but in order that they might be consistent with the general plan to maintain as nearly an even rate of combustion as possible throughout any one test, and thus be available for other comparisons, they vary slightly above or below, depending largely upon the closeness with which the draft requirements were pre-estimated. For the smaller sizes of fuel, however, the problem as previously noted resolved itself into a determination of the most favorable conditions for maximum results and the results obtained are generally not only below 210 horse-power but themselves vary considerably.

Other desirable features in order that the results should be free from modifications in the air supply not due to variation in the thickness of fuel bed, are:

(*a*) Uniformity of the fuel.
(*b*) Uniform area of the fuel bed.
(*c*) Uniform conditions of the fuel bed.
(*d*) Uniformity as to clinkering or caking.
(*e*) Leakage influenced normally in respect to draft pressure.

61. Taking these desiderati into account, and guided by the exacting criticisms of the data that have been made in connection with the discussions of Table 5 to 14, a number of tests have been rejected. Those which conform more closely are tabulated in Tables 20 and 21. The following tests have been used in these tables:

Fuel 5.0200W,—tests 12, 13, 14, 15 and 16.
Fuel 4.0700W,—tests 17, 18, 19 and 20.
Fuel 6.0402W,—tests 21, 22, 23 and 24.
Fuel 5.1610W,—tests 28, 29 and 30.
Fuel 7.1610—,—tests 31, 33 and 34.
Fuel 6.0200W,—tests 48, 50 and 51.
Fuel 5.1006W,—tests 38, 39 and 40.

TABLE 20 RELATION OF EFFICIENCY TO THE THICKNESS OF THE FUEL BED

Thickness of Fuel Bed, inches	Fuel 5.0200W			Fuel 4.0700 W			Fuel 6.0402 W			Fuel 5.1610 W		
	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E_2	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E_2	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E_2	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	Boiler and Furnace" Efficiency, E_2
1	2	3	4	5	6	7	8	9	10	11	12	13
4	49.56	10.29	55.32	64.69	6.66	67.04	68.56	4.31	71.65	.....	....	.....
5	49.76	7.98	54.08	63.82	4.13	66.55	68.90	4.63	72.24	64.18	2.96	66.14
6	51.55	5.61	54.65	64.68	3.33	66.80	67.84	4.35	70.92	64.52	2.69	66.28
7	.....	.....	.....	.....	....	.....	66.98	3.01	68.46	65.19	1.82	66.38

TABLE 21 RELATION OF EFFICIENCY TO THE THICKNESS OF THE FUEL BED

Thickness of the Fuel Bed, inches	Fuel 7.1610—				Fuel 6.0200 W				Fuel 5.1006 W			
	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E_2	Furnace Effect	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E_2	Furnace Effect	Over-all Efficiency, E_1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E_2	Furnace Effect
1	2	3	4	5	6	7	8	9	10	11	12	13
5	64.40	2.45	65.90	618	57.57	4,69	60.43	395	70.10	1.79	71.37	738
6	64.58	2.31	66.13	646	58.10	3.78	60.41	401	68.42	1.73	69.64	718
7	64.56	2.15	65.97	644	.....	....	.....	...	66.49	1.78	67.69	705

62. The tests of fuel 5.1006W were affected by increased clinkering with increased thickness of the fuel bed. This feature seemed to be characteristic of this fuel. However, the three tests need not be given the same weight as the other tests selected. The tests of fuel 5.0602W, Table 22, may be usefully reviewed in this connection, for although the fuel bed areas were irregular as compared with the conditions for the tests of Tables 20 and 21, and although no attention was given to diminish sources of air leakage (the general efficiency was uniformly low on this account), it will be seen that the results for the different thicknesses of fuel bed are parallel to those of the closely similar grade 6.0402W. The lesser values for the 6-and 7-in. beds, as previously stated, page 25, are partly attributable to irregularity of the grate performance.

TABLE 22 FUEL 5.0602 W

Thickness of Fuel Bed inches	Over-all Efficiency E1 Item 73.1	Per cent of Total Combustible Lost in the Ash and Refuse	"Boiler and Furnace" Efficiency, E2 Item 72.1
4	64.72	2.91	66.66
5	64.42	2.60	66.16
6	61.91	2.20	64.38
7	62.00	1.73	63.09

63. The values for the furnace effect in Table 21, columns 5, 9 and 13, eliminate the variations due to radiation losses for those tests and serve as a qualitative check on the direction of the variations. For the fuel 7.1610—, the figures indicate that a decreased excess air resulted with thickened fuel bed. No difference is shown for the 5-and 6-in. fuel beds of fuel 6.0200W. For the fuel 5.1006W an increase in the excess air with thickened fuel bed is shown. Column 6, Table 24, gives directly the excess air figures for these tests. Inspection of the results for the different fuels shows, except for fuels 5.1006W and 5.0602W, a variation in the over-all efficiency E_1 of less than 2 per cent for the range of thickness tried.

64. The tendency toward decrease in ashpit loss as the fuel bed is thickened, has already been noted. Decrease in ashpit loss has its proportionate effect upon the over-all efficiency, so that the effect of different thicknesses upon the utilization of the air supply would be better shown by the efficiency E_2.

65. The effect of radiation and conduction losses for the tests of Table 20 and for the fuel 5.0602W cannot be shown. For those tests for which values for the radiation and conduction losses have been obtained, Table 16, it will be noted that the variations in those losses are not great for tests of one grade which were run at approximately the same rate of combustion, though exception must be made for the tests of fuel 5.1006W in which various irregularities occurred. These facts may be noted by inspection and it will be seen that the conclusions based upon the selected data above, it so happens, are not modified.

66. The reason E_2 fails to show a definite increase with increase in the thickness of the fuel bed, must be explained by the facts that leakage of air otherwise than through the fuel bed proper is proportional to the draft pressure, while the total rate of air flow is approximately constant under the conditions. Compare column 6, Table 24, for the tests analyzed. Stated in other words, the resistance of the natural leakage points is more nearly constant than is the fuel bed resistance which increases with increased thickness of the fuel bed.

67. Since the variation in results due to different thicknesses of fuel bed is only of such magnitude as may result from slight irregularities in furnace control, and is smaller than those due to possible irregularities under ordinary operation, it is evident that the selection of fuel bed depth should be governed by the attention required for uniform results. The test records from the furnace observer's report show that a five-inch fuel bed is most satisfactory for the fuels below the size 1¾ to 1; for the latter size, a 6-in. fuel bed was preferred.

IX. Relation of Grade to the Rate of Combustion and Horse Power

68. In the various tabulations given elsewhere in the report, the rates of combustion and horse-power obtained as results of the experiments are included. With the exception of those grades that show a maximum rate within the limits of the experiments, there is no doubt that the grades tested should give any range in rates of combustion desirable for stationary practice, provided suitable draft capacity is available.

69. Very satisfactory means are at hand for a comparison of the economic values of fuels, and it seems that some means of comparing rate of combustion and horse-power would be of commensurate usefulness. Obviously, such a comparison must give due consideration to draft conditions, and in any steam plant it would be most direct to compare fuels under the draft conditions prevailing. Mr. Abbott's tests show an interesting comparison of power obtained with various fuels under restricted draft conditions.

70. Numerous factors modify draft conditions, such as height and capacity of chimney, capacity of the draft fan, difference in the friction within the boilers, the capacity of the lateral flues, the number of furnaces served by each flue, the rate at which they are driven, etc. To consider all of these factors makes the question of draft conditions an extremely complicated one, so much so that all efforts of engineers to formulate a rational treatment of the subject has been unsuccessful. Empirical and approximate formulas supplemented by the judgment of the designer, are relied upon in designing draft systems, so that until more rational methods are devised, the results obtained under one set of plant conditions naturally must be looked upon as restricted in their application.

71. A satisfactory comparison of rates of combustion should eliminate all modifying factors except those of the furnace and the fuel, and the comparative figures obtained should be applicable to any condition of draft within the range of requirements of the fuels in question.

72. It is sometimes thought that a fundamental basis for comparing rates of combustion should be found in some arbitrarily chosen draft pressure, but though the knowledge of draft pressure requirements for each separate grade is invaluable for proper furnace control, a comparison of the draft pressure requirements over an extended range for several grades will show that as many relative values for rates of combustion may be selected as there are possibilities of choosing a basic draft pressure value. This is true for a comparison upon the basis of the drop in draft pressure, whether the drop for the fuel bed, or the boiler, or the two combined is considered. These complications are, of course, due to the fact that the draft pressure is never a measure of the quantity of air supply except under very special conditions.

It seems, therefore, that a logical comparison must necessarily be based upon factors that are fundamental in the actual combustion of the fuel and not upon incidental factors.

73. In the comparisons made below, the principles set forth on page 18 are made use of. It is evident that at a constant rate of air supply, the "ratio of the air used to the air supplied" is equal to the ratio (at constant rate of air supply) of the weight of fuel consumed, to the weight of fuel which it is possible to consume under complete utilization of the air supplied.

This ratio is termed here the *relative rate of combustion*.

$$\text{The relative rate} = \frac{\text{Rate of combustion obtained}}{\text{Maximum possible rate}} \times 100$$

$$= \frac{\text{air used per pound of fuel}}{\text{air supplied per pound of fuel}} \times 100$$

74. *Comparison of Rates of Combustion.* The following comparisons are based upon the principles just outlined. The values for the relative rate are those given in column 5, Table 24; the values for the volume of air supplied per second are those of column 6 of the same table. A review of the comparisons made under three (3) below will show that it is not essential that the figures for the volume of air supply exactly agree.

(1) A comparison of the larger grades upon the basis of 1.5 cu. ft. of air per sq. ft. of grate surface per second is as follows:

Test No.	Fuel	Relative Rate	Rate of Combustion (Test Data)
30	5.1610W	55.0	19.35
34	7.1610--	56.3	21.02
43	5.1006 W	63.8	24.45
63	4.0703 W	64.7	24.55

(2) Comparison of three smaller grades and the fuel 7.1610— at 2 cu. ft. of air supplied per second shows:

Test No.	Fuel	Relative Rate	Rate of Combustion (Test Data)
36	7.1610—	54.2	26.05
44	5.1006W	58.5	30.10
56	4.0300 W	42.4	21.70
47	4.0200 W	33.2	16.62

(3) Comparisons within individual grades with respect to relative rates of combustion with various rates of air supply show:

Fuel 4.0300W

Test No.	Air Supply	Relative Rate	Rate of Combustion (Test Data)
54	1.808	37.0	16.81
53	2.036	39.3	20.45
55	2.093	39.4	20.71
56	2.095	42.4	21.70

Fuel 6.0200W

49	1.735	30.6	13.27
50	1.759	36.0	15.86
51	1.860	35.4	16.28
48	1.888	35.1	16.81
a45	1.919	28.2	13.35
52	1.933	37.2	17.80
b47	2.026	33.2	16.62
a46	2.154	29.2	15.71

a. Very dry fuel.
b. Very wet fuel.

Fuel 5.1610W

30	1.42	55.0	19.61
29	1.46[1]	52.3[1]	19.06
28	1.48[1]	52.4[1]	19.35

NOTE 1. Gas sample diluted by leak.

Fuel 7.1610—

31	1.408	55.8	19.32
32	1.423[2]	54.0[2]	18.90
33	1.466	56.2	20.44
34	1.507	56.3	21.02
35	1.664	56.9	23.40
36	1.943	54.2	26.05

NOTE 2. Gas sample diluted by leak.

Fuel 5.1006W

42	0.96	64.6	15.92
38	1.102	65.8	17.88
39	1.166	65.1	18.32
40	1.233[3]	63.0[3]	19.03
41	1.396	65.9	23.51
43	1.503	63.8	24.45
44	1.997	58.5	30.10

NOTE 3. Fuel bed clinkered badly.

Fuel 4.0703W

64	0.655	72.5	12.33
59	0.847	71.6	15.73
60	1.088	64.8	18.27
61	1.230	63.9	20.10
57	1.250	65.2	20.71
58	1.266	64.4	20.68
63	1.480	64.7	24.55
62	1.589	63.1	25.79

Inspection of these tabulations shows for the larger grades a tendency toward decreasing relative rate as the rate of air supply and the rate of combustion increase; with the fine sizes an opposite tendency is shown, but with all grades the average magnitude of the relative rate characterizes the fuel grade. This comparison it will be observed, is simply a special adaptation of the air supply data.

75. *Comparison of Horse-power.* No fundamental unit of comparison of the power obtainable with various fuels is at hand as there is in the case of the rates of combustion. However, since at constant temperature of the gases the horse-power developed is principally determined by the rate of air supply, comparison upon the basis of equal rate of air supply and the actual horse-power obtained appears to be most logical. A comparison in this manner is made below. The results, however, apply only to the 210 H. P. boiler supplied by a grate area of 38.2 sq. ft., and since actual figures and not ratios are compared, accuracy in this demands that the air supply in each case should be the same. In the comparisons made, horse-power values at rates of air supply closely agreeing in value with the rate of air supply taken as a reference datum, have been chosen and a correction has been applied in each case by multiplying the values by the ratio of the unit rate of air supply chosen to the actual rate of air-supply, the assumption being that for moderate variations in the rate of air supply and horse power, the efficiency variation would be negligible.

1. Air supply, cu. ft. per second = 1.5 × 38.2

Test No.	Fuel	Air Supply	H. P.	H.P. Corrected to basis of 1.5 cu. ft. of air supply
30	5.1610 W	1.421	215.3	227.0
34	7.1610 —	1.507	231.9	231.0
43	5.1006 W	1.503	271.5	270.5
63	4.0703 W	1.480	283.1	286.7

2. Air supply, cu. ft. per second = 2.0 × 38.2

Test No.	Fuel	Air Supply	H. P.	H.P. Corrected to basis of 2 cu.ft. of air supply
36	7.1610 —	1.943	275.0	282.9
44	5.1006 W	1.997	321.8	322.0
56	4.0300 W	2.095	210.4	201.0
47	6.0200 —	2.026	151.4	149.5

X. Draft and Draft Pressure Requirements of the Different Grades

76. Inspection of the draft pressure data given in Tables 5 to 14 and in the curves numbered 3 in Fig. 1, 3, 5, 6 and 8, will show the characteristic differences in the draft pressure requirements for various rates of combustion of different grades. The rate of increase of the drop in draft pressure through the fuel bed and grate as the rate of air supply is increased, is shown for five grades by the slopes of the curves in Fig. 10. The curves are shown to be straight lines within work-

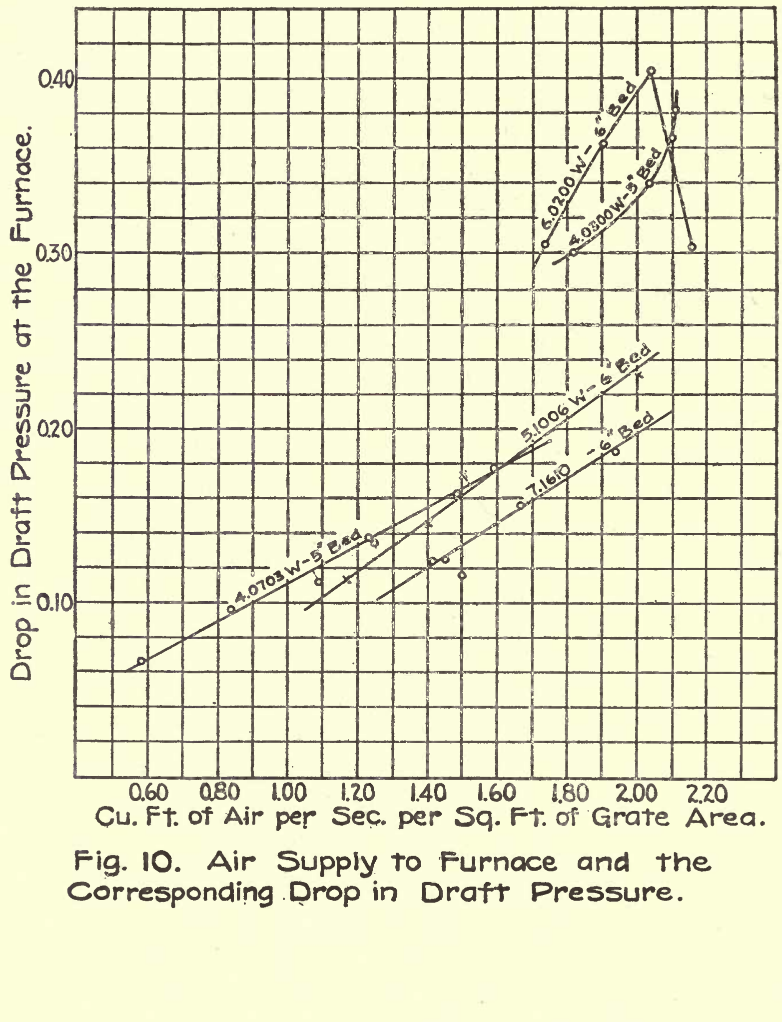

Fig. 10. Air Supply to Furnace and the Corresponding Drop in Draft Pressure.

ing range. Below the ranges shown, such curves, it is known, bend toward the horizontal. Variation from a straight line within the range of these experiments is due to an increased proportion of leakage induced by irregularities in the fuel bed or by clinkering or caking. The curve for fuel 4.0300 W shows the influence of gradually increased caking. As previously noted, the smaller grades, 6.0200 W and 4.0300 W reach a maximum respectively at about 2.0 and about 2.1 cu. ft. of air supplied per square foot of grate surface per second. The air actually passing through the fuel bed itself was, of course, in all cases less than the amounts shown.

77. *General Draft Relations.* For the purpose of showing the comparisons in Table 23, one test with a 5-in. fuel bed and at as

TABLE 23 AIR SUPPLY AND DRAFT PRESSURES FOR GRADES TO DEVELOP THE BOILERS' RATED CAPACITY

5-inch thickness of fuel bed

Index No.	Test No.	Horse Power	Air Supply, cu. ft. per sq. ft. of Grate per sec.	CO_2 Per cent	Drop in Draft Pressure through			Combustible Consumed per sq. ft. of Grate Surface per hour, pounds
					Fuel and Grate inches Water	Fuel, Grate and Boiler inches Water	Boiler inches Water	
1	2	3	4	5	6	7	8	9
5.1610 W	30	215.3	1.421	9.38	0.10	0.32	0.22	19.61
7.1610—	31	216.2	1.408	9.32	0.09	0.32	0.23	19.32
5.1006 W	38	211.5	1.102	11.09	0.09	0.23	0.14	17.85
4.0703 W	60	214.8	1.088	11.26	0.11	0.24	0.13	18.27
4.0700 W	17	213.3	.....	.....	0.13	0.45	0.32	19.92
5.0602 W	8	216.3	.....	.....	0.09	0.32	0.23	19.71
6.0402 W	23	207.6	.....	.....	0.11	0.35	0.25	17.28
4.0300 W	56	210.4	2.095	6.90	0.38	0.89	0.51	21.70
6.0200 W	52	175.5	1.933	6.20	0.36	0.83	0.47	17.80

nearly boiler rating as possible, was made with each grade.

Tests 8 and 17 as elsewhere explained are not directly comparable with the tests of the remaining grades. With increased attention to the fuel bed for those tests, less air for the same horse-power would have resulted, and consequently the draft pressure drop through the boiler would have been less. With fuel 6.0200 W, 173.5 horse-power was developed. The builders' rated horse-power as previously noted was not obtainable with that fuel. Air supply figures are not calculated for those tests for which the flue gas samples were unsatisfactory.

In these tests, as in all tests, the quantity of excess air could have been reduced by keeping the fuel slightly banked at the rear of the grate. In so operating, increased temperature of the furnace gases and corresponding decreased draft requirements throughout for the same horse-power developed would result, but with uncertain effect upon the ashpit loss and the over-all economy.

XI. Air Supply

78. In Table 24 are presented the various air supply data for tests 28 to 64. A description of the manner of taking the gas samples, upon the analyses of which computations of these items are based, is given on page 117. The items of columns 3 and 4 have been referred to the basis of one pound of combustible consumed. Multiplying them by the factor $(100-c) \div 100$ will convert them to the basis of one pound of combustible as fed, where c is the per cent of carbon in the ash and refuse referred to the combustible as fed. The ratios, columns 5 and 6 and the rate column 8 are, of course, independent of the fuel unit.

The items in the various columns were calculated as follows:

Column 3. Weight of air supplied per pound of combustible consumed,

$$= \frac{N}{.33\,(CO_2 + CO)} \times \frac{C - c}{100 - c},$$

where N, CO_2 and CO denote respectively the percentages of nitrogen, carbon dioxide and carbon monoxide in the flue gases as given in Table 36, C denotes the per cent of carbon in the combustible = Item 37.1, Table 39, and c the per cent of combustible in the carbon lost in the ash and refuse. Column 5, Table 15.

Column 4. Weight of air used per pound of combustible consumed,

$$= \frac{N - 3.77 \times O}{.33\,(CO_2 + CO)} \times \frac{C - c}{100 - c},$$

where O denotes the percentage of oxygen in the flue gas.

This item gives the minimum air requirement for the combustible composition consumed.

Column 5. *Ratio of air used to air supplied, per cent,*

= Column 4 ÷ Column 5.

It also may be obtained directly from the flue gas analysis by means of the formula,

$$\frac{\text{Air used}}{\text{Air supplied}} = \frac{N - 3.77 \times O}{N}$$

Column 6. *Ratio of excess air to air used, per cent,*

$$= \frac{3.77 \times O}{N - 3.77\ O}$$

Column 7. *Weight of dry flue gases per pound of combustible fed,*

$$= \frac{11\ CO_2 + 8\ O + 7\ (CO + N)}{3\ (CO_2 + CO)} \times \frac{C - c}{100}$$

Column 8. *Cu. ft. of standard air per sq. ft. of grate surface per sec.,*

= (Column 3 × lb. of Comb. consumed per sq. ft. of grate surface per Hr. × 12.39) ÷ 3600.

79. The resulting air supply items of this table are extremely interesting in that they show the principal cause of variation in the economic results of the tests. The relation thereto and the relation to the rate of combustion have been discussed in the preceding pages.

TABLE 24 AIR SUPPLIED

No.	Laboratory File No.	Air per lb. of Combustible Consumed: Lb. Supplied	Air per lb. of Combustible Consumed: Lb. Used	Ratio of Air Used to Air Supplied, per cent	Ratio of Excess Air to Air Used, per cent	Dry Flue Gases per lb. of Combustible Fed, pounds	Cu. ft. Standard Air per sec. per sq. ft. of Grate Surface
1	2	3	4	5	6	7	8
28	93—5.1610 W	22.28	11.67	52.4	90.94	22.19	1.484
29	94— "	22.21	11.60	52.3	91.51	21.94	1.457
30	95— "	21.05	11.58	55.0	81.76	20.75	1.421
31	96—7.1610—	21.55	12.05	55.8	79.29	21.00	1.432
32	97— "	21.88	11.82	54.0	85.09	21.63	1.423
33	98— "	20.85	11.72	56.2	77.93	20.65	1.466
34	99— "	20.83	11.73	56.3	77.56	20.60	1.507
35	100— "	21.30	11.96	56.9	75.70	20.50	1.692
36	101— "	21.67	11.75	54.2	84.41	21.43	1.943
37	102—5.1006 W	19.00	11.96	62.9	58.82	18.99	1.278
38	104— "	17.93	11.81	65.8	51.81	17.86	1.102
39	107— "	18.50	12.05	65.1	53.52	18.38	1.166
40	109— "	18.83	11.86	63.0	58.70	18.75	1.233
41	110— "	17.25	11.37	65.9	51.73	17.32	1.396
42	112— "	17.91	11.58	64.6	54.83	17.62	0.980
43	113— "	17.86	11.40	63.8	56.65	17.89	1.503
44	114— "	19.27	11.28	58.5	70.82	19.28	1.997
45	115—6.0200 W	41.77	11.73	28.2	256.11	38.54	1.919
46	116— "	39.84	11.65	29.2	241.86	38.35	2.154
47	117— "	35.41	11.72	33.2	202.25	35.08	2.026
48	118— "	32.64	11.51	35.2	183.64	31.72	1.888
49	119— "	38.00	11.72	30.9	224.33	36.34	1.735
50	120— "	32.23	11.60	36.0	177.93	30.80	1.759
51	121— "	33.20	11.65	35.1	185.12	32.17	1.860
52	122— "	31.56	11.71	37.2	169.47	30.76	1.933
53	124—4.0300 W	28.93	11.35	39.3	154.85	27.33	2.036
54	125— "	31.25	11.56	37.0	170.45	29.65	1.808
55	126— "	29.37	11.58	39.4	153.57	27.94	2.093
56	127— "	28.05	11.89	42.4	135.87	26.40	2.095
57	128—4.0703 W	17.54	11.43	65.2	53.46	17.32	1.250
58	129— "	17.79	11.43	64.4	55.70	17.82	1.266
59	130— "	15.66	11.21	71.6	39.67	15.52	0.847
60	131— "	17.30	11.21	64.8	54.34	17.31	1.088
61	132— "	17.78	11.36	63.9	56.52	17.72	1.230
62	133— "	17.90	11.30	63.1	58.47	17.87	1.589
63	134— "	17.52	11.33	64.7	54.63	17.47	1.480
64	135— "	15.45	11.20	72.5	37.88	15.49	0.655

APPENDIX I

THE TESTING PLANT

APPENDIX I

THE TESTING PLANT

81. *Equipment Used.*—The equipment especially provided for the steaming tests of fuels is located in the south bay of the Mechanical Engineering Laboratory. It includes a 210 horse-power Heine water-tube boiler, designed for a working pressure of 160 pounds, a Green traveling link grate and furnace, a Sturtevant induced draft apparatus and economizer,* and the usual small auxiliary apparatus. Additional equipment for use in experimental investigations includes the usual and special apparatus for weighing the coal and ash, for weighing and measuring feed water, for determining pressures, temperatures, and the quality of the steam, and for sampling and analyzing gases. Special apparatus for high temperature measurements which are available includes the Wanner optical pyrometer, Fery radiation pyrometer, thermo-electric, and platinum resistance thermometers.

82. *General Plan.*—The general plan of the testing plant is shown in Fig. 11. This arrangement was adopted with the object of facilitating experimentation, but was limited somewhat by the available floor area. The space occupied by the plant is 30 by 45 feet. The floor is of concrete, and all water supply pipes, drains, exhaust pipes from the auxiliary engines, and the blow-off pipes from the boiler, are laid in concrete trenches which connect at the rear of the plant with a 24-by 24-inch branch of the main laboratory pipe tunnel. The trenches are covered with cast-iron floor plates flush with the floor. The 24- by 24-inch trench, carrying the blow-off pipe and drains, leads through the south wall of the building and discharges into a creek running near by.

To provide easy access to the breeching and upper parts of the boiler, there is a deck surrounding the setting on three sides and extending to the south wall of the building at an elevation of 10½ ft. This is constructed of iron channels supported by iron columns and wall brackets. The floors are of iron grating and plates. It extends along the west wall and joins the central gallery of the building, and along the south wall toward the rear of the boiler room opens into a 14 by 24 ft. laboratory at the same elevation, (Fig. 11 and Fig. 14.) At the front of the boiler, (Fig. 12,)

*Not used in the present experiments.

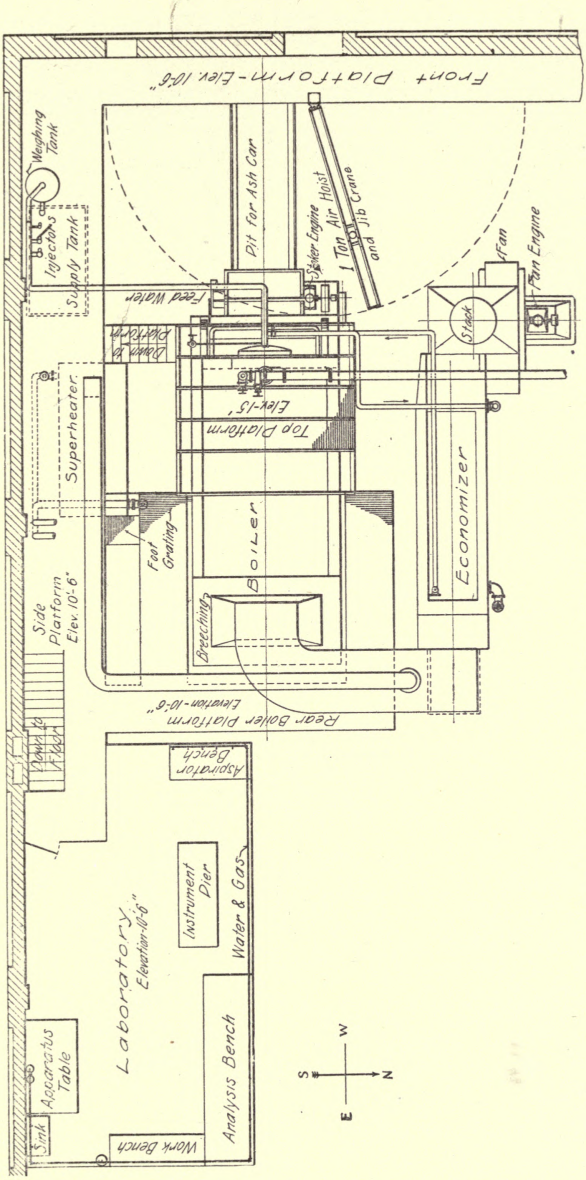

FIG. 11 GENERAL PLAN OF THE TESTING PLANT.

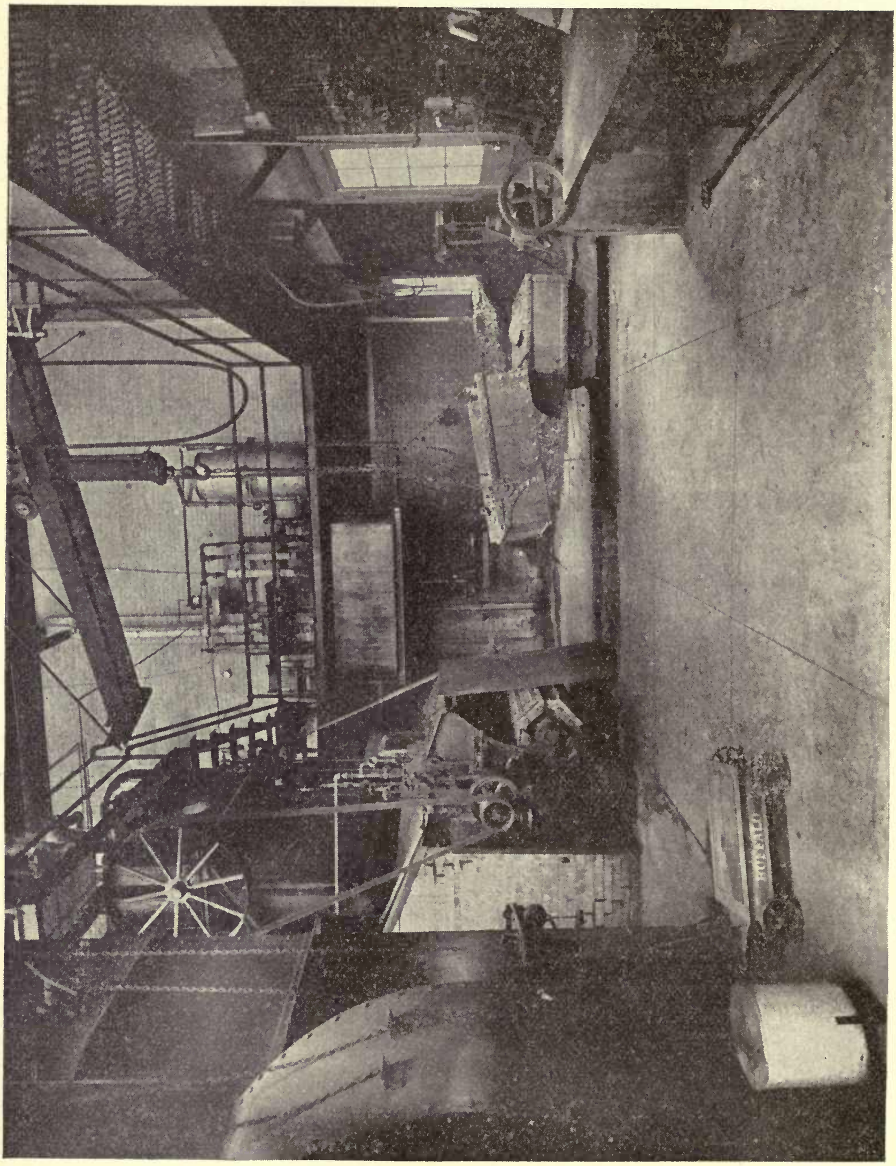

FIG 12. FRONT VIEW OF BOILER ROOM

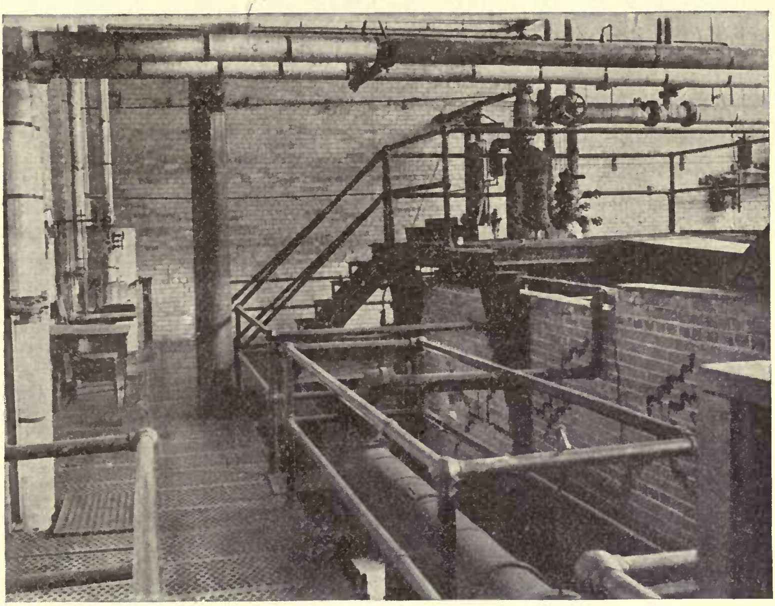

FIG. 13. ARRANGEMENT OF THE UPPER DECKS

FIG. 14. LABORATORY FOR GAS ANALYSIS

a short stair leads to a platform grating surrounding the uptake and header, and on the main deck at the foot of these stairs are located the feed water weighing tank and injectors. The 14-by 24-ft. laboratory, Fig. 14, is used for all observations that can be made at a distance from the boiler. Here are located the aspirators for drawing gas samples, apparatus for gas analysis and the various kinds of indicating and recording apparatus for temperature measurements. A 3- by 7-ft. stone-capped instrument pier is provided to support galvanometers and delicate instruments.

Fig. 11 shows, also, the location of a Foster independently fired superheater which is a part of the general equipment of the Steam Engineering Laboratory.

82. *Boiler and Combustion Chamber.*—The Heine water-tube boiler installed in this plant is similar in every respect to the boilers which were in use for some two years at the fuel testing plant of the United States Geological Survey at the World's Fair Grounds, St. Louis, and with the exception of material used in the construction, the setting is the same and the boilers similarly baffled. The essential difference is in the furnaces, the Geological Survey's boilers being equipped with plain and with rocking grates.

A sectional elevation of the boiler is shown in Fig. 15 and the baffling and other features of the setting in Fig. 16. The walls of

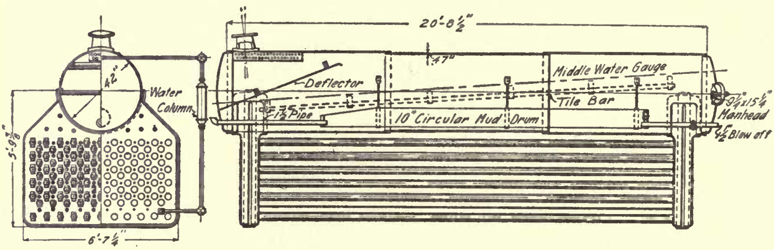

FIG. 15. DETAILS OF THE 210 H. P. HEINE BOILER

the setting are 20 in. thick with a 2-in. air space as shown. Hard face brick, closely laid, were used on the outside walls, and in the furnace, combustion chamber and gas passage, the fire brick lining extends to the top row of tubes. Regular Heine *C* tube tiles are used in the construction of the combustion chamber roof which extends to within 43 inches of the rear water leg.

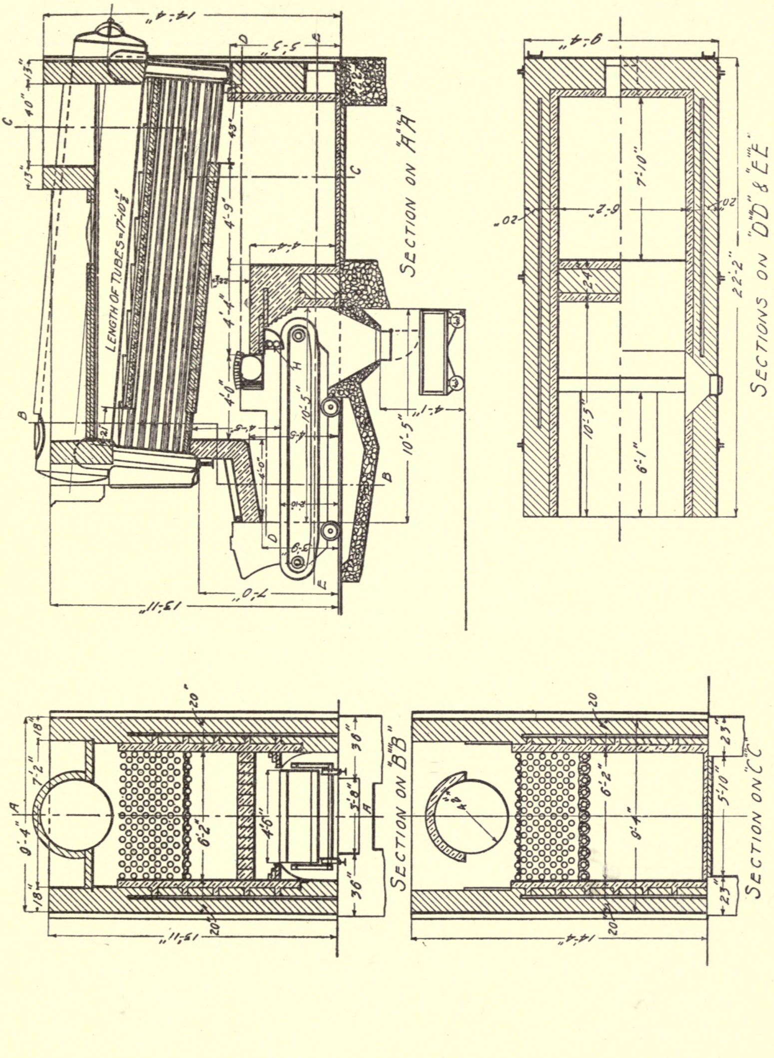

FIG. 16. DETAILS OF THE BOILER SETTING

83. *The Principal Dimensions of the Heine Boiler*, and the traveling link grate and furnace are as follows:

Rated horse-power		210.0
Number of steam drums		1
Length of steam drum	feet	21.583
Inside diameter of drum	inches	42
Number of tubes		116
Outside diameter of tubes	inches	3.5
Inside diameter of tubes	inches	3.26
Mean length of tubes exposed to gases	feet	17.875
Kind of grate		Green traveling link
Width of grate	inches	54
Effective length of grate	inches	102
Area of grate surface	sq. ft.	38.2
Area of air space in grate	sq. ft.	8.25
Ratio of air space to grate area		0.216
Mean height of furnace between ignition arch and bridge wall	inches	48
Length of ignition arch	inches	48
Mean height of ignition arch	inches	15
Kind of draft		Induced
Height of stack above grate	feet	45.5
Diameter of stack	inches	40.0
Sectional area of stack	sq. in.	1250
Area of gas passage over the bridge wall	sq. in.	1665
Smallest area of gas passage between grate and lower baffle	sq. in.	1665
Area of opening through lower baffle	sq. in.	1677
Smallest area of gas passage between upper and lower baffle	sq. in.	1612
Area of opening through upper baffle	sq. in.	746
Area of gas passage entering breeching	sq. in.	625
Ratio of smallest gas passage to grate area		.113
Water heating surface in tubes	sq. ft.	1900
Water-heating surface in shell, legs, etc	sq. ft.	127.4
Total water-heating surface	sq. ft.	2027.4
Ratio of heating surface to grate surface		53.1
Total water space	cu. ft.	273
Total steam space	cu. ft.	85

84. *Grate and Furnace.*—The traveling link grate, Fig. 17, and furnace are the standard type supplied by the Green Engineering Company. Two features of this grate are the long flat ignition arch and the high bridge wall. The special ledge plates shown in the section *B B*, Fig. 16, are, however, a slight modification of the standard installation, being so designed that for experimentation, a change can be made to a hand-fired grate without changing the walls of the setting.

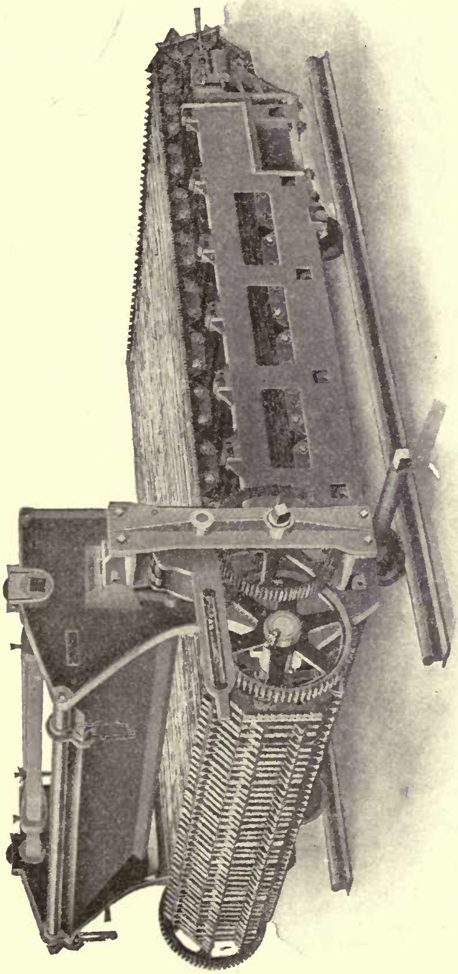

FIG. 17. THE GREEN TRAVELING LINK GRATE

85. *The Water-Back.*—The Harrington automatic water-back installed with this grate is indicated at *H* in Fig. 16. It consists of two connected iron cylinders extending across the width of the grate, supported by the furnace settings and so hung that the lower one rides upon the ash and clinker, and is free to move in a circular arc about the axis of the upper stationary cylinder. The free adjustability of the lower cylinder necessitates a flexible coupling to the water supply and for this reason the circulating water is supplied independently of the boiler.

86. *Ash Handling.*—Ash from the grate is removed by means of a car which runs along a track at the bottom of the ash tunnel to the front of the boiler, where it is handled by a one-ton air hoist and jib crane for removal to trucks, or, first, to scales for weighing as desired. The ashpit is provided with a concrete hopper fitted with a hinged door so that the ash may be retained in the hopper while the ash car is being emptied.

87. *Induced Draft.*—The plan and elevation of the induced draft system and economizer are shown in Fig. 18. By reference

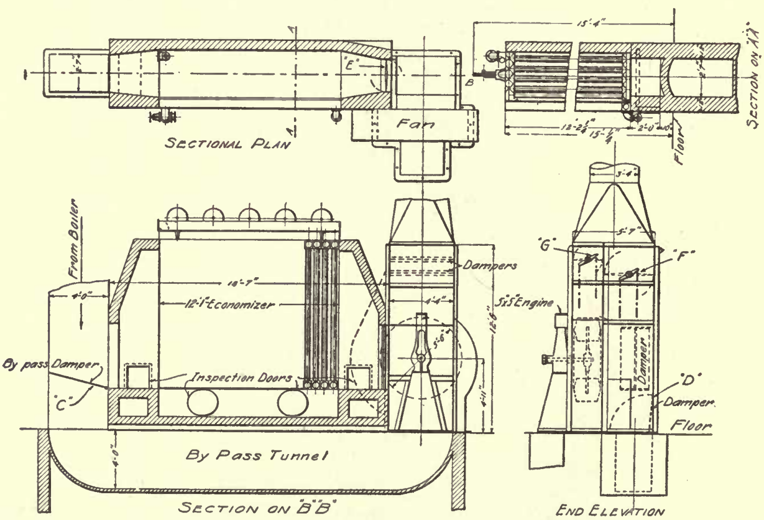

Fig. 18. Sectional Views of the Induced Draft System and the Economizer.

to this it will be seen that there is a by-pass tunnel for the escaping gases so that when it is desired to cut out the economizer, damper *C* can be thrown to a vertical position, damper *E* set at right angles to the center line of the economizer, and *D* raised to a vertical position. Provision is also made for direct chimney draft by leaving damper *G* as shown and setting *F* vertical, the draft pressure being controlled by an independent damper in the breeching or by the damper *F*. The height of the stack, however, is not sufficient for operation under chimney draft.

The fan is a regular Sturtevant steel plate exhaust fan with blast wheel 5½ ft. in diameter and 22½ in. in width, directly connected to a 5 by 5 upright enclosed engine mounted on a sub-base which stands directly against the fan housing. The inner bearings of the engine are water cooled. Since installation, this engine has been fitted with a Waters' throttling governor.

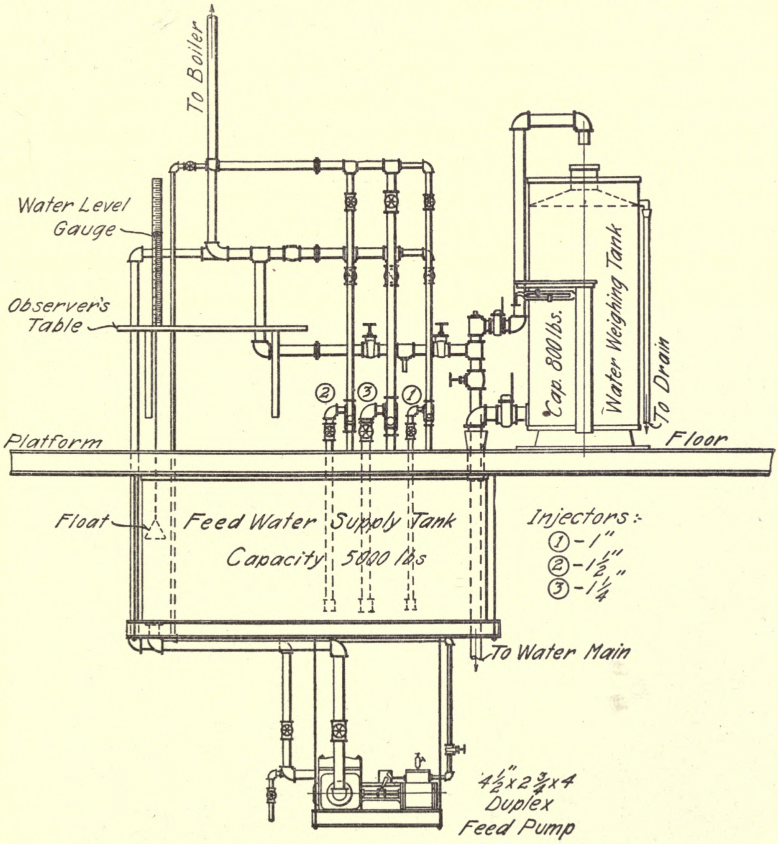

FIG. 19. SHOWING ARRANGEMENT OF WATER-WEIGHING APPARATUS, INJECTORS, PUMP, ETC.

88. *The Economizer.*—The economizer was not used in these tests, but to complete the description of the plant a description is given. This economizer, one of B. F. Sturtevant Company's standard design, consists of 80 pipes, 4 9-16 in. outside diameter and 9 ft. in length, giving a total heating surface of 1001 sq. ft., (4.77 sq. ft. per rated boiler horse-power independent of economizer), and a capacity of 5040 lb. of water. The pipes are arranged in twenty sections of four pipes each, and are staggered. The location of the economizer is shown in Fig. 11. The feed water connections are by-passed so that the economizer may be cut in or out at will. During the series of tests reported in this paper, the connections between the boiler and economizer were removed.

89. *Piping.*—For supplying feed water to the boiler there are provided both injectors and a 4½- by 2¾- by 4-inch duplex steam pump; the latter is controlled by a Vigilant feed water regulator. All steam and feed lines are well lagged with magnesia covering, and all water by-pass valves are in duplicate, and the intervening dead space vented so that no undetected leakage can occur; flanged couplings are also used to provide for blanking off the by-pass lines when necessary. A similar arrangement of stop-off valves and vents is used for detecting leakage through the blow-off valves.

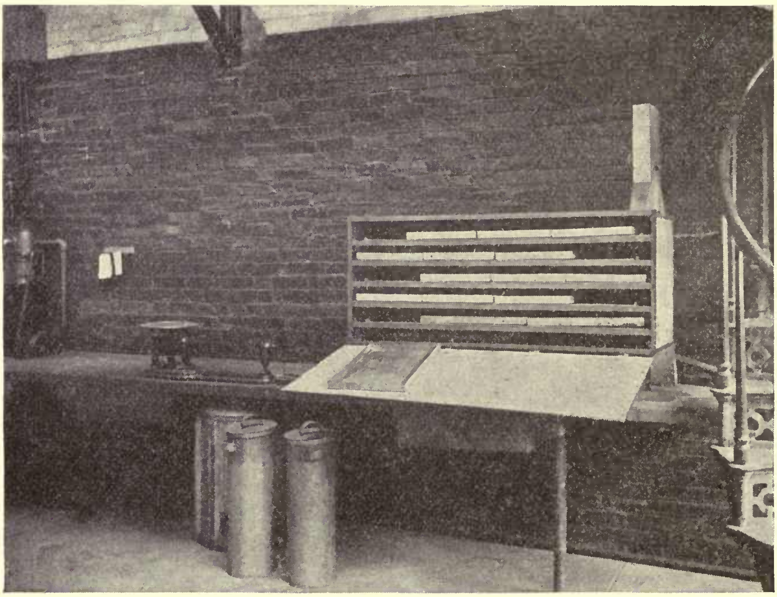

FIG. 20. OVEN FOR AIR-DRYING COAL SAMPLES

90. *Setting Wall Diagrams.*—The diagrammatic sketches, Fig. 21 and 22, which show opposite sides of the boiler setting, give the location of the points at which various routine and special observations have been taken. They are the permanent lab-

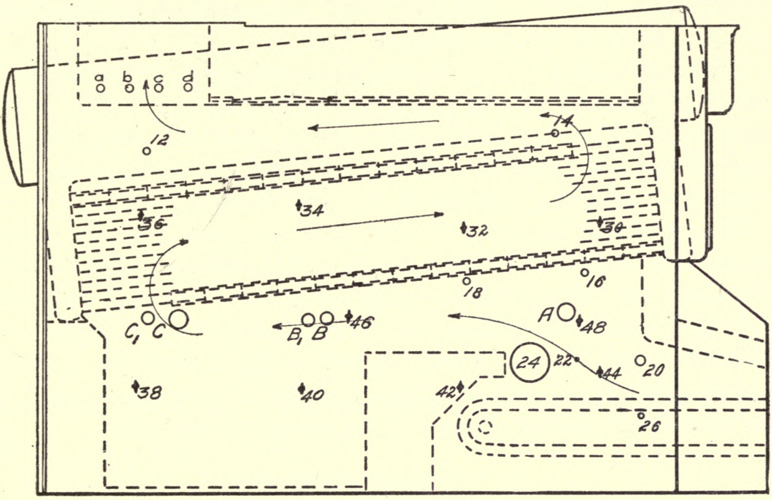

FIG. 21. NORTH SETTING WALL

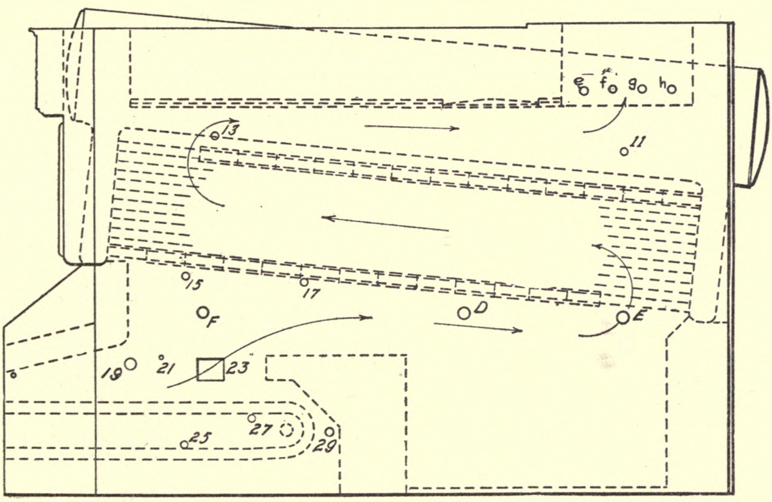

FIG. 22. SOUTH SETTING WALL

oratory record of such locations, consequently some openings appear in the diagram which have been subsequently closed.

The points 11 to 29, excluding 23 and 24, which are the furnace inspection doors, are openings used at various times for the measurement of draft pressure and temperature observations within the furnace or gas passage.

Openings *a*, *b*, *c*........*h*, were used for special investigations relating to methods of gas sampling. See page 88. The points numbered in even numbers from 30 to 48 show the location of mercury thermometers imbedded in the surface of the wall; they are useful in keeping a check on the wall temperature.

The openings A, B, B_1, C, (Fig. 21), etc., are used for special furnace temperature measurements with various types of pyrometers and for observations relating to the extent of the flame within the combustion chamber. They consist of iron pipes extending through the walls and capped on the outer end. The interior is observed through smaller holes in the caps, and the holes closed by sliding shutters between observations.

APPENDIX II

EXPERIMENTS RELATING TO FLUE GAS DATA AND METHODS OF MAKING AND RECORDING FURNACE OBSERVATIONS

APPENDIX II

Sampling Flue Gases

91. It is common experience that samples of flue gas taken simultaneously at different points across any section of the gas stream flowing through a boiler, show different proportions of air and combustion gases. This condition is due to the fact that the air supplied to the furnace is never uniformly distributed, and does not become diffused in the passage through the boiler; also, unless the utmost care is observed, samples taken at the breeching or across the base of the stack may be further affected by leakage of air through the setting. The worst feature of the latter occurrence, even when the analysis is desired only for computation of heat loss, is that such excess air has even less chance to become diffused than that entering the furnace.

92. For the purpose of determining what the actual conditions were in this experimental plant, eight separate sampling pipes, perforated with $\frac{1}{16}$ in. holes along their full length were inserted at points *a*, *b*, ------*h*. See Fig. 21 and 22, page 85. The setting walls are of pressed brick and every precaution was taken to insure against leakage of air into the gas passages between the furnace and sampling tubes. The sampling tubes were connected by separate tubes to a large Richards aspirator. While the gas was thus being drawn at a uniform rate for all tubes, one-minute samples were simultaneously drawn from the tubes through connections. Four sets of samples were drawn in this manner on different days. Analyses of these are given in Table 25, which shows the percentage by volume of carbon dioxide in the gases.

TABLE 25 Variation in Flue Gas Samples

	Trial	Tubes							
		a	b	c	d	e	f	g	h
Carbon Dioxide per cent	A	4.2	4.8	4.6	4.6	5.6	4.2	5.2	4.2
	B	4.8	5.4	5.1	....	7.1	7.1	7.1	4.5
	C	7.2	8.4	10.6	10.8	8.8	6.2	7.2	5.8
	D	7.5	8.0	9.6	10.4	10.2	9.6	8.8	7.3

93. The imperfect mixing of the gases and air as they come from the furnace is attributed to the fact that free air enters along

the sides and rear of the grate, and as there are no mixing baffles in the furnace and the boiler is baffled horizontally, the different streams are never wholly intermixed. The outside streams are consequently diluted. Tracing the course through the boiler of an imaginary layer of free air flowing into the furnace at the rear of the grate, will afford sufficient explanation for the difference in dilution shown.

94. As a result of the conditions disclosed by these results, it was decided to try some means of mixing the gases, the outcome of which is the device shown in Fig. 23. This arrangement con-

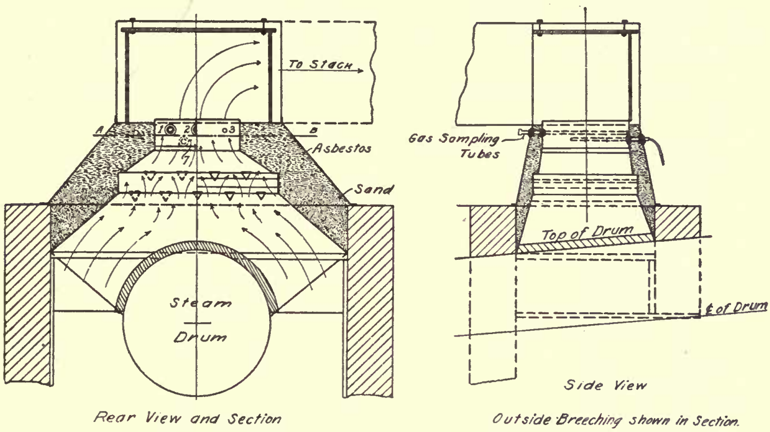

Fig. 23. Sections of Breeching Showing Flue Gas Mixing Baffles and Sampling Tubes

sists of a well insulated false or inner breeching, within which the gases are compelled to pass through a series of mixing baffles and converge into an uptake constricted to 21 by 21 in., the latter forming a sampling section across which the gases are thus compelled to flow with nearly uniform velocity. To prevent leakage from the outer breeching into this inner breeching, all seams are effectually closed with iron cement, the filling of insulating sand acting as a further precaution.

95. Three gas sampling tubes 1, 2, and 3, Fig. 23, consisting of $\frac{3}{8}$- in. pipe, capped on the inner end, and perforated with a double row of $\frac{1}{16}$ in. holes spaced 3 in. apart along the under side, were equally spaced across the gas passage. These were brought together on the outside by means of $\frac{1}{4}$-in. lead pipe uniting in a junction box, from which a single lead pipe conducted the gas sample to the gas apparatus and aspirator. By means of tees in

the leads to the junction box, simultaneous samples could be drawn from each of the separate tubes while the aspirator was in action drawing the regular test sample. A number of samples were taken in this manner during several tests, care being taken as in the previous experiments that the rate of sampling from each tube was equal. The results of analyses of these samples are given in Table 26 and 27. An inspection of the results shows that marked improvement in the sample was thus effected.

TABLE 26 COMPARISON OF GAS SAMPLES DRAWN FROM SEPARATE TUBES FIG. 23

No.	Per cent Carbon Dioxide				No.	Per cent Carbon Dioxide			
	Tube No. 1	Tube No. 2	Tube No. 3	Average		Tube No. 1	Tube No. 2	Tube No. 3	Average
1	7.6	7.2	6.9	7.2	18	11.7	11.7	11.4	11.6
2	7.5	7.0	6.8	7.1	19	10.7	10.0	8.5	9.7
3	7.5	7.1	6.8	7.1	20	9.8	8.9	8.0	8.9
4	11.1	10.9	10.6	10.9	21	9.9	9.9	8.8	9.5
5	9.8	9.5	9.4	9.6	22	11.2	10.0	9.0	10.1
6	4.5	4.7	4.9	4.7	23	10.1	9.7	9.0	9.6
7	3.9	3.7	3.7	3.8	24	11.4	11.5	11.2	11.4
8	6.8	6.1	6.0	6.3	25	11.0	11.1	11.0	11.0
9	6.7	6.5	5.8	6.3	26	9.2	9.2	9.2	9.2
10	6.7	6.1	5.9	6.2	27	8.5	8.6	8.3	8.5
11	6.2	6.0	5.8	6.0	28	11.1	10.5	10.5	10.7
12	8.2	7.1	6.6	7.3	29	12.6	11.1	10.7	11.5
13	12.8	11.1	10.8	11.6	30	13.6	13.9	13.8	13.8
14	12.5	11.2	10.8	11.5	31	9.9	10.0	9.8	9.9
15	11.9	11.3	10.5	11.2	32	12.3	10.8	10.5	11.2
16	13.9	13.8	13.4	13.7	33	10.2	9.2	9.0	9.5
17	12.1	11.6	10.9	11.5	34	9.6	9.6	9.3	9.5

TABLE 27 COMPARISON OF GAS SAMPLES DRAWN FROM SEPARATE TUBES FIG. 23

No.	Carbon Dioxide				Oxygen				Nitrogen			
	Tube No. 1	Tube No. 2	Tube No. 3	Av.	Tube No. 1	Tube No. 2	Tube No. 3	Av.	Tube No. 1	Tube No. 2	Tube No. 3	Av.
1	5.7	5.8	5.7	5.7	14.4	14.3	14.3	14.3	79.9	79.9	80.0	79.9
2	8.1	7.8	7.5	7.8	11.6	11.9	12.2	11.9	80.3	80.3	80.3	80.3
3	8.5	7.7	7.5	7.9	11.5	12.4	12.7	12.2	80.0	79.9	79.8	79.9
4	7.6	7.2	6.9	7.2	12.1	12.5	12.8	12.5	80.3	80.3	80.3	80.3
5	7.5	7.0	6.8	7.1	12.1	12.7	12.8	12.5	80.4	80.3	80.4	80.4
6	7.5	7.1	6.8	7.1	11.7	12.8	13.1	12.5	80.1	80.8	80.1	80.3
7	13.9	13.8	13.4	13.7	5.8	5.8	5.8	5.8	80.3	80.4	80.8	80.5
8	12.1	11.6	10.9	11.5	6.7	7.4	8.3	7.5	80.8	81.0	81.2	81.0
9	9.4	8.8	8.3	8.8	10.2	10.9	11.3	10.8	80.4	80.3	80.4	80.4

96. *Improved Form of Gas Sampling Tubes.* At the close of the present series of tests, an improved form of gas sampling tube designed by the writer was introduced. This consists of a pair of tubes intended to compensate for drop in pressure along the tube. See Fig. 24. The lower parts of the loops are per-

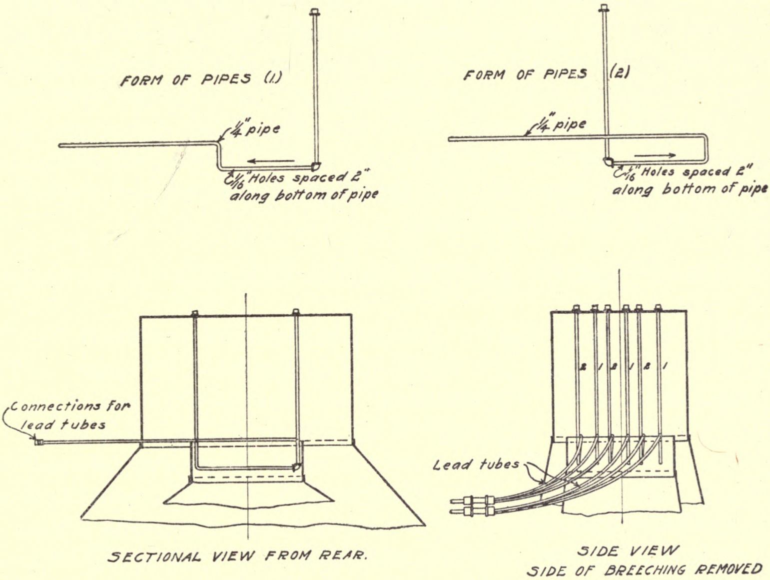

FIG. 24. IMPROVED FORM OF GAS SAMPLING TUBES

forated with single rows of $\frac{1}{16}$-in. holes spaced two inches apart, the gas traveling in the direction of the arrows. The other sampling pipes were removed and three pairs of these tubes placed across the sampling box. The tubes drop into the sampling box from above so that perforation of the box is avoided and the possibility of leakage is further eliminated. At the outside, the pipes are brought together by means of $\frac{1}{4}$-in. lead tubing, into a junction box from which a $\frac{1}{4}$-in. lead tube conducts the gas to the apparatus bench and thence to the aspirator as before. The capped ends of the sampling tubes are bent upward and pass out through the breeching to facilitate cleaning. Just previous to the start of each test the tubes are cleaned with compressed air, which is applied through the junction box, and the end caps are removed occasionally to permit blowing out dust which gradually accumulates at the bend near the last hole. Special tests of the new sampler have not been made so that it is not known whether any real advantage has resulted.

97. It should be remembered that this gas mixing device was designed to meet special conditions brought about by the course which the gases take in leaving this boiler and by the sharp angle in the breeching just above the boiler. It is possible that had the boiler been surmounted by a straight stack, other and more simple means could have been employed. The effect of the baffles on the draft is so considerable that it can be used only where high force of draft is available.

Method of Making and Recording Furnace Observations

98. A careful record of the characteristics shown by the fuel bed is a necessity in the study and comparison of fuels. With the exception of the flue gas data, no other set of data is as generally useful in the analysis of variations which show up in the results. However, if such a record is to be of use, the relative value of various occurrences which affect the furnace and fuel performance must be clearly recognized and the notations which are made during the experiment, recorded in a systematic manner. Experience with the common methods of recording furnace observations and certain isolated test data in the form of running notes has shown the insufficiency of such methods for the purpose of a comparable record, not because such notes may not be made sufficiently full, but chiefly because of their lack of system both in arrangement and in the descriptive terminology used. To eliminate discordance from those sources in this series of tests and to provide for a general summary of the data, two convenient report forms were used.

99. See Form 1, p. 93; Form 2, 96–97. The description which follows will show the various purposes which these forms have served. Their presentation here is essential in that they will convey some idea of the effort made to secure consistent operation and comparable data.

Form S-9-6-07-1000-Bre.

ENGINEERING EXPERIMENT STATION

SHEET 9 UNIVERSITY OF ILLINOIS FILE..........

Observer..........

Date.......... Fireman..........

FURNACE CONDITIONS

TIME	CONDITION OF FUEL BED						TIME OF		
	AT REAR OF GRATE			Change of Grate Speed	Avg. Hole Area Sq. In.	REMARKS	Leveling	Leveling	Slicing
	Maximum Opening Inches	Minimum Opening Inches	Average Inches						
1	2	3	4	5	6	7	8	9	10

100. *The Furnace Condition* log is a record of the various items included and affords a permanent record of variations in the operation of the grate and furnace.

101. *The Furnace Observer's Report*, which was always made out immediately upon the close of each test, takes care of the averages from the furnace log and a number of miscellaneous items, a permanent record of which is desirable. Further and of more importance, the report is intended to maintain a daily balance of the deductions reached, relative to the fuel, from the point of view of the furnace observer. An explanation of the various items is as follows:

The Furnace Conditions Log

"*Condition of Fuel Bed at Rear of Grate*"

In recording the degree of adherence to the conditions adopted for the control of the furnace and the fuel bed area, the following terms have been useful.

1. "*Banked*"—Live fuel against the water-back and thicker than at the center of the grate, live fuel also falling into the ash-pit.

2. "*Close*"—Live fuel against the water-back, but none passing to the ashpit.

3. "*Clear*"—Edge of fuel line completely burned out just at the water-back.

4. "*Inches of grate clear*"—Distance in inches, estimated, of the live fuel line from the water-back.

In using these terms the fuel was considered to be completely burned when both flame and incandescence had disappeared.

102. *Recording the Observations*—Observations relating to the area of the fuel bed were not made simply at the regular 15 minute periods. The three columns 2, 3 and 4, provide for a record of the maximum, minimum and average distances from the water-back, so that the record is really a continuous one. The average recorded is a weighted average, depending upon the judgment of the observer. It is not the mean of the maximum and minimum observations. A mica window in the inspection door allowed easy observation of the conditions within the furnace. The simple fact that continuous record is being kept of the maximum and minimum

area of the fuel bed has a salutary effect in preventing uncalled-for irregularities in the operation of the grate.

Change of Grate Speed—Column 5. In this column the number of adjustments found necessary to comply with the other requirements is recorded.

Average Area of Holes in the Fuel Bed—Column 6. Any entirely burned out spot in the fuel bed greater than six inches in diameter was considered a hole in the bed, and the average total area of these was recorded for each 15-minute period. The mean of column 6 was recorded on the Furnace Observer's Report, also the maximum and minimum area shown by the 15 minute readings.

A tabulation of the results of these observations, taken from the Furnace Observer's Report, will be found in Table 40.

Leveling the Fire—Columns 8 and 9 provide for recording the time of leveling. Leveling in the sense in which we have used the term does not have the significance for which it is used in a hand-fired furnace. That is, it does not signify that the whole fuel bed has been leveled. In these tests, whenever holes were leveled or fuel pushed to the sides of the grate, a, "leveling" was recorded. In the Furnace Observer's Report, in order to facilitate comparison, this item is based on a four-hour period.

Slicing—Column 10. Slicing the fuel bed in chain grate operation usually consists simply of running the slice bar along the ledge to remove any adhering clinker which might otherwise accumulate, to reduce the grate area or disturb the fuel bed along the sides.

A record of the number of slicings and the time at which they were made gives double assurance that trouble from this source has been avoided.

Furnace Observer's Report

Items 1 to 8. These items are intended as a check on some of the principal items of the test. It was one of the duties of the furnace observer to assure himself of the accuracy of the recorded weight of fuel and to see that the general and special control conditions were carried out. Item 8 is intended to keep track of any change in the control conditions outlined for the test. This item often constitutes valuable data, especially when it is found that the fuel will not respond to the draft pressure assigned, and further keeps track of changes made upon verbal instruction which might be misunderstood.

File No.____________

Class______________ No.__________ Observer____________________

Fuel Index No.____________________ Firemen____________________

Series Test No.____________________ ____________________

Date______________________________

FURNACE OBSERVER'S REPORT

1. Flues when last blown: time________A. M.,________P. M., Date__________
2. Boiler and mud-drum when last blown off; Time________A. M.,________P. M.
3. Time of starting test____________, time of closing test______________
4. Total pounds test fuel fired since last test______________________
5. Total pounds test fuel fired during test__________________________
6. Thickness of fuel bed, inches__________________________________
7. Av. difference of pressure above and below grate, in. of water__________
8. Change in control conditions preceding or during test______________

____

Why ____

____

____

SUMMARY OF FURNACE OBSERVATIONS

1. Conditions during the hour preceding start of test: Load ____________

   Draft, in furnace ______________, in breeching______________

2. Conditions of fuel bed at rear of grate, per cent of time: Banked________,

   close______________, ______________, nches clear__________

3. Fuel bed sliced__________time, leveled__________, times av. four hr. period.
4. Area of holes in fuel bed, sq. in. (average of column 6);____________

   Max., for 15 min. period__________, Min. for 15 min. period __________

5. Grate speed, constant or variable? Av. speed sq. ft. per hour__________
6. Was load easily maintained?______________Why?______________
7. Was maximum rate of combustion attained?______________________
8. Estimated increase of capacity obtainable by forcing______________
9. Would lower draft increase the evaporation?______________________
10. Considering previous tests on this fuel (Index No.________) which condition if any necessitated:

(a) Least attention to fuel bed and grate________________

(b) Most attention to fuel bed and grate________________

11. The preceding tests in order of the most favorable conditions are, ____

Remarks____

General Remarks

Note—A list of descriptive terms has been selected for use in describing the general characteristics of the fuel bed, flame, etc. These should be adhered to as closely as possible. See "Instructions to Furnace Observer."

1. General appearance of fuel bed________________________

2. Character of the flame______________________________

3. Appearance of refuse, clinker, etc.________________________

4. Change of firemen during test—time, etc.________________

5. Change of furnace observer on this fuel__________________

Remarks____

Date________________ Signed____________________

Summary of Furnace Observations

Item 1—This item relates to the condition of the fuel bed and furnace at the start of the tests.

Items 2, 3, 4 and 5—See under "Furnace Conditions" log above.

Items 6, 7, 8 and 9—Deductions entered under these items call into play the judgment of the observer. They are useful mainly in outlining further work on the fuel, though an observer of some experience will usually make very close deductions.

Items 10 and 11—Sub-items (a) and (b) are filled out after each test. They are useful in formulating the deductions called for under Item 11. The entry under the latter item and under "Remarks" summarizes the conclusions of the observer as far as his personal observations go.

General Remarks

Item 1—The entries under this item are difficult to systematize. The fuel bed may be open and burning evenly, broken and burning in spots, light and bulky, or it may lie on the grate in a compact mass with level surface. There are as many different modifications of fuel beds as there are kinds and grades of fuel. The fuel bed should be fully described, as upon its characteristics depend the distribution of the air supply and consequently the rate of combustion and the temperature obtainable.

Item 2—The amount of flame present in the furnace depends upon the amount of the volatile matter in the fuel and the proportion of air supplied. Observation of the flame is of interest chiefly in relation to the production or non-production of smoke. In the experiments flame which did not persist beyond point B (see Fig. 21, page 85) was denoted as "short" flame; flame which persisted beyond B was designated as "medium long" while flame of any volume entering the tube space at *C*, Fig. 16, was designated "long" flame. Flame, it should be understood, is long only because there is not sufficient oxygen in thorough mixture with the volatile matter to cause rapid combustion.

Item 3—Clinkering seldom gives serious trouble in chain grate operation. This item, however, takes care of any unusual occurrences.

Items 4 and 5—These items are intended to put on record in a conspicuous place any changes in the personal factor entering into the operation of the furnace.

APPENDIX III

EXPERIMENTAL METHODS

APPENDIX III

I. Experimental Methods

An effort was made so to arrange the testing plant and to provide such instruments and facilities that the requirements of a test could be carried out with essential accuracy. In this appendix will be found a detailed description of the routine method pursued in collecting the data. The details of boiler performance are liable to so many uncertainties not accounted for in the mere statement of the code of the American Society of Mechanical Engineers that it is believed a description of the methods may assist engineers and students who may wish to make use of the collected data to give proper weight thereto.

In the tabulation of results, Tables 28 to 40, p. 121, the mean of the test readings from the observed data is given as recorded on the logs for each test, essential corrections to agree with the calibration of instruments having been made. Where data known to have been affected by inaccuracies are retained in the tables, attention is directed thereto in the itemized descriptions.

Weighing the Fuel and Ash.—In firing the furnace during a test, it has been found most satisfactory to feed the coal into the hopper by hand, although a specially designed coal bucket was available. The coal was weighed in a steel charging car made with one side hinged, shown in the photograph, page 76. The dimensions of this car are 2½ ft. by 4½ ft. by 1½ ft. deep, and its capacity was about 700 lb.

During the tests, 500 lb. of coal was weighed at a time, the coal feed hopper was kept continually heaped a little more than full, and after each 500 lb. charge had been shovelled into the hopper, the coal was allowed to feed until a straight edge drawn across the top would give a level just even with the top edges of the hopper. The interval of time elapsing was recorded as the time of firing the charge. Other readings coincident with the time of firing were height of water in the water gage and the level of the water in the feed water supply tank. The time of weighing ash and refuse was likewise coincident with a "time of firing," though at less frequent intervals.

Sampling the Coal.—Samples of coal and ash could not be taken care of at the chemical laboratory until the morning following a test, consequently, to avoid unaccounted-for changes in moisture content, the preliminary reducing, crushing and air drying of all samples were made in the boiler room.

In collecting the coal sample, two half shovelfuls of coal were taken for each 500 lb. charged during a test. The samples taken at each charge were at once crushed to less than quarter-inch size in a laboratory jaw crusher, and collected in a closely covered vessel. At the close of the test, a complete sample, weighing between 100 and 150 lb. or about 1 to 2 per cent of the total weight of coal fired during the test, depending upon the size of the coal, was carefully mixed and quartered down to about five pounds. From this, one kilogram was weighed out into a shallow pan for the determination of the moisture loss upon air drying.

Coal too wet for reducing at once in the jaw crusher was first sampled down to 10 kilograms, and this weight was given a preliminary drying in large pans set upon the grating surmounting the boiler. The temperature there ranged from 90° to 100° Fahr., and the drying was usually allowed to proceed over night. A record was then made of the loss, and the entire sample was reduced in the jaw crusher and further mixed and quartered down, and the air drying was concluded upon a 1000 gram sample, the total air drying loss in such case being given by the formula:

Moisture, per cent $= a + \frac{100-a}{100}\, b$; where a = the per cent loss in the preliminary drying and b = the per cent loss on the final sample.

A No. 80 Troemner's solution scale was used for weighing samples. This scale is very accurate and its construction allows the use of sample pans of any necessary size, the small sample pans used being 10 by 18 by 1 in. in depth, and the large pans 18 by 18 by 1 in.

In the final air-drying these pans were set away in a special sheet-iron oven, Fig. 20, the shelves of which are staggered to allow free circulation of air, which is induced by a Bunsen flame in the flue at the top. Since the air used for drying was not heated, the drying thus, at room temperature, required from three to four days, during which time the samples were weighed each day until the loss for the day preceding was less than 5 grams in 1000, when the samples were at once bottled in "Lightning" fruit jars and delivered to the chemical laboratory for final reducing and analysis.

Sampling the "Ash and Refuse."—The "ash and refuse" was removed from the ashpit, generally three or four times during a test. The contents of the car, weighing usually from 100 to 300 pounds, were dumped upon a smooth concrete floor and the clinker crushed with an iron tamp until all pieces were reduced to about 1½ in. in size. The entire bulk was then mixed by twice shifting the pile, each shovelful being poured upon the center of the new heap so that the larger and heavier particles would, if possible, be evenly distributed. This bulk was then quartered, opposite quarters rejected and the tamping, mixing and quartering repeated until about 20 lb. remained. The particles were then reduced to about ½ in. or less. This portion was then further reduced to ⅛ in. or less by means of the jaw crusher, thoroughly mixed and a weight equivalent to 5 per cent of the original bulk preserved. This procedure was repeated for each quantity of "ash and refuse," and at the close of the test the aliquot samples thus obtained were thoroughly intermingled and quartered down to about two pounds, which was at once bottled for delivery to the chemical laboratory.

Feed Water.—The arrangement of the feed water system is shown in Fig. 19. The weighing tank has a capacity of 800 pounds, and is of the form commonly used for accurate measurement. It is provided with a small neck and an overflow. The tank is fitted with a 2-in. Lunkenheimer "Handy" gate valve on the supply pipe and a 3-in. similar valve on the discharge. It can be filled and emptied in about two minutes.

The number of tanks of feed water supplied to the boiler was recorded in the usual manner, recording both the time and number of the tank, and a check of the counts was maintained by means of a Bristol recording water-level gage connected to the 5000-lb. capacity supply tank. The temperature of the feed water was taken in the weighing tank before discharging. With the exception of tests 25 and 31, for which the pump was used, the boiler was fed by injector throughout the series. Three injectors, sizes 1, 1¼ and 1½ in. were supplied so that a fairly steady feed was obtained for any rate of evaporation demanded from the boiler. The overflow from the injectors was returned to the supply tank, but since the temperature of the feed water was taken in the weighing tank, no correction for the weight or heat content of this overflow was necessary.

The total weight of water fed to the boiler, column 4, Table

32, is the weight of feed water by tank corrected for the following items:

1. Difference between the quantity of water weighed out and the quantity fed to the boiler; shown by the difference of the level of water in the supply tank at the start and close of the test.

2. Weight of feed water equivalent to the difference between the level of the water in the boiler at the start and close, with correction for the heat contained.

3. Water equivalent to the difference in the total heat of the boiler's water content at the start and close, due to difference between the steam pressures at those events.

4. Correction for leakage at the blow-off; pump leak, etc.

The total feed water weighed and the total correction applied, together with the data upon which this correction is based, are given in the water log, Table 31. The methods of arriving at the separate corrections follow:

1. Correction for level in supply tank: The supply tank was fitted with a delicate float gage which indicated the difference in level on a scale above. Each inch scale reading represented 145.5 lb. at 60° Fahr.

2. Correction for difference of water level in the boiler: It was endeavored to keep the water level within 3 to 6 inches, as shown on the water gage, middle gage being at 4.5 inches, and this was generally accomplished throughout the tests.

To allow correction for any differences of level at start and close, the boiler was carefully calibrated to each half inch on the glass. By this calibration, the water capacity of the boiler to middle gage is 17022 lb., and the average water capacity for each inch shown on the gage from 2½ to 6½ in. is 358.6 lb. at 62° Fahr. At 365° Fahr., corresponding to 150 lb. gage pressure, and further corrected for expansion of the boiler, one inch of water on the water gage represents 318 lb. average. This value was made the base for compensation for the thermal content of the weight represented by the difference in level in inches.

With more water in the boiler at the close than at the start, credit must be given for the heat required to raise the difference in weight from feed water to steam temperature. With the conditions reversed, credit must be given for evaporating the difference but not with heating it to steam temperature.

The correction to be applied to the feed water for each inch difference in level in the gage is given by the formula,

$$318 \times \left\{ 1 - \frac{q - q_1}{q - q_1 + \left(\frac{100 - x}{100}\right) r} \right\}$$

where q = the heat of the liquid at steam temperature, q_1 = the heat of the liquid at feed water temperature, r = the heat of vaporization, and x = the per cent of moisture in the steam. The latter may be neglected in the calculations.

The corrections per inch of gage reading used in the test calculations were obtained from a chart based upon the above formula.

It will be seen that since the feed water temperature was from 55° to 60° Fahr. and the pressure from 145 to 155 pounds gage, the correction applied to the total weight of water fed was about constant at 233 lb. per inch of water gage difference.

3. Feed water correction for difference in steam pressure at start and close: This correction is a minor one, amounting to but 5.8 lb. of feed water to be added or subtracted per pound difference in steam pressure within the range of the experiments.

4. Correction for leakage at the blow-off valves: The lower blow-off valve began leaking during test No. 20 and continued until test No. 27, before repairs could be made. The leakage was conducted into a weighed tank of cold water and the weight of feed water to be subtracted in correction calculated by the formula:

$$\text{Correction} = (\text{Wt. of leakage}) \times \left\{ 1 - \frac{q - q_1}{q - q_1 + r} \right\}$$

The symbols have the usual significance. Peabody's steam tables were used throughout for the thermal properties.

Character of the Feed Water.—The water used in the test boiler and in the central heating plant comes from 125-ft. wells on the University grounds. The water is characterized by the presence of free sodium carbonate in amount greater than is necessary to satisfy any sulphates present, and consequently is absolutely non-scale forming.

Water of this character is found at a depth varying from 125 to 165 feet throughout an area of about 4000 sq. miles centering about the University. It is also found in several other sections in Illinois at depths varying from 400 to 850 ft. A description of this water has been given recently by Professor S. W. Parr.* The normal amount of free alkali is about 5 grains per gallon.

During the progress of the tests, the writer personally inspected the boiler tubes on four occasions but no scale whatever was found. At the close of the series the tubes were as clean as when the boiler was first fired, save for the light coating of sludge dust which could be brushed away with the finger.

The Water-Back.—To avoid unnecessarily complicating the feed water system, the cooling water for the water-back was wasted to the drain. A measure of this water was kept by means of a carefully calibrated Breslau water meter placed in the inlet pipe, and to insure approximately a steady rate of flow through the meter, the temperature of the outflow was normally adjusted to a temperature from 80 to 100° Fahr., so that some variation in the range of temperature was allowable without complicating the measurements by too frequent adjustments.

Temperatures of the inflow and outflow and the meter's reading were taken at the regular intervals, and the amount of heat carried away by the cooling water was computed by taking the product of the total weight of water used during the test, corrected to agree with the calibration of the meter, and the average difference in temperature. The fact that an average was used here in place of the true mean introduces but a negligible error since the per cent loss of heat is in itself a relatively small item.

It may be said that the water-back can not be considered as being under practical test, but if one wishes to compute the amount of cooling water that would be required for various temperatures of the outflow, it may readily be done from the data given in Table 30.

The use of the adjustable water-back in the experimental plant has given the advantage of uniform conditions for fuels of varying character and ash content. No assumption is made, however, as to whether or not the adjustable water-back results in an economy over other methods of controlling the air leakage.

Compensated Water Items.—It will be noted that the tabulated water items and dependent items are expressed in two ways. Un-

* "Some Notes on the Service Waters of a Railway System," Jour. of the American Chemical Society, Vol. XXVIII, 5, 640, May, 1906.

der the regular A. S. M. E. code numbers are given the values obtained by actual performance, (designated "performance" in the headings). In adjacent columns and designated by the same code numbers, but with a decimal suffix, these items are raised to values which, it must be assumed, would have resulted had the water-back been of a stationary type in which the circulation water is taken from and returned to the boiler. These items are designated in the table headings "compensated for water-back" in brief for "compensated for the heat lost on account of the water-back". They are introduced for the purpose of eliminating variations. In making the compensations, the percentage loss of heat in the cooling water to the total heat of the fuel consumed has been added directly to the "boiler and furnace" efficiency per cent numbers, and the related water items and the numbers for Item 73 raised by the factor $\frac{\text{Item 72} + \text{Heat loss per cent.}}{\text{Item 72}}$

Details of the calculations for different items are shown on pages 109 to 120.

Care of the Boiler.—Soot and dust are removed from the heating surface of the Heine boiler by means of a steam or air nozzle inserted through hollow stay bolts in the front and rear water legs. The nozzle used consists of a long pipe perforated at the end by a number of radical holes.

The surfaces were carefully cleaned, preceding each test, with an air blast of from 70 to 100 lb. pressure, blowing through each stay bolt in both front and rear legs and inserting the pipe the full length of the tubes. Several inspections of the tube surfaces showed that this treatment given each day maintained a remarkably clean surface, and since the furnace operated with but occasional traces of smoke, opportunity for coatings of tenacious character to form was entirely absent.

Starting and Stopping the Tests.—Running start and stop was necessarily made. With the chain grate the amount of ash upon the grate is practically constant, the depth of fuel entering the furnace is fixed by the gate opening and is not disturbed by motion of the grate. These circumstances are favorable to a running start yet the possibility of serious error is not obviated. Variation in weight of fuel upon the chain grate at start and close of the test may occur from one or all of several causes occurring or operating for a period required to displace the grate one effective grate length just preceding either event. These are:

1. Difference in actual length of fuel bed.
2. Irregularity in speed of grate travel.
3. Variations in air supply.
4. Difference in the relative amounts of fine-sized fuel falling through the grate.
5. Differences occasioned by irregular attention to condition of the fuel bed.
6. Difference in clinkering or caking.

It is found that to bring the fuel bed to the same length just at the time of starting and stopping is not sufficient for accuracy. If it is necessary to quickly close up a short fuel bed to bring this about, the conditions are bad. One linear foot of grate travel carries into the furnace from 70 to 150 lb. of coal, depending upon the width of grate and depth of gate opening. Sudden changes of grate speed, consequently, produce excess or deficiency from the normal amount of fuel which should be upon the grate. Ideal conditions demand uniform rate of combustion and fuel bed length during the periods of time that determine the weight of fuel that will be upon the grate.

Variations due to these factors were avoided as far as possible by operating the grate under assigned test conditions for a period of from 30 minutes to 1 hour just preceding the start. The principal conditions observed were regularity of grate travel, and area of fuel bed and a constant "normal" draft pressure (see definitions, page 12).

For those tests in which the fuel clinkered more or less seriously, it was of course impossible to assure a uniform rate of combustion, and satisfactory agreement between starting and stopping conditions was more difficult to obtain. This difficulty was experienced with the fuel 5.1006 W. Satisfactory agreement was also difficult to obtain with the fine-sized coals. For several of the tests of fine sizes the furnace was operated under test conditions from 3 to 4 hours before acceptable conditions for starting were obtained.

Preceding all tests, the fireman operated the furnace as nearly as possible under assigned test conditions for two hours before the arrival of the regular observers, a check on the regulation during this period being maintained by means of recording gages for draft pressure and for temperature of the flue gases.

As an additional check on the starting conditions for all tests following test No. 27, the regular water readings were taken for 1 hour preceding the start and the load computed. If proper conditions of the furnace or load were not reached, the preliminary run was continued, taking readings as in the test proper. After one or two tests on each grade of coal, satisfactory starting conditions were usually obtained without trouble. The grate once adjusted to the requirements of the fuel and draft, closing conditions were usually readily obtained.

The fire was started each morning at 5 o'clock from a heavy banked fire, and was under full fire from 1½ to 3 hours preceding all tests. The fuel to be tested was used during this period in order that the furnace and setting wall would be heated only to the normal temperature for that fuel; except in a few tests of the No. 5 coal, screenings were used for the first hour to bring the furnace to temperature more quickly. A check on the temperature of the furnace walls was obtained by means of thermometers slightly imbedded in the surface. The indications of these thermometers at all times varied more from drafts of air through the boiler room than from any difference of temperature within the furnace.

II. Observed and Calculated Results of Tests

In the calculation of the results given in the tables following, the methods set forth in the code for boiler testing of the American Society of Mechanical Engineers, wherever they apply, have been followed in detail. Those items are tabulated under the regular code item numbers, and have the usual significance. Additional items are indicated by letters or by decimal suffixes to the usual code numbers.

In order to collect the results into compact and convenient tables and to provide space for additional items, it has been necessary in some cases to arrange the items in a different order from that usually followed in the A. S. M. E. code. For example, the items under the sub-head "water per hour" follow directly after "fuel per hour" in Table 33; the average steam pressure will be found under the heading "steam" in Table 30; draft pressures and air temperatures will be found under the headings "air" in Table 36; and the analysis of the flue gases and the per cent of smoke observed will be found in the same table. Other items which are displaced from the arrangement of the A. S. M. E. code are "size of coal" and "thickness of fuel bed" Table 28; "temperature of the feed water" Table 32; "analysis of ash and refuse" Table 29; and "calorific value of the fuel" Table 39. In the following summary, the items are taken up in the order in which they appear in the tables.

TABLE 28. Principal Conditions—In this table those conditions which have the greatest effect upon the results of the tests are given. The items of Table 40 should also be consulted in a comparison of test results.

Column 1. Test number for this series.

Column 2. Laboratory file number. This number appears in each of the tables in the report and should serve as a convenient cross index to the fuel tested. The first part of the number refers to the files of the laboratory. All boiler or fuel tests made at the Engineering Experiment Station are given a general number and filed in that order regardless of the test series. General numbers not included are tests in other series, central heating plant tests or tests with house-heating boilers. The second part of the number is the fuel symbol, an explanation of which will be found on page4.

Item 2. Duration of trial. The total time reduced to decimal number.

Commercial boiler trials are usually run for a ten hour period, the idea being that within that period sufficient total weight of fuel will be fired to minimize a reasonable and unavoidable error in judging the conditions and weight of fuel upon the grate at the start and close. In the adoption of a shorter trial period for this series, it is not intended to advocate any change in existing practice. Satisfactory starting and closing conditions with the chain grate, since they must be running conditions, are often and especially with non-uniform coal, much more difficult to obtain than for the plain grate using the "alternate method" of the American Society of Mechanical Engineers.

In these tests the duration of the trial has been wholly determined by the conditions under which the start and stop could be made, conditions which were in most cases favored by the superior and uniform grades of coal tested. It was usually endeavored to prolong the trial until 200 lb. of coal had been fired per square foot of grate surface. This, however, was not always accomplished; a trial was to be run each day, the time of several men had to be regulated, and time allowed for the care of the boiler and the operation of the furnace under suitable conditions preliminary to the start.

The majority of the tests of short duration or in which less than a total of 200 lb. of coal was burned per square foot of grate surface, are duplicated on the same lot of coal. A comparison of the conditions and results for these duplicates is of interest. Short duration in tests 15, 44 and 64 was due to lack of sufficient supply of test coal for a longer period; however, the tests were run under favorable conditions. The conditions of test 15 duplicate those of test 14. The conditions under which tests 44 and 64 were made are not exactly duplicated by other tests. Test 8 was closed suddenly because of the blowing out of a gasket in the rear water leg. The close of the test was accepted as the time of the last coincident coal, ash and water reading; comparisons show the results to be good.

Item 23, Column 5. Size of coal.

Item 23, Column 6. Condition of coal.

Item 81, Thickness of fuel bed, inches. This is taken as the depth of the gate opening. The average thickness of the fuel bed upon the chain grate is, of course, less than this, but on account of the progressive combustion, this average can not be judged. However, a knowledge of the average would be of no more practical value than a record of the gate opening which can always be duplicated.

Item 13.1. Draft pressure in the furnace (assigned). This is the normal draft pressure assigned for the test. The averages of observed draft pressures are given in Table 30.

Column 9. Furnace control.

Column 10. Total coal fired per sq. ft. of grate area, pounds = Item 25 ÷ 38.2.

TABLE 29. Coal and Ash—This table contains all items necessary for the calculation of the combustible consumed except the per cent of ash in the dry coal, Item 42, Table 38.

Item 25. Total weight of coal fired, pounds.

Item 26. Percentage of moisture in the coal as fired, pounds. See Item 34, Table 37.

Item 27. Total weight of dry coal fired, pounds=Item 25 × (1 — Item 26).

The term "fired" for obvious reasons is introduced here in place of the term "consumed" as used in the A. S. M. E. code. The term "consumed" is used in this report only in connection with that portion of the fuel or combustible which has been delivered beyond the bridge wall in the form of gases or carbon, i. e., the fuel or combustible fired minus that portion accounted for in the "ash and refuse".

Item 28. Total weight of dry ash and refuse, pounds.

Item 30. Total weight of combustible consumed. This is equal to the total weight of combustible (ash free dry coal) fired minus the weight of carbon in the "ash and refuse" = Item 27 × (1 — Item 42) — (Item 28 × Item 44).

Item 31. Per cent of "ash and refuse" referred to dry coal = Item 28 ÷ Item 27.

Item 44. Per cent of carbon in dry "ash and refuse." By chemical analysis.

Item 45. Per cent of earthy matter in dry "ash and refuse". By chemical analysis.

Item 30.1. Total weight of dry coal minus the total weight of "ash and refuse", pounds = Item 27 — Item 38.

This item is given as a rough check on Item 30. Item 30.1 will generally be greater than Item 30 by a weight equal to the weight of ash carried beyond the bridge wall or collected on the walls of the furnace, though with well-sized clean coal the difference is usually small. Where Item 30.1 is the greater, it is usually due to increase in Item 28 from melting of the slag and fine ash which has accumulated on the face of the furnace walls and bridge wall during preceding operations. No error is introduced in Item 30 because of these gains or losses of ash, since the calculation is based upon the chemical analysis of the ash and refuse. Also any coal particles carried beyond the bridge wall settle in the combustion chamber and are completely burned in this furnace

TABLE 30. Steam and the Water-Back—This table contains all of the steam and water-back data and factors.

Steam:—

Column 3. Barometric pressure in lb. per sq. in.

Item 11. Average steam pressure by gage. The test boiler discharged its steam directly into a branch main of the central heating and power station, the normal pressure of which ranged between 130 and 145 pounds. The test boiler pressure was maintained at approximately 150 lb. gage by regulating the main steam valve. This was attended to by the water observer. An extra steam gage located below the valve and in view from the lower deck facilitated the regulation.

The steam pressures tabulated are the averages from Bristol recording gage charts. The steam pressures recorded at start and close, Table 31, are the indications of a standard gage of the Bourdon type. Both the recording and the standard gage were mounted on the same gage board and the two were compared at the start and close of each test. Both instruments were frequently checked by calibration.

Item 11.1. Absolute steam pressure = Item 11 + Column 3.

Item 54. Percentage of moisture in the steam. During the earlier portion of the tests, the moisture carried by the steam was determined by means of a Carpenter separating calorimeter. The six-inch vertical steam riser was well lagged; the sampling nipple was of standard design and located about 3 ft. above the boiler. At 4½ ft. above the boiler the riser ends in an ell connecting a special main 20 ft. in length. This short main connects with the branch main of the central heating plant by a down connection 10 ft. in length. However, to insure further that no condensation from the 20 ft. horizontal could return to the boiler, it was given a positive slope of 1 in. in 10 ft. The velocity of the steam in the riser is about 35 ft. per second when the boiler is delivering 210 H. P. The steam from the separating calorimeter was condensed in a special small worm condenser, the accuracy of the weight delivered by the orifice in no case being accepted.

This calorimeter was used up to test No. 24 when two other calorimeters were added for the purpose of checking. One of these was a throttling calorimeter of standard design; the other a very large special separating calorimeter so constructed that the orifice could be changed to different sizes as desired. It was found that the throttling calorimeter gave approximately constant moisture readings. A series of experiments carried out at the same time by means of the large separating calorimeter, in which the total sample of steam drawn was gradually increased until the radiation from the well lagged calorimeter became negligible, confirmed the indications of the throttling calorimeter so that in the tests following test No. 23 the indications given by the throttling calorimeter were accepted.

It was found that a line drawn through all of the percentages thus obtained, the variation being from 0.5 to 0.7 of one per cent, was a constant at about 0.57. Since the radiation correction for the throttling calorimeter varies between 0.1 and 0.3 of one per cent it was concluded that the moisture content of the steam was constant at about 0.57 per cent, and this value was used in all tests following test No. 31, with the exception of tests 40, 41 and 42 where the variations were slightly in excess of the usual variation, as was the case likewise in the tests 24 to 30.

Item 56. Factor for correction for quality of steam =

$$1 - \left\{ \frac{\text{Item 54}}{100} \times \frac{q - q_1}{r + q - q_1} \right\}$$ where q = the heat of the liquid at the steam temperature, q_1 = the heat of the liquid at feed water temperature, and r = the heat of evaporation at steam pressure. Values for q, q_1 and r were taken from Peabody's steam tables and a curve constructed from which the factors were taken for the computations.

The Water-Back. See page 82.

Item a. Total weight of cooling water used.

Item b. Temperature of inflow, average, degrees Fahrenheit.

Item c. Temperature of outflow, average, degrees Fahrenheit.

Item d. Ratio of the heat lost to the water-back to the total heat of the fuel consumed = Item *a* (Item *c*—Item *b*) ÷ (Item 30 × Item 51).

Item e. Water equivalent correction factor for the heat lost to the water-back = Item 72.1 ÷ Item 72. See page 106.

TABLE 31. Water Log Data—An explanation of this table together with the means of obtaining the weight of feed water, also the necessary corrections applied, are given on page 102.

TABLE 32. Total Water—All of the total water items are contained in this table.

Item 20. Temperature of feed water entering the boiler, degrees F. See above.

Item 57. Total weight of water fed to the boiler, pounds. See above.

Item 58. Equivalent water fed to the boiler from and at 212° F., pounds = Item 57 × Item 60.

Item 59. Water actually evaporated corrected for quality of steam, pounds = Item 57 × Item 56.

Item 60. Factor of evaporation = $(q - q_1 + r) \div 965.8$.

The thermal quantities were taken from Peabody's steam tables.

Item 61. Equivalent water evaporated into dry steam from and at 212° F., (performance) pounds = Item 59 × Item 60.

Item 61.1. Equivalent water evaporated into dry steam from and at 212° F., compensated for water-back loss, pounds = Item *e* × Item 61.

Item f. Total loss of equivalent evaporation charged against the water-back = Item 61.1 — Item 61.

TABLE 33. Fuel and Water per Hour—All fuel and water items calculated to the basis of one hour are collected under this head.

Fuel per Hour:

Item 46. Dry fuel fired per hour, pounds, = Item 27 ÷ Item 2.

Item 47. Combustible consumed per hour, pounds, = Item 30 ÷ Item 2.

Item 48. Dry coal fired per square foot of grate surface per hour, pounds = Item 46 ÷ 38.2.

Item 49. Combustible consumed per hour per square foot of water heating surface, pounds, = Item 47 ÷ 2027.

Water per Hour:

Item 62. Water evaporated per hour, corrected for quality of steam, pounds, = Item 59 ÷ Item 2.

Item 63. Equivalent evaporation per hour from and at 212° F. pounds, = Item 61 ÷ Item 2.

Item 64. Equivalent evaporation per hour from and at 212° F. per square foot of water heating surface, pounds, = Item 63 ÷ 2027.

Item 63.1. Equivalent evaporation per hour from and at 212° F. compensated for the water-back loss, pounds, = Item 63 × Item *e.*

Item 64.1. Equivalent evaporation per hour from and at 212° F. per square foot of water-heating surface, compensated for the water-back loss, pounds = Item 64 × Item *e.*

TABLE 34. *Horse-power and Economic Results*

Item 65. Horse-power developed = Item 63 ÷ 34.5.

Item 67. Percentage of builders' rated horse-power developed, per cent, = Item 65 ÷ 210.

Items 65 and 67 compensated for the water-back loss are given in Table 5 to 14.

Economic Results by Actual Performance:

Item 68. Water apparently evaporated under actual conditions per pound of coal as fired, pounds = Item 57 ÷ Item 25.

Item 69. Equivalent evaporation from and at 212° per pound of coal as fired, pounds, = Item 61 ÷ Item 25.

Item 70. Equivalent evaporation from and at 212° per pound of dry coal fired, pounds, = Item 61 ÷ Item 67.

Item 71. Equivalent evaporation from and at 212° per pound of combustible consumed, pounds, = Item 61 ÷ Item 30.

Economic Results Compensated for Water-Back Loss:

Item 68.1. Water apparently evaporated per pound of coal as fired, pounds = Item 68 × Item *e.*

Item 69.1. Equivalent evaporation from and at 212° per pound of coal as fired, pounds = Item 69 × Item *e.*

Item 70.1. Equivalent evaporation from and at 212° per pound of dry coal fired, pounds = Item 70 × Item *e.*

Item 71.1. Equivalent evaporation from and at 212° F. per pound of combustible consumed, pounds = Item 71 × Item *e.*

TABLE 35. Efficiency and cost of Evaporation—.

Item 72. Efficiency of the "Boiler and Furnace" = (Item 71 × 965.8) ÷ Item 51.

Item 73. The over-all efficiency = (Item 70 × 965.8) ÷ Item 50.

Item 72.1. Efficiency of the "Boiler and Furnace", compensated for water-back loss = Item 72 + Item *d.* See Table 30 for Item *d.*

Item 73.1. Over-all efficiency, compensated for water-back loss = Item 73 × Item *e*.

Cost of Evaporation:

Item 74. Cost of coal per ton of 2000 lb. delivered in boiler room. This is arbitrarily taken as one dollar.

Item 75. Cost of coal for evaporating 1000 lbs. of water under observed conditions, dollars, = 0.5 ÷ Item 68.1.

Item 76. Cost of coal used for evaporating 1000 lb. of water from and at 212 degrees, dollars, = 0.5 ÷ Item 69.1.

TABLE 36. Air and Flue Gases. This table contains the items relating to the air supply and flue gases including the smoke observations.

Item 12. Average draft pressure between damper and boiler, in. of water. This was taken by means of an Ellison differential draft gage, the point of observation for tests following test 28 being at hole 12, see Fig. 21, page 85. For test preceding test 29 the observation was taken at the turn in the breeching.

Item 13. Average draft pressure in furnace, in. of water. Taken by means of an Ellison differential draft gage of $\frac{1}{2}$ in. range, graduated to $\frac{1}{400}$ of 1 in. For the majority of the tests readings were taken at two points, 21 and 22, Fig. 21 and 22, the gages being connected up differentially to holes 27 and 26, respectively, so that the averages tabulated are actual net pressures on the fuel bed.

Item 15. Average temperature of external air, degrees Fahrenheit, obtained from the record of a Bristol recording thermometer.

Item 16. Average temperature of boiler room, °F, obtained from the record of a Bristol recording thermometer.

Item 21. Average temperature of the escaping flue gases; F.° Readings for the flue gas temperatures during tests 1 to 27 were taken by means of a single high grade mercury thermometer inserted at the base of the breeching in a position which was supposed to be average. The data are retained in the table but they are unreliable. For tests 28 to 37 the temperature data are the average of three high grade Jena borosilicate glass thermometers located in the sampling section above the mixing baffles. Fig. 23. In the tests following test 37 temperature measurements were taken by means of five copper-constantan thermo-couples distributed in the sampling section.

Items 85, 86, and 88. Analysis of dry flue gases. For tests No. 1 to 27 the gas samples were drawn from a single tube, extending centrally across the base of the breeching. This tube was made up of ½-in. pipe capped at one end and perforated with three rows of $\frac{1}{32}$-in. holes spaced 3 in. apart. The results from the analyses of samples taken from this tube are of uncertain accuracy for the reasons set forth on page 88, and with but few exceptions the tabulated percentages of carbon dioxide for those tests are probably too high. This was recognized at the time the tests were in progress, and for that reason it was considered useless to make more complete analyses until time should permit devising and installing improved means for taking the sample. During the temporary interruption of the work which occurred between the tests 27 and 28, opportunity permitted the introduction of the sampling arrangement, previously described, and all subsequent gas samples for the series were taken under those improved conditions.

The sampling tube or tubes in both types of samplers were connected with the sampling bench by a ¼-in. lead tubing, through which a steady stream of gas was kept flowing by means of a larger sized Richards laboratory ejector. The sample for analysis was drawn from a tee connection in this tube. The usual arrangement of one-gallon side-necked aspirator bottles was used for collecting the sample and an average sample collected for each half hour during the test. In some of the earlier tests the samples were drawn for a longer period. Distilled water saturated with the flue gas was used in the collecting vessels.

The analyses throughout were made by means of an Orsat apparatus provided with a 100 cc. water jacketed burette with 25 cc. tube of special wide graduation, and the readings taken subsequently corrected to the true calibration of the burette, including a correction for the gas volume contained in the capillary tube between the 100 cc. mark and the drop tubes, the total correction necessary being between 0.1 and 0.2 of 1 cc. representing a percentage correction of about the same magnitude in the observed percentages of carbon dioxide and oxygen.

Item 77. Smoke observations—Ringelmann's numbers. The observations taken were recorded in No. 0, ½, 1, 2, etc., no attempt being made to judge shades varying between. The tabulated values, however, being the time average of all readings, result in fractional values. These should be interpreted as being simply greater or less than Ringelmann Chart No. 1 or No. 2 as the case may be, for example, test No. 44 shows 0.21 smoke. That is, the average smoke reading for this test was less than No. 1 Ringelmann.

To summarize these readings for the series; three tests show No. 1 smoke, 13 tests what may be called, on the average, a faint haze, and for the remainder, 48 tests, one could not tell from observation of the stack, that the plant was in operation.

Chemical Analyses:

The chemical analyses of the coal and of the "ash and refuse" were made in the University chemical laboratories, under the direction of Professor S. W. Parr.

The data obtained from the analyses were more elaborate than apply directly to the needs of this report, and, no doubt, will contribute to the accumulation of available data for a more general study of the chemical and physical properties of Illinois coal, a problem which is receiving the attention of Professor Parr in connection with the State Geological Survey. All chemical analyses were made in duplicate and in case of an occasional disagreement, the results were checked by a third determination. The results reported by the chemical laboratory were the average of two closely agreeing analyses.

The methods of analysis followed were: total moisture equals the per cent loss upon air drying plus the loss in drying in an air oven at 105° C.; proximate analyses, following the methods recommended by the Committee on coal analysis of the American Chemical Society*; sulphur by gravimetric method after fusion with sodium peroxide in the Parr calorimeter, nitrogen by the Kjeldahl method; total carbon and hydrogen by the usual combustion train method, carbon in the "ash and refuse" by difference after determining the moisture and ash contained, and the calorific value of the coal by means of a platinum lined Mahler-Atwater calorimeter.

Determinations regularly made upon each test sample of coal were moisture, ash, sulphur, nitrogen and the calorific value, and upon the "ash and refuse" sample, moisture, ash and carbon.

* Jour. Amer. Chem. Society, Vol. XXI, p. 1130.

Complete proximate and ultimate analyses were made upon two samples from each carload of coal tested. One of those samples was a regular test sample, the second a composite sample made up from the regular analytical samples in portions of each representing by weights the separate original weights of coal sampled.

These composite analyses are presented on pages 5 to 6 in connection with the description of the coal used.

Where complete analyses have been made of individual test samples, they are given in Tables 37, 38 and 39. Figures set in regular type indicate results from analyses of the individual test samples. The italicised figures are calculated values based upon the percentages of fixed carbon and volatile matter, total carbon, hydrogen and oxygen found in the composite sample and the percentages of moisture, ash, sulphur, and nitrogen found in the individual test samples, the principle being that the average chemical character of the "combustible" portion of the coal excluding sulphur will be approximately constant throughout the car. How nearly this was true will be seen by comparison of the values calculated for the combustible composition from the composite analyses, and the similar values for the individual samples, Table 39, making allowance in the comparison for any variation which occurs in the percentages of sulphur and nitrogen.

The method of calculating these figures is given below.

In these tables both analytical and calculated results for coal as fired or for moisture-free coal are given the regular A. S. M. E. code item numbers, while the similar items computed to the basis of combustible are distinguished by a decimal 1, suffixed. Similarly, to distinguish them in the formulas which follow, items relating to determinations made upon the composite samples are indicated by suffixing a decimal 2 to the regular A. S. M. E. code numbers.

TABLE 37. Proximate Analyses:

Item 32. Fixed carbon $= \text{Item } 32.2 \times \dfrac{100-(\text{Item } 34 + \text{Item } 35)}{\text{Item } 32.2 + \text{Item } 33.2}$

$= \text{Item } 32.2 \times k$ (a constant). Item 34 and 35 are those values given in the same table. Items 32.2 and 33.2 may be taken from either Table 2, 3 or 4. Those from table 2 were used.

Item 33. Volatile matter $= \text{Item } 33.2 \times k$.

TABLE 38. Ultimate Analyses of Moisture Free Coal

Item 37.

$$\textit{Total carbon} = \text{Item } 37.2 \times \frac{100 - \text{Item } 40 + \text{Item } 41 + \text{Item } 42}{\text{Item } 37.2 + \text{Item } 38.2 + \text{Item } 39.2}$$

= Item 37.2 × m. Item 40, 41 and 42 are those values given in the same table. Items 37.2, 38.2 and 39.2 may be taken from either Table 2, 3 or 4. Those from Table 2 were used.

Item 38. Hydrogen = Item 38.2 × m.

Item 39. Oxygen = Item 39.2 × m.

TABLE 39. Calorific Value and Ultimate Analyses of Combustible:

Item 59 and 51, Calorific values, B. t. u.

Item 37.1, 38.1, 39.1, 40.1 and 41.1 are calculated by multiplyng the items of Table 38 by the factor $\frac{100}{100 - \text{Item } 42}$

TABLE 40. Furnace Conditions:

An explanation of the items contained in this table has been given on page 92.

TABLE 28 PRINCIPAL CONDITIONS

No.	Laboratory File No.	Date of Trial	Duration	Principal Conditions					
				Size of Coal (Commercial)	Condition of Coal	Thickness of Fuel Bed	Draft Pressure in Furnace Assigned	Furnace Control	Total Coal Fired per Sq. Ft. of Grate Area
1	2	3	4	5	6	7	8	9	10
	Code Item	1	2	23	23	81	13		
			Hr.	In.		In.	In.		Lb.
1	21—4.0703 W	Dec. 7, '06	8.17	⅞—⅜	Washed	6	0.20	See Page 21, for Method of Furnace Control	301
2	23— "	Dec. 10, '06	6.08	"	"	5	0.16		209
3	24— "	Dec. 11, '06	8.17	"	"	4	0.12		236
4	25— "	Dec. 12, '06	7.97	"	"	7	0.25		291
5	26— "	Dec. 13, '06	7.63	"	"	4	0.10		262
6	30—5.0602 W	Dec. 18, '06	8.00	¾—¼	"	4	0.10		209
7	31— "	Dec. 19, '06	7.87	"	"	4	0.12		223
8	32— "	Dec. 20, '06	5.55	"	"	5	0.11		144
9	34— "	Jan. 10, '07	7.25	"	"	6	0.14		196
10	35— "	Jan. 11, '07	8.13	"	"	7	0.17		209
11	36— "	Jan. 12, '07	8.08	"	"	6	0.16		209
12	37—5.0200 W	Jan. 14, '07	6.43	¼—0	"	5	0.29		196
13	39— "	Jan. 17, '07	7.93	"	"	6	0.39		249
14	40— "	Jan. 18, '07	7.78	"	"	6	0.45		249
15	41— "	Jan. 21, '07	5.70	"	"	4	0.23		209
16	42— "	Jan. 22, '07	5.10	"	"	4	0.29		183
17	43—4.0700 W	Jan. 23, '07	8.15	⅞—0	"	5	0.14		236
18	44— "	Jan. 24, '07	8.07	"	"	5	0.14		236
19	45— "	Jan. 25, '07	8.08	"	"	4	0.12		236
20	46— "	Jan. 26, '07	7.90	"	"	6	0.16		236
21	47—6.0402 W	Jan. 28, '07	8.32	¾—¼	"	6	0.15		209
22	48— "	Jan. 29, '07	8.25	"	"	7	0.14		196
23	49— "	Jan. 30, '07	8.22	"	"	5	0.10		183
24	50— "	Jan. 31; '07	8.32	"	"	4	0.90		209
25	51—5.1610 W	Feb. 1, '07	8.40	1¾—1	"	6	0.13		196
26	52— "	Feb. 2, '07	8.12	"	"	6	0.13		209
27	53—6.0402 W	Feb. 4, '07	8.40	¾—¼	"	6	0.13		209
28	93—5.1610 W	Apr. 26, '07	8.22	1¾—1	"	7	0.15		196
29	94— "	Apr. 27, '07	7.82	"	"	6	0.13		183
30	95— "	Apr. 29, '07	8.07	"	"	5	0.11		196
31	96—7.1610—	Apr. 30, '07	8.25	"	Unwashed	5	0.10		196
32	97— "	May 1, '07	7.20	"	"	6	0.13		170

TABLE 28 PRINCIPAL CONDITIONS (*Concluded*)

No.	Laboratory File No.	Date of Trial	Duration	Principal Conditions: Size of Coal (Commercial)	Condition of Coal	Thickness of Fuel Bed	Draft Pressure in Furnace Assigned	Furnace Control	Total Coal Fired per Sq. Ft. of Grate Area
1	2	3	4	5	6	7	8	9	10
	Code Item	1	2	23	23	81	13		
			Hr.	In.		In.	In.		Lb.
33	98—7.1610—	May 2, '07	8.38	1¾—1	Unwashed	7	0.15	See Page 21. for Method of Furnace Control	209
34	99— ''	May 3, '07	8.07	''	''	6	0.12		209
35	100— ''	May 4, '07	6.80	''	''	6	0.17		196
36	101— ''	May 6, '07	8.10	''	''	6	0.20		262
37	102—5.1006 W	May 7, '07	6.05	1 —¾	Washed	5	0.10		144
38	104— ''	May 8, '07	8.18	''	''	5	0.09		183
39	107— ''	May 9, '07	8.10	''	''	6	0.12		183
40	109— ''	May 10, '07	7.82	''	''	7	0.15		183
41	110— ''	May 11, '07	7.55	''	''	6	0.15		223
42	112— ''	May 13, '07	7.85	''	''	5	0.10		157
43	113— ''	May 14, '07	7.30	''	''	6	0.19		223
44	114— ''	May 15, '07	4.82	''	''	6	0.25		183
45	115—6.0200 W	May 16, '07	8.02	¼—0	''	4	0.23		157
46	116— ''	May 17, '07	6.00	''	''	6	0.40		132
47	117— ''	May 18, '07	6.68	''	''	6	0.43		165
48	118— ''	May 20, '07	7.95	''	''	6	0.38		196
49	119— ''	May 21, '07	7.38	''	''	6	0.32		144
50	120— ''	May 22, '07	8.17	''	''	5	0.32		196
51	121— ''	May 23, '07	8.00	''	''	5	0.37		196
52	122— ''	May 24 '07	8.42	''	''	5	0.38		223
53	124—4.0300 W	May 27, '07	7.87	⅜—0	''	5	0.34		262
54	125— ''	May 28, '07	8.12	''	''	5	0.30		223
55	126— ''	May 29, '07	6.00	''	''	5	0.38		200
56	127— ''	May 30, '07	7.02	''	''	5	0.40		246
57	128—4.0703 W	May 31, '07	8.27	⅞—⅜	''	5	0.13		236
58	129— ''	June 1, '07	6.80	''	''	5	0.12		204
59	130— ''	June 3, '07	7.25	''	''	5	0.10		157
60	131— ''	June 4, '07	8.15	''	''	5	0.12		209
61	132— ''	June 5, '07	8.73	''	''	5	0.14		241
62	133— ''	June 6, '07	7.95	''	''	5	0.18		275
63	134— ''	June 7, '07	7.37	''	''	5	0.16		251
64	135— ''	June 8, '07	7.00	''	''	5	0.06		120

TABLE 29 COAL AND ASH

No.	Laboratory File No.	Total Coal and Ash							Analyses of Ash and Refuse	
		Weight of Coal as Fired	Percentage of Moisture in Coal	Total Weight of Dry Coal Fired	Total Ash and Refuse	Total Dry Coal Minus Ash and Refuse	Total Combustible Consumed	Percent of Ash and Refuse Referred to Dry Coal	Carbon	Earthy Matter
1	2	3	4	5	6	7	8	9	10	11
	Code Item	25	26	27	28	30.1	30	31	44	45
		Lb.	%	Lb.	Lb.	Lb.	Lb.	%	%	%
1	21—4.0703 W	11500	18.38	9386	1386	8000	7878	14.80	45.15	54.85
2	23— "	8000	18.63	6510	737	5773	5698	11.32	24.13	75.87
3	24— "	9000	17.35	7438	911	6527	6407	12.25	29.66	70.34
4	25— "	11100	19.11	8979	1040	7939	7849	11.58	23.48	76.52
5	26— "	10000	18.71	8129	1046	7083	6965	12.87	26.13	73.87
6	30—5.0602 W	8000	12.24	7021	861	6160	6028	12.25	21.03	78.97
7	31— "	8500	13.15	7382	999	6383	6277	13.53	34.98	65.02
8	32— "	5500	12.48	4814	560	4254	4178	11.63	19.90	80.10
9	34— "	7500	13.13	6515	686	5829	5723	10.53	14.75	85.25
10	35— "	8000	11.30	7096	695	6401	6255	9.79	15.81	84.19
11	36— "	8000	12.41	7007	716	6291	6221	10.22	19.56	80.44
12	37—5.0200 W	7500	15.80	6315	1117	5198	4960	17.69	38.51	61.49
13	39— "	9500	14.59	8114	1248	6866	6526	15.38	34.52	65.48
14	40— "	9500	16.20	7961	1177	6784	6436	14.78	29.84	70.16
15	41— "	8000	14.40	6848	1388	5460	5226	20.27	43.90	56.10
16	42— "	7000	17.84	5751	1162	4589	4408	20.21	43.97	56.03
17	43—4.0700 W	9000	18.68	7318	1117	6201	6203	15.26	27.44	72.56
18	44— "	9000	19.32	7261	955	6306	6219	13.15	24.03	75.97
19	45— "	9000	18.33	7350	1072	6278	6298	14.58	41.91	58.09
20	46— "	9000	18.79	7309	936	6373	6259	12.81	23.01	76.99
21	47—6.0402 W	8000	10.72	7142	919	6223	6271	12.86	31.07	68.93
22	48— "	7500	10.72	6696	636	6060	5999	9.50	20.28	79.72
23	49— "	7000	11.32	6208	763	5445	5420	12.29	34.45	65.55
24	50— "	8000	11.23	7102	952	6150	6211	13.40	29.42	70.58
25	51—5.1610 W	7500	11.43	6643	954	5689	5735	14.36	34.52	65.48
26	52— "	8000	10.94	7125	912	6213	6237	12.80	27.37	72.63
27	53—6.0402 W	8000	10.21	7183	679	6504	6492	9.45	20.61	79.39
28	93—5.1610 W	7500	8.79	6841	757	6084	6074	11.07	14.92	85.08
29	94— "	7000	8.06	6436	732	5704	5691	11.37	21.45	78.55
30	95— "	7500	8.44	6867	853	6014	6045	12.42	21.70	78.30
31	96—7.1610 —	7500	7.14	6965	874	6091	6177	12.50	17.82	82.18
32	97— "	6500	7.14	6036	684	5352	5196	11.33	17.87	82.13

TABLE 29 Coal and Ash (*Concluded*)

No.	Laboratory File No.	Total Coal and Ash: Weight of Coal as Fired	Total Coal and Ash: Percentage of Moisture in Coal	Total Coal and Ash: Total Weight of Dry Coal Fired	Total Coal and Ash: Total Ash and Refuse	Total Coal and Ash: Total Dry Coal Minus Ash and Refuse	Total Coal and Ash: Total Combustible Consumed	Total Coal and Ash: Percent of Ash and Refuse Referred to Dry Coal	Analyses of Ash and Refuse: Carbon	Analyses of Ash and Refuse: Earthy Matter
1	2	3	4	5	6	7	8	9	10	11
	Code Item	25	26	27	28	30.1	30	31	44	45
		Lb.	%	Lb.	Lb.	Lb.	Lb.	%	%	%
33	98—7.1610—	8000	6.79	7457	879	6578	6548	11.79	16.38	83.62
34	99— "	8000	7.61	7391	949	6442	6480	12.84	16.15	83.85
35	100— "	7500	7.78	6916	835	6081	6172	12.07	16.18	83.82
36	101— "	10000	7.34	9266	1065	8201	8057	11.49	17.44	82.56
37	102—5.1006 W	5500	8.58	5028	488	4540	4517	9.70	13.81	86.19
38	104— "	7000	10.12	6292	675	5617	5578	10.73	15.11	84.89
39	107— "	7000	9.40	6342	667	5675	5669	10.52	14.88	85.12
40	109— "	7000	8.99	6371	717	5654	5684	11.25	14.40	85.60
41	110— "	8500	9.38	7703	848	6855	6782	11.01	13.61	86.39
42	112— "	6000	8.90	5466	692	4774	4849	12.66	14.47	85.53
43	113— "	8500	9.74	7672	845	6827	6821	11.01	14.95	85.05
44	114— "	7000	9.25	6353	718	5635	5539	11.30	14.90	85.10
45	115—6.0200 W	6000	13.94	5164	810	4354	4087	15.69	46.18	53.82
46	116— "	5053	13 97	4347	506	3841	3602	11.64	33.74	66.26
47	117— "	6300	21.49	4946	496	4450	4242	10.03	16.59	83.41
48	118— "	7500	18.52	6111	709	5402	5101	11.60	28.31	71.69
49	119— "	5500	17.34	4546	627	3919	3745	13.79	32.48	67.52
50	120— "	7500	19.27	6055	834	5221	4952	13.77	33.60	66.40
51	121— "	7500	19.63	6028	751	5277	4976	12.46	27.78	72.22
52	122— "	8500	19.49	6843	807	6036	5724	11.79	25.30	74.70
53	124—4.0300 W	10000	21.61	7839	1266	6573	6144	16.15	33.80	66.20
54	125— "	8500	21.72	6654	1021	5633	5207	15.34	32.84	67.16
55	126— "	7627	21.35	5999	864	5135	4748	14.40	33.77	66.23
56	127— "	9404	21.25	7406	1156	6250	5819	15.61	34.98	65.02
57	128—4.0703 W	9000	17.24	7448	759	6689	6539	10.19	25.75	74.25
58	129— "	7777	22.63	6017	534	5483	5375	8.88	15.65	84.35
59	130— "	6000	17.95	4923	726	4197	4354	14.75	18.81	81.19
60	131— "	8000	19.83	6414	629	5785	5688	9.81	17.87	82.13
61	132— "	9201	17.68	7574	733	6841	6709	9.68	19.69	80.31
62	133— "	10500	16.48	8770	845	7925	7828	9.64	18.84	81.16
63	134— "	9600	19.29	7748	763	6985	6912	9.85	19.20	80.80
64	135— "	4600	19.49	3703	414	3289	3300	11.17	14.59	85.41

TABLE 30 Steam and Water Back

			Steam				Water Back				
					Quality						
No.	Laboratory File No.	Barometric Pressure	Average Gage Pressure	Absolute Pressure	Percentage of Moisture	Factor for Correction for Quality	Total Weight of Water Used	Temperature of Inflow	Temperature of Outflow	Per cent of Total Heat Lost to Water Back	Water Equivalent Correction Factor
1	2	3	4	5	6	7	8	9	10	11	12
	Code Item		11	11.1	54	56	a	b	c	d	e
		Lb.	Lb.	Lb.	%		Lb.	°F.	°F.	%	
1	21—4.0703 W	14.60	151.0	165.6	1.05	.9923	41186	55.0	82.7	1.02	1.0165
2	23— "	14.59	151.0	165.6	1.20	.9912	30916	57.0	94.0	1.41	1.0218
3	24— "	14.64	152.0	166.6	2.16	.9842	47405	57.0	92.0	1.81	1.0291
4	25— "	14.42	152.0	166.4	1.23	.9911	46244	56.0	85.0	1.20	1.0191
5	26— "	14.34	152.0	166.3	1.18	.9914	44462	57.0	97.6	1.82	1.0280
6	30—5.0602 W	14.67	152.0	166.7	2.34	.9828	62390	56.0	84.6	2.04	1.0316
7	31— "	14.51	151.3	165.8	2.10	.9846	46780	56.0	92.9	1.90	1.0291
8	32— "	14.32	151.4	165.7	2.91	.9787	38228	56.0	89.8	2.14	1.0334
9	34— "	14.29	150.5	164.8	1.88	.9856	35960	56.0	97.9	1.82	1.0298
10	35— "	14.40	150.0	164.4	1.70	.9876	43892	57.0	91.2	1.66	1.0270
11	36— "	14.50	150.0	164.5	1.59	.9884	37570	56.0	103.7	1.98	1.0317
12	37—5.0200 W	14.50	150.0	164.5	2.25	.9832	29500	57.0	98.2	1.71	1.0327
	38— "	14.43	150.0	164.4	1.70	.9876	38498	57.0	99.8	1.69	
13	39— "	14.40	150.0	164.4	2.00	.9854	43060	57.0	97.4	1.86	1.0354
14	40— "	14.38	150.0	164.4	1.87	.9863	39332	57.0	96.3	1.67	1.0314
15	41— "	14.53	150.0	164.5	1.75	.9872	23471	55.0	99.5	1.39	1.0260
16	42— "	14.65	150.0	164.7	2.15	.9843	26314	56.0	101.3	1.88	1.0349
17	43—4.0700 W	14.60	150.0	164.6	1.52	.9889	41543	56.0	105.8	2.34	1.0372
18	44— "	14.36	150.0	164.4	1.53	.9888	48059	56.0	106.7	2.73	1.0420
19	45— "	14.45	150.1	164.6	1.60	.9883	56481	56.0	96.2	2.52	1.0391
20	46— "	14.53	150.0	164.5	1.71	.9875	40416	55.0	113.0	2.61	1.0406
21	47—6.0402 W	14.60	150.0	164.6	1.60	.9883	52811	57.0	112.0	3.19	1.0471
22	48— "	14.48	150.0	164.5	1.95	.9857	65935	56.0	93.8	2.84	1.0433
23	49— "	14.55	150.0	164.6	1.80	.9868	45114	57.0	119.4	3.58	1.0521
24	50— "	14.40	150.0	164.4	0.74	.9946	65277	56.5	97.2	2.96	1.0431
25	51—5.1610 W	14.43	150.0	164.4	0.80	.9942	56076	56.8	102.4	3.04	1.0467
26	52— "	14.39	150.0	164.4	0.75	.9945	69329	56.4	92.4	2.76	1.0423
27	53—6.0402 W	14.48	147.0	161.5	0.67	.9951	63780	54.7	93.8	2.65	1.0410
28	93—5.1610 W	14.39	149.9	164.3	1.00	.9927	73131	56.1	81.2	2.08	1.0323
29	94— "	14.38	152.8	167.2	1.00	.9927	150302	56.3	69.9	2.48	1.0389
30	95— "	14.27	150.0	164.3	1.00	.9927	53404	57.3	94.5	2.27	1.0355
31	96—7.1610—	14.37	150.4	164.8	0.57	.9959	61215	55.8	85.6	2.02	1.0316
32	97— "	14.67	152.3	167.0	0.55	.9959	50718	56.1	91.7	2.19	1.0334

TABLE 30 STEAM AND WATER BACK (*Concluded*)

No.	Laboratory File No.	Barometric Pressure	Steam				Water Back				
			Average Gage Pressure	Absolute Pressure	Quality: Percentage of Moisture	Quality: Factor for Correction for Quality	Total Weight of Water Used	Temperature of Inflow	Temperature of Outflow	Per cent of Total Heat Lost to Water Back	Water Equivalent Correction Factor
1	2	3	4	5	6	7	8	9	10	11	12
	Code Item		11	11.1	54	56	a	b	c	d	e
		Lb.	Lb.	Lb.	%		Lb.	°F.	°F.	%	
33	98—7.1610—	14.40	150.3	164.7	0.57	.9959	57843	56.4	88.5	1.96	1.0306
34	99— "	14.33	148.2	162.5	0.57	.9959	61228	56.8	83.5	1.73	1.0269
35	100— "	14.44	148.2	162.6	0.57	.9959	54740	56.7	83.0	1.62	1.0258
36	101— "	14.31	146.7	161.0	0.57	.9959	58320	56.5	87.8	1.59	1.0255
37	102—5.1006 W	14.31	147.8	162.1	0.57	.9959	52030	56.9	81.4	1.96	1.0282
38	104— "	14.26	146.7	161.0	0.57	.9959	61168	56.6	86.2	2.24	1.0324
39	107— "	14.29	147.5	161.8	0.57	.9959	77517	57.2	77.9	1.96	1.0290
40	109— "	14.28	148.1	162.4	0.45	.9967	62528	56.8	81.0	1.84	1.0279
41	110— "	14.36	148.5	162.9	0.45	.9967	78897	56.0	78.2	1.78	1.0264
42	112— "	14.16	148.5	162.7	0.75	.9945	75948	57.6	80.1	2.44	1.0360
43	113— "	14.64	148.7	163.3	0.57	.9959	67233	58.0	83.2	1.76	1.0264
44	114— "	14.24	148.1	162.3	0.57	.9959	34393	57.0	86.3	1.28	1.0199
45	115—6.0200 W	14.32	147.1	161.4	0.57	.9959	44895	57.1	79.5	1.74	1.0337
46	116— "	14.23	145.1	158.3	0.57	.9959	40410	57.0	76.4	1.56	1.0304
47	117— "	14.26	145.5	159.8	0.57	.9959	43105	57.9	77.1	1.37	1.0251
48	118— "	14.43	145.8	160.2	0.57	.9959	57240	57.7	79.3	1.70	1.0290
49	119— "	14.44	146.3	160.7	0.57	.9959	62017	56.9	70.8	1.62	1.0298
50	120— "	14.29	147.3	161.6	0.57	.9959	56761	57.0	82.6	2.08	1.0356
51	121— "	14.26	146.3	160.6	0.57	.9959	65280	57.5	75.5	1.67	1.0285
52	122— "	14.25	148.6	162.8	0.57	.9959	72134	57.6	77.0	1.73	1.0293
53	124—4.0300 W	14.38	149.0	163.4	0.57	.9959	72612	56.1	72.2	1.36	1.0233
54	125— "	14.36	148.5	162.9	0.57	.9959	63312	57.0	76.6	1.71	1.0289
55	126— "	14.31	149.2	163.5	0.57	.9959	64500	56.7	71.1	1.40	1.0238
56	127— "	14.27	149.5	163.8	0.57	.9959	62100	57.0	73.7	1.28	1.0215
57	128—4.0703 W	14.22	148.6	162.8	0.57	.9959	94657	56.9	75.4	1.90	1.0272
58	129— "	14.11	149.2	163.3	0.57	.9959	73984	56.7	76.2	1.89	1.0277
59	130— "	14.21	149.1	163.3	0.57	.9959	71182	56.9	79.7	2.62	1.0381
60	131— "	14.14	149.4	163.5	0.57	.9959	85371	57.0	77.4	2.16	1.0308
61	132— "	14.28	149.4	163.7	0.57	.9959	86456	57.0	79.3	2.09	1.0296
62	133— "	14.31	148.3	162.6	0.57	.9959	97785	57.3	76.8	1.76	1.0254
63	134— "	14.17	148.3	162.5	0.57	.9959	69250	57.0	82.1	1.78	1.0257
64	135— "	14.28	147.3	161.6	0.57	.9959	51450	57.7	90.4	3.58	1.0516

TABLE 31 Water Log Data

No.	Laboratory File No.	Feed Water Weighed: Number of Tanks Weighed	Feed Water Weighed: Weight per Tank	Feed Water Weighed: Total Water Weighed	Feed Water Corrections: Water Gage: Reading at Start	Water Gage: Reading at Close	Feed Tank: Level at Start	Feed Tank: Level at Close	Steam Pressure: Start, Gage	Steam Pressure: Close, Gage	Miscellaneous Corrections	Total Correction
1	2	3	4	5	6	7	8	9	10	11	12	13
			Lb.	Lb.	In.	In.	In.	In.	Lb.	Lb.	Lb.	Lb.
1	21—4.0703 W	75	801	60075	4.25	4.00	14.70	17.40	153	150		— 351
2	23— "	55	803	44165	5.60	1.20	25.20	25.00	150	151		+1056
3	24— "	61	804	49044	3.70	4.50	20.50	20.00	150	151		+ 184
4	25— "	77	803	61831	4.25	4.80	27.50	34.00	153	150		—1092
5	26— "	69	803	55407	4.00	3.10	31.75	28.70	151	147	406a	+ 223
6	30—5.0602 W	60	806	48360	5.00	2.50	29.00	28.00	153	153		+ 726
7	31— "	62	806	49972	5.50	4.75	35.00	26.00	154	151		+1468
8	32— "	42	806	33852	4.25	7.50	30.25	22.75	154	154		— 49
9	34— "	54	808	43632	6.00	4.25	24.50	25.25	150	149		+ 292
10	35— "	60	806	48360	5.25	6.00	22.75	24.75	149	150	300b	— 159
11	36— "	60	805	48300	3.75	3.25	26.25	22.75	153	148		+ 591
12	37—5.0200 W	40	806	32240	4.75	4.50	25.50	24.50	148	147		+ 196
13	39— "	53	806	42718	4.50	4.75	23.75	21.50	152	148		+ 241
14	40— "	52	806	41912	4.50	4.00	26.75	22.25	149	149		+ 772
15	41— "	44	806	35464	3.50	5.25	28.25	30.25	149	148		— 706
16	42— "	37	806	29822	5.25	5.75	23.25	26.00	152	150		— 240
17	43—4.0700 W	60	805	48300	3.75	4.50	24.00	22.75	147	147		+ 7
18	44— "	62	806	49972	4.50	5.25	23.25	20.50	150	150		+ 225
19	45— "	61	806	49166	5.00	5.00	29.50	20.75	152	151		+1266
20	46— "	61	806	49166	5.75	6.00	26.50	19.25	151	150	146c	+ 883
21	47—6.0402 W	66	805	53130	4.50	4.50	25.00	22.75	148	151	214c	+ 200
22	48— "	63	805	50715	4.50	6.00	26.00	27.50	147	149	301c	— 774
23	49— "	59	805	47495	4.75	5.50	26.25	27.00	146	145	510c	— 665
24	50— "	67	805	53935	4.80	6.50	27.00	27.30	152	149	494c	— 823
25	51—5.1610 W	59	805	47495	4.00	3.50	22.25	22.80	150	151	530c	— 344
26	52— "	63	806	50778	4.50	4.25	22.25	20.75	150	152	480c	— 61
27	53—6.0402 W	66	805	53130	4.25	4.50	25.25	25.50	149	151	781c	— 884
28	93—5.1610 W	61	807	49227	6.00	6.50	24.00	26.00	149	153		— 380
29	94— "	55	807	44385	7.00	5.00	29.00	26.00	148	150		+ 917
30	95— "	59	807	47613	4.00	3.50	28.00	25.00	152	150		+ 540
31	96—7.1610—	60	807	48420	7.00	5.75	29.00	23.80	150	151		+1054
32	97— "	53	807	42771	4.00	5.00	27.50	29.75	147	155		— 515

a. Leakage from Pump. b. Valve in weighing tank accidentally opened.
c. Leakage through Blow-off Valve.

TABLE 31 WATER LOG DATA (*Concluded*)

		Feed Water Weighed			Feed Water Corrections							
					WaterGage		Level at Start		Steam Pressure			
No.	Laboratory File No.	Number of Tanks Weighed	Weight Per Tank	Total Water Weighed	Reading at Start	Reading at Close	Level at Start	Level at Close	Start, Gage	Close, Gage	Miscllaneous Corrections	Total Correction
1	2	3	4	5	6	7	8	9	10	11	12	13
			Lb.	Lb.	In.	In.	In.	In.	Lb.	Lb.	Lb.	Lb.
33	98—7.1610—	64	807	51648	6.00	6.00	29.00	25.80	150	148	......	+ 454
34	99— "	65	807	52455	3.00	4.80	27.00	26.00	150	147	......	— 291
35	100— "	60	807	48420	3.25	5.50	29.00	28.50	145	153	......	— 397
36	101— "	77	807	62139	3.50	2.50	27.00	28.00	149	146	......	+ 70
37	102—5.1006 W	48	807	38736	5.00	3.25	25.00	25.50	152	144	......	+ 289
38	104— "	58	807	46806	7.00	5.00	31.00	25.75	153	151	......	+1218
39	107— "	60	807	48420	3.00	4.00	26.00	29.00	147	139	.....	— 716
40	109— "	58	807	46806	4.00	7.00	27.00	24.00	154	155	......	— 256
41	110— "	70	807	56490	5.50	3.50	28.00	28.00	156	148	......	+ 410
42	112— "	50	807	40350	2.25	1.75	28.00	30.00	145	141	......	— 198
43	113— "	68	807	54876	6.00	3.50	26.50	27.00	150	142	......	+ 464
44	114— "	55	807	44385	5.00	5.75	25.00	29.50	150	148	......	— 842
45	115—6.0200 W	31	807	25017	5.00	3.50	26.50	24.50	150	148	......	+ 628
46	116— "	28	807	22596	5.00	5.50	24.00	27.00	141	152	.....	— 490
47	117— "	34	807	27438	3.50	2.50	29.50	25.00	150	148	......	+ 876
48	118— "	46	807	37122	4.50	5.75	25.50	27.00	144	153	......	— 457
49	119— "	30	807	24210	6.75	4.50	28.00	27.00	147	150	......	+ 688
50	120— "	44	807	35508	3.50	4.00	27.50	29.50	151	147	......	— 430
51	121— "	44	807	35508	4.75	3.50	26.00	28.00	151	148	......	— 17
52	122— "	51	807	41157	6.50	4.50	25.00	28.50	145	150	......	— 14
53	124—4.0300 W	54	807	43578	4.00	3.50	27.00	30.00	141	146	......	— 291
54	125— "	46	807	37122	5.00	3.50	25.00	28.00	151	150	.. ..	— 93
55	126— "	42	807	33894	5.50	3.75	23.50	28.00	154	146	......	— 293
56	127— "	51	807	41157	6.50	4.00	24.50	26.25	155	153	......	+ 316
57	128—4.0703 W	68	807	54876	4.50	3.00	27.00	25.00	154	150	......	+ 618
58	129— "	57	807	45999	4.00	5.00	26.50	26.75	151	147	......	— 292
59	130— "	45	807	36315	5.00	4.50	27.17	26.00	148	146	......	+ 274
60	131— "	62	807	50034	1.75	6.25	25.00	27.50	149	154	......	—1384
61	132— "	68	807	54876	5.00	2.00	26.75	23.00	150	146	......	+1221
62	133— "	82	807	66174	2.00	5.00	25.00	24.00	150	148	......	— 565
63	134— "	70	807	56490	7.00	3.00	30.75	24.50	151	146	......	+1808
64	135— "	34	807	27438	5.50	3.25	27.50	27.00	148	150	......	+ 609

TABLE 32 TOTAL WATER

No.	Laboratory File No.	Total Water							
		Temperature of Feed Water Entering Boiler	Total Weight of Water Fed to Boiler	Equivalent Water Fed to Boiler from and at 212° F.	Water Actually Evap. Corrected for Quality of Steam	Factor of Evaporation	Equivalent Evaporation from and at 212° F.		
							Performance	Compensated for Water Back	Total Loss of Evap. Charged to Water Back
1	2	3	4	5	6	7	8	9	10
	Code Item	20	57	58	59	60	61	61.1	f
		°F.	Lb.	Lb.	Lb.		Lb.	Lb.	Lb.
1	21—4.0703 W	56.0	59724	72326	59274	1.2110	71781	72965	1184
2	23— "	55.5	45221	54817	44828	1.2122	54340	55525	1184
3	24— "	56.0	49228	59630	48450	1.2113	58688	60395	1707
4	25— "	57.0	60739	73512	60198	1.2103	72858	74249	1391
5	26— "	57.0	55630	67329	55152	1.2103	66750	68619	1869
6	30—5.0602 W	56.0	49086	59458	48242	1.2113	58436	60283	1847
7	31— "	56.0	51440	62284	50647	1.2108	61323	63087	1784
8	32— "	56.0	33803	40946	33083	1.2113	40073	41411	1338
9	34— "	56.0	43924	53183	43291	1.2108	52417	53979	1562
10	35— "	58.0	48201	58261	47603	1.2087	57538	59091	1553
11	36— "	57.0	48891	59143	48324	1.2097	58458	60311	1853
12	37—5.0200 W	57.0	32436	39238	31891	1.2097	38579	39840	1261
13	39— "	57.5	42959	51950	42332	1.2093	51192	53004	1812
14	40— "	57.8	42684	51600	42101	1.2089	50896	52494	1598
15	41— "	56.0	34758	42085	34313	1.2108	41546	42626	1080
16	42— "	56.0	29582	35812	29118	1.2106	35250	36480	1230
17	43—4.0700 W	56.0	48307	58490	47771	1.2108	57841	59992	2151
18	44— "	56.0	50197	60779	49635	1.2108	60098	62622	2524
19	45— "	56.0	50432	61063	49842	1.2108	60349	62708	2559
20	46— "	55.5	50049	60624	49423	1.2113	59866	62296	2430
21	47—6.0402 W	56 0	53330	64572	52706	1.2108	63816	66822	3006
22	48— "	56.5	49941	60439	49227	1.2102	59575	62154	2579
23	49— "	56.5	46830	56669	46212	1.2101	55921	58834	2913
24	50— "	56.0	53112	64250	52825	1.2097	63902	66656	2754
25	51—5.1610 W	57.0	47151	57015	46878	1.2092	56685	59332	2647
26	52— "	56.5	50717	61378	50438	1.2102	61040	63622	2582
27	53—6.0402 W	54.8	52246	63296	51990	1.2115	62986	65568	2582
28	93—5.1610 W	56.5	48847	59115	48490	1.2102	58683	60578	1895
29	94— "	57.1	45302	54820	44971	1.2101	54419	56535	2116
30	95— "	56.3	48153	58289	47801	1.2105	57863	59917	2054
31	96—7.1610 —	56.1	49474	59893	49271	1.2106	59647	61531	1884
32	97— "	56.7	42256	51155	42083	1.2106	50945	52646	1701

TABLE 32 TOTAL WATER (*Concluded*)

No	Laboratory File No.	Total Water					Equivalent Evaporation from and at 212° F.		
		Temperature of Feed Water Entering Boiler	Total Weight of Water Fed to Boiler	Equivalent Water Fed to Boiler from and at 212° F.	Water Actually Evap. Corrected for Quality of Steam	Factor of Evaporation	Performance	Compensated for Water Back	Total Loss of Evap. Charged to Water Back
1	2	3	4	5	6	7	8	9	10
	Code Item	20	57	58	59	60	61	61.1	f
		°F.	Lb.	Lb.	Lb.		Lb.	Lb.	Lb.
33	98—7.1610—	56.5	52102	63059	51888	1.2103	62800	64721	1921
34	99— "	56.8	52164	63092	51950	1.2095	62833	64523	1690
35	100— "	56.7	48023	58093	47821	1.2097	57849	59341	1492
36	101— "	56.6	62209	75254	61948	1.2097	74938	76849	1911
37	102—5.1006 W	57.0	39025	47193	38861	1.2093	46995	48320	1325
38	104— "	56.6	48024	58090	47827	1.2096	57851	59725	1874
39	107— "	56.7	47704	57698	47504	1.2095	57456	59122	1666
40	109— "	57.0	46550	56298	46396	1.2094	56111	57676	1565
41	110— "	56.9	56900	68832	56712	1.2097	68605	70416	1811
42	112— "	57.5	40152	48536	39931	1.2088	48269	50006	1737
43	113— "	57.9	55340	66878	55113	1.2085	66604	68362	1758
44	114— "	57.0	43543	52657	43364	1.2093	52140	53483	1043
45	115—6.0200 W	57.0	25645	31010	25540	1.2092	30883	31923	1040
46	116— "	57.0	22106	26724	22015	1.2089	26614	27423	809
47	117— "	57.9	28314	34206	28198	1.2081	34066	34921	855
48	118— "	58.0	36665	44291	36515	1.2080	44110	45389	1279
49	119— "	58.0	24898	30079	24796	1.2081	29956	30848	892
50	120— "	57.6	35078	42395	34934	1.2086	42221	23724	1503
51	121— "	58.0	35491	42877	35345	1.2081	42700	43917	1217
52	122— "	58.0	41143	49717	40974	1.2084	49513	50963	1450
53	124—4.0300 W	56.9	43287	52360	43109	1.2096	52145	53360	1215
54	125— "	57.6	37029	44761	36877	1.2088	44577	45865	1288
55	126— "	57.0	33601	40640	33463	1.2095	40473	41436	963
56	127— "	57.1	41473	50157	41302	1.2094	49951	51024	1073
57	128—4.0703 W	57.3	55494	67092	55266	1.2090	66817	68634	1817
58	129— "	57.0	45707	55283	45520	1.2095	55056	56581	1525
59	130— "	57.0	36589	44254	36439	1.2095	44073	45751	1678
60	131— "	57.0	48650	58842	48451	1.2095	58601	60406	1805
61	132— "	57.0	56097	67855	55867	1.2096	67577	69577	2000
62	133— "	58.0	65609	79275	65340	1.2083	78950	80955	2005
63	134— "	58.0	58298	70441	58059	1.2083	70153	71955	1802
64	135— "	59.0	28047	33856	27932	1.2071	33717	35456	1739

TABLE 33 Fuel and Water per Hour

No.	Laboratory File No.	Fuel per Hour				Water per Hour				
		Dry Coal Fired	Combustible Consumed	Dry Coal Fired per Sq. Ft. of Grate Surface	Combustible Consumed per Sq. Ft. of Water Heating Surface	Evaporated—Corrected for Quality of Steam	Equivalent Evaporation from and at 212° F.			
							Total	Per Square Foot of Water Heating Surface	Compensated for Water Back	
									Total	Per Sq. Ft. of Water Heating Surface
1	2	3	4	5	6	7	8		10	11
	Code Item	46	47	48	49	62	63	64	63.1	64.1
		Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
1	21—4.0703 W	1148	964	30.05	0.475	7255	8786	4.33	8931	4.40
2	23— "	1070	937	28.05	0.462	7373	8937	4.41	9132	4.51
3	24— "	910	784	23.83	0.387	5930	7183	3.54	7392	3.64
4	25— "	1127	985	29.50	0.486	7553	9141	4.51	9315	4.60
5	26— "	1065	913	27.88	0.450	7228	8748	4.32	8993	4.44
6	30—5.0602 W	878	754	22.98	0.372	6030	7304	3.60	7535	3.71
7	31— "	938	798	24.56	0.394	6438	7795	3.85	8022	3.96
8	32— "	867	753	22.70	0.371	5961	7221	3.56	7462	3.68
9	34— "	899	789	23.52	0.389	5971	7230	3.57	7445	3.67
10	35— "	872	769	22.84	0.379	5853	7074	3.49	7265	5.58
11	36— "	867	770	22.69	0.380	5980	7234	3.57	7463	3.68
12	37—5.0200 W	982	771	25.69	0.380	4957	5997	2.96	6193	3.05
13	39— "	1023	823	26.78	0.406	5336	6453	3.18	6681	3.29
14	40— "	1023	827	26.78	0.408	5409	6539	3.22	6744	3.32
15	41— "	1201	917	31.45	0.452	6020	7289	3.60	7478	3.69
16	42— "	1128	864	29.53	0.426	5710	6912	3.41	7153	3.53
17	43—4.0700 W	898	761	23.51	0.375	5861	7097	3.50	7361	3.63
18	44— "	900	771	23.57	0.380	6154	7451	3.68	7764	3.83
19	45— "	909	779	23.80	0.384	6166	7466	3.69	7758	3.83
20	46— "	925	792	24.22	0.391	6256	7579	3.74	7886	3.89
21	47—6.0402 W	859	754	22.48	0.372	6339	7675	3.79	8036	3.97
22	48— "	812	727	21.25	0.359	5967	7221	3.56	7536	3.71
23	49— "	756	660	19.78	0.325	5624	6806	3.36	7160	3.53
24	50— "	854	747	22.35	0.368	6351	7683	3.79	8014	3.95
25	51—5.1610 W	791	683	20.70	0.337	5581	6748	3.33	7063	3.48
26	52— "	878	768	22.98	0.379	6213	7519	3.71	7837	3.86
27	53—6.0402 W	855	773	22.38	0.381	6189	7498	3.70	7805	3.85
28	93—5.1610 W	833	739	21.79	0.365	5901	7142	3.52	7372	3.63
29	94— "	823	728	21.55	0.359	5753	6962	3.43	7232	3.56
30	95— "	851	749	22.28	0.370	5926	7174	3.54	7428	3.66
31	96—7.1610—	844	738	22.10	0.364	5972	7230	3.57	7458	3.68
32	97— "	838	722	21.90	0.356	5845	7076	3.49	7312	3.61

TABLE 33 FUEL AND WATER PER HOUR (*Concluded*)

No.	Laboratory File No.	Fuel per Hour				Water per Hour				
							Equivalent Evaporation from and at 212° F.			
									Compensated for Water Back	
		Dry Coal Fired	Combustible Consumed	Dry Coal Fired per Sq. Ft. of Grate Surface	Combustible Consumed per Sq. Ft. of Water Heating Surface	Evaporated—Corrected for Quality of Steam	Total	Per Square Foot of Water Heating Surface	Total	Per Sq. Ft. of Water Heating Surface
1	2	3	4	5	6	7	8	9	10	11
	Code Item	46	47	48	49	62	63	64	63.1	64.1
		Lb.	Lb.	Lb.	Lb.	Lb	Lb.	Lb.	Lb.	Lb.
33	98—7.1610—	890	781	23.28	0.385	6190	7491	3.70	7720	3.81
34	99— "	916	803	23.98	0.396	6494	7789	3.84	7998	3,94
35	100 - "	1017	894	26.62	0.441	7032	8507	4.20	8726	4.31
36	101-- "	1144	995	29.90	0.491	7648	9251	4.57	9487	4.68
37	102—5.1006 W	831	747	21.75	0.368	6424	7768	3.83	7987	3.94
38	104— "	769	682	20.13	0.336	5844	7070	3.49	7299	3.60
39	107— "	783	700	20.49	0.345	5865	7093	3.50	7298	3.60
40	109— "	815	727	21.34	0.359	5935	7178	3.54	7378	3.64
41	110— "	1020	898	26.70	0.443	7510	9084	4.48	9324	4.60
42	112— "	696	608	18.23	0.300	5086	6149	3,03	6370	3.14
43	113— "	1051	934	27.51	0.461	7550	9124	4.50	9365	4.62
44	114— "	1319	1150	34.54	0.568	9002	10886	5.37	11102	5.47
45	115—6.0200 W	644	510	16.86	0.251	3186	3852	1.90	3982	1.96
46	116— "	725	600	18.97	0.296	3670	4436	2.19	4571	2.25
47	117— "	740	635	19.37	0.313	4219	5097	2.51	5225	2.57
48	118— "	769	642	20.12	0.316	4593	5549	2.74	5710	2.82
49	119— "	616	507	16.12	0.250	3358	4057	2.00	4177	2.06
50	120— "	741	606	19.41	0.299	4277	5170	2.55	5354	2.64
51	121-- "	754	622	19.73	0.307	4418	5338	2.63	5490	2.70
52	122-- "	813	680	21.28	0.335	4864	5883	2.90	6055	2.98
53	124—4.0300 W	996	781	26.08	0.385	5479	6628	3.27	6782	3.34
54	125— "	820	642	21.46	0.316	4543	5492	2.71	5651	2.79
55	126— "	1000	791	26.17	0.390	5577	6745	3.32	6905	3.40
56	127— "	1055	829	27.62	0.409	5886	7119	3.51	7272	3.58
57	128—4.0703 W	901	791	23.58	0.390	6685	8082	3.98	8302	4.09
58	129— "	885	790	23.16	0.390	6694	8096	3.99	8320	4.10
59	130 — "	679	601	17.77	0.296	5026	6079	3.00	6311	3.11
60	131— "	787	698	20.60	0.344	5945	7190	3.54	7411	3.65
61	132— "	867	768	22.70	0,379	6397	7738	3.82	7967	3.93
62	133— "	1103	985	28.87	0.486	8219	9931	4.90	10183	5.02
63	134— "	1052	938	27.55	0.463	7881	9523	4.70	9768	4.82
64	135— "	529	471	13.85	0.233	3990	4817	2.38	5065	2.50

TABLE 34 Horse Power and Economic Results

No.	Laboratory File No.	Horse Power: Developed	Horse Power: Percentage of Builders Rating Developed	Economic Results — Performance: Apparent Evaporation per pound of Coal as Fired	Performance — Equivalent Evaporation from and at 212° F.: Per Pound of Coal as Fired	Performance — Equivalent Evaporation from and at 212° F.: Per Pound of Dry Coal	Performance — Equivalent Evaporation from and at 212° F.: Per Pound of Combustible	Compensated for Water Back: Apparent Evaporation per Pound of Coal as Fired	Compensated for Water Back — Equivalent Evaporation from and at 212° F.: Per Pound of Coal as Fired	Compensated for Water Back — Equivalent Evaporation from and at 212° F.: Per Pound of Dry Coal	Compensated for Water Back — Equivalent Evaporation from and at 212° F.: Per Pound of Combustible
1	2	3	4	5	6	7	8	9	10	11	12
	Code Item	65	67	68	69	70	71	68.1	69.1	70.1	71.1
		H. P.	%	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
1	21—4.0703 W	254.7	121.3	5.19	6.24	7.65	9.11	5.28	6.34	7.78	9.26
2	23— "	259.0	123.3	5.65	6.79	8.35	9.54	5.77	6.94	8.53	9.75
3	24— "	208.2	99.1	5.47	6.52	7.89	9.16	5.63	6.71	8.12	9.43
4	25— "	265.0	126.2	5.47	6.56	8.11	9.28	5.57	6.69	8.26	9.46
5	26— "	253.6	120.8	5.56	6.68	8.21	9.58	5.72	6.87	8.44	9.85
6	30—5.0602 W	211.7	100.8	6.14	7.30	8.32	9.69	6.33	7.53	8.58	10.00
7	31— "	225.9	107.6	6.05	7.21	8.31	9.77	6.23	7.42	8.55	10.05
8	32— "	209.3	99.7	6.15	7.29	8.32	9.59	6.36	7.53	8.60	9.91
9	34— "	209.6	99.8	5.86	6.99	8.05	9.16	6.03	7.20	8.30	9.43
10	35— "	205.0	97.6	6.03	7.19	8.11	9.20	6.19	7.38	8.33	9.45
11	36— "	209.7	99.9	6.11	7.31	8.34	9.40	6.30	7.54	8.60	9.70
12	37—5.0200 W	173.8	82.8	4.32	5.14	6.11	7.78	4.46	5.31	6.31	8.03
13	39— "	187.0	89.0	4.52	5.39	6.31	7.84	4.68	6.62	6.53	8.12
14	40— "	189.5	90.2	4.49	5.36	6.39	7.91	4.63	5.53	6.59	8.16
15	41— "	211.3	100.6	4.34	5.19	6.07	7.95	4.45	5.32	6.23	8.16
16	42— "	200.3	95.4	4.22	5.04	6.13	8.00	4.37	5.22	6.34	8.28
17	43—4.0700 W	205.7	98.0	5.37	6.43	7.90	9.32	5.57	6.67	8.17	9.67
18	44— "	216.0	102.9	5.58	6.68	8.28	9.66	5.81	6.96	8.63	10.07
19	45— "	216.4	103.0	5.60	6.71	8.21	9.58	5.82	6.97	8.53	9.95
20	46— "	219.7	104.6	5.56	6.65	8.20	9.56	5.79	6.92	8.53	9.95
21	47—6.0402 W	222.5	106.0	6.67	7.98	8.94	10.18	6.98	8.36	9.36	10.66
22	48— "	209.3	99.7	6.66	7.94	8.90	9.94	6.95	8.28	9.29	10.37
23	49— "	197.3	94.0	6.69	7.99	9.01	10.32	7.04	8.41	9.48	10.86
24	50— "	222.7	106.0	6.64	7.99	9.00	10.29	6.93	8.33	9.39	10.73
25	51—5.1610 W	195.6	93.1	6.29	7.56	8.53	9.88	6.58	7.91	8.93	10.33
26	52— "	217.9	103.8	6.34	7.63	8.57	9.79	6.61	7.95	9.04	10.20
27	53—6.0402 W	217.3	103.5	6.53	7.87	8.77	9.70	6.80	8.19	9.13	10.10
28	93—5.1610 W	207.0	98.6	6.51	7.82	8.58	9.66	6.72	8.07	8.86	9.97
29	94— "	201.8	96.1	6.47	7.77	8.46	9.56	6.72	8.07	8.79	9.93
30	95— "	207.9	99.0	6.42	7.72	8.43	9.57	6.65	7.99	8.73	9.91
31	96—7.1610—	209.6	99.8	6.60	7.95	8.56	9.66	6.81	8.20	8.83	9.96
32	97— "	205.1	97.7	6.50	7.84	8.44	9.80	6.72	8.10	8.72	10.13

TABLE 34 HORSE POWER AND ECONOMIC RESULTS (*Concluded*)

No.	Laboratory File No.	Horse Power		Economic Results							
				Performance				Compensated for Water Back			
					Equivalent Evaporation from and at 212° F.				Equivalent Evaporation from and at 212° F.		
		Developed	Percentage of Builders Rating Developed	Apparent Evaporation per pound of Coal as Fired	Per Pound of Coal as Fired	Per Pound of Dry Coal	Per Pound of Combustible	Apparent Evaporation per pound of Coal as Fired	Per Pound of Coal as Fired	Per Pound of Dry Coal	Per Pound of Combustible
1	2	3	4	5	6	7	8	9	10	11	12
	Code Item	65	67	68	69	70	71	68.1	69.1	70.1	71.1
		H. P.	%	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
33	98—7.1610—	217.1	103.4	6.51	7.85	8.42	9.59	6.71	8.09	8.68	9.88
34	99— "	225.8	107.5	6.52	7.85	8.50	9.70	6.70	8.06	8.73	9.96
35	100— "	246.6	117.4	6.40	7.71	8.36	9.37	6.57	7.91	8.58	9.61
36	101— "	268.1	127.7	6.22	7.49	8.09	9.30	6.38	7.68	8.30	9.54
37	102—5.1006 W	225.2	107.2	7.10	8.55	9.35	10.40	7.30	8.81	9.61	10.69
38	104— "	204.9	97.6	6.86	8.26	9.19	10.37	7.08	8.53	9.40	10.71
39	107— "	205.6	97.9	6.81	8.21	9.06	10.14	7.01	8.45	9.32	10.43
40	109— "	208.1	99.1	6.65	8.02	8.81	9.87	6.85	8.24	9.06	10.15
41	110— "	263.3	125.4	6.69	8.07	8.91	10.12	6.87	8.28	9.15	10.39
42	112— "	178.2	84.9	6.69	8.04	8.83	9.95	6.93	8.33	9.15	10.31
43	113— "	264.5	126.0	6.51	7.84	8.68	9.77	6.68	8.05	8.91	10.03
44	114— "	315.5	150.2	6.22	7.49	8.25	9.47	6.34	7.64	8.41	9.66
45	115—6.0200 W	111.7	53.2	4.27	5.15	5.98	7.56	4.41	5.32	6.18	7.81
46	116— "	128.6	61.2	4.37	5.27	6.12	7.39	4.50	5.43	6.31	7.61
47	117— "	147.7	70.3	4.49	5.41	6.89	8.03	4.60	5.55	7.06	8.23
	118— "	160.8	76.6	4.89	5.89	7.21	8.65	5.03	6.06	7.42	8.90
49	119— "	117.6	56.0	4.53	5.45	6.59	8.00	4.67	5.61	6.79	8.24
50	120— "	149.9	71.4	4.68	5.63	6.97	8.53	4.85	5.83	7.22	8.83
51	121— "	154.7	73.7	4.73	5.69	7.08	8.58	4.87	5.85	7.28	8.82
52	122— "	170.5	81.2	4.84	5.83	7.23	8.65	4.98	6.00	7.44	8.90
53	124—4.0300 W	192.1	91.5	4.33	5.22	6.65	8.48	4.43	5.34	6.81	8.68
54	125— "	159.2	75.8	4.36	5.25	6.70	8.56	4.49	5.40	6.89	8.81
55	126— "	195.5	93.1	4.41	5.30	6.74	8.52	4.51	5.42	6.90	8.72
56	127— "	206.3	98.2	4.41	5.31	6.74	8.59	4.50	5.42	6.88	8.77
57	128—4.0703 W	234.3	111.6	6.17	7.43	8.97	10.21	6.34	7.63	9.23	10.49
58	129— "	234.7	111.8	5.88	7.08	9.15	10.04	6.04	7.28	9.40	10.32
59	130— "	176.2	83.9	6.10	7.35	8.95	10.12	6.33	7.63	9.29	10.51
60	131— "	208.4	99.2	6.09	7.33	9.14	10.30	6.28	7.56	9.42	10.62
61	132— "	224.3	106.8	6.10	7.35	8.92	10.07	6.28	7.57	9.18	10.37
62	133— "	287.9	137.1	6.25	7.52	9.00	10.09	6.41	7.71	9.23	10.35
63	134— "	276.0	131.4	6.07	7.31	9.05	10.15	6.23	7.50	9.28	10.41
64	135— "	139.6	66.5	6.10	7.33	9.11	10.22	6.41	7.71	9.58	10.75

TABLE 35 EFFICIENCY AND COST OF EVAPORATION

No.	Laboratory File No.	Efficiency				Cost of Coal		
		"Boiler and Furnace"	Over-all	Compensated for Water Back: "Boiler and Furnace"	Compensated for Water Back: Over-all	Per Ton of 2000 Pounds, Delivered	Used to Evaporate 1000 Pounds of Water Under Observed Conditions	Used to Evaporate 1000 Pounds of Water from and at 212° F.
1	2	3	4	5	6	7	8	9
	Code Item	72.	73	72.1	73.1	74	75.1	76.1
		%	%	%	%	Dollars	Dollars	Dollars
1	21—4.0703 W	61.76	57.25	62.78	58.19	1.00	0.095	0.079
2	23— "	64.55	62.60	65.96	63.96	1.00	0.087	0.073
3	24— "	62.13	59.61	63.94	61.34	1.00	0.090	0.075
4	25— "	62.70	60.78	63.90	61.94	1.00	0.090	0.075
5	26— "	64.97	62.53	66.79	64.28	1.00	0.088	0.074
6	30—5 0602 W	64.62	62.74	66.66	64.72	1.00	0.080	0.067
7	31— "	65.22	61.80	67.12	63.60	1.00	0.081	0.068
8	32— "	64.02	62.34	66.16	64.42	1.00	0.080	0.067
9	34— "	61.11	60.08	62.93	61.87	1.00	0.084	0.070
10	35— "	61.43	60.37	63.09	62.00	1.00	0.082	0.068
11	36— "	62.40	60.98	64.38	62.91	1.00	0.080	0.067
12	37—5.0200 W	52.37	48.19	54.08	49.76	1.00	0.114	0.096
13	39— "	52.61	49.39	54.47	51.14	1.00	0.108	0.091
14	40— "	53.17	50.38	54.84	51.96	1.00	0.109	0.092
15	41— "	53.49	47.93	54.88	49.17	1.00	0.114	0.095
16	42— "	53.88	48.27	55.76	49.95	1.00	0.116	0.097
17	43—4.0700 W	62.97	60.00	65.31	62.23	1.00	0.091	0.076
18	44— "	65.06	62.79	67.79	65.42	1.00	0.087	0.073
19	45— "	64.52	62.26	67.04	64.69	1.00	0.087	0.073
20	46— "	64.19	62.16	66.80	64.68	1.00	0.088	0.073
21	47—6.0402 W	67.73	64.79	70.92	67.84	1.00	0.073	0.061
22	48— "	65.62	64.20	68.46	66.98	1.00	0.073	0.061
23	49— "	68.66	65.49	72.24	68.90	1.00	0.072	0.060
24	50— "	68.69	65.73	71.65	68.56	1.00	0.073	0.061
25	51—5.1610 W	65.12	61.60	68.16	64.47	1.00	0.077	0.064
26	52— "	65.21	62.70	67.97	65.35	1.00	0.077	0.064
27	53—6.0402 W	64.60	63.25	67.25	65.84	1.00	0.074	0.062
28	93—5.1610 W	64.30	63.15	66.38	65.19	1.00	9.075	0.063
29	94— "	63.80	62.10	66.28	64.52	1.00	0.075	0.063
30	95— "	63.87	61.97	66.14	64.18	1.00	0.076	0.063
31	96—7.1610 W	63.88	62.42	65.90	64.00	1.00	0.074	0.062
32	97— " —	65.47	64.01	67.82	66.35	....	0.075	0.062

TABLE 35 EFFICIENCY AND COST OF EVAPORATION (*Concluded*)

No.	Laboratory File No.	Efficiency		Compensated for Water Back		Cost of Coal		
		"Boiler and Furnace"	Over-all	"Boiler and Furnace"	Over-all	Per Ton of 2000 Pounds, Delivered	Used to Evaporate 1000 Pounds of Water Under Observed Conditions	Used to Evaporate 1000 Pounds of Water from and at 212° F.
1	2	3	4	5	6	7	8	9
	Code Item	72	73	72.1	73.1	74	75.1	76.1
		%	%	%	%	Dollars	Dollars	Dollars
33	98—7.1610—	64.01	62.64	65.97	64.56	1.00	0.075	0.062
34	99— "	64.40	62.89	66.13	64.58	1.00	0.075	0.063
35	100— "	62.86	61.54	64.48	63.12	1.00	0.077	0.064
36	101— "	62.22	60.82	63.81	62.35	1.00	0.079	0.066
37	102—5.1006 W	69.62	68.62	71.58	70.55	1.00	0.069	0.057
38	104— "	69.13	67.90	71.37	70.10	1.00	0.071	0.059
39	107— "	67.68	66.50	69.64	68.42	1.00	0.072	0.059
40	109— "	65.85	64.69	67.69	66.49	1.00	0.074	0.061
41	110— "	67.47	66.33	69.25	68.08	1.00	0.073	0.061
42	112— "	67.69	65.30	70.13	67.69	1.00	0.073	0.061
43	113— "	66.71	65.46	68.47	67.19	1.00	0.075	0.063
44	114— "	64.23	62.99	65.51	64.24	1.00	0.079	0.066
45	115—6.0200 W	51.62	47.27	53.36	48.86	1.00	0.115	0.095
46	116— "	51.27	48.94	52.83	50.44	1.00	0.113	0.093
47	117— "	54.49	53.46	55.86	54.80	1.00	0.110	0.091
48	118— "	58.71	56.46	60.41	58.10	1.00	0.101	0.084
49	119— "	54.30	51.49	55.92	53.02	1.00	0.109	0.090
50	120— "	58.48	55.32	60.56	57.29	1.00	0.105	0.087
51	121— "	58.63	56.25	60.30	57.86	1.00	0.104	0.086
52	122— "	58.97	56.93	60.70	58.60	1.00	0.101	0.084
53	124—4.0300 W	58.37	54.61	59.73	55.88	1.00	0.114	0.095
54	125— "	59.27	55.69	60.98	57.30	1.00	0.113	0.094
55	126— "	58.75	55.37	60.15	56.68	1.00	0.112	0.093
56	127— "	59.45	55.56	60.73	56.76	1.00	0.112	0.093
57	128—4.0703 W	69.98	68.00	71.88	69.85	1.00	0.080	0.066
58	129— "	68.24	68.54	70.13	70.40	1.00	0.083	0.070
59	130— "	68.81	66.69	71.43	69.23	1.00	0.080	0.054
60	131— "	70.20	68.86	72.36	70.98	1.00	0.080	0.067
61	132— "	68.68	67.25	70.71	69.24	1.00	0.080	0.067
62	133— "	69.38	67.98	71.14	69.68	1.00	0.079	0.065
63	134— "	69.36	67.82	71.14	69.66	1.00	0.081	0.067
64	135— "	69.37	68.13	72.95	71.65	1.00	0.079	0.066

TABLE 36 AIR AND FLUE GASES

No.	Laboratory File No.	Air: Average Draft Pressure in. Water: Between Damper and Boiler	Air: Average Draft Pressure in. Water: In Furnace	Air: Average Temps.: External Air	Air: Average Temps.: Boiler Room	Flue Gases: Average Temperature of Escaping Flue Gases	Flue Gases: Analysis of Dry Gases: Carbon Dioxide	Flue Gases: Analysis of Dry Gases: Oxygen	Flue Gases: Analysis of Dry Gases: Carbon Monoxide	Flue Gases: Analysis of Dry Gases: Nitrogen	Flue Gases: Average Smoke Ringelmann Chart Number
1	2	3	4	5	6	7	8	9	10	11	12
	Code Item	12	13	15	16	21	84	85	86	88	77
				°F	°F	°F	%	%	%	%	
1	21—4.0703 W	....	0.195	20.7	51.6	622	10.36	....	......	....	1.50
2	23— ''	....	0.157	37.0	63.0	678	8.77	....	......	....	0.00
3	24— ''	....	0.116	37.0	61.0	611	10.26	....	......	....	0.00
4	25— ''	....	0.213	....	....	708	8.86	....	......	....	0.00
5	26— ''	....	0.115	47.0	68.0	675	7.82	....	......	....	0.00
6	30—5.0602 W	0.254	0.102	33.0	61.0	639	7.04	....	......	....	0.00
7	31— ''	0.746	0.104	29.8	59.2	638	10.10	....	.....	....	0.00
8	32— ''	0.324	0.090	31.0	61.0	650	9.54	....	......	....	0.00
9	34— ''	0.650	0.134	32.0	69.0	645	9.47	....	......	....	0.00
10	35— ''	0.715	0.162	34.0	61.0	642	6.22	....	.....	....	0.08
11	36— ''	0.680	0.150	39.5	62.3	653	8.05	....	......	....	0.08
12	37—5.0200 W	0.880	0.270	38.0	60.7	641	7.10	....	......	....	0.00
13	39— ''	1.330	0.380	40.8	59.6	634	6.40	....	......	....	0.00
14	40— ''	1.440	0.430	39.0	62.1	626	5.84	....	.....	....	0.00
15	41— ''	1.450	0.290	27.8	57.9	638	7.02	....	......	....	0.00
16	42— ''	1.420	0.270	....	55.2	620	5.95	....	......	....	0.00
17	43—4.0700 W	0.450	0.130	22.2	51.0	586	10.50	....	......	....	0.00
18	44— ''	0.510	0.130	35.6	59.0	587	10.60	....	......	....	0.00
19	45— ''	0.460	0.106	18.6	66.3	589	11.20	....	......	....	0.00
20	46— ''	0.650	0.145	14.3	44.0	617	9.94	....	......	....	0.00
21	47—6.0402 W	0.420	0.127	28.0	54.9	599	12.40	....	......	....	0.00
22	48— ''	0.500	0.138	33.1	59.5	606	11.01	....	......	....	0.00
23	49— ''	0.350	0.105	31.2	58.2	583	11.79	....	......	....	0.00
24	50— ''	0.340	0.085	35.0	60.1	612	12.08	....	......	....	0.00
25	51—5.1610 W	0.400	0.122	39.2	64.3	615	10.30	....	......	....	0.00
26	52— ''	0.540	0.122	26.0	71.1	647	10.00	....	......	....	0.00
27	53—6.0402 W	0.540	0.122	21.0	51.6	648	9.60	....	......	....	0.00
28	93—5.1610 W	0.399	0.145	53.6	72.7	610	8.88	10.22	0	80.90	0.00
29	94— ''	0.375	0.124	60.7	72.9	608	8.88	10.25	0	80.87	0.00
30	95— ''	0.321	0.103	55.0	74.5	609	9.38	9.66	0	80.96	0.00
31	96—7.1610—	0.321	0.093	42.0	70.3	606	9.32	9.52	0	81.16	0.00
32	97— ''	0.311	0.124	53.4	70.7	600	9.00	9.89	0	81.11	0.00

TABLE 36 AIR AND FLUE GASES (*Concluded*)

No.	Laboratory File No.	Air: Average Draft Pressure in. Water: Between Damper and Boiler	Air: Average Draft Pressure in. Water: In Furnace	Air: Average Temps.: External Air	Air: Average Temps.: Boiler Room	Flue Gases: Average Temperature of Escaping Flue Gases	Flue Gases: Analysis of Dry Gases: Carbon Dioxide	Flue Gases: Analysis of Dry Gases: Oxygen	Flue Gases: Analysis of Dry Gases: Carbon Monoxide	Flue Gases: Analysis of Dry Gases: Nitrogen	Flue Gases: Average Smoke Ringelmann Chart Number
1	2	3	4	5	6	7	8	9	10	11	12
	Code Item	12	13	15	16	21	84	85	86	88	77
				°F	°F	°F	%	%	%	%	
33	98—7.1610—	0.354	0.143	62.1	71.5	611	9.40	9.43	0	81.17	0.00
34	99— "	0.371	0.116	53.9	73.7	627	9.47	9.40	0	81.13	0.00
35	100— "	0.508	0.157	50.7	72.3	655	9.52	9.28	0	81.20	0.00
36	101— "	0.720	0.188	56.9	75.2	683	9.02	9.85	0	81.13	0.00
37	102—5.1006 W	0.266	0.097	65.2	74.9	617	10.56	8.00	0	81.44	0.00
38	104— "	0.228	0.088	62.7	72.6	611	11.09	7.38	0	81.53	0.00
39	107— "	0.250	0.113	76.3	80.3	599	10.79	7.55	0.01	81.65	0.00
40	109— "	0.305	0.144	66.2	77.7	607	10.56	7.99	0.01	81.44	0.00
41	110— "	0.404	0.146	54.7	74.1	670	11.48	7.34	0.01	81.17	0.00
42	112— "	0.184	0.091	80.6	84.3	565	11.27	7.62	0	81.11	0.00
43	113— "	0.500	0.174	73.4	82.9	676	11.12	7.78	0	81.10	0.11
44	114— "	0.864	0.230	46.8	61.9	748	10.27	8.89	0	80.84	0.21
45	115—6.0200 W	0.560	0.165	54.8	70.3	562	4.62	15.28	0	80.10	0.00
46	116— "	0.818	0.313	69.0	75.5	568	4.88	15.03	0	80.09	0.02
47	117— "	0.893	0.414	75.4	80.8	581	5.53	14.24	0	80.23	0.00
48	118— "	0.830	0.363	60.4	72.6	595	5.98	13.78	0	80.24	0.00
49	119— "	0.624	0.303	58.3	67.9	556	5.11	14.71	0	80.18	0.00
50	120— "	0.681	0.305	73.7	82.2	574	6.04	13.64	0	80.32	0.00
51	121— "	0.862	0.346	82.0	86.9	576	5.87	13.83	0	80.30	0.02
52	122— "	0.831	0.364	73.4	81.2	607	6.20	13.41	0	80.39	0.00
53	124—4.0300 W	0.845	0.339	54.2	73.1	622	6.56	12.97	0	80.47	0.00
54	125— "	0.667	0.298	64.4	71.0	581	6.16	13.44	0	80.40	0.00
55	126— "	0.891	0.367	67.3	74.9	610	6.58	12.93	0	80.49	0.00
56	127— "	0.891	0.381	73.0	80.9	624	6.90	12.34	0	80.76	0.00
57	128—4.0703 W	0.303	0.132	57.6	72.2	618	11.08	7.52	0.01	81.39	0.16
58	129— "	0.348	0.118	55.0	70.8	633	11.03	7.71	0	81.26	1.20
59	130— "	0.150	0.096	67.4	73.3	533	12.50	6.13	0.01	81.36	0.10
60	131— "	0.241	0.111	68.4	76.7	574	11.26	7.58	0	81.16	0.20
61	132— "	0.325	0.137	69.5	79.0	604	10.98	7.78	0.01	81.23	0.15
62	133— "	0.561	0.174	73.1	79.0	667	10.93	7.94	0	81.13	0.18
63	134— "	0.495	0.161	66.1	75.6	665	11.18	7.61	0	81.21	0.23
64	135— "	0.067	0.058	66.5	76.1	489	12.55	5.94	0.01	81.50	1.00

TABLE 37 PROXIMATE ANALYSES OF COAL

No.	Laboratory File No.	Proximate Analyses								
		Coal as Fired				Pure coal		Italicized Figures are Calculated from Analyses of Composite Samples Indicated	Referred to Combustible	
		Fixed Carbon	Volatile Matter	Moisture	Ash	Fixed Carbon	Volatile Matter		Moisture	Ash
1	2	3	4	5	6	7	8	9	10	11
	Code Item	32	33	34	35	32.1	33.1		34.1	35.1
		%	%	%	%	%	%	Chem. Lab. No.[a]	%	%
1	21—4.0703 W	*41.48*	*32.46*	18.38	7.68	*56.10*	*43.90*	Comp. No. 253	24.86	10.39
2	23— "	*41.21*	*32.24*	18.63	7.92	*56.10*	*43.90*	"	25.36	10.78
3	24— "	41.37	32.83	17.35	8.45	55.75	44.25	....	23.38	11.39
4	25— "	*40.90*	*32.01*	19.11	7.98	*56.10*	*43.90*	Comp. No. 253	26.21	10.95
5	26— "	*40.60*	*31.78*	18.71	8.91	*56.10*	*43.90*	"	25.85	12.31
6	30—5.0602 W	*47.85*	*29.76*	12.24	10.15	*61.65*	*38.35*	Comp. No. 272	15.77	13.08
7	31— "	47.59	30.38	13.15	8.88	61.04	38.96	....	16.87	11.39
8	32— "	*48.05*	*29.91*	12.49	9.55	*61.65*	*38.35*	Comp. No. 273	16.02	12.25
9	34— "	*47.87*	*29.78*	13.13	9.22	*61.65*	*38.35*	"	16.91	11.87
10	35— "	*49.04*	*30.52*	11.30	9.14	*61.65*	*38.35*	"	14.20	21.49
11	36— "	49.28	30.28	12.41	8.08	61.92	38.08	....	15.61	10.16
12	37—5.0200 W	*43.08*	*28.78*	15.80	12.33	*59.95*	*40.05*	Comp. No. 303	21.98	17.16
13	39— "	*43.93*	*29.33*	14.59	12.18	*59.95*	*40.05*	"	19.92	16.63
14	40— "	*42.82*	*28.61*	16.20	12.36	*59.95*	*40.05*	"	22.68	17.30
15	41— "	*43.73*	*29.21*	14.40	12.66	*59.95*	*40.05*	"	19.74	17.36
16	42— "	*42.13*	*28.14*	17.84	11.89	*59.95*	*40.05*	"	25.39	16.92
17	43—4.0402 W	*39.41*	*32.98*	18.68	8.93	*54.43*	*45.57*	Comp. No. 302	25.80	12.34
18	44— "	*39.00*	*32.65*	19.32	9.03	*54.43*	*45.57*	"	26.96	12.60
19	45— "	*40.81*	*34.16*	18.33	6.70	*54.43*	*45.57*	"	24.45	8.94
20	46— "	39.91	32.02	18.79	9.28	55.48	44.52	....	26.12	12.90
21	47—6.0402 W	*49.52*	*32.45*	10.72	7.31	*60.41*	*39.59*	Comp. No. 304	13.08	8.92
22	48— "	50.12	31.58	10.72	7.58	61.35	38.65	....	13.12	9.28
23	49— "	*49.04*	*32.14*	11.32	7.50	*60.41*	*39.59*	Comp. No. 304	13.94	9.24
24	50— "	*49.01*	*32.12*	11.23	7.64	*60.41*	*39.59*	"	13.84	9.42
25	51—5.1610 W	54.05	26.80	11.48	7.72	66.85	33.15	....	14.14	9.55
26	52— "	*49.78*	*31.31*	10.94	7.97	*61.40*	*38.60*	Comp. No. 502	13.49	9.83
27	53—6.0402 W	*50.08*	*32.82*	10.21	6.89	*60.41*	*39.59*	Comp. No. 304	12.32	8.31
28	93—5.1610 W	*50.65*	*31.84*	8.79	8.72	*61.40*	*38.60*	Comp. No. 502	10.66	10.57
29	93— "	*51.29*	*32.25*	8.06	8.40	*61.40*	*38.60*	"	9.65	10.06
30	95— "	*51.01*	*32.07*	8.44	8.48	*61.40*	*38.60*	"	10.16	10.21
31	93—7.1610	51.01	33.43	7.14	8.42	60.41	39.59	....	8.46	9.97
32	97— "	*50.06*	*31.76*	7.14	11.04	*61.18*	*38.82*	Comp. No. 519	8.73	13.49

(*a*) For Analysis of the Composite Samples, see page 5.

TABLE 37 PROXIMATE ANALYSES OF COAL (*Concluded*)

No.	Laboratory File No.	Proximate Analyses: Coal as Fired: Fixed Carbon	Coal as Fired: Volatile Matter	Coal as Fired: Moisture	Coal as Fired: Ash	Pure Coal: Fixed Carbon	Pure Coal: Volatile Matter	Italicized Figures are Calculated from Analyses of Composite Samples Indicated	Referred to Combustible: Moisture	Referred to Combustible: Ash
1	2	3	4	5	6	7	8	9	10	11
	Code Item	32	33	34	35	32.1	33.1		34.1	35.1
		%	%	%	%	%	%	Chem. Lab. No.	%	%
33	98—7.1610—	*51.18*	*32.47*	6.79	9.56	*61.18*	*38.82*	Comp. No. 519	8.12	11.43
34	99— "	*50.73*	*32.10*	7.61	6.47	*61.18*	*38.82*	"	9.18	11.42
35	100— "	*51.45*	*32.64*	7.78	8.13	*61.18*	*38.82*	"	9.25	9.67
36	101— "	*50.44*	*31.99*	7.34	10.23	*61.18*	*38.82*	"	8.90	12.41
37	102—5.1006 W	52.02	31.31	8.58	8.09	62.43	37.57	....	10.30	9.71
38	104— "	*50.68*	*30.46*	10.12	8.74	*62.46*	*37.54*	Comp. No. 571	12.47	10.77
39	107— "	*51.46*	*30.93*	9.40	8.21	*62.46*	*37.54*	"	11.41	9.96
40	109— "	*51.64*	*31.03*	8.99	8.34	*62.46*	*37.54*	"	10.87	10.09
41	110— "	*50.66*	*30.46*	9.38	9.50	*62.46*	*37.54*	"	11.56	11.71
42	112— "	*51.53*	*30.97*	8.90	8.60	*62.46*	*37.54*	"	10.79	10.42
43	113— "	*51.04*	*30.69*	9.74	8.53	*62.46*	*37.54*	"	11.92	10.44
44	114— "	*50.37*	*30.28*	9.25	10.10	*62.46*	*37.54*	"	11.47	12.52
45	115—6.0200 W	46.56	27.79	13.94	11.71	62.62	37.38	....	18.75	15.75
46	116— "	*46.60*	*28.07*	13.97	11.36	*62.41*	*37.59*	Comp. No. 578	18.71	15.21
47	117— "	*42.84*	*25.80*	21.49	9.87	*62.41*	*37.59*	"	31.31	14.38
48	118— "	*44.12*	*26.58*	18.52	10.78	*62.41*	*37.59*	"	26.20	15.25
49	119— "	*44.81*	*26.99*	17.34	10.86	*62.41*	*37.59*	"	34.15	15.13
50	120— "	*43.53*	*26.22*	19.27	10.98	*62.41*	*37.59*	"	27.63	15.74
51	121— "	*43.14*	*25.99*	19.63	11.24	*62.41*	*37.59*	"	28.40	16.26
52	122— "	*43.52*	*26.22*	19.49	10.77	*62.41*	*37.59*	"	27.95	15.44
53	124—4.0300 W	36.65	29.07	21.61	12.67	55.77	44.23	....	32.88	19.28
54	125— "	*36.47*	*28.73*	21.72	13.08	*55.94*	*44.06*	Comp. No. 600	31.31	20.06
55	126— "	*36.96*	*29.11*	21.35	12.58	*55.94*	*44.06*	"	32.31	19.04
56	127— "	*37.02*	*29.15*	21.25	12.58	*55.94*	*44.06*	"	32.11	19.01
57	128—4.0703 W	42.94	31.89	17.24	7.93	57.39	42.61	....	23.04	10.60
58	129— "	*39.56*	*30.64*	22.63	7.17	*56.35*	*43.65*	Comp. No. 608	33.24	10.21
59	130— "	*42.17*	*32.67*	17.95	7.21	*56.35*	*43.65*	"	23.98	9.63
60	131— "	41.60	30.89	19.83	7.68	56.39	42.61	....	27.36	10.59
61	132— "	*41.97*	*32.51*	17.68	7.84	*56.35*	*43.65*	Comp. No. 608	23.74	10.53
62	133— "	42.82	33.24	16.48	7.46	56.30	43.70	....	21.67	9.81
63	134— "	*41.43*	*32.09*	19.29	7.19	*56.35*	*43.65*	Comp. No, 608	26.24	9.78
64	135— "	41.62	31.43	19.49	7.46	56.98	43.02	....	26.68	10.21

TABLE 38 Ultimate Analyses of Coal

No.	Laboratory File No.	Ultimate Analyses of Moisture Free Coal						
		Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Italicized Figures Are Calculated from Analyses of Composite Samples Indicated
1	2	3	4	5	6	7	8	9
	Code Item	37	38	33	40	41	42	
		%	%	%	%	%	%	Chem.Lab. No.
1	21—4.0703 W	*72.92*	*4.70*	*9.65*	1.22	2.10	9.41	Comp. No. 253
2	23— "	*72.48*	*4.68*	*9.59*	1.22	2.29	9.74	"
3	24— "	72.00	4.95	9.37	1.22	2.24	10.22	....
4	25— "	*72.51*	*4.68*	*9.59*	1.25	2.10	9.87	Comp. No. 253
5	26— "	*71.51*	*4.61*	*9.47*	1.24	2.21	10.96	"
6	30—5.0602 W	*72.51*	*4.61*	*8.47*	1.35	1.50	11.56	Comp. No. 273
7	31— "	73.54	4.64	8.67	1.36	1.56	10.23	....
8	32— "	*73.09*	*4.65*	*8.54*	1.37	1.44	10.91	Comp. No. 273
9	34— "	*73.40*	*4.67*	*8.56*	1.38	1.38	10.61	"
10	35— "	*73.48*	*4.68*	*8.58*	1.47	1.49	10.30	"
11	36— "	74.37	4.44	9.34	1.35	1.28	9.22	....
12	57—5.0200 W	*69.46*	*4.32*	*8.76*	1.37	1.44	14.65	Comp. No. 303
13	39— "	*69.81*	*4.34*	*8.81*	1.39	1.39	14.26	Comp. No. 303
14	40— "	*69.46*	*4.32*	*8.75*	1.36	1.36	14.75	"
15	41— "	*69.23*	*4.31*	*8.73*	1.53	1.41	14.79	"
16	42— "	*69.51*	*4.33*	*8.77*	1.55	1.37	14.47	"
17	43—4.0700 W	*70.29*	*4.60*	*10.50*	1.50	2.07	11.04	Comp. No. 302
18	44— "	*70.10*	*4.60*	*10.48*	1.48	2.15	11.19	"
19	45— "	*72.60*	*4.76*	*10.85*	1.47	2.12	8.20	"
20	46— "	70.80	4.59	9.76	1.19	2.23	11.43	....
21	47—6.0402 W	*74.72*	*4.77*	*9.08*	1.68	1.56	8.19	Comp. No. 304
22	48— "	74.77	4.70	9.29	1.33	1.42	1.42	....
23	49— "	*74.46*	*4.76*	*9.04*	1.68	1.60	1.60	Comp. No. 304
24	50— "	*74.39*	*4.76*	*9.03*	1.68	1.54	1.54	"
25	51—5.1610 W	74.39	4.53	9.40	1.35	1.61	8.72	....
26	52— "	*73.49*	*4.99*	*9.45*	1.71	1.41	8.95	Comp. No. 502
27	53—6.0402 W	*75.22*	*4.81*	*9.14*	1.69	1.47	7.67	Comp. No. 304
28	93—5.1610 W	*73.35*	*4.99*	*9.44*	1.29	1.37	9.56	Comp. No. 502
29	94— "	*73.66*	*5.01*	*9.47*	1.31	1.41	9.14	"
30	95— "	*73.59*	*5.00*	*9.47*	1.30	1.38	9.26	"
31	96—7.1610 W	73.65	5.34	8.83	1.24	1.87	9.07	....
32	97— "	*71.02*	*4.58*	*9.13*	2.19	1.19	11.89	Comp. No. 519

TABLE 38 Ultimate Analyses of Coal

No.	Laboratory File No.	Ultimate Analyses of Moisture Free Coal: Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Ash	Italicized Figures Are Calculated from Analyses of Composite Samples Indicated
1	2	3	4	5	6	7	8	9
	Code Item	37	38	39	40	41	42	
		%	%	%	%	%	%	Chem. Lab. No.
33	98—7.1610—	*71.88*	*4.62*	*9.23*	1.21	2.79	10.27	Comp. No. 519
34	99— ''	*72.35*	*4.67*	*9.31*	1.37	2.05	10.25	''
35	100— ''	*73.53*	*4.74*	*9.45*	1.38	2.09	8.81	''
36	101— ''	*71.18*	*4.59*	*9.15*	1.33	2.71	11.04	''
37	102—5.1006 W	74.43	5.04	8.91	1.42	1.36	8.84	....
38	104— ''	*72.97*	*4.61*	*9.73*	1.45	1.52	9.73	Comp. No. 571
39	107— ''	*73.70*	*4.65*	*9.83*	1.47	1.29	9.06	''
40	109— ''	*72.60*	*4.64*	*9.81*	1.46	1.33	9.16	''
41	110— ''	*72.44*	*4.57*	*9.66*	1.40	1.40	10.48	''
42	112— ''	*73.47*	*4.63*	*9.79*	1.43	1.23	9.45	''
43	113— ''	*73.44*	*4.63*	*9.73*	1.36	1.33	9.45	''
44	114— ''	*72.06*	*4.55*	*9.60*	1.34	1.32	11.13	''
45	115—6.0200 W	70.15	4.48	8.95	1.20	1.61	13.61	Comp. No. 587
46	116— ''	*70.27*	*4.39*	*9.36*	1.08	1.70	13.21	....
47	117— ''	*70.77*	*4.41*	*8.41*	1.22	1.62	12.57	''
48	118— ''	*70.20*	*4.38*	*9.34*	1.21	1.64	13.23	''
49	119— ''	*70.31*	*4.39*	*9.35*	1.21	1.61	13.13	''
50	120— ''	*69.99*	*4.37*	*9.30*	1.18	1.56	13.60	''
51	121— ''	*69.55*	*4.33*	*9.25*	1.19	1.69	13.99	''
52	122— ''	*70.12*	*4.38*	*9.32*	1.21	1.60	13.37	''
53	124—4.0300 W	66.47	4.47	9.28	1.17	2.45	16.16	....
54	125— ''	*66.89*	*4.39*	*8.47*	1.09	2.45	16.71	Comp. No. 600
55	126— ''	*67.53*	*4.43*	*8.55*	1.11	2.39	15.99	''
56	127— ''	*67.51*	*4.44*	*8.55*	1.09	2.43	15.98	''
57	128—4.0703 W	77.91	4.69	10.44	1.23	2.15	9.58	....
58	129— ''	*72.55*	*4.82*	*10.33*	1.20	1.84	9.26	Comp. No. 608
59	130— ''	*73.00*	*4.85*	*10.39*	1.25	1.73	8.78	''
60	131— ''	72.02	5.11	10.25	1.20	1.85	9.57	....
61	132— ''	*72.23*	*4.80*	*10.28*	1.22	1.95	9.52	Comp. No. 608
62	133— ''	*72.83*	*4.84*	*10.36*	1.21	1.83	8.93	''
63	134— ''	*72.84*	*4.84*	*10.37*	1.24	1.81	8.90	''
64	135— ''	72.66	4.77	10.24	1.23	1.83	9.27	....

TABLE 39 ULTIMATE ANALYSES OF COMBUSTIBLE AND CALORIFIC VALUES

No.	Laboratory File No.	Ultimate Analyses of Pure Coal						Calorific Value by Oxygen Calorimeter	
		Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Italicized Figures Are Calculated from Analyses of Composite Samples Indicated	Per Pound of Moisture Free Coal	Per Pound of Combustible
1	2	3	4	5	6	7	8	9	10
	Code Item	37.1	38.1	39.1	40.1	41.1		50	51
		%	%	%	%	%	Chem. Lab. No.	B. t. u.	B. t. u.
1	21—4.0703 W	*80.49*	*5.19*	*10.65*	1.35	2.32	Comp. No. 253	12906	14247
2	23— ‘‘	*80.32*	*5.18*	*10.61*	1.35	2.54	‘‘	12883	14273
3	24— ‘‘	80.20	5.51	10.44	1.36	2.49	....	12784	14239
4	25— ‘‘	*80.45*	*5.19*	*10.64*	1.39	2.33	Comp. No. 253	12886	14295
5	26— ‘‘	*80.31*	*5.18*	*10.64*	1.39	2.48	‘‘	12680	14241
6	30—5.0602 W	*82.00*	*5.22*	*9.57*	1.52	1.69	Comp. No. 273	12808	14483
7	31— ‘‘	81.92	5.17	9.66	1.51	1.74	....	12987	14467
8	32— ‘‘	*82.05*	*5.22*	*9.58*	1.54	1.61	Comp. No. 273	12889	14468
9	34— ‘‘	*82.11*	*5.22*	*9.59*	1.54	1.54	‘‘	12941	14477
10	35— ‘‘	*81.92*	*5.22*	*9.56*	1.64	1.66	‘‘	12975	14465
11	36— ‘‘	81.92	4.89	10.29	1.49	1.41	....	13208	14549
12	37—5.0200 W	*81.38*	*5.06*	*10.26*	1.61	1.69	Comp. No. 303	12246	14348
13	39— ‘‘	*81.42*	*5.06*	*10.28*	1.62	1.62	Comp. No. 303	12339	14391
14	40— ‘‘	*81.47*	*5.07*	*10.26*	1.60	1.60	‘‘	12249	14368
15	41— ‘‘	*81.24*	*5.06*	*10.25*	1.80	1.65	‘‘	12230	14353
16	42— ‘‘	*81.28*	*5.06*	*10.25*	1.81	1.60	‘‘	12266	14341
17	43—4.0700 W	*79.01*	*5.17*	*11.80*	1.69	2.33	Comp. No. 302	12717	14295
18	44— ‘‘	*78.93*	*5.18*	*11.80*	1.67	2.42	‘‘	12735	14340
19	45— ‘‘	*79.08*	*5.19*	*11.82*	1.60	2.31	‘‘	12735	14340
20	46— ‘‘	79.94	5.18	11.02	1.34	2.52	....	12740	14384
21	47—6.0402 W	*81.38*	*5.20*	*9.89*	1.83	1.70	Comp. No. 304	13327	14516
22	48— ‘‘	81.71	5.14	10.15	1.45	1.55	....	13388	14630
23	49— ‘‘	*81.34*	*5.20*	*9.87*	1.84	1.75	Comp. No. 304	13288	14516
24	50— ‘‘	*81.39*	*5.21*	*9.88*	1.84	1.68	‘‘	13225	14469
25	51—5.1610 W	81.50	4.96	10.30	1.48	1.76	....	13375	14653
26	52— ‘‘	*80.71*	*5.48*	*10.38*	1.88	1.55	Comp. No. 502	13201	14499
27	53—6.0402 W	*81.47*	*5.21*	*9.90*	1.83	1.59	Comp. No. 304	13391	14503
28	93—5.1610 W	*81.10*	*5.52*	*10.44*	1.43	1.51	Comp. No. 502	13122	14509
29	94— ‘‘	*81.08*	*5.51*	*10.42*	1.44	1.55	‘‘	13149	14472
30	95— ‘‘	*81.10*	*5.51*	*10.44*	1.43	1.52	‘‘	13131	14471
31	96—7.1610 —	81.00	5.87	9.71	1.36	2.06	....	13251	14573
32	97— ‘‘	*80.60*	*5.20*	*10.36*	1.35	2.49	Comp. No. 519	12737	14456

TABLE 39 ULTIMATE ANALYSES OF COMBUSTIBLE AND CALORIFIC VALUES

No.	Laboratory File No.	Ultimate Analyses of Pure Coal						Calorific Value by Oxygen Calorimeter	
		Carbon	Hydrogen	Oxygen	Nitrogen	Sulphur	Italicized Figures Are Calculated from Analyses of Composite Samples Indicated	Per Pound of Moisture Free Coal	Per Pound of Combustible
1	2	3	4	5	6	7	8	9	10
	Code Item	37.1	38.1	39.1	40.1	41.1		50	51
		%	%	%	%	%	Chem.Lab.No.	B. t. u.	B. t. u.
33	98—7.1610 —	*80.10*	*5.16*	*10.28*	1.35	3.11	Comp. No. 519	12985	14470
34	99— "	*80.62*	*5.20*	*10.37*	1.53	2.28	"	13057	14548
35	100— "	*80.63*	*5.21*	*10.37*	1.51	2.29	"	13127	14395
36	101— "	*80.00*	*5.16*	*10.29*	1.50	3.05	"	12842	14436
37	102—5.1006 W	81.65	5.53	9.77	1.56	1.49	....	13152	14427
38	104— "	*80.83*	*5.10*	*10.77*	1.61	1.69	Comp. No. 571	13077	14487
39	107— "	*81.05*	*5.11*	*10.80*	1.62	1.42	"	13159	14470
40	109— "	*81.02*	*5.11*	*10.80*	1.60	1.47	"	13151	14477
41	110— "	*80.92*	*5.11*	*10.78*	1.62	1.57	"	12969	14487
42	112— "	*91.13*	*5.12*	*10.81*	1.58	1.36	"	13062	14425
43	113— "	*81.10*	*5.11*	*10.81*	1.51	1.47	"	12808	14145
44	114— "	*81.09*	*5.11*	*10.80*	1.51	1.48	"	12655	14240
45	115—6.0200 W	81.20	5.19	10.36	1.39	1.86	....	12220	14145
46	116— "	*80.97*	*5.06*	*10.76*	1.25	1.96	Comp. No. 587	12081	13920
47	117— "	*80.94*	*5.05*	*10.76*	1.39	1.86	"	12444	14233
48	118— "	*80.91*	*5.04*	*10.77*	1.40	1.88	"	12345	14229
49	119— "	*80.94*	*5.06*	*10.76*	1.39	1.85	"	12361	14229
50	120— "	*81.00*	*5.06*	*10.76*	1.37	1.81	"	12171	14087
51	121— "	*80.86*	*5.04*	*10.76*	1.37	1.97	"	12156	14133
52	122— "	*80.94*	*5.05*	*10.76*	1.39	1.86	"	12272	14166
53	124—4.0300 W	79.29	5.33	11.07	1.39	2.92	....	11764	14031
54	125— "	*80.30*	*5.28*	*10.17*	1.31	2.94	Comp. No. 600	11617	13948
55	126— "	*80.39*	*5.27*	*10.18*	1.32	2.84	"	11766	14005
56	127— "	*80.35*	*5.28*	*10.18*	1.30	2.89	"	11724	13954
57	128—4.0703 W	79.53	5.19	11.54	1.36	2.38	....	12740	14990
58	129— "	*79.96*	*5.31*	*11.38*	1.32	2.03	Comp. No. 608	12893	14210
59	130— "	*80.03*	*5.32*	*11039*	1.37	1.89	"	12963	14212
60	131— "	79.64	5.65	11.34	1.32	2.05	....	12815	14171
61	132— "	*79.83*	*5.30*	*11.37*	1.35	2.15	Comp. No. 608	12813	14161
62	133— "	*79.97*	*5.31*	*11.38*	1.33	2.01	"	12791	14045
63	134— "	*79.96*	*5.31*	*11.38*	1.36	1.99	"	12875	14133
64	135— "	79.98	5.25	11.39	1.36	2.02	....	12910	14229

TABLE 40 FURNACE CONDITIONS

No.	Laboratory File No.	Furnace Conditions During Test									
		Fuel at Rear of Grate				Fuel Bed for Four Hour Period		Area of Holes in Fuel Bed			Average Stoker Travel square feet per hour
		Per cent of Time			Average Distance Clear	Number of Times		Average	For 15 Min. Period		
		Banked	Close	Clear		Sliced	Leveled		Maximum	Minimum	
1	2	3	4	5	6	7	8	9	10	11	12
		Per cent			In.	No.	No.	Square inches			Sq. ft.
1	21—.40703 W	23	50	27	6	...	2	0	0	0	65.5
2	23— "	0	42	58	4½	1	0	0	0	0	68.8
3	24— "	8	48	44	9½	1	0	0	0	0	67.9
4	25— "	0	32	68	3	1	0	0	0	0	53.7
5	26— "	0	7	93	3½	1	0	0	0	0	101.2
6	30—5.0602 W	0	20	80	4	1	0	0	0	0	75.1
7	31— "	8	0	92	2	1	0	0	0	0	82.9
8	32— "	0	47	53	3½	1	0	0	0	0	59.0
9	34— "	0	48	52	8	1	0	0	0	0	50.9
10	35— "	4	48	48	4½	1	0	0	0	0	42.4
11	36— "	4	48	48	4½	1	0	0	0	0	49.1
12	37—5.0200 W	10	90	0	0	0	16	210	300	0	72.1
13	39— "	5	20	75	7	0	6	100	300	0	53.1
14	40— "	0	15	85	6½	0	15	150	400	150	64.0
15	41— "	0	5	95	7	0	8	300	600	0	124.0
16	42— "	0	5	95	8	0	9	100	400	0	128.4
17	43—4.0700 W	5	25	70	5	1	....	0	0	0	70.4
18	44— "	8	3	89	6	1	0	0	0	0	72.4
19	45— "	0	0	100	3½	1	0	0	0	0	92.4
20	46— "	3	0	97	3	1	0	0	0	0	62.1
21	47—6.0402 W	0	0	100	4	1	30	0	0	0	51.0
22	48— "	0	0	100	3	1	20	0	0	0	40.7
23	49— "	0	12	88	3	1	20	0	0	0	53.7
24	50— "	0	20	80	4	1	5	0	0	0	76.4
25	51—5.1610 W	0	64	36	4	1	8	0	0	0	46.9
26	52— "	0	40	60	5	1	8	0	0	0	50.0
27	53—6.0402 W	0	12	88	5½	1	8	0	0	0	50.0
28	93—5.1610 W	0	0	100	3¾	1	6	0	0	0	40.2
29	94— "	0	0	100	3½	2	6	3	100	0	46.8
30	95— "	0	0	100	4	2	6	0	0	0	58.3
31	96—7.1610 —	0	0	100	3½	4	12	6	200	0	55.0
32	97— "	0	0	100	3½	4	10	0	0	0	43.1

TABLE 40 FURNACE CONDITIONS (*Concluded*)

No.	Laboratory File No.	Furnace Conditions During Test									
		Fuel at Rear of Grate				Fuel Bed for Four Hour Period		Area of Holes in Fuel Bed			Average Stoker Travel square feet per hour
		Per cent of Time			Average Distance Clear	Number of Times		Average	For 15 Min. Period		
		Banked	Close	Clear		Sliced	Leveled		Maximum	Minimum	
1	2	3	4	5	6	7	8	9	10	11	12
		Per cent			In.	No.	No.	Square inches			Sq. ft.
33	98—7.1610—	0	0	100	3½	5½	11	0	0	0	40.8
34	99— "	0	0	100	4	3	7	0	0	0	50.5
35	100— "	0	0	100	4¼	1	7	0	0	0	55.3
36	101— "	0	6	94	3	2	7	0	0	0	61.4
37	102—5.1006 W	0	0	100	4	2	9	0	0	0	55.4
38	104— "	0	0	100	4	3	8	0	0	0	52.8
36	107— "	0	0	100	3½	3½	11	0	0	0	42.8
40	109— "	0	0	100	3¾	3½	12	0	0	0	38.3
41	110— "	0	0	100	4	2	12	0	0	0	55.7
42	112— "	0	0	100	3¾	2	11	0	0	0	45.0
43	113— "	0	0	100	3½	1	12	0	0	0	56.7
44	114— "	0	0	100	3½	2	12	10.5	200	0	68.7
45	115—6.0200 W	0	0	100	5	0	18	22.0	500	0	85.7
46	116— "	0	0	100	4½	1	17	0	0	0	55.9
47	117— "	0	0	100	4¼	1	18	0	0	0	44.6
48	118— "	0	0	100	3¾	2	17	0	140	0	52.2
49	119— "	0	0	100	4¼	1½	16	2	50	0	44.4
50	120— "	0	0	100	4	1½	15	2	50	0	63.0
51	121— "	0	0	100	4⅜	1½	17	2	50	0	62.1
52	122— "	0	0	100	4	2	22	0	0	0	64.3
53	124—4.0300 W	0	0	100	4	1	16	0	0	0	87.8
54	125— "	0	0	100	4¼	1	15	0	0	0	69.6
55	126— "	0	0	100	3⅞	1½	18	0	0	0	86.6
56	127— "	0	0	100	3¼	2	21	0	0	0	89.3
57	128—4.0703 W	0	0	100	4	1	13	0	0	0	69.2
58	129— "	0	0	100	4	1½	6	0	0	0	75.2
59	130— "	0	0	100	4⅛	2	8	1.6	50	0	51.7
60	131— "	0	0	100	4	1½	10	0	0	0	59.8
61	132— "	0	0	100	4	1	10	0	0	0	64.5
62	133— "	0	0	100	4¼	1	11	0	0	0	85.3
63	134— "	0	0	100	3½	2	12	0	0	0	82.8
64	135— "	0	0	100	3½	2	7	0	0	0	38.7

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