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FUEL TESTS WITH ILLINOIS COAL

(Compiled from Tests Made by the Technologic Branch of the United States Geological Survey, at the St. Louis Fuel Testing Plant, 1904—June 30, 1907).

BY

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CONTENTS

I Introduction

The United States Geological Survey Technologic Branch has conducted at the St. Louis, Missouri, fuel testing plant, a series of investigations on the fuels of the United States. These tests included a large number of Illinois coals. The results of the tests have been published from time to time in a series of government bulletins which contain very full descriptions of methods and very complete details of the results obtained. A complete list of the government bulletins is given at the end of this publication.

The tests included:

(*a*) Steaming tests under boilers
(*b*) Producer-gas tests
(*c*) Washing tests
(*d*) Coking tests
(*e*) Briquetting tests
(*f*) Chemical tests for composition and heating values
(*g*) Field work tests, sampling tests and a few other minor investigations.

It is the purpose of this circular to present in compact form the important results of the government tests so far as these tests relate to Illinois coals. The Engineering Experiment Station hopes that by bringing together in one circular the tests made by the government on Illinois coals, it may do a service to the engineering, industrial and fuel interests of the State. The compiler has presented a few conclusions which seem justified by a study of the results recorded from tests already made. It is, however, fair to say that in a few cases the number of tests made is scarcely sufficient to warrant any general application of the conclusions stated.

II A Summary of Conclusions

The results of the United States Geological Survey tests of Illinois coal, presented in the following pages, seem to justify the conclusions given below.

1. The chemical properties of the coals tested indicate that

on a basis of the volatile-carbon total-carbon ratio ($\frac{VC}{C}$), all Illinois coals tested belong in Class B or Class D*. The maximum value of this ratio is 33.4 per cent and the minimum value is 20.9 per cent.

2. The average calorific value of Illinois coal is 14319 B. t. u. per pound of pure coal (ash and moisture free). But few samples tested varied from this value by an amount more than 2 per cent.

3. The quality of Illinois coal is greatly increased by washing. The reduction in ash and in sulphur is as follows:—

When raw coal contains 8% ash, the reduction in ash is 20%.
When raw coal contains 12% ash, the reduction in ash is 30%.
When raw coal contains 16% ash, the reduction in ash is 43%.
When raw coal contains 20% ash, the reduction in ash is 53%.
When raw coal contains 2% sulphur, the reduction in sulphur is 13%.
When raw coal contains 3% sulphur, the reduction in sulphur is 17%.
When raw coal contains 4% sulphur, the reduction in sulphur is 22%.
When raw coal contains 5% sulphur, the reduction in sulphur is 28%.

4. The material rejected by the washing jig contains $\frac{2}{3}$ coal and $\frac{1}{3}$ noncombustible refuse.

5. One-fourth of the coal tested may be used for the manufacture of coke.

6. The evaporative efficiency of Illinois coal when burned in a hand-fired furnace under a water-tube boiler averages 62.7 per cent. This performance compares favorably with that of any other bituminous coal tested at the United States Geological laboratory.

7. The evaporative efficiency of Illinois coal is but slightly affected by the moisture contained in it.

8. The evaporative efficiency of Illinois coal decreases as the ash and sulphur increase. Each additional per cent of ash and sulphur results in 0.4 per cent decrease in efficiency.

9. The evaporative efficiency of Illinois coal, when burned in a hand-fired furnace, decreases as the per cent of fine coal contained in it increases.

10. Briquetting improves the evaporative efficiency of Illinois coal only when the raw coal is in the form of slack or screenings.

11. The performance of Illinois coal in a gas producer compares favorably with that of any other bituminous coal tested at the United States Geological Survey laboratory.

12. The value of Illinois coal as fuel for a gas-producer

*Professor Parr's classification of coal, see page 11 of this circular.

decreases as the ash contained in it increases and as the calorific value decreases.

13. In small plants it requires at least two and one-half times as much coal to develop one horse-power when used in steam boiler service as when used in gas producer service.

14. Gas producers can be continuously operated with Illinois coal developing one electrical horse-power with 1.7 lb. of dry coal.

III The Coals Tested

1. *The mining centers and districts of Illinois*, recognized by the trade and defined with reference to geographical position, have been described as follows.*

(*a*) Williamson, Franklin, and Perry Counties. Williamson County led the production of the State in 1907 with more than 5,500,000 tons. No. 7, the Blue Band seam, which is from 5 to 10 feet thick, averaging 9 feet over a large area, is the greatest producer. It maintains an approximate uniformity in physical character and thickness but varies from place to place in fuel value. At Spillertown another seam, 4 feet thick, is mined 60 feet below No. 7. This seam is probably equivalent to No. 5 of Saline County and may have a wide distribution in the Williamson County district.

(*b*) Sangamon, Macoupin, Christian, Logan, and Macon Counties. The Springfield district, extending into several adjoining counties, has long been one of the most important. Sangamon produced more than 5,000,000 tons in 1907. The coal of the district is commonly known as No. 5, though recent work tends to confirm the suggestion that there are probably two distinct beds mined in this district,–No 5, in the area north of Chatham, and in No. 6 south of that town. The average thickness is a little less than 6 feet at Springfield, about 4.5 feet at Decatur and from 6 to 8 feet in Macoupin County.

(*c*) St. Clair, Madison, Clinton, and Randolph Counties. St. Clair County produced more than 4,500,000 tons in 1907. This district, known as the Bellville district, is not sharply set off from its neighbors since the same coal bed is mined under similar conditions in adjoining counties. It is the Blue Band seam and has a thickness of from 5 to 7 feet over much of the area. The seam is reached by shafts from 100 to 300 feet deep.

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*The Coal Resources of Illinois, by Frank W. DeWolf, Amer. Inst. of Mining Engineers, October, 1908.

(*d*) Vermilion County. During 1907 Vermilion County produced nearly 3,000,000 tons. It has long been an important area, shipping principally to the Chicago market. There are three persistent seams, two of which are worked. The top or Danville, No. 7, appears west of Vermilion river and is mined along the outcrop and by shafts from 75 to 200 feet deep. The other, known as the Grape Creek coal, No. 6, lies from 20 to 80 feet below the Danville and is the more important of the two.

(*e*) Saline County. Saline County is one of the newest and most rapidly growing producers. In 1907 its output was about 2,125,000 tons, a gain of 125 per cent over 1906. There are two seams, No. 7 and No. 5, underlying the northern two-thirds of this county and much of Gallatin on the east, each approximately 5 feet thick and lying 90 to 150 feet apart vertically.

(*f*) Fulton and Peoria Counties. Fulton County produced more than 2,000,000 tons in 1907 and Peoria about half as much. Here the principal seam, called No. 5, is from 4 to 4.5 feet thick. Shafts reach the coal at from 75 to 150 feet. In all, seven beds are present.

(*g*) La Salle, Bureau and Grundy Counties. The La Salle district includes three principal counties and produces more than 5,000,000 tons yearly. The largest production is by long-wall mining from seam No. 2, or the Third Vein. The coal averages 3 feet thick and is of good quality. About 140 feet above it, lies seam No. 5. It is about 4 feet thick. About 40 feet above No. 5 is seam No. 7. This is extensively mined by room-and-pillar methods.

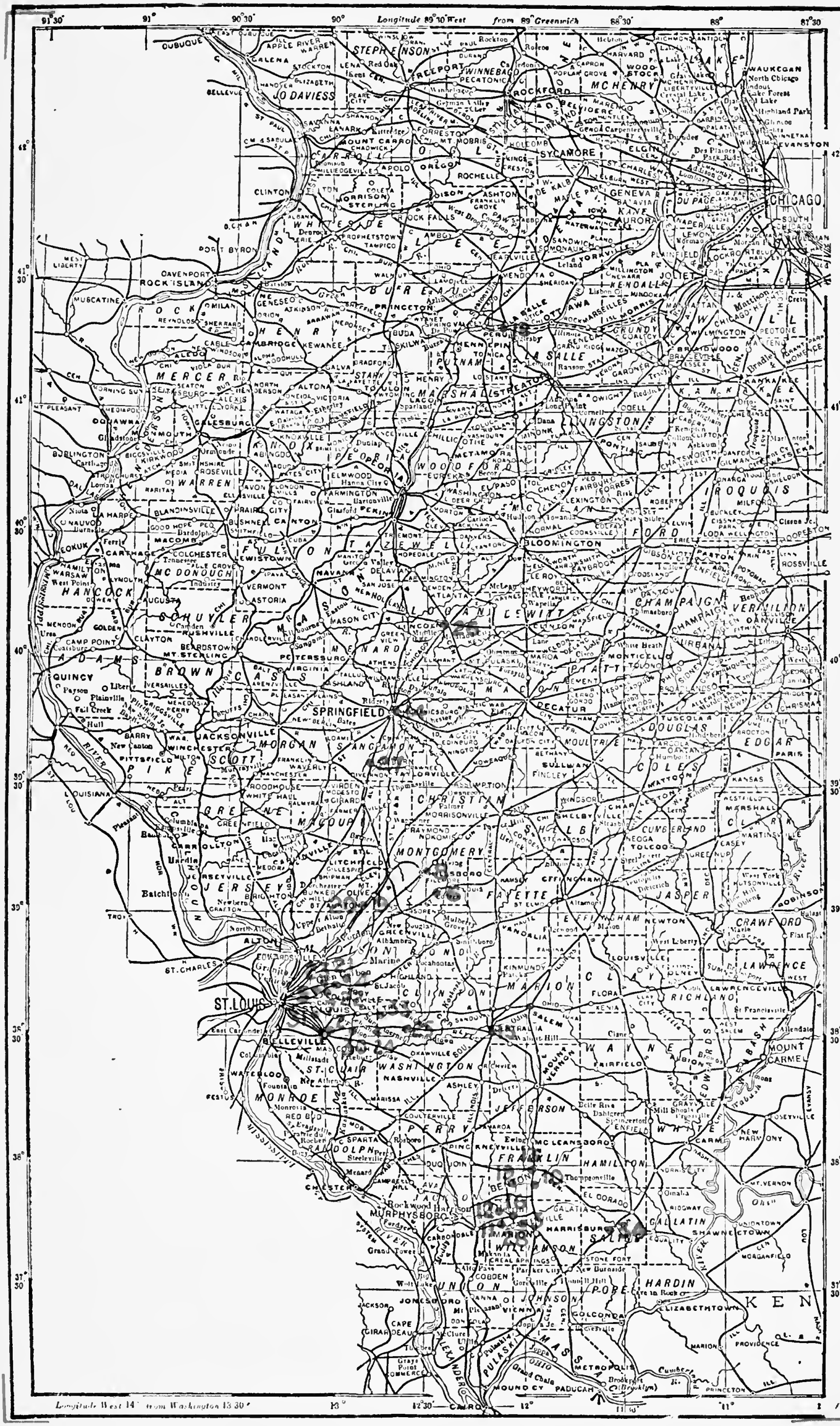
2. *The samples tested* were procured from 5 of the 7 districts described in the preceding paragraph. They were furnished by the several coal mining companies of the state free of cost, and were shipped to the fuel testing laboratory under the supervision of an expert inspector whose chief care was to secure a sample for testing which fairly represented the normal product of the mine. The cars were numbered consecutively in the order of shipment, and this number has been retained as the laboratory designation of the sample. When two or more car lots consisting of different grades, such as lump, nut, etc., were shipped from the same mine, each lot was designated by a letter. For example, Illinois 11A is screened coal, 11B run-of-mine and 11C No. 5 washed coal, all from the same mine.

A complete list of the car-load samples of Illinois coal received and tested is given in Table 1. In this table the location

TABLE 1 SAMPLES OF ILLINOIS COAL TESTED

U. S. G. S. Number	Coal Bed or Seam	Location of Mine	County	Operator	Name or Number of Mine	Depth of Mine, feet
1	2	3	4	5	6	7
1	6	O'Fallon	St. Clair	Western Anthracite Coal and Coke Co	Nigger Hollow No. 1	....
2	6	"	"	"	"	....
3	7	Marion	Williamson	Southern Illinois Coal Co	No. 3	....
4	7	Troy	Madison	Donk Brothers Coal and Coke Co	No. 3	....
5	6	Collinsville	"	"	No. 1	....
6A	5	Coffeen	Montgomery	Clover Leaf Coal Co	Clover Leaf Shaft No. 1	....
6B	5	"	"	"	"	....
7A	6	Near Collinsville	Madison	Lamaghi Coal Co	No. 2	....
7B	6	"	"	"	No. 2	....
7C	6	"	"	"	No. 2	....
7D	6	"	"	"	No. 2	....
7E	6	"	"	"	No. 2	....
8	6	Paisley	Montgomery	Dering Coal Co	Paisley	....
9A	6	Near Staunton	Macoupin	Mt. Olive and Staunton Coal Co	No. 2	....
9B	6	"	"	"	No. 2	....
10	7	West Frankfort	Franklin	Dering Coal Co	West Franklin	....
11A	7	Near Carterville	Williamson	St. Louis and Big Muddy Coal Co	Daws Shaft	....
11B	7	"	"	"	"	....
11C	7	"	"	"	"	....
11D	7	"	"	"	"	....
12A	7	Bush	"	Western Coal and Mining Co	Bush No. 1	....
12B	7	"		"	"	....
13	7	Benton	Franklin	The Benton Coal Co	Benton	....
14	5	East Side of Springfield	Sangamon	Capital Coal Co	No. 2	....
15	6	Centralia	Marion	Peettinger and Davis	South	....
16	7	Herrin	Williamson	Big Muddy Coal and Iron Co	No. 7	....
18	2	La Salle	La Salle	La Salle County Carbon Coal Co	La Salle Shaft	....
19A	7	Zeigler	Franklin	Zeigler Coal Co	Zeigler	....
19B	7	"	"	"	"	....
19C	7	"	"	"	"	....
19D	7	"	"	"	"	....
19E	7	"	"	"	"	....
20	6	Staunton	Macoupin			....
21	6	Troy	Madison			275

22A	6	Maryville	"			260
22B	6	"	"			260
23A	6	Donkville	"			145
23B	6	"	"			145
24A	6	New Baden	Clinton			320
24B	6	"	"			320
25A	6	Germantown	"			345
25B	6	"	"			345
26	5	Lincoln	Logan			276
27	6	Auburn	Sangamon			
28A	7	Herrin	Williamson			167
28B	7	"	"			167
28C	7	"	"			167
29A	5	Livingston	Madison			286
29B	5	"	"			286
30	7	Shiloh Station	St. Clair			126
31	6	Warder	"			300
33	7	Trenton	Clinton			320
34A	5	Harrisburg	Saline			165
34B	5	"	"			165



Longitude 89°30' West from 89° Greenwich
Longitude West 14° from Washington 13 30'
CHICAGO
ROCKFORD
SPRINGFIELD
PEORIA
BLOOMINGTON
DECATUR
QUINCY
ST. LOUIS
BELLEVILLE
CAIRO
GALESBURG
JOLIET
AURORA
ELGIN
DAVENPORT
ROCK ISLAND
DUBUQUE
PADUCAH
JO DAVIESS
STEPHENSON
WINNEBAGO
McHENRY
CARROLL
WHITESIDE
LEE
BUREAU
HENRY
MERCER
KNOX
WARREN
PEORIA
WOODFORD
LA SALLE
GRUNDY
KANKAKEE
IROQUOIS
FORD
CHAMPAIGN
VERMILION
McLEAN
LOGAN
MENARD
CASS
BROWN
ADAMS
HANCOCK
McDONOUGH
SCHUYLER
FULTON
TAZEWELL
MACON
PIATT
DOUGLAS
EDGAR
COLES
MOULTRIE
SHELBY
CHRISTIAN
SANGAMON
MORGAN
SCOTT
PIKE
GREENE
MACOUPIN
MONTGOMERY
FAYETTE
EFFINGHAM
JASPER
CRAWFORD
CLARK
CUMBERLAND
JERSEY
MADISON
BOND
CLINTON
MARION
CLAY
RICHLAND
LAWRENCE
WABASH
WAYNE
EDWARDS
WHITE
ST. CLAIR
MONROE
RANDOLPH
PERRY
WASHINGTON
JEFFERSON
FRANKLIN
HAMILTON
GALLATIN
SALINE
WILLIAMSON
JACKSON
UNION
JOHNSON
POPE
HARDIN
MASSAC
PULASKI
ALEXANDER
KEN

of the mine, the geological bed or seam and the name of the mine or its depth are given. Referring to the table it will be seen that fifty-three car samples from thirty-three different mines were tested, and that the mines are distributed throughout twelve of the principal coal mining counties of the State. The location of each mine is plotted on the map, Fig 1.

A comparison of the coal output of the several localities designated in paragraph 2, with the number of mines submitting samples, shows that the coal tested is fairly representative and while it is true that two comparatively important coal producing localities are not included, the results of tests should be accepted as characteristic of Illinois coal in general.

3. *The plan of the tests* as adopted by the United States Geological Survey included a complete chemical analysis of samples submitted, an investigation of the advantages of washing, an investigation of the coking qualities of the coal, and a series of boiler and gas producer trials. In carrying out this plan each sample was tested under conditions as nearly identical as possible, and every effort was made to secure results which would admit of direct comparison.

IV Chemical Properties of the Coals Tested

To determine the chemical properties of the coals tested, samples were taken both from the working face of the mine and from each car-load shipped.

4. *The mine samples* were obtained as follows: After a general inspection of the mine to determine the variations of coal in thickness and in quality, two representative points were selected in opposite parts of the mine. The face of the coal at these places was cleaned in order to remove any weathered coal or powder smoke, and a cut made across the face of the coal from roof to floor, including all the benches mined and such impurities as were not removed in ordinary work. The coal obtained, amounting to 25 or 30 pounds, was pulverized and quartered down according to generally accepted rules, and the sample placed in an air-tight iron can. This was mailed to the chemical laboratory where it was received and analyzed within two or three days.

5. *The car samples* were obtained during the process of unloading at the testing plant. A quantity never less than 200 pounds and often as great as 600 pounds was collected, a shovelful at a time from every part of the car. This was thoroughly crushed and quartered down until 25 or 30 pounds remained, placed in an air-tight can and immediately shipped to the chemical laboratory. Here the sample was pulverized and again quartered until a convenient amount for analysis was obtained.

6. *The chemical work* included calorific determinations, and ultimate and proximate analyses. The calorific value was determined in duplicate for each car sample. A determination was also made for one of the two mine samples corresponding to each carload. An ultimate analysis was made in duplicate on each car sample. The approximate analysis and the determination of sulphur were made for practically every sample that came into the laboratory, and were made in duplicate for all car samples.

7. *The results of the chemical analyses* are given in Tables 2 and 3, (p. 12, et seq.) Column 1 gives the laboratory number, Column 2 the U. S. G. S. number, Column 3, the coal bed or seam and Column 4, the location from which the sample was taken. Column 5 gives the designation of the sample. The proximate analysis is given in Columns 6 to 14. These results are given both for air-dry coal (Columns 7 to 10) and for pure coal (Columns 12 to 14). The calorific value is given in terms of dry coal in Column 11 and in terms of pure coal in Column 15. Referring to the latter it will be seen that the maximum value is 14900 and the minimum 13900, a range of about 6.7 per cent. The average, however, is 14319 and but few of the recorded values vary from this by an amount greater than two per cent. The ultimate analysis is given in Columns 16 to 21. For convenience in comparing the results this is put in terms of dry coal. Columns 22, 23 and 24 have been calculated from the ultimate and proximate analyses. The combustible volatile is equal to the difference between the total volatile (Column 12) and the inert volatile (Column 23). The inert volatile is equal to 100 minus the total carbon, the ash, the water, the sulphur and the available hydrogen all divided by 100 minus the ash and water. The ratio of the volatile carbon to the total carbon (Column 24) is equal to total carbon as shown by the ultimate analysis minus the fixed carbon as shown by the proximate analysis divided by the total carbon.

The values included in Columns 22, 23 and 24 have been calculated in order to make possible a classification based on the ratio of volatile carbon to total carbon. This is the classification suggested by Professor S. W. Parr, and, in brief, is as follows.*

COAL	Anthracite	Anthracite Proper	Ratio $\frac{VC}{C}$ below 4%
		Semi-Anthracite	Ratio $\frac{VC}{C}$ between 4% and 8%
		Semi-Bituminous	Ratio $\frac{VC}{C}$ between 10% and 15%
	Bituminous Proper	A	Ratio $\frac{VC}{C}$ from 20% to 32%; Inert Volatile from 5% to 10%
		B	Ratio $\frac{VC}{C}$ from 20% to 27%; Inert Volatile from 10% to 16%
		C	Ratio $\frac{VC}{C}$ from 32% to 44%; Inert Volatile from 5% to 10%
		D	Ratio $\frac{VC}{C}$ from 27% to 44%; Inert Volatile from 10% to 16%
	Black Lignites		Ratio $\frac{VC}{C}$ from 27% up; Inert Volatile from 16% to 20%
	Brown Lignites		Ratio $\frac{VC}{C}$ from 27% up; Inert Volatile from 20% to 30%

It will be seen that in this system of classification all samples of Illinois coal tested fall in one of two divisions, bituminous B and bituminous D. In Table IV (p. 18) they have been arranged in the order of their volatile-carbon total-carbon ratio. Referring to Column 2 of this table the minimum value of the ratio $\frac{VC}{C}$ is 20.9 and the maximum 33.4. The inert volatile calculated on the pure coal basis varies from 12.5 to 16.3.

The classification of the several coal beds or seams of the state as used in the state coal reports has often been questioned; nevertheless it is of interest to note that in so far as the present tests can be taken as an index, seam No. 7 falls in Class B, and seam No. 6 falls in Class D. Furthermore if, as has been pointed out, (paragraph 2, section b, Chapter II) certain of the Blue Band

*Composition and Character of Illinois Coals, by S. W. Parr, Illinois State Geological Survey, Bulletin No. 3.

TABLE 2 CHEMICAL ANALYSES

Laboratory No.	U. S. G. S. No.	Coal Bed or Seam	County in Which Mine is Located	Designation of Sample	Loss in Moisture in Air-Drying, Per cent	Proximate Analysis of Air-Dry Coal, Per cent				B. t. u. per pound of Air-dry Coal	Proximate Analysis of Pure Coal (Ash and Moisture Free), Per cent			B. t. u. per pound of Pure Coal
						Moisture	Volatile Matter	Fixed Carbon	Ash		Volatile Matter	Fixed Carbon	Sulphur	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	6	St. Clair	Mine Sample No. 1	4.40	7.08	41.12	41.00	10.80	11738	50.1	49.9	5 36	14294
2	1	6	"	Mine Sample No. 2	3.20	7.09	41.66	40.85	10.40	.....	50.4	49.6	5.05	.....
3	1	6	"	Car Sample	3.70	6.28	38.92	41.08	13.72	11448	48.6	51.4	5.32	14310
4	2	6	"	"	7.10	5.31	34.29	36.24	24.16	9848	48.6	51.4	6.10	13963
5	3	7	Williamson	Mine Sample No. 1	1.50	6.09	32.16	51.49	7.26	12556	37 2	62.8	1.15	14490
6	3	7	"	Mine Sample No. 2	1 80	5.63	34 92	51.78	7.67	.....	40.3	59.7	2.49	.....
7	3	7	"	Car Sample	2.70	5.96	30.29	52.16	11.59	12103	36.8	63.2	2.17	14679
8	4	7	Madison	Mine Sample No. 1	3.20	12.28	32.02	48.03	7.67	11520	40.0	60.0	.94	14390
9	4	7	"	Mine Sample No. 2	3.00	11.77	33.18	45.97	9.08	.....	41.8	58.2	1.99	.....
10	4	7	"	Car Sample	1.70	11.40	32.59	44.30	11.85	.....	42.4	57.6	1.74	.....
11	5	6	"	"	12.50	5.16	34.98	40.67	19.19	10651	46.1	53.9	4.98	14079
12	6	5	Montgomery	Mine Sample No. 1	5.60	9.84	36.86	44.96	8.34	11669	45.1	54.9	4.66	14262
13	6	5	"	Mine Sample No. 2	4.00	10.38	38.35	42.94	11.36	.....	45.1	54.9	5.10	.....
14	6A	5	"	Car Sample A	9.80	5.13	32.68	47.46	14.73	.....	40.8	59.2	5.55	.....
15	6	5	"	Mine Sample No. 3	6.60	12.90	33.77	42.25	11.08	10856	44.4	55 6	4.97	14280
16	6B	5	"	Car Sample B	8.10	11.93	29.99	43.90	14.18	10303	40.6	59.4	5.81	13943
17	7	6	Madison	Mine Sample No. 1	5.90	12.27	37.22	39.16	11.35	.....	48.7	51.3	6.11	.....
18	7	6	"	Mine Sample No. 2	5.90	11.87	36.57	39.98	11.58	10768	47.7	52.3	6.21	14066
19	7B	6	"	Car Sample B	5.00	11.46	34 98	36.25	17.81	10026	49.1	50.9	6.17	14075
20	7D	6	"	Car Sample D	3.50	10.83	36.24	39.75	13.18	10816	47.7	52.3	5.96	14233
21	8	6	Montgomery	Car Sample	4.40	13 20	34.33	39.94	12.53	10514	46.2	43.8	5.99	14156
22	9	6	Macoupin	Mine Sample No. 1	7.70	13.29	37.07	40 74	8.90	11162	47.6	52.4	5.30	14345
23	9	6	"	Mine Sample No. 2	7.70	15.27	36.19	39.34	9.20	.....	47.9	52.1	4.90	.....
24	9A	6	"	Car Sample A	9.00	13.54	35.56	40.03	10.74	10807	47.0	53.0	5.33	14297
25	9B	6	"	Car Sample B	10.10	13.72	36.24	39.72	10.32	10870	47.7	52,3	5.21	14310
26	9C	6	"	Car Sample C	13.30	15.25	28.57	40.83	15.35	9790	41.2	58.8	4.58	14107
27	10	7	Franklin	Car Sample	6.90	9.50	31.98	47.08	11.44	11506	40.4	59.6	1.83	14553
28	11	7	Williamson	Mine Sample	4.90	8.30	33.75	48.69	9.26	11999	41.0	59.0	3.42	14555

29	11A	7	Williamson.	Car Sample A	4.80	7.76	31.44	50.19	10.61	11957	38.5	61.5	2.41	14648
30	11B	7	''	Car Sample B	5.80	8.86	31.25	48.23	11.66	11702	39.3	60.7	3.10	14723
31	11C	7	''	Car Sample C (washed coal)	6.40	8.61	32.40	51.33	7.66	12236	38.7	61.3	1.97	14613
32	12	7	''	Mine Sample No. 1	5.20	8.26	31.19	49.69	10.83	11837	38.5	61.5	3.47	14635
33	12	7	''	Mine Sample No. 2	5.60	8.41	34.27	45.44	11.88	.....	43.0	57.0	4.56	.....
34	12A	7	''	Car Sample A	3.60	8.20	32.26	46.59	12.95	11362	40.9	59.1	4.42	14410
35	12B	7	''	Car Sample B (washed coal)	13.30	15.87	28.19	46.42	9.52	10784	37.7	62.3	3.14	14454
36	12B	7	''	''	9.00	12.61	30.08	46.81	10.50	11066	39.1	60.9	3.08	14391
37	12B	7	''		12.40	15.31	28.93	45.29	10.47	10820	39.0	61.0	3.13	14578
38	13	7	Franklin	Mine Sample No. 1	5.30	10.28	32.04	49.74	7.94	.....	39.2	60.8	1.30	.....
39	13	7	''	Mine Sample No. 2	5.20	9.46	33.55	48.87	8.12	11990	40.7	59.3	1.98	14547
40	13	7	''	Car Sample	4.60	8.31	31.65	49.56	10.48	11727	39.0	61.0	1.91	14440
41	14	5	Sangamon	Mine Sample No. 1	10.80	13.89	33.96	40.89	11.26	10636	45.2	54.8	5.12	14201
42	14	5	''	Mine Sample No. 2	11.20	14.45	34.79	40.10	10.66	.....	46.4	53.6	4.62	.....
43	14	5	''	Car Sample	8.00	12.77	34.68	40.77	11.78	10757	45.9	54.1	5.51	14257
44	15	6	Marion	Mine Sample No. 1	7.20	10.25	37.43	39.79	12.53	11077	48.5	51.5	4.79	14345
45	15	6	''	Mine Sample No. 2	7.80	11.88	35.84	43.45	8.83	.....	45.2	54.8	4.10	.....
46	15	6	''	Car Sample	4.20	9.95	34.76	42.06	13.23	10960	45.2	54.8	5.04	14267
47	16	7	Williamson	Mine Sample No. 1	5.70	9.37	30.69	52.57	7.37	12058	36.8	63.2	1.50	14482
48	16	7	''	Mine Sample No. 2	4.80	8.59	31.07	53.37	6.97	.....	36.8	63.2	2.12	.....
49	16	7	''	Car Sample	4.00	8.43	30.08	51.89	9.60	11959	36.7	63.3	1.39	14589
50	18	2	La Salle.	Mine Sample No. 1	11.00	13.87	37.26	38.56	10.31	10985	49.2	50.8	4.53	14488
51	18	2	''	Mine Sample No. 2	11.20	15.55	36.21	40.66	7.58	.....	47.1	52.9	3.91	.....
52	18	2	''	Car Sample	8.40	12.39	36.89	41.80	8.92	11399	46.9	53.1	4.98	14486
53	19	7	Franklin	Mine Sample No. 1	5.20	9.90	28.67	53.69	7.74	12001	34.81	65.2	.58	14571
54	19	7	''	Mine Sample No. 2	5.60	10.53	29.06	53.01	7.40	.....	35.4	64.6	.57	.....
55	19A	7	''	Car Sample A	9.10	14.91	26.66	49.50	8.93	10958	35.0	65.0	.68	14388
56	19B	7	''	Car Sample B	5.60	10.72	29.86	50.06	9.36	11686	37.4	62.6	1.14	14622
57	19C	7	''	Mine Sample No. 3	.....	9.65	30.87	53.22	6.25	.....	36.8	63.2	.57	.....
58	20	6	Macoupin	Mine Sample	12.40	16.68	31.32	40.32	13.68	10053	43.8	56.2	5.43	14033
59	21	6	Madison	Mine Sample No. 1	10.50	15.22	31.42	44.32	9.03	10901	41.5	58.5	2.10	14392
60	21	6	''	Mine Sample No. 2	13.30	17.79	28.78	42.34	11.09	.....	40.4	59.6	1.97	.....
61	21	6	''	Car Sample	10.40	15.54	31.26	42.27	10.93	10507	42.5	57.5	1.88	14289
62	21	6	''	Car Sample	8.20	15.30	30.59	43.40	10.71	....	41.3	58.7	1.93	.....
63	22	6	''	Mine Sample No. 1	9.20	13.51	34.64	41.70	10.15	10881	45.4	54.6	5.25	14253
64	22	6	''	Mine Sample No. 2	9.90	13.83	34.16	42.24	9.77	.....	44.7	55.3	5.37	.....
65	22A	6	''	Car Sample A	5.90	11.91	35.65	39.43	13.01	10615	47.5	52.5	7.11	14138
66	22B	6	''	Car Sample B	11.20	13.03	32.65	39.79	14.53	10191	45.1	54.9	6.00	14068
67	23	6	''	Mine Sample No. 1	8.90	13.07	34.85	42.02	10.06	10949	45.3	54.7	4.67	14243
68	23	6	''	Mine Sample No. 2	9.70	12.79	35.67	40.25	11.29	.....	47.0	53.0	5.19	.....
69	23A	6	''	Car Sample A	11.50	13.47	34.35	40.65	11.53	10510	45.8	54.2	5.88	14013
70	23B	6	''	Car Sample B	13.20	15.68	31.28	37.45	15.59	9655	45.5	54.5	5.79	14048
71	24	6	Clinton	Mine Sample No. 1	10.10	13.43	33.02	44.37	9.18	10937	42.7	57.3	4.33	14132
72	24	6	''	Mine Sample No. 2	9.60	12.73	33.35	44.32	9.60	.....	42.9	57.1	4.64	.....
73	24B	6	''	Car Sample B	7.40	11.44	33.93	43.92	10.71	10958	43.6	56.4	6.35	14076
74	25	6	''	Mine Sample No. 1	6.70	11.64	35.41	44.29	8.66	11290	44.4	55.6	5.41	14166
75	25	6	''	Mine Sample No. 2	7.60	12.15	35.60	42.97	9.28	.....	45.3	54.7	5.10	.....
76	25B	6	''	Car Sample B	5.90	11.35	34.62	40.63	13.40	10733	46.0	54.0	6.33	14263
77	26	5	Logan	Mine Sample No. 1	11.30	14.77	32.90	39.75	12.58	.....	45.3	54.7	5.44	.....
78	26	5	''	Mine Sample No. 2	12.10	15.52	32.27	39.86	12.35	.....	44.7	55.3	5.06	.....
79	26	5	''	Car Sample	12.70	15.68	32.41	39.82	12.09	10215	44.8	55.2	4.86	14142
80	27	6	Sangamon	Mine Sample No. 1	10.20	14.29	37.17	40.36	8.18	11007	47.9	52.1	5.69	14197

TABLE 2 CHEMICAL ANALYSES (*continued*)

Laboratory No	U. S. G. S No.	Coal Bed or Seam	County in which Mine is Located	Designation of Sample	Loss in Moisture in Air-Drying, Per cent	Proximate Analysis of Air-Dry Coal, Per cent				B. t. u. per pound of Air-dry Coal	Proximate Analysis of Pure Coal (Ash and Moisture Free), Per cent			B. t. u. per pound of Pure Coal
						Moisture	Volatile Matter	Fixed Carbon	Ash		Volatile Matter	Fixed Carbon	Sulphur	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
81	27	6	Sangamon	Mine Sample No. 2	10.50	14.18	34.85	41.11	9.86	.....	45.9	54.1	5.74	.....
82	27	6	"	Car Sample	10 00	16.00	32.41	37.82	13.77	9940	46.2	53.8	5.77	14153
83	28	7	Williamson	Mine Sample No. 1	.....	8.72	30.38	53.28	7.62	12200	36.3	63.7	1.20	14583
84	28	7	"	Mine Sample No. 2	.....	8.88	29.49	53.60	8.03	.....	35.5	64.5	1.19	.....
85	28C	7	"	Car Sample C	3.00	7.78	29.84	52.39	9.98	11959	36.3	63.7	1.49	14542
86	29	5	Madison	Mine Sample No. 1	.....	14.25	35.52	40.79	9.44	10892	46.6	53.4	4.88	14273
87	29	5	"	Mine Sample No. 2	.....	12.69	37.40	41.15	8.76	11236	47.6	52.4	4.61	14304
88	29A	5	"	Car Sample A	8.60	13.15	30.73	40.12	16.00	9983	43.4	56.6	5.88	14090
89	29B	5	"	Car Sample B	7.30	12.47	33.12	41.85	12.56	10667	44.2	55.8	5.83	14228
90	29B	5	"	Car Sample B	5.50	12.25	33.76	41.66	12.33	10719	44.7	63.3	5 86	14212
91	30	7	St. Clair	Mine Sample No. 1	2.30	10.73	39.60	40.41	9.26	.....	49.5	50.5	5.15	.....
92	30	7	"	Mine Sample No. 2	.....	9.88	42.26	37.05	10.81	11439	53.3	46.7	4.83	14423
93	30	7	"	Car Sample	8.70	11.69	35.70	39.42	13.19	10699	47.5	52.5	5.83	14243
94	31	6	"	Mine Sample No. 1	8.00	13.17	34.79	41.75	10.29	.....	45.4	54.6	4.21	.....
95	31	6	"	Mine Sample No. 2	9.40	14.38	33.92	42.95	8.75	10858	44.1	55.9	4.07	14125
96	31	6	"	Car Sample	9.70	13.10	32.16	41.49	13.25	10363	43.7	56.3	4.97	14070
97	33	7	Clinton	Mine Sample No. 1	4.70	14.45	29.76	46.16	9.63	.....	39.2	60.8	2.75	.....
98	33	7	"	Mine Sample No. 2	4.80	15.06	29.48	45.81	9.65	10726	39.1	60.9	1.39	14438
99	33	7	"	Car Sample	.....	11.50	25.41	42.37	20.69	.....	37.5	62.5	2.24	.....
100	34	5	Saline	Mine Sample No. 1	1.20	7.55	33.85	51.45	7.15	.....	39.7	60.3	1.83	.....
101	34	5	"	Mine Sample No. 2	.....	7.51	32.81	52.20	7.48	12686	38.6	61.4	1.86	14923
102	34A	5	"	Car Sample A	6.60	9.33	30.92	47.86	11.89	11572	39.2	60.8	3.50	14689
103	34B	5	"	Car Sample B	5.80	7.81	33.54	50.27	8.38	12418	40.0	60.0	2.82	14817

TABLE 3 CHEMICAL ANALYSES

Laboratory No.	U. S. G. S. No.	Coal Bed or Seam	Designation of Sample	Ultimate Analysis of Dry Coal (Per cent)						Combustible Volatile, (Pure Coal Basis)	Inert Volatile, (Pure Coal Basis)	Ratio of Volatile Carbon to Total Carbon
				Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Ash			
1	2	3	5	16	17	18	19	20	21	22	23	24
1	1	6	....	....	.....	....	....	....	.....	....	....	....
2	1	6	....	....	.....	....	....	....	.....	....	....	....
3	1	6	Car Sample..........	4.69	66.16	1.14	8.84	4.54	14.63	35.6	13.0	33.8
4	2	6	Car Sample..........	4.21	57.09	.82	7.83	4.54	25.51	35.7	12.9	33.0
5	3	7	....	....	.....	....	....	....	.....	....	....	....
6	3	7	....	....	.....	....	....	....	.....	....	....	....
7	3	7	Car Sample..........	4.53	71.57	1.52	8.18	1.89	12.31	24.6	12.2	22.5
8	4	7	....	....	.....	....	....	....	.....	....	....	....
9	4	7	....	....	.....	....	....	....	.....	....	....	....
10	4	7	Car Sample..........	4.58	69.74	1.32	9.48	1.51	13.37	30.1	12.3	28.3
11	5	6	....	....	.....	....	....	....	.....	....	....	....
12	6	5	....	....	.....	....	....	....	.....	....	....	....
13	6	5	....	....	.....	....	....	....	.....	....	....	....
14	6A	5	Car Sample A..........	4.54	63.78	1.30	10.16	4.69	15.53	26.3	13.5	21.5
15	6	5	....	....	.....	....	....	....	.....	....	....	....
16	6B	5	Car Sample B..........	4.41	64.65	1.15	8.82	4.87	16.10	27.4	13.2	22.9
17	7	6	....	....	.....	....	....	....	.....	....	....	....
18	7	6	....	....	.....	....	....	....	.....	....	....	....
19	7B	6	Car Sample B..........	4.27	61.62	1.06	8.53	4.97	19.55	35.9	13.2	33.6
20	7D	6	Car Sample D..........	4.64	65.76	1.11	8.65	5.05	14.79	35.0	12.7	32.1
21	8	6	Car Sample..........	4.65	65.96	1.17	8.63	5.15	14.44	33.5	12.7	30.3
22	9	6	....	....	.....	....	....	....	.....	....	....	....
23	9	6	....	....	.....	....	....	....	.....	....	....	....
24	9A	6	Car Sample A..........	4.86	67.87	1.10	9.11	4.65	12.41	35.0	13.0	31.8
25	9B	6	Car Sample B..........	4.89	68.32	1.13	9.11	4.59	11.96	34.8	12.9	30.8
26	9C	6	Car Sample C..........	4.15	63.65	.97	8.62	4.50	18.11	28.2	13.0	24.4
27	10	7	Car Sample..........	4.70	70.54	1.50	9.03	1.60	12.63	27.1	13.3	26.2
28	11	7	....	....	.....	....	....	....	.....	....	....	....

TABLE 3 CHEMICAL ANALYSES (*Continued*)

Laboratory No.	U. S. G. S. No.	Coal Bed or Seam	Designation of Sample	Ultimate Analysis of Dry Coal (Per cent)						Combustible Volatile, (Pure Coal Basis)	Inert Volatile, (Pure Coal Basis)	Ratio of Volatile Carbon to Total Carbon
				Hydrogen	Carbon	Nitrogen	Oxygen	Sulphur	Ash			
1	2	3	5	16	17	18	19	20	21	22	23	24
29	11A	7	Car Sample A	4.93	72.15	1.43	7.85	2.14	11.50	26.9	11.6	24.6
30	11B	7	Car Sample B	4.67	70.54	1.41	7.88	2.70	12.80	27.5	11.8	25.0
31	11C	7	Car Sample C	4.84	70.56	1.46	8.95	1.81	8.38	26.1	12.6	24.7
32	12	7	....	....	....	....	....	....	....	....	....	....
33	12	7	....	....	....	....	....	....	....	....	....	....
34	12A	7	Car Sample A	4.55	68.11	1.20	8.25	3.79	14.10	27.7	12.7	25.5
35	12B	7	Car Sample B	4.71	70.91	1.26	9.16	2.78	11.18	24.7	13.0	22.2
36	12B	7	Car Sample B	4.54	71.13	1.06	8.55	2.71	12.01	27.0	12.1	24.7
37	12B	7	Car Sample B	4.61	70.73	1.23	8.35	2.73	12.35	26.9	12.1	22.7
38	13	7	....	....	....	....	....	....	....	....	....	....
39	13	7	....	....	....	....	....	....	....	....	....	....
40	13	7	Car Sample	4.65	71.97	1.61	8.83	1.69	11.43	26.0	13.0	24.7
41	14	5	....	....	....	....	....	....	....	....	....	....
42	14	5	....	....	....	....	....	....	....	....	....	....
43	14	5	Car Sample	4.67	67.33	1.25	8.48	4.77	13.15	33.5	12.4	30.6
44	15	6	....	....	....	....	....	....	....	....	....	....
45	15	6	....	....	....	....	....	....	....	....	....	....
46	15	6	Car Sample	4.61	66.22	1.15	9.02	4.30	14.70	32.0	13.2	29.5
47	16	7	....	....	....	....	....	....	....	....	....	....
48	16	7	....	....	....	....	....	....	....	....	....	....
49	16	7	Car Sample	4.63	73.51	1.64	8.47	1.25	10.49	24.2	12.5	22.9
50	18	2	....	....	....	....	....	....	....	....	....	....
51	18	2	....	....	....	....	....	....	....	....	....	....
52	18	2	Car Sample	5.10	69.95	1.14	9.15	4.47	10.18	34.2	12.7	31.8
53	19	7	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
54	19	7	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
55	19A	7	Car Sample A	4.42	73.75	1.59	9.13	.61	10.50	21.7	13.3	21.0
56	19B	7	Car Sample B	4.60	74.76	1.57	7.57	1.02	10.48	26.1	11.3	25.0

57	19C	7	Mine Sample No. 3	....	....	....	....	....	....	....	....	....
58	20	6	Mine Sample	4.43	64.71	1.17	9.11	4.55	16.03	30.2	13.6	26.9
59	21	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
60	21	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
61	21	6	Car Sample A	4.57	68.70	1.29	10.86	1.63	12.95	26.2	16.3	23.7
62	21	6	Car Sample B	....	....	....	....	....	....	....	....	....
63	22	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
64	22	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
65	22A	6	Car Sample A	4.42	65.10	1.14	8.51	6.06	14.77	34.9	12.6	31.3
66	22B	6	Car Sample B	4.37	64.33	1.02	8.58	5.00	16.70	32.3	12.8	27.1
67	23	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
68	23	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
69	23A	6	Car Sample A	4.77	66.58	1.05	9.18	5.19	13.32	32.3	13.5	29.4
70	23B	6	Car Sample B	4.37	62.72	1.06	8.64	4.72	18.49	33.3	13.20	29.2
71	24	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
72	24	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
73	21B	6	Car Sample B	4.65	67.81	1.15	8.71	5.58	12.10	31.1	12.5	26.9
74	25	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
75	25	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
76	25B	6	Car Sample B	4.68	64.70	1.19	8.95	5.37	15.11	32.6	13.4	29.2
77	26	5	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
78	26	5	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
79	26	5	Car Sample	4.53	67.31	1.26	8.40	4.16	14.34	32.3	12.5	29.8
80	27	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
81	27	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
82	27	6	Car Sample	4.49	64.15	1.08	9.06	4.83	16.39	32.7	13.5	29.8
83	28	7	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
84	28	7	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
85	28C	7	Car Sample C	4.55	73.15	1.31	8.74	1.43	10.82	23.8	12.5	20.9
86	29	5	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
87	29	5	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
88	29A	5	Car Sample A	4.37	62.43	1.02	8.96	4.80	18.42	29.6	13.8	26.1
89	29B	5	Car Sample B	4.56	65.31	1.14	9.65	4.99	14.35	30.2	14.0	26.8
90	29B	5	Car Sample B	4.65	66.43	.91	8.92	5.04	14.05	32.0	12.7	28.5
91	30	7	Mine Sample No. 1	....	....	....	....	....	....	....	..	....
92	30	7	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
93	30	7	Car Sample	4.71	64.71	1.06	9.62	4.96	14.94	33.5	14.0	31.0
94	31	6	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
95	31	6	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
96	31	6	Car Sample	4.59	65.95	1.18	8.82	4.21	15.25	30.6	13.1	27.6
97	33	7	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
98	33	7	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
99	33	7	Car Sample	3.72	61.46	1.02	8.70	1.72	23.38	24.7	12.8	31.0
100	34	5	Mine Sample No. 1	....	....	....	....	....	....	....	....	....
101	34	5	Mine Sample No. 2	....	....	....	....	....	....	....	....	....
102	34A	5	Car Sample A	4.50	69.32	1.42	8.60	3.05	13.11	26.1	13.1	25.4
103	34B	5	Car Sample B	4.82	73.11	1.56	8.86	2.56	9.09	27.3	12.7	25.4

coals of Sangamon County in reality belong to Seam 6 instead of 5, Class B would also include all coals tested from seam No. 5. The single sample from Seam No. 2, (U. S. G. S. 18) falls in Class D, well up towards the lignites.

TABLE IV

CLASSIFICATION OF ILLINOIS COAL ON THE BASIS OF THE VOLATILE-CARBON AND TOTAL-CARBON RATIO

U. S. G. S. Number	Ratio of Volatile Carbon to Total Carbon	Inert Volatile (Pure Coal Basis)	Class	Coal Bed or Seam
1	2	3	4	5
28	20.90	12.50	B	7
6	22.20	13.35	B	5
3	22.50	12.20	B	7
16	22.90	12.50	B	7
19	23.00	12.30	B	7
12	23.63	12.20	B	7
21	23.70	16.30	B	6
13	24.70	13.00	B	7
11	24.77	12,00	B	7
34	25.40	12.90	B	5
10	26.20	13.30	B	7
24	26.90	12.50	D	6
20	26.90	13.60	D	6
29	27.13	13.50	D	5
31	27.60	13.10	D	6
4	28.30	12.30	D	6
9	29.00	13.00	D	6
22	29,20	12.70	D	6
23	29.30	13.30	D	6
25	29.20	13.40	D	6
15	29 50	13.20	D	6
26	29 80	12.50	D	5
27	29.80	13.50	D	6
8	30.30	12.70	D	6
14	30.60	12.40	D	5
30	31.00	14.00	D	6
33	31.00	12.80	D	7
18	31.80	12.70	D	2
7	32.80	12.95	D	6
1 & 2	33.40	12.95	D	6

V WASHING TESTS

8. *The equipment for the washing tests* of Illinois coal consists of one modified Stewart jig and one jig especially designed for the laboratory, a Cornish tooth-roll crusher, an adjustable-mesh bumping screen, and bins of suitable capacity for storing the coal. The Stewart jig, shown in Fig. 2, provides for the washing of coal not exceeding 1½ inches in diameter. The special jig may be used for larger sizes. It is of the center-plunger type, that is, the plunger is directly beneath the screen. Its upward stroke causes the pulsation, and its downward stroke, by an arrangement of valves at the side of the jig body, admits the water sup-

ply. The screen is 4 feet wide by 5 feet long and is constructed of No. 10 wire set 1-16 inch apart. The length of stroke and the depth of the coal bed are adjustable.

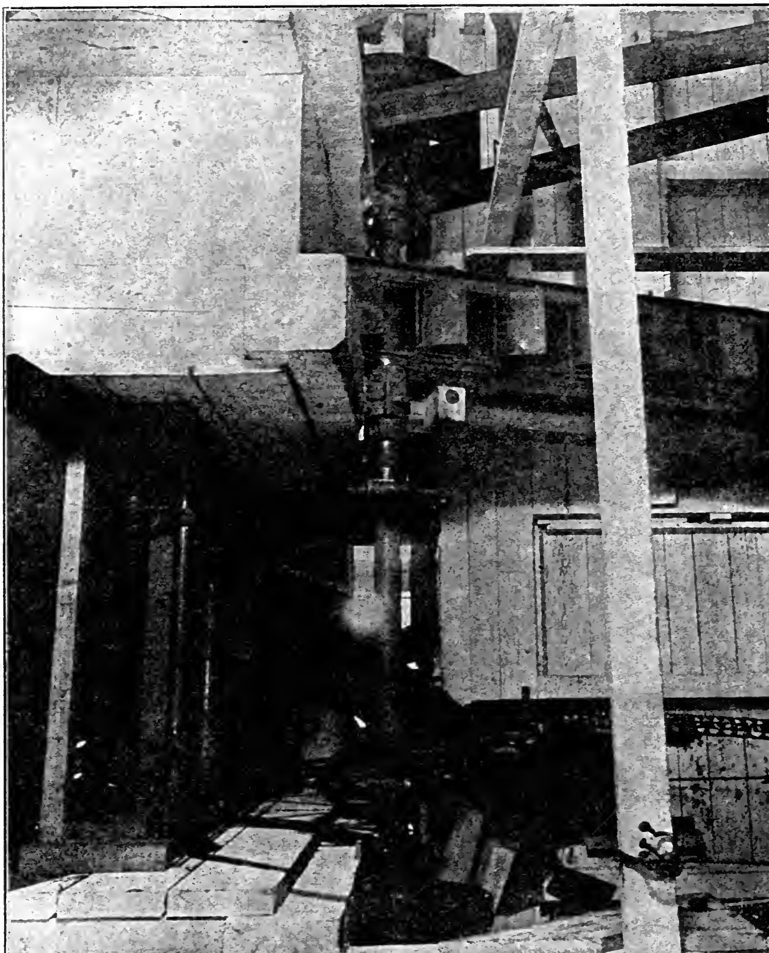


FIG. 2 STEWART JIG (PROF. PAPER 48, p. 1460)

9. *The tests* involved the weighing of the raw and washed coal, and the refuse. Samples of the coal were collected before and after it was fed to the jig. These were sent to the chemical laboratory for analysis. Altogether 31 tests were made on 24 kinds of coal.

10. *The results of the tests* are given in Table 5. Column 1 of this table is the U. S. G. S. coal number, Column 2 the jig used

TABLE 5 WASHING TESTS

U. S. G. S. No.	Jig Used	Size of Coal	Proximate Analysis of Raw Coal, Per cent					Proximate Analysis of Washed Coal, Per cent			Raw Coal pounds	Washed Coal pounds	Refuse, Per cent of Raw Coal
			Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur (Separately Determined)	Moisture	Ash	Sulphur (Separately Determined)			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
2	Stewart	Slack	12.03	.....	.....	22.41	4.00	19.07	9.42	3.35	27280	.....	....
2	"	Run of Mine	.....	.....	.....	10.59	1.45	.....	5.86	1.41	.....	.....	....
5		No. 5 Nut	.....	.....	.....	17.56	3.25	.....	9.18	2.71	.....	.....	....
6	Stewart, modified	Run of Mine crushed to 2 in.	14.43	29.48	42.81	13.28	4.01	15.23	8.64	3.30	14710	13586	7.6
7C	"	Slack	10.69	33.08	36.14	20.09	4.06	16.64	8.59	3.25	15809	11238	28.9
7D	"	Run of Mine crushed to 2 in.	10.83	36.24	39.75	13.18	4.53	12.45	9.30	3.65	14000	11790	15.8
9A	"	"	13.54	35.69	40.03	10.74	4.03	15.65	7.57	3.38	18000	13920	22.7
10	"	Slack	9.50	31.98	47.08	11.44	1.45	11.86	6.67	1.38	14710	12795	13.0
12	"	Run of Mine crushed to 2 in.	8.21	32.26	46.59	12.95	3.48	13.30	8.91	2.48	18000	15900	11.7
13	"	Egg crushed to 2 in.	8.31	31.65	49.56	10.48	1.55	11.15	7.49	1.27	29950	27550	8.0
14	"	Lump crushed to 2 in.	12.77	34.68	40.77	11.78	4.16	16.52	9.37	3.29	18000	15955	11.4
15	"	Lump & Egg crushed to 2 in.	9.95	34.76	42.06	13.23	3.87	11.81	8.41	3.00	18000	13055	27.6
16	"	"	8.43	31.65	49.56	10.48	1.55	11.15	7.49	1.27	29950	27550	10.7
18	"	Lump crushed to 2 in	12.39	36.89	41.80	8.92	3.92	14.99	5.77	2.98	18000	14400	20.0
20	"	Screenings crushed to 2 in.	14.68	31.32	40.32	13.68	3.88	16.80	10.26	3.21	63280	57000	10.0
21	"	Lump crushed to 2 in.	15.30	30.59	43.40	10.71	1.43	8.25	8.09	1.25	17000	14000	13.9
22A	"	"	11.91	35.65	39.43	13.01	5.34	14.02	8.58	3.69	19100	17000	12.4
22B	"	Nut & Slack crushed to 2 in.	13.03	32.65	39.79	14.53	4.35	16.78	9.99	3.79	40000	32000	20.0
23A	"	Lump crushed to 2 in.	13.47	34.35	40.65	11.53	4.41	13.81	8.78	3.54	28000	24000	14.3
23B	"	Screenings crushed to 2 in.	15.68	31.28	37.45	15.59	3.98	16.83	8.75	3.22	80000	63000	21.2
24A	"	"	11.44	33.93	43.92	10.91	4.91	15.10	9.75	3.18	20000	15000	25.0
24B	"	Nut crushed to 2 in.	11.44	33.93	43.92	10.91	4.94	14.36	8.38	3.31	18745	16660	11.1
25A	"	Run of Mine crushed to 2 in.	12.96	33.01	39.60	14.43	4.09	14.14	8.98	3.05	14556	12000	17.5
26	"	"	15.68	32.41	39.82	12.09	3.51	15.96	9.40	2.76	18000	16000	11.1
27	"	"	16.00	32.41	37.82	13.77	4.05	16.11	7.76	3.26	18000	15545	13.6
28C	"	Lump crushed to 2 in.	7.78	29.85	52.39	9.98	1.32	9.75	7.12	1.05	24000	19925	17.0
29A	"	Screenings crushed to 2 in.	13.10	30.73	40.12	16.00	4.17	15.86	7.70	3.06	18000	13750	23.6
29A	"	"	13.10	30.73	40.12	16.00	4.17	15.86	7.70	3.06	59500	41500	30.4
30	"	Nut crushed to 2½ in.	11.69	35.70	39.42	13.19	4.38	12.36	9.44	3.26	30000	23200	22.6
30	Special	Nut crushed to 1 in.	11.69	35.70	39.42	13.19	4.38	13.67	7.89	2.15	24900	20200	18.9
34A	"	Screenings crushed to 1 in.	9.33	30.92	47.86	11.89	2.76	8.68	7.44	2.19	49300	39100	20.7

and Column 3 the size of the coal. The proximate analysis of the raw and washed coal is given in Columns 4 to 11. The weight of raw coal tested is given in Column 12 and the washed coal produced in Column 13. Column 14 gives the refuse expressed in per cent of raw coal fed to the jig.

11. *The improvement in quality of the coal* effected by washing is well shown in Columns 4 to 11. For example the per cent of ash content is, in every case, decreased by washing. This is shown graphically in Fig. 3. In this figure the per cent of ash in the washed coal is plotted against per cent of ash in the raw coal. The average line shows that by resorting to the process of washing, it is possible to reduce the ash content from 22 per cent to 8.7 per cent and from 10 per cent to 6.9 per cent. Expressed in per cent the amount of reduction is as follows:

When raw coal contains 8% ash, the reduction is 20%.
When raw coal contains 12% ash, the reduction is 30%.
When raw coal contains 16% ash, the reduction is 43%.
When raw coal contains 20% ash, the reduction is 53%.

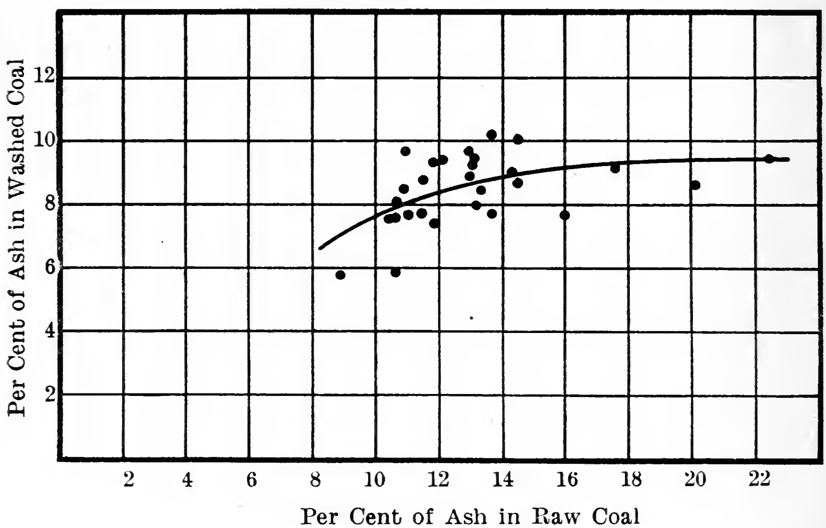


FIG. 3 REDUCTION OF ASH DUE TO WASHING

In a similar way the reduction in sulphur due to washing is shown in Fig. 4. Referring to this figure it will be seen that:

When raw coal contains 2% sulphur, the reduction is 13%.
When raw coal contains 3% sulphur, the reduction is 17%.
When raw coal contains 4% sulphur, the reduction is 22%.
When raw coal contains 5% sulphur, the reduction is 28%.

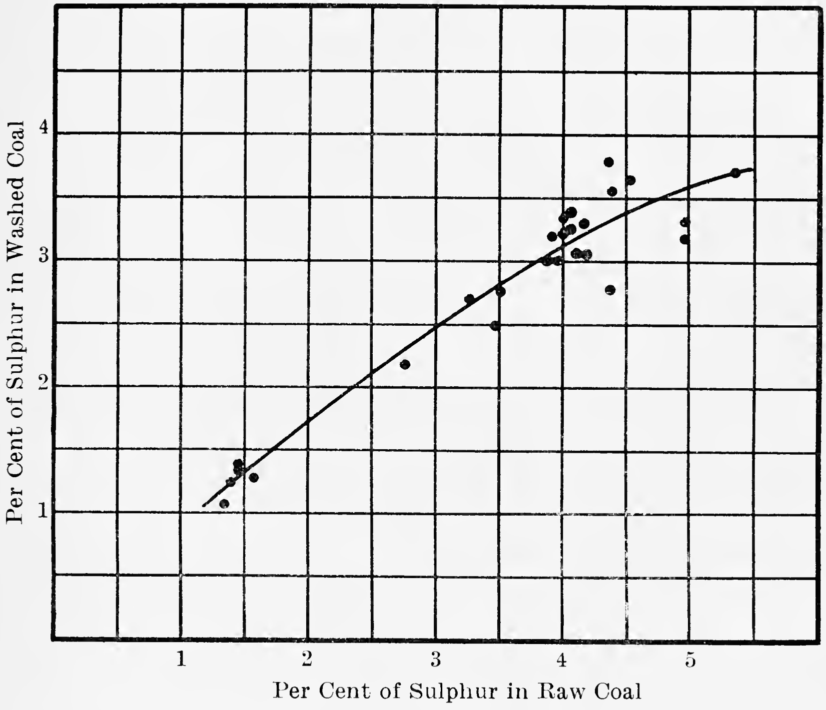


FIG. 4 REDUCTION OF SULPHUR DUE TO WASHING

In bringing about this improvement in the quality of coal by washing, much good coal which can not be recovered is carried off with the refuse from the jig. For example, the tests show that, based on the average of all tests, the refuse amounts to 16.8 per cent of the raw coal. The ash in the raw coal is 12.6 per cent, but in the washed coal this is reduced to 8.34 per cent, therefore $12.6 - 83.2 \times 8.34$ or 5.7 per cent is the ash content in the refuse. It appears, then, that the material thus discharged is made up of about $\frac{2}{3}$ pure coal and $\frac{1}{3}$ ash.

VI. Coking Tests

12. *The ovens* in which tests of the coking qualities of the coal were made are of the regular beehive pattern. Originally they were arranged in a battery of three, two of standard size, 12 feet in diameter, by 7 feet high, and the third 12 feet in diameter by 6 feet 4 inches high; later, however, one of the standard ovens was removed. Since the two remaining ovens may be considered as end ovens, that is, those placed at the ends of the battery, the results obtained are directly comparable.

13. *The tests.*—To prepare the coal for test it was finely crushed in a Williams mill. It was then placed on the larry and delivered to the oven. The larry used when the work was begun had a capacity less than one ton. This necessitated the filling and emptying of the larry six or eight times before the charge was complete. Each portion thus had time to emit a large amount of gas and often to burst into flames before the next portion of the charge was added. This resulted in much injurious cross lamination of the coke in many of the earlier tests. Afterwards when a larger larry was installed and the time of charging reduced from one hour to less than seven minutes the laminations and cross-breakage disappeared.

Directly after drawing the charge the ovens were closed for a period of one or two hours during which time they were allowed to gather heat for the next charge.

A sample of coal was taken at regular intervals as the charge was emptied into the larry. The total weight collected was 40 or 50 pounds. A sample of coke was taken from 5 different parts of the oven, one piece 2 feet from the oven floor, one 2 feet from each side on a line drawn from the center of the oven, one from the center of the oven, and one 2 feet from the back wall. The separate pieces of coke extended the whole height of the charge and were as nearly uniform in size as possible.

14. *The results of the tests* are given in Table 6. Column 1 of this table is the test number, Column 2 the U. S. G. S. number, and Column 3 the size as shipped to the laboratory. The proximate analysis of the coal and coke produced from it is given in Columns 4 to 13. Column 14 gives the weight of coal in the charge. The coke produced in per cent of the weight of the coal charged is given in Column 15, and the per cent of breeze in Column 16. The total yield as given in Column 17 is the sum of the coke and breeze produced. A brief description of the physical

TABLE 6 Coking Tests

Test No.	U. S. G. S. No.	Size of Coal	Proximate Analysis of Coal: Moisture	Proximate Analysis of Coal: Volatile Matter	Proximate Analysis of Coal: Fixed Carbon	Proximate Analysis of Coal: Ash	Proximate Analysis of Coal: Sulphur Separately Determined	Proximate Analysis of Coke: Moisture	Proximate Analysis of Coke: Volatile Matter	Proximate Analysis of Coke: Fixed Carbon	Proximate Analysis of Coke: Ash	Proximate Analysis of Coke: Sulphur Separately Determined
1	2	3	4	5	6	7	8	9	10	11	12	13
10	1	Lump and nut	10.46	36.11	37.48	15.95	4.14	....	....	.....	.....	....
9	2	Washed slack	17.20	35.77	37.84	9.19	3.03	1.57	2.83	75.42	20.18	2.75
29	3	Run of mine	8.25	30.32	50.95	10.59	1.45	....	....	.....	.....	....
28	3	Washed run of mine	9.52	32.05	52.57	5.86	1.41	6.11	.42	82.55	10.92	1.13
45	5	Washed slack	17.86	31.65	32.93	17.56	3.25	....	....	.....	.....	....
59	5	"	25.15	28.68	36.99	9.18	2.71	....	....	.....	.....	....
60	5	"	14.60	30 76	36.48	18.16	3.44	....	....	.....	.....	....
1	7D	Run-of-mine crushed	10.88	35.27	38.44	15.41	4.53	2.26	1.84	72.68	23.20	3.95
4	7D	Run-of-mine crushed and washed	12.45	36.17	42.08	9.30	3.64	1.04	.61	82.10	16.25	3.24
5	11D	No 3 crushed and washed	8.24	31.64	52.81	7.31	1.55	1.19	.93	85.97	11.91	1.44
3	13	Egg, crushed	10.56	30.08	49.08	10.28	1.71	2.73	1.36	79.30	16.61	1.77
2	13	Egg, crushed and washed	11.44	30.95	50.16	7.45	1.25	4.60	1.68	82.08	11.64	1.27
7	16	Lump and Egg crushed	.....	.....	.....	.....	.....	....	....	.....	.....	....
10	16	Lump and Egg crushed and washed	9.79	30.35	51.79	8.07	1.09	2,14	1.46	83.96	12.44	1.02
11	19A	¾ in. crushed	14.91	26.66	49.50	8.93	.52	....	....	.....	.....	....
15	19A	"	14.91	26.66	49.50	8.93	.52	....	....	.....	.....	....
19	19B	3 in. Lump crushed	10.72	29.86	50.06	9.36	.91	....	....	.....	.....	....
106	20	Screenings crushed	17.04	32.59	40.77	9.60	3.23	0.57	.66	82.49	16.28	3.01
107	20	Screenings crushed and washed	14.36	34.61	42.63	8.40	3.23	0.53	.29	84.87	14.31	2.73
126	21	Lump crushed	13.37	31.17	43.15	12.31	1.46	....	....	.....	.....	....
127	21	Lump crushed and washed	17 45	30.01	44.24	7.80	1.10	....	....	.....	.....	....
117	22B	Screened Lump and Nut, crushed	11.98	33.87	37.72	16.43	4.74	.98	.72	72.18	26.12	4.61
118	22B	Screened Lump and Nut, crushed and washed	16.19	34.14	39.53	10.14	3.79	.65	1.60	80.76	16.99	3.65
111	23A	Lump crushed	13.74	36.47	41.01	8.78	3.57	.66	.74	83.45	15.15	3.09
112	23B	Slack	15.85	35.02	40.57	8.56	3.27	.96	1.14	82.66	15.24	2.87
114	23B	Slack	15.93	35.88	40.16	8.03	3.25	1.36	1.19	82.83	14.62	2.84
119	24A	Screenings	13.28	29.93	39.03	17.76	4.05	....	....	.....	.....	....
155	24A	Screenings crushed, washed	15.18	32.13	43.46	9.23	3.07	....	....	.....	.....	....
145	24B	Lump, crushed and washed	8.93	35.22	46.29	9.56	3.41	5.62	1.46	79.01	13.73	2.97
120	25A	Run of mine	12.96	33.01	39.60	14.43	4.09	....	....	.....	.....	....
140	25A	Run-of-mine crushed and washed	13.40	33.83	43.66	9.11	2.99	2.71	4.67	77.69	14.93	2,32
143	26	Run-of-mine washed and crushed	15.18	33.46	41.53	9.83	2.73	5.27	3.36	75.98	15.40	2,80
144	27	Run-of-mine crushed and washed	16.39	34.26	41.57	7.78	3.22	3.51	1.55	81.14	13.80	3.40
166	28C	Lump crushed and washed	9.37	30.38	53.36	6.89	1.09	2.82	.60	86.12	10.46	.98
169	29A	Screenings crushed and washed	15.63	33.88	42.81	7.68	3.13	.72	.90	84.62	13.76	2.57
170	29A	"	18.39	32.87	41.53	7.21	3.06	2.78	.74	83.35	13.13	2.49
190	34B	Run-of-mine crushed and washed	9.91	33.33	50.65	6.11	1.75	.19	.35	87.91	11.55	1.48

TABLE 6 COKING TESTS (*Continued*)

Test No.	U. S. G. S. No.	Coal Charged pounds	Coke Produced per cent	Breeze Produced per cent	Total Yield per cent	REMARKS
1	2	14	15	16	17	18
10	1	9000	0	0	0	No valuable coke produced
9	2	9000	37.6	3.9	41.5	Poor dark colored coke
29	3	9000	0	0	0	No coke produced
28	3	13000	49.0	6.4	55.4	Comparatively good, light colored coke; brittle and friable
45	5	8000	0	0	0	No coke produced
59	5	5000	0	0	0	"
60	5	9000	0	0	0	"
1	7D	8000	48.84	5.65	54.49	Good hard coke; sulphur and ash too high
4	7D	8000	52.00	2.60	54.60	Good strong, light colored coke; sulphur too high
5	11D	10000	54.00	3.00	57.00	Good strong, light colored coke
3	13	12000	44.65	11.06	55.71	Dull colored, comparatively soft coke
2	13	10000	46.00	7.18	53.18	Good hard coke
7	16	....	.....	.....	.....	Test discontinued on account of accident
10	16	10000	55.79	9.10	64.89	Dull gray colored; poor coke physically
11	19A	10000	0	0	0	No coke produced
15	19A	6000	0	0	0	"
19	19B	6000	0	0	0	"
106	20	10000	42.55	6.28	48.83	Poor, dull gray coke
107	20	10000	46.59	3.98	50.57	Dull gray coke. Slightly better phys cally than coke from unwashed coal
126	21	12000	0	0	0	No coke produced
127	21	11690	0	0	0	"
117	22B	10000	50.46	5.34	55.80	Poor, dull gray coke
118	22B	12000	46.80	4.78	51.58	Light colored, comparatively good coke
111	23A	10000	42.11	3.47	45.58	Good, light colored, heavy coke
112	23B	10000	44.07	3.89	47.96	" "
114	23B	14000	46.02	4.29	50.31	Fairly good, light colored coke
119	24A	10000	0	0	0	No coke produced
155	24A	11410	0	0	0	"
145	24B	11830	39.81	11.41	51.22	Poor, soft, dense, coke
120	25A	10000	0	0	0	No coke produced
140	25A	11830	45.27	6.00	51.27	Poor, soft dense, dull colored coke
143	26	11750	49.79	10.64	60.43	Dense, soft, coke
144	27	11550	43.87	3.51	47.38	"
166	28C	12600	50.40	5.25	55.65	Poor dense, dark colored, soft coke
169	29A	12010	41.22	5.70	46.92	Poor dense, coke
170	29A	11680	42.38	2.89	45.27	"
190	34A	12980	50.25	2.43	52.68	Good light colored coke

properties of the coke produced is given in Column 18.

In reviewing the results of the tests as set forth in Table 6, it should be remembered that the necessary routine work involved in the testing of so many coals made it possible to make but few tests on each coal. The data presented, therefore, show the results obtained under conditions which of necessity had to be controlled by observations made from time to time as the coking proceeded, a procedure which tended to make the conditions of operations by no means ideal.

Of the 37 tests made with Illinois coal 9 resulted in the production of comparatively good coke and 14 in the production of a poor grade of coke. The remaining 14 samples apparently proved to be non-coking coals. Referring to the approximate analyses of the coke produced it will be seen that in a number of cases the quality of the coke is by no means inferior, though in all cases the ash and sulphur content is slightly greater than is desirable. Seven samples (11D washed, 13, 13 washed, 16, 22B washed, and 29 washed) were successfully used in a foundry cupola.

VII Steaming Tests

15. *The apparatus comprising the plant for steaming tests* consisted of two standard Heine water-tube boilers equipped with hand-fired furnaces and an Allis–Chalmers Corliss engine operating a 200 kilowatt Bullock generator. A plan and elevation of one of the boilers and its setting are shown in Fig. 5 and the general appearance as set up in the laboratory in Fig. 6.

The equipment used for testing the boilers provided convenient and accurate means for measuring the coal and water and for making all observations of pressure, temperature, etc., specified in the boiler testing code of the American Society of Mechanical Engineers. It consisted principally of water-weighing tanks, scales, charging cars, sampling cans, apparatus for analyzing flue gases, pressure gages, calorimeters, thermometers and draft gages*.

* This apparatus is described in detail in "Professional Paper No. 48" United States Geological Survey.

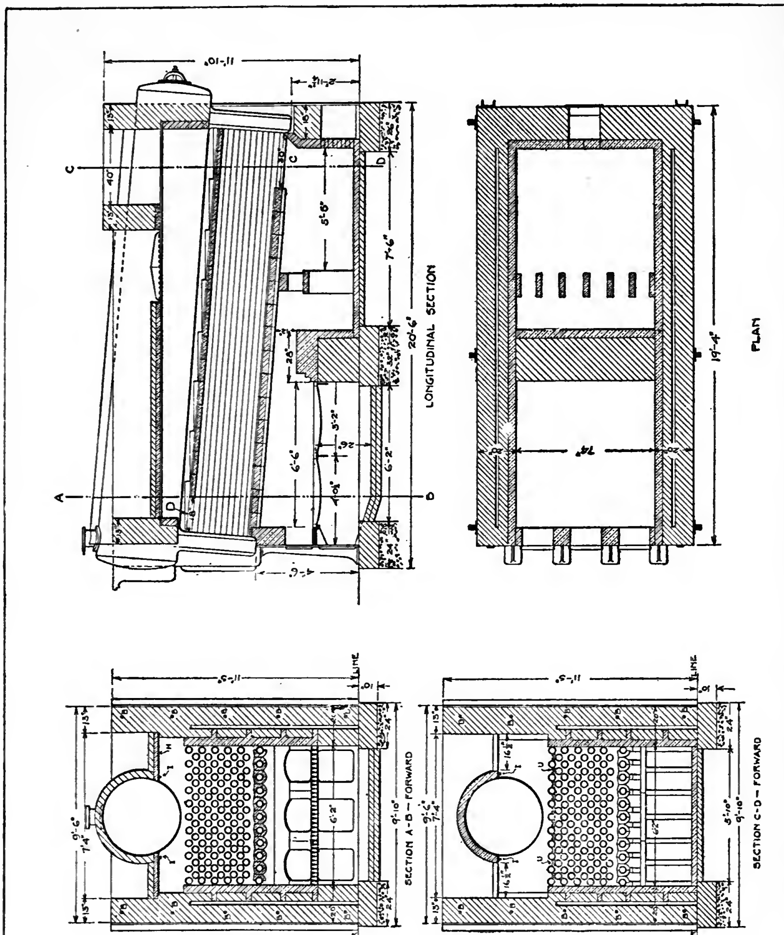


Fig. 5 Plan and Elevation of Boiler and Setting (Professional Paper 48, p. 307)

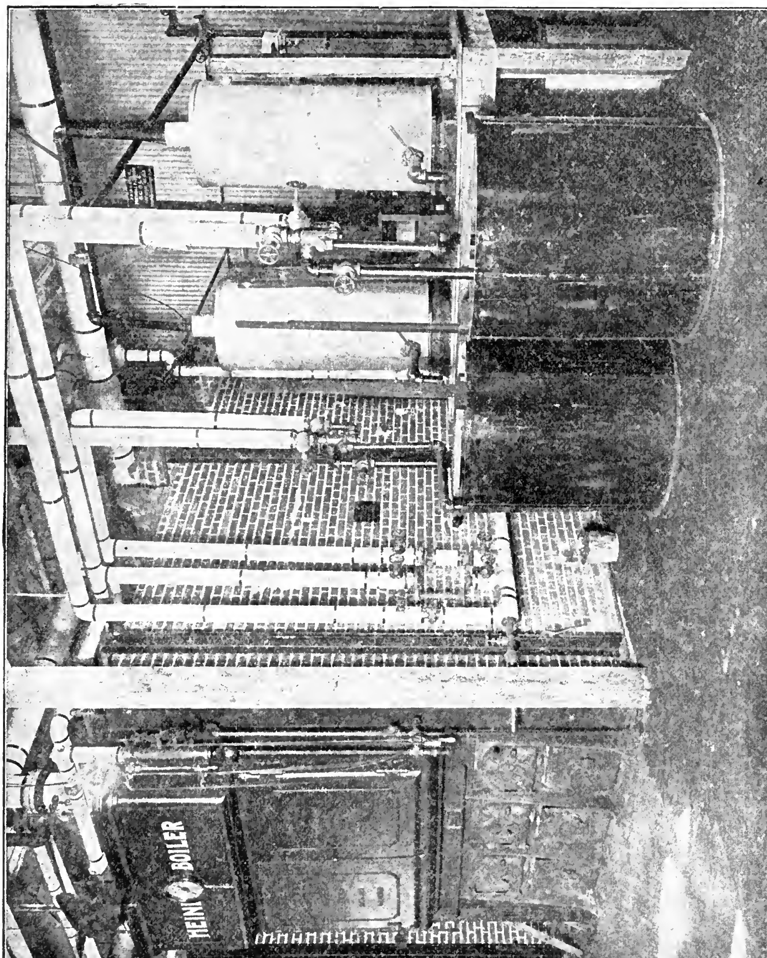


FIG. 6 EXPERIMENTAL BOILER AND TANKS FOR WEIGHING FEED WATER
(PROF. PAPER 48, p. 304 "B")

The principal dimensions of the boiler and furnace are as follows:—

Length of drum	feet	21.58
Inside diameter of drum	inches	42.
Number of tubes, 11 tubes high by 11 tubes wide		116
Outside diameter of tubes	inches	3.5
Width of furnace	feet	6.16
Length of furnace	feet	6.58
Mean height of furnace	inches	26.00
Grate area	square feet	40.55
Ratio of grate area to air space		40.17
Water-heating surface in tubes	square feet	1897
Water-heating surface in water legs	square feet	91
Water-heating surface in shell	square feet	43
Total water-heating surface	square feet	2031
Ratio of heating surface to grate area		50.1

16. *The Tests.* Since the establishment of the fuel testing division of the United States Geological Survey, more than 500 boiler trials have been made, and of these, 112 involved the use of Illinois coal. Tests were made with each of the 34 samples submitted, the coal being used either in its natural state or in the form of briquets, or both. A number of tests were also made with washed coal.

A summary of the principal observed and derived results of tests with Illinois coals is given in Tables 7 and 8. In these tables only such values as have a direct relation to boiler performance are included; additional data, however, may be found in the reports published by the United States Geological Survey.*

17. *The description of the coal tested* given in Table 7, Column 1, of this table is the serial number of the test and is useful as a means of identification. The number describing the location from which the sample was taken, is given in Column 2 and the number of the coal bed or seam, in Column 3. The size of the coal is given

* Bulletin No. 332 and Professional Paper No. 48.

in Columns 4 to 9. The size as shipped (Column 9) was not always the same as that used in the tests since in some cases it was crushed or screened after it was received. The actual size as determined from samples taken during each test is given in precise terms in Columns 5, 6, 7 and 8, and the average diameter calculated from these data is given in Column 9. The proximate analyses (Columns 10 to 14) were made from samples collected for each test and are given in the tables in terms of coal as fired. Calorific values were not determined for every test. The values given (Column 15) were calculated from the proximate analysis and the calorific value determined from the car sample, on the assumption that the B. t. u. per pound of pure coal (ash and moisture free) is the same for each car load shipped to the testing plant.

18. *The performance of the boiler and furnace* is given in Table 8. Column 17 gives the average boiler pressure in pounds per square inch. The standard pressure was 75 but it will be seen that the values given vary from 68 to 81. The draft above the fire (Column 18) was measured in inches of water. In some tests it was as great as .3 inch; the average however, is a little less than .2 inch.

The furnace temperature (Column 19) was observed with a Wanner optical pyrometer. The results given are averages of a number of readings which varied over a considerable range throughout the test. The lowest temperature recorded is 1887° and the highest 2829° F.

The rate of combustion in terms of dry coal fired per hour, per square foot of grate surface (Column 20) is, for most tests, about 25 pounds. This rate, it will be seen, is sufficient to evaporate, in most cases 5½ pounds of water from and at 212° F. per square foot of heating surface per hour (Column 21) or 100 per cent of the rated horse-power (Column 22).

The evaporative efficiency is given in Columns 23, 24 and 25. In Columns 23 and 24 the equivalent evaporation per pound of coal as fired and per pound of dry coal, respectively, is given. The values given in Column 25 represent the over-all efficiency, that is, the ratio of the heat absorbed by the water in the boiler to the potential heat in the coal fed to the furnace. It is evident, therefore, that this is the best measure of the value of any particular fuel for steam generation since it expresses the exact proportion of heat purchased in the form of coal which can be converted into useful energy in the form of steam. Referring to the

TABLE 7 STEAMING TESTS—DESCRIPTION OF COAL

Test No.	U. S. G. S. No.	Coal Bed or Seam	Size of Coal as Shipped	Size of Coal per cent				Average Diameter of Coal, inches	Proximate Analysis of Coal as Fired per cent				Per cent of Sulphur in Coal	Heating value B. t. u. per Pound of Dry Coal
				Over 1 inch	⅜ to 1 inch	¼ to ⅜ inch	Under ¼ inch		Moisture	Volatile Matter	Fixed Carbon	Ash		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
18	1	6	....	....	60.	40.	....	....	9.64	36.91	38.21	15.19	5.86	11855
19	2	6	....	....	20.	80.	....	....	10.45	37.77	41.72	10.06	3.75	12569
38	3	7	....	....	50.	50.	....	....	8.51	31.19	48.75	11.55	1.64	12857
48	4	7	....	....	90.	10.	....	....	13.47	33.48	41.59	11.45	1.48	12427
50	4	7	....	....	60.	40.	....	....	12.58	32.44	43.63	11.35	1.55	12459
73	6	5	....	....	60.	40.	....	....	13.19	32.31	39.62	14.88	4.01	11594
106	6B	5	Run of Mine, washed	4.7	19.3	21.5	54.5	.42	15.33	33.76	42.18	8.73	3.12	12762
313	6B	5	Briquets	....	....	....	....	....	13.80	31.54	42.86	11.80	3.61	12028
314	6B	5	"	....	....	....	....	....	13.21	31.96	42.12	2.71	3.70	12101
122	7C	6	Slack	....	12.8	18.3	68.9	.30	10.54	31.18	32.98	25.30	4.18	9999
129	7C	6	Slack, washed	....	10.5	25.5	64 0	.31	16.45	34.43	40.18	8.94	3.22	12730
142	7D	6	Run of Mine	33.5	23.3	15.0	28.2	.82	10.38	34.33	39.08	16.21	4.28	11673
143	7D	6	"	32.1	22.0	15.6	30.3	.79	10.29	32.34	38.95	18.42	4.66	11212
146	7D	6	"	24.3	23.3	18.1	34.3	.70	10.29	32.16	38.35	19.20	5.01	11088
516	7E	6	Screened nut	4.8	24.7	25.1	45.4	.47	14.47	28.14	35.16	22.23	3.73	10283
101	8	6	Nut	58.0	21.9	8.7	11.4	1.12	13.31	34.61	39.39	12.69	5.16	12047
102	8	6	"	50.4	25.5	10.6	13.5	1.05	12.67	34.23	40.00	13.10	4.68	12002
103	9A	6	Run-of-Mine	....	....	....	....	....	12.76	36.12	40.78	10.34	3.94	12506
104	9A	6	"	....	....	....	....	....	12.21	36.38	40.27	11.14	3.89	12483
105	9A	6	"	33.3	26.0	15.8	24.9	.83	12.10	36.23	41.05	10.62	4.08	12555
113	9A	6	Run-of-Mine, washed	24.6	27.8	20.4	27.2	.74	14.66	36.71	41.19	7.44	3.34	12947
121	9B	6	Lump	35.7	29.1	15.0	20.2	.89	10.70	35.84	41.82	11.64	4.11	12438
492	9C	6	Briquets	....	....	....	....	....	14.62	32.38	39.13	13.87	3.51	12037
107	10	7	Slack	2.9	23.1	26.4	47.6	.44	11.62	30.59	44.93	12.86	1.45	12429
108	10	7	"	7.6	19.2	21.1	52.1	.45	9.29	31.24	47.84	11.63	1.44	12685
109	10	7	"	22.8	30.1	17.3	29.8	.73	10.32	30.01	46.27	13.40	1.46	12373
110	10	7	"	19.2	22.6	18.4	29.8	.70	9.29	32.54	48.11	10.06	1.40	12929
114	10	7	Slack, washed	12.8	27.5	23.4	36.3	.60	11.67	32.37	49.87	6.09	1.22	13545
137	11A	7	Screenings	21.2	23.6	18.2	37.0	.66	7.84	28.08	51.54	12.54	2.35	12348
138	11A	7	"	17.4	21.9	15.6	45.0	.59	7.66	29.76	48.65	13.93	2.16	12159
139	11A	7	"	17.3	19.1	15.8	47.8	.57	7.54	30.09	49.31	13.06	2.57	12254
141	11A	7	"	20.4	25.3	18.5	35.8	.66	7.65	30.06	50.50	11.79	2.09	12505
111	11B	7	Run-of-Mine	39.4	25.2	14.5	20.9	.91	8.17	31.53	48.21	12.09	2.82	12643

TABLE 7 STEAMING TESTS—DESCRIPTION OF COAL (*Continued*)

Test No.	U. S. G. S. No.	Coal Bed or Seam	Size of Coal as Shipped	Size of Coal per cent: Over 1 inch	½ to 1 inch	¼ to ½ inch	Under ¼ inch	Average Diameter of Coal, inches	Proximate Analysis of Coal as Fired per cent: Moisture	Volatile Matter	Fixed Carbon	Ash	Per cent of Sulphur in Coal	Heating Value B. t. u. per Pound of Dry Coal
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
112	11B	7	Run-of-Mine	28.9	21.3	17.8	32.0	.75	8.93	30.73	48.21	12.13	2.33	12775
115	11B	7	"	24.6	24.0	18.2	33.2	.71	8.85	28.12	48.08	14.95	2.24	12321
116	11B	7	"	40.1	21.6	15.2	23.1	.90	7.29	31.34	50.07	11.30	2.50	12933
117	11B	7	Lump	33 6	24.8	16.3	25.3	.83	6.69	32.95	47.59	12.77	3.47	12537
118	11B	7	"	20.4	18.2	17.4	44.0	.61	6.16	33.21	48.91	11.72	3.14	12801
119	11B	7	"	27.6	24.5	18.3	29.6	.76	6.43	32.23	50.58	10.76	2.22	13079
120	11C	7	¾ to 5-16 in	....	16.4	45.8	37.8	.40	9.14	31.03	52.33	7.50	1.64	13370
312	11C	7	Briquets	....	....	....	....	....	9.54	31.60	50.92	7.94	1.92	13361
127	12	7	Run-of-Mine	30.8	26.5	17.1	25.6	.81	8.49	31.04	45.25	15.22	3.79	11963
128	12	7	"	46.4	21.2	12.3	20.1	.97	7.93	31.85	46.18	14.04	3.92	12154
131	12	7	"	23.8	18.1	16.6	41.5	.65	9.54	29.52	43.97	16.97	4.18	11709
133	12	7	"	26.4	24.3	17.9	31.4	.74	8.79	30.70	44.97	15.61	4.14	11849
135	12	7	Run-of-Mine, washed	22.5	28.6	24.1	24.8	.74	10.19	33.30	47.27	9.24	2.58	13104
136	12	7	" "	15.3	22.9	20.8	41.0	.59	10.39	29.39	44.64	15.58	3.56	11867
463	12B	7	Briquets	....	....	....	....	....	6.99	32.36	50.24	10.41	2.41	12859
132	13	7	1½ to 6 in	31.0	22.6	15.0	31.4	.77	9.95	30.22	47.73	12.10	1.32	12528
134	13	7	"	23.8	23.8	20.8	31.6	.71	9.64	30.50	48.81	11.05	1.59	12667
144	13	7	½ to 6 in., washed	30.0	27.2	19.0	23.8	.81	9.67	32.59	50.18	7.56	1.30	13261
145	13	7	" "	25.2	18.7	20.1	36.0	.69	10.60	31.38	50.84	7.18	1.34	13306
123	14	5	Lump	23.3	27.9	19.6	29.2	.72	11.65	34.67	40.12	13.56	4.62	12008
125	14	5	"	30.4	25.2	17.7	26.7	.79	12.61	33.60	41.30	13.49	4.13	12125
130	14	5	"	21.4	27.7	25 0	25.9	.72	15.83	33.50	41.38	9.29	3.24	12731
126	15	6	"	20.5	25.9	21.1	32.5	.68	10.00	33.39	41.20	15.41	4.36	11749
152	15	6	Lump	25.5	31.3	21.8	21.4	.78	11.81	37.09	51.04	8.41	3.00	13104
150	16	7	Lump and egg	48.1	21.0	12.3	18.6	.99	9.16	29.57	41.73	10.23	1.76	12874
140	18	2	Lump	37.3	22.2	15.9	24.6	.86	11.72	37.27	42.00	9.28	4.07	12951
147	18	2	Lump, washed	9.5	25.5	29.6	35.4	.55	14.99	37.24	42.14	5.63	2.98	13554
148	18	2	Lump	27.1	25.7	17.9	29.3	.75	11.10	37.11	42.00	9.79	3.37	12991
149	18	2	Lump, washed	21.7	22.7	28.8	26.8	.70	16.61	36.13	41.51	5.27	2.72	13432
160	19A	7	¾ in. Nut	....	21.3	32.0	46.7	.39	12.79	27.24	51.73	8.24	.49	13036
161	19A	7	"	....	13.6	27.2	59.2	.33	13.43	27.60	50.08	8.89	.50	12911
163	19A	7	"	....	17.7	34.7	47.6	.38	12.86	28.30	50.80	8.04	.51	13068
170	19A	7	"	....	13.6	31.3	55.1	.34	13.28	27.72	49.75	9.25	.50	12857

171	19A	7	"	....	13.6	31.8	54.6	.34	13.19	27.56	50.83	8.92	.50	12917
175	19B	7	3 in. Lump	60.2	15.7	9.2	14.9	1.10	10.72	29.77	49.30	10.21	.47	13005
204	19B	7	"	44.0	17.2	12.3	26.5	.91	9.56	29.40	51.11	9.93	.61	13050
205	19B	7	"	54.4	15.1	10.7	19.8	1.03	10.30	29.20	50.27	10.23	.55	13001
420	19C	7	Run-of-Mine	20.2	24.2	19.1	36.5	.66	8.72	28.41	50.58	12.29	.63	12431
423	19C	7	"	15.8	19.5	18.3	46.4	.57	9.42	28.05	50.72	11.81	.61	12496
424	19D	7	Lump	23.9	24.5	18.7	32.9	.71	8.45	29.65	50.24	11.66	.53	12416
425	19D	7	"	37.9	27.4	15.0	19.7	.91	8.51	30.27	49.85	11.37	.51	12460
421	19E	7	1½ in. Nut	18.0	45.9	16.6	19.5	.78	9.22	29.28	50.25	11.25	.59	12454
422	19E	7	"	14.4	44.0	17.8	23.8	.72	9.75	28.45	50.67	11.13	.61	15578
292	20	6	Screenings, washed	20.1	22.9	18.7	38.3	.64	14.52	31.98	38.01	15.49	4.32	11425
301	20	6	" "	17.1	27.7	23.7	31.5	.66	16.51	32.17	40.87	10.45	3.25	12506
302	20	6	" "	22.5	28.1	21.9	27.5	.73	16.36	33.54	39.84	10.26	3.22	12548
315	21	6	Lump	34.0	21.3	18.1	26.6	.81	14.95	30.33	40.96	13.76	1.60	11945
316	21	6	"	33.6	20.6	16.2	29.6	.80	15.07	30.78	41.90	12.25	1.27	12240
318	21	6	"	....	....	*	*	*	17.31	30.40	42.28	10.01	1.28	12469
324	22A	6	Lump	84.6	5.8	3.5	6.1	3.46	11.50	33.44	39.27	15.79	6.24	11484
325	22A	6	"	87.4	5.4	2.6	4.6	3.56	10.53	35.63	40.04	13.80	6.07	11876
328	22A	6	Lump, washed	34.1	27.0	22.0	16.9	.87	14.35	36.86	40.57	8.22	3.75	12924
306	23A	6	Lump	37.3	19.5	16.2	27.0	.85	14.49	32.37	39.69	13.45	4.62	11759
317	23A	6	Lump, washed	18.9	26.7	24.3	30.1	.68	14.64	35.72	40.76	8.88	3.23	12794
321	23B	6	Slack	....	†	†	†	†	13.54	36.38	41.67	8.41	3.21	12996
322	23B	6	"	....	†	†	†	†	13.54	36.38	41.67	8.41	3.21	12996
335	24B	6	Lump	49.7	19.9	12.4	18.0	1.00	12.14	33.71	42.48	11.67	4.53	12245
336	24B	6	"	22.1	25.2	19.6	33.1	.69	12.60	34.40	43.13	9.87	3.83	12623
337	24B	6	"	92.0	3.2	1.6	3.2	1.88	13.52	32.84	43.17	10.47	3.97	12474
338	25A & B	6	Lump and Run-of-mine	61.4	14.3	9.1	15.2	1.99	12.28	35.52	40.53	11.67	3.57	12519
339	25A & B	6	" "	82.4	7.2	4.0	6.4	2.17	11.53	34.93	39.75	13.79	4.89	12022
341	26	5	Run-of-mine	78.5	8.9	4.4	8.2	2.17	13.55	33.11	40.24	13.10	4.45	12029
342	26	5	"	78.1	9.2	5.8	6.9	2.59	15.68	32.41	39.82	12.09	3.51	12260
353	27	6	"	72.4	11.1	6.8	9.7	2.29	16.00	32.41	37.82	13.77	4.05	11831
354	27	6	"	34.6	25.7	17.6	22.1	.93	15.82	32.50	37.73	13.95	4.80	11713
459	28A	7	Screenings, washed	....	....	*	*	....	7.32	30.72	49.84	12.12	1.29	12557
457	28B	7	Screenings	....	....	*	*	....	5.81	30.86	52.41	10.92	2.03	12839
448	28C	7	Lump	32.3	21.1	13.7	31.9	.79	4.82	30.81	53.82	10.55	1.47	12920
452	28C	7	"	58.4	21.3	9.0	11.3	1.12	7.02	29.93	53.51	9.54	1.18	13070
495	29A	5	Screenings	....	....	*	....	....	14.23	34.63	43.96	7.18	2.84	13120
460	29B	5	Run-of-mine	34.1	21.5	13.2	31.2	.81	11.09	33.68	41.17	14.06	4.63	11945
461	29B	5	"	51.4	22.4	10.7	15.5	1.04	12.41	35.42	42.15	10.02	3.51	12728
466	29B	5	"	....	....	*	....	....	10.00	36.33	43.01	10.66	3.24	12762
511	30	7	Nut	....	....	*	....	....	9.75	39.25	42.69	8.31	3.21	13271
489	31	6	Screenings	....	....	*	...	....	14.52	33.74	39.40	12.34	3.36	12303
491	31	6	"	....	....	*	....	....	10.81	33.72	42.74	12.73	3.50	12335
513	33	7	"	...	....	*	....	....	11.50	25.44	42.37	20.69	1.52	11099
509	34B	5	Run-of-mine	44.3	22.8	13.4	19.5	1.23	6.56	34.15	51.57	7.72	2.17	13621

*Briquets. †Briquets broken.

TABLE 8 Steaming Tests—Performance of Boiler and Furnace

Test No.	Boiler Pressure lb. per sq. in.	Draft above Fire inches of Water	Temperature of Furnace Degrees F.	Dry Coal per sq. ft. of Grate Surface Per Hour, pounds	Equivalent Evaporation from and at 212° F. per sq. ft. of Heating Surface Per Hour, pounds	Per Cent of Rated Horsepower Developed	Equivalent Pounds of Water Evaporated from and at 212° F. Per Pound: Of Coal as Fired	Of Dry Coal	Efficiency of Boiler Including the Grate Per Cent	Dry Coal Per Electrical Horsepower Hour, pounds
1	16	17	18	19	20	21	22	23	24	25
18	....	.18	1887	24.90	3.59	100.7	6.51	7.21	58.73	4.85
19	....	.15	....	22.36	3.57	100.1	7.16	8.00	61.47	4.38
38	....	.21	....	21.23	3.41	95.5	7.35	8.04	60.39	4.34
48	...	.16	...	19.84	2.92	81.9	6.38	7.34	57.27	4.73
50	....	.21	....	23.13	3.36	94.2	6.36	7.27	56.36	4.80
73	....	.23	....	22.34	3.30	92.5	6.43	7.40	61.64	4.72
106	75	.25	2213	25.94	3.39	95.3	5.56	6.56	49.64	5.32
313	72	.17	....	17.24	2.81	78.7	7.03	8.16	65.51	....
314	68	.07	2359	24.81	3.42	95.9	5.99	6.91	55.14	....
122	72	.30	....	20.08	2.19	61.4	5.44	6.08	58.71	5.74
129	73	.24	....	19.92	3.19	89.6	6.70	8.02	60.84	4.36
142	81	.16	....	20.07	2.97	83.3	6.65	7.44	61.39	4.70
143	79	.18	....	18.74	2.69	75.5	6.46	7.20	62.01	4.85
146	67	.22	....	20.21	2.68	75.2	6.64	7.40	64.45	4.72
516	79	.13	....	31.99	3.70	103.7	4.95	5.79	54.38	6.03
101	83.5	.32	....	28.82	3.21	90.1	5.39	6.22	49.86	5.61
102	78	.25	....	38.36	3.62	101.5	5.58	6.39	51.41	5.46
103	81	.27	2218	26.53	3.61	101.1	5.94	6.81	52.59	5.13
104	80	.19	2155	23.22	3.01	84.4	5.70	6.50	50.28	5.37
105	78	.25	2220	30.26	4.08	114.3	5.93	6.75	51.92	5.17
113	75	.20	....	25.60	3.05	85.6	5.68	6.66	49.67	5.24
121	75	.19	....	26.60	3.57	100.0	6.69	7.49	58.15	4.66
492	76.5	.16	....	22.52	3.50	98.2	6.65	7.79	62.50	4.48
107	76	.32	2229	21.00	3.20	89.9	6.76	7.65	59.44	4.56
108	76	.21	....	22.24	3.13	87.6	6.39	7.04	53.60	4.96
109	78	.29	....	21.46	2.96	83.0	6.90	7.70	60.10	4.53
110	75	.26	....	20.66	2.48	69.6	6.08	6.71	50.12	5.20
114	75	.21	....	24.23	3.52	98.7	7.16	8.11	57.82	4.30
137	74	.16	....	20.98	3.17	88.8	7.76	8.42	64.51	4.14
138	74	.18	2376	19.94	2.97	83.4	7.68	8.32	66.08	4.20
139	77	.18	2435	19.70	3.06	85.9	8.02	8.67	68.33	4.03
141	79	.15	....	18.81	3.11	87.3	7.66	8 29	64.02	4.21
111	73.5	.28	....	24.35	2.93	82.0	6.15	6.70	51.18	5.21
112	80	.27	...	22.36	2.90	81.2	6.59	7.23	54.65	4.83
115	76	.26	....	22.89	3.42	95.9	6.83	7.49	58.71	4.66
116	76	.22	....	24.19	3.61	101.3	6.94	7.48	55.85	4.67
117	75.5	.20	....	23.80	3.42	95.8	6.71	7.19	55.38	4.85
118	77	.16	....	23.16	3.32	93.1	6.74	7.19	54.26	4 85
119	75	.25	....	25.70	3.75	105.0	6.84	7.31	53.97	4.78
120	72	.23	....	25.41	3.55	99.5	7.08	7.79	56.27	4.48
312	71	.11	2400	19.38	3.40	95.4	7.96	8.80	63.60	....
127	73	.19	....	21.49	3 35	94.0	7.15	7.81	63.04	4.50
128	75	.19	....	21.45	3.51	98.3	7.54	8.19	65.07	4.26
131	74	.19	....	20.87	2.91	81.50	7.04	7.74	64.08	4.49
133	81	.22	....	22.91	3.15	88.2	7.00	7.67	62.51	4.55
135	74	.18	....	23.09	3.62	101.3	7.86	8.75	64.48	3.99
136	75	.21	....	20.77	2.91	81.5	7.00	7.81	63.56	4.47
463	81	.11	2490	18.67	3.20	89.7	7.98	8.58	64.44	4.07
132	76	.13	....	22.06	3.37	94.5	7.67	8.52	65.67	4.10
134	78	.18	....	22.55	3.39	95.0	7.58	8.39	63.96	4.16
144	79	.10	....	20.42	3.70	103.8	8.20	9.08	66.12	3.84
145	75	.13	....	20.14	3.38	94.7	8.37	9.36	67.93	3.73
123	73	.28	....	23.60	3.10	87.0	6.49	7.34	59.03	4.76
125	74	.20	....	20.30	3.08	86.2	6.62	7.58	60.37	4.61
130	77	.14	....	21.63	3.33	93.3	6.49	7.71	58.48	4.53
126	69	.18	....	20.44	3.11	87.2	6.86	7.62	62.62	4.58

TABLE 8 STEAMING TESTS—PERFORMANCE OF BOILER AND FURNACE (*Continued*)

Test No.	Boiler Pressure lb. per sq. in.	Draft above Fire inches of Water	Temperature of Furnace Degrees F.	Dry Coal per sq. ft. of Grate Surface per hour, pounds	Equivalent Evaporation from and at 212° F. per sq. ft. of Heating Surface Per Hour, pounds	Per Cent of Rated Horsepower Developed	Equivalent Pounds of Water Evaporated from and at 212° F Per Pound: Of Coal as Fired	Equivalent Pounds of Water Evaporated from and at 212° F Per Pound: Of Dry Coal	Efficiency of Boiler Including the Grate Per Cent	Dry Coal Per Electrical Horsepower Hour, pounds
1	16	17	18	19	20	21	22	23	24	25
152	75	.13	2439	19.63	3.36	94.3	7.57	8.59	63.30	4.06
150	74	.11	....	19.63	3.56	99.8	8.24	9.08	68.11	3.85
140	75	.18	....	18.51	2.86	80.1	7.60	8.61	64.20	4.06
147	72	.17	....	19.53	3.12	87.4	7.57	8.91	63.48	3.92
148	73	.19	....	18.86	2.99	83.9	7.06	7.94	59.02	4.40
149	74	.14	2060	17.83	3.29	92.2	7.70	9.23	66.36	....
160	77	.14	2428	18.47	3.07	86.1	7.27	8.33	61.71	4.19
161	77	.20	2080	17.77	3.12	87.6	7.62	8.80	65.82	3.97
163	78	.17	2227	20.79	3.57	100.2	7.50	8.61	63.63	4.06
170	79	.16	2039	20.22	3.10	87.0	7.42	8.56	64.29	4.08
171	77	.17	....	20.08	3.23	90.6	7.79	8.97	67.06	3.89
175	74	.09	2470	20.54	3.73	104.7	8.13	9.10	67.50	3.84
204	72.5	.11	2447	20.69	3.50	98.2	8.54	9.45	69.93	3.70
205	71	.12	2448	20.38	3.38	94.9	8.32	9.27	68.86	3.77
420	79.5	.12	....	19.95	3.35	93.9	7.67	8.40	65.26	4.16
423	78.5	.14	....	16.94	2.89	81.0	7.73	8.53	65.92	4.09
424	83.5	.12	....	18.67	3.18	89.1	7.81	8.53	66.35	4.09
425	81	.14	....	19.33	3.32	93.0	7.87	8.61	66.73	4.05
421	82	.11	....	19.46	3.30	92.5	7.70	8.48	65.76	4.12
422	78.5	.12	....	19.46	3.39	95.0	7.88	8.73	67.03	4.00
292	70.5	.10	2020	15.49	2.37	66.3	6.55	7.66	64.75	4.56
301	69	.30	....	24.61	3.54	99.3	6.71	8.04	62.08	4.34
302	76	.17	2708	25.69	3.81	106.7	6.91	8.27	63.65	4.22
315	74.5	.16	2499	20.05	3.27	91.6	6.94	8.16	65.97	4.28
316	69	.15	2401	20.05	3.19	89.3	6.76	7.96	62.80	4.39
318	69.5	.04	2508	25.30	4.11	115.3	6.73	8.14	63.04	4.29
324	71.5	.20	2850	23.08	3.60	100.9	6.91	7.81	65.67	4.47
325	72	.18	2828	22.61	3.60	101.0	7.14	7.97	64.81	4.38
328	71	.14	2829	26.73	4.34	121.8	6.97	8.14	60.82	4.29
306	67	.13	2402	18.50	3.01	84.3	6.97	8.15	66.93	4.29
317	70.5	.13	2397	19.63	3.23	90.4	7.02	8.23	62.12	4.24
321	70.0	.27	....	23.75	3.78	106.0	6.89	7.97	59.22	4.38
322	74.5	.16	....	24.54	3.80	106.6	6.71	7.76	57.66	4.50
335	74.5	.22	2708	20.49	3.30	92.6	7.09	8.07	63.68	4.33
336	73.5	.26	...	21.48	3.29	92.3	6.71	7.67	58.68	4.55
337	72	.20	....	23.63	3.82	107.0	7.00	8.10	62.71	4.31
338	71.5	.21	...	21.36	3.10	87.0	6.38	7.28	56.16	4.80
339	73	.21	....	23.63	3.54	99.1	6.63	7.50	60.25	4.66
341	76	.34	....	20.91	2.84	79.7	6.56	7.58	60.85	4 61
342	77	.30	2264	23.02	3.16	88.6	6.47	7.67	60.42	4.55
353	78	.18	2360	19.83	3.14	88.0	6.66	7.93	64.73	4.40
354	76	.17	2162	19.26	3.08	86.4	6.75	8.02	66.12	4.36
459	80	.15	2601	18.72	3.13	87.7	7.75	8.36	64.29	4.18
457	81	.16	2606	19.85	3.42	95.9	8.13	8.64	64.99	4.04
448	79	.17	2862	22.52	3.88	108.8	8.21	8.63	64.50	4.05
452	82.5	.14	2833	21.97	3.94	110.5	8.35	8.98	66.35	3.89
465	75.5	.15	2665	20.35	3.62	101.5	7.65	8.91	65.58	3.92
460	81.5	.18	2759	21.38	3.44	96.3	7.16	8.05	65.08	4.34
461	80.5	.18	2816	22.32	3.72	104.2	7.31	8.34	63.28	4.19
466	79.5	.16	2784	22.32	3.90	109.2	7.87	8.74	66.14	3.99
511	79.5	.19	....	20.94	3.59	100.7	7.76	8.60	62.58	4.06
489	74	.14	....	21.16	3.49	97.7	7.06	8.25	64.76	4.23
491	82	.20	....	21.65	3.56	100.0	7.35	8.24	64.51	4.24
513	82	.10	2465	26.41	3.23	90.7	5.43	6.13	53.34	5.69
509	82	.22	....	21.50	3.79	106.2	8.24	8.82	62.53	....

values given, it will be seen that but few fall below 55 per cent or above 65 per cent, the maximum and minimum efficiency recorded being 68.11 and 49.64 respectively.

In reviewing the results set forth in Tables 7 and 8 it should be remembered that they apply only to the performance of a hand-fired water-tube boiler of the Heine type and that any conclusions which may be drawn are thus limited. Had it been possible to provide a furnace especially adapted to the burning of each particular coal, the relative efficiency as established by the tests might have been slightly different. The results obtained, however, may be accepted as fairly indicative of the value of the coals tested. With this in view, then, it will be of more than ordinary interest to study the effect of the physical and chemical properties of the fuel upon the performance of the boiler and furnace as set forth in the tables.

19. *Furnace temperature.* It will be seen that while the results do not show any exact relation between efficiency, furnace temperature and rate of combustion, nevertheless they clearly indicate that as the rate of combustion increases, the temperature increases, but that efficiency is only slightly affected by change in combustion-chamber temperature. A comparison with values representing capacity (Column 22) shows that as the combustion chamber temperature increases the capacity is increased.

20. *The evaporative efficiency as affected by moisture in the coal* is not well defined by the results of the tests. While they seem to indicate that coals high in moisture generally give low efficiency it must be remembered that high moisture is often accompanied by high ash content or by poor mechanical structure, either of which properties has a more deleterious effect on efficiency than moisture. That this is true is emphasized by the fact that the heat required to evaporate the water in Illinois coal containing 15 per cent moisture is but little more than 1.5 per cent of its total calorific value.

21. *The effect of sulphur and ash upon evaporative efficiency.* Sulphur is an undesirable element in coal. It generally occurs in combination with iron, as pyrites, and in combination with calcium as gypsum. Of the two sulphur compounds, the former is generally contained in larger quantity in coal and is harmful because it increases the tendency of the coal to clinker. The clinkering is especially bad if the percentage of ash is small in proportion to the sulphur. In such coals the pyrites and the ash fuse and form a thin layer of solid clinker, which effectively stops the

passage of air through the grate, thus permitting the grate bars to become heated from the hot fuel bed just above. The heat warps the grate bars and the clinker has such corrosive action on the hot iron that destruction results in a short time. When such clinkering occurs, any attempt to slice the fire fails and only slow and very difficult cleaning of the fires will remove it. Most Illinois coals having a large sulphur content are also high in ash so that the injurious effect of sulphur is not so pronounced as in some other coals. In making the tests it was found that the use of steam served to prevent the clinker from melting into the grate when the ash and sulphur content is large.

Referring to Columns 13, 14, and 25 of Tables 7 and 8 the decrease in efficiency with increasing ash and sulphur will be readily seen. In Fig. 7, which shows this relation graphically, efficiency is plotted against per cent of ash plus sulphur based on dry coal, for all tests run with lump, egg and nut coal. Although many of the plotted points lie at a considerable distance from the average line, its position and direction are rather well defined. It shows that the efficiency drops from 66.5 per cent when the ash plus sulphur is 10 per cent to 55 per cent when ash plus sulphur is 30 per cent. For increases in ash and sulphur beyond 18 per cent the drop in efficiency is relatively rapid.

22. *The effect of size on evaporative efficiency.* The discussion in the preceding paragraph does not take into account the fact that size has much to do with the efficiency with which coal can be burned, and this is one of the chief reasons for the poor alignment of many of the points. The efficiency shown by the same tests together with those made with slack have therefore been plotted against size, expressed in per cent of coal under ¼-inch in diameter. The resulting relation is shown in Fig 8. Here, too, the points are widely scattered but the slope of the average line is fairly well fixed. Thus a coal giving an efficiency of 66 per cent when 10 per cent of it is under ¼-inch in diameter, will give an efficiency of only 62 per cent when 60 per cent of it is under ¼-inch in diameter.

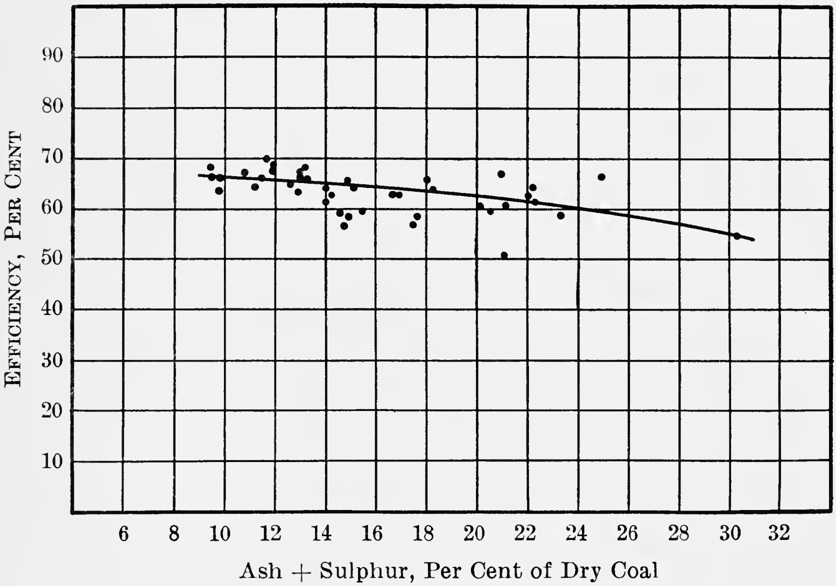


Fig. 7 Evaporative Efficiency as Affected by Ash and Sulphur

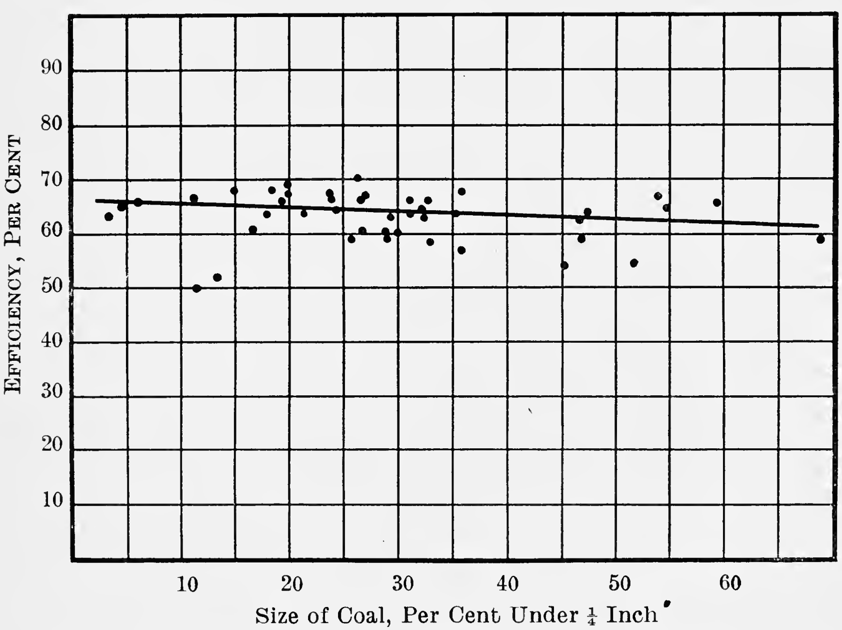


Fig. 8 Evaporative Efficiency as Affected by Size of Coal

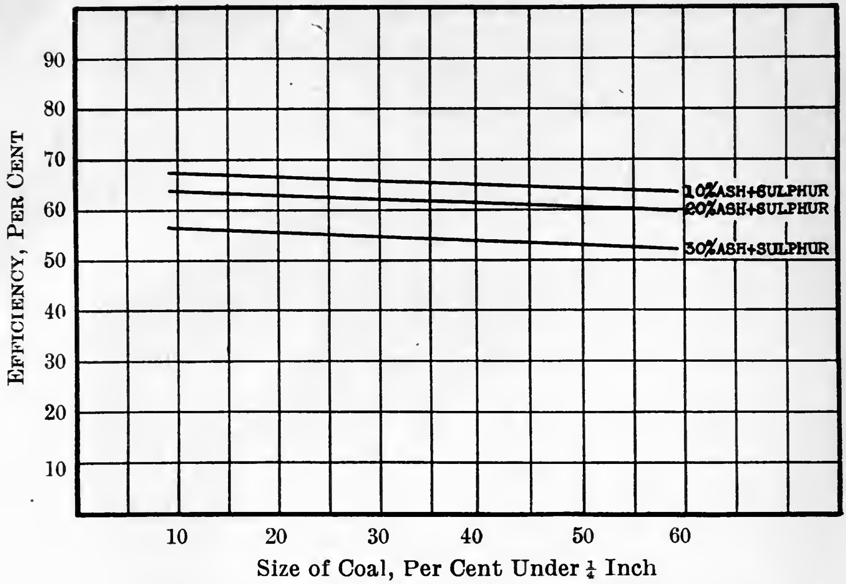


FIG. 9 COMBINED EFFECT OF SULPHUR PLUS ASH AND SIZE ON EVAPORATIVE EFFICIENCY

Fig. 9 has been drawn to show the combined effect of sulphur plus ash and size, on the evaporative efficiency of Illinois coal. In it lines have been drawn showing the decrease in efficiency with decrease in size for coals having 10, 20 and 30 per cent ash plus sulphur based on dry coal. There are, of course, other factors which affect efficiency but the results of the present tests seem to point to these as the most important. The lines given therefore, may be accepted as defining with considerable accuracy, the performance of Illinois coal when burned in a hand-fired furnace under a water-tube boiler.

23. *Comparative efficiency resulting from the use of washed and unwashed coal.*—It has been shown that the process of washing Illinois coal is effective in reducing the ash and sulphur content. That the evaporative efficiency of the coal thus treated is increased follows directly from the facts just developed. The extent of the

improvement is set forth by Table 9. In this table tests are grouped in the order of the size of coal used. A comparison of the average values given shows that where slack is used washing effects an increase of 4.2 per cent in evaporative efficiency, 2.3 per cent where nut is used, .7 per cent when run-of-mine is used and .6 per cent when lump is used. The extremely small gain for

TABLE 9

COMPARATIVE EFFICIENCY OF WASHED AND UNWASHED COAL

U. S. G. S. Coal No.	Size	Efficiency	
		Unwashed	Washed
1	2	3	4
1	Slack	58.73	61.47
7C	Slack	58 71	60.84
10	Slack	50,12	57.82
Average		55.85	60.04
9A	R. o. m.	50.28	49.67
12	R o. m.	62.51	64.48
Average		56.40	57.08
13	Nut	65.67	67.93
13	Nut	63.96	66.12
Average		64.68	67.02
23A	Lump	66.93	62.12
18	Lump	64.20	63 48
18	Lump	59.02	66.39
Average		63.38	64.00

the last two sizes named is explained by the fact that, in the process of washing, the coal was crushed to a size under 2 inches, a size which has been shown not to be so well adapted to the kind of grate and furnace used as the larger size.

24. *Comparison of efficiency resulting from the use of raw and briquetted coal.*—Of the 112 boiler tests made, 15 tests were run with briquetted coal. Comparing the results shown in Table 8 with the results of similar tests with raw coal, it will be seen that in most cases where the raw coal is in the form of screenings or

slack, briquetting improves the evaporative efficiency, but where it is in the form of egg, nut or lump, but little difference in performance results. As in the case of coal in its natural state, efficiency decreases as the ash and sulphur content increases. This is shown graphically in Fig. 10. The rather close alignment of the plotted points in this figure is due principally to the uniformity in size of the fuel.

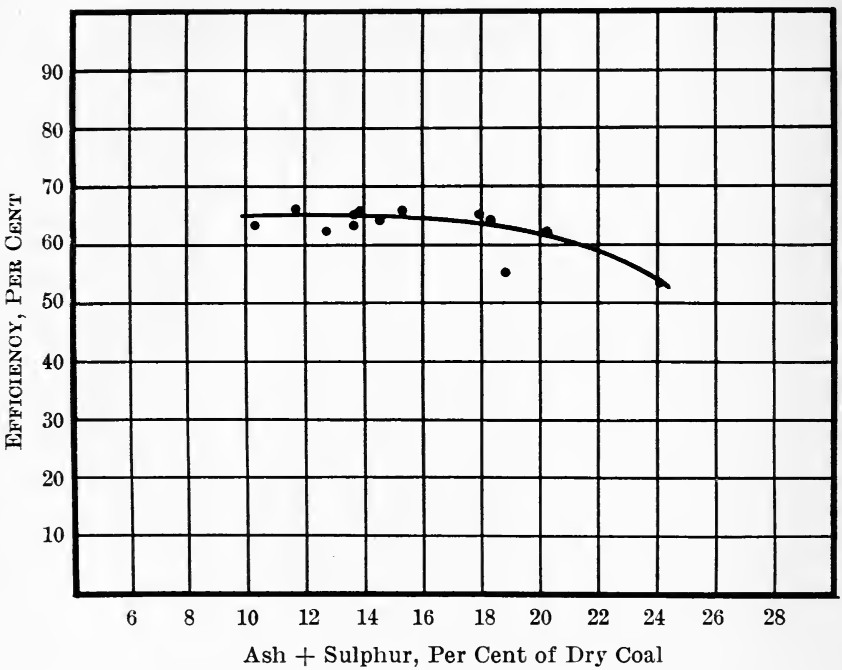


Fig. 10 Evaporative Efficiency As Affected by Ash and Sulphur in Briquet

25. *The evaporative efficiency of Illinois coal compared with that of coal from other states*, as shown by the United States Geological Survey tests, is presented in Table 10. Only tests with bituminous and semi-bituminous coal are here included and the average values given are based only on tests which were made under simi-

TABLE 10 COMPARATIVE RESULTS OBTAINED FROM COAL FROM VARIOUS STATES

State	Kind of Coal	No. of Tests	No. of Coals	Average per cent of Rated Horse-Power Developed	Equivalent Evaporation from and at 212° F. per pound Dry Coal	Efficiency of Combined Boiler and Furnace	B. t. u. per pound of Dry Coal
1	2	3	4	5	6	7	8
Alabama	Bituminous	10	4	91.9	8.43	64.31	12656
Arkansas	Bituminous	8	7	89.3	9.03	63.54	13707
Colorado	Bituminous	1	1	71.9	7.21	55.36	12577
Illinois	Bituminous	52	25	89.6	7.95	62.66	12249
Iowa	Bituminous	5	5	90.7	7.13	59.55	11650
Indiana	Bituminous	24	11	89.5	8.23	63.76	12549
Kansas	Bituminous	8	6	83.4	8.10	61.26	12780
Kentucky	Semi-Bituminous	8	3	91.0	9.77	65.41	14417
Kentucky	Bituminous	3	3	88.9	8.37	62.82	12883
Missouri	Bituminous	9	7	92.2	7.73	60.18	12246
New Mexico	Bituminous	6	3	104.3	8.28	64.68	12507
Ohio	Bituminous	18	9	92.2	8.82	64.88	13130
Pennsylvania	Bituminous	18	9	89.9	9.75	66.22	14248
Tennessee	Bituminous	24	9	102.3	8.81	64.18	13261
Virginia	Semi-Bituminous	10	4	94.2	9.73	65.07	14436
West Virginia	Bituminous and Semi-Bituminous	36	21	95.5	9.86	65.89	14451

lar conditions of operation. Column 1 gives the name of the state, Column 2 the kind of coal, Column 3 the number of tests included in the average, Column 4 the number of samples of coal, Column 5 the average rate of power developed, Column 6 the efficiency in terms of equivalent evaporation per pound of dry coal, Column 7 the efficiency in per cent and Column 8 the heating value of the coal in B. t. u., per pound of dry coal. The values given in the table show that the average evaporative efficiency of Illinois coal is 62.66 per cent. This compares favorably with the results from any other coal tested and in fact is nearly identical with the general average, 63.1.

VIII Producer–Gas Tests

26. *The producer-gas plant* used for the United States Geological Survey tests of Illinois coal consists of two Taylor pressure producers arranged to discharge into a single scrubber, a Westinghouse three-cylinder vertical gas engine rated at 235 horse-power, and a six-pole, 175 kilowatt Westinghouse direct current generator. Auxiliary apparatus was provided for measuring accurately the coal and gas, the steam used by the producer, and all temperatures and pressures necessary for a complete determination of plant efficiency. The general arrangement of the plant is well shown in Fig. 11, and a section through the producer in Fig. 12, (pp. 45, 46).

The principal dimensions of the producer plant are as follows:—

Producer		
Capacity, horse-power		250
Outside diameter	feet	7.0
Inside diameter	feet	6.5
Height	feet	15
Area of fuel-bed	square feet	38.5
Diameter of gas delivery pipe	inches	22
Type of feed, Bildt automatic continuous feed.		
Economizer		
Diameter	feet	3
Height	feet	16.5
Number of 7-inch tubes		6

Scrubber		
Diameter	feet	8
Height	feet	20
Material used in scrubber, gas-house coke.		
Tar extractor		
Speed, revolutions per minute		1500
Purifier		
Length of sides	feet	8
Height	feet	3.25
Material used in purifier, oxidized iron filings and wood shavings.		
Gas holder		
Diameter	feet	20
Height	feet	13
Capacity	cubic feet	4000

27. *The tests* were conducted alternately on the two producers, one being charged while the other was in operation. The schedule adopted involved two sixty-hour runs per week. The first eight or twelve hours of each test were used for bringing the fuel bed to a uniform condition. During this preliminary running, observations were made as in the regular tests, but the record data include only the last 48 or 50 hours, when the running conditions were maintained as uniform as possible. Special attention was directed to the accurate measurements of the coal actually used and charts and checking devices were introduced for this purpose.

Owing to the lack of reliability in the operation of the gas engine, many of the tests made at the beginning of the series were only of a few hours' duration; later, however, no difficulty was experienced in starting the engine and continuing it in operation for a period of 120 hours. During this time two different coals were tested. Altogether 30 tests were made involving the use of 23 different samples of Illinois coal.

28. *Results of the tests.*—The more important observed and calculated results of the tests are given in Table 11. Column 1 of this table is the laboratory number of the test, Column 2 the U. S. G. S. number of the sample tested and Column 3 the size of the coal tested. The proximate analyses of the coal as fired are given in Columns 4 to 8 and the heating value in B. t. u. per pound of dry coal is given in Column 4. The brake horse-power given in Column 10 is the power delivered by the gas engine. Column 11 is the cubic feet of gas delivered by the producer per hour, in terms of standard gas, that is, gas at atmospheric pressure and 60° F. temperature. Column 12 is the calorific value of the gas expressed in B. t. u. per cubic foot of standard gas. Column 13

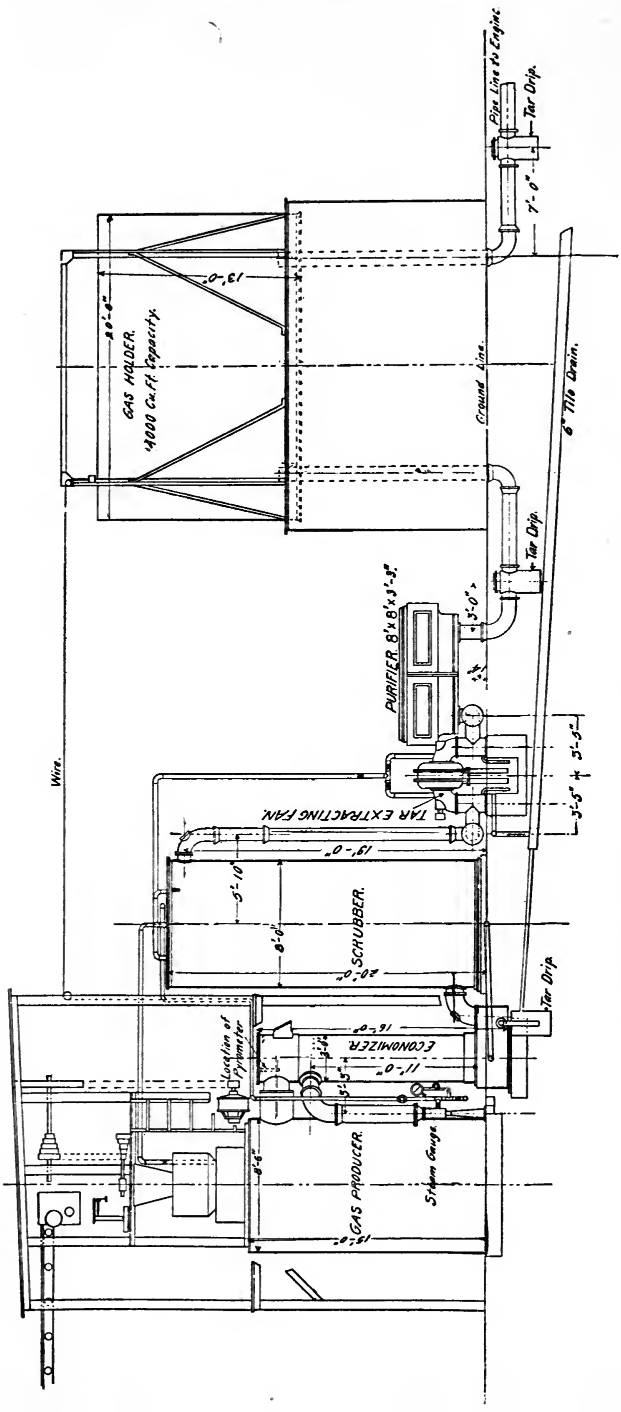


FIG. 11 SECTION THROUGH GAS PRODUCER (Prof. Paper 48, p. 984)

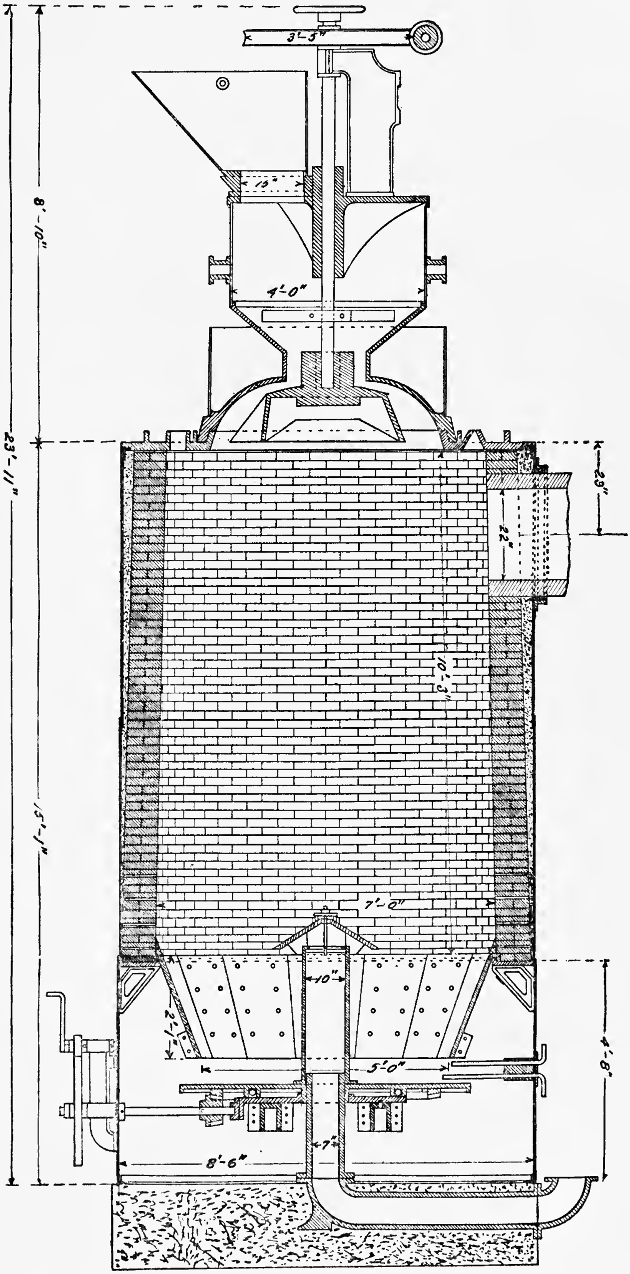


FIG. 12 ELEVATION SHOWING GENERAL ARRANGEMENT OF PRODUCER-GAS PLANT (Prof. Paper 48, p. 983)

TABLE 11 Producer Tests

Test No.	U. S. G. S. No.	Size of Coal	Proximate Analysis of Coal as Fired, per cent: Moisture	Volatile Matter	Fixed Carbon	Ash	Sulphur, Per cent (Separately Determined)	B. t. u. per pound of Dry Coal	Brake Horse-Power	Cubic feet of Standard Gas per hour	B. t. u. per cubic foot of Standard Gas	Cubic feet of Standard Gas per pound of Dry Coal	B. t. u. Contained in Gas per pound of Dry Coal Fired	Pounds of Dry Coal Consumed per Brake Horse-Power hour
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
6	3	....	7.62	30.87	51.78	9.73	1.69	13041	235.0	17412	154.8	53.9	8330	1.43
9	4	....	12.43	32.65	45.70	9.22	1.41	12834	233.0	17881	151.5	58.4	8840	1.37
35	6B	Lump	11.47	31.67	40.78	16.08	4.59	11453	243.0	18070	152.0	52.4	7965	1.50
26	7A	Slack	12.76	32.35	33.37	21.52	3.82	10721	163.0	17320	109.3	30.6	3350	3.69
27	7B	Nut and pea	11.92	33.95	36.67	17.46	4.15	11308	240.2	19580	138.6	48.8	6770	1.75
38	7C	Slack	10.08	32.71	38.26	18.95	4.15	11072	205.8	19780	120.2	46.2	5540	2.24
29	8	Nut	12.91	33.83	41.67	11.59	4.64	12263	244.8	18610	147.0	55.9	8220	1.43
28	9B	Lump	11.99	35.90	40.63	11.48	4.92	12334	244.8	18958	143.7	54.6	7840	1.49
31	10	Slack	8.57	32.31	48.45	10.67	1.35	12874	244.2	19580	140.7	68.7	9660	1.24
30	11A	Egg	7.08	32.62	49.44	10.86	2.09	12919	247.0	17630	173.4	65.0	11275	1.18
36	11C	No. 5 washed	12.78	28.03	47.63	11.56	1.65	12456	204.6	21330	109.8	43.1	4730	2.60
42	11D	No. 3 washed	8.67	30.69	53.36	7.28	1.53	13534	236.5	18925	146.1	82.3	12020	1.04
48	11D	"	7.99	32.08	52.76	7.17	1.56	13554	238.3	.....	154.9	....	.....	1.02
41	13	Egg	8.72	31.07	49.94	10.27	1.66	12798	245.5	18320	156.8	59.2	9280	1.33
37	14	Lump	12.68	33.36	41.57	12.39	4.16	12231	234.1	17172	150.6	59.1	8900	1.32
39	15	Lump and egg	.....	....	.....	.....	....	.....	.....	.....	.....	....	.....	....
40	15	"	9.44	35.48	41.53	13.55	4.06	12107	236.0	19130	142.9	62.3	8900	1.39
43	16	"	7.68	30.62	51.33	10.37	1.47	12911	236.7	18050	149.5	56.7	8480	1.42
45	18	"	13.19	35.93	40.84	10.04	4.59	12717	237.3	17814	147.7	63.4	9360	1.26
55	19B	No. 3 Lump	9.64	30.68	50.22	9.46	.53	13140	236.7	17430	164.1	69.1	11340	1.13
128	19C	Run-of-mine	9.82	29.64	50.34	10.20	.49	12744	166.0	17100	137.8	65.8	9080	1.68
105	21	Lump	14.68	30.98	42.93	11.41	1.33	12343	225.5	18170	156.1	57 5	8970	1.47
103	24B	"	11.48	33.93	43.92	10.71	4.94	12375	236.0	15730	160.5	60.6	9730	1.16
98	23A	No. 5 Lump	11.87	36.37	39.87	11.89	4.65	12103	233.3	17760	147.9	56.0	8280	1.43
100	23B	Slack	14.77	35.23	40.98	9.02	3.46	12676	213.5	17520	145.0	59.6	8640	1.45
102	22A	Lump	11.29	35.60	39.94	13.17	4.88	12100	231.2	17250	159.6	56.1	8950	1.42
104	25	"	11.35	34.62	40.63	13.40	4.76	12105	236.0	14540	168.0	51.3	8620	1.27
126	26	Run-of-mine	13.29	32.02	38.81	15.88	3.52	11547	205.4	17560	147.2	63.1	9290	1.45
127	27	"	11.35	33.59	41.20	13.86	4.54	11828	147.0	16910	122.5	59.4	7280	2.13
139	29B	"	12.25	33.76	41.66	12.33	4.42	12250	228.7	.....	141.2	....	.....	1.39
157	30	Washed	5.59	39.30	45.45	9.66	3.37	12910	234.0	15800	154.4	51.6	7980	1.36

is the cubic feet of standard gas per pound of dry coal. Column 14 is the B. t. u. contained in the gas per pound of dry coal fired. This value divided by the heating value of the coal (Column 9) equals the thermal efficiency of the producer. Column 15 is the pounds of dry coal consumed by the producer per brake-horse-power available for outside purposes.

In comparing the results of the producer tests as set forth in Table 11, too much emphasis can not be given the fact that they were subjected to absolutely no refinements. With the exception of three coals one test only has been made on each kind and grade, and the result of each test has, to a great extent, depended upon the ability of the operator to discover the best methods of handling a given coal within the 8 or 10 hours allowed preliminary to the official test. Moreover, all tests were made on one type and in one size of producer, a type designed primarily for anthracite coal, and in carrying out the plan of the tests more effort was made to develop the required power than to observe the proper relation between the gas producing qualities of the coal and the area of the fuel bed.

In spite of all these restrictions it is the opinion of those who were in charge of the tests that certain general relationships have

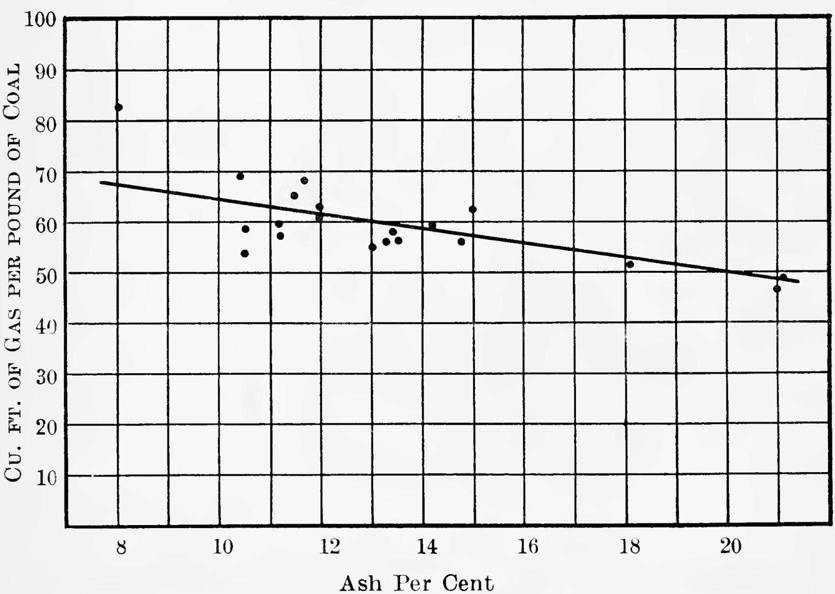


Fig. 13 Cubic Feet of Gas per pound of Coal as Affected by Per Cent of Ash in Dry Coal

been fairly well established. They may be subject to modification in the light of future investigations, but the conclusions to be drawn from them are sufficiently significant for presentation.

29. *Efficiency as affected by ash in the coal.*—The cubic feet of gas delivered by the producer per pound of coal fired is, perhaps, the most convenient measure of efficiency. Referring to Column 13, Table 11, it will be seen that in general as the ash in the coals increases this quantity decreases. The exact relation for all tests made at full load is shown graphically in Fig. 13. In this figure, cubic feet of standard gas per pound of dry coal is plotted against ash expressed in per cent of dry coal. The average line is drawn so as to include as many of the plotted points as possible. It shows that when the coal contains 8 per cent ash the output of the producer is 67 cubic feet per pound of dry coal fired and that when ash is 20 per cent the output is decreased to 50 cubic feet.

30. *Efficiency as affected by calorific value of the coal.*—The cubic feet of gas per pound of dry coal plotted against B. t. u. per pound of dry coal for all tests made at full load is shown in Fig. 14. Since the heating value of Illinois coal is very nearly inversely proportional to the ash content the relation shown is merely a restatement of the facts brought out in Fig. 13. The points, however, fall in better alignment. It appears from the curve that the output of gas in cubic feet per pound of coal increases from 49 when the calorific value is 11000 B. t. u. per pound of dry coal, to 65 when the calorific value is 13000. Fig. 15 shows the efficiency expressed in per cent plotted against the heating value of the coal. Here the same rise in efficiency is again shown. The average value at 11000 is 58 per cent and at 13000 it is 76 per cent.

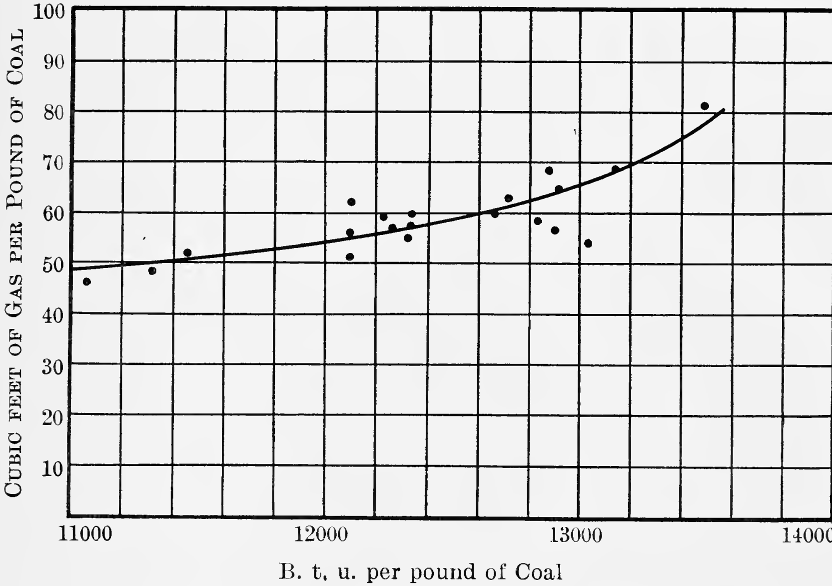


Fig. 14 Cubic Feet of Gas per pound of Coal, as Affected by Calorific Value of the Coal

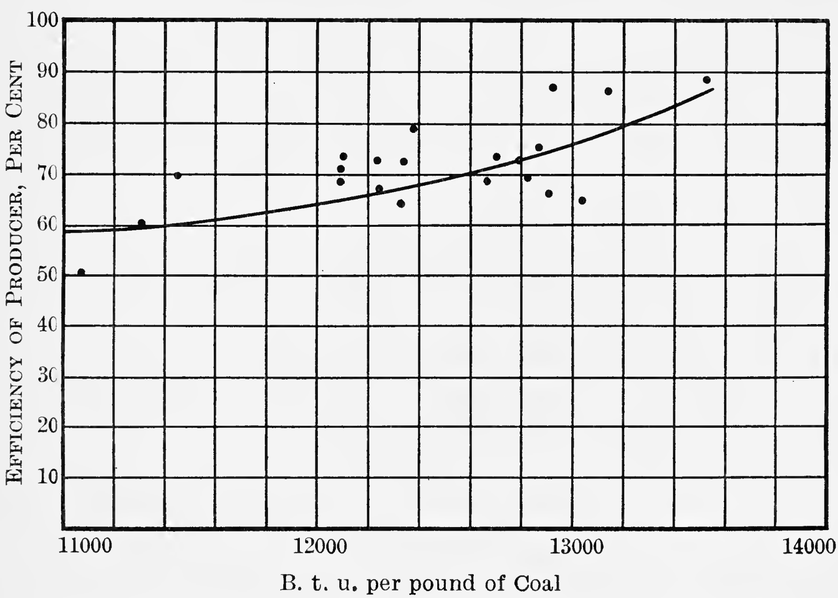


Fig. 15 Efficiency of Producer as Affected by Calorific Value of the Coal

31. *A comparison of Illinois coal with other bituminous coals.* A condensed summary of the more important items relating to Illinois coals compared with those relating to all other bituminous coals tested, is presented in Table 12. The average values given

TABLE 12

A COMPARISON OF ILLINOIS COAL WITH BITUMINOUS COALS FROM OTHER STATES FOR GAS PRODUCER SERVICE

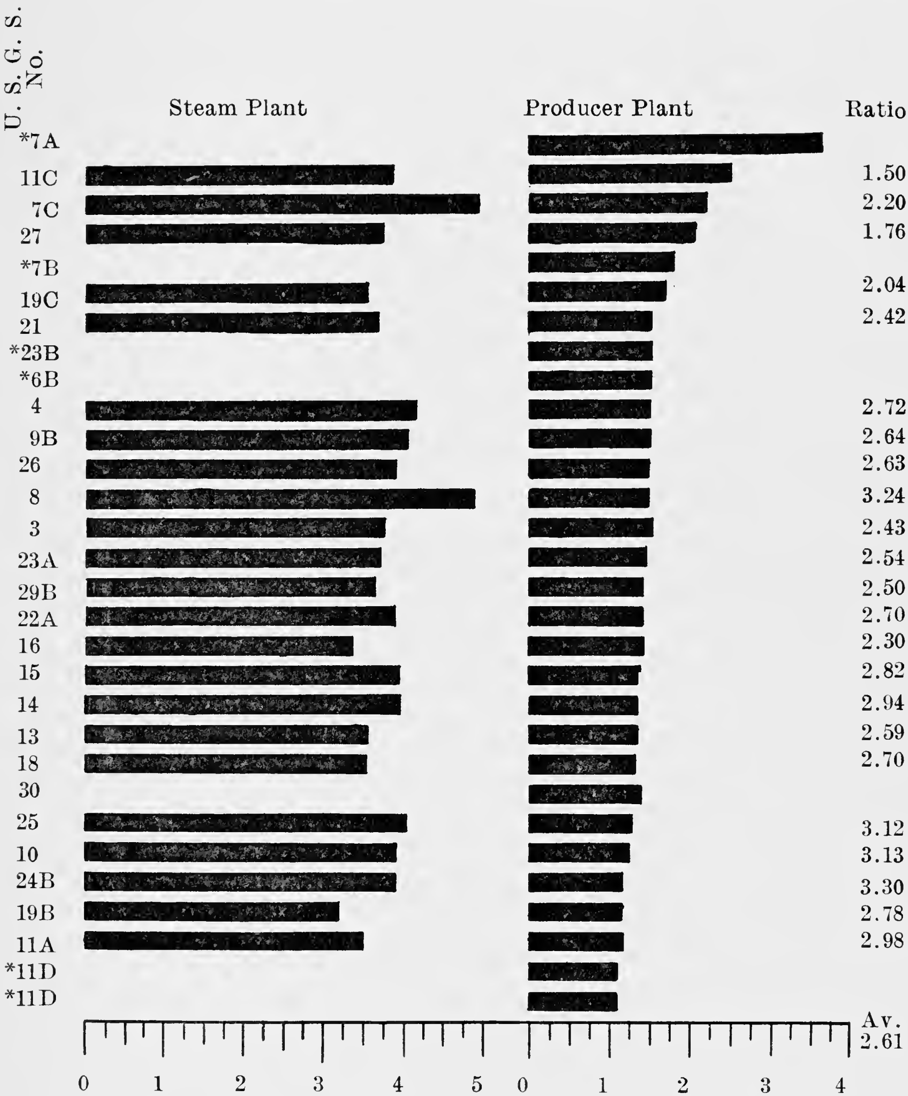
	Average of Tests with Ill. Coal	Average of All Tests with Bituminous Coal
Composition of fuel, per cent:		
Moisture	10.84	6.82
Volatile matter	33.06	33.06
Fixed carbon	44.06	49.80
Ash	12.04	10.32
Sulphur	3.15	2.41
B. t. u. per pound of dry coal	12000.	13150.
Composition of gas, volume per cent:		
Carbon dioxide	9.60	9.84
Oxygen	.03	.04
Nitrogen	56.81	55.60
Hydrocarbons	3.21	3.30
Carbon monoxide	18.31	18.28
Hydrogen	12.01	12.90
B. t. u. per foot of standard gas	146.5	152.1
Cubic feet of standard gas per pound of dry coal	59.1	64.7
Pounds of dry coal per brake horse power, hour	1.36	1.26

are computed only from tests in which the producer was operated at its rated capacity. It will be noted that while the analysis shows that the Illinois coal contains 4 per cent more moisture and $2\frac{1}{3}$ per cent more ash the quality of the gas produced is but slightly inferior. Thus the heating value is 146.5 B. t. u. per foot of standard gas when Illinois coal is used and 152.1 when other bituminous coal is used. The output of gas, measured in cubic feet per pound of dry coal, is 59.1 in the one case and 64.7 in the other. Comparing the efficiency at the engine it will be seen that it requires 1.36 pounds of Illinois coal to develop a horse-power and 1.26 pounds when other bituminous coals are used. This comparison is by no means unfavorable and considering the lower selling prices which prevail for Illinois coals the very slight difference in efficiency is almost insignificant.

32. *Relative results of steam and producer-gas tests.*—From theoretical considerations it may easily be shown that it is possible for the gas engine to utilize a much larger amount of the

Relative Amount of Illinois Coal Used by Steam and Producer Plant

POUNDS PER BRAKE HORSE-POWER HOUR



* No producer test.

Fig. 16 Relative Coal Consumption in Gas and Steam Plants.

heat supplied than the steam engine. The results of the present tests show how much of this saving is realized in practice.

The ratios of the total coal per brake horse-power hour required by the steam plant and producer gas plant under full load conditions are presented in Fig. 16. The values representing producer plant performance are those of Column 15, Table 11, and those representing steam plant performance are calculated from those of Column 25, Table 8, allowing 85 per cent as the efficiency of the dynamo. It will be seen that the maximum ratio is 3.13 and the minimum 1.50 while the average is 2.61.

United States Geological Survey Publications on Fuel Testing

The following publications, except those to which a price is affixed, can be obtained free by applying to the Director, Geological Survey, Washington, D. C. The priced publications can be purchased from the Superintendent of Documents, Government Printing Office, Washington, D. C.

Bulletin No. 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp, 10 cents.

Professional Paper No. 48. Report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1906. In three parts. 1492 pp. 13 pls $1.50.

Bulletin No, 290. Preliminary report on the operations of the fuel-testing plant of the United States Geological Survey at St. Louis, Mo., 1905, by J. A. Holmes. 1906. 240 pp. 20 cents.

Bulletin No. 323. Experimental work conducted in the chemical laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 1907. 49 pp.

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Circular No. 1. High-Speed Tool Steels, by L. P. Breckenridge. 1905. (*Out of print.*)

Bulletin No. 2. Tests of High-Speed Tool Steels on Cast Iron, by L. P. Breckenridge and Henry B. Dirks. 1905. (*Out of print.*)

Circular No. 2. Drainage of Earth Roads, by Ira O. Baker. 1906. (*Out of print.*)

Circular No. 3. Fuel Tests with Illinois Coal. (Compiled from tests made by the Technologic Branch of the U. S. G. S., at the St. Louis, Mo., Fuel Testing Plant, 1904-1907, by L. P. Breckenridge and Paul Diserens. 1909.

Bulletin No. 3. The Engineering Experiment Station of the University of Illinois, by L. P. Breckenridge. 1906. (*Out of print.*)

Bulletin No. 4. Tests of Reinforced Concrete Beams, Series of 1905, by Arthur N. Talbot. 1906.

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Bulletin No. 7. Fuel Tests with Illinois Coals, by L. P. Breckenridge, S. W. Parr and Henry B. Dirks. 1906. (*Out of print.*)

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Bulletin No. 9. An Extension of the Dewey Decimal System of Classification Applied to the Engineering Industries, by L. P. Breckenridge and G. A. Goodenough. 1906.

Bulletin No. 10. Tests of Concrete and Reinforced Concrete Columns, Series of 1906, by Arthur N. Talbot. 1907. (*Out of print.*)

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Bulletin No. 31. Fuel Tests with House-heating Boilers, by J. M. Snodgrass. 1909.

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