THE UNIVERSITY OF MISSOURI BULLETIN

Bulletin No. 8

ENGINEERING EXPERIMENT STATION SERIES

VOLUME 3. NUMBER 2

FIRING TESTS ON MISSOURI COAL

BY

H. N. SHARP

UNIVERSITY OF MISSOURI
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The Engineering Experiment Station of the University of Missouri was established by order of the Board of Curators July 1st, 1909.

The object of the Station is to be of service to the people of the State of Missouri.

First: By investigating such problems in Engineering lines as appear to be of the most direct and immediate benefit and publishing these studies and information in the form of bulletins.

Second: By research of importance to the manufacturing and industrial interests of the State and to Engineers.

The staff of the Station consists at present of a Director and one research assistant together with a number of teachers who have undertaken research under the direction of the Station.

Suggestions as to problems to be investigated, and inquiries will be welcomed.

Any resident of the State may on request obtain bulletins as issued or if particularly interested, may be placed on the regular mailing list. Address the Engineering Experiment Station, University of Missouri, Columbia, Missouri.

NOTE BY THE EDITOR.

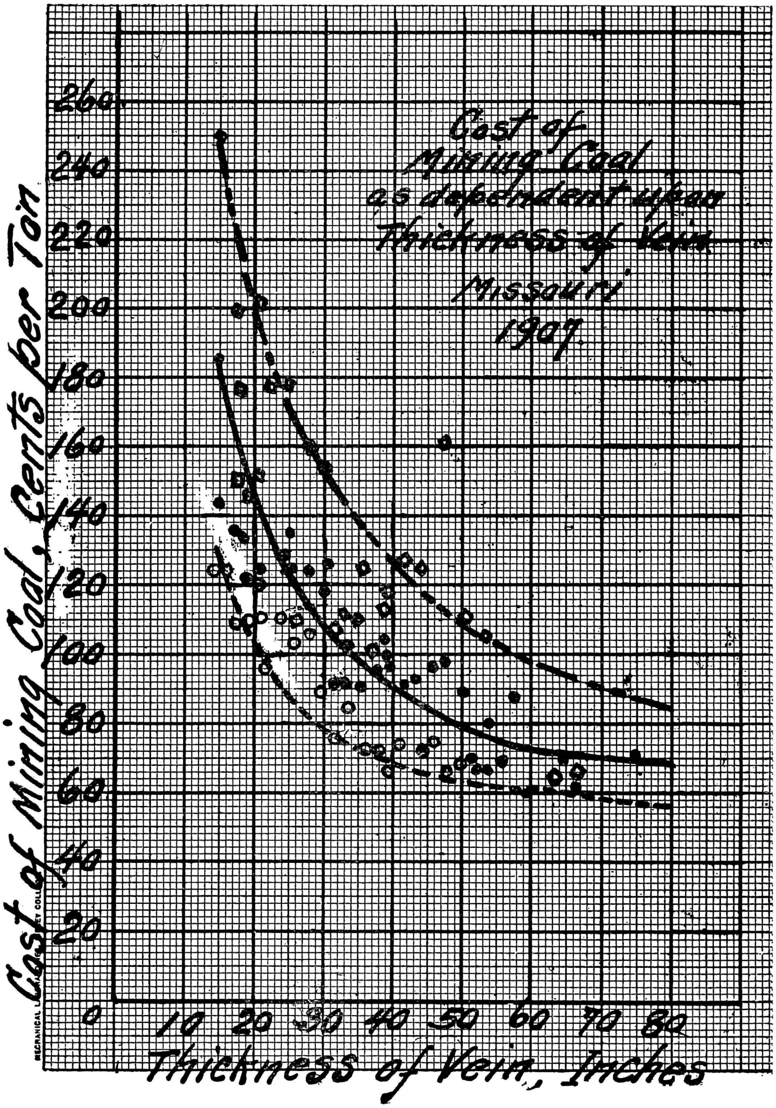
One can hardly overemphasize the importance of an adequate supply of local coal for domestic and industrial use or the value of definite information in regard to its location and quality.

The Engineering Experiment Station of the University of Missouri has published a bulletin, Vol. II, No. 1, "The Heating Value and Proximate Analysis of Missouri Coals", a reprint of a bulletin by Professor C. W. Marx and Dr. Paul Schweitzer, first issued in 1901. There is also available a bulletin "The Storage of Coal" by E. A. Fessenden and J. R. Wharton issued prior to the establishment of the Station. Both of the above are somewhat technical in character, whereas the present bulletin is more directly practical, and shows that the Missouri coal used compares favorably with other bituminous coals mined in the middle west, a fact confirmed by some boiler acceptance tests made under the direction of the writer.

Of prime importance in considering the mining, sale, and use of Missouri coal is the effect of the thickness of vein upon the cost of mining. As more than half the total cost of coal purchased outside the state is for freight and haulage to cities in the middle of the state, there is great opportunity for the development of local coal fields with short-haul transportation. Successful competition with outside coal depends on the reliability of supply, which probably necessitates storage, and on the total cost delivered. If the cost of mining and transportation of Missouri coal for local use can be made even slightly less than competing coal of corresponding heating value, and if coal is available as needed, sufficient capital for development should be easily obtainable, with resulting economy to both mine operators and users.

The cost of transporting short distances can easily be made low by providing proper facilities, but on the other hand the cost of mining very thin veins may be prohibitively high, and unfortunately the coal veins thin out considerably near the edges where they outcrop.

To get the approximate effect of the thickness of vein upon the cost of mining I tabulated the data contained in the "Twenty-first Annual Report of the Bureau of Mines and Mine Inspection, State of Missouri, 1907", and for convenience constructed the accompaning chart which shows the maximum, average, and minimum costs per ton of mining coal plotted against the thickness of the vein.



Naturally other influences affect the cost of mining, so the chart should be considered as a general representation, not as an exact measure of the cost in a particular instance. For example, the chart evidences that it will not generally pay to mine very thin veins except possibly for individual use where the cost of transportation is very low.

H. B. SHAW.

INTRODUCTION

Half of the 114 counties in Missouri, more than one third of the total area of the state, are underlaid with coal. The coal is bituminous (soft) and compares favorably with other Western bituminous coals in heating value and general adaptability for power plant purposes. The coal mining industry, however, is not very well developed and a great deal of the coal used in the state for domestic and industrial purposes is shipped in from the neighboring states of Illinois, Kansas and Oklahoma.

The price of Missouri coals at the mines is somewhat higher than in the neighboring states, Illinois for example.* This is because the methods of mining are generally not as good, the coal seams are not as thick and high freight rates make it unnecessary to maintain low prices in competition with a distant market. An increased use of native Missouri coal in preference to that shipped in from neighboring states would stimulate the mines of the state to greater activity and more modern methods of mining. The price of coal at the mine could then be lowered and both consumer and producer would be benefited.

Many coal consumers use Missouri coal. In many cases the results are entirely satisfactory, in others difficulties have arisen to cause dissatisfaction and in some cases have led to the use of coal from other states. It is quite possible that much of the dissatisfaction has been caused by improper methods of handling the coal.

It is the purpose of this bulletin to interest the coal users of the state in Missouri coal and to point out methods and controlling conditions by which better economy may be obtained and the coal burned satisfactorily in small hand fired power plants. No set of definite rules can be given because of the widely different conditions which obtain at different plants, but the discussion covers the nature of the coal, its handling and combustion, together with other factors affecting the operation of a boiler plant. These are all of importance to every one who is interested in fuel burning and fuel economy.

Most of the smaller power plants of the state are equipped with hand fired, return tubular boilers. The boilers and setting are not generally kept in the best condition. More or less scale is allowed to accumulate in the boiler and the setting leaks are usually large.

*Illinois bituminous coal is used as a basis of comparison in several places in this bulletin because Illinois is the largest coal producing state in the Middle West and because the quality of Illinois coal is generally well known.

The discussion in this bulletin is based on a number of tests made with a representative Missouri coal, hand fired under a return tubular boiler. The boiler and setting were not in good condition. They probably represent about average practice and the results obtained are such as might be expected from the ordinary small plant.

Particular attention is called to the use of slack and screenings. These are very low priced, compared with run of mine and lump coal. They can be used with economy if carefully fired.

Missouri coal is often condemned because of clinker troubles. These may also be largely overcome by careful firing.

PART I

FIRING TESTS ON MISSOURI COAL

TESTS.

The tests were made on one of the boilers in the power plant of the University of Missouri. The boiler is a return tubular boiler, hand fired. The principal dimensions of the boiler are given on page 9.

The fireman used in the tests was selected from the regular force of firemen at the power plant. The same fireman fired all the tests. He handled the fire about as he did every day under ordinary working conditions except that he fired a certain number of shovelsful of coal at regular intervals and was told when to slice or clean. The fire was raked and leveled occasionally and kept free from holes.

The operating conditions were kept as nearly uniform as possible for all the tests. Only one condition was allowed to vary for any one test and this the one whose effect was being investigated.

The boiler was kept in regular use throughout the entire period over which the tests extended. It was cleaned and overhauled at regular intervals just as though no tests were in progress. All this was done in order that the test results might be representative of ordinary power plant operation. Washing out the boiler, cleaning tubes, etc., varied the operating conditions somewhat, so that the tests are arranged in several groups, separated by cleaning periods. The condition of the boiler for any one group of tests was not changed in any way except that it became dirty as the time for its regular cleaning approached.

The test apparatus was left set up ready for use. When a test was to be run the steam pressure and water level were brought to their normal mark; then the fire was cleaned, fired with Missouri coal and the test started with the first firing after cleaning. The same plan was folowed when the test was finished, the test being stopped at the first firing after cleaning. With the exception of the variation in firing methods which were being investigated, the tests were all run under ordinary operating conditions.

An injector was used to feed the boiler. Its capacity was too large so that it had to be started and stopped throughout the test. The feed water was weighed by a Kennicott automatic water weigher; the weigher was tested and found accurate within one-half of one per cent.

The flue gas temperature was recorded on a Bristol recording electric pyrometer which was compared with a high grade mercury thermometer and found accurate within a few degrees.

A record of the percent of a carbon dioxide in the flue gases was made with a Uehling continuous CO_2 recorder. This was checked occasionally by an Orsat gas analysis apparatus and found accurate.

The coal was weighed on the platform scales regularly used in the boiler room.

The steam pressure was taken from a new Ashcroft guage, carefully calibrated. The steam quality was determined with a throttling calorimeter.

All the coal used, except that for test No. 6, was stored in a room in the power house protected from the effects of the weather. The coal used in test No. 6 was exposed to a heavy snow. The coal varied from lump coal to slack. The lump coal was broken up before firing.

Tests Nos. 1, 2, 3, 4 and 5 were made with Illinois coal of average quality. All the other tests were made with a typical Missouri coal from Higbee, Mo.

Special care was taken in sampling the coal used in the tests for the determination of the proximate analysis and calorific value. A shovelful of coal was taken from each car (small boiler room coal passing cars) of coal used during a test when the car was about half full. These were kept until the test was finished, then broken and quartered down to about two pounds. In spite of all precautions taken in sampling it is believed that the ash, as shown by the proximate analysis, is too high is tests Nos. 14, 18 and 27, so that the efficiencies of these tests are probably higher than they should be. The high ash shown by the analysis may be caused by including an exceptionally slaty piece of coal in the sample. For this reason these three tests are disregarded in most of the conclusions drawn. The coal sample was analysed as soon as possible after the test. The heating value was determined by a calorimeter of the Parr type.

TEST DATA.

(The figures in parenthesis refer to the code for boiler tests of the American Society of Mechanical Engineers.)

Tests made by H. N. Sharp, for the University of Missouri Engineering Experiment Station, at the University Power Plant, Columbia, Missouri.

Kind of boiler, Horizontal return tubular.

Kind of fuel, Tests Nos. 1, 2, 3, 4, 5.

Illinois run of mine coal.

All other tests—Higbee, Mo., run of mine coal.

Kind of furnace, hand fired, plain grate.

Method of starting and stopping the test, alternate.
Number of boiler (plant number) 7.

(3) Grate surface	28 sq. ft.
(3.1) Width of grate	6.5 ft.
(3.2) Length of grate	4.31 ft.
(4) Height of furnace (distance from top of grate to shell)	21.5 inches
(5) Approximate width of air space in grate	9-16 inches
(6) Proportion of air space to whole grate area	34.5%
(7) Water heating surface	1200 sq. ft.
(7.1) Outside diameter of shell	5.5 ft.
(7.2) Length of shell	16 ft.
(7.3) Number of tubes	72
(7.4) Diameter of tubes — Outside	3.75 inches
(7.4) Diameter of tubes — Inside	3.51 inches
(7.5) Length of tubes exposed	16 ft.
(9) Ratio $\frac{\text{Water heating surface}}{\text{Grate surface}}$	42.8

Test Number	Date 1912	Weather	Object of Test	Date of B—Blowing Down C—Cleaning S—Scraping	Duration of Test Hours	Steam Pressure, pounds per sq. inch: Gauge	Steam Pressure, pounds per sq. inch: Absolute	Barometer inches of mercury	Draft between Damper and Boiler, inches of water
	(1)				(2)	(11)		(11.1)	(12)
1	Feb. 8	Cloudy-Snow	Preliminary..............	C. Jan. 21...	8.40	103.	117.4	29.3	0.6
2	21	Cloudy-Snow	Preliminary..............	C. Feb. 18...	10.07	98.	112.3	29.16	0.62
4	28	Cloudy	Preliminary..............	....	9.93	99.5	113.9	29.38	0.64
5	Mar. 1	Clear	Preliminary..............	....	9.89	106.	120.6	29.74	0.61
6	Mar. 7	Cloudy-Snow	Firing Interval...........	C. Mar. 3....	9.98	100.	114.3	29.18	0.62
7	9	Clear	Firing Interval...........	....	9.82	104.	118.5	29.55	0.64
8	11	Cloudy-Rain	Firing Interval...........	....	8.50	99.	133.3	29.04	0.63
9	12	Cloudy-Rain	Fire Thickness...........	....	9.53	103.2	117.5	29.09	0.62
10	13	Clear	Firing Method............	....	9.58	102.6	116.9	29.13	0.61
11	Mar. 29	Clear	Preliminary..............	C. Mar. 24...	8.68	102.	116.2	28.94	0.47
12	Apr. 2	Clear	Firing Interval...........	S. Mar. 26...	10.13	98.7	112.9	29.0	0.41
13	3	Clear	Firing Interval...........	....	10.47	97.6	112.	29.24	0.41
14	4	Clear	Firing Interval...........	....	10.20	97.	111.4	29.32	0.4
15	5	Clear	Draft.....................	....	10.28	100.5	114.8	29.1	0.28
16	6	Cloudy	Draft.....................	....	9.88	97.3	111.7	29.39	0.25
17	8	Clear	Draft.....................	....	10.17	95.3	109.7	29.4	0.4
18	Apr. 16	Cloudy	Cleaning Boiler...........	B.&S.Apr. 12	10.54	96.2	110.5	29.2	0.42
19	24	Clear	Firing Method............	C. Apr. 14...	9.67	96.5	111.	29.43	0.42
20	25	Cloudy-Rain	Firing Method............	....	10.15	98.7	113.	29.15	0.42
21	26	Clear	Fireman B	....	10.17	99.5	113.8	29.06	0.41
22	May 8	Clear	Firing Method............	C. Apr. 28...	10.13	97.5	111.7	28.98	0.4
23	9	Clear	Setting Leakage...........	S. May 2....	10.17	98.	112.3	29.02	0.41
24	10	Showers	Setting Leakage..........	....	9.90	95.	109.1	28.77	0.47
25	May 14	Clear	Scraped Tubes	C. May 12...	9.98	105.1	119.5	29.26	0.4
27	17	Clear	Firing Method............	S.&B.May 13	10.03	100.	114.4	29.33	0.41
28	21	Clear	Moisture..................	....	9.88	99.8	114.1	29.05	0.41
30	May 24	Cloudy	Forcing...................	C. May 23...	9.35	99.1	113.4	29.21	0.52

Test Number	Temperature of External Air, Degrees F.	Temperature of Fire Room, Degrees F.	Temperature of Steam, Degrees F.	Temperature of Feed Water, Degrees F.	Temperature of Flue Gases, Degrees F.	Fuel, Kind, Size and Condition	Weight of Coal as Fired, pounds	Weight of Dry Coal, pounds	Weight of Ash and Refuse, pounds	Combustible consumed, pounds	Percent of Ash and Refuse in Dry Coal	Fixed Carbon, Percent	Volatile Matter, Percent	Moisture, Percent.	Ash, Percent.
	(15)	(16)	(17)	(18)	(21)	(23)	(25)	(27)	(28)	(30)	(31)	(32)	(33)	(34)	(35)
1	19	47.2	339.6	60.5	777	Illinois, R. of M., damp, dirty	7147	6250	1026	5325	16.42	41.5	35.25	12.5	10.53
2	27	60.3	336.3	60.8	748	Do.	7698	6760	927	5845	13.7	42.6	37.7	12.2	7.5
4	28	57.	337.3	60.3	614	Do.	6080	5355	826	4527	15.41	42.55	36.2	12.0	9.25
5	22	53.1	332.0	59.8	653	Do.	6115	5280	994	4280	18.81	40.3	36.65	13.5	9.55
6	34	62.4	337.6	60.3	751	Mo., R. of M., ½ slack, wet	8077	7453	1307	6147	17.52	45.6	35.4	7.73	11.27
7	20	51.3	340.3	59.9	786	Mo. R. of M, little slack, dry	8451	7679	1341	6333	17.48	47.75	35.92	9.2	8.12
8	30	61.7	336.9	59.9	735	Mo., R. of M., ½ slack, wet	6991	6331	.....	.....	......	46.15	35.9	9.44	8.51
9	30	64.7	339.7	60.0	815	Do.	9487	8478	1929	6551	22.73	42.78	32.6	10.64	13.98
10	26	59.	339.3	59.9	719	Do.	8513	7481	1405	6076	18.78	41.2	32.58	12.12	14.1
11	48	75.	338.8	61.3	660	Mo., R. of M., lump, dry ...	5412	4998	.....	.....	......	43.35	34.27	7.65	14.73
12	48	72.5	336.7	61.3	713	Do.	7660	7019	1089	5931	15.5	45.6	37.05	8.98	8.37
13	51	75.	336.0	61.6	731	Do.	7812	7184	1231	5954	17.12	44.05	33.0	8.04	14.91
14	64	84.7	335.6	61.3	672	Mo., R. of M., ¼ slack, dry	7368	6816	1126	5690	16.52	38.1	27.43	7.47	27.0
15	68	89.8	337.9	61.6	672	Do.	6872	6267	1111	5156	17.72	45.72	32.82	8.8	12.66
16	59	88.8	335.9	61.8	673	Do.	6097	5569	1035	4534	18.58	45.15	32.89	8.66	13.3
17	51	77.	334.6	61.7	662	Mo., R. of M., ½ slack, dry	6732	6078	958	5111	15.74	45.3	32.5	9.72	12.48
18	46	70.8	335.0	61.6	665	Do.	7403	6829	1178	5652	17.24	42.7	32.5	7.75	17.05
19	60	85.7	335.4	61.8	681	Do.	5647	5238	801	4537	15.39	45.8	37.05	7.25	9.9
20	60	82.6	336.7	62.0	713	Do.	6235	5684	885	4790	15.55	44.63	35.4	8.84	11.13
21	63	87.1	337.2	61.9	729	Do.	6134	5589	974	4616	17.41	44.83	35.34	8.89	10.94
22	68	92.6	335.9	62.3	749	Do.	6797	6218	1091	5128	17.53	43.1	34.17	8.52	14.21
23	68	94.5	336.2	62.6	690	Mo., R. of M., ¼ slack, dry	6689	6237	1132	5105	18.15	44.0	37.05	6.76	12.19
24	72	94.4	334.2	62.4	645	Mo., R. of M., ½ slack, dry	5983	5401	1220	4208	22.58	43.85	35.0	9.72	11.43
25	55	80.1	340.9	61.5	682	Do.	6740	6268	1017	5242	16.21	44.9	35.57	7.01	12.52
27	55	82.	337.6	61.7	780	Do.	7232	6491	1147	5344	17.67	38.81	31.88	10.24	19.67
28	76	96.7	337.4	62.8	745	Do., with 5.62% water add.	6547	5632	963	4471	17.10	39.9	33.2	13.98	12.92
30	74	92.7	337.0	62.8	764	Mo., R. of M., ½ slack, dry	7691	7123	1214	5909	17.05	47.72	35.2	7.39	13.68

Test Number	Dry Coal Consumed per Hour, pounds.	Combustible Consumed, per hour, pounds.	Dry Coal per sq. ft. of Grate per Hour, pounds.	Combustible per sq. ft. of Heating Surface, per Hour, pounds.	B. t. u. per pound of Dry Coal, by Calorimeter.	B. t. u. per Pound of Combustible.	Quality: Moisture in Steam, Percent.	Quality: Factor of Correction (dry steam unity)	Total Water fed to Boiler, pounds.	Equivalent Water, from and at 212 degrees F., pounds.	Water Actually Evaporated, Corrected for Steam Quality, lbs.	Factor of Evaporation	Equivalent Water into Dry Steam, pounds.
	(46)	(47)	(48)	(49)	(50)	(51)	(54)	(56)	(57)	(58)	(59)	(60)	(61)
1	745.	622.6	27.6	0.556	12221	13896	0.535	99.594	34751	41559	34610	1.1959	41340
2	672.5	581.	24.9	0.518	12822	14134	0.75	99.43	38514	46038	45775	1.1953	45775
4	573.	485.	21.2	0.443	12790	14298	0.137	99.9	29062	34749	29033	1.1957	34715
5	534.5	433.	19.78	0.387	12645	14216	0.365	99.719	27910	33411	27831	1.1971	33317
6	746.	615.5	26.65	0.513	12703	14474	0.239	99.819	36901	44119	36834	1.1956	44039
7	781.5	644.5	27.9	0.537	13440	14770	0.069	99.948	42339	50467	42317	1.1967	50441
8	745.	....	26.6	....	13210	14590	0.137	99.896	34139	40786	34092	1.1947	40730
9	889.	687.	31.75	0.572	12088	14320	Dry	Dry	43674	52252	43674	1.1964	52252
10	782.	635.	27.92	0.529	12180	14550	Dry	Dry	41623	49798	41623	1.1964	49798
11	575.	....	20.55	....	12022	14320	0.205	99.85	28741	34317	28695	1.1949	34263
12	692.	585.	24.7	0.487	13120	14450	0.056	99.969	38507	45995	38495	1.1945	45976
13	690.	572.	24.65	0.476	11910	14220	0.079	99.94	39520	47187	39496	1.1940	47159
14	667.5	558.	23.85	0.465	9690	13790	0.181	99.861	36350	43411	36299	1.1943	43350
15	610.	501.5	21.8	0.418	12410	14420	0.125	99.905	32870	39265	32839	1.1946	39227
16	564.	459.	20.15	0.383	12077	14137	0.442	99.664	30338	36212	30236	1.1939	36090
17	594.	502.5	21.35	0.418	12697	14119	0.453	99.655	35034	41818	34913	1.1936	41674
18	647.7	535.5	23.13	0.437	11786	14292	0.011	99.992	40333	48147	40330	1.1937	48143
19	542.	459.	19.33	0.383	13333	14926	Assumed	99.8	30586	36507	30525	1.1936	36434
20	560.	472.	20.0	0.294	12846	14634	Assumed	99.8	33389	39856	33322	1.1937	39776
21	549.5	453.5	21.22	0.378	12809	14556	Assumed	99.8	32234	38487	32170	1.1940	38410
22	613.5	506.	21.9	0.422	11807	13978	0.419	99.681	34299	40926	34189	1.1932	40795
23	613.	502.	21.9	0.418	12792	14496	0.25	99.807	32163	38367	32102	1.1929	38293
24	546.	425.	19.5	0.354	12972	14859	0.147	99.888	26124	31155	26044	1.1926	31120
25	628.	525.	22.4	0.437	12637	14607	0.114	99.913	37721	45084	37688	1.1952	45045
27	646.	532.	23.05	0.443	11121	14118	0.942	99.284	36670	43788	36407	1.1941	43174
28	573.	455.	20.50	0.379	12637	14873	0.432	99.671	31893	38048	31788	1.1930	37923
30	762.	631.5	27.2	0.526	12406	14355	0.023	99.982	37682	44951	37675	1.1929	44942

Test Number.	Water Evaporated per Hour, corrected for Quality, pounds.	Equivalent Evaporation per Hour, from and at 212 degrees F, pounds.	Equivalent Evaporation per Hour, per sq. ft. of Heating Surface, pounds.	Boiler Horse Power Developed (34.5 pounds from and at 212 degrees per hour).	Per cent of Rating Developed.	Water Apparently Evaporated per pound of Coal as Fired, pounds.	Equivalent Evaporation per Pound of Coal as Fired, pounds.	Equivalent Evaporation per Pound of Dry Coal, pounds.	Equivalent Evaporation per Pound of Combustible, pounds.	Efficiency of Boiler, per cent.	Efficiency of Boiler and Grate, per cent.	Cost of Evaporating 1000 Pounds of Water, Observed Conditions*	Cost of Evaporating 1000 Pounds of Water from and at 212 degrees F.*
	(62)	(63)	(64)	(65)	(67)	(68)	(69)	(70)	(71)	(72)	(73)	(75)	(76)
1	4125	4842	4.03	140.3	93.6	4.87	5.74	6.62	7.92	55.3	52.55	$.1027	$.0863
2	3690	4550	3.79	131.9	87.8	5.00	5.95	6.78	7.83	53.75	51.3	.10	.0841
4	2925	3484	2.91	101.3	67.6	4.88	5.71	6.48	7.66	52.0	49.2	.1023	.0877
5	3377	3367	2.81	97.5	65.0	4.56	5.45	6.31	7.78	53.1	48.3	.1096	.0912
6	3689	4411	3.67	127.8	85.2	4.57	5.45	5.91	7.17	48.05	45.15	.1094	.0918
7	4307	5134	4.27	148.9	99.2	5.02	5.97	6.57	7.965	52.3	47.4	.0997	.0838
8	4011	4792	3.99	139.0	92.7	4.88	5.83	6.43	....	....	47.25	.1024	.0859
9	5482	5482	4.57	158.9	105.9	4.60	5.51	6.165	7.98	54.0	49.5	.1087	.0908
10	4355	5205	4.34	150.9	100.4	4.89	5.79	6.66	8.19	54.6	53.1	.1021	.0863
11	3242	3947	3.29	114.4	76.3	5.32	6.33	6.86	....	....	55.3	.094	.0789
12	3798	4535	3.78	131.3	87.7	5.03	6.00	6.55	7.75	52.0	48.4	.0995	.0833
13	3780	4520	3.76	131.0	87.3	5.06	6.03	6.56	7.92	54.0	53.45	.0988	.0829
14	3557	4250	3.54	123.1	82.0	4.93	5.88	6.365	7.62	53.6	63.75	.1013	.0851
15	3200	3820	3.182	110.8	73.8	4.78	5.71	6.37	7.62	51.3	49.	.1045	.0876
16	3056	3652	3.04	106.8	71.2	4.98	5.92	6.48	7.96	54.3	52.1	.1003	.0845
17	3440	4110	3.42	119.0	79.3	5.21	6.19	6.85	8.16	53.75	52.3	.0962	.0808
18	3825	4560	3.797	132.1	88.1	5.45	6.50	7.05	8.52	57.8	58.1	.0918	.0769
19	3160	3770	3.195	112.7	75.1	5.42	6.46	6.96	8.22	53.4	50.65	.0923	.0774
20	3280	3920	3.26	113.6	75.8	5.35	6.34	7.00	8.30	55.0	52.8	.0934	.0788
21	3165	3780	3.15	109.4	73.0	5.27	6.26	6.875	8.325	55.5	52.1	.0944	.0799
22	3370	4030	3.365	117.0	78.0	5.05	6.01	6.56	7.95	55.2	53.83	.099	.0833
23	3160	3770	3.14	111.0	74.0	4.81	5.73	6.145	7.50	50.2	46.6	.104	.0873
24	2640	3145	2.62	90.2	60.1	4.365	5.20	5.76	7.40	48.3	43.1	.1147	.0962
25	3780	4510	3.76	130.7	87.2	5.60	6.68	7.185	8.60	57.1	55.1	.0893	.0748
27	3625	4330	3.61	125.5	83.7	5.025	6.01	6.70	8.13	56.8	58.3	.0995	.0833
28	3215	3835	3.195	111.1	74.1	4.87	5.79	6.74	8.48	55.3	53.2	.1026	.0864
30	4030	4805	4.05	139.2	92.9	4.90	5.85	6.31	7.61	50.7	48.3	.102	.0855

*If coal costs $1.00 per ton.

Test Number.	Method of Firing	Thickness of Fire, Inches.	Firing Intervals, Minutes.	No. of Slicings.	No. of Cleanings, taking out Clinker.	Per cent CO_2 in Flue Gases.	REMARKS.
	(80)	(81)	(82)	(83)		(84)	
1	Spreading	8.	7.03	1	1	9.5	Firing Interval Irregular.
2	Do	8.	8.39	1	1	9.3	Do
4	Do	7.2	10.45	2	0	7.7	Do
5	Do	6.07	8.86	4	0	6.4	Do
6	Do	5.72	7.59	8	0	8.4	Efficiency appears low because coal sample dried before analyzed.
7	Do	5.12	4.91	7	0	8.1	
8	Do	5.42	9.81	6	....	8.2	Ash not weighed in this test.
9	Do	9.87	6.02	2	2	10.8	Thick fire, large capacity.
10	Alternate	5.91	5.0	4	1	9.0	Large capacity.
11	Spreading	5.6	9.48	1	1	7.22	Ash not weighed in this test. CO_2 appears too low, exh't'd chemical
12	Do	5.0	5.2	6	0	8.8	
13	Do	5.44	7.45	4	0	9.8	
14	Do	5.21	9.72	3	0	10.0	Ash abnormally high, making efficiency appear too high.
15	Do	5.35	7.52	3	0	11.5	
16	Do	5.61	7.52	2	1	12.1	
17	Do	5.93	7.72	2	0	10.2	
18	Do	5.98	7.63	3	0	10.0	Ash abnormally high, making efficiency appear too high.
19	Alternate	6.1	7.44	2	0	9.3	Steam quality assumed, accident to calorimeter.
20	Do	6.0	7.52	2	0	10.0	Do
21	Do	4.7	7.44	2	0	9.5	Do
22	Do	5.47	5.47	2	1	10.1	
23	Do	5.17	5.55	4	2	8.1	16'' x 16'' door in rear of setting open about 4''.
24	Do	5.21	5.17	4	2	6.9	16'' x 16'' door in rear of setting wide open.
25	Do	5.12	5.3	5	0	10.2	
27	Spreading	5.03	5.52	4	0	10.5	Ash abnormally high, making efficiency appear too high.
28	Alternate	4.73	7.71	2	0	9.9	5.62% water added to coal to find the effect of wetting.
30	Spreading	5.24	5.61	3	2	11.8	Thickness of fire varied from 4½ to 8 inches.

THE TEST RESULTS.

General.

It is noticeable that the Missouri coal gave as good, or slightly better, average efficiency than the Illinois coal. The boiler was in a little better condition for the Missouri coal tests than for the Illinois coal. This may account for the slightly higher efficiency with the Missouri coal. These two kinds of coal are so much alike that there should be but little difference in the economic results obtained from them. The fireman had no difficulty in firing the Missouri coal and stated that he would as soon fire one as the other.

These observations are confirmed by the United States Geological Survey tests with Illinois and Missouri coals fired under a Heine boiler. These tests comprised a large number of trials with Illinois coals and a smaller number with Missouri coals. The average boiler and grate efficiency with the Illinois coals was about 64%, while that for Missouri coals was 62%.

Firing Methods.

The system of firing employed, whether "spreading" or "alternate", appears to have but little effect upon the efficiency. The efficiency of boiler and grate for all of our tests on Missouri coal grouped by the method of firing is given in Table I.

TABLE I.

EFFECT OF METHOD OF FIRING.

SPREADING METHOD			ALTERNATE METHOD		
Test No.	Efficiency of Boiler.	Efficiency of Boiler and Grate.	Test No.	Efficiency of Boiler.	Efficiency of Boiler and Grate.
	%	%		%	%
6	48.05	45.15?	10	54.6	53.1
7	52.3	47.4	19	53.4	50.65
8	.....	47.25	20	55.	52.8
9	54.	49.5	21	55.5	52.1
11	.....	55.3	22	55.2	53.83
12	52.	48.4	23	50.2	46.6
13	54.	53.45	24	48.3	43.1
14	53.6	63.75?	25	57.1	55.1
15	51.3	49.	28	55.3	53.2
16	54.3	52.1			
17	53.75	52.3			
18	57.8	58.1?			
27	56.8	58.3?			
30	50.7	48.3			
Mean	53.21	52.02	Mean	53.84	51.16
Mean, with tests marked (?) omitted,		50.3			

If the results of all the tests are taken the spreading method appears to be slightly better, but if certain tests (marked ?) are thrown out because of probable errors in sampling the coal for the determination of the calorific value, the alternate method gives results a very little better than the spreading method. The difference is so small that it might easily be explained by many other causes, such as the thickness of the fire, the draft or the firing interval.

Further light may be shed on the question of the method of firing by examining certain tests with all the operating conditions nearly the same. The tests collected in Table II were run with a fire thickness between 4.7 inches and 6.1 inches, the average being 5.49 inches. The draft ranged between .4 inches and .47 inches of water, averaging .42 inches. The load carried was from 110 to 131 boiler horsepower and the firing interval varied as indicated.

TABLE II.

EFFECT OF METHOD OF FIRING.

SPREADING					ALTERNATE				
Test No.	Draft, inches.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.	Test No.	Draft, inches.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
				%					%
12	.41	5.	5.2	48.4	22	.4	5.47	5.47	53.83
13	.41	5.44	7.45	53.45	25	.4	5.12	5.3	55.1
17	.4	5.93	7.72	52.3	19	.42	6.1	7.44	50.65
11	.47	5.6	9.48	55.3	20	.42	6.	7.52	52.8
					21	.41	4.7	7.44	52.1
			Mean	52.36					
									52.89

This table of test results, selected with the idea of eliminating all the variables except the two methods of firing, shows that there is but little choice between them, the alternate method giving slightly better results.

This conclusion is confirmed by the following results published by the United States Bureau of Mines, Bul. No. 23. This bulletin gives the data of a very large number of boiler tests upon a 210 H. P. Heine boiler, handfired, with coal from all parts of the United States. Table III is compiled for the several Missouri coals used.

TABLE III.

RESULTS WITH MISSOURI COALS.

U. S. Geological Survey Fuel Testing Plant. 210 H. P. hand-fired Heine boiler.

Test No.	Designation of Coal.	Kind of Coal.	Draft, inches.	Thickness of Fire, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate.
		ALTERNATE METHOD.				
						%
326	Mo. 6	Lump	.73	6	3.6	63.40
327	Mo. 6	Lump	.75	6	3.9	60.64
15	Mo. 1	Small coal and slack	.37	8	4.5	62.32
70	Mo. 4	Small coal and slack	.52	8	5.6	60.06
319	Mo. 5	Run of mine	.61	8	4.2	61.57
329	Mo 7A	No. 1 nut	.60	8	3.5	61.26
330	Mo. 7A	No. 1 nut	.71	8	3.3	60.49
12	Mo. 1	Run of mine	.40	9	4.7	63.18
320	Mo. 5	Run of mine	.73	10	3.6	62.90
332	Mo. 10	No. 2 nut	.71	10	4.1	55.92
					Average	61.17
		SPREADING METHOD.				
78	Mo. 3	Small coal and slack	.70	6	6.9	58.94
37	Mo. 2	Small coal and slack	.62	7	6.7	59.45
44	Mo. 2	Small coal and slack	.32	7	8.3	60.68
77	Mo. 3	Small coal and slack	.65	7	7.1	56.93
					Average	59.00

If tests Nos. 332 and 77 are omitted as being considerably lower than the others the efficiency becomes 61.76% for the tests with alternating firing and 59.69% for spreading firing.

Similar results were obtained in a series of tests to determine the best method of firing with Illinois coal conducted by the United States Geological Survey. Table IV exhibits these. (See Bul. No. 373 U. S. Geological Survey or Bul. No. 40 U. S. Bureau of Mines, page 146.

TABLE IV.

EFFECT OF METHOD OF FIRING.

U. S. G. S. Test No.	Method of Firing.	Firing Interval, minutes.	Black Smoke.	Efficiency.
			%	%
500, 504	Alternate	3.5	15.8	59.87
505	Alternate	3.4	14.9	60.20
503	Ribbon*	2.3	5.0	62.22
501	Spread	9.3	32.0	57.56
502	Coking	7.4	15.0	60.49

*Ribbon firing is a special type of alternate firing. In the test quoted the doors were fired alternately. This test shows a higher efficiency than any of the other methods and about 5% higher than the spreading method.

Firing Interval.

Authorities on steam boiler practice are united in the opinion that the operation of a boiler is improved by firing the coal in small quantities at short intervals of time. There is a limit to the short interval, however, which is reached when the inrush of cold air through the fire doors causes a loss which balances the gain due to better combustion and constant fire conditions.

There is no question but that firing "little and often" will do much towards preventing smoke. This is borne out by the results of Table IV. In this series of tests the amount of black smoke produced was approximately proportional to the firing interval. It was not possible to make any observations on this phase of the question in the tests run at the Engineering Experiment Station because all the boilers in the power plant, including the one tested, discharge their smoke and gases into a common stack.

The data in Table IV indicates that the efficiency increases as the firing interval decreases. This is to be expected in the light of what has just been said about smoke prevention because smokeless firing is efficient firing unless smokelessness has been secured by admitting a very large amount of excess air.

The results of our tests collected in Table V show in a general way that short firing intervals are accompanied by higher efficiency when the alternate method of firing is used but not for the spreading method.

TABLE V.

EFFECT OF FIRING INTERVAL.

SPREADING.				ALTERNATE.			
Test No.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate. %	Test No.	Fire Thickness, inches.	Firing Interval, minutes.	Efficiency of Boiler & Grate. %
7	5.12	4.91	47.4	10	5.91	5.	53.1
12	5.	5.2	48.4	25	5.12	5.3	55.1
30	5.24	5.61	48.3	22	5.47	5.47	53.83
9	9.87	6.02	49.5	21	4.7	7.44	52.1
13	5.44	7.45	53.45	19	6.1	7.44	50.65
15	5.35	7.52	49.	20	6.	7.52	52.8
16	5.61	7.52	52.1	28	4.73	7.71	53.2
17	5.93	7.72	52.3				
11	5.6	9.48	55.3				
8	5.42	9.81	47.25				

Thickness of Fire and Clinker Troubles.

It was our intention to make tests to show the effect of different thickness of fire. The idea was abandoned after one test, No. 9. This test was made with a thick fire, averaging 9.87 inches, and so much trouble was experienced with clinker that the fire had to be cleaned twice in the 9½ hours run. This test clearly demonstrated that the clinkering properties of this coal prevented its successful use with thick fires.

Thick fires are generally economical because the higher resistance to the passage of air through the grate and fire bed reduces the amount of excess air entering the furnace and thus increases the temperature of the fire and gases of combustion. In general these are conditions desirable for high efficiencies, but they are not desirable when the coal has a tendency to form clinker. The high temperature of the fire bed causes the ash to melt and fuse together. The result is a clinker.

A similar condition of affairs is shown in Tests Nos. 23 and 24. In these tests, although the fire was not thick, the draft over the fire was low, only about 1-10 inch of water. This resulted in a low air supply and a hot fire. A heavy clinker formed and the fire had to be cleaned twice during the ten hour tests.

In Test No. 30 an attempt was made to get the maximum capacity out of the boiler. The fire was forced too much and very bad clinker formed. The fire had to be cleaned twice and the capacity reached was not as high as in Test No. 10. In Test No. 30, however, the coal was very poor, being mostly slack and fine dust. More coal was fired than would burn and the fire varied from 4½ to 8 inches in thickness*. The average thickness was 5.6 inches. The principal difficulty in this test was that the fire was too thick for the fine coal which was being fired.

Tests Nos. 15 and 16 were also run with low draft, but in these cases the coal contained but little slack and the capacity developed was not large. These factors account for the absence of much clinker.

Wetting Coal.

Test No. 28 was made to determine the effect of wetting the coal upon the efficiency. Wetting the coal will often benefit clinker troubles by keeping the fire bed cooler. When fine coal is being fired wetting the coal sometimes serves as a kind of binder which holds the coal together and reduces the loss of good fuel through the grates. The results of Test No. 28 show a slight decrease in efficiency when compared with Tests Nos. 25 and 27, which are in the same group but which were run with a shorter firing interval. Test No. 28 should be compared also with Nos. 19, 20 and 21 in which the firing conditions are about the same, or with Nos. 15, 16 and 17, where the operating conditions are similar but which are fired by the spreading method instead of the alternate. These comparisons indicate that wetting the coal has but little effect upon the efficiency and that the heat lost in evaporating the water on the coal is balanced by decreased loss of fuel through the grate and by the

*This wide variation in fire thickness is accounted for by the fact that all other conditions were sacrificed to the endeavor to reach a high capacity with the poor coal. Ordinarily the fire was kept at practically constant thickness.

reduction of clinker troubles. It should be noticed that Test No. 28 required no cleaning and was sliced but twice. This is less than any of the other tests run at about the same time.

Test No. 6 was also run with a very wet coal which had been exposed to a heavy snow storm. This is not shown in the analysis of the coal because the glass jar holding the sample was accidentally cracked. The crack was not noticed and the sample dried out before the analysis was made. This test shows an equivalent evaporation per pound of coal as fired about 10% lower than other tests run under the same conditions.

The United States Geological Survey found that the boiler efficiency fell off about 1% for every 3% increase in the moisture in the coal.

In general it is important to keep coal dry and protected from the weather. Besides the loss in efficiency which often results from the use of wet coal, it is well known that wet coal, unless stored submerged under water, deteriorates more rapidly than coal which is kept dry and protected from the weather.

Cleaning.

The greatest improvement in the efficiency of the boiler appears when the effect of cleaning the boiler is invstigated. This is well shown in Table VI, by the tendency of the higher efficiencies to collect at the top of the table in the region up to 6 days after cleaning.

TABLE VI.

EFFECT OF CLEANING.

Test No.	Days after Cleaning.	Efficiency of Boiler & Grate.
25	1	55.1 %
11	3	55.3
18	4	58.1
22	6	53.83
7	6	47.4
12	7	48.4
28	8	55.3
13	8	53.45
8	8	47.25
9	9	49.5
10	10	53.1
19	10	50.65
15	10	49.0
20	11	52.8
16	12	52.1
21	11	52.1
17	13	52.3

It is to be noted that the efficiency for the first few days after cleaning is increased by 5% to 6% over the average of all the tests. This indicates the importance of frequent and thorough cleaning of the entire boiler.

In these tests the boiler was fed from a cold water supply through the injector. The cold water contains considerable scale forming material. In the intervals between tests the boiler was fed with hot water from the heating returns passed through feed-water heaters.

Geo. H. Barrus (Engineering Record, June 24, 1911, p. 690) describes two tests to show the effect of cleaning the heating surface of a boiler. The evaporation increased about 5% after cleaning.

Air Leakage in Setting.

Tests Nos. 22, 23 and 24 were made to determine the effect of air leakage in the setting. It is known that the setting itself is about as tight as any ordinary boiler setting in average condition. The leakage was increased by opening the 16″ x 16″ cleaning door in the rear of the setting about 4 inches on Test No. 23 and wide open on Test No. 24. For Test No. 22 this door was closed and the boiler operated under ordinary conditions. The same firing conditions were maintained for the three tests. The results are:

Test No. 22,	door closed.........	53.83% efficiency	10.1% CO_2
23,	door open 4″.......	46.6	8.1
24,	door open wide.....	43.1	6.9

These indicate the importance of making the setting as tight as possible. They also show that the percent of carbon dioxide in the flue gases is indicative of the amount of air leakage.

Firemen.

The fireman is by far the most important factor in securing higher boiler economy. A good fireman is careful and consciencious in the handling of his fire and studies his boiler and his fuel in an endeavor to get the largest possible evaporation per dollar's worth of coal fired. A good skillful fireman can undoubtedly increase the efficiency of the operation of a boiler by 10% to 15% over that secured by an indifferent and careless fireman. A really good fireman is not easily picked up and when one is secured it is well worth while to pay him enough to secure his interest and loyalty to the plant.

A series of tests described in the Engineering Magazine, Vol. 40, p. 83, shows this difference in firmen clearly. The boiler upon which the tests were made was equipped with a Hawley down-draft furnace. One fireman fired large quantities of coal at long intervals and frequently threw coal on the lower grate. He claimed that he could not carry the load without this understoking. The second fireman fired small quantities of coal at frequent intervals. He worked the boiler carefully and did not resort to understoking, although he carried a larger load. The efficiency with the first fireman was 67.5% and with the second 81%. The 13.5% gain was due to careful attention and proper firing.

CO_2 Recorder.

Other things being equal a reasonably high percentage of carbon dioxide (about 14% for Missouri coals) is indicative of maximum efficiency. A good CO_2 recording instrument is of considerable value in showing combustion conditions and furnishes a guide for the fireman in handling his fire. This is illustrated by two tests recorded in Power, Dec. 8, 1908. The tests were of 24 hours duration on a 500 horsepower boiler equipped with a Roney automatic stoker, located in the plant of the Malden (Mass.) Electric Co. In the first test the CO_2 recorder was covered so that the fireman could not see it, in the second it was open for his inspection and guidance. The average results were:

Test No. 1. 7.7% CO_2; 59380 lbs. coal used. Equivalent evaporation, 9.9 lbs.

Test No. 2. 11.2% CO_2; 55955 lbs. coal used. Equivalent evaporation, 10.8 lbs.

A CO_2 recorder is a rather delicate instrument and must be carefully attended. In itself it has absolutely no effect upon the operation of the boiler, but if it is used to show what is happening in the furnace its indications may be made the foundation upon which a considerable increase in efficiency may be built.

Summary.

1. An increased use of Missouri coals would stimulate Missouri coal mines, improve their working conditions, decrease the cost of coal and increase the prosperity of the state.

2. Missouri coals, when properly handled, may be used with as high efficiency as any of the bituminous coals of the neighboring states.

3. Missouri coals are not harder to fire than other middle west bituminous coals.

4. The alternate method of firing gives slightly better results than the spreading method.

5. Short firing intervals are desirable with the alternate method of firing.

6. The thickness of the fire must be varied to suit the size of coal fired. For broken run-of-mine coal, under boilers similar to the one tested, the fire thickness should be about 5 or 6 inches.

7. Missouri coal tends to clinker when the excess air supply is low, when the boiler is forced, and when the fire is too thick.

8. Wetting the coal is sometimes successful in reducing clinker and the loss of unburned fuel through the grates. Otherwise it tends to reduce the efficiency.

9. It is highly important that the boiler be kept clean and free from scale and the tubes free from soot. Frequent cleaning and non-scaling water are well worth their cost.

10. Air leaks in the setting greatly reduce the efficiency. The setting should be carefully inspected periodically and all leaks repaired.

11. A careful fireman is a prime requisite for high efficiency and is worth higher wages than are usually paid.

12. A CO_2 recorder may be made a valuable guide to the fireman in handling his fire.

PART II.

GENERAL PRINCIPLES OF COMBUSTION AND BOILER OPERATION.

COAL.

Coal is a solid, opaque, combustible substance consisting mainly of carbon. It is found in layers or seams up to thirty or more feet in thickness in the upper crust of the earth. Coal mines are rarely deep mines. The average thickness of minable coal seams in Missouri is about 4 feet.

Coal is generally understood to be the remains of prehistoric forests of plants similar to those found in tropical countries today, but much larger and much more rapid in their growth. The refuse of these forests which fell to the ground collected for years and centuries until a thick layer, possibly hundreds of feet thick, was formed. Then, by some disturbance on the unstable surface of the earth, this layer of vegetable matter sank down and became covered with water, followed by the disposition of mud and sand which was brought to the sea by the rivers and covered the layer of vegetable matter deeper and deeper. Finally through the combined effects of time, pressure and heat the bed of vegetable matter became a seam of coal. In burning coal we burn the forests of prehistoric times.

Coals from different seams differ in their chemical and physical characteristics. This has caused the division of coal into several classes which have no well defined line of separation. These are:

Anthracite
Semi-anthracite
Semi-bituminous
Bituminous
Lignite.

Anthracite coal is the oldest coal formation. It is very hard, has a bright lustre and is not so dirty as bituminous coal. The common name, "hard coal", describes it well.

Semi-anthracite and semi-bituminous coal are coals which lie between anthracite and bituminous. They closely resemble one or the other of these two larger classes as their names suggest.

Bituminous or "soft" coal, is easily broken and shows a stratified structure clearly. The surface is usually dull, but a freshly broken piece shows some lustre. Bituminous coals often have thin white or bronze colored seams running through them. This is a deposit of earthy or mineral matter which forms ash when the coal is burned.

Lignite has a brown or black-brown color and is soft and easily broken. It often shows a vegetable structure and deteriorates rapidly when exposed to the action of the weather.

Missouri coals are all bituminous coals of about the same general characteristics as the coal of Illinois and the other Middle West coal producing states.

Coal consists of a combination of the following six substances:

Carbon
Hydrogen
Oxygen
Nitrogen
Sulphur
Ash.

Carbon occurs in many different forms. Lamp black and soot are nearly pure carbon. Charcoal and coke are part of the carbon with the ash of wood and coal respectively. Carbon is the principal combustible material in coal.

Hydrogen, oxygen and nitrogen are gases. Hydrogen is the only one of them that is combustible. When it is supplied with the proper amount of oxygen it burns with a very hot, nearly colorless flame. The product of the union of hydrogen and oxygen in combustion is highly superheated steam and may be condensed into water.

Oxygen does not itself burn but must be supplied in order for any combustible substance to burn. For this reason it is called a "supporter of combustion."

Nitrogen will not unite with oxygen or other substances under ordinary conditions. It is said to be an inert gas. It forms about 79% of the total volume of the air, the remaining 21% being oxygen. There are a few other gases besides oxygen and nitrogen in the air, but their volume is so small that it is not considered. Nitrogen in coal is usually present in small amounts combined with other substances. The nitrogen in the air and that in the coal does not undergo any change in passing through the furnace and contributes nothing to the heat of combustion. It dilutes the oxygen and increases the total volume of the products of combustion.

Sulphur burns with a bluish flame. It does not occur free in the coal but is combined with other substances. Sulphur is regarded as undesirable in coal. It adds but little to the heating value and is usually thought to increase the tendency to form clinker.

Ash is the inert noncombustible material of coal.

In the "ultimate" analysis of a sample of coal, the amount of each of the six substances just described is determined and is expressed as a percentage of the total weight of the coal.

Coal is often described by the "proximate" analysis. This is much easier to make than the "ultimate" analysis. In this analysis the following four substances are determined and expressed as a percentage of the total weight of the coal:

Fixed carbon
Volatile matter
Moisture
Ash

Fixed carbon is carbon in a nearly pure form. It is the coke which a certain coal will produce minus the ash which is contained in the coke.

Volatile matter consists mainly of hydrocarbon compounds, that is, chemical combinations of carbon and hydrogen. It includes the gases of coal, like illuminating gas, together with tarry vapors and other similar substances.

Moisture and ash are self explanatory.

The method of making the proximate analysis is given briefly below.* It also illustrates the manner in which the various constituents in the coal behave when the coal is burned.

A sample of the coal is finely ground so as to pass a sieve with from 60 to 100 meshes per inch. One gram of this is accurately weighed in a crucible and then placed in a drying oven which is kept at a constant temperature slightly above the boiling point of water under atmsopheric pressure. After one hour the sample is removed, cooled and weighed again. The object of this operation is to drive off the moisture. The loss in weight before and after drying gives the weight of moisture in the one gram sample.

The same sample in a crucible with a loosely fitting cover is then placed over a Bunsen flame of a certain size and left for seven minutes, cooled and again weighed. While heated over this flame the volatile matter in the form of gases, tarry vapors, etc., are driven off and burn around the edges of the crucible cover. After weighing, the difference in weight before and after this operation is the amount of volatile matter. The time seven minutes with a definite size flame has been adopted as a standard, because by longer or shorter heating slightly greater and lesser amounts of the material in the coal would be distilled off as volatile matter. The term "volatile matter" is somewhat loose and there is no well defined point for separating the carbon in the volatile matter from the fixed carbon, except by such an arbitrarily chosen method as outlined.

*For more complete details see:
Journal of the American Chemical Society, Vol. XXI, No. 12, Dec, 1899. (Published by Chemical Publishing Co., Easton, Pa.)
Also, Technical Paper No. 8, United States Bureau of Mines. (Address "Director, Bureau of Mines, Washington, D. C."

What remains of the original sample is now the coke of the coal. It consists of the fixed carbon and the ash. The fixed carbon is determined by placing the coke sample uncovered over a very hot flame and leaving it there until only the ash remains. This may take several hours. Weighing again the difference in weight before and after burning out the fixed carbon gives its weight. The weight of the remaining ash is then known by subtracting the weight of the empty crucible from the weight of the crucible and the ash.

Summarizing, it is seen that coal is complex in its structure and consists of several chemical elements which may be collected into the substances determined by the proximate analysis.

(a) Moisture.

(b) Volatile matter, consisting of gases and tarry vapors, easily driven off when the coal is heated. It burns quickly.

(c) Fixed carbon, requiring a long time for its combustion.

(d) Ash, incombustible material.

The percent which each of these bear to the total weight of the coal is given in the proximate analysis. Sulphur is occasionally given also, but it is determined separately by an entirely different method.

The classification of coals is often based upon the amount of fixed carbon which they contain. This is not the best classification but it is the one most used.

	Percent of Fixed carbon in the Combustible*	Percent of Volatile Matter in the Combustilble.
Anthracite	100 to 92.3	0 to 7.7
Semi-anthracite	92.3 to 87.5	7.7 to 12.5
Semi-bituminous	87.5 to 75.	12.5 to 25.
Bituminous	75. to 50.	25. to 50.
Lignite	50. to 0.	over 50.

Coal is mined in all sizes from large lumps to fine dust. This mixture of sizes just as it comes from the mine is known as "run-of-mine" coal. The run of mine coal is often passed over screens to separate it into different sizes before it is sold. The large lumps which pass over the screen are called "lump coal" and the fine stuff which passes through the screen is called "slack", "breeze" or "screenings". Sometimes an additional screen is used to separate out what is called "sized egg" or "nut" coal. The name suggests the size.

*By "combustible" is meant the combustible matter of the coal, i. e., the total coal minus the ash and moisture.

At some mines coal is graded according to the following table:

No. 1—Coal passing through	3	inch screen and over	1¾	in. screen
No. 2—Coal passing through	1¾	inch screen and over	1	in. screen
No. 3—Coal passing through	1	inch screen and over	¾	in. screen
No. 4—Coal passing through	¾	inch screen and over	¼	in. screen
No. 5—Coal passing through	¼	inch screen		

COMBUSTION.

Combustion is the rapid union of a substance with oxygen. Heat is given off in the process. The substance which burns, or with which the oxygen unites, is called "the combustible".

Carbon burns, or unites with oxygen, and the combustion may be **complete** or **incomplete.**

Complete combustion results when carbon is supplied with all the oxygen with which it can unite. This can be determined by definite laws of chemistry. When complete combustion of carbon takes place an inert, combustible gas, called carbon dioxide, is formed. This gas is sometimes represented by the chemical symbol CO_2.

If the oxygen supply for the carbon is deficient, incomplete combustion will take place. In this case a combustible gas, carbon monoxide (represented by the symbol CO) is evolved.

Heat is always given off when combustion occurs and the same amount of heat* is always generated when a given amount of the same substance is burned to the same completeness of combustion. Thus when one pound of pure carbon is burned completely to carbon dioxide (CO_2), 14500 B. t. u. are always given off. When one pound of pure carbon is burned to carbon monoxide (CO), 4400 B. t. u. are evolved. Furthermore, when the carbon monoxide resulting from the incomplete combustion of one pound of carbon is burned, the product of the combustion is carbon dioxide, and the heat evolved is 10100 B. t. u. Thus the same amount of heat is evolved, viz. 14500 B. t. u., when a pound of carbon is burned, whether the combustion proceeds directly to completeness or goes through two processes to completeness. If the combustion passes through two stages, however, and some of the carbon monoxide passes away unburned, the heat which it would furnish, at the rate of 10100 B. t. u. per pound of carbon, is lost.

The complete combustion† of one pound of hydrogen forms steam and about 62000 B. t. u. are given off.

*The unit of heat is the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit. This is called the "British Thermal Unit (B. t. n.)."

†The combustion of most of the substances occuring in coal except carbon is always complete.

The oxygen necessary for the combustion of coal in a furnace comes from the air. Air, being a mixture of oxygen and nitrogen in the proportion of 21% and 79% by volume respectively, supports combustion. The nitrogen of the air passes through the furnace without change. In boiler practice in order to be sure that sufficient air is provided it is necessary to supply somewhat more than just enough air to carry in exactly the amount of oxygen for the combustion. In the best practice only about 40% excess air is supplied, but in many plants the excess may be 200% and more.

The amount of carbon dioxide (CO_2) formed is always the same for the complete combustion of a given weight of carbon, no matter how much excess air is supplied. The per cent of carbon dioxide, or the volume of carbon dioxide compared with the total volumes of all the gases (CO_2, CO, hydro-carbons, air, nitrogen, etc.) leaving the furnace, becomes smaller as the amount of the other gases increase. This can be illustrated by the following example: Suppose a quart of milk and a quart of water are mixed together, the milk will then be one half, or 50% of the total mixture. Now increase the water to three quarts with one quart of milk. The actual amount of milk is the same but now it is only one fourth, or 25%, of the mixture. In the same way the percent of carbon dioxide, CO_2, in the gases leaving the furnace decreases as the amount of excess air increases.

When a shovel full of soft coal is thrown on a bed of hot incandescent fuel, the moisture and volatile gases are first driven off very rapidly, and in large volumes. The action is so rapid and the volumes of gas so large that there is but little opportunity for proper mixture with air for burning. Furthermore, some heat is necessary to warm up the coal and drive off the volatile matter, so that the process cools off the furnace. The volatile gases are the same as those driven off by the Bunsen burner in the proximate analysis. In order to thoroughly understand what occurs in the furnace it is necessary to study those volatile gases.

Experience with common illuminating coal gas, and also with producer gas, has shown that these gases contain a large amount of tar which must be removed before the gases can be used for light or in a gas engine. We should expect to find the same tar present in the volatile gases driven off in a boiler furnace.

An idea of the behavior of the tar in the furnace may be gained by pouring a little tar on a hot iron plate. A dense brown tarry smoke is given off. We know that this is probably not a gas for gases are usually transparent and invisible. It is hard to imagine that this smoke is made up of little solid particles. It is more probable that the color is given to the smoke by small particles of the tar in a liquid or semi-liquid form, like the spray from an atomizer. It is quite easy to imagine tiny little globules of tar, small and light enough to be carried along with the gases. They are similar to the nicotine carried along with tobacco smoke, which may be caught as a deposit if the smoke is blown through a cloth.

The soot deposited on the tubes and that which passes out of the stack and blackens the surrounding neighborhood is evidence of little solid particles of unburned carbon.

Thus in the products passing out of the furnace we may expect to find volatile gases, liquids in the shape of small, round, tarry globules, and small solid particles of carbon. If all of the possible heat of the fuel is obtained all of these things must be completely burned.

There are three conditions necessary for the complete combustion of any substance:

1. A sufficient supply of oxygen, usually in the form of air.

2. The maintenance of a temperature above the ignition temperature of the substance to be burned.

3. A thorough mixture of the combustible with the oxygen or air so that every particle of the combustible may find the oxygen necessary for its combustion.

The first condition is easily obtained in boiler practice by adjusting the air supply with the dampers.

High temperature will follow when good combustion is secured provided the excess air is not too great.

A satisfactory mixture of air with some of the combustible material is the most difficult to obtain. With the true gases the mixture is comparatively easy because it is the nature of gases to diffuse readily and become intermingled into a homogeneous mixture. With the tar globules the problem is quite different and a good mixture is difficult to obtain.

Consider one of the tar globules as it is carried along in the current of gas. It travels at about the same rate as the gas stream so that there is but little tendency for the gases to rub past it or have any kind of scrubbing action upon it. The result is that after the outer layer of the globule is burnt it becomes surrounded by a blanket of inert gases. These do not have time to diffuse into the surrounding gas stream and are not scrubbed away by it so that they prevent further burning of the tar globule by keeping the necessary oxygen from coming into contact with it. The behavior of solid particles of carbon which are formed by the decomposition of some of the gases is quite similar to that of the tar globules, so that these two constitutents of the products of the furnace tend to pass out of the stack incompletely burned. They appear as soot or smoke.

The principles of combustion and the effect of proper mixture and air supply may be illustrated by the common oil lamp.

If the chimney is removed black smoke is formed. This is caused both by the cooling effect of the large amount of air which has access to the flame and because the unconfined air and gases move at a low velocity and do not scrub away the burnt gases fast enough. If the chimney is replaced the air and gases inside the chimney are confined and move with much higher velocity and the flame is protected from the cooling effect of the outer air. The higher velocity of the gas inside the chimney scrubs off the burnt gases so that the air supply from the bottom of the chimney has easy access to the combusible gases. If the hand is placed over the openings at the base of the chimney so that the air supply is cut off, a smoky flame is again produced because the air supply is insufficient.

Going back to where the shovel full of coal was fired, it is found that the fixed carbon is left after the moisture and volatile matter is driven off. The fixed carbon burns as a bed of yellow or white hot coals upon the grate. Air passes up through the grate and burns the first or lower layers of carbon to carbon dioxide (CO_2). In the presence of very hot carbon and little air the carbon dioxide formed unites with carbon in its passage upward through the fuel bed and forms carbon monoxide (CO). This operation takes up heat, 10100 B. t. u. per pound of carbon. The carbon monoxide mixed with some unchanged carbon dioxide issues from the top of the fuel bed and if the carbon monoxide is supplied with air it will burn to carbon dioxide and return the 10100 B. t. u. previously taken up. The air for this combustion may be furnished over the top of the fuel bed or may come from excess air passing up through the grate.

Geo. H. Barrus (Engineering Record, June 24, 1911, p. 690) shows by two tests that an increase of 10% in the equivalent evaporation per pound of coal was obtained by admitting air over the fuel bed to burn the volatile gases and carbon monoxide.

One pound of average Missouri coal gives off about 12600 B. t. u. when it is fully consumed. In the ordinary plant only about 45% to 70% (averaging about 50% in the majority of the smaller plants) of this heat is present in the steam formed. That is, only about one-half of the coal supplied is actually used in making the steam, the other half supplying the losses. There are several of these losses and the majority of them are unavoidable.

1. There is a loss due to unconsumed fuel falling through the grate, or wasted by being pulled out with the clinker when cleaning

the fire. This is a direct loss of unconsumed fuel, but it is unavoidable, except that in many cases an excessive amount is carelessly pulled out in cleaning. This loss is small, usually in the neighborhood of 4% to 6%.

2. The loss due to the incomplete combustion of the carbon that burns to carbon monoxide amounts to as much as 3% to 4%. It can be eliminated by sufficient air supply and proper mixing.

3. The heat lost in evaporating the moisture in the coal may reach as high as 6% in some cases and is unavoidable, except that the percent of moisture in the coal can be reduced to a minimum by keeping the coal in a dry place.

4. There is a loss due to the moisture formed in burning hydrogen, amounting to about 5%. This is unavoidable.

5. Heat radiates from the setting and this loss amounts to some 2% to 5%. It is unavoidable but it can be reduced to a small extent by insulation of the walls of the setting. This is seldom practiced.

6. There is an avoidable loss in the unconsumed fuel which passes out of the furnace in the form of carbon particles and little tar globules and is directly seen as soot and smoke. This loss is often as large as 10% and nearly all of it can be prevented by proper air supply, proper firing and a thorough mixture of air with the volatile gases. The loss due to carbon particles or soot alone is probably 1% or 2%.

7. Another large and partially avoidable loss is that due to the heat carried away by the chimney gases. This loss amounts to as high as 40% in some boiler plants, but by careful manipulation and adjustment of the air supply it may be reduced to about 15% or 18%.

The last two of these losses are large and are the ones which can often be considerably reduced with a corresponding increase in the boiler efficiency.

The loss in the unconsumed fuel which passes out of the furnace with the volatile matter may be reduced in two ways:

First, from the description of the tar globules and their behavior it appears that if sufficient scrubbing action by the hot gases upon the envelop of inert gas surrounding the tar globules could be produced, the loss would be reduced because more of the tar would be burned. To increase the mixing and scrubbing action wing walls and mixing piers are used in the furnace. They tend to break up the stream of gas and form swirls and eddies. They are difficult to keep in repair because of the high temperature to which they are subjected. The second and better method is to prevent as far as possible, the formation of the tarry globules. This is what is accomplished by the use of automatic stokers and down draft furnaces.

In the stoker the coal moves into the furnace slowly and is gradually heated up. The process is not almost instantaneous as when a shovelful of coal is thrown on a hot bed of coals. As a result the gases are distilled off slowly instead of in great volumes all at once. Ample time is thus given for mixing with the air necessary for combustion. The distilled gases must pass over the hot fuel bed and be scrubbed by the hot air rising through it. The little tar globules are exposed to a high temperature longer and may even become gaseous and easily burned. An automatic stoker is coking firing and firing "little and often" reduced to the lowest possible limit.

Stokers have one further advantage in that the conditions inside the furnace are practically constant and uniform, instead of constantly and rapidly changing as in a hand fired furnace. Thus if the draft and air supply are once properly adjusted, they will continue to be correct until the feed of the stoker is changed.

Stokers reduce the boiler room labor costs in large plants but not in small plants.

The down draft furnace also serves to distill the volatile matter slowly.

An important factor in securing complete combustion of the volatile matter is in the use of tile roofs over the grate. If the gases strike a comparatively cool surface, such as the boiler shell or tubes, they are cooled below their ignition point and condensed into the tarry globules which are so hard to burn.

In the hand fired furnace, except the down draft type, it is difficult to prevent rapid distillation because the firing must necessarily be intermittent. Much can be done by breaking the coal into uniform pieces, about egg size, and by carefully scattering small charges of coal at frequent intervals. With small uniform sized lumps of coal the distillation is general instead of localized as is the case when large lumps are fired. In the latter case little opportunity is given for mixing and heating because the volume of the gas distilled at one place is so large.

Frequent firing well scattered gives an opportunity for mixing and approaches the operation of a stoker with continuous distillation.

The loss carried away as sensible heat in the flue gases can be reduced by reducing the temperature and weight of the flue gases. These gases act as a carrier of the heat from the furnace to the boiler. The boiler cannot remove or absorb any heat which exists as heat in the gases below the temperature of the boiler. Thus the gases must always carry off some heat up the stack. When reduced to a minimum this loss is necessary and unavoidable. It is necessary because the hot chimney gases cause the draft which draws air into the furnace and it is unavoidable because it is impossible for the boiler to absorb the heat when the gases are at or near the temperature of the steam.

This loss will be a minimum when the weight of the flue gases multiplied by their absolute temperature is a minimum.

The direct cause of the extremely large loss found in the average small plant is due to the large amount of excess air supplied, for it is this alone that increases the weight of the gases. All the excess air, together with the nitrogen in the required air, is heated from the temperature of the fire room to that of the chimney gases. The heat to do this comes from the coal. The excess air may come through too thin a fire, holes in the fire or leaks in the setting.

The loss of heat from air leakage is apparent. Every fireman knows that if the fire doors are left open the pressure will begin to drop. He never leaves the doors open after firing if he expects to make steam.

It is quite an easy matter to cut down an excessive air supply. In many cases it will be found that the excess air is passing through holes in the fire. This may appear to be a trifling matter, but a few holes in a fire may together have the same area as the fire door. They then admit as much air as the fire door would if it were left open. If it is important to keep the fire doors closed it is just as important to watch the fire and keep the holes in it closed.

The amount of air which a setting, apparently in the best condition, will leak is surprising. The settings of the test boilers of the U. S. Geological Survey plant were kept in the very best condition. One of their bulletins states that one man was almost constantly employed for nothing else than patching air leaks and keeping the settings in good repair. Test results on these boilers showed an air leakage of about 26%, that is, about one-fourth as much air leaked through the setting as was supplied through the grates. It is quite probable that the leakage in ordinary settings is very large, possibly 50% to 70%.

In good practice about 40% excess air is required in order to have sufficient to insure good mixing. This corresponds to about 13% to 14% CO_2 in the flue gases for average Missouri bituminous coal. In many of the average smaller plants 200% or more excess air is admitted. The corresponding proportion of CO_2 is about 6%. The avoidable loss (waste) in such a case is about 10%.

Clinker.

Clinker is caused by the fusion, or melting and running together, of the ash left when coal is burned. It has been shown lately that the ash of different coals have different fusing temperatures. The ash of one coal may fall through the grate unchanged because the temperature of the fire was too low to fuse it, while the ash of another coal under similar conditions may melt and run together to form a hard clinker. The ash with a high fusing temperature may partially melt and become soft so that a thick and pasty, but porous mass is formed which sticks together but still allows the passage of some air. Under similar conditions the ash of low fusing temperature melts and forms a sticky, semi-fluid mass which spreads out and runs over the entire grate, covering it with a thin vitreous clinker which effectually prevents the passage of air. This type of clinker covers a larger area than the other and does not admit even a small amount of air through it. It also tends to run down between the grate bars so that it is very difficult to remove.

When the fuel bed over the grate is cool very little clinker forms. This can be seen by watching the fire just after it is cleaned. At first there is no ash on the grate and the cold air rushing up through the bars, keeps the fuel bed near the grate cool. When the ash begins to collect and pack together the air passages are partially closed up and the cooling action reduced. As a result the temperature of the fuel bed near the grate increases. This tendency continues to increase as the amount of ash collected on the grate increases. Finally a point is reached where the ash fuses and clinker begins to form. Before this the coal burns freely and quickly upon the grate and it requires close attention to keep holes out of the fuel bed. As soon as the clinkers begin to form the coal does not burn so readily and the fire begins to increase in thickness.

Forcing the fire increases the temperature and therefore increases the tendency to form clinker, and the clinker formed is likely to be quite fluid so that it spreads over a large part of the grate area. If it is not removed it gradually reduces the air supply and causes the capacity to fall off because of the difficulty of burning the coal. A clinker of this kind is so soft that it is hard to handle when cleaning or slicing the fire.

The tendency to clinker can often be reduced by wetting the coal, the use of steam jets under the grate or water in the ash pit. All of these means have their effect by cooling down the fire. They all results in a direct loss of heat but sometimes make forcing possible under conditions and with fuel which would not otherwise allow it.

Fire Thickness.

The question is often asked, "What is the best and most economical thickness of fire?" No definite answer can be given because so many variable factors enter into the circumstances which control the best fire thickness.

One of the most important of these factors is the size of the coal used. If the coal is all fine slack the fire must be kept thin. The fine particles of coal pack together and tend to fill up the voids or interstices in the coal, making it difficult for the air to get through. If the fuel bed is thick it may not be possible for enough air to pass through to burn the coal. Only such coal as receives the necessary air will burn, so that a thick bed of fine coal will evaporate less water into steam than a thinner fire bed which allows the necessary air to pass through it. If the draft is increased more air will, of course, be drawn through the thick fuel bed, but the losses from the leakage of cold air through the setting are also increased.

With nearly uniform sized egg coal a thicker fire should be carried than with fine coal because the air easily passes through the larger crevices formed in the bed of larger fuel. In order to keep the excess air down to a reasonable amount it is necessary to make the fuel bed thicker so as to increase the resistance to the flow of air.

In general, the larger the lumps and the less slack in the coal, the greater the thickness of the fuel bed. On account of the difficulty of burning the large volumes of volatile matter set free, it is essential that large lumps be crushed. Lumps larger than a man's fist should not be fired. Besides the difficulty of imperfect combustion of the volatile matter, it is found that large lumps cause a fire to burn in holes. The air comes in around the edges of a lump and burns the surrounding small fuel faster than the lump. Soon a hole is left around the lump.

Up to a certain thickness, depending upon the size of the coal and the draft, a thick fire will give greater capacity because holes are less likely to form. A thin fire requires great regularity of firing and close attention to keep all holes covered. A thick fire is easier to fire and takes less attention, but the economy is likely to be lower. Thick fires are more subject to clinker troubles than thin ones. The draft as well as the size of the coal, is of importance in fixing the proper thickness of the fire. With a low draft, for any size coal, the fire bed must be thinner than with a high draft, because with low draft the resistance to the passage of air must be low. A high draft requires a thick fire to increase the air resistance and cut down the excess air.

Draft Capacity and Rate of Combustion.

In most plants the practice is to use all of the draft available. If the steam pressure rises too high, some firemen open the furnace doors, others close the flue damper, open the breeching door or close the ashpit doors.

The practice of opening the fire doors is very bad, first, because it makes an increased loss due to the large amount of heat carried off by the air, and second, the cold air rushing in cools the boiler plate quickly and causes sudden contractions and temperature stresses. These weaken the plate and produce leaky seams.

Closing the stack damper or opening the breeching doors is to be preferred to closing the ashpit doors, because these do not cause an increase of air to be drawn in through the setting leaks as is the case with closing the ash pit doors.

For a large capacity, the rate of combustion must be increased, a larger amount of coal must be burned on the same grate, requiring more air and a good draft. When boilers must be forced particular attention should be paid to keeping the setting tight and free from leaks.

The rate of combustion depends directly on the intensity of the draft and the thickness of the fire. A thick fire is usually necessary when a large capacity is to be developed but thick fires do not burn coal with the best efficiency. Accompanying a thick fire there is likely to be a large loss due to incomplete combustion of carbon because the air supply is reduced to a minimum.

We found the maximum rate of combustion for the Missouri coal we tested to be about 25 or 30 pounds of coal per square foot of grate surface per hour, with a draft of about .6 inch of water at the stack damper. Even at this rate the fire was white hot and the clinker very soft. Much slicing and cleaning was necessary with a consequent large loss of combustible drawn out with the clinker. A lower rate of combustion would have given a better efficiency and less clinker trouble.

Too high a draft will cause the fine coal to be carried away from the fuel bed unburned. Even a draft of .15 inch of water over the fuel bed was found to carry fine particles over the bridge wall. In locomotive practice the draft is very high, compared with stationary practice, and large pieces of carbon, many one-fourth inch in diameter, are thrown out of the stack. Tests by the U. S. Geological Survey have shown the loss due to these cinders thrown out the stack to be in some cases as high as 5%, with run of mine coal, the draft being about 2½ inches of water over the fuel bed.

Too low a draft will cause a very hot fuel bed and consequently much trouble with clinker. It will be noticed that much the same effect is produced by reducing the draft or thickening the fuel bed as both decrease the air supply.

Cleaning and Slicing.

Fires are usually cleaned or sliced when there is sufficient clinker to cut off the air supply and reduce the capacity appreciably. If the clinker is rather thick, porous and easily broken, such as is obtained by a slow rate of combustion, a slice bar can be run underneath the clinker and raised just high enough to break the clinker a little, shake some ash down and allow more air to pass through the fuel bed. In this operation care must be taken not to raise the slice bar through the fuel bed because the green coal, ash and hot fuel are then all mixed together. This increases clinker troubles, and produces a fire full of holes.

Sometimes a fire is in such a condition that the large clinker can be removed with the slice bar, but unless all of the clinker is removed and a thorough cleaning takes place, the fire is usually left mixed up and in very bad condition.

An attempt to slice a very hot fire where the clinker is in a pasty mass, usually ends in a bad fire with clinkers sticking to the grate. It may be necessary to let the fire cool somewhat before slicing.

The method of cleaning a fire by pulling the clinker out with a slice bar does not waste as much combustible but takes more time than the regular method. It cannot always be done on account of high temperature and soft clinker. The common method of cleaning described below is probably the best way to treat a fire which is not developing the required capacity, unless the clinker is porous and can be broken up by a careful slicing without disturbing the fuel bed.

In the ordinary method of cleaning enough fuel is fired to give a good bed of coals. After it has gotten well started the fuel on one side is thrown or "winged" over to the other side with a bar. Care should be taken to get all of the combustible away leaving only ash and clinker on the grate. This clinker bed is broken up by slipping the bar underneath and raising it up. The mass of clinker and ash is then pulled out of the fire door with a hoe into a barrow or on to the floor. The burning fuel is then scattered over the clean grate by placing the bar in the other door and throwing the fuel back, leaving only ash and clinker on the second side. The first side should now be fired in order to have a good live fire to scatter over the second side when the grate is clean. This will require a good heavy firing.

Before breaking up the second side it is well to let the fire burn a while to get a good start. If the clinker is very hot or sticky this wait after firing the first side allows the clinker to cool and it contracts and will not stick to the grates as badly as when it is hot.

The second side is then broken up and pulled through the fire door in the same way and the good burning fuel scattered over the clean grate as before. Both sides are then fired, completing the operation. The doors should be open only when necessary and the cleaning done as quickly as possible.

The following method of cleaning fires is recommended by the Smoke Abatement Department of St. Louis. It has been successfully used in the University Power Plant, and when the directions are properly followed it produces less smoke than the ordinary method during the cleaning and immediately afterwards. It probably has very little effect upon the boiler and furnace efficiency:

"Do not clean out when fires are low, or when fresh fuel has just been added. Have a good bed of coal. Throw all the red fuel over on other side from one to be cleaned. Loosen up cinder with slice bar and pull out with hoe or rake. Break up coal to first size, and scatter four to six shovels on bare grates. Then throw hot coal back over fresh fuel on side that has been cleaned, and leave door ajar a minute or two. Wait for at least two firings before cleaning the second side, in the meantime firing somewhat heavier in front. See that the coal is incandescent, and proceed as with first side. Cleaning out in this manner will avoid making dense smoke, and will not lower the temperature of the boiler as much as the careless, usual way of cleaning fires."

Methods of Firing.

There are three methods of firing used in ordinary boiler practice, viz., **coking, spreading** and **alternate.**

In the **coking method,** after about all of the volatile matter is distilled off, the hot fixed carbon is pushed with a hoe to the back of the grate near the bridge wall. Here it makes a heap of bright, white-hot coals without smoke. Fresh coal is fired near the fire doors across the furnace, so that at all times the grate is covered with white hot coals at the back and green coal at the front.

The object sought for in this method is to distill the gases off of the green coal in front and to burn them while kept hot by passing over the hot bed of coals at the back. When the volatile gases are all driven off from the fresh coal in front leaving a bed of white hot coke, it is pushed back to replenish the hot bank in the rear and more fresh fuel is supplied at the front.

This method is seldom used in the Middle West. It is not an easy way of firing and is not suitable when large capacities are to be developed. It is often advised as a means of reducing smoke. There is a large loss of green fuel through the grates, and the frequent stirring of the fire tends to increase the clinker. The frequent opening of the fire doors increases the temperature stresses in the boiler and cools the furnace.

When this method of firing is used air should be admitted over the grate to help burn the volatile gases distilled from the green fuel.

The **spreading method** is the most commonly used method. It does not require as good a fireman or as much attention as the coking method.

Depending upon the size of the grate, two to six shovelfuls of coal are fired at a time, scattering the coal evenly over the grate. The fire is kept nearly level, a little thicker at the sides and back.

The fireman is apt to fire too much at a time or to fail to scatter the coal. If the coal is not well scattered, but each shovelful falls in one large mass, the fire will be cooled and deadened in spots. This causes uneven burning and the formation of holes. Holes are most likely to form at the sides and especially near the bridge wall. Fresh coal should not be used to fill up holes, but the fire should be leveled with a wide hook. All lumps should be broken up. Care must be taken not to dig in the fuel bed and stir up the ash with the hot live coals because this will increase the tendency to form clinker.

A good method of scattering the coal after the bed is level is to begin a strip at the back and scatter the coal over the strip while working to the front. A little practice will enable a good fireman to scatter a shovel full from the back to the front. Several of these strips will cover the entire grate.

The **alternate method** is much the same as the spreading method except that about one-half of the grate is fired at a time. For example, in a long line of boilers, the fireman goes down the line firing the first, third, fifth, etc., doors the first time, then making a second trip to fire the second, fourth, sixth, etc. The plan of firing in strips applies here as well as in the spreading method.

Where a three door furnace is used, the front half of the first and third doors and the back half of the second door are fired at one time. Then the next time the back half of the first and third doors and the front half of the second door are fired.

It is important that the fire be watched carefully and fresh fuel fed promptly, because the coke beds are apt to burn down letting an excess of air through. The object in leaving the coked bed is the same as in the coking method, the hot coke helps to burn the gases distilled from the fresh coal. Holes should be kept covered and the fire about level as in the other method.

In both the spreading and alternate methods of firing particular attention should be given to the scattering or sprinkling of the fresh fuel. Many firemen do not give this point care enough and it is very important. The practice of throwing the coal on the fire in heaps and firing enough to last fifteen or twenty minutes cannot be too severely condemned if high economy is desired. The fire is completely covered up and a dense cloud of smoke, indicating much unburned combustible, pours out of the chimney. Much of the fire is wasted and the firebed is left full of holes. If the coal is sprinkled over the fire, each lump separated from the others, the gases are exposed to the hot fuel bed and become well mixed with air. Good combustion then follows. In order to secure this result a few shovelsful frequently fired must be the rule. The importance of the length of time between firing has been mentioned in the first part of this bulletin. In general the shorter the firing interval the higher the efficiency and the less smoke. This is illustrated in Table IV, p. ...

The difference between a good and a poor fireman is usually due to the difference in the care and interest they have in their work, the difference in their skill in sprinkling the coal and keeping holes covered and in the frequent firing of small amounts of coal by the good fireman as compared to the fireman who piles in enough coal to last twenty minutes and then lets the fire burn full of holes.

Rules for Firing Using Illinois and Indiana Coal in Hand Fired Furnaces.

(Formulated by the Coal Stoking and Anti-Smoke Committee of the Illinois Coal Operator's Association.)

1. Break all lumps and do not throw any in furnace any larger than one's fist. The reason for this is, that large lumps do not ignite promptly and their presence also causes holes to form in the fire, which allow the passage of too much air.

2. Keep the ash pits bright at all times. If they become dark it is evident that the fire is getting dirty and needs cleaning, which, if not done, will cause imperfect combustion and smoke. If the furnace is equipped with a shaking grate, it should be opened often enough to prevent any accumulation of ashes in the fire. Do not allow ashes to collect in the ash pits, as they not only shut off the air supply, but may cause the grate to be burned.

3. In firing do not land the coal all in a heap, but spread it over as wide a space as possible as it leaves the shovel. A little practice will enable one to catch the proper motion to give the shovel to make the coal spread properly.

4. Place the fresh coal from the bridge wall forward to the dead plate and do not add more than three or four shovels at a charge. If this amount makes smoke it should be reduced till smoke ceases, which means, of course, that firing will be at more frequent intervals than formerly to keep up steam. This rule applies in cases

where the boiler is worked at a large capacity. In such instances, however, where a small capacity only is required, firing by the coking method is the best, wherein the fresh coal is placed at the front of the fire and pushed back and leveled when it has become coked.

5. Fire one side of the furnace at a time so that the other side containing a bright fire will ignite the volatile gases from the fresh charge.

6. Do not allow the fire to burn down well before charging. If this is done, it will not only result in a smoky chimney, but an irregular steam pressure.

7. Do not allow holes to form in the fire; should one form, fill it by leveling and not by a scoop full of coal. Keep the fire even and level at all times. As far as possible level the fire after the coal has become coked.

8. Carry as thick a fire as the draft will allow, but in deciding on the proper thickness, judgment must be exercised. If the draft is poor a thin fire will be in order, but if strong, a thicker fire should be carried.

9. Regulate the draft by the bottom or ash pit doors and not by the stack dampers, because when the stack damper is used it tends to cause a smoky chimney, as it reduces the draft, while the closing of the ash pit door diminishes the capacity to burn coal. If strict attention is given to firing, and according to demand for steam, there will be no occasion to have recourse to dampers, except where there is a sudden interruption in the amount of steam being used.

10. A good general rule is to fire little and often, rather than heavy and seldom. The former means economy in fuel and a clean chimney, while the latter signifies extravagance in fuel and a smoky chimney.

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