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TESTS OF RUN-OF-MINE AND BRIQUETTED COAL IN A LOCOMOTIVE BOILER

BY

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TESTS OF RUN-OF-MINE AND BRIQUETTED COAL IN A LOCOMOTIVE BOILER.

By WALTER T. RAY AND HENRY KREISINGER.

INTRODUCTION.

HISTORICAL STATEMENT.

In its investigation of more efficient methods for utilizing the coals and lignites in the United States, to the end that waste may be avoided, the value of low-grade coals increased, and the life of the nation's fuel resources prolonged, the United States Geological Survey has carried on a study of the factors involved in the manufacture and use of briquets, including the suitability of various coals for briquetting, the cheapest and most satisfactory binders, and the furnace behavior and evaporative efficiency of briquetted fuel. The investigations began with the work done at the coal-testing plant at the Louisiana Purchase Exposition, St. Louis, Mo., in 1904, and were continued at St. Louis and later at Norfolk, Va., as an essential part of the scheme of technologic research by the government fuel-testing plant. Accounts of various tests and statements of the conclusions to be drawn from them have appeared in a number of bulletins.[a]

In connection with the work at Norfolk, comparative steaming tests were made in stationary, marine, and locomotive boilers with run-of-mine coal and the same coal formed into briquets of two sizes. The tests in a locomotive boiler that are described in detail in this bulletin were undertaken to add cumulative evidence to work done at other places. They were made possible through the courtesy of the Seaboard Air Line Railway Company in supplying both the locomotive and the coal used. During the trials the locomotive stood on a side track in the shop yards of the railway company at Portsmouth, Va. No running tests were made.

PERSONNEL.

J. A. Holmes, expert in charge, technologic branch, United States Geological Survey, had general supervision of the investigations carried on at the Norfolk fuel-testing plant. H. M. Wilson, chief

[a] See Bulls. U. S. Geol. Survey Nos. 261, 290, 332, 343, 363, and 366; also Prof. Paper No. 48, p. 3.

engineer, arranged for the locomotive tests here described, and had immediate control of the work done by the writers.

ACKNOWLEDGMENTS.

The authors wish to express their appreciation and thanks for the suggestions and criticisms of Messrs. H. M. Wilson and D. T. Randall, and of their consulting advisers, Profs. L. P. Breckenridge and W. F. M. Goss; but it is to be distinctly understood that none of them is to be held committed by any statements or opinions of the authors found herein.

The authors also desire to express their thanks to the officials of the Seaboard Air Line Railway, without whose interested aid and co-operation the tests could not have been made, especially to President Garrett and to Master Mechanic Poole and his assistant, Mr. Henry; also, to Mr. Greenwood, superintendent of shops, and his assistant, Mr. Yearwood, and to Chief Engineer Andrews.

OBJECT OF THE TESTS.

The primary object of the tests was to study the relative performances of the two types of briquets and of the coal, with reference to efficiency, tendency to smoke, and the ease with which steam could be kept up, when each of the three varieties of fuel was burned at several rates of combustion. Many secondary objects were in mind, the data concerning which are discussed under "Effect of varying rates of combustion," pages 20-27.

One object kept especially in mind was the finding of ways for working locomotive boilers harder, although with present locomotive designs the steam production may sometimes be made sufficient to keep the wheels slipping, so that the engines have no use for additional steaming ability of the boiler.

SUMMARY OF RESULTS.

The most useful secondary conclusion demonstrated is that the combustion of suitable fuel can be kept about the same in completeness over a very wide range. This result is a consequence of the scrubbing action of rapidly moving currents of gases. In the case of combustion in the fuel bed the CO_2 formed at the surface of the particles of fuel and clinging to it is scrubbed off and replaced by fresh uncombined oxygen.

The more important results and conclusions for the locomotive used are briefly summarized here:

At low rates of working, run-of-mine coal gives a higher equivalent evaporation than briquets; at medium rates there is little difference; at high rates briquets do considerably better.

There is little difference between the large and the small briquets; the larger ones crumble less.

The smaller briquets are easier to fire and to level on the fire than are the larger ones; either form gives the fireman far less work and trouble than run-of-mine coal.

In sparks briquet fires lose less than coal fires.

On roads having heavy grades it will probably pay well to burn briquets, at least part of the time.

The high-capacity test run with briquets (test 14) was by no means the upper limit of fairly efficient combustion and evaporation, but it was higher than is likely ever to be attained by such draft as is feasibly available from a nozzle.

These particular briquets produced about as much smoke as the coal under similar conditions; some of the blame for this tendency to smoke may rest on the pitch binder.

Perhaps it would pay to add combustion chambers several feet long to the front ends of some locomotive fire boxes, and use a larger number of boiler tubes of shorter lengths and smaller diameters.

FUELS, APPARATUS, AND METHODS.

THE COAL AND THE BRIQUETS.

All the coal was run-of-mine from the Turkey Gap mine, working the Pocahontas No. 3 bed at Ennis, McDowell County, W. Va. Part of it went to the briquetting section of the fuel-testing plant at Norfolk, where it was made into two sizes of briquets.

The smaller of these two sizes was circular in horizontal cross section, 3¼ inches in diameter. Its vertical cross section was nearly oval, 2¾ inches at the center by 1½ inches near the circumference. The larger size was rectangular in either cross section, its dimensions being 3 by 4½ by 6¾ inches. The small briquets were compressed at about 1,000 pounds and the large ones at about 2,500 pounds per square inch. The pitch used was approximately the same in kind and percentage.[a]

[a] For detailed description of methods of manufacture and physical tests of briquets see Briquetting tests at Norfolk, Va.: Wright, C. L., Bull. U. S. Geol. Survey No. 385, 1909.

THE LOCOMOTIVE AND OTHER TESTING APPARATUS.

The locomotive used in these tests was of the 10-wheel, freight type, built in 1906. The principal dimensions of its furnace and boiler were as follows:

TABLE 1.—*Principal dimensions of furnace and boiler.*

Furnace:	
Length ....inches..	108
Width near grate ....do....	41
Width at widest place ....do....	55
Height..........................do....	55
Rocking, finger-type grate:	
Length..........................do....	104
Width...........................do....	41
Area ....square feet..	29.65
Ratio to heating surface	1 to 87.2
Approximate air space .....per cent..	30

Boiler:	
Diameter of shell............inches..	63.5
Waist diameter ....do....	72
Number of tubes	328
Inside diameter of tubes.....inches..	2
Length of tubes ....feet..	$14\frac{1}{8}$
Heating surface:	
Of fire box ....square feet..	167.5
Of tubes.........................do....	2,416.5
Total...........................do....	2,584
Approximate minimum cross-sectional area of gas passage.......square feet..	1

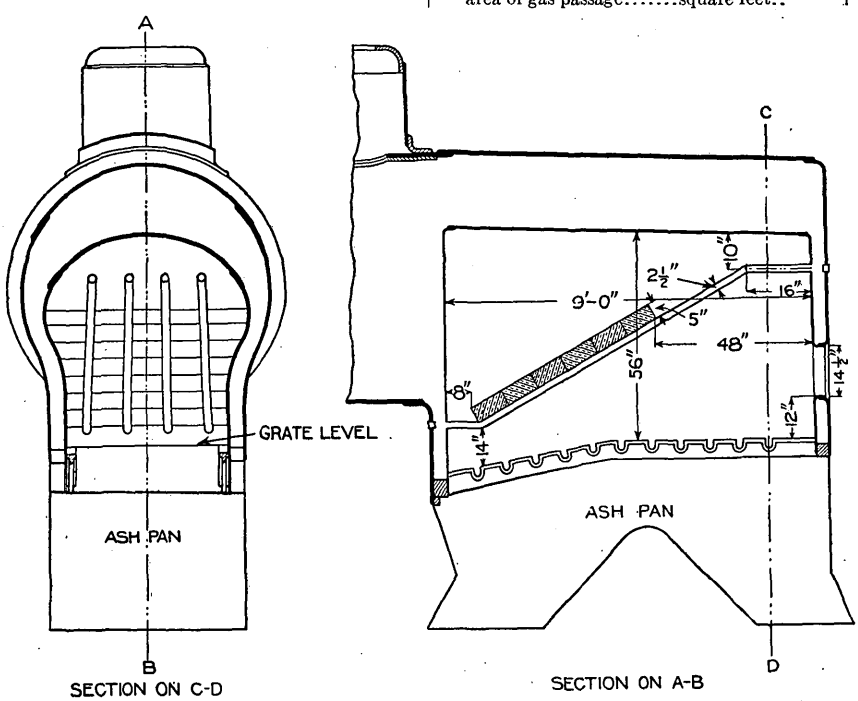

FIGURE 1.—Construction of arch in furnace.

The furnace was equipped with a fire-brick arch supported by four $2\frac{1}{2}$-inch water tubes. The position and construction of the arch are shown in figure 1.

Figure 2 shows the internal arrangement of the smoke box. CDF is a solid sheet-iron partition, FG an adjustable apron, HJK a screen of perforated sheet iron,[a] LM a deflecting plate made of cast iron, N

[a] Most of the locomotives of this road are now equipped with a wire network screen, which offers less resistance to the flow of air through it.

the exhaust nozzle, and S the steam pipe. The partition CDE and the spark screen HJK separate the smoke box into three chambers, which are designated *a*, *b*, and *c*. Chamber *a* receives the gases as they leave the boiler tubes. From chamber *a* the gases flow through the contracted passage between G and L into chamber *b*. As the passage is very narrow they must flow through it at very high velocities, and the high velocities must in some degree be imparted to the sparks in chamber *a*. The sparks are deflected upward from their straight course by the plate LM and thrown against the screen HJK; they are partly broken by impact against the deflecting plate and the screen, and the small pieces pass through the latter and out through the stack.

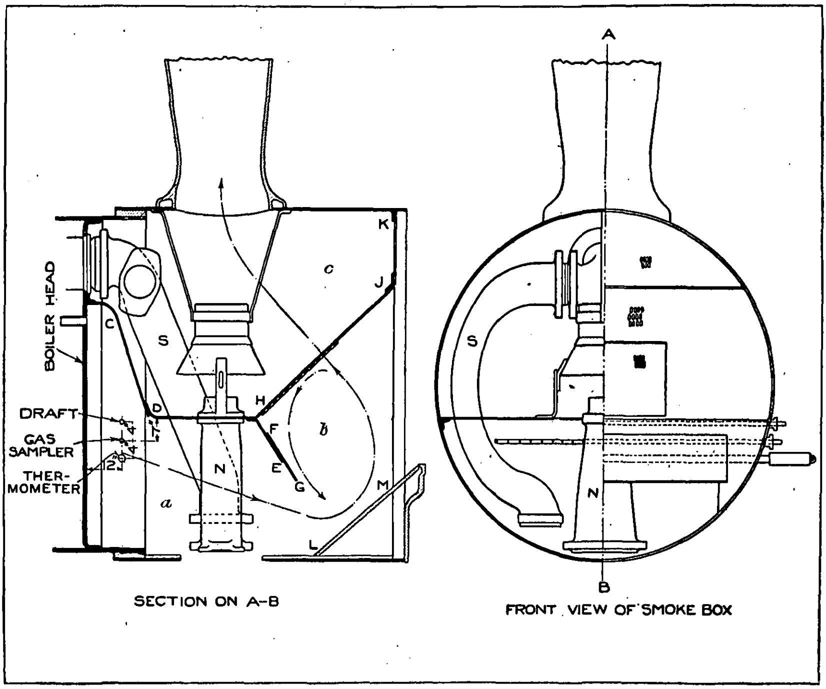

FIGURE 2.—Construction of smoke box.

Larger pieces are reflected back and fall down toward the apron, most of them into the high-velocity current of gas which again hurls them against the deflecting plate and the screen; eventually practically 100 per cent pass through the stack. Just what amount of "draft"[a] energy is required to effect this pulverization is unknown; probably it is very small. The sliding apron FG can be lowered or raised so as to make the passage beneath it smaller or larger. The purpose of all

[a] Wherever the word "draft" is used in its usual sense in discussing the motive force which moves the air and gases through the fuel bed and boiler, it is placed in quotation marks, to call to mind the misusage; in the sense under consideration there is really no such thing as "draft." "With gases there is no pulling, only pushing." "Draft" may be defined as the static difference between the pressures at two points of a flowing stream of gas.

these fittings in the smoke box is to reduce the size of the sparks before ejectment so as to make them less noticeable and less dangerous to fields, buildings, etc. Locomotives equipped with such smoke-box arrangements are sometimes termed "self-sparking." It is very probable that a part of the sparks are burned in the smoke box, in chambers *a* and *b*. The fact that a considerable quantity of clinker was found in chamber *a*, when cleaning the locomotive before testing, strengthens this probability.

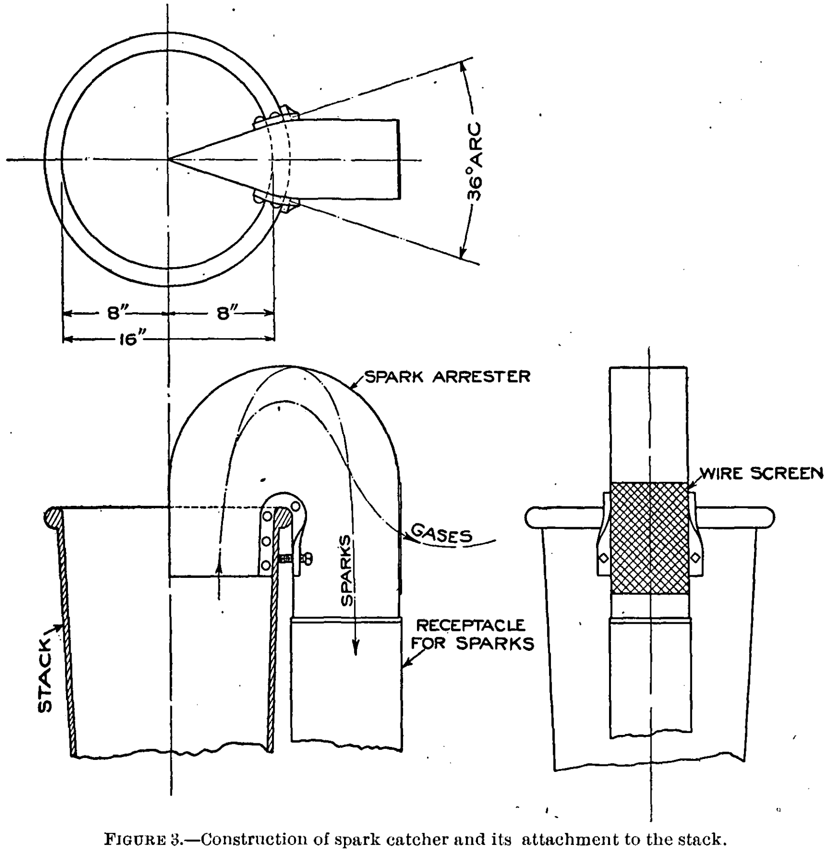

FIGURE 3.—Construction of spark catcher and its attachment to the stack.

Figure 2 shows also the location of "draft"-gage connections, flue-gas sampler, and a thermometer for measuring flue-gas temperature approximately.[a] The flue-gas sampler was made of $\frac{3}{8}$-inch pipe, having the free end plugged, and $\frac{1}{16}$-inch holes drilled on both sides in staggered rows; it extended nearly across the smoke box. The

[a] Granting that the thermometer in use was absolutely correct, it nevertheless read too low because it could "see" some water-cooled surfaces, to which it radiated some of its heat. In the case of a certain stationary boiler this error was over 35° F. Probably 99 per cent of all boiler tests published give readings of flue temperatures 10° to 200° too low. In this particular case the error was probably considerably less than 35°, because most of the surface the thermometer could "see" was nearly as hot as the gases, and the current of gas in which the thermometer was placed was very fast; the faster the current of gas the less the error.

"draft" pipe was of ¼-inch nominal size, with no holes in its sides, and having the open end situated at the center of the smoke box. The bulk of the thermometer was also placed close to the end of the pipe.

Figure 3 shows, attached to the stack, the spark catcher especially designed and constructed for these tests. Its object was to collect the sparks from a sector of the exit end of the stack, the sector constituting one-tenth of the total exit area, so that the total weight of sparks leaving the stack was approximately ten times the weight collected in the receptacle.

The spark catcher consists of a V-shaped vessel made of sheet iron, the V-shaped opening being inverted over the stack, and being a sector of a circle having an angular area of 36°. The portion outside is nearly rectangular in cross section and ends in a detachable sheet-iron receptacle into which the sparks fall. The outside wall of this outer portion is partly replaced by a wire netting having 24 meshes to the inch; the gases pass through, but most of the sparks fall down as mentioned above. When the sparks are thrown out at a rapid rate, the bottom receptacle can be emptied and replaced while continuing the test. The spark catcher was placed on the stack at right angles to the axis of the boiler.

METHODS OF CONDUCTING TESTS.

Steam pressures.—All tests were made while the locomotive was standing out of doors in the yard of the Portsmouth shops of the Seaboard Air Line Railway. "Draft" was produced by removing both valves from the steam chests and blowing steam through the main throttle and the cylinders into the nozzle (fig. 4) and out through the stack. Steam not thus used was discharged through special pipe connections into the main steam header of one of the stationary boiler plants. This plant carried a pressure of less than 100 pounds per square inch, while the pressure in the locomotive was 200 pounds; a globe valve, in the pipe between the locomotive and the header, was used to regulate the pressure in the locomotive.

Steam pressure was read off the regular locomotive gage, which was reliable within 2 or 3 pounds. The pressure was also automatically recorded by a Crosby recording gage, which was accurate within 2 or 3 pounds.

Starting and closing.—A modification of the "alternate method" was used in starting and closing tests. Fire was kindled with wood on a clean grate and built up very rapidly with coal. As soon as the steam pressure had risen to 200 pounds the fire was leveled and the test started. This preparatory firing took one to two hours and required the burning of 300 to 500 pounds of coal. On starting the test the thickness of the fuel bed was measured as accurately as possible with a prong, and readings were taken of steam pressure, height of water in the boiler, height of water in the tender, and "draft" in the furnace. Closing conditions of the tests were made as nearly as possible the same as those of starting. The tests were usually started with a layer of burning coal 3 or 4 inches thick.

Ash and refuse.—Just at closing the thickness of the bed of fuel above the layer of clinker was estimated as nearly as possible. After closing the test the fire was burned down entirely, the clinkers pulled out through the fire door, weighed, and charged to the test. It was impracticable to clean the fire before the close of the test,

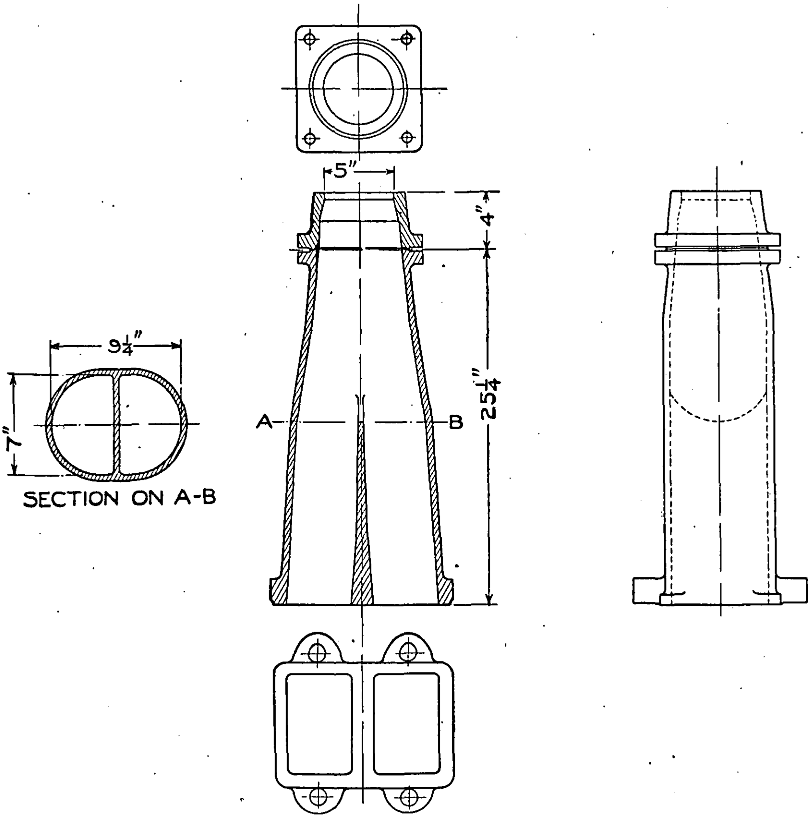

FIGURE 4.—Construction of nozzle regularly used on locomotive.

because the lower edge of the fire door was 14 inches above the grate. Immediately before starting each test the ash pan was cleaned. After closing and removing the clinker from the grate all the ash was taken from the ash pan, weighed, and charged to the test. At first thought it might appear that the weight of ash thus obtained must be too great, but the chemical analysis of the coal shows that it was too low in all cases excepting one. Items figured from the weight of ash actually obtained are inaccurate and are given to show the futility of calculation and deductions so based.

Fuel fired.—Coal was weighed with small platform scales on which was placed a box of 300 pounds capacity. The scales with the box thereon were located in the front part of the tender directly in front of the furnace, and one side of the box was let down so that coal could be easily fired from it. The time of each firing was recorded, the coal being weighed only each time the box was filled, the times of filling being recorded. Each time while the box was being filled a sample of coal was taken for analysis, a little at a time, amounting to a total of about a shovelful per box.

Feed water.—Water was weighed on a small platform scale in a tank having a capacity of 636 pounds. The scale and tank were placed on top of the tender near the rear end. Specially erected piping carried water from the city main to the weighing tank. The water drained from the weighing tank into the tender tank, and on each occasion the time of emptying and the weight of water were recorded. A long glass water-level gage was connected to the tender tank so that the height of water in it could be read from a scale at regular or special observations. Tests were opened with the tender tank nearly full of water and closed at the same level. A thermometer was immersed in the water in the tender and temperatures taken at regular intervals.

Leaks and injector overflow.—During tests all leakage from the boiler and tender was caught in buckets and weighed, and its total weight was subtracted from the total weight of the water put into the tender tank. The overflows from the injectors were likewise caught and allowed for.

Flue gas.—Flue gas was sampled with the specially constructed gas sampler described on page 10 and piped into a box car set just behind the tender. In the car was an improvised laboratory in which the gas was analyzed for CO_2, O_2, and CO, in an Orsat apparatus. The gas was drawn into the car with a steam ejector. Samples thus collected were occasionally checked by samples taken immediately at the smoke box.

On most of the tests the smoke-box temperature was measured with a mercury thermometer; on two or three of the high-capacity tests it was measured with a platinum and platinum-rhodium thermocouple, the position of which inside the smoke box is shown in figure 2.

Measuring "drafts."—Gas pressures ("drafts") were measured on all tests, over the fuel bed, at the exit of the boiler tubes in chamber *a* (fig. 2), and near the nozzle in chamber *c*. On the first six tests the pressures were also taken over the arch in the fire box. Ordinary U-tube manometers were used for all these readings.

Smoke observations.—A set of Ringlemann smoke charts was prepared as an aid in the estimation of the comparative darkness of smoke; but inasmuch as the darkness was usually between No. 0 and No. 1 the charts were of little advantage and were seldom used. The densities of smoke given in Table 2 are averages of the estimates of two or three observers.

Sparks.—The weight of sparks ejected from the stack was determined with the apparatus shown in figure 3 and described on page 11. As is there stated, this apparatus collected sparks from one-tenth of the total cross-sectional area of the stack, so that the total weight of sparks ejected from the stack could be fairly well obtained by multiplying by 10 the amount caught in the receptacle. In most cases the sparks were collected during the entire time of the test. On the high-capacity tests the receptacle was removed when about full and the time noted. It was then emptied and replaced. After weighing the sparks from the whole test they were carefully mixed and a sample of about 2 pounds taken and sent in an air-tight can for chemical analysis. The chemical analyses of the sparks and of the coal and refuse were made under the immediate supervision of Mr. Fred M. Stanton in the chemical laboratories of the technologic branch of the United States Geological Survey at Pittsburg, Pa.

Moisture in steam.—A throttling calorimeter was attached to the steam pipe leading from the steam dome to the stationary-boiler plant and the moisture in the steam was determined at regular intervals. Of course the steam used in producing "draft" was not sampled by the calorimeter, but the location of the latter was the best under the given conditions.

DATA AND RESULTS OF TESTS.

OBSERVATIONS AND COMPUTATIONS.

In all, 14 tests were made; 6 on run-of-mine coal, 4 on large briquets, and 4 on small briquets. The tests were made at various rates of combustion, the lowest being 18 pounds of dry fuel per hour per square foot of grate surface when burning coal, and the highest being about 110 pounds of dry fuel when burning small briquets. The recorded observations made during the tests and the results calculated therefrom are given in Table 2.

The computations embodied in the table were made according to the method given in Bulletin 325.[a] This method is in practical accord with the recommendations of the American Society of Mechanical Engineers. The figures in parentheses at the heads of columns in the table are the item numbers of the society's code for boiler tests.

[a] Breckenridge, L. P., A study of four hundred steaming tests: Bull. U. S. Geol. Survey No. 325, 1907, pp. 151-152.

TABLE 2.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, February 7-27, 1908*—Continued.

Test No.	Ash and refuse in dry fuel (per cent).	Proximate analysis (per cent).									
		Fixed carbon.		Volatile matter.		Moisture.		Ash.		Sulphur.[a]	
		In moist coal.	In "combustible."	In moist coal.	In "combustible."	In fuel as fired.	([b])	Moist basis.	Dry basis.	Moist basis.	Dry basis.
1	24 (31)	25 (32)	26	27 (33)	28	29 (34)	30	31	32 (42)	33	34 (41)
1	8.57	73.35	83.13	14.97	16.87	3.66	4.13	7.62	7.91	0.45	0.47
2	7.82	73.67	83.49	14.56	16.51	4.35	4.93	7.42	7.76	.49	.51
3	....	74.24	84.46	13.66	15.54	4.76	5.42	7.34	7.71	.36	.38
4	....	73.25	84.48	13.46	15.52	3.78	4.36	9.51	9.88	.38	.39
5	....	73.13	81.67	16.41	18.33	3.43	3.83	7.03	7.28	.52	.54
6	....	73.12	82.35	15.67	17.65	4.25	4.79	6.96	7.27	.50	.50
7	5.62	73.47	82.85	15.21	17.15	4.63	5.22	6.69	7.01	.51	.53
8	6.00	72.12	81.04	16.86	18.96	4.31	4.85	6.71	7.01	.42	.44
9	6.03	71.24	82.58	15.01	17.42	6.64	7.70	7.11	7.62	.54	.58
10	9.83	74.41	81.07	17.37	18.93	2.42	2.53	5.80	5.94	.39	.40
11	6.14	72.66	80.87	17.18	19.13	3.01	3.45	7.15	7.37	.47	.48
12	....	73.82	80.43	17.96	19.57	2.24	2.44	5.98	6.12	.51	.52
13	....	73.17	83.91	14.03	16.09	6.18	7.09	6.62	7.06	.52	.55
14	6.32	69.04	80.30	16.93	19.70	4.56	5.31	9.47	9.92	.58	.61

Test No.	Ultimate analysis, dry basis (per cent).					Earthy matter in refuse, including moisture.	Heat value per pound (B. t. u.).		Steam (per cent).	
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Carbon in refuse.		Dry fuel.	"Combustible."	Moisture in.	Quality of.
1	35 (37)	36 (38)	37 (39)	38 (40)	39 (44)	40	41 (50)	42 (51)	43 (54)	44 (56)
1	83.15	4.29	3.14	1.04	46.28	53.72	14,463	15,705	0.5	0.996
2	84.30	4.23	2.21	.99	20.40	79.60	14,494	15,720	.7	.995
3	82.73	4.11	4.02	1.05	25.14	74.86	14,553	15,782	.3	.998
4	81.38	4.13	3.19	1.03	17.42	83.58	14,245	15,816	.5	.996
5	84.84	4.31	2.05	.98	22.31	77.69	14,693	15,844	1.4	.990
6	83.66	4.16	3.41	1.00	34.51	65.49	14,789	15,945	.9	.992
7	83.98	4.22	3.32	.94	27.68	72.32	14,702	15,815	1.0	.993
8	84.19	4.18	3.07	1.11	29.42	70.58	14,753	15,868	1.0	.993
9	84.12	4.18	2.54	.96	26.91	73.09	14,503	15,688	.8	.994
10	84.48	4.05	4.03	1.10	34.69	65.31	14,897	15,838	1.0	.993
11	83.19	4.16	3.99	.81	26.57	73.43	14,742	15,743	1.0	.993
12	84.62	4.42	3.31	1.01	26.08	73.92	14,936	15,915	.7	.995
13	84.73	4.23	2.45	.98	28.31	71.69	14,571	15,680	.9	.993
14	82.21	4.25	2.03	.98	34.92	65.08	14,292	15,871	1.4	.988

[a] Separately determined.
[b] Accompanying 100 per cent of "combustible."

TABLE 2.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, February 7–27, 1908.*[a]

Test No.	Form and condition of fuel.	Date of trial.	Duration (hours).	Average pressures.		"Draft"[b] below atmosphere (inches of water).				Clinker in ash and refuse (per cent).
				Barometer (inches of mercury).	Steam[c] (pounds per sq. in.).	Near nozzle.	Over fuel bed.	Over furnace arch.	Leaving boiler tubes.	
1	2	3 (1)	4 (2)	5 (11)	6 (11.1)	7	8	9	10	11 (29)
1...	Run of mine.....	Feb. 7	6.08	30.34	171	0.77	0.39	0.48	0.61	52.7
2...	.....do.[d]..........	Feb. 8	5.08	30.51	172	2.30	1.05	1.01	1.86	52.7
3...	.....do..........	Feb. 10	6.17	30.68	149	2.27	.87	1.12	1.86	45.0
4...	.....do............	Feb. 11	7.00	30.50	159	.59	.33	.41	.53	52.7
5...	Large briquets...	Feb. 12	5.28	30.52	171	1.25	.57	.70	1.00	46.0
6...	.....do............	Feb. 13	4.50	30.31	162	2.63	1.03	1.37	1.96	56.0
7...	.....do............	Feb. 14	4.45	29.97	186	5.48	1.95	2.54	3.69	28.3
8...	.....do............	Feb. 17	3.80	30.06	182	7.70	....	3.01	4.10	45.8
9...	Run of mine[e]....	Feb. 18	3.92	30.36	168	7.36	....	2.65	4.54	19.7
10...	Small briquets[f]..	Feb. 19	4.07	29.80	167	2.11	....	.56	1.59	21.5
11...	.....do............	Feb. 20	3.07	30.03	182	8.10	....	2.73	5.48	22.2
12...	.....do............	Feb. 21	3.48	30.16	171	5.07	....	1.95	3.69	24.5
13...	Run of mine.....	Feb. 26	4.18	29.67	168	5.50	....	2.41	3.89	21.6
14...	Small briquets[g]..	Feb. 27	2.02	29.78	150	11.80	....	3.10	8.74	21.8

Test No.	Average temperatures (° F.) of—				Fuel (total weights in pounds).			"Combustible*"[h] consumed (lbs.).	Fired per hour (pounds).			
									Dry fuel.		"Combustible*."[h]	
	Atmosphere.	Steam.	Feed water in tank.	Gases leaving boiler tubes.	As fired.	Dry.	Ash and refuse.		For grate.	Per sq. ft. of grate.	For grate.	(*i*)
1	12 (15)	13 (17)	14 (18)	15 (21)	16 (25)	17 (27)	18 (28)	19 (30)	20 (46)	21 (48)	22 (47)	23 (49)
1....	45	375	55	530	4,600	4,432	210	3,985	729	24.60	655	0.253
2....	40	376	63	580	5,500	5,260	425	4,770	1,035	34.83	955	.368
3....	39	365	49	596	7,200	6,856	472	6,208	1,112	37.53	1,026	.395
4....	37	370	48	487	3,986	3,834	324	3,400	548	18.47	494	.187
5....	44	375	51	550	4,367	4,217	272	3,849	799	26.95	729	.282
6....	56	371	51	612	6,000	5,748	231	5,247	1,277	43.10	1,166	.451
7....	63	375	50	663	7,420	7,073	465	6,451	1,590	53.62	1,450	.561
8....	36	380	51	697	9,030	8,638	522	7,882	2,274	76.70	2,074	.803
9....	36	374	49	666	9,070	8,469	517	7,685	2,160	72.85	1,960	.759
10....	55	374	49	595	4,800	4,683	474	4,242	1,151	38.80	1,024	.403
11....	41	380	48	804	7,500	7,271	450	6,618	2,369	79.90	2,155	.834
12....	41	375	46	684	6,300	6,156	391	5,680	1,770	59.69	1,632	.631
13....	51	374	48	679	7,800	7,318	651	6,617	1,750	59.02	1,583	.613
14....	40	365	46	910	6,800	6,489	417	5,701	3,213	108.30	2,822	1.092

[a] Code numbers (in parentheses at the top of certain columns) refer to corresponding items described in Bull. U. S. Geol. Survey No. 325, pp. 151–153. See also Prof. Paper U. S. Geol. Survey No. 48, pt. 2.
[b] The word "draft" is placed in quotation marks because it is misused when applied to the moving of gases or to the pressure difference which causes them to move.
[c] Above atmosphere.
[d] Wet, much slack.
[e] Wet, mostly slack.
[f] 10 per cent crumbled.
[g] 30 per cent crumbled.
[h] The "combustible" factor in all columns of this table marked thus (*) is obtained by subtracting from the total weight of dry fuel fired the weight of ash therein, as figured from the chemical analysis, and further substracting weight of the combustible in the refuse, the latter combustible being calculated from the total weight of refuse and its analysis; the composition of the refuse combustible is loosely considered to be the same as that of the "combustible" of the dry fuel.
[i] Per square foot of water-heating surface.

TABLE 2.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, February 7–27, 1908*—Continued.

Test No.	Water fed to boiler (pounds).							Evaporation.		Equivalent evaporation per pound of—		
	Total.	Equivalent evaporated from and at 212°.				Actually evaporated.*a*		(*b*)	Factor of.	Fuel as fired.	Dry fuel.	"Combustible*."*d*
		Total.	Per hour.	(*c*)	Into dry steam.	Total.	Per hour.					
1	**45** (57)	**46** (58)	**47** (63)	**48**	**49** (61)	**50** (59)	**51** (62)	**52** (68)	**53** (60)	**54** (69)	**55** (70)	**56** (71)
1....	43,655	52,998	8,681	3.36	52,786	43,480	7,151	9.49	1.214	11.47	11.91	13.24
2....	50,064	60,452	11,840	4.58	60,125	49,814	9,806	9.10	1.207	10.94	11.43	12.61
3....	61,028	74,332	12,023	4.65	74,183	60,906	9,871	8.48	1.218	10.30	10.82	11.95
4....	36,333	44,363	6,312	2.442	44,186	36,188	5,170	9.11	1.221	11.08	11.52	13.00
5....	40,070	48,885	8,977	3.474	47,397	39,669	7,513	9.18	1.220	10.85	11.24	12.31
6....	52,713	64,204	14,153	5.48	63,690	52,291	11,620	8.79	1.218	10.62	11.08	12.14
7....	63,688	77,890	17,381	6.726	77,345	63,242	14,211	8.58	1.223	10.42	10.93	11.99
8....	72,558	88,593	23,151	8.966	87,973	72,050	18,960	8.03	1.221	9.74	10.18	11.03
9....	60,283	73,704	18,689	7.233	73,262	59,921	15,285	6.64	1.223	8.08	8.65	9.53
10....	43,305	52,832	12,889	4.99	52,462	43,002	10,565	9.02	1.221	10.93	11.20	12.36
11....	62,998	77,109	24,941	9.64	76,569	62,557	20,377	8.40	1.224	10.21	10.52	11.57
12....	53,956	66,096	18,898	7.313	65,766	53,686	15,429	8.56	1.225	10.44	10.68	11.58
13....	59,484	72,689	17,268	6.682	72,180	59,068	14,131	7.63	1.222	9.25	9.86	10.91
14....	47,730	58,326	28,528	11.040	57,627	47,157	23,345	7.02	1.222	8.48	8.88	10.11

Test No.	Horsepower developed.		Efficiency of the boiler, etc.		Average thickness of fuel bed (inches).*g*	Average time intervals (minutes) between—		Analysis of dry flue gasses (per cent).			
	In boiler.	Per cent of rated.*e*	(*)*f*	Including grate.		Firings.	Leveling and breaking up.	CO_2.	O_2.	CO.	N_2.
1	**57** (65)	**58** (67)	**59** (72)	**60** (73)	**61** (81)	**62** (82)	**63** (83)	**64** (84)	**65** (85)	**66** (86)	**67** (88)
1......	251.7	97.4	81.44	79.48	8	3–4	16	11.45	6.92	....	81.63
2......	343.2	132.8	77.48	76.18	10–12	3	10	11.96	7.00	0.23	80.81
3......	348.5	134.4	73.14	71.79	12	3	12	11.46	7.49	.10	80.95
4......	183.0	70.8	79.39	78.12	6	4–5	40	11.10	7.84	.23	80.83
5......	260.0	100.6	75.00	73.90	14–16	3	40	11.96	7.07	.14	80.83
6......	410.2	159.0	73.50	72.37	14–16	3	(*h*)	12.45	5.87	.22	81.46
7......	503.8	195.0	73.26	71.81	18	3	80	11.50	7.08	.17	81.25
8......	671.0	259.5	67.16	66.67	16	3	(*h*)	12.05	6.93	.15	80.87
9......	541.1	209.3	58.69	57.61	16	3	20	10.16	8.49	.13	81.22
10......	373.6	144.5	75.39	72.62	6–8	....	(*h*)	13.87	4.75	.25	81.13
11......	722.9	279.7	70.99	68.94	12	3	(*h*)	13.57	4.49	.03	81.91
12......	547.7	211.9	70.29	69.08	8	3	(*h*)	11.78	6.74	.30	81.18
13......	500.5	193.7	67.21	65.36	14–16	3	16	12.20	6.94	.05	80.81
14......	827.0	320.0	61.56	60.02	16–18	(*i*)	(*h*)	11.15	7.52	.20	81.13

a Corrected for quality of steam.
b Apparent per pound of coal as fired.
c Per hour per square foot of water-heating surface.
d Figured from chemical analyses of ash and coal.
e Arbitrarily rated by authors, counting 10 square feet of heating surface to a boiler horsepower.
f Figured from chemical analyses of ash and coal.
g Method of firing, spreading.
h Fire not disturbed.
i Firing continuous.

TABLE 2.—*Summary of observed data and calculated items of 14 tests made with a locomotive boiler, February 7–27, 1908*—Continued.

Test No.	Per cent smoke.	Sparks (pounds).			Heat balance.[a]					
		Total collected.	Ejected.		Heat value of 1 pound of "combustible."		Heat absorbed by boiler (1).		Loss in sparks.	
			During test.	Per hour.	B. t. u.	Per cent.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	68 (77)	69	70	71	72	73	74	75	76	77
1	0	1	10	1.65	15,705	100	12,790	81.44	....	....
2	15.4	7	70	13.77	15,720	100	12,181	77.48	137.1	0.88
3	19.4	21	210	34	15,782	100	11,544	73.14	215	1.36
4	24	No sparks collected.			15,818	100	12,558	79.39	....	....
5	10	2	20	3.79	15,846	100	11,891	75.00	41	.26
6	10	9	90	20	15,955	100	11,727	73.50	161	1.00
7	10	14	140	31.5	15,810	100	11,582	73.26	216	1.36
8	8	31	310	81.6	15,865	100	10,655	67.16	441	2.78
9	8	[b]27	529	135	15,688	100	9,206	58.69	861	5.49
10	12	5	50	12.3	15,838	100	11,940	75.39	112	.71
11	0	35	350	114	15,743	100	11,177	70.99	603	3.83
12	0	22	220	63.2	15,915	100	11,186	70.29	431	2.71
13	0	23	230	55	15,680	100	10,539	67.21	361	2.30
14	0	37.5	375	185	15,865	100	9,766	61.56	683	4.32

Test No.	Heat balance.[a]									
	Loss due to moisture—				Heat lost in dry flue gases (4).		Loss due to incomplete combustion of carbon in CO (5).		Loss in escaping hydrocarbons, radiation, and unaccounted for (6).	
	In fuel (2).		Of hydrogen (3).							
	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	78	79	80	81	82	83	84	85	86	87
1	53.1	0.34	539	3.43	2,302	14.65	....	....	21	0.14
2	64.8	.41	542.7	3.45	2,451	15.60	173.6	1.10	170	1.08
3	71.7	.45	529.9	3.36	2,603	16.50	79	.50	741	4.69
4	55.5	.35	525	3.32	2,158	13.64	186	1.18	335.5	2.12
5	50	.32	542	3.42	2,307	14.56	107	.69	908	5.74
6	63	.39	530	3.31	2,384	14.91	176	1.17	914	5.72
7	73	.46	573	3.63	2,795	17.68	139	.88	432	2.73
8	71	.45	591	3.73	2,951	18.61	113	.78	1,043	6.56
9	111	.71	588	3.75	3,340	21.28	117	.74	1,465	9.34
10	34	.21	506	3.19	2,089	13.18	162	1.02	995	6.28
11	49	.31	574	3.65	3,058	19.43	20	.13	262	1.66
12	33	.21	577	3.62	2,894	18.18	227	1.43	567	3.56
13	96	.61	553	3.53	2,821	17.99	38	.24	1,272	8.12
14	78	.50	758	4.75	4,214	26.56	163	1.03	203	1.28

[a] Heat-balance items (designated by numbers in parentheses under this heading) are explained in Bull. U. S. Geol. Survey No. 325, p. 153.
[b] Sparks collected for two hours only.

NOTES ON INDIVIDUAL TESTS.

Test 1, run-of-mine coal.—The coal caked badly; the top of the fuel bed fused over and greatly hindered the ascent of air; the cakes had to be broken with the rake very often.

The clinkers were not removed after the close of the test; probably 200 pounds were left in the furnace.

Test 2, run-of-mine coal.—The coal caked badly, probably because it contained a great deal of slack and was wet. The fuel bed had to be raked very often. During the first two hours of the test a high "draft" could not be obtained because the relief valves had been taken off the steam chests; after 12.15 p. m. the openings were plugged and a higher "draft" was used. A thicker fire was carried without the appearance of much CO in the flue gases.

After closing the test the fire was allowed to burn down entirely, the clinkers were pulled out, weighed, and charged to the test.

Test 3, run-of-mine coal.—The coal caked badly and the fire required frequent raking. The layer of clinkers on the grate at the close of the test was about 3 inches thick.

Test 4, run-of-mine coal.—The coal swelled in the fire and caked. No sparks were caught during this test, their comparative absence probably being due to the fact that the draft was lower than during test 1.

Test 5, large briquets.—The briquets burned freely and quickly, did not cake, but stayed together in the fire, which appeared to be very hot. After about 3½ hours the fire became unmanageable because a thin but solid layer of clinker had formed over the entire grate surface, shutting off the air. The trouble was probably caused by rocking the grate too often.

Test 6, large briquets.—The briquets burned freely and stayed together. At the close of the test there was a layer of clinker on the grate, but it was porous and not troublesome. The porosity of the clinker was undoubtedly due to the fact that the fuel bed was not disturbed at all during the test. Compare notes on test 5. The truth is that the best results can be obtained with large briquets by disturbing the fire as little as possible. Of course the fire must be occasionally leveled with a rake because the briquets can not be thrown in so as to keep the fuel bed level. Below the surface the fire should not be disturbed.

Test 7, large briquets.—The briquets stayed together in the fire. The fuel bed was easily worked with; during the test it was raked only when leveling it. It seems best to disturb the fuel as little as possible, because raking breaks up the briquets and rocking the grate causes troublesome clinker. The briquets made a hot fire, burned quickly, and smoked very little.

Test 8, large briquets.—The briquets burned freely and quickly and made a very hot, smokeless fire. The fuel bed was not disturbed. No trouble was experienced from clinkers at any time, although at the close of the test a 2-inch layer of them was found on the grate. They were light and porous and easily removed.

Test 9, run-of-mine coal.—The coal caked badly; difficult to keep fire in good condition. Holes were always forming in the fuel bed, so that the latter required frequent raking.

Test 10, small briquets.—The briquets burned freely and quickly and stayed together; they made a very hot fire which was easily kept in good condition. When a thicker fuel bed was carried with a low draft the briquets smoked more than the run-of-mine coal would have done under the same conditions. When smoke appeared there was also a high percentage of CO in the flue gases.

At the end of the test a layer of clinker about 1½ inches thick was on the grate; it was porous and light and had given no trouble.

Test 11, small briquets.—The briquets made a very hot fire which was easily kept in good condition. No difficulty was experienced from clinker. After the test only a little clinker was found on the grate in the rear of the furnace.

Test 12, small briquets.—The briquets made a very hot fire which was easily kept in good condition. No trouble was experienced from clinkers; those found on the grate at the close of the test were light and porous and in separate pieces, not in a continuous layer. The small briquets could be spread more evenly over the grate than the large ones. The arch was perhaps too low for the latter.

Test 13, run-of-mine coal.—The coal caked badly; holes formed in the fuel bed so that it had to be raked frequently; difficulty was experienced in keeping it in good condition. After the close of the test the grate was found covered with a layer of clinker about 2 inches thick; however, the clinkers had not produced any especial trouble.

Test 14, small briquets.—For this test all the briquets were weighed before starting and placed in the tender. During the test the fire door was closed after each shovelful had been thrown into the furnace. The fire was built up gradually after starting, the "draft" being increased with the thickness of the fuel bed. Before the close of the test the "draft" was again gradually reduced as the fuel bed burned down. After the test was well under way, and before the fuel bed had started to burn down, the rate of combustion was much higher than the average for the whole test. The shortness of the test was due to the lack of more briquets.

About 30 per cent of the briquets used on this test had been crumbled by repeated transfers before they were fired. If they had been in good condition, the results undoubtedly would have been better.

EFFECT OF VARYING RATES OF COMBUSTION.

ON EVAPORATION.

The curves of figure 5 should be used with the scales indicated by the respective arrows. The curves labeled B show the relation of evaporation to varying rates of combustion, indicating that with all the fuels the equivalent evaporation falls off as the rate of combustion increases and that such decrease is much more rapid with the run-of-mine coal than with either style of briquet. There is not much difference between the two kinds of briquets. The last point of the small-briquet curve is undoubtedly too low because about 30 per cent of the fuel was crumbled when put into the furnace and the crumbled particles were blown up from the fire before being burned.

The curves labeled A (fig. 5) were plotted to see whether or not the evaporation was lessened by an increased supply of air. The curves indicate that within the covered range of rate of combustion the weight of air supplied per pound of "combustible" was very nearly uniform. This introduces a feature well worth remembering: The more rapidly air is supplied to a burning fuel the faster the fuel burns, and the resulting composition of exit gases remains about the same. This feature is discussed more fully in two bulletins by the present authors, one of which has been published[a] and the other, on the "Transmission of heat in steam boilers, condensers, etc.," will soon be ready for publication.

With the run-of-mine coal the supply of air was somewhat higher than with the briquets, which fact probably accounts for the lower evaporation. The larger air supply in the tests on coal was the outcome of the caking characteristics of the coal. Holes and cracks formed in the fuel bed, through which streams of air flowed into the furnace, thus unduly increasing the air supply, and this in spite of constant raking. The smaller supply of air on the tests with small briquets as compared with those with large briquets was very likely due to the fact that the small ones could be spread over the fuel bed much more evenly than the large ones.

[a] Ray, W. T., and Kreisinger, Henry, Significance of drafts in steam-boiler practice: Bull. U. S. Geol. Survey No. 367, 1909.

ON RATED CAPACITY.

The curves labeled C (fig. 5) show the relation between the capacity developed by the boiler and the rate of firing dry coal. The rated capacity in this case is assumed to be 258.4 boiler horsepower, according to a rule which has been widely adopted in stationary practice to the effect that 10 square feet of heating surface are required to supply one boiler horsepower. This rule is, however, not a logical one, because area of heating surface is only one of four factors which determine the amount of steam produced by a boiler per hour; see Bulletin 325[a] and the above-mentioned bulletin on heat transmission.

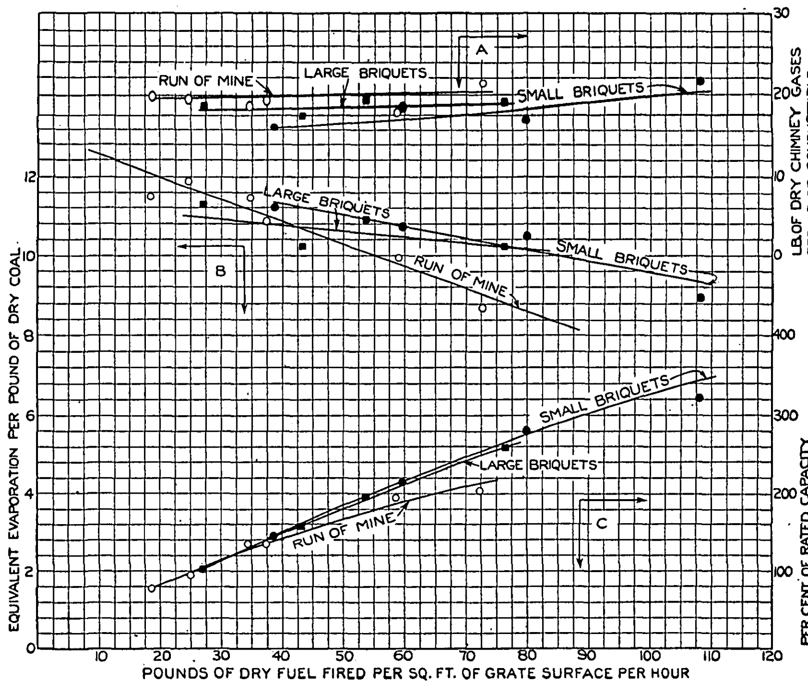

FIGURE 5.—Curves showing relations of rates of combustion to: A, Pounds of dry chimney gases per pound of "combustible;" B, equivalent evaporation per pound of dry coal fired; C, per cent of rated capacity developed by boiler.

In locomotive practice a boiler horsepower is usually made on much less than 10 square feet of boiler heating surface; the above figure was taken mainly to have a basis on which to compare the tests among themselves and also on which to compare them with other tests made by the technologic branch of the Geological Survey. The curves show that the capacity increases almost directly with the nominal rate of combustion. With run-of-mine coal the rise is not quite so fast as with briquets, because the efficiency of evaporation drops off faster.

[a] Breckenridge, L. P., A study of four hundred steaming tests: Bull. U. S. Geol. Survey No. 325, 1907.

ON WEIGHT OF SPARKS.

Figure 6 shows the relation between the pounds of sparks escaping out of the stack per hour and the rate of firing dry coal on the grate. The large briquets are somewhat superior to the small, as might be anticipated, because of their relatively smaller surface. Perhaps much of the inferiority of the smaller size was due to the incidental fact that in consequence of having been handled oftener and more roughly before testing they were more broken up; for instance, about 30 per cent of the fuel of test 14 had crumbled. In this connection it is interesting to note that tumbler tests of the two sizes of briquets show that a larger percentage by weight of the smaller ones chip off, be-

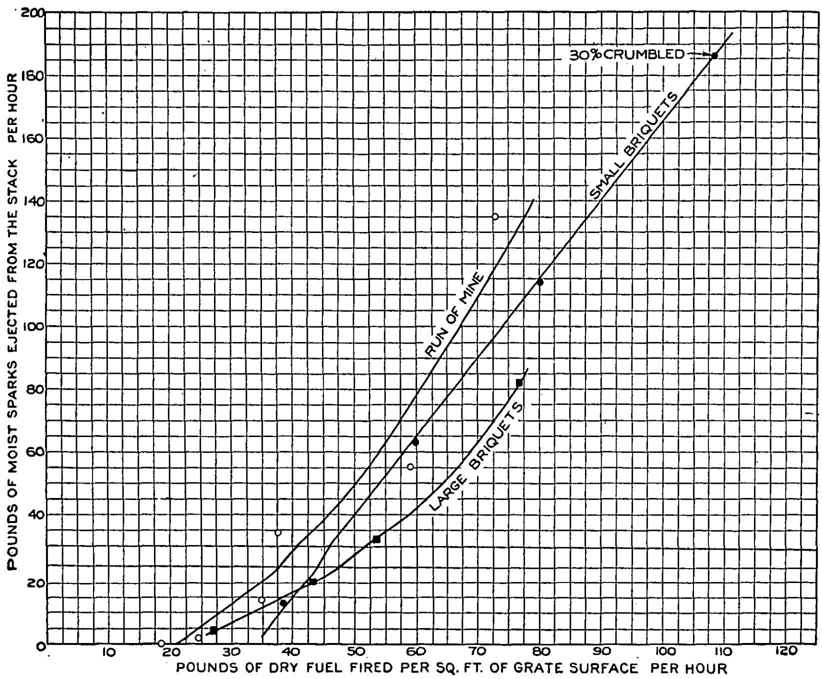

FIGURE 6.—Relation of weight of sparks collected to rates of combustion.

cause of their greater surface exposed, notwithstanding their rounded surface as contrasted with the angular outlines of the larger ones. Either shape of briquet is somewhat superior to coal as regards loss in sparks. The vertical ordinate (of fig. 6) is in terms of moist sparks; sometimes they were dampened by exhaust steam before weighing, but chemical analysis showed the moisture percentage to be negligibly low.

ON HEAT DISTRIBUTION.

Graphic showing.—Figures 7 and 8 show the distribution of the potential heat of the combustible gasified. The arrow heads near each group of curves point to the scales which should be used with each particular group.

Heat absorbed by boiler.—In figure 7 the curves under B show how much of the total heat of the combustible gasified was absorbed by the boiler at various rates of combustion; or, in other words, they show the relation between boiler efficiency (item 72*, Table 2) and the rate of putting dry coal on the fire. This boiler efficiency is based on the potential heat in the combustible ascending from the grate; the amount of combustible ascending is determined by deducting from the amount fired that which falls through the grate, but not that which escapes as sparks. The loss in sparks is given in Table 2 as one of the items in the heat balance. In most of the tests the spark loss was of little consequence, but in some it deserves consideration,

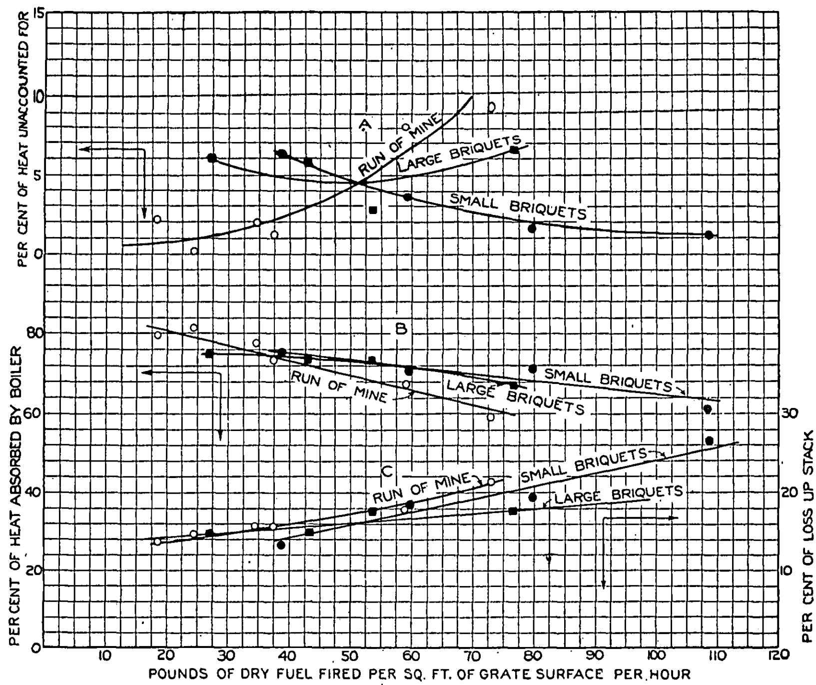

FIGURE 7.—Curves showing relations of rates of combustion to: A, Per cent of heat unaccounted for; B, per cent of heat absorbed by boiler; C, per cent of heat lost in dry chimney gases ("up stack").

especially in test 9, in which it constituted 5.49 per cent of the total heat of the combustible which ascended from the grate. Assuming that if this heat had been liberated only 65 per cent of it would have been absorbed by the boiler, then this 65 per cent of 5.49 per cent would have raised the 72* efficiency from 58.69 to about 62.3. In test 14 the efficiency 72* would have been about 64.1 instead of 61.56; in fact, the improvement of test 14 would have been still greater, because all of the sample of sparks was not caught during the latter end of the test on account of part of the screen of the spark catcher having been worn away.

However, after making due allowance for absorbable heat wasted in sparks, it is still true that the efficiency falls with increasing steam production from about 80 to about 65 per cent. The number of pounds of air supplied per pound of "combustible" was about the same in all tests, and the gas analysis shows that, at least when using briquets, the combustion was nearly as complete at high rates as at low. Why, then, is there so large a drop in over-all efficiency?

Some experimental work done by the United States Geological Survey on small multitubular boilers fed with air heated electrically showed that if more and more air, all at the same initial temperature, were forced through a boiler, the efficiency of the boiler as a heat absorber fell rapidly at first (from 100 per cent) and gradually assumed a nearly constant value, determined by the characteristics of each boiler. This result was, however, obtained with tubes free from soot and scale and far enough apart to allow unusually good water circulation. The locomotive tubes were fairly clean inside and out, but were so close together that the water circulation between them must have been greatly hindered. Further, the rate of transmitting heat through the tubes was sufficient to cause a considerable rise of tube-metal temperature with rise of capacity, thus lowering the efficiency of the boiler as a heat absorber.

Returning now to the locomotive tests, on the whole efficiency from coal to steam is higher than that usually obtained from stationary boilers; much of the margin is due to the burning quality of the coal, but more is due to the high efficiency of the boiler proper, which is a consequence of the larger ratio of the length of the tubes to their internal diameter. They are 170 inches long and 2 inches in internal diameter, the ratios of these two values being 170 : 2=85, which is much greater than is usually the case with stationary multitubular boilers. The gases would have left them at about the same temperature if they had been twice as long and of twice the diameter, or half as long and of half the diameter.[a]

This group of curves (B, fig. 7) shows that when burning run-of-mine coal the percentage of heat absorbed by the boiler dropped rapidly as the rate of combustion increased, but that with the briquets the drop was much smaller.

Loss of heat "up stack."—The curves labeled C (fig. 7) indicate that the loss of heat in the dry chimney gases rose with the rate of combustion, and that about one-half of the drop in boiler efficiency went to increase the loss in the dry chimney gases. For the same rate of combustion the chimney loss is larger with the run-of-mine coal than with either style of briquet, and it increases faster when the rate of combustion increases. The small briquets show a greater loss in the heat in the flue gases than do the large ones; this is perhaps due to the probable fact that the flue thermometer was inaccurate and read too high. On the last two tests with the small briquets it was noticed

[a] For a discussion of the effect of changes in the length and diameter of boiler tubes see Bull. U. S. Geol. Survey No. 325, 1907, pp. 121-124.

that the mercury thread in the thermometer was very erratic, as though the mercury was boiling.

Heat unaccounted for.—The group of curves under A (fig. 7) shows the relation between the per cent of heat unaccounted for and the nominal rate of combustion. The unaccounted-for heat is that left after deducting from the potential heat in the coal gasified (as determined by calorimetric analysis)—

(1) Heat absorbed by the boiler;
(2) Heat escaping in the dry flue gases;
(3) Heat lost in heating the moisture of the coal to flue temperature;
(4) Heat lost in heating to flue temperature the moisture formed by the burning of the hydrogen of the coal;
(5) Heat lost in burning some of the carbon of the coal to CO only instead of to CO_2; and
(6) Heat lost by noncombustion of the carbon of the sparks.

The unaccounted-for heat includes radiation, incomplete combustion (other than CO loss mentioned above), and all errors of observation and instruments, as well as any errors of sampling the coal, ash, and sparks, and any very slight errors of analyzing them chemically. In other words, any irregularities or false indications in the curves labeled A may be due to any of these causes or errors.

The locomotive boiler was well jacketed, so that the radiation was very small. It is very likely that the radiation is substantially constant in amount, because it depends only on the temperatures of the steam and the outside air, and if it is about constant it decreases in percentage as the rate of steam production increases.

The unaccounted-for heat of most of the tests is unusually small, which shows an unusual completeness of combustion, probably due to very careful firing and to the fact that most of the tests were on briquets of coal which has good burning qualities even when not briquetted.

Heat loss in moisture.—The group of curves under A in figure 8 shows the relation between the heat carried away in the moisture of the flue gases and the nominal rate of combustion of dry fuel. In the moisture is included that in the coal (item 2 in the heat balance) and that formed by burning the hydrogen of the coal (item 3 of the heat balance). All the curves show a slight increase. Inasmuch as the amounts of moisture and hydrogen in the coal and the briquets is nearly the same for all tests, the increase is undoubtedly due to the rise of flue-gas temperature.

Heat loss in CO.—In this same figure 8 the curves labeled B show the relation between the heat lost in burning some of the carbon of the coal to CO only (instead of to CO_2) and the nominal rate of combustion. The curves are somewhat irregular, but they seem to indicate that more heat is lost in CO when burning briquets than when burning run-of-mine coal; the small briquets show a greater loss than the larger ones. The larger loss with briquets is very likely due to the fact that less air was used with them than with the run-of-mine coal.

Heat loss in sparks.—The group of curves marked C (fig. 8) shows that as the nominal rate of combustion increases the loss in sparks rises. The rise is greater with run-of-mine coal than with either kind of briquet, and greater with the small briquets than with the large ones. The higher loss from the coal is undoubtedly due to the presence of slack, which is partly carried through the flues without burning. Some of the small briquets were more or less crumbled when

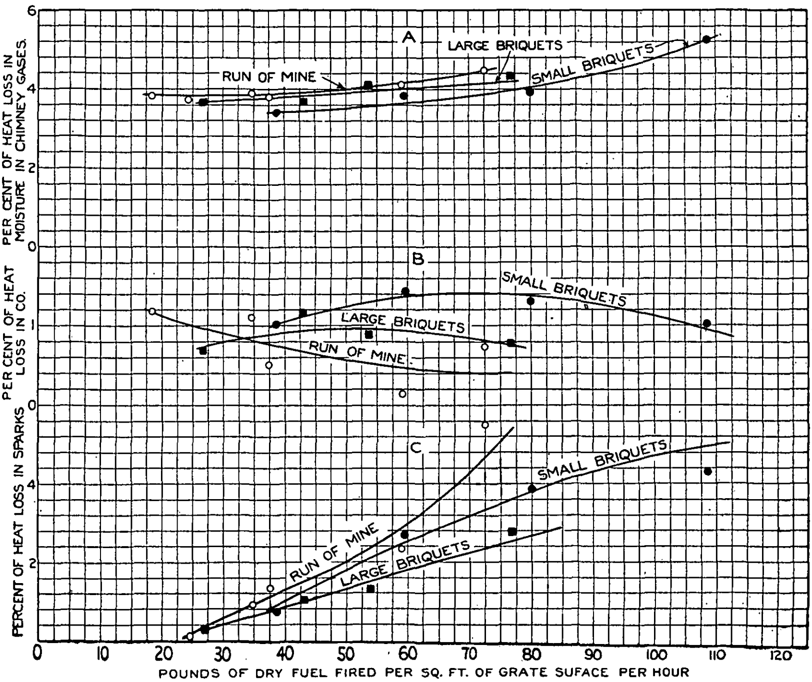

FIGURE 8.—Curves showing relations of rates of combustion to: A, Per cent of heat lost in moisture in chimney gases (that is, in the free moisture of the coal plus the moisture formed by the burning of hydrogen); B, per cent of heat lost by burning some of the carbon only to CO instead of to CO_2; C, per cent of heat lost as sparks.

fired, so it is probable that their higher loss in sparks was due to the fact that some of the finer particles were carried up unburned.

ON COST OF STEAM.

Figure 9 shows the relative costs of steam when run-of-mine coal and the two kinds of briquets are burned at various rates. The scale at the left is based on the assumption that the raw coal costs $2.50 per ton in the tender; the cost of steam from it is obtained directly from the equivalent evaporation. The cost of steam from the briquets is obtained by multiplying the values similarly obtained from the equivalent evaporation by 112.5, 125, 137.5, and 150 per cent, to cover various costs of briquetting. Thus the briquet curves labeled 1.125 give the cost of steam if the briquets cost 1.125 times as much as run-of-mine coal on the tender; the briquet curves labeled 1.25 give the cost of steam if the briquets cost 1.25 times as much as run-of-mine coal, and so on. In computing all these costs of steam no allowance was made for the labor of the fireman, for water, for repairs, depreciation, etc. It may be stated with reasonable safety that it is easier for a fireman to fire 1¼ tons, or even 1½ tons, of briquets than a ton of coal in the same time, for he is saved the raking. The curves show that at low

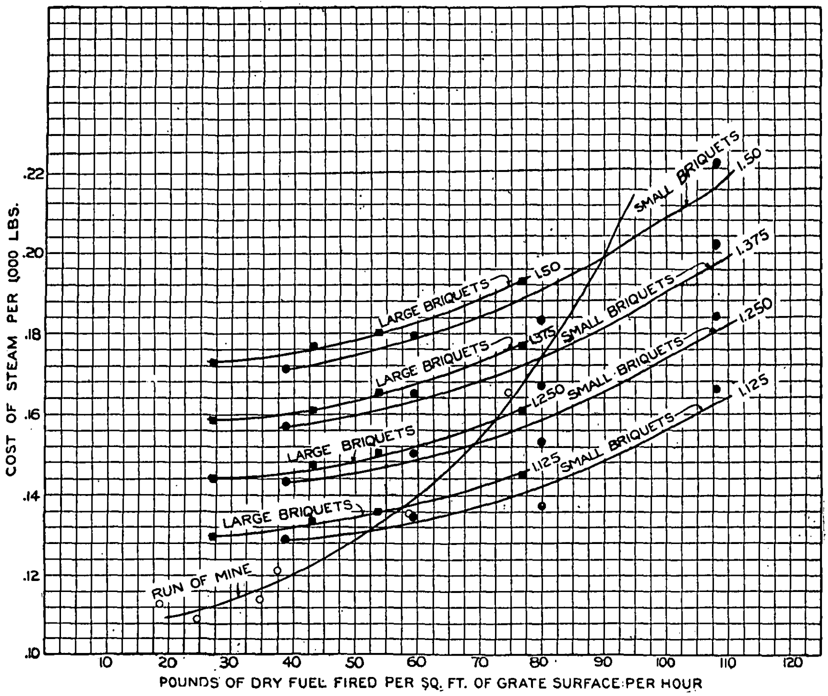

FIGURE 9.—Curves showing relative costs of steam per 1,000 pounds when burning run-of-mine coal and two kinds of briquets at various costs for briquetting, all at various rates of combustion. The assumed basis of cost for coal is $2.50 per ton of 2,000 pounds. The figures at the upper end of each briquet curve indicate the cost of briquets for comparison with the cost of the coal, which is taken as unity.

rates of combustion it does not pay to burn briquets; nevertheless, as the rate increases the cost of steam, when generated from run-of-mine coal, rises very rapidly, so that when burning 60 or 70 pounds per square foot of grate per hour the briquets give better economy. With a well-equipped briquetting plant the cost of making briquets should not exceed $1.25 to $1.50 per ton, to which must be added the cost of the coal, which, if the briquetting is done at the mine and slack coal used, may be placed at a very low figure. Inasmuch as locomotives are already worked at high rates of combustion, and as higher and higher rates will be desired, the use of briquets has a rather promising future in steam-locomotive service.

ADVANTAGES OF BRIQUETS FOR LOCOMOTIVE USE.

Higher equivalent evaporation.—At higher rates of combustion briquets give better equivalent evaporation than run-of-mine coal. According to figure 5 (p. 21), as the nominal rate of combustion increases beyond 50 pounds of fuel per square foot of grate surface per hour the evaporation from briquets remains increasingly higher than from coal. In present locomotive practice the usual rate of combustion is about 65 pounds, at which rate the briquets give about 10 per cent higher equivalent evaporation. At an 80-pound rate the evaporation is about 15 per cent higher than with coal. For still higher rates the discrepancy is still higher.

The cost of steam from briquets is of course increased by the cost of briquetting the coal, which, with a well-equipped plant, and especially when working up slack, should not exceed the cost of run-of-mine coal by more than 12 to 15 per cent. By consulting figure 9 (p. 27) it will be seen that at such a cost of briquetting the cost of steam, at the present usual rate of combustion (65 pounds) would be somewhat lower from the briquets.

Ease of manipulating fires.—The burning qualities of briquets are so much superior to those of ordinary run-of-mine coal as to cause the fireman much less work. The fact that usually a briquet fuel bed had better not be disturbed for hours makes it possible to burn fuel much faster with no more labor. (Compare under "Notes on individual tests," beginning at p. 18.)

Possible increase in rate of steam production.—Owing to the feasibility of burning briquets much faster than run-of-mine coal with the same "draft," it is possible to increase the tractive power of present locomotives, and thus shorten the time required to pull a given train over a certain road or to increase the train load.

It may be possible to increase the present steaming ability of locomotives by 25 or even 50 per cent; part of this increase may possibly be obtained by providing different exhaust nozzles, such as will produce greater pressure drops ("drafts") through the fuel bed and boiler, with the same expenditure of energy; that is, with the same back pressure on the pistons. (See under "Suggested changes in design and construction of locomotive," p. 30.) By simultaneously changing fuel from run-of-mine to briquetted coal this margin might be further increased. The resulting increase in the earning power of a locomotive would be accompanied by some increase in operating expenses.

Table 3 gives tentative figures, indicating what may be expected when increasing the hauling power of present locomotives. According to the statistics of the Interstate Commerce Commission, in 1906 the average freight locomotive earned about $70,000, gross. The operating expenses of the average railroad were 70 per cent of its operating income, and the remaining 30 per cent went to pay incidental expenses, bond interest, note interest, insurance, dividends, betterments, and to surplus.

To make our problem simpler, it is assumed that only the operating expenses would increase directly with the increase in earning power per locomotive—probably a safe assumption; for certainly some of the operating expenses would not be increased, and the others would not increase as fast as the earnings per locomotive.

The table speaks in favor of increasing the hauling power. Nevertheless the figures are tentative only, being derived through rough and simple approximations; for any division of any road all details should be carefully included.

TABLE 3.—*Estimated results of increasing the haulage power of freight locomotives.*

Rate of working freight locomotive.	Average ton-miles per annum per freight locomotive.	Per average freight locomotive.					
		Earnings.		Operating cost.		Net earnings.	
		Dollars.	*Per cent.*	*Dollars.*	*Per cent.*	*Dollars.*	*Per cent.*
Present[a]	7,000,000	70,000	100	49,000	70	21,000	30
Increased by 25 per cent	8,750,000	87,500	100	49,000 + 6,125 55,125	63.4	32,375	36.6
Increased by 50 per cent	10,500,000	105,000	100	49,000 +12,250 61,250	58.3	33,750	41.7

[a] From report of Interstate Commerce Commission for 1906.

DISADVANTAGES OF BRIQUETS FOR LOCOMOTIVE USE.

Storage capacity.—When briquets are shoveled or dropped into a tender spaces are always left, which, in the case of run-of-mine coal, are largely filled with slack. The presence of these air spaces reduces the capacity of the tender 20 to 28 per cent. Of course the large so-called "square" briquets could be laid up like bricks by hand, so as to leave almost no vacant spaces, but the extra trouble probably would not pay.

Difficulty of shoveling.—When first beginning to handle briquets most firemen have considerable difficulty in getting them into the scoop; the annoyance often founds a prejudice. Intelligent effort will eliminate the trouble, especially with the small ovoid shape.

GENERAL DEDUCTIONS.

At the usual rate of combustion in locomotives the equivalent evaporation with either kind of briquet is 10 to 15 per cent higher than with run-of-mine coal.

So far as blackness of smoke is concerned there seems to be little advantage in briquets over run-of-mine coal. However, the loss in sparks is less, and especially with the larger size of briquets.

It is a great deal easier to raise and to keep up steam with briquets than with run-of-mine coal. Higher rates of combustion are feasible, and consequently higher power, which is of especially great advantage on long grades.

As to efficiency, there is practically no difference between the two kinds of briquet, but the smaller ones are easier to handle.

SUGGESTED CHANGES IN DESIGN AND CONSTRUCTION OF LOCOMOTIVE.

Grate and combustion chamber.—Although the combustion of this particular coal and of briquets made therefrom was very complete, combustion is not usually at all good with most of the coals of the country, even when briquetted. The fire-brick arches of this type of boiler are undoubtedly of great benefit in mixing the gases and in igniting freshly fired coal, but some roads object to them because they interfere with stay-bolt inspection. The great trouble is that the time elapsing between the instant the gases leave the fuel bed and the instant they enter the tubes is much too short with ordinary coals. One way of materially remedying this trouble, which is being more and more employed, is to add a "combustion chamber" inside the cylindrical portion of the boiler, opening out of the front side of the fire box. To accomplish much improvement this additional length of gas travel must amount to several feet. It is usual to keep the fire tubes the same length and to make the whole boiler so much longer—a subterfuge to which there are practical objections.

Dimensions of fire tubes.—In Bulletin 325[a] there is an extended discussion, touching, among other things, on the ratios between the length and diameter of boiler tubes as affecting their efficiency and capacity as heat absorbers. Specifically stated for the present case, if the tubes were made half as long and of half the internal diameter, the gases would leave them a little cooler than now; if they were made two-thirds as long, and of two-thirds the internal diameter, the gases would also still leave them a little cooler than now. That is, the efficiency of a tube, aside from slight modifying factors, depends solely on the ratio of its length to its internal diameter, other conditions of cleanliness, etc., being the same. This sameness of efficiency is nearly independent of the amount of gas passing through. It is certainly the case that if the tubes were made half as long, of half the internal diameter, and if four times as many were used (to give the same area of flow for the gases), then the total weight of gas passing through per minute would be fully as great, and the total amount of heat absorbed somewhat greater. It is indeed probable that the number of tubes would not have to be quadrupled for the same "draft" in the smoke box, but perhaps only doubled.

[a] Breckenridge, L. P., op. cit., p. 121-124.

One objection to making the tubes smaller is that they would choke up more quickly; nevertheless the authors have sometimes observed that about one-third of the tubes of locomotives are choked up anyhow within a short time after cleaning, although such is probably not the general condition of such boilers. The higher velocity of gas through the smaller tubes should tend to keep them clean, unless they fill up at the entrance.

It is well here to introduce a short calculation of the effect of reduced dimensions on the strength of tubes against shearing ("cutting off") at the tube sheets. Suppose the tube to be halved in all its dimensions, including thickness, then it will weigh one-eighth as much and have one-half the bearing surface in tube sheets of the same thickness as before; it is therefore about one-fourth as likely to cut off, although the reasoning is mathematically only approximate.

As to bending, the tube may be considered to be a beam uniformly subjected along its entire length to a live load of its own weight, though here again the reasoning is only approximate. A calculation with formulas for hollow cylinders used as beams shows that the smaller tube will be one-half as apt to bend from jarring.

"Draft" production.—The function of a locomotive called "draft" production is so intimately connected with speed, steam pressure, per cent of cut-off, etc., that it would probably be hard to greatly improve nozzles; the very fact that the present shapes are the result of a long evolution is fair evidence that they are reasonably satisfactory, especially when we recall that the Master Car Builders' Association has experimented considerably on nozzles. Figure 4 shows the nozzle of this locomotive, which is representative of a type commonly used.

Nevertheless, it is hard for a layman to believe that it is necessary to absorb so large a part of the possible power in moving air through the fuel bed and boiler tubes; if nothing can be done to make nozzles more efficient, there is likely hope in the direction of utilizing some of the unavoidable impact of the locomotive front against the air; the fact that certain experiments of this kind have failed is not conclusive negation. The tests herein described show that this one boiler is capable of producing enough steam for two or three locomotives; part of the increase could be utilized in this one locomotive, providing the "draft" was economically obtainable and more weight was put on the drivers; or, in western portions of the United States, the gain could be utilized in making better time or by pulling longer trains when using poorer coals than are commonly used at present.

SURVEY PUBLICATIONS ON FUEL TESTING AND BRIQUETTING.

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 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 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 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 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. 10 cents.

Bulletin 325. A study of four hundred steaming tests, made at the fuel-testing plant, St. Louis, Mo., 1904, 1905, and 1906, by L. P. Breckenridge. 1907. 196 pp. 20 cents.

Bulletin 332. Report of the United States fuel-testing plant at St. Louis, Mo., January 1, 1906, to June 30, 1907; J. A. Holmes, in charge. 1908. 299 pp.

Bulletin 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 cents. (See Bull. 373.)

Bulletin 336. Washing and coking tests of coal and cupola tests of coke, by Richard Moldenke, A. W. Belden, and G. R. Delamater. 1908. 76 pp. 10 cents.

Bulletin 339. The purchase of coal under government and commercial specifications on the basis of its heating value, with analyses of coal delivered under government contracts, by D. T. Randall. 1908. 27 pp. 5 cents. See Bull. 378.

Bulletin 343. Binders for coal briquets, by J. E. Mills. 1908. 56 pp.

Bulletin 362. Mine sampling and chemical analyses of coals tested at the United States fuel-testing plant, Norfolk, Va., in 1907, by J. S. Burrows. 1908. 23 pp. 5 cents.

Bulletin 363. Comparative tests of run-of-mine and briquetted coal on locomotives, including torpedo-boat tests and some foreign specifications for briquetted fuel, by W. F. M. Goss. 1908. 57 pp., 4 pls.

Bulletin 366. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 1908. 44 pp., 3 pls.

Bulletin 367. Significance of drafts in steam-boiler practice, by W. T. Ray and Henry Kreisinger. 1909. 61 pp.

Bulletin 368. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. R. Delamater, and J. W. Groves. 1909. 54 pp., 2 pls.

Bulletin 373. The smokeless combustion of coal in boiler plants, by D. T. Randall and H. W. Weeks. 1909. 188 pp.

Bulletin 378. Results of purchasing coal under government specifications, by J. S. Burrows; Burning the small sizes of anthracite for heat and power purposes, by D. T. Randall. 1909. 44 pp.

Bulletin 385. Briquetting tests at Norfolk, Va., by C. L. Wright. 1909. 41 pp., 9 pls.

Bulletin 403. Comparative tests of run-of-mine and briquetted coal on the torpedo boat *Biddle*, by W. T. Ray and Henry Kreisinger. 1909.

Mineral Resources, 1907. Coal briquetting in 1907, by E. W. Parker, pp. 223–228.

Mineral Resources, 1908 Coal briquetting in 1908, by E. W. Parker. 1909.