DEPARTMENT OF THE INTERIOR
BUREAU OF MINES
JOSEPH A. HOLMES, DIRECTOR

COMPARATIVE TESTS
OF
RUN-OF-MINE AND BRIQUETTED COAL
ON THE
TORPEDO BOAT BIDDLE

Made with the collaboration of Lieut. Commander Kenneth McAlpine, U. S. N.
and Ensign J. W. Hayward, U. S. N.

BY

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COMPARATIVE TESTS OF RUN-OF-MINE AND BRIQUETTED COAL ON THE TORPEDO BOAT BIDDLE.

By Walter T. Ray and Henry Kreisinger.

INTRODUCTION.

General statement.—The briquetting tests conducted by the technologic branch of the United States Geological Survey had their beginning in the testing of coals and lignites at the Louisiana Purchase Exposition, St. Louis, Mo., in 1904. Briquetting tests were made at the fuel-testing plants at St. Louis, Mo., and at Norfolk, Va. Similar tests to be made at the experiment station of the Bureau of Mines at Pittsburg, Pa., form an essential part of investigations looking to the determination of the fuel value of the coals and lignites belonging to or for the use of the United States.

The tests have comprised (1) the manufacture of briquets to determine the adaptability of different coals and lignites to the process and the merits of different binding materials; (2) physical tests to establish the fitness of the briquets to withstand weathering, transportation, and handling; and (3) steaming tests to prove the calorific value of the briquets in boilers of different types used by the Government, and, by comparison with the raw coals, the benefits to be derived from briquetting.

Details of the tests have been issued in other publications. A list of Government publications on fuel testing and briquetting is given at the close of this volume.

Tests at Norfolk.—The fuel tests conducted at Norfolk included a detailed investigation of a number of Virginia and West Virginia coals that are bought by the United States Government for the Navy and for use in constructing the Panama Canal, and are extensively used by the merchant marine, manufacturing plants, and railroads. Through a cooperative arrangement with the Navy Department steaming tests of the coals were undertaken to determine the relative merits of the same coal when burned raw or as briquets in marine boilers.

Preliminary arrangements were made between Joseph A. Holmes, then expert in charge of the technologic branch of the United States

Geological Survey and now director of the Bureau of Mines, and Rear-Admiral Charles W. Rae, Chief Engineer of the United States Navy. The tests were made on board the U. S. torpedo boat *Biddle,* designated for the purpose, beginning December 6, 1907, and ending January 27, 1908.

The coal used in these tests came from the Sewell and Beckley beds in the New River district of West Virginia. With the particular equipment used in the tests both coal and briquets were far from smokeless; consequently the data of this bulletin are applicable only by analogy to parallel operation with a coal more nearly smokeless, but nevertheless applicable with much reliability. The possibilities of coals of different composition are indicated by the data to be published in a bulletin of the Bureau of Mines, wherein the present authors describe a number of tests in which only a very slight amount of smoke was emitted while burning raw coal from the Pocahontas No. 3 bed, West Virginia, and briquets made therefrom at rates of combustion very much higher than any rates used in the torpedo-boat boiler. At a combustion rate of 120 pounds of the Pocahontas briquets per square foot of grate surface there was scarcely any smoke.

It was the original intention to make a set of preliminary steaming tests alongside a dock (which tests furnish material for this bulletin) and to finish with a set of running tests at sea; but the running tests were never made, for lack of time and men.

PERSONNEL.

The conduct of the tests, on behalf of the navy, was under the immediate supervision of Lieut. Commander Kenneth McAlpine assisted by Ensign J. W. Hayward, in command of the *Biddle.* The Geological Survey was represented by Walter T. Ray and Henry Kreisinger of the steam-engineering section.

Messrs. McAlpine and Hayward directed the preparation of the boat and other apparatus for the tests and had all the special appliances made in the navy-yard shops. All tests were supervised by Messrs. Hayward and Kreisinger. The navy supplied water tenders, firemen, and a number of machinists. The latter acted as observers and recorders of pressures, temperatures, and weight of water. Weight of coal fired was recorded currently by Mr. Kreisinger, who supervised the management of fires. Flue-gas analyses were made usually by a representative of the Geological Survey; many of them were made by J. K. Clement, physicist of the technologic branch, who very kindly volunteered to help with the work during the first eight tests. The flue-gas analyses on the rest of the tests were made by Mr. Ray. Firing on all the tests was done by the navy firemen, who were found to be exceptionally skillful in this work.

COALS AND BRIQUETS.

The coal used in these tests was all run-of-mine and came from four different mines, all of which are located on the Chesapeake and Ohio Railway and in the New River coal field. The designations given these four coals at the United States fuel-testing plant are followed in this bulletin.

Jamestown No. 6 coal came from the Sewell bed at Red Star, Fayette County, W. Va. Jamestown No. 9 coal came from the Sewell bed, mined near Winona, Fayette County, W. Va. Jamestown No. 10 coal came from the Beckley bed, at Stanaford, Raleigh County, W. Va. Jamestown No. 11 coal came from the Beckley bed, at West Raleigh, Raleigh County, W. Va.

Part of the Jamestown 6 coal was made into briquets 6¾ by 4¼ by 3 inches in size, at the United States fuel-testing plant on a briquetting press built in England. The compression on these large briquets was about 2,500 pounds per square inch. The binder used was 6 per cent of water-gas pitch, described in Bulletin 385[a] under laboratory number 5563.

Portions of the Jamestown 9 and 11 coals were made into briquets circular in horizontal section, 3¼ inches in diameter, 2⅜ inches thick in the center and 1¼ inches at the circumference. The compression on these small briquets was about 1,000 pounds per square inch. In both coals the binder used was 6 per cent of water-gas pitch, described in Bulletin 385[a] under laboratory number 5941.

OBJECTS OF THE TESTS.

The main object of these tests was to determine whether the use of briquetted coal on torpedo boats has any advantages over the use of raw coal. Besides comparing the economy obtained with briquetted and raw coal, the following properties of the two fuels were given particular attention: (*a*) The tendency to smoke; (*b*) the amount of sparks emitted from the stack; (*c*) the rate at which steam can be made and the ease with which the fires are handled; (*d*) the ease of transferring fuel from the coal bunkers into the fireroom.

APPLIANCES.

BOAT AND BOILER PLANT.

The torpedo boat *Biddle* is 157 feet in length on load water line, 17 feet 7½ inches extreme beam, and 175 tons displacement. Its equipment includes two triple-expansion engines and two water-tube

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[a] Wright, Charles L., Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907-8: Bull. U. S. Geol. Survey No. 385 (Bureau of Mines Bulletin 30), p. 8.

boilers. The engines are in separate compartments amidships. The boilers are in separate boiler rooms, one at each end of the engine compartments, the fronts of the boilers facing the latter. In front of each boiler is a space about 10 feet square used as the fireroom, in which is placed an auxiliary feed pump and the wheel of a blower fan. The blower is run by the engine in the main compartment. Alongside each boiler room are two coal bunkers, each capable of holding about 22.5 tons of soft coal. In cross section each coal bunker is approximately a segment of a circle with the chord of the segment placed vertically and with its tips cut off by the deck and the floor of the bunker. This floor of the bunker is, however, only about 8 to 12 inches wide, which fact, in connection with the ribs of the sides of the boat projecting inward, makes shoveling coal from the bunker rather difficult. Two feed-water reserve tanks alongside the engine compartments, of shapes similar to those of the coal bunkers, have each a water capacity of about 700 gallons.

The two boilers are exactly alike in size, construction, and setting (fig. 1). Only the forward boiler was used for tests. It is of the curved water-tube type known as the Normand boiler. The boiler proper consists of the steam drum S, connected to two mud drums M by 1,552 curved water tubes $1\frac{3}{16}$ inches in external diameter and two $10\frac{3}{4}$-inch downcomers in the rear of the boiler. The steam drum is provided with a steam dome in which the intake of the steam pipe is placed. Feed water is fed into the steam drum.

The furnace is placed under the steam drum between the two nests of water tubes and the mud drums. It is equipped with a plain grate for hand firing. The coal is charged through two firing doors 12 by 14 inches, the lower edges of which are 14 inches above the grate, which feature of construction makes the process of removing clinker from the fuel bed while running rather difficult. In the front portion of the boiler on both sides the first and second rows of tubes next the furnace are so curved and placed with respect to each other that they form a nearly gas-tight baffle. On the outside of each nest of tubes the last two rows are similarly placed along the full length of the boiler. This constructional feature is shown in figure 1 in the front view and in the section across the nest of tubes.

The products of combustion flow to the rear of the furnace, where they enter the tube nests through the spaces between the tubes, which are left open for this purpose. Through the nests of tubes the gases flow to the front of the boiler and there turn up into the hood and out through the stack. The gases pass through the tube spaces only once. The path of the gases is indicated in the longitudinal section through the boiler.

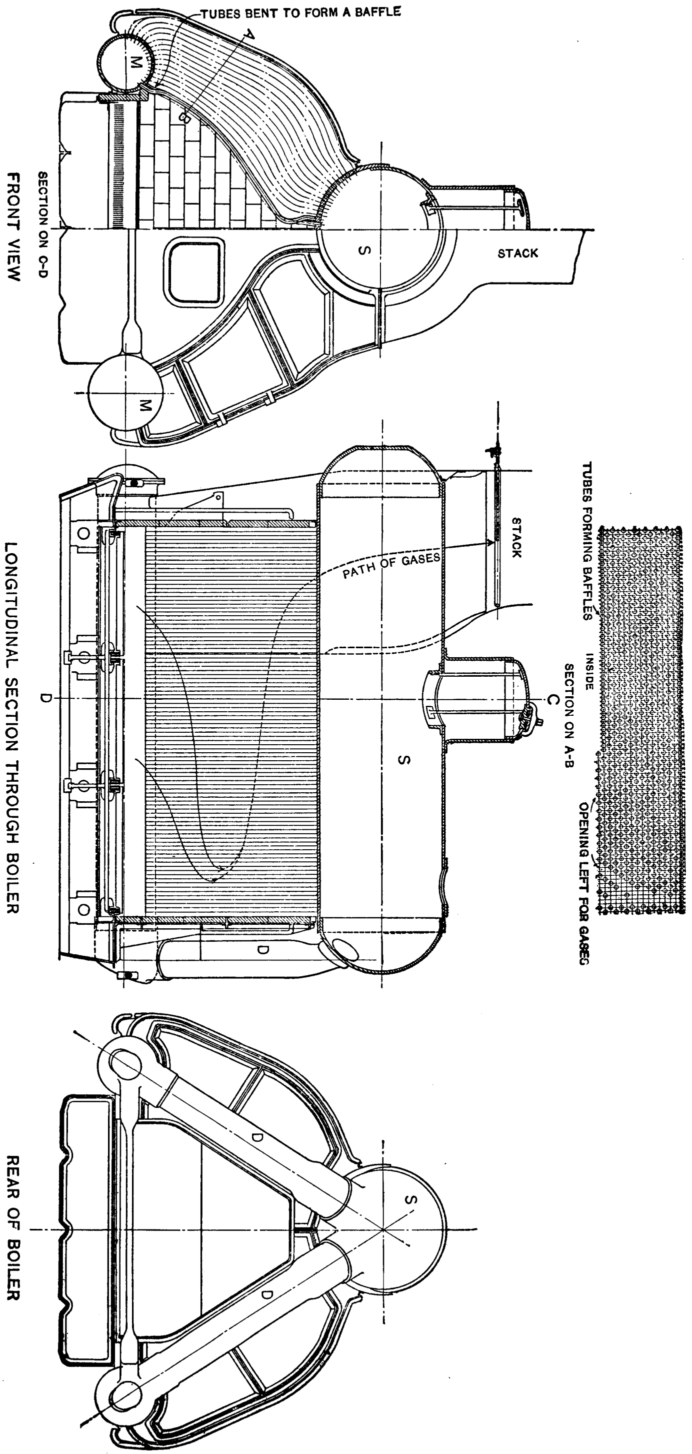

FIGURE 1.—Construction and setting of Normand water-tube boiler.

The principal dimensions of the boiler and furnace are shown in Table 1.

TABLE 1.—*Dimensions of Normand water-tube boiler and plain-grate furnace.*

Diameter of steam drum	inches	35.43
Length of steam drum	do	150.00
Diameter of mud drums	do	10.75
Length of mud drums	do	141.75
Diameter of downcomers	do	10.75
Number of tubes		1,552
Outside diameter of tubes	inches	1$\frac{3}{16}$
Approximate length of tubes	do	75.5
Total heating surface	square feet	2,776.19
Length of furnace	feet	9.16
Width of furnace	do	6.40
Height of furnace from grate to steam drum	do	4.65
Height of furnace from grate to bend of tubes	do	3.76
Approximate combustion space above grate	cubic feet	136
Distance from front of furnace to opening among tubes	feet	5.5
Length of bars	inches	37.5
Average width of grate bars on top	do	.375
Average width of air spaces	do	.56
Air spaces in grate (approximate)	per cent	.55
Area of grate	square feet	58.6
Ratio of grate area to combustion space		2.33
Inner dimensions of stack	inches	36 x 40
Height of stack above grate	feet	15

The whole boiler and furnace were inclosed in a cast-iron casing, which was lined with fire brick at the front and rear of the combustion space and with sheet asbestos along the nests of tubes. In front the casing had tight-fitting doors opening into the tube nests to facilitate the cleaning of soot from the tubes.

The stack, which was slightly elliptical in cross section, was made of two concentric tubes with 1$\frac{1}{2}$-inch annular air space between, open to the air at the top and also at the base of the stack. The object of this construction was to circulate air between the inner and outer tubes, thus keeping the outer shell cool.

FLUE-GAS SAMPLER.

The flue-gas sampler was inserted in the stack immediately above the hood, as shown in the longitudinal cross section (fig. 1). The sampler was especially made for these tests and consisted of a $\frac{3}{4}$-inch pipe closed at both ends and having a number of $\frac{3}{32}$-inch holes drilled in a staggered way on two opposite sides of the pipe. Through a cap closing one of the ends of this pipe was inserted a $\frac{1}{4}$-inch pipe, which extended to the middle of the $\frac{3}{4}$-inch pipe. The gas was drawn through the inner pipe. The object of this construction was to draw gas at nearly the same rate from many places in the stack, so that the gas thus collected may be taken as a rough average of the gases flowing up through the stack. The construction of this sampler is shown in figure 2. Connection was made to a steam injector, which drew a continuous stream of gas through the sampler. The sample collected for analysis was drawn through a pet cock placed between the sampler and the injector.

SPARK CATCHERS.

Figure 3 shows four spark catchers in position, as used during the tests. Each spark catcher consists of a U-shaped sheet-iron vessel open at both ends and placed with the open ends down over the top of the stack. The end inside the stack is in shape nearly a sector of a circle covering an angular area of 9 degrees, so that the total area covered by the four spark catchers is 0.1 of the total cross-sectional area of the stack. The outside end of the U-shaped vessel is nearly rectangular in cross section and terminates in a detachable sheet-iron receptacle. This U-shaped vessel catches gases and sparks from a sector of the stack area and changes their direction downward. The gases are allowed to escape through an opening in the outside end of the U-shaped vessel, which opening is provided with wire netting of 24 meshes to an inch. The sparks are kept in by the wire netting and fall into the

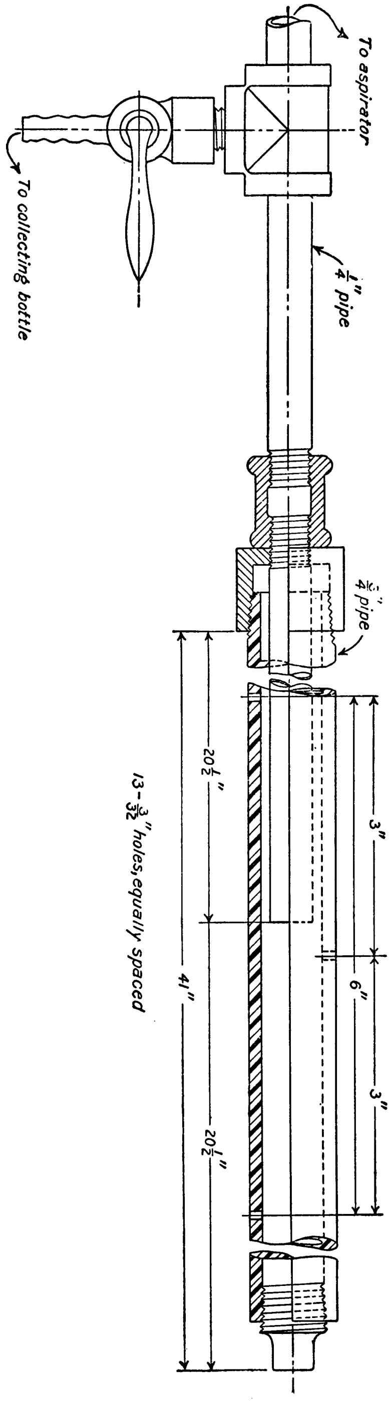

FIGURE 2.—Flue-gas sampler.

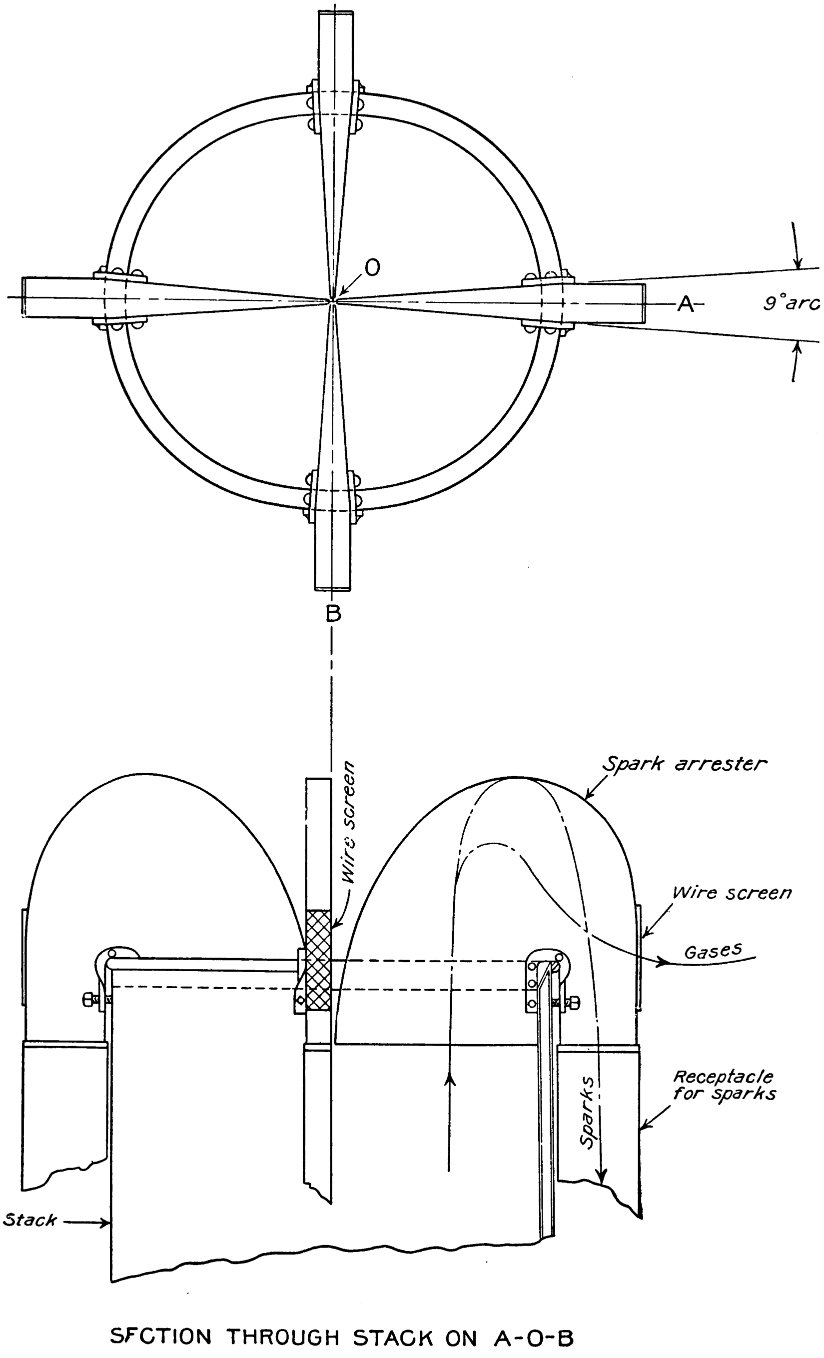

FIGURE 3.—Spark catchers.

receptacle, where they accumulate. As these spark catchers cover about 0.1 of the area of the stack, the amount of sparks collected in the receptacle is about 0.1 of the total sparks ejected from the stack.

These spark catchers were specially designed and constructed for these tests in order to determine the comparative losses in sparks when burning raw coal and the two kinds of briquets.

THE BLOWER.

The necessary air required for the combustion of the fuel in the furnace was supplied by a blower which forced air into the fireroom, which was kept as nearly air-tight as practicable. Thus, by changing the speed of the blower, any desired excess of pressure over the outside atmosphere could be kept in the fireroom and under the grate, and within certain limits any rate of combustion could be obtained.

The wheel of the blower was 5 feet in diameter and was placed directly in the fireroom; it had no casing and was protected only by a wire screen. The blades were curved in the direction opposite to that of the rotation of the wheel. The maximum speed of the blower was about 1,000 revolutions per minute.

METHODS OF CONDUCTING TESTS.

General statement.—All tests were made using the forward boiler while the boat was tied to the docks at the Norfolk Navy-Yard. Steam was generated at 200 pounds pressure and discharged into the atmosphere. The water tender on duty also regulated the steam pressure in the boiler. During a test all regular observations were made every twenty minutes.

Starting and closing.—In starting and closing the tests a modification of the "alternate method" was used. The boiler was kept under steam pressure all night with a low fire covering the front third of the grate. About one hour before starting a test the fire was spread over the whole grate and gradually built up to 3 or 4 inches height. During this building of the fire about 500 pounds of coal were put into the furnace. On starting the test the height of the fuel bed was measured as accurately as possible with the prongs of a rake, and readings were taken of the steam pressure and height of water in the boiler. The reserve water tank from which the boiler was fed was always completely filled when a test was started. Closing conditions of the tests were made as nearly as possible the same as those of starting.

Weight of ash and refuse.—Before closing a test the fuel bed was burned down so that its height above the layer of clinker was the same as at the start, as nearly as could be estimated by means of the prongs of a rake. The test was started with the ash pan clean. After closing the test the free ash was removed from the ash pan, weighed, and charged to the test. The fire was then burned down entirely, the clinkers pulled out through the fire doors, weighed, and also charged to the test. The small amount of free ash falling into the ash pan during the process of pulling out clinkers was not charged to the test. It was impracticable to clean the fire before the close of the test on account of the lower edge of the fire door being 14 inches above the grate.

Weight of coal fired.—The fireroom was so small that it was impossible to place a scale in it and weigh the coal as it was fired; therefore on most of the tests the coal was weighed before the test and put in sacks of 100 pounds each and delivered to the coal bunkers. During the test 3 or 4 sackfuls of coal were emptied on the floor of the fireroom and fired in two to four firings. The number of sackfuls and the time of emptying them were recorded. This method of recording coal enabled the man having charge of the fire to keep the rate of combustion uniform. In a few tests a definite amount of the coal was weighed before the test and put into an empty coal bunker without sacking it. The small amounts of coal used before tests were delivered directly to the fireroom and were not taken from the weighed coal in the bunker. During a test an approximately known quantity of coal, measured with a large sheet-iron bucket, was put on the firing floor at a time, the approximate weight and time of delivery being recorded. In this manner the rate of combustion was maintained at the desired rate, and all the weighed coal in the bunker was burned before closing the test. On all tests when a new supply of coal was delivered from the bunker to the firing floor a sample for chemical analysis was taken and put into a covered can. This sample coal was weighed and subtracted from the total coal weighed for the test.

Weight of water fed to boiler.—Water was measured in a tank with a capacity of 2,239 pounds placed on deck above the reserve water tank. The bottom of the measuring tank was funnel-shaped, to permit quick emptying. The top of the tank was contracted by means of a cone into a narrow 8-inch neck in order that when filling the tank any difference of level due to tossing of the boat would introduce only an inappreciable error. From the measuring tank the water was run into the reserve tank and thence was pumped by the auxiliary feed pump into the boiler. Tests were started with the reserve tank full, and during the test the number of measuring tanks emptied and the times of emptying were recorded. At the end of a test any quantity of water left in the measuring tank and not required to fill the reserve tank completely was weighed in a smaller tank placed on a platform scale and proper correction made of the total water weight.

Feed-water temperature.—A thermometer was immersed in the reserve tank and read at regular intervals.

Flue-gas sampling.—Flue gas was sampled with the specially constructed gas sampler described on page 10–11. The sample was collected on the deck at the stack and then taken to the cabin, where it was analyzed for CO_2, O_2, and CO. The location of the sampler is shown in figure 1.

Flue-gas temperature.—The flue-gas temperature was measured with a platinum and platinum-rhodium thermocouple. The thermocouple was placed in the center of the stack near the flue-gas sampler and was connected with a cord to a galvanometer placed on the dock and reading in degrees Centigrade.

Furnace temperature.—Furnace temperature was measured with a Wanner optical pyrometer. For this purpose a hole 1¼ inches in diameter was drilled in the furnace casing in the back of the boiler and about 3 feet above the grate. This temperature was taken with other readings at regular intervals.

Gas pressures ("drafts").—Gas pressures were measured on all tests at the base of the stack, over the fuel bed, and in the fireroom. For pressures up to 1.5 inches of water above atmosphere the Ellison differential draft gages were used; high pressures were determined with an ordinary U-tube manometer. The gas-pressure gages were placed on the deck and properly piped.

Steam pressures.—Steam pressures were read off a standard gage, which was located on the deck and which was reliable within a pound. The pressures were also automatically recorded by a Crosby recording gage, which was located in the fireroom and which was accurate within 3 pounds.

Moisture in steam.—The moisture in the steam was determined with a throttling calorimeter on the upper end of a ½-inch pipe 30 inches long, which ascended vertically from a short piece of horizontal steam main between the boiler and the throttle valve. It was impossible to get a horizontal piece of piping into the steam main for lack of space; therefore the vertical piece of piping was run up and the calorimeter placed above the deck. The connecting pipe and the calorimeter were well covered with hair felt. The nipple or the part of the pipe fitted into the steam main extended nearly across the main and was perforated with ⅛-inch holes in the usual manner. Readings of the calorimeter were taken at the regular twenty-minute intervals along with other readings.

Smoke.—Observations of smoke were taken fifteen minutes out of every thirty minutes. Individual readings were taken fifteen seconds apart. The density of smoke was estimated by comparison with Ringelmann's smoke charts. In the tests run at a high rate of combustion there was occasional flaming in the stack, the flame sometimes reaching 10 feet above its top. The flaming was recorded by the smoke observer.

Weight of sparks.—The weight of sparks ejected from the stack was determined with the spark catchers shown in figure 3 and described on pages 11, 13. These spark catchers collected sparks from 0.1 of the total area of the stack, so that by multiplying by 10 the weight of sparks collected the approximate weight of all the sparks ejected from the stack was obtained. The spark receptacles were large enough to hold the sparks collected during the entire test. At the end of the test the receptacles were removed, the sparks weighed and carefully sampled. A sample of about 2 pounds was sent in an air-tight can for chemical analysis.

Chemical analyses.—All chemical analyses of coal, ash, and sparks were made at the chemical laboratory of the technologic branch of the Survey at Pittsburg, Pa., in charge of F. M. Stanton.

OBSERVED DATA AND CALCULATED ITEMS.

EFFECT OF RATE OF COMBUSTION.

THE TABULAR SHOWING.

In all, 21 tests were made, 10 with run-of-mine coal, 3 with large briquets, and 8 with small briquets. It was planned to make four tests with each run-of-mine coal, varying the rate of combustion from 15 to 60 pounds of coal per square foot of grate per hour, and then duplicate each test with briquets, but the fuel supply was insufficient and only three tests could be made. For this reason no test was run with the rate of combustion below 20 pounds per square foot of grate per hour. For the sake of comparison the tests on briquets were made at approximately the same rates of combustion as the tests on the run-of-mine coal of which the respective briquets were made. The averages of the data taken during the test and the calculated results are given in Table 2. The calculated results given in the table were computed according to the method given in United States Geological Survey Bulletin 325, pages 151–153, being substantially the method recommended by the American Society of Mechanical Engineers.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908.*[a]

Test No.	Designation of coal.	Form of fuel.	Date of trial.	Duration (hours).	Average pressures.		"Draft"[b] (inches of water).		
					Barometer (inches of mercury).[c]	Steam above atmosphere (pounds per square inch).	At base of stack.	Over fuel bed.	In ash pit.
1	**2**	**3**	4 (1)	5 (2)	**6** (3)	**7** (11.1)	**8** (12)	**9** (13)	**10** (14)
1	Jamestown 6..	Run of mine..	1907. Dec. 6	5.25	30	204.5	−0.11	+0.39	+1.23
2			Dec. 7	3.33	30	204.0	− .44	+ .98	+2.48
3			Dec. 10	7.15	30	199.0	− .10	+ .24	+ .57
4		Large briquets	Dec. 12	6.23	30	206.0	− .13	+ .23	+ .54
5			Dec. 13	5.10	30	199.0	− .16	+ .39	+ .83
6			Dec. 16	4.03	30	200.3	− .21	+ .83	+2.37
7	Jamestown 11.	Run of mine..	Dec. 18	4.70	30	203.1	− .23	+ .47	+1.13
8			Dec. 19	5.98	30	202.3	− .19	+ .34	+ .65
9			Dec. 20	4.05	30	202.8	− .51	+1.30	+2.35
10		Small briquets	1908. Jan. 3	3.97	30	202.0	− .29	+ .48	+ .97
11			Jan. 6	4.08	30	202.0	− .50	+1.45	+2.55
12			Jan. 8	6.08	30	207.0	− .17	+ .27	+ .84
13			Jan. 10	2.37	30	203.0	− .68	+2.22	+3.39
14	Jamestown 9..	Run of mine..	Jan. 13	6.78	30	204.1	− .14	+ .36	+ .79
15			Jan. 14	4.62	30	203.0	− .33	+ .57	+1.33
16			Jan. 17	4.30	30	202.8	− .74	+1.50	+3.95
17		Small briquets	Jan. 20	5.30	30	203.9	− .11	+ .27	+ .83
18			Jan. 21	4.20	30	205.0	− .29	+ .88	+1.76
19			Jan. 23	3.85	30	200.0	− .55	+1.97	+3.73
20	Jamestown 11.	.....do........	Jan. 25	1.58	30	201.0	− .60	+2.32	+4.92
21	Jamestown 10.	Run of mine..	Jan. 27	4.10	30	204.0	− .16	+ .77	+1.67

Test No.	Revolutions per minute of fan.	Average temperatures (°F.) of—					Moisture in fuel (per cent).	Fuel (total weight in pounds).			Clinker in ash and refuse (per cent).
		Atmosphere.	Steam.	Feed water in tank.	Gases leaving boiler tubes.	Furnace.		As fired.	Dry.	Ash and refuse.	
1	**11** (14.5)	**12** (15)	**13** (17)	**14** (18)	**15** (21)	**16** (22.1)	**17** (26)	**18** (25)	**19** (27)	**20** (28)	**21** (29)
1	....	54	380	50	739	2,673	1.64	9,171	9,021	1,423	16.65
2	....	53	380	50	739	2,615	1.50	8,076	7,955	642	41.90
3	312	66	....	51	646	2,367	1.64	8,283	8,147	739	24.90
4	276	44	381	51	681	2,460	1.76	7,771	7,634	707	32.11
5	347	40	378	50	802	....	1.48	8,678	8,550	519	32.18
6	544	57	379	51	919	2,586	1.78	10,778	10,586	615	39.51
7	426	60	380	50	655	2,273	1.92	8,368	8,207	666	21.62
8	324	45	379	50	597	2,347	2.91	7,249	7,038	828	26.40
9	635	49	380	50	728	2,624	2.50	10,941	10,667	605	35.70
10	389	45	379	50	696	2,662	1.26	7,390	7,297	487	34.70
11	626	43	379	49	797	2,921	1.87	10,912	10,708	643	23.48
12	320	49	380	49	583	2,633	1.57	7,313	7,198	617	28.04
13	744	40	379	49	807	3,097	1.79	9,074	8,912	351	15.10
14	357	47	....	49	583	2,502	2.55	8,530	8,312	597	28.81
15	436	42	383	49	668	2,881	2.29	8,224	8,036	481	36.59
16	701	42	383	49	716	....	2.81	13,375	12,999	839	38.74
17	309	55	383	48	637	2,442	1.39	7,464	7,360	485	30.93
18	375	60	384	48	709	2,765	1.71	9,239	9,081	423	45.15
19	382	50	382	50	752	2,950	2.36	11,836	11,557	447	32.89
20	750–800	31	380	45	817	3,070	1.79	6,670	6,551	343	44.02
21	....	44	383	47	601	2,498	2.61	7,098	6,913	432	69.44

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[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.

[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] Taken as constant.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908*—Continued.

Test No.	"Combustible"*[a] consumed (pounds).	Ash and refuse in dry fuel (per cent).	Proximate analysis (per cent).							Sulphur (separately determined).	
			Fixed carbon.		Volatile matter.		Moisture.		Ash.	Moist basis.	Dry basis.
			In moist coal.	In "combustible."	In moist coal.	In "combustible."	In fuel as fired.	Accompanying 100 per cent "combustible."			
1	**22** (30)	**23** (31)	**24** (32)	**25**	**26** (33)	**27**	**28** (34)	**29**	**30** (35)	**31** (36)	**32** (41)
1	7,738	15.77	74.29	79.97	18.61	20.03	1.64	1.77	5.46	0.76	0.77
2	7,167	8.07	73.57	79.97	18.43	20.03	1.50	1.63	6.50	.71	.72
3	7,427	9.07	74.57	79.20	19.58	20.80	1.64	1.74	4.21	.65	.66
4	6,967	9.26	70.75	75.74	22.66	24.26	1.76	1.88	4.83	.90	.92
5	7,864	6.07	70.54	75.32	23.11	24.68	1.48	1.58	4.87	.89	.90
6	9,804	5.81	72.34	77.56	20.93	22.44	1.78	1.91	4.95	.86	.88
7	7,364	8.12	77.54	83.96	14.81	16.04	1.92	2.08	5.73	.70	.71
8	6,243	11.76	74.69	81.98	16.42	18.02	2.91	3.19	5.98	.97	1.00
9	9,694	5.67	74.32	81.89	16.44	18.11	2.50	2.75	6.74	.73	.75
10	6,684	6.67	75.71	81.48	17.21	18.52	1.26	1.36	5.82	.78	.79
11	9,740	6.00	74.21	80.52	17.95	19.48	1.87	2.03	5.97	.80	.82
12	6,529	8.57	75.11	81.16	17.43	18.84	1.57	1.70	5.89	.77	.78
13	8,195	3.94	74.48	80.64	17.88	19.36	1.79	1.94	5.85	.86	.88
14	7,422	7.18	67.46	74.98	22.51	25.02	2.55	2.83	7.48	.61	.63
15	7,291	5.99	68.98	75.81	22.01	24.19	2.29	2.52	6.72	1.01	1.03
16	12,108	6.45	69.24	74.76	23.38	25.24	2.81	3.03	4.57	.42	.43
17	6,843	6.59	69.74	74.63	23.71	25.37	1.39	1.49	5.16	.65	.66
18	8,474	4.66	69.37	74.62	23.60	25.38	1.71	1.84	5.32	.67	.68
19	10,739	3.87	69.44	75.06	23.07	24.94	2.36	2.55	5.13	.66	.68
20	6,054	5.24	69.75	74.98	23.28	25.02	1.79	1.92	5.18	.68	.69
21	6,114	6.25	72.62	82.53	15.37	17.47	2.61	2.97	9.40	.79	.81

Test No.	Ultimate analysis, dry basis (per cent).					Carbon in refuse (per cent).	Earthy matter in refuse, including moisture (per cent).	Fired per hour (pounds).			Heat value per pound (B.t.u.).	
								Dry fuel.		"Combustible" (*).		
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Ash.			For grate.	Per square foot of grate.		Dry fuel.	"Combustible."
1	**33** (37)	**34** (38)	**35** (39)	**36**(40)	**37**(42)	**38** (44)	**39** (45)	**40** (46)	**41** (48)	**42** (47)	**43** (50)	**44** (51)
1	82.58	4.55	5.10	1.45	5.55	54.95	45.05	1,718	29.62	1,474	14,845	15,715
2	83.39	4.49	3.42	1.38	6.60	40.99	59.01	2,389	41.20	2,152	14,591	15,622
3	84.39	4.65	4.63	1.39	4.28	50.22	49.78	1,139	19.64	1,039	15,098	15,773
4	84.98	4.57	3.11	1.50	4.92	41.29	58.71	1,225	21.12	1,118	14,927	15,699
5	84.23	4.61	3.93	1.39	4.94	50.73	49.27	1,676	28.90	1,542	14,879	15,652
6	82.64	4.39	5.87	1.18	5.04	40.44	59.56	2,627	45.29	2,433	14,933	15,726
7	84.38	4.44	3.19	1.44	5.84	54.63	45.37	1,746	30.10	1,567	14,769	15,685
8	83.61	4.29	3.55	1.39	6.16	43.70	56.30	1,177	20.29	1,044	14,720	15,686
9	83.77	4.23	2.86	1.48	6.91	39.00	61.00	2,634	45.41	2,394	14,702	15,793
10	83.21	4.54	4.16	1.41	5.89	37.56	62.44	1,838	31.68	1,684	14,980	15,918
11	84.53	4.37	2.80	1.40	6.08	49.14	50.86	2,625	45.26	2,388	14,816	15,775
12	83.06	4.49	4.32	1.37	5.98	38.61	61.39	1,184	20.41	1,074	14,794	15,735
13	83.69	4.42	3.60	1.45	5.96	53.02	46.98	3,760	64.83	3,458	14,805	15,743
14	80.95	4.73	4.52	1.49	7.68	42.16	57.84	1,226	21.14	1,095	14,368	15,563
15	82.00	4.73	3.86	1.50	6.88	39.88	60.12	1,739	29.98	1,578	14,564	15,640
16	83.95	4.82	4.57	1.53	4.70	33.40	66.60	3,023	52.12	2,816	14,884	15,618
17	84.12	4.72	3.85	1.42	5.23	27.26	72.74	1,389	23.95	1,291	14,949	15,774
18	83.75	4.76	4.03	1.37	5.41	27.26	72.74	2,162	37.28	2,018	14,803	15,650
19	84.05	4.72	3.92	1.38	5.25	47.03	52.97	3,002	51.76	2,789	14,906	15,732
20	84.13	4.65	3.77	1.49	5.27	44.12	55.88	4,146	71.48	3,832	14,796	15,619
21	79.18	4.36	4.69	1.31	9.65	30.43	69.57	1,686	29.07	1,491	14,180	15,695

[a] 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 subtracting 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.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908*—Continued.

Test No.	Steam.		Water fed to boiler (pounds).						Evaporation.	
	Moisture in (per cent).	Quality of.	Total.	Equivalent evaporated from and at 212°.			Actually evaporated.[a]		Apparent per pound of coal as fired.	Factor of.
				Total.	Per hour.	Into dry steam.	Total.	Per hour.		
1	**45** (54)	**46** (56)	**47** (57)	**48** (58)	**49** (63)	**50** (61)	**51** (59)	**52** (62)	**53** (68)	**54** (60)
1	1.10	99.22	68,579	83,989	15,873	83,333	68,044	12,961	7.48	1.2247
2	1.13	99.20	58,940	72,184	21,503	71,606	58,468	17,558	7.30	1.2247
3	1.67	98.81	64,985	79,470	10,983	78,525	64,212	8,981	7.85	1.2229
4	1.73	98.77	59,102	72,335	11,468	71,445	58,375	9,370	7.61	1.2239
5	1.55	98.90	57,483	70,359	13,644	69,586	56,851	11,147	6.62	1.2240
6	1.61	98.86	68,569	83,874	20,575	82,917	67,787	16,821	6.36	1.2232
7	1.57	98.89	59,121	72,400	15,233	71,596	58,465	12,439	7.06	1.2246
8	1.61	98.86	57,811	70,784	11,702	69,977	57,152	9,557	7.98	1.2244
9	1.73	98.77	75,855	92,884	22,652	91,742	74,922	18,499	6.93	1.2245
10	1.90	98.65	55,607	68,085	16,918	67,166	54,856	13,818	7.52	1.2244
11	2.35	98.33	78,415	96,090	23,158	94,484	77,105	18,898	7.19	1.2254
12	1.85	98.69	60,065	73,646	11,954	72,681	59,278	9,750	8.21	1.2261
13	2.42	98.29	57,697	70,708	29,324	69,498	56,710	23,928	6.36	1.2255
14	2.16	98.47	64,975	79,640	11,567	78,422	63,981	9,437	7.62	1.2257
15	1.98	98.60	58,624	71,850	15,334	70,843	57,803	12,511	7.13	1.2256
16	2.25	98.41	88,247	108,147	24,750	106,427	86,844	20,196	6.60	1.2255
17	1.68	98.81	54,875	67,315	12,550	66,514	54,222	10,231	7.35	1.2267
18	1.71	98.83	65,493	80,347	18,906	79,407	64,727	15,411	7.09	1.2268
19	2.32	98.40	82,503	100,992	25,812	99,376	81,183	21,086	6.97	1.2241
20	2.51	98.23	41,270	50,741	31,547	49,844	40,540	25,658	6.19	1.2295
21	2.56	98.19	51,075	62,710	15,018	61,575	50,151	12,232	7.20	1.2278

Test No.	Equivalent evaporation per pound of—			Horsepower developed.		Efficiency of the boiler, etc.		Per cent smoke.	Average thickness of fuel bed (inches).[c]
	Fuel as fired.	Dry fuel fired.	"Combustible" (*).	In boiler.	Per cent of builders' rated.[b]	(*)	Including grate.		
1	**55** (69)	**56** (70)	**57** (71)	**58** (65)	**59** (67)	**60** (72)	**61** (73)	**62** (77)	**63** (81)
1	9.09	9.24	10.77	460.1	166	66.17	60.11	64.50	12
2	8.87	9.00	9.99	623.3	225	61.75	59.57	60.89	14
3	9.48	9.64	10.57	318.3	115	64.71	61.66	58.75	8
4	9.19	9.36	10.25	332.4	120	63.05	60.55	69.54	16
5	8.02	8.14	8.85	395.5	143	54.60	52.83	70.54	16
6	7.69	7.83	8.46	596.4	215	51.95	50.64	67.20	6
7	8.56	8.72	9.72	441.5	159	59.84	57.02	29.88	10
8	9.65	9.94	11.21	339.2	122	69.01	65.21	35.87	8
9	8.39	8.61	9.46	656.6	236	57.85	56.56	30.57	16
10	9.09	9.20	10.05	490.4	177	60.97	59.31	48.75	8
11	8.66	8.82	9.70	671.3	242	59.38	57.49	37.86	10
12	9.94	10.10	11.13	346.5	125	68.31	65.93	31.02	8
13	7.66	7.80	8.48	850.0	306	52.02	50.88	37.81	10–12
14	9.19	9.43	10.57	335.3	121	65.58	63.38	47.41	8
15	8.61	8.82	9.72	444.5	160	60.02	58.48	48.84	10
16	7.96	8.19	8.79	717.4	254	54.35	53.14	43.03	12
17	8.91	9.04	9.72	363.8	131	59.51	58.39	46.14	8–9
18	8.59	8.74	9.37	548.1	197	57.82	57.02	49.28	8–9
19	8.40	8.60	9.25	748.2	270	56.78	55.72	21.71	10–12
20	7.47	7.61	8.23	914.4	330	50.89	49.67	51.33	12
21	8.67	8.91	10.07	435.3	157	61.96	60.68	31.86	10

[a] Corrected for quality of steam.
[b] Arbitrarily rated, counting 10 square feet of heating surface to a boiler horsepower.
[c] Method of firing, side alternate.

TABLE 2.—*Summary of observed data and calculated items of 21 tests made with the forward boiler, U. S. S. Biddle, December 6, 1907, to January 27, 1908*—Continued.

Test No.	Analysis of dry flue gases (per cent).				Pounds of dry flue gases per pound of "combustible."	Sparks ejected (pounds).		Heat Value of 1 pound of "combustible" (B. t. u.).	Heat balance. [a]			
	CO_2.	O_2.	CO.	N_2.		During test.	Per hour.		Heat absorbed by boiler (1).		Heat lost in dry flue gases (4).	
									B. t. u.	Pr. ct.	B. t. u.	Pr. ct.
1	**64** (84)	**65** (85)	**66** (86)	**67** (88)	**68**	**69**	**70**	**71**	**72**	**73**	**74**	**75**
1	7. 90	10. 53	0. 12	81. 45	26. 97	200	38. 2	15,717	10,401	66. 17	4,342	27. 63
2	9. 06	9. 60	. 08	81. 26	24. 28	412	123. 7	15,622	9,647	61. 75	3,933	25. 18
3	9. 27	9. 44	. 03	81. 26	23. 59	125	17. 0	15,773	10,207	64. 71	3,199	20. 28
4	10. 52	7. 30	. 14	82. 04	20. 94	35	5. 6	15,699	9,898	63. 05	3,087	19. 66
5	11. 70	5. 03	. 00	83. 27	18. 98	265	52. 0	15,652	8,546	54. 60	3,371	21. 54
6	12. 41	4. 64	. 00	82. 95	17. 63	230	57. 0	15,726	8,170	51. 95	3,600	22. 89
7	9. 86	8. 22	. 00	81. 92	22. 65	......	......	15,685	9,387	59. 84	3,289	20. 97
8	9. 16	9. 30	. 00	81. 54	24. 18	......	......	15,686	10,825	69. 01	3,111	19. 83
9	10. 27	7. 95	. 00	81. 78	21. 88	......	......	15,793	9,136	57. 85	3,497	22. 14
10	10. 37	7. 65	. 02	81. 96	21. 25	......	......	15,918	9,705	60. 97	3,233	20. 31
11	10. 40	7. 40	. 00	82. 20	21. 60	400	97. 0	15,775	9,367	59. 38	3,841	24. 35
12	9. 50	9. 13	. 00	81. 37	23. 15	80	13. 2	15,735	10,748	68. 31	2,879	18. 30
13	11. 86	5. 53	. 00	82. 61	18. 83	380	100. 0	15,743	8,189	52. 02	3,426	21. 76
14	10. 00	8. 40	. 00	81. 60	21. 87	180	26. 5	15,563	10,207	65. 58	2,714	17. 44
15	10. 97	7. 00	. 00	82. 03	20. 09	210	45. 5	15,640	9,387	60. 02	2,951	18. 87
16	9. 85	8. 07	. 00	82. 08	22. 28	410	95. 0	15,618	8,489	54. 35	3,529	22. 60
17	9. 58	8. 20	. 00	82. 22	23. 06	60	11. 3	15,774	9,387	59. 51	3,121	19. 79
18	9. 60	8. 10	. 00	82. 30	22. 95	240	57. 0	15,650	9,049	57. 82	3,503	22. 38
19	9. 36	8. 12	. 00	82. 52	....	440	114. 0	15,732	8,933	56. 78	3,906	24. 83
20	10. 30	6. 85	. 00	82. 85	21. 50	380	240. 0	15,619	7,948	50. 89	3,988	25. 53
21	10. 40	7. 47	. 00	82. 13	21. 04	180	44. 0	15,695	9,725	61. 96	27.67	17. 62

Test No.	Heat balance. [a]										Smoke and flame showing above stack.		
	Loss due to moisture—				Loss due to incomplete combustion of carbon in CO (5).		Loss in sparks.		Loss in escaping hydrocarbons, radiation, and unaccounted for (6).		F.	S.	Per cent.[b]
	In fuel (2).		Formed by burning 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	**76**	**77**	**78**	**79**	**80**	**81**	**82**	**83**	**84**	**85**	**86**	**87**	**88**
1	24	0. 15	591	3. 76	133	0. 85	307	1. 96	−81	−0. 52	0	608	0. 0
2	22	. 14	592	3. 80	79	. 50	648	4. 15	703	4. 50	7	360	2. 0
3	23	. 15	571	3. 62	29	. 18	186	1. 18	1,558	9. 88	1	720	. 1
4	25	. 16	578	3. 68	119	. 76	51	. 32	1,941	12. 37	6	660	. 9
5	22	. 14	611	3. 90	0	....	348	2. 22	2,751	17. 60	65	480	13. 5
6	28	. 18	602	3. 83	0	....	248	1. 58	3,078	19. 57	214	508	42. 8
7	28	. 18	569	3. 63	0	....	....	....	2,412	15. 38	13	480	2. 7
8	42	. 27	536	3. 42	0	....	....	....	1,172	7. 47	0	664	. 0
9	37	. 23	557	3. 53	0	....	....	....	2,566	16. 25	6	452	1. 3
10	18	. 11	585	3. 68	17	. 11	....	....	2,360	14. 82	19	480	4. 0
11	28	. 18	587	3. 72	0	....	389	2. 46	1,563	9. 91	24	420	5. 7
12	22	. 14	555	3. 52	0	....	113	. 72	1,418	9. 01	0	686	. 0
13	27	. 17	598	3. 80	0	....	470	2. 99	3,033	19. 26	59	292	20. 2
14	37	. 24	594	3. 82	0	....	266	1. 71	1,745	11. 21	1	764	. 1
15	34	. 22	613	3. 92	0	....	295	1. 89	2,360	15. 08	7	500	1. 4
16	41	. 26	621	3. 98	0	....	369	2. 36	2,569	16. 45	9	456	2. 0
17	19	. 12	587	3. 72	0	....	87	. 55	2,573	16. 31	16	600	2. 7
18	25	. 16	608	3. 89	0	....	314	2. 01	2,151	13. 74	8	420	1. 9
19	35	. 22	617	3. 92	0	....	443	2. 82	1,798	11. 43	13	420	3. 1
20	27	. 17	629	4. 03	0	....	744	4. 76	2,283	14. 62	14	240	5. 8
21	39	. 25	569	3. 63	0	....	323	2. 06	2,474	14. 48	1	420	. 2

[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] $\text{Per cent} = \frac{\text{Flame readings}}{\text{Smoke readings}} \times 100.$

NOTES ON INDIVIDUAL TESTS.

Test 1, J-6 coal, run-of-mine.—Coal caked badly. Fuel bed required much attention; the cakes had to be broken about every other firing. During the test the fuel bed was 12 to 14 inches thick.

It was impracticable to clean fire before closing test. After test was closed and the fuel bed had entirely burned down the clinkers were removed from the grate, weighed, and charged to the test. All ashes were then taken out of the ash pan, weighed, and charged to the test. It is possible that the weight of ash on this test is too high, because, when removing the clinkers from the grate, some free ash which really did not belong to the test fell into the ash pan and was weighed with the rest.

Test 2, J-6 coal, run-of-mine.—Coal caked badly; fires had to be raked after each firing. The fact that the fire doors had to be partly open while raking the fire possibly accounts for the high oxygen content in the flue-gas analysis. It was difficult to keep the fuel bed in good condition.

The fire was not cleaned before closing the test. After the test was closed, all the ashes were pulled out of the ash pan, weighed, and charged to the test. Then, after the fuel bed had entirely burned down, the clinkers were removed from the grate, weighed, and charged to the test. The firing was better on this test than on test 1; less coal was allowed to fall through the grate.

Test 3, J-6 coal, run-of-mine.—Coal caked badly; it was necessary to break the cakes after every other firing. After closing the test the free ash was pulled out of the ash pan and weighed. Then, after the fire had entirely burned down, the clinkers were pulled out of the furnace, weighed, and charged to the test. The free ash which fell through the grate during the process of pulling clinkers was not charged to the test, as there was about an equal quantity of ash on the grate when the test was started. This method of determining ash and clinkers was used for all the following tests.

Test 4, J-6 coal in large briquets.—Briquets burned freely and quickly and stayed together in the fire. Fire handled easily. Thickness of fire during test, 12 to 14 inches.

Test 5, J-6 coal in large briquets.—Briquets burned freely and quickly and stayed together in the fire. The fire was easily handled. Thickness of fire, 14 to 16 inches.

Test 6, J-6 coal in large briquets.—Briquets burned freely and quickly and did not crumble in the fire. The fire was apparently in good condition during the entire test. Thickness of fire, 14 to 16 inches. Excessive flaming in the stack was observed.

Test 7, J-11 coal, run-of-mine.—Coal caked badly; fire required raking after every other firing. About 100 pounds of coal fired at a time, alternately on each side half of the grate every three or four minutes. Thickness of fire, 10 to 12 inches. Water was used in the ash pan during the test.

Test 8, J-11 coal, run-of-mine.—Coal caked badly; fire required breaking up every other firing. About 75 to 100 pounds of coal fired at a time, alternately on each side half of the grate every four or five minutes. Thickness of the fuel bed, about 8 inches. Water was used in the ash pan.

Test 9, J-11 coal, run-of-mine.—Coal caked badly. It was necessary to break up the cakes after every other firing. About 100 pounds of coal was charged alternately on each side half of the grate every two or three minutes. Thickness of fuel bed, about 14 to 16 inches. Water was used in the ash pan during the test.

Throughout this test much fuel was blown out through the stack in the form of cinders or sparks. At the close of the test the deck was covered with a layer of sparks varying from one-eighth to three-eighths of an inch thick.

Test 10, J-11 coal in small briquets.—Briquets burned freely; stayed together in the fire. About 100 pounds were charged alternately on each side half of the grate every three or four minutes. Fire handled easily and did not require much attention. Thickness of the fuel bed, about 8 inches. Water was used in the ash pan.

Test 11, J–11 coal in small briquets.—Briquets burned freely; stayed together in the fire. About 100 pounds were fired alternately on each side half of the grate every two or three minutes. Fire handled easily. Effort was made to keep the fuel bed 8 to 10 inches thick. Better results seemed to have been obtained with a light fire than with a heavy one. Water was used in the ash pan.

Test 12, J–11 coal in small briquets.—Briquets burned freely; did not crumble in the fire. About 100 pounds charged alternately on one-half of the grate every five or six minutes. Fire handled easily. Thickness of fuel bed, about 6 inches. Water was used in the ash pan.

Test 13, J–11 coal in small briquets.—Briquets burned freely and made a very hot fire. About 130 pounds charged alternately on each side half about every one or two minutes. The fuel bed was easily handled. Thickness, about 10 to 12 inches. Water was used in the ash pan.

Test 14, J–9 coal, run-of-mine.—Coal caked badly. Fire had to be raked after every other firing. About 300 pounds was charged alternately on each side half of the grate every four or five minutes. Thickness of fuel bed, about 8 inches. Water was used in the ash pan.

Test 15, J–9 coal, run-of-mine.—This coal was exceptionally bad in regard to caking. The fuel bed had to be raked every other firing and sliced about every fourth or fifth firing in order to keep it loose. About 300 pounds was charged alternately on each side half of the grate every two or three minutes. Thickness of fuel bed, about 10 inches. Water was used in the ash pan.

Test 16, J–9 coal, run-of-mine.—Coal caked considerably. Fuel bed had to be raked after every other firing. About 150 pounds fired alternately on each side half of the grate every three or four minutes. Thickness of fire, about 12 inches. Water was used in the ash pan. During the latter part of this test the screens in the spark catchers were burned out so as to catch only about three-fourths of the full tenth of the sparks.

Test 17, J–9 coal in small briquets.—The briquets swelled in the fire, and their surfaces opened cracks in many places, but did not crumble unless broken with a rake. About 75 pounds charged alternately on each side half of the grate every three or four minutes. These briquets burned best in this furnace at this rate of combustion, with about an 8-inch fuel bed. When the fuel bed was thickened the gases flamed in the stack.

Test 18, J–9 coal in small briquets.—About 120 pounds fired alternately on each side half about every three minutes. These briquets burned best at this rate of combustion, with about an 8 to 10 inch fuel bed. When the bed was thicker, gases flamed in the stack. Water was used in the ash pan.

Test 19, J–9 coal in small briquets.—Briquets swelled in the fire, but did not crumble. About 120 pounds fired alternately one each side half of the grate about every two minutes. To avoid flaming the stack, the fuel bed could not be made thicker than 12 inches.

Test 20, J–11 coal in small briquets.—About 10 per cent of the briquets were crumbled when fired. This test was short on account of shortage of fuel. After it was well under way the rate of combustion was much higher than the average given in the table. The method of firing used was side alternate, as in the previous tests. Thickness of fuel bed, about 12 inches; when thicker, flaming began in the stack. A higher rate of combustion and capacity of boiler could have been obtained with these briquets if more fuel had been available, and even higher rates would be obtainable by running the fan faster, as it well could be.

Test 21, J–10 coal, run-of-mine.—Coal caked badly, making it necessary to rake the fuel bed after every other firing. Method of firing, side alternate, as in all the prior tests. Thickness of fire, about 10 inches.

DATA AND CALCULATIONS SHOWN GRAPHICALLY.

EXPLANATION OF FIGURES.

Figures 4 to 10, inclusive, show graphically the relations of the results of the tests to the rate at which coal was burned. The abscissas are pounds of dry coal fired per square foot of grate per hour; the ordinates are various quantities and are given directly at the left of each group of curves or group of points. All points are for individual tests; trials on large briquets are denoted by solid rectangles, those on small briquets by dots, and those on run-of-mine coal by light circles. Where it was possible to discriminate between the kinds of fuel solid heavy lines were drawn through points representing the results on coal, long dash lines through points representing results on large briquets, and short dash lines through points representing tests on small briquets.

ON CAPACITY DEVELOPED.

The points shown in succession at the top of figure 4 represent the relation between the rate of combustion and the capacity developed by the boiler. In order to have a basis of comparison between these tests and tests made on other boilers the rated capacity of the Normand boiler of the *Biddle* was assumed as 277.6 boiler horsepower; that is, 10 square feet of heating surface is taken to be equivalent to 1 boiler horsepower. All the points of this group fall so nearly along one straight line that it is hard to tell whether the run-of-mine coal or the briquets did better. The shape and the inclination of the curve passing through these points indicate that the capacity increases almost directly with the rate of combustion; this fact is perhaps self-evident—the greater the amount of coal burned the greater the amount of heat generated in the furnace and the greater the amount of heat absorbed by the boiler. It is worthy of note that on all the tests this particular boiler with its heating surface developed two or three times as much boiler horsepower as stationary boilers ordinarily do. This indicates that the rule of thumb which states that 10 square feet of heating surface are required to give 1 boiler horsepower has no substantial foundation.

ON EVAPORATION.

The points in the middle group of figure 4 show the relation between rate of combustion and evaporation per pound of dry fuel fired, and indicate that the run-of-mine coal and the small briquets do about equally well, the briquets probably giving a very slightly better evaporation than the coal. The large briquets fall considerably lower in evaporation than the other two fuels. This lower evaporation, however, was not caused by the inferiority of the

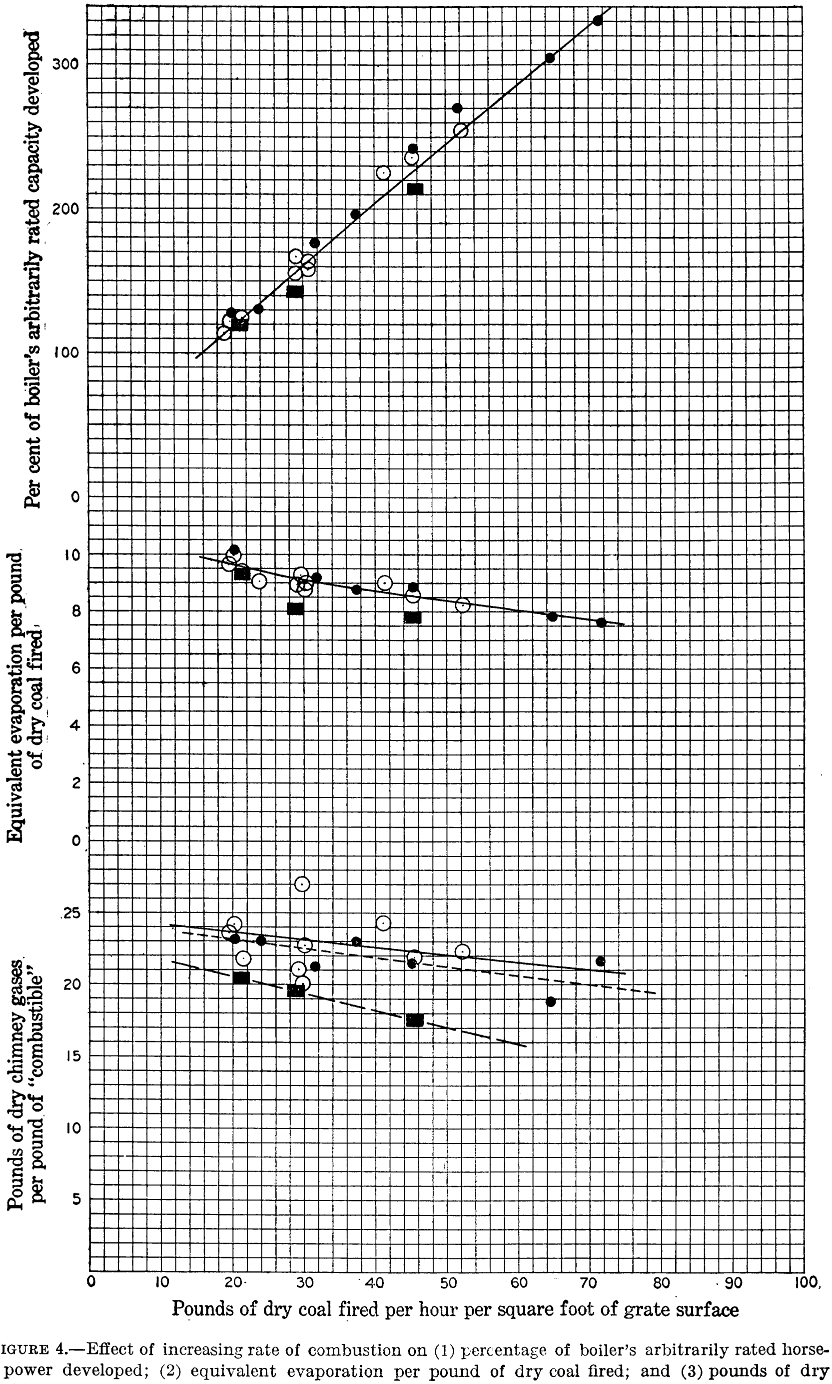

FIGURE 4.—Effect of increasing rate of combustion on (1) percentage of boiler's arbitrarily rated horsepower developed; (2) equivalent evaporation per pound of dry coal fired; and (3) pounds of dry chimney gases per pound of "combustible."

briquets as a fuel, but was due to the fact that the fuel beds carried on these tests were too thick, and the resulting insufficient air supply caused incomplete combustion. Although the flue-gas analyses on these tests show a very low CO percentage, the presence of flames in and above the stack indicated that combustible gases other than CO were escaping. It was thought, because the voids in the fuel bed of large briquets were higher in percentage than with the other fuels, that better results could be obtained with the thicker fuel beds. This reasoning, however, proved false, at least with the particular briquets tested.

A general curve drawn through these points indicates that the evaporation per pound of dry coal drops considerably as the rate of combustion increases. Thus at the rate of 20 pounds the equivalent evaporation per pound of dry coal is a little above 10 pounds, while at the rate of 71 pounds the equivalent evaporation is less than 8 pounds of water. This drop in evaporation when the rate of combustion increases is chiefly due to less complete combustion of the fuel; it will be shown later that only a little of it is due to the inability of the boiler proper to absorb the heat.

ON DRY FLUE GASES.

The points in the lowest group of figure 4 show the relation between the rate of combustion and the weight of dry flue gases per pound of "combustible" [a] ascending from the grate.

In general, the points indicate that with all three kinds of fuel the weight of air used to burn 1 pound of "combustible" decreases as the rate of combustion increases. This feature is well worthy of note in the respect that the higher the gas-pressure drop through the fuel bed (the resistance of the latter remaining about the same) the higher is the velocity of air passing through the burning fuel and the higher is the rate of combustion; now, the dropping of the points at the right hand tells us that the combustion more than keeps up with the velocity of the current of air through the fuel bed. This statement is true throughout the full range of rate of combustion ordinarily used in practice.

The points also show that on the average about the same weight of air is used to burn 1 pound of "combustible" whether the fuel be run-of-mine coal or small briquets. With the large briquets the weight of air used was much less. This fact undoubtedly accounts for the less perfect combustion and lower evaporation on tests with large briquets.

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[a] The combustible here referred to is the "combustible" in the fuel as fired, figured from chemical analysis minus the combustible lost in ash and refuse, but including the combustible ejected in sparks. In this bulletin the word combustible is placed in quotation marks whenever it is loosely used in the sense of "coal free from moisture and ash."

ON SMOKE.

The points in the lower group of figure 5, that is, the points which are connected by broken lines, are intended to show the relation between the per cent of black smoke and the rate of combustion. Each point in the figure represents the average of the whole test. The percentage of black smoke refers to Ringelmann smoke charts; chart 1 is called 20 per cent black smoke, and each successive chart is 20 per cent higher, so that chart 5 is 100 per cent black. Fractional gradations are similarly interpreted within the respective 20 per cent steps.

The lines connecting the points of each kind of fuel fall in such a zigzag fashion that there does not seem to be any relation between the blackness of smoke and the rate of combustion. The most reasonable conclusion probably is that the combustion space of the furnace is so small and the "cold" heating surface of the boiler is so near the fuel that even the rate of combustion of 20 pounds of fuel per square foot of grate is too high to burn the gases and tarry vapors so that the smoke-producing property of the furnace apparently can not be made any worse by increasing further the rate of combustion. The smoke-producing property of this furnace lies in the fact that the path of the gases from the fuel bed into the nests of the water tubes is so short that the tar vapors which are important constituents of visible smoke have not sufficient time to burn before they are driven among the tubes where the combustion stops. As all these visible tars are in liquid or solid form their complete combustion requires considerably more time than is afforded to them on their way from the fuel bed to the nests of tubes. It seems then that no amount of care taken in firing smoky fuels in this type of furnace will produce smokeless combustion.

The points of the same group show that the tendency of a coal to smoke is not reduced by briquetting the fuel; in fact it is shown that rather more smoke was made with briquetted than with run-of-mine coal. The high percentage of black smoke made with the large briquets is partly due to a smaller supply of air, as is shown by the lowest group of points in figure 4.

The points of the upper group of figure 5 show the amount of flaming observed above the stack. Every time the smoke observer read smoke he also made a note of flaming above the stack when the same was observable. The upper ordinate of figure 5 represents the number of times flame was observed above the stack expressed as a percentage of total smoke readings. It is shown that there was more flaming with either style of briquet than with run-of-mine coal.

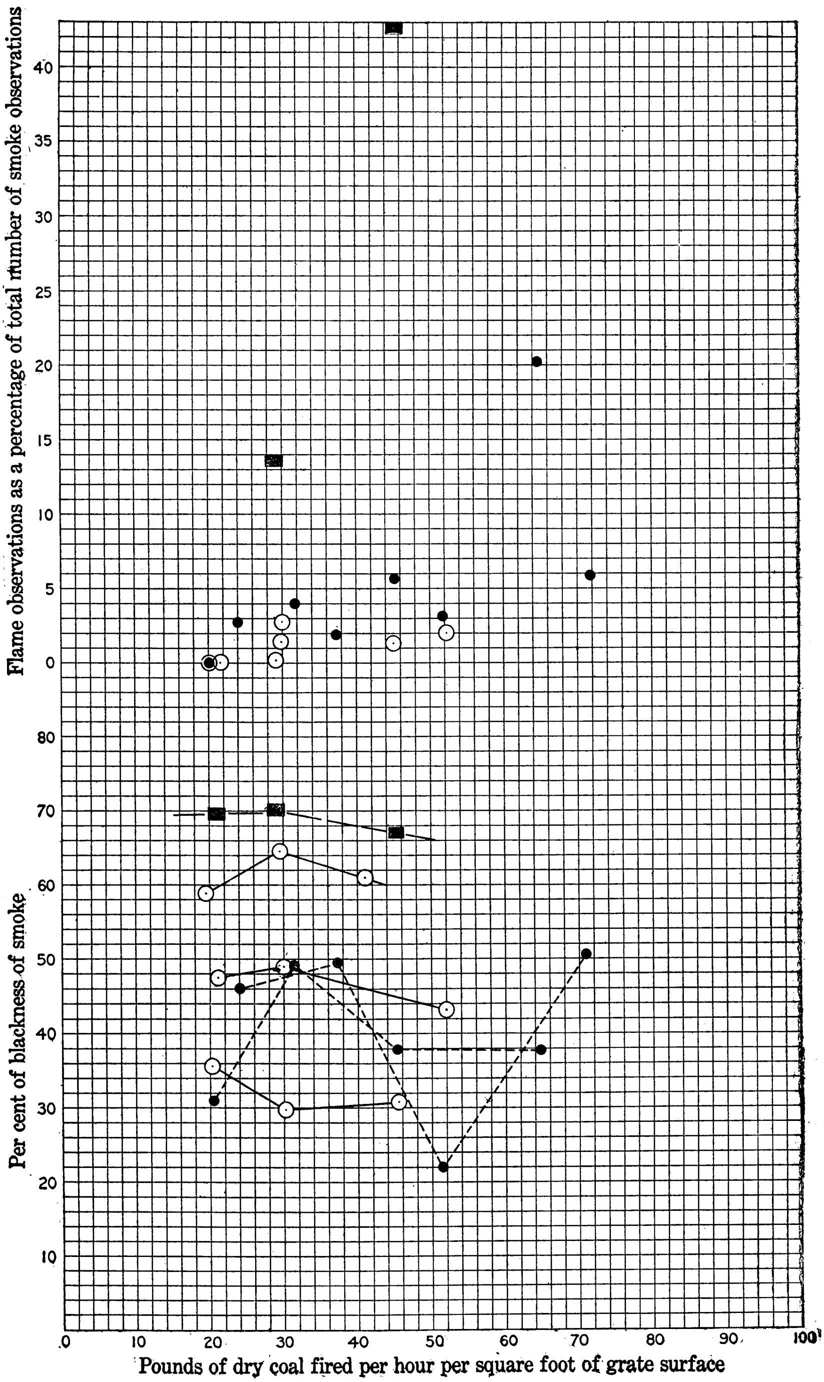

FIGURE 5.—Effect of increasing rate of combustion on flame observations as a percentage of **total** number of smoke observations (above) and percentage of black smoke (below).

ON DISTRIBUTION OF HEAT.

Figure 6 and the two lower groups of points of figure 7 show how the distribution of the heat of the "combustible" ascending from the grate varied with the rate of combustion. All heat quantities in these two figures are expressed in percentage of the total heat in "combustible" ascending from grate.

ON HEAT LOSSES.

The points grouped at the top of figure 6 represent the heat carried up the stack in the moisture formed by burning of hydrogen and also in the free moisture in the coal (item 2 + item 3 in the heat balance). The points show that the heat loss due to moisture in the flue gases is very nearly the same for all rates of combustion. There is also little or no difference between the three kinds of fuel.

The points of the middle group of figure 6 show the relation of the heat lost in dry flue gases (item 4 in the heat balance) and the rate of combustion. In general, the points show that this heat loss increases but little with the rate of combustion. On the average this increase is 4 to 5 per cent as the rate of burning the fuel increases from 20 to 70 pounds. This item does not show any essential difference between the three kinds of fuel.

The points in the lowest group of figure 6 show the relation of the heat loss in sparks to the rate of combustion. The indication is that this loss increases almost directly with the rate of combustion. The points also show somewhat higher losses in sparks in the tests of run-of-mine coal than of the small briquets. There are not enough tests on large briquets to warrant definite conclusions regarding the spark losses. The higher spark loss shown in tests with run-of-mine coal was undoubtedly due to the high percentage of slack in the coal and also to the fact that the fuel bed had to be frequently stirred. The stirring of the fuel bed loosened small particles of burning fuel which were apt to be carried out through the boiler and stack by the current of gas. The higher spark loss with increasing rate of combustion resulted from higher pressure drops ("drafts") and higher velocities of the furnace gases which had to be maintained in order to effect the higher rates of combustion.

ON HEAT ABSORPTION.

The points in the middle group of figure 7 show the relation of the rate of combustion to the heat absorbed by boiler (item 1 in heat balance). As stated before, this heat is expressed as a percentage of the total heat of the "combustible" ascending from the grate; in other words, this item is the ratio of the two heats multiplied by 100. Generally this ratio is called the "*efficiency of the boiler*," and is so

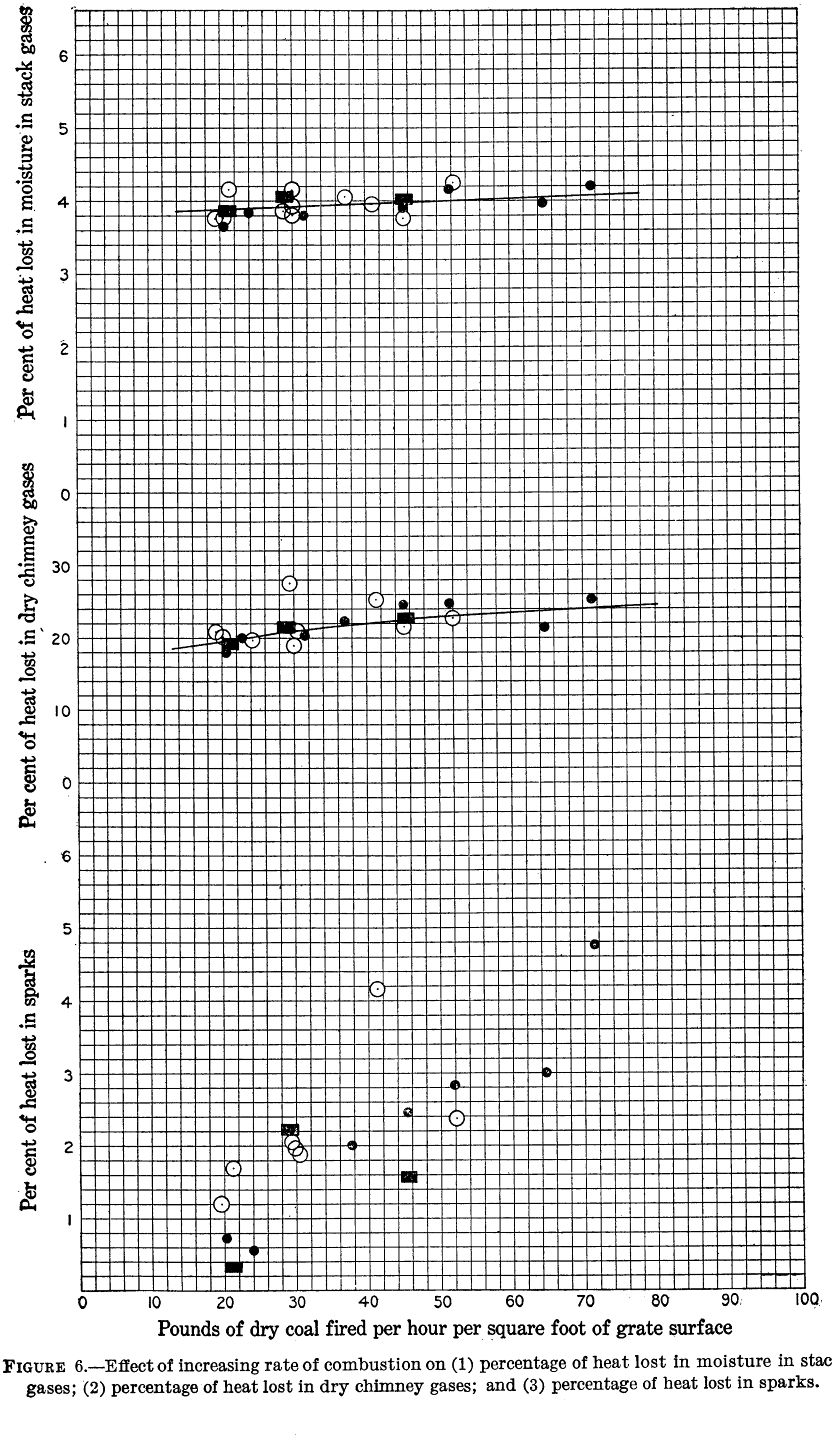

FIGURE 6.—Effect of increasing rate of combustion on (1) percentage of heat lost in moisture in stack gases; (2) percentage of heat lost in dry chimney gases; and (3) percentage of heat lost in sparks.

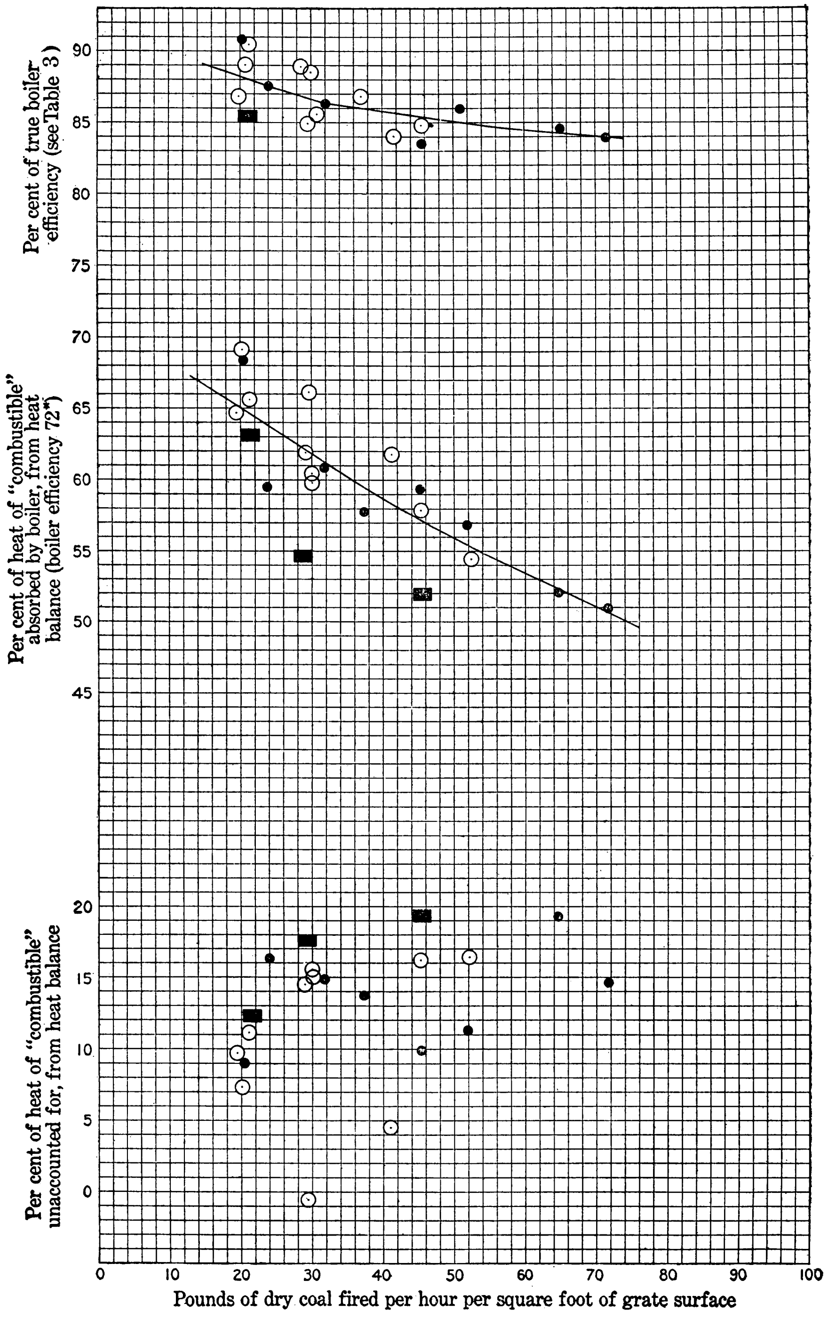

FIGURE 7.—Effect of increasing rate of combustion on (1) percentage of true boiler efficiency; (2) percentage of heat of "combustible" absorbed by boiler, from heat balance (boiler efficiency 72*); and (3) percentage of heat of "combustible" unaccounted for in the heat balance.

denoted by the code of the American Society of Mechanical Engineers, where it is defined as "the heat absorbed by the boiler per pound of combustible divided by the heat of 1 pound of combustible."

The indication of the points is that as the rate of combustion increases the boiler absorbs a considerably smaller percentage of the total heat of the "combustible" ascending from the grate. This apparently large decrease in the boiler efficiency is, however, rather the fault of the furnace as a heat generator than of the boiler as a heat absorber; in other words, it is mainly due to the drop in furnace efficiency. As the rate of firing coal increases, the volume of gases generated in the fuel bed per unit of time increases in the same ratio. The result is that this increasing volume of gases must pass through the combustion space of the furnace at a higher velocity, and therefore a proportionately shorter time is afforded for burning any combustible gases or tar vapors contained in the furnace gases. As a result of this shortened time the combustible gases and tars are only partly burned. Thus, as the rate of firing coal increases, the combustion becomes more and more incomplete.

The potential heat of the combustible gases and tars leaving the furnace and passing out through the boiler and stack is not liberated and therefore is not available for absorption by the boiler. Liberation of heat from fuel is the function of a furnace, and therefore any drop in "boiler efficiency," as the term is commonly used, caused by failure of the furnace to liberate all the heat of the fuel, is directly chargeable to the furnace.

ON UNACCOUNTED-FOR LOSSES.

The determination of the tars and the combustible gases, other than CO, escaping from the furnace is extremely difficult, so that the incompleteness of combustion ordinarily can be estimated only by an indirect method. The usual method is that employed in making a heat balance such as is presented for these tests in columns 72–85, of Table 2. In this heat balance all the losses are accounted for except the radiation loss, the loss due to incomplete combustion of hydrocarbon gases and tars, and a few other minor losses. The remainder of the heat not accounted for (commonly called the "unaccounted for") is principally the loss due to radiation and to incompleteness of combustion. Unfortunately all the errors of observations, of sampling, and of chemical determinations are accumulated in the "unaccounted for," so that the losses by radiation and by incomplete combustion can be only roughly estimated by taking all the possibilities of error into consideration.

The points in the lowest group of figure 7 have been plotted to show the relation between the "unaccounted for" in the heat balance and the rate of combustion. For reasons previously given, the points do not fall along a single line. The two lowest points in the figure represent the first two tests made in which the flue-gas analysis is unreliable because of leaky joints in the gas-sampling device. On account of this leak the weight of air used to burn 1 pound of "combustible," calculated from the gas analysis, is too high, and consequently the loss up the stack unduly high, leaving the unaccounted-for loss either too low or negative. This illustrates how errors in data affect this item.

The general indication of this group of points is that the unaccounted-for loss increases with the rate of combustion. The radiation loss depends on the temperature of the radiating surfaces of the boiler and therefore should rather decrease in percentage with the increasing capacity accompanying the increased rate of combustion. The increasing unaccounted-for loss when the rate of combustion increases may then be rightly ascribed to the increasing incompleteness of combustion. This fact supports the conclusion arrived at in discussing the middle group of points of the same figure, namely, that the drop in the percentage of heat absorbed by the boiler is mostly due to incomplete combustion of tar vapors and combustible gas other than CO.

ON RUN-OF-MINE COAL AND BRIQUETS.

Referring again to the middle group of points of figure 7, and considering the three kinds of fuel, it is plain that as far as efficiency of the steam-generating apparatus is concerned, there is no advantage in briquetting the fuel. The run-of-mine coal does as well as the small briquets and perhaps better than the large ones. However, any deductions in regard to the efficiency of large briquets must necessarily be reserved until more tests have been made with them. The three tests herein reported were run under rather unfavorable conditions for the good combustion of these briquets. It has been already said that in an attempt to reduce the amount of excess air used in combustion, for the purpose of obtaining high furnace temperature, the latter being one of the requisites for high economy, the fuel bed was carried somewhat too thick (14 to 16 inches). This thickening of the fuel bed and the resulting reduction of air supply very likely caused so much incomplete combustion that the over-all efficiency dropped considerably. Subsequent tests disclosed the fact that in this particular furnace it is not well to increase the CO_2 in the flue gases over 10 or 11 per cent, inasmuch as the combustion space above the fuel bed is too small. This deduction applies to Now River coals; for Pocahontas coal it would probably have to be somewhat modified.

ON FLUE-GAS AND FURNACE TEMPERATURES.

In figure 8 the points of the highest group are the averages of furnace temperatures for each test; the points in the middle group are the averages of flue-gas temperatures for each test; both are platted

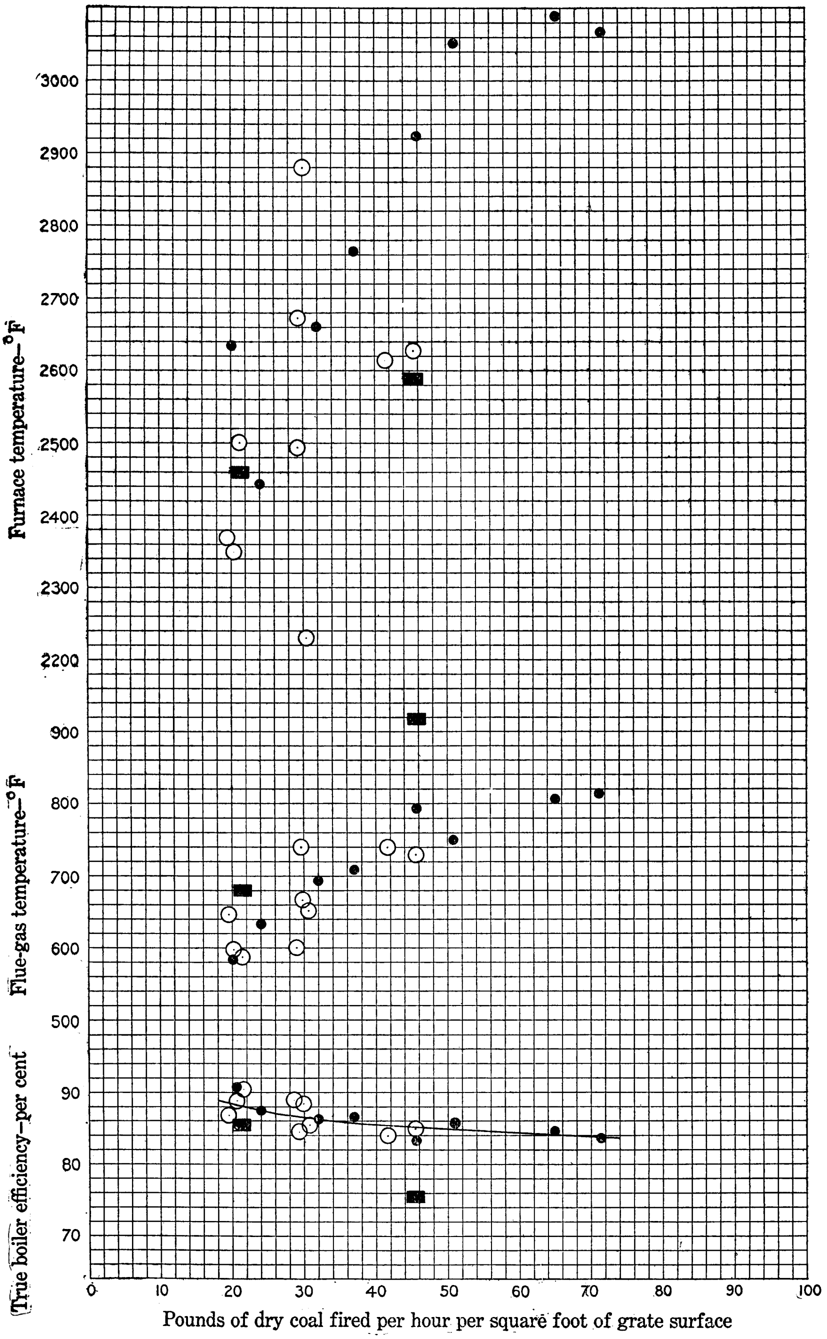

FIGURE 8.—Relation between rate of combustion and (1) furnace temperature in degrees Fahrenheit; (2) flue-gas temperature in degrees Fahrenheit; and (3) true boiler efficiency in percentage.

with the rate of combustion as abscissas. In general, both temperatures seem to rise with the rate of combustion; however, this rising may be an incidental feature whose portrayal was not the object of platting the temperatures. The object of platting was to show a peculiar relation between the two temperatures, which relation seems to be but little affected by the rate of combustion. The furnace temperature here platted is the temperature of the furnace gases as they enter the boiler. The flue-gas temperature is the temperature of the gases as they leave the heating surface of the boiler. The difference between the two is the drop in temperature of these gases due to the absorption of heat from them by the boiler. As the weight of gases entering the boiler and the weight of gases leaving the boiler is the same (neglecting leakage), the temperature drop of the gas is proportional to the heat absorbed by the boiler. In this reasoning it is assumed that the specific heat of furnace gases at constant pressure remains constant, which is not strictly true. Recent experiments show that the specific heat of CO_2 and other gases increases appreciably with temperature. However, as the consideration of the small variations in the specific heats of furnace gases would change the final results only by a fraction of a per cent, it was thought best not to complicate the course of reasoning by considering the variations in specific heat of the furnace gases. Since heat flows only from a hotter body to a colder one, it is possible for the boiler to reduce the temperature of the gases down to its own, or to the temperature of the water in the boiler, which is presumably the same as the temperature of the steam at the pressure under which the boiler is working. Therefore, the difference between the furnace and the steam temperature is called the available temperature drop for the furnace gases, and the heat in the furnace gases which is above the temperature of the steam in the boiler is called the heat available for absorption. The ratio of the heat which the boiler actually absorbs to the heat which is available for absorption is called the true boiler efficiency. This ratio is the only true measure of the boiler's ability to absorb heat. The boiler efficiencies ordinarily used do not take into consideration the fact that part of the heat in the furnace gases is below the temperature of the boiler and, therefore, can not be absorbed by the boiler.

It has been stated that the heat absorbed by the boiler is proportional to the temperature drop of the furnace gases as the latter pass through the boiler. Applying the same reasoning, it can be said that the heat available for absorption is proportional to the available temperature drop. Therefore the ratio of the two temperatures is the same as the ratio of the two heats. This being so, it is possible to obtain the true boiler efficiency by calculating the ratio of the actual drop to the available drop in temperature of the furnace gases.

This ratio has been calculated for most of the tests reported in this bulletin and is given, with the method of calculating it, in Table 3.

TABLE 3.—*Data used in calculating that portion of true boiler efficiency which is a consequence of heat absorption by convection only.*

Test No.	Fuel used.	Dry fuel fired per square foot of grate per hour (pounds).	Temperature (° F.).			Column 5 minus—		Column 7 divided by column 8.[c]
			In stack.	In furnace.	Of steam.	Column 4.[a]	Column 6.[b]	
1	2	3	4	5	6	7	8	9
1	Run-of-mine coal....	29.62	739	2,673	380	1,934	2,293	84.7
2	.....do...............	41.20	739	2,615	380	1,876	2,235	84.0
3	.....do...............	19.64	646	2,367	380	1,721	1,987	86.6
4	Large briquets.......	21.12	681	2,460	381	1,779	2,079	85.6
5	.....do...............	28.90	802	....	....	....	....	....
6	.....do...............	45.29	919	2,586	379	1,667	2,207	75.6
7	Run-of-mine coal....	30.10	655	2,273	380	1,618	1,893	85.4
8	.....do...............	20.29	597	2,347	379	1,750	1,968	89.0
9	.....do...............	45.41	728	2,624	380	1,896	2,244	84.6
10	Small briquets.......	31.68	696	2,662	379	1,966	2,283	86.1
11	.....do...............	45.26	797	2,921	379	2,124	2,542	83.6
12	.....do...............	20.41	583	2,633	380	2,050	2,253	90.9
13	.....do...............	64.83	807	3,097	379	2,290	2,718	84.3
14	Run-of-mine coal.....	21.14	583	2,502	380	1,919	2,122	90.5
15	.....do...............	29.98	668	2,881	383	2,213	2,498	88.5
16	.....do...............	52.12	716	....	....	....	....	....
17	Small briquets.......	23.95	637	2,442	383	1,805	2,060	87.6
18	.....do...............	37.28	709	2,765	384	2,056	2,381	86.3
19	.....do...............	51.76	752	2,950	382	2,198	2,568	85.5
20	.....do...............	71.48	817	3,070	380	2,253	2,690	83.8
21	Run-of-mine coal.....	29.07	601	2,498	383	1,897	2,115	89.6

[a] Column 5 — column 4 = approximately the actual temperature reduction effected by the boiler.
[b] Column 5 — column 6 = maximum theoretical reduction of temperature by a perfect boiler.
[c] Column 7 ÷ column 8 = the true boiler efficiency so far only as heat absorption by convection is concerned.

ON TRUE BOILER EFFICIENCY.

The results shown in the last column of Table 3 are platted at the bottom of figure 8 as true boiler efficiency. These points and the curve passed through them show the relation between the true boiler efficiency and the rate of combustion. Thus as the rate of combustion increases from 20 to 71 the true boiler efficiency drops only 4 per cent. The indication is that as the rate of combustion increases the true boiler efficiency remains nearly constant. This is the relation of the temperature of the furnace to that of the flue gas already discussed; that is, the temperature difference between the gas in the furnace and in the flue bears a constant ratio to the temperature elevation of the furnace gases above the temperature of the steam in the boiler, or, in other words, the flue-gas and furnace temperatures rise and fall together, no matter what the rate of combustion may be. It should be borne in mind, however, that in these statements the phrase "heat absorbed by the boiler" refers only to the heat which the boiler absorbs from the furnace gases as the latter pass through the boiler, or the heat which the boiler receives by convection. The boiler receives heat also by radiation from the fuel bed and from the incandescent gases while the latter flow through the furnace. The furnace temperature recorded on these tests is the temperature of the gases about as they enter the nests of tubes.

This agrees very well with laboratory experiments made by the United States Geological Survey on small multitubular boilers fed with air heated in an electric furnace. The results of these experiments are to be given in a bulletin of the Bureau of Mines now in press.

One point in figure 8, representing a test on large briquets, shows low efficiency because of the unduly high temperature of the flue gases. By referring to figure 5 it is seen that the same test shows unusual flaming in the stack. The explanation is that the flue gas contained a large percentage of combustible gases which burned in the stack and caused the flaming and also produced a much higher flue-gas temperature. This high flue-gas temperature is not chargeable against the boiler for the reason that the heat was generated in the stack after the gases had passed the heating surface of the boiler. Such heat could not be available for absorption.

The true boiler efficiency has been also platted in figure 7 on the same scale as the commonly used boiler efficiency (item 72*) for the purpose of comparing the two. It is quite apparent that the "boiler efficiency" drops much faster than the true boiler efficiency with the increasing rate of combustion. In previous discussion of the middle curve of figure 7 it has been said that the boiler efficiency drops at the high rates of combustion because the furnace fails to develop all the heat in the fuel and not because the boiler does not absorb heat fast enough. This statement is confirmed by the true boiler-efficiency curve; the latter drops only about 4 per cent while the boiler efficiency, or rather the efficiency of the whole steam-generating apparatus which it really is, drops 14 per cent. At least 10 per cent of this total drop of 14 per cent is very likely due to the drop of furnace efficiency.

ON PRESSURE DROP.

The points grouped at the top of figure 9 show the relation between the pressure drop through the fuel bed and the rate of combustion. The pressure drop through the fuel bed was obtained by subtracting the absolute pressure over the fuel bed from the absolute pressure in the ash pit. Although the points do not fall along a single curve, the indication is that the pressure drop through the fuel bed increases with the rate of combustion. With any fuel of uniform size this relation is a necessity; to burn more fuel more air must be passed through the fuel bed, and to pass more air through the fuel bed there must be a higher pressure drop. Different sizes of fuel offer different resistances to the passage of air through them

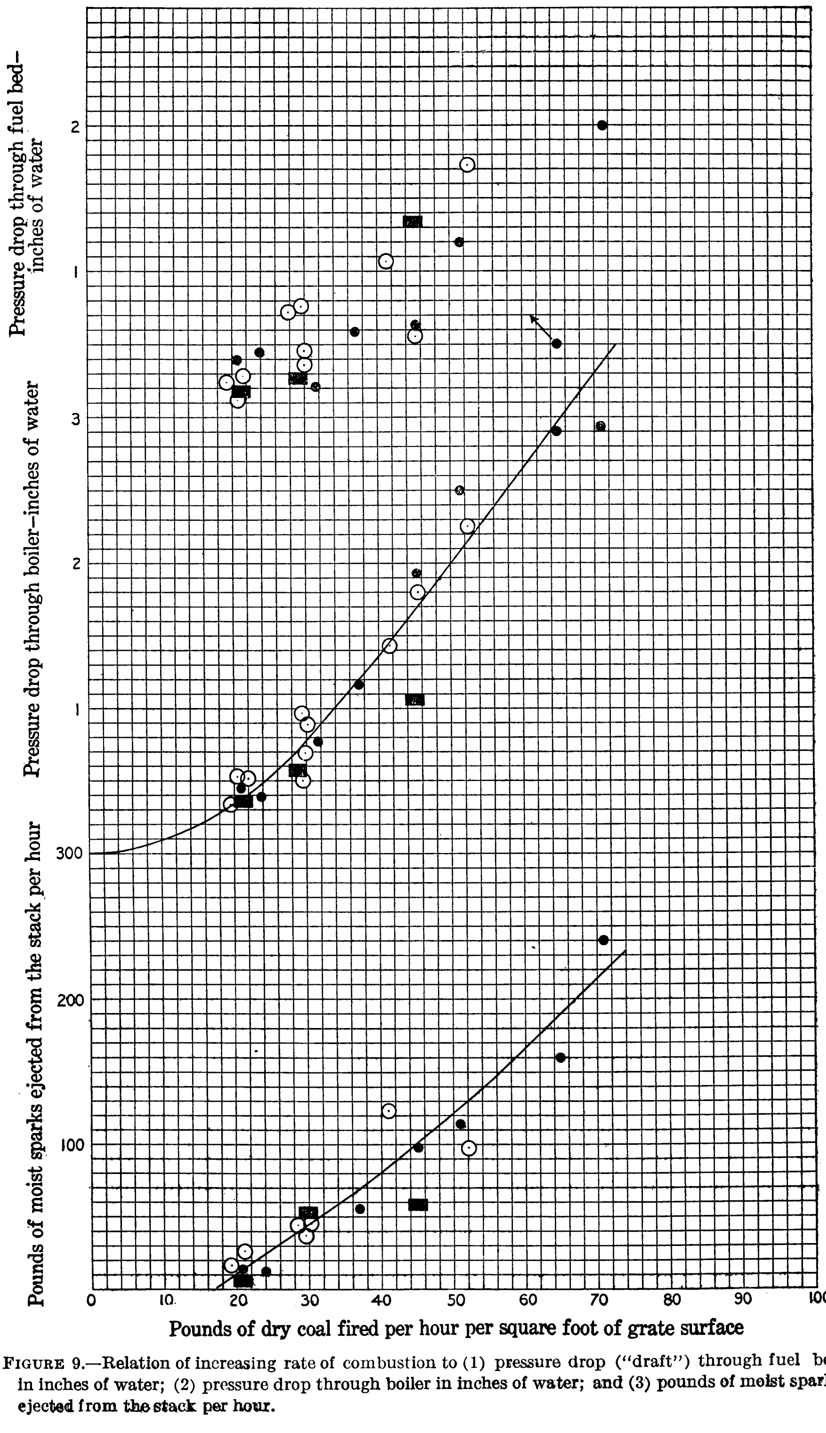

FIGURE 9.—Relation of increasing rate of combustion to (1) pressure drop ("draft") through fuel bed in inches of water; (2) pressure drop through boiler in inches of water; and (3) pounds of moist sparks ejected from the stack per hour.

and therefore different pressure drops must be used with different fuels to obtain the same rate of combustion. As three different kinds of fuels are represented on the figure, the points are somewhat scattered. The run-of-mine coal was a mixture of various sizes and therefore offered higher resistance to the passage of air, and a higher pressure drop than with the briquets had to be maintained to obtain the same rate of combustion.

In the same figure the points of the middle group show the relation between the pressure drop through boiler and the rate of combustion. The pressure drop through the boiler was obtained by subtracting the absolute pressure at the base of the stack from the absolute pressure in the furnace. Since the pressure at the base of the stack was recorded in inches of water below atmospheric pressure and the pressure in the furnace in inches of water above atmospheric pressure, the required difference is obtained by adding the two quantities.

These points fall much better along a single curve than the upper group. This close agreement among the points is due to the fact that the resistance of the gas passage of the boiler remains constant. To put the same volume of gas through the boiler the same pressure drop is needed, no matter what the fuel burned may be, so long as the temperature remains about the same. The curve shows that the pressure drop through the boiler increases a little faster than the rate of combustion. The shape of the curve suggests the law which is commonly used in connection with the flow of gases; that is, the pressure drop through the boiler varies as the square of the rate of combustion.

ON SPARKS.

The points of the lowest group of figure 9 show that the weight of sparks ejected from the stack rises rapidly as the rate of combustion increases. This, of course, can be expected, because in order to obtain a higher rate of combustion a higher pressure drop had to be maintained through the fuel bed, and the resulting increased velocity of gases carried more sparks away. There does not seem to be much difference in the weight of sparks when using the three kinds of fuel; briquets are nearly as bad as run-of-mine coal, at least within the range of the rates of combustion investigated.

ON WEIGHT OF AIR.

The upper curve of figure 10 shows the relation between the weight of air supplied to the furnace and the rate of combustion. The weight of air for platting these points was obtained by multiplying the total weight of "combustible" burned per hour by the weight of air used per pound of "combustible," as figured from the analysis of the flue gases. The curve shows that the total weight of air supplied to the

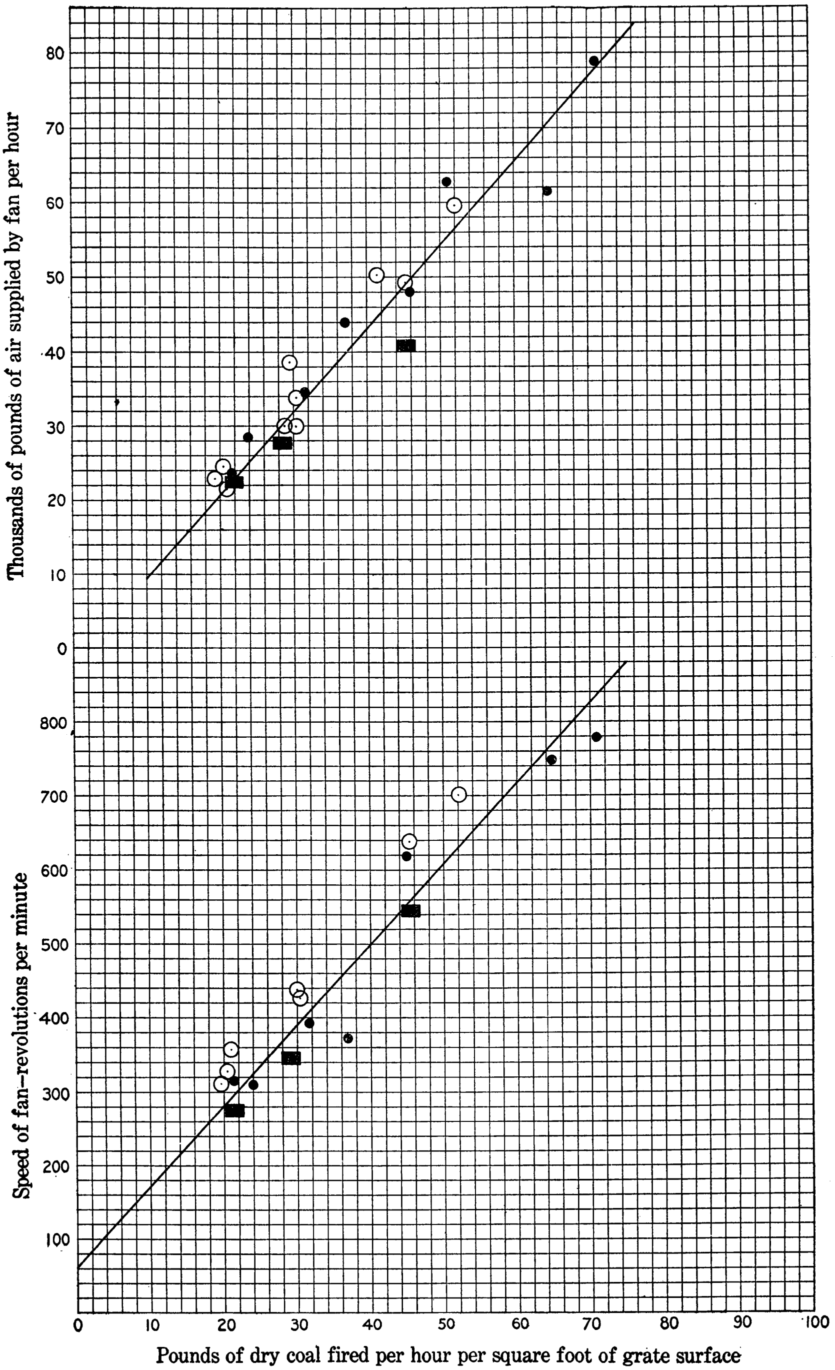

FIGURE 10.—Relation between rate of combustion and thousands of pounds of air supplied by the fan per hour (above), and speed of fan in revolutions per minute (below.)

furnace increases directly with the rate of combustion. In other words, to double the rate of combustion twice as much air must be supplied; to triple the rate three times as much air must be supplied, and so on. This relation is quite natural and could be expected. The kind of fuel seems to make no difference.

ON SPEED OF FAN.

The lower curve of figure 10 shows the relation of the rate of combustion to the speed of the fan, which was obtained by direct measurement with a speed indicator. The curve indicates that the speed of the fan varies directly with the rate of combustion; this means that to obtain twice the rate of combustion the speed of the fan must be doubled, approximately, and to triple the rate the speed of the fan must be tripled, approximately, and so on. It must not, however, be assumed that since the air supplied to the furnace and the speed of the fan vary directly with the rate of combustion the work required from the fan varies in the same way. This is far from being the case. It has been shown in figure 9 that both the pressure drops, through the fuel bed and through the boiler, increase faster than the rate of combustion. This means that when the rate of combustion is to be increased the fan has to supply not only proportionately more air, but that it has to force it against much higher pressure. As the work of the fan is equal to the product of the volume of air which the fan displaces multiplied by the pressure against which this volume of air is forced, it is quite apparent that the work required from the fan increases much faster than the rate of combustion. In Bulletin 367[a] it is shown that the work of a fan varies approximately as the cube of the rate of combustion or the capacity of the boiler.

All points representing raw coal are above the curve (lower curve, fig. 10), and nearly all points representing briquets are below the curve. This means that less work was required from the fan to burn briquets than to burn run-of-mine coal. This fact is undoubtedly due to the smaller resistance of the fuel bed to the passage of air when burning briquets. The run-of-mine coal contained a high percentage of slack, which stopped the air passages in the fuel bed. Then, to obtain the same rate of combustion with coal as with the briquets, greater pressure drop through a fuel bed is required and more work must be done by the fan.

DEDUCTIONS.

ECONOMY.

It was found on many locomotive tests and on some tests made under stationary boilers that briquets gave better economy than run-of-mine coal. The question may be asked why similar results were

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[a] Ray, W. T., and Kreisinger, Henry, The significance of drafts in steam-boiler practice: Bull. U. S. Geol. Survey No. 367 (Bureau of Mines Bulletin 21), p. 55.

not obtained on the fuel tests made under a torpedo-boat boiler. At present no definite answer can be given.

It may be that the combustion space of the furnace, which is less than one-half of the combustion space in an ordinary locomotive, is far too small to show any of the advantages due to the better burning qualities of the briquets. It may also be that what little betterment is gained by the size and uniformity of the briquetted fuel is more than offset by the increase in percentage of volatile combustible due to the addition of pitch as a binder. Table 4 gives for comparison the proximate analyses of the run-of-mine coal and briquets used in these tests, moisture-free basis. The large briquets, which have shown the lowest efficiency, indicate the largest increase in percentage of volatile matter. The same percentage of pitch was used in making both sizes of briquets. However, as the small briquets exposed to the atmosphere a larger surface than the large ones, compared with their volume, and also as they were exposed longer to the atmosphere before testing, it is possible that more of the pitch was evaporated from the small briquets.

TABLE 4.—*Comparison of proximate analyses of coal and briquets.*

Test No.	Designation of coal.	Form of use.	Proximate analysis of dry fuel.		
			Volatile matter.	Fixed carbon.	Ash.
1	Jamestown 6	Run of mine	18.92	75.53	5.55
2			18.71	74.69	6.60
3			19.91	75.81	4.28
		Average	19.18	75.34	5.48
4		Large briquets	23.07	72.01	4.92
5			23.46	71.60	4.94
6			21.31	73.65	5.04
		Average	22.61	72.42	4.97
7	Jamestown 11	Run of mine	15.10	79.06	5.84
8			16.91	76.93	6.16
9			16.86	76.23	6.91
		Average	16.29	77.41	6.30
10		Small briquets	17.43	76.68	5.89
11			18.29	75.63	6.08
12			17.71	76.31	5.98
13			18.21	75.83	5.96
		Average	17.91	76.11	5.98
14	Jamestown 9	Run of mine	23.10	69.22	7.68
15			22.53	70.59	6.88
16			24.06	71.24	4.70
		Average	23.23	70.35	6.42
17		Small briquets	24.04	70.73	5.23
18			24.01	70.58	5.41
19			23.63	71.12	5.25
20			23.70	71.03	5.27
		Average	23.84	70.87	5.29

COMBUSTION SPACE.

The size of combustion space of a furnace and its relation to the grate area and the rate of combustion is very important with volatile fuels such as soft coal, because a considerable percentage of the combustible has to be burned as gas and tar vapors. In a furnace which affords insufficient space these forms of combustible remain in the combustion space only a fraction of a second, which is far too short a time for their complete oxidation. Table 5 gives, for three furnaces, the usual relation of combustion space to grate area, the rate of combustion, and the average time each cubic foot of gas is allowed to stay in the furnace.

TABLE 5.—*Usual relation of combustion space to grate area, the rate of combustion, and the average time each cubic foot of gas stays in the furnace.*

Type of furnace.	Grate area (square feet).	Combustion space (cubic feet).		Ratio of columns—		Customary rate of combustion (pounds of fuel per square foot of grate per hour).	Gases generated per second (cubic feet).[a]	Time each cubic foot of gas stays in furnace (seconds).
		Total.	Effective when fuel bed is 12 inches thick.	2 and 3.	2 and 4.			
1	2	3	4	5	6	7	8	9
Torpedo boat Biddle...	58.6	136	78	2.34	1.33	40	1,010	0.077
Modern locomotive.....	30	160	130	5.34	4.33	60	780	.17
Stationary boiler, Heine, 200 horsepower................	35	250	215	7.14	6.14	25	380	.58

[a] Assuming that 20 pounds of gas and water vapor are formed per pound of coal and that the furnace temperature is 2,500° F.

Columns 5 and 6 show that the ratio of combustion space to grate area in the torpedo-boat furnace decreases much more rapidly with the thickness of fire than it does in either of the other two furnaces. A thick fuel bed reduces not only the supply of air to the furnace, but also the available space for the burning of combustible gases and tars. These facts applied to the fuel tests made under a torpedo-boat boiler help to explain why better results were obtained with comparatively thin fuel beds. Column 9 gives approximately the average length of time each cubic foot of gas is allowed to stay within the combustion space of the furnace. In the case of the torpedo-boat boiler the time usually is very short; in fact, too short for any chemical reaction which is not almost instantaneous. For this reason fuels which burn on the grate and not in the space above would be burned most economically in this particular type of furnace. Such fuels, however, are slow burning, and therefore not quite suitable for a torpedo boat where the rate of making steam is very important. Again, the limitations of a torpedo boat do not permit the combustion space to be enlarged. Therefore, the selection of fuel is usually a compromise between efficiency and rate of making steam.

RELATIVE CAPACITY OF STORAGE SPACE.

To determine the approximate relative storage capacity of coal bunkers when filled with run-of-mine coal, small briquets, and large briquets, a large rectangular wooden box was filled even full with each of the three fuels and the contents were weighed in each case. All three fuels were shoveled into the box in the same way as they would be into the coal bunkers of a boat. The box was 8 by 6 feet inside, and 3 feet deep.

When level full the box held 8,593 pounds of coal, 6,645 pounds of small briquets, and 6,272 pounds of large briquets. Considering the capacity of the coal bunkers when filled with coal as 100 per cent, this space when filled with each of the two kinds of briquets is reduced to $6,645 \div 8,593 = 77.4$ per cent for small briquets and $6,272 \div 8,593 = 73$ per cent for large briquets, showing a considerable loss in the storage capacity of coal bunkers when filled with briquets. This is a serious obstacle to the use of briquets for naval purposes.

TRANSFERRING FUEL FROM BUNKERS TO FIREROOM.

The coal bunkers on a torpedo boat are long, narrow spaces, the floors of which are elevated only about 2 feet above the floor of the fireroom. On account of their shape and location a large part of the contents of the coal bunkers must be shoveled out when wanted in the fireroom. The spaces are so narrow that a man can not turn around inside of them with a shovelful. The openings into the bunkers are near their ends, and fuel at the far ends has first to be shoveled to the opening and then out upon the floor of the fireroom. In doing this work the coal shoveler has to dig with his shovel into the coal pile from the top as he recedes toward the farther end of the coal bunker, always facing the end where the opening is. It is comparatively easy to force the shovel into run-of-mine coal, but almost impossible to force it into a pile of briquets. Starting at the opening and forcing the shovel under the briquets on the floor would be a slow process, because as the coal shoveler got farther away from the opening he would have to walk backward to the opening with every shovelful. Besides, the numerous ribs of the boat would be frequently in the way of his shovel. During the test the quickest way of getting the briquets out of the farther portions of the bunker was by throwing them by hand toward the opening and then shoveling them into the fireroom.

CONCLUSIONS.

The following conclusions apply only to the tests of New River run-of-mine coals when burned under a boiler of the Normand type and on vessels of the torpedo-boat class.

There is little or no gain in efficiency in burning briquets of either size.

Both large and small briquets make as much (or more) smoke as run-of-mine coal.

There seems to be more flaming in stack with briquets than with run-of-mine coal.

About the same amount of sparks are emitted from the stack whether briquetted or run-of-mine coal is burned.

When burning briquets the fire does not need to be disturbed; with coal the fuel bed has to be broken up, generally after each firing.

A somewhat higher boiler capacity can be obtained with briquets than with run-of-mine coal.

Steam can be raised more quickly with briquets than with run-of-mine coal.

Run-of-mine coal is transferred much more readily than briquets from the coal bunker to the fireroom.

With briquets the capacity of a coal bunker is reduced by 23 to 27 per cent.

A FUNDAMENTAL PRINCIPLE IN THE COMBUSTION OF SMOKY FUELS.

On page 26 of this bulletin it was reasoned that in the torpedo-boat furnace the combustion of fuels was imperfect because the combustion space was too small and that the combustible gases and tar vapors [a] did not stay within the furnace a sufficient length of time to become completely oxidized. This means that time is an important element in the combustion of fuels.

The combustion of coal in a boiler furnace is a chemical process in which the oxygen reacts with the carbon and the latter's various combinations with hydrogen. This reaction, being between the gaseous oxygen on one side and gaseous, "liquid," and solid combustibles on the other, is very complicated.

The word "liquid" as used in this discussion denotes all the forms of combustible between gaseous and solid; that is, such substances as in a strict physical sense are not gases or solids. For example, if we pour some coal tar in its viscous semiliquid form into a hot coal fire, a very dense brown "smoke" will issue from it. We know that this smoke is not gas; it is also hard for us to believe that all this smoke would consist of tiny, angular pieces of solid carbon. It is perhaps easier to think that at least a part of the smoke is composed of minute globules of the tar which have been boiled off, somewhat like the visible "steam" coming out of boiling water. For lack of better expression, we say that the combustible in the globules is in "liquid" form.

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[a] In a strict physical sense these tars are not in the form of vapor at all, but rather in the form of visible mist consisting of minute globules of liquid, or a pasty softening solid. Preston, in his "Theory of heat," defines vapor as transparent gas which is below its critical temperature.

When in the use of a hand-fired furnace a fresh charge of soft coal is spread over the hot fuel bed, the coal is heated up very rapidly and part of the combustible matter is boiled or distilled off immediately after the coal reaches the fuel bed. This combustible which is distilled off is perhaps mostly in the form of gases and such forms as are here called "liquids." There are also numerous tiny pieces of solid fuel in the form of lampblack and even pieces of coal carried along with the gases. The combustible left on the grate is the "fixed carbon" in solid form, which burns there. The gaseous combustible which has been distilled off is free hydrogen, carbon monoxide, and some of the lighter hydrocarbons. The "liquids" are heavy hydrocarbons and carbon-hydrogen compounds of the benzine series, which, although surrounded by gases at a high furnace temperature, may exist as minute tar globules. It is these globules of tars which greatly add to the apparent brown smoky color of the gases. All of these forms of combustible driven off from the fuel bed are in more or less perfect mechanical mixture with the air, with the already-formed carbon dioxide, and with the water vapor resulting from evaporating the moisture in the coal, and from the combustion of part of the free hydrogen. The velocity of chemical reaction (combination) between the combustible gas and the free oxygen (or the rapidity with which the combustible gas burns) depends upon the concentration of the two gases; that is, the rapidity of combustion will be the product of the amount of free oxygen times some power of the amount of combustible gas present in a unit of volume. The combination of simple gases, such as hydrogen and carbon monoxide, perhaps consist of a single reaction, while the combustion of the unsaturated hydrocarbons, as ethylene, and acetylene may be series of two or three, or even more, reactions, the first reactions of each series partly burning the gases and partly reducing them to simple combustibles, either gaseous or solid. Ordinarily, the velocity of these reactions or the rapidity of burning gaseous combustible is high, so that with any reasonable amount of oxygen this combustion is nearly complete in a fraction of a second. The tar vapors, however, being partly in "liquid" form, require, even in the case of a uniform mixture with oxygen, a much longer time for their complete combustion, because oxygen can act only on the surface of each minute globule. As each globule burns, an insulating film of the products of combustion is formed around it, preventing contact with more oxygen. The globules are carried in the current of gas, and since they have very nearly the same velocity, there is little or no friction between the gas stream and the globules. The chief way in which the insulating film around each globule can be dispersed and more oxygen brought into contact with the surface of the globule is by natural diffusion between the gas comprising the film and the free oxygen outside the film. This process of natural diffusion is rather slow, and as each globule contains many times more combustible matter than a like volume of gas, the process of oxidation of the globules of tar may extend over a considerable length of time, during which they may be carried out of the furnace and cooled below their ignition point. Such unoxidized tar globules appear at the top of the stack as dark smoke, and probably form the greater part of the loss in incomplete combustion.

These tar globules are similar in character to tobacco smoke, which is not a product of combustion, but a product of decomposition; it is not a slightly colored gas, but a large number of tobacco-oil globules held in suspension by the current of gas. Every smoker knows that if he pass the smoke from his cigar through a clean, white linen cloth, the visible smoke which consists of the tobacco-oil globules will condense and leave a light-brown oil spot on the linen, having a very strong, characteristic smell. The tarry globules escaping from a coal fire, if collected and condensed in some such way, generally appear as a thick, black, pasty liquid, having the strong coal-tar odor, which we are accustomed to smell around a certain class of gas producers or around gas works. Tar vapors from a wood fire have a different odor than those coming from a coal fire. In fact, every fuel gives off tar vapors with odors peculiar to that fuel and somewhat different from those of any other.

In the case of a boiler furnace, any attempt to determine the tar loss by volumetric chemical analysis of the flue gases must necessarily fail, because these tars have comparatively little volume; furthermore, they generally condense in the gas-sampling apparatus.

The slow combustion of the tar globules can be made faster by increasing the rate of diffusion of the film of products of combustion enveloping the globule. This can be done by creating a relative velocity between the gas stream and the globules; that is, by making one move faster than the other or by changing slightly the direction of the main stream of gas. The resulting friction facilitates diffusion by a process of scrubbing, which removes from the globules the insulating film of products of combustion. Insertion of brick piers in the path of the gases or changing the cross section of the gas passages so that the gases have to contract and expand perhaps induces such relative difference of velocities.

That some such film as is herein described does prevent the free oxygen from coming into contact with the surface of the globules seems to be certain from the fact that gas samples taken by water-jacketed samplers from a stream of gas apparently rich in the tar vapors show usually several per cent of free oxygen.

As the tar vapors are perhaps a whole series of very complex hydrocarbons, their complete oxidation undoubtedly consists of several simultaneous or consecutive reactions more or less dependent on each other. This is probably another cause of their slow combustion.

What has been said about the slow combustion of the tars is perhaps in an intensified degree true of the small particles of solid combustible held in suspension by the gases.

By far the larger part of the coal burns on the grate, where the combustion is mostly a reaction between the solid carbon and gaseous oxygen. The rate of formation of CO_2 seems to vary directly with the velocity of the free oxygen passing over the surfaces of the pieces of solid carbon. The higher the blast of air passing through the fuel bed of burning carbon the faster the latter burns, the chemical composition of the products of combustion remaining about the same. Undoubtedly the scrubbing action of the blast of air removes from the surfaces of the solid carbon the film of the products of combustion and facilitates the access of free oxygen. If the fuel bed is not carried too thick, very good combustion of the fixed carbon is obtained without any difficulty.

In the preceding discussion of the combustion of the various forms of combustibles in a boiler furnace it has been shown that the gaseous combustible is easy to burn because it burns quickly, and that the fixed carbon is easy to burn because it stays on the grate until completely burned; also, that the tar vapors, the lampblack, and the tiny pieces of coal held in suspension by the gases are difficult to burn because they burn slowly, and usually can not be kept long enough within the furnace to be completely burned. The proper way to burn coal would be to treat it in such a way as to distill as volatile matter only light, easily burning gases, and leave all the rest of the combustible on the grate and burn it as a fixed solid. Laboratory experiments[a] show that the amount and quality of the combustible driven off the coal by heating depends largely on the rate of heating; that is, when the rate of heating is slow, the total combustible matter driven off as volatile is small in quantity and gaseous in composition, while if the rate of heating the coal is very rapid the total volatile matter driven off is not only high in quantity but contains much tar vapor. It seems as though the hydrogen of the coal must be distilled off before burning and that when the coal is heated slowly the hydrogen on distillation takes only a small amount of carbon with it, leaving most of the latter on the grate as "fixed carbon;" if, however, the coal is heated very rapidly, the hydrogen comes off with a large amount of carbon and escapes as volatile matter, leaving a smaller quantity of the carbon on the grate in a fixed form. These facts bring us to the realization that there is no definite line between "fixed carbon" and "volatile matter." We know, for

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[a] See Porter, H. C., and Ovitz, F. K., The volatile matter of coal: Bureau of Mines Bulletin 1.

instance, that coal tars which escape from a gas producer entirely as volatile matter show from 40 to 50 per cent of "fixed carbon" when subjected to proximate analysis. Similarly, if the tars from a boiler furnace, particularly from a hand-fired one, were caught and analyzed by the proximate method, they would likely show a considerable percentage of "fixed" carbon. This "fixed carbon" of the tar should have been left on the grate and not carried away by the process of distillation.

According to the above, firing coal by hand is not the right way to burn it, because the pieces of coal fall on a very hot fuel bed and are heated in two or three minutes through a range of temperature of about 2,400° F. This is a very high rate of heating and much of the carbon which, with a slow rate of heating would be left on the grate as "fixed," is driven away in combination with hydrogen in the form of heavy tar vapors. These tar vapors generally do not stay long enough in the furnace to burn, and hence leave the stack as smoke.[a]

Most mechanical stokers are designed so that the coal is fed into the furnace gradually, and therefore the rate of heating is slow. The result is that a comparatively small amount of combustible is driven off as volatile matter, and it consists chiefly of easily burning gases, most of the carbon being left and burnt on the grate as fixed carbon; very small amounts of tarry vapors are distilled, whence the success of most mechanical stockers in burning smoky fuel. As an example, on a well-operated chain-grate stoker, it takes perhaps fifteen to twenty minutes to heat the coal through the same temperature range of 2,400° F., which takes only two or three minutes in the hand-fired furnace. In general, the success of these mechanical stokers lies not in the fact that they consume smoke but that they burn the coal without producing much smoke at all.

Tar vapors and other heavy carbon-hydrogen compounds which are the product of distillation of coal under certain treatment burn slowly, and in order to burn them nearly completely they must be kept a comparatively long time within the furnace. To fulfill this condition the furnace must be provided with a large combustion space. Such furnaces, however, are objectionable for obvious reasons. The best remedy probably is to avoid the formation of all these slow-burning volatile compounds by using the principle of the low rate of heating of fresh fuel.

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[a] It must not be understood that these tar vapors are the only constituents of visible smoke. Small particles of carbon or soot, resulting from the decomposition of illuminant gases such as C_2H_4 and C_2H_2 add to the darkness of the smoke; however, the tar vapors probably represent the greatest loss of heat.

PUBLICATIONS ON FUEL TESTING.

The following publications, except those to which a price is affixed, may be obtained without cost by applying to the Director, Bureau of Mines, Washington, D. C. The priced publications may be obtained by sending the price, in cash, to the Superintendent of Documents, Government Printing Office, Washington, D. C.

PUBLICATIONS OF THE BUREAU OF MINES.

BULLETIN 1. The volatile matter of coal, by H. C. Porter and F. K. Ovitz. 1910. 56 pp., 1 pl.

BULLETIN 2. North Dakota lignite as a fuel for power-plant boilers, by D. T. Randall and Henry Kreisinger. 1910. 42 pp., 1 pl.

BULLETIN 3. The coke industry of the United States as related to the foundry, by Richard Moldenke. 1910. 32 pp.

BULLETIN 4. Features of producer-gas power-plant development in Europe, by R. H. Fernald. 1910. 27 pp. 4 pls.

BULLETIN 5. Washing and coking tests of coal at Denver, Colo., by A. W. Belden, G. F. Delamater, J. W. Groves, and K. M. Way. 1910. 62 pp.

BULLETIN 7. Essential factors in the formation of producer gas, by J. K. Clement, L. H. Adams, and C. N. Haskins. 1911. 57 pp. 1 pl.

BULLETIN 8. The flow of heat through furnace walls, by W. T. Ray and Henry Kreisinger. 1911. 32 pp.

BULLETIN 9. Recent development of the producer-gas power plant in the United States, by R. H. Fernald. 82 pp. Reprint of United States Geological Survey Bulletin 416.

BULLETIN 11. The purchase of coal by the Government under specifications, by G. S. Pope. 80 pp. Reprint of United States Geological Survey Bulletin 428.

BULLETIN 12. Apparatus and methods for the sampling and analysis of furnace gases, by J. C. W. Frazer and E. J. Hoffman. 1911. 22 pp.

BULLETIN 13. Résumé of producer-gas investigations, October 1, 1904, to June 30, 1910, by R. H. Fernald and C. D. Smith. 1911. (In press.)

BULLETIN 14. Briquetting tests of lignite at Pittsburg, Pa., 1908–9; with a chapter on sulphite-pitch binder, by C. L. Wright. 1911. 60 pp. 11 pls.

BULLETIN 21. The significance of drafts in steam boiler practice, by W. T. Ray and Henry Kreisinger. 62 pp. Reprint of United States Geological Survey Bulletin 367.

BULLETIN 24. Binders for coal briquets, by J. E. Mills. 56 pp. Reprint of United States Geological Survey Bulletin 343.

BULLETIN 27. Tests of coal and briquets as fuel for house-heating boilers, by D. T. Randall. 45 pp. Reprint of United States Geological Survey Bulletin 366.

BULLETIN 28. Experimental work conducted in the laboratory of the United States fuel-testing plant at St. Louis, Mo., January 1, 1905, to July 31, 1906, by N. W. Lord. 49 pp. Reprint of United States Geological Survey Bulletin 323.

BULLETIN 30. Briquetting tests at the United States fuel-testing plant, Norfolk, Va., 1907–8, by C. L. Wright. 41 pp. Reprint of United States Geological Survey Bulletin 385.

BULLETIN 31. Incidental problems in gas-producer tests, by R. H. Fernald, C. D. Smith, J. K. Clement, and H. A. Grine. 29 pp. Reprint of United States Geological Survey Bulletin 393.

BULLETIN 32. Commercial deductions from comparisons of gasoline and alcohol tests on internal-combustion engines, by R. M. Strong. 33 pp. Reprint of United States Geological Survey Bulletin 392.

PUBLICATIONS OF THE UNITED STATES GEOLOGICAL SURVEY.

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 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. 25 cents.

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 362. Mine sampling and chemical analyses of coal 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 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. 10 cents.

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