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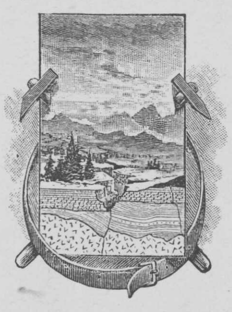
Bulletin 373

THE SMOKELESS COMBUSTION OF COAL IN BOILER PLANTS

WITH A CHAPTER ON CENTRAL HEATING PLANTS

BY

D. T. RANDALL and H. W. WEEKS



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THE SMOKELESS COMBUSTION OF COAL IN BOILER PLANTS.

By D. T. Randall and H. W. Weeks.

INTRODUCTION.

THE PROBLEM AND ITS SOLUTION.

The burning of coal without smoke is a problem which concerns the Government directly because of the advantages of smokeless combustion both in public buildings and on naval vessels. In addition, smoke abatement is a factor in conserving the fuel resources of the United States. Hence, as part of its general investigation of the best methods of utilizing the coals of this country, the United States Geological Survey has made extended tests to determine the conditions necessary for the smokeless combustion of bituminous coal in boiler plants, and has obtained information relating to the setting and operation of boilers at industrial establishments where coal high in volatile matter is burned without smoke.

Bulletin 334, a preliminary report on the subject of smoke abatement, treated the problem from a theoretical point of view, detailing the steps that are now being taken by municipalities, manufacturers, and citizens to stop the evil, also showing the possibility of a clean city. The present bulletin not only shows that bituminous coals high in volatile matter can be burned without smoke, but also that large plants carrying loads that fluctuate widely, where boilers over banked fires must be put into service quickly and fires forced to the capacity of their units, can be operated without producing smoke that is objectionable. Proper equipment, efficient labor, and intelligent supervision are the necessary factors.

INVESTIGATION OF INDUSTRIAL PLANTS.

SCOPE AND PURPOSE.

In the investigation of industrial establishments a study was made of the conditions in thirteen of the larger cities in Illinois, Indiana, Kentucky, Maryland, Michigan, Missouri, New York, Ohio, and Pennsylvania, between 400 and 500 plants being inspected. Sufficient information was collected to make the data from 284 plants of value for this report. In nearly every city visited coal was supplied from points both in and out of the State, so that although but nine States were visited, the facts ascertained apply to coals from a greater number.

The main purpose of the inspection was to obtain a better knowledge as to the influence on smoke production of furnace design and of the conditions under which combustion takes place.

SUMMARY OF CONCLUSIONS.

The results of this investigation are set forth in detail on later pages of this volume. The general conclusions to be drawn can be summarized in a few paragraphs.

Smoke prevention is possible. There are many types of furnaces and stokers that are operated smokelessly.

Any one kind of apparatus is effective only if so set under boilers that the principles of combustion are respected. The value to the average purchaser of a manufacturer's requirement on this point lies in the fact that he is thus reasonably certain of good installation. A good stoker or furnace poorly set is of less value than a poor stoker or furnace well set. Good installation of furnace equipment is necessary for smoke prevention.

Stokers or furnaces must be set so that combustion will be complete before the gases strike the heating surface of the boiler. When partly burned gases at a temperature of, say, 2,500° F., strike the tubes of a boiler at, say, 350° F., combustion is necessarily hindered and may be entirely arrested. The length of time required for the gases to pass from the coal to the heating surface probably averages considerably less than one second, a fact which shows that the gases and air must be intimately mixed when large volumes of gas are distilled, as at times of hand firing, or the gas must be distilled uniformly, as in a mechanical stoker. By adding mixing structures to a mechanical stoker equipment both the amount of air required for combustion and the distance from the grates to the heating surface may be reduced for the same capacity developed. The necessary air supply can also be reduced by increasing the rate of combustion.

No one type of stoker is equally valuable for burning all kinds of coal. The plant which has an equipment properly designed to burn the cheapest coal available will evaporate water at the least cost.

Although hand-fired furnaces can be operated without objectionable smoke, the fireman is so variable a factor that the ultimate solution of the problem depends on the mechanical stoker—in other words, the personal element must be eliminated. There is no hand-fired furnace from which, under average conditions, as good results can be obtained as from many different patterns of mechanical stoker, and of two equipments the one which will require the less attention from the fireman gives the better results. The most economical hand-fired plants are those that approach most nearly to the continuous feed of the mechanical stoker.

The small plant is no longer dependent on hand-fired furnaces, as certain types of mechanical stokers can be installed under a guaranty of high economy, with reduction of labor for the fireman.

In short, smoke prevention is both possible and economical.

PERSONNEL.

This investigation was carried out under the direction of D. T. Randall, L. F. Beers and H. W. Weeks procuring most of the data. Mr. Weeks has also prepared a large portion of the report. In the collection of the information much assistance was given by the city smoke inspectors, by manufacturers of boiler-room equipment, and by the owners of the plants visited, and to them especial thanks are hereby extended for their active cooperation.

METHOD OF COLLECTING DATA.

On entering a city a list was obtained of the plants where mechanical stokers or special devices for hand-fired furnaces were in operation without smoke. Smoke observations were taken on the stacks at these plants, or records at the smoke inspector's office were reviewed to determine the plants to be visited. The stack was always watched at times when the plant was running under average conditions, and always without the knowledge of the engineer or fireman. The length of the observations varied from one hour to ten hours, although a one-hour record determined whether a stack was good or bad. The observer usually checked this record by watching the stack during several shorter periods while he was in the city.

During the visit to each plant an attempt was made to obtain data enough so that the furnace and boiler setting could be duplicated. All information except that in regard to drafts and furnace measurements was supplied by the manager or the engineer in charge of the plant. The engineer usually knew the approximate amount of coal burned per day on heavy and light loads and the number of boilers used to carry the load. Draft readings were taken to obtain the drop in draft through the boiler and to learn the effective draft which burned the coal. Special notice was taken of the methods of operation to determine whether in case the plant was duplicated the same results could be expected if it was operated by the average fireman.

SIZES OF COAL.

The size of the coal which was being burned at the various plants inspected is stated in the tables as run-of-mine, sized egg or nut, and screenings, except for the Illinois plants, where the sizes are given as Nos. 1, 2, 3, 4, or 5. The standard for sizing coal is not uniform over the whole State of Illinois, but in Williamson County washed coal is passed over screens with round openings and is sized and numbered as follows:

No. 1, coal passing through 3-inch screen and over $1\frac{3}{4}$-inch screen.
No. 2, coal passing through $1\frac{3}{4}$-inch screen and over 1-inch screen.
No. 3, coal passing through 1-inch screen and over $\frac{3}{4}$-inch screen.
No. 4, coal passing through $\frac{3}{4}$-inch screen and over $\frac{1}{4}$-inch screen.
No. 5, coal passing through $\frac{1}{4}$-inch screen.

About half the washeries in Illinois size coal according to the above scheme.

DEFINITION OF BOILER HORSEPOWER.

To determine the percentage of the rated capacity being developed it was necessary to assume the amount of coal each plant burned per boiler horsepower per hour. To a mechanical engineer the term "boiler horsepower" suggests two things—a measure of the rate of work and a measure of the capacity of the boiler.

Rate of work.—The measure of the rate of work of a boiler is based on an arbitrary unit of an evaporation of 30 pounds of water per hour from a feed-water temperation of 100° F. into steam at 70 pounds gage pressure. This unit is termed a boiler horsepower, and was suggested as of possible value at a time when a good engine had a water rate of about 30 pounds per hour. It became so widely used that in 1885 it was adopted by the American Society of Mechanical Engineers as a standard for conducting steam-boiler trials. The revised code of the society defines it as follows: "The unit of commercial horsepower developed by a boiler shall be taken as $34\frac{1}{2}$ units of evaporation per hour—that is, $34\frac{1}{2}$ pounds of water evaporated per hour from a feed-water temperature of 212° F. into dry steam of the same temperature. This standard is equivalent to 33,137 British thermal units per hour. It is also practically equivalent to an evaporation of 30 pounds of water from a feed-water temperature of 100° F. into steam at 70 pounds gage pressure." The unit of evaporation is thus equivalent to 965.7 British thermal units.

Capacity of boilers.—The measure of the capacity or rating of a boiler is variable, there being no standard. Under a proper method of rating the proposed rated capacity should be attained when using average coal, giving average attention to firing, and using only part of the available draft, yet obtaining good economy. To rate all boilers, whether of the water-tube or fire-tube type or a combination of the two, on the basis of 10 square feet of heating surface per boiler horsepower is becoming a general practice, as this method comes within the required conditions.

DETERMINATION OF TOTAL HEATING SURFACE.

The determination of the total heating surface with sufficient accuracy for ordinary purposes is not difficult. A short approximate method for any boiler is to figure the heating surface in the tubes and divide it by 0.85 for a return tubular boiler or by 0.90 for a water-tube boiler. In case the return tubular boiler has an arch over the top for gas passage, giving a so-called third return, it is necessary to add from 100 to 200 square feet to the result to obtain the total heating surface.

This short method may be proved by two examples, as follows:

(1) Take a return tubular boiler which is 18 feet long and 6 feet in diameter, with 72 4-inch tubes. According to Kent, the square feet per foot length for a 4-inch tube $=1.047$; then—

$1.047 \times 18 \times 72 = 1{,}357$ square feet in tubes.

$3.1416 \times 6 \times 18 = 339$ square feet in shell.

$(3.1416 \times 9) - (72 \times 3.1416 \times 0.172) \times 2 = 44$ square feet in tube sheets.

Hence the total effective heating surface $= 1357 + \frac{339}{2} + 44 = 1570$; but $\frac{1{,}357}{1{,}570} = 0.863+$, hence approximately 85 per cent of the total effective heating surface of a return tubular boiler is in the tubes.

(2) Take a Heine water-tube boiler having 116 tubes $3\frac{1}{2}$ inches in diameter and 18 feet long and a 42-inch drum 21 feet 6 inches long. According to Kent, the square feet per foot length for a $3\frac{1}{2}$-inch tube $=0.916$; then $0.916 \times 18 \times 116 = 1{,}912$ square feet in tubes. The approximate dimensions of the water legs are 6 feet 6 inches by 4 feet $=26$ square feet; the tube area in water legs $=8$ square feet; and the heating surface in water legs $= (26 \times 2) - (8 \times 2) = 36$ square feet. The effective heating surface in drum $= \frac{3.1416 \times 3.6 \times 21.5}{2} =$ 118 square feet. Thus, the total effective heating surface $=$ $1{,}912 + 36 + 118 = 2{,}066$ square feet; but $\frac{1{,}912}{2{,}066} = 0.925+$, hence approximately 92 per cent of the total effective heating surface of a Heine water-tube boiler is in the tubes. In other types of water-tube boilers the ratio was found to be lower; but 90 per cent may be assumed as a fair average ratio.

TESTS BY THE GEOLOGICAL SURVEY.

GENERAL STATEMENT.

During 1904 to 1906 coals from all parts of the United States were burned at the government fuel-testing plant at St. Louis, in furnaces which were in the main of the same design. Most of the tests[a]

[a] For descriptions of the plant and tests see Bull. U. S. Geol. Survey Nos. 261, 290, 323, and 332.

were made on a hand-fired furnace under a Heine water-tube boiler. The lower row of tubes of the boiler supported a tile roof for the furnace, giving the gases from the coal a travel of about 12 feet before coming into contact with the boiler surface. This furnace is more favorable to complete combustion than those installed in the average plant. A number of coals were burned in this furnace with little or no smoke, but many coals could not be burned without making smoke that would violate a reasonable city ordinance when the boiler was run at or above its rated capacity. Boilers having furnaces installed under less favorable conditions will give off more smoke.

In 1907 the steaming section of the St. Louis plant was moved to Norfolk, Va., where subsequent tests of this nature have been made. The plant at Norfolk was equipped with two furnaces—one fired by hand and the other by a mechanical stoker. Both were operated under Heine boilers.

In the course of the steaming tests at St. Louis and Norfolk some special smoke tests were made and the influence of various factors in smoke production was noted. As the tests were made as far as possible under standard conditions, with a minimum of variation in boiler-room labor, the results bring out the importance of other factors such as character of fuel and furnace design.

SUMMARY OF CONCLUSIONS.

A detailed discussion of these tests, with numerous tables, is presented on pages 139–167 of this volume. A brief summary of the general conclusions is as follows:

A well-designed and operated furnace will burn many coals without smoke up to a certain number of pounds per hour, the rate varying with different coals, depending on their chemical composition. If more than this amount is burned, the efficiency will decrease and smoke will be made, owing to the lack of furnace capacity to supply air and mix gases.

High volatile matter in the coal gives low efficiency, and vice versa. The highest efficiency was obtained when the furnace was run at low capacity. When the furnace was forced the efficiency decreased.

With a hand-fired furnace the best results were obtained when firing was done most frequently, with the smallest charge.

Small sizes of coal burned with less smoke than large sizes, but developed lower capacities.

Peat, lignite, and subbituminous coal burned readily in the type of tile-roofed furnace used and developed the rated capacity with practically no smoke.

Coals which smoked badly gave efficiencies 3 to 5 per cent lower than the coals burning with little smoke.

Briquets were found to be an excellent form for using slack coal in a hand-fired plant. They can be burned at a fairly rapid rate of combustion with good efficiency and with practically no smoke. High-volatile coals when briquetted are perhaps as valuable as low-volatile coals when not briquetted.

A comparison of tests on the same coal washed and unwashed showed that under the same conditions the washed coal burned much more rapidly than the raw coal, thus developing high rated capacities. In the average hand-fired furnace washed coal burns with lower efficiency and makes more smoke than raw coal. However, washed coal offers a means of running at high capacity, with good efficiency, in a well-designed furnace.

Forced draft did not burn coal any more efficiently than natural draft. It supplied enough air for high rates of combustion, but as the capacity of the boiler increased the efficiency decreased and the percentage of black smoke increased.

Most coals that do not clinker excessively can be burned with 1 to 5 per cent greater efficiency and with a smaller percentage of black smoke on a rocking grate than on a flat grate.

Air admitted freely at firing and for a short period thereafter increases efficiency and reduces smoke.

As the CO in the flue gas increases the black smoke increases; the percentage of CO in the flue gas is therefore, in general, a good guide to efficient operation. However, owing to the difficulty of determining this factor, combustion can not be regulated by it.

The simplest guide to good operation is pounds of coal burned per square foot of grate surface per hour.

REPRESENTATIVE BOILER PLANTS BURNING COAL WITHOUT SMOKE.

GENERAL STATEMENT.

Bulletin 334, the preliminary report on smokeless combustion, takes up information collected and conclusions reached while assembling the data summarized in the present report and sets forth many facts of general interest that are not discussed in the following pages. This paper deals especially with the equipment of particular boiler plants which were found to be burning coal without smoke, and with the essentials of good furnace design. A brief summary of the general conclusions is presented on pages 171–172. The details on which these conclusions are based are set forth in the following pages.

For the sake of clearness the important features of the equipment of the boiler plants visited are stated in tabular form.

Although there were very few plants at which all the items covered by the tables could be ascertained, the more essential details—those bearing directly on the subject of smoke prevention—were obtained at nearly every plant. The density of the smoke is stated on a percentage basis, 0 meaning a clean stack and 100 per cent meaning dense black smoke.

In the tables the furnace dimensions are checked by letters from A to H, which refer to the dimensions indicated by the corresponding letters on the illustrations showing typical installations of furnaces under boilers of various types. These illustrations are intended to show especially the average and the minimum travel of the gases from the fire to the first cooling surface in the boiler, the height of the furnace, and the length of the coking arch.

In the illustrations some makes of boilers appear more frequently than others. This does not imply any preference for certain models. Boilers of widely differing patterns have shown equal efficiency in steaming trials, and it is coming to be a general belief that among the types of boilers ordinarily used at power plants peculiarities of tube arrangement count for less than proper furnace design. This report of what has been done to effect smokeless combustion emphasizes the importance of furnace design and management and makes no comparisons between boilers. The illustrations show details of furnace construction and the importance of certain features.

For convenience of treatment the following order is adopted in discussing the equipment of the various plants:

Mechanical stoker plants.
- (*a*) Overfeed stokers.
  1. Chain grates.
  2. Front feed.
  3. Side feed.
- (*b*) Underfeed stokers.

Hand-fired plants.
- (*a*) Furnaces under water-tube boilers.
- (*b*) Furnaces under return tubular boilers.
  1. Down-draft furnaces.
  2. Furnaces using steam jets.
  3. Furnaces with miscellaneous equipment.

PLANTS WITH MECHANICAL STOKERS.

The use of mechanical devices for firing coal reduces labor in the boiler room, but the main object of mechanical stoking is to feed a steady, regulated supply of coal and air to the furnace. The advantages of feeding a fire steadily were seen in the early days of steam engineering, but defects in design or faulty installation and management kept mechanical stokers from coming into general use. Within the last decade, however, their use has greatly increased. They are of two general types—overfeed and underfeed.

OVERFEED STOKERS.

CHAIN GRATES.

GENERAL DISCUSSION.

The earliest mechanical stoker was of the treadmill type, so called because the arrangement of the grate bars as a traveling belt resembled the apron of a treadmill. It was patented in England as far back as 1841. Improved in details of construction, this type, under the name chain grate, has come into extensive use in this country. The coal is fed from a hopper, which extends the entire width of the grate and has a plate at the back for regulating the depth of the bed of coal, to a continuously revolving grate, the top of which is made to move from front to rear by power applied to the front or rear sprocket shaft. As usually installed, the surface of the grate is horizontal, but occasionally chain grates are given a slight incline. Back of the hopper and extending over the whole width of the grate is a fire-brick arch. The length of this arch differs in plants equipped by different makers, but the present tendency is to lengthen the arch and to proportion its length and slope to the grade of coal to be used.

In operation, coal from the hopper begins to ignite as it passes under the arch and the grates carry the burning coal toward the bridge

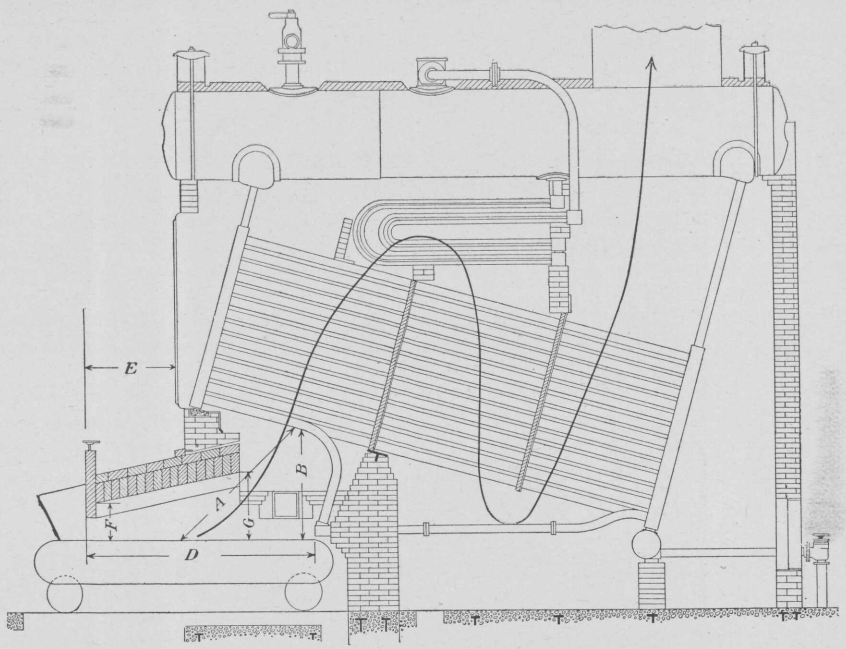

FIGURE 1.—Chain-grate stoker and Babcock & Wilcox boiler with uptake in rear.

wall at a rate which permits complete combustion before the chain passes the rear sprocket and the refuse falls into the ash pit below.

The majority of the stokers of this type are particularly adapted to a free-burning coal high in volatile matter, such as is mined in the central and western fields, and give less satisfaction with the higher fixed carbon coking coals of the Appalachian field. As they can burn the poorest grades of noncoking coal with complete combustion, they offer a valuable means of producing cheap power. At all the plants visited where these stokers were in use small coal was burned.

As has been said, the chief difference at present among chain grates as put in by the various makers is in the length of the fire-brick arch.

In many water-tube boilers this arch is made short, and the gases of combustion are led to the tubes by the shortest path. A furnace and boiler with stoker thus set are shown in figure 1. In this setting the distance of travel for the gases from the grates to the tube heating surface, indicated by the line *B*, is reduced to a minimum and the average distance from the fire to the first cooling surface encountered (*A*) approaches a minimum.

This type of installation is common in the Middle West, where a higher proportion of chain grates is in use than in any other section of the United States, but the short arch and the brief travel of the gases to the first tube heating surface are features unfavorable to smokeless combustion.

A water-tube boiler of another make with furnace fed by chain grates is shown in figure 2.

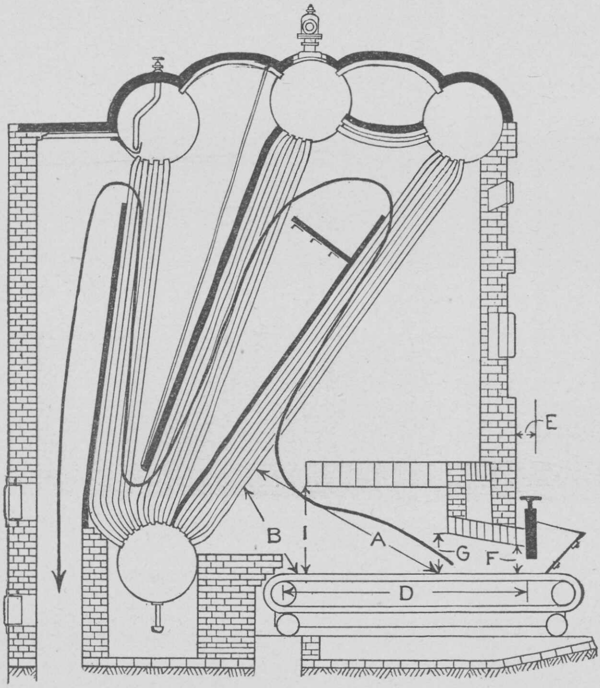

FIGURE 2.—Chain-grate stoker and Stirling boiler.

A method of setting designed to lengthen the travel of the combustible gases from the bed of coal and allow them to mix and be completely burned before entering the boiler is shown by figure 3. Here the type of boiler illustrated by figure 1 is baffled so that the uptake is in front; the fire-brick arch over the grates is no longer than in the other furnace, but it is supplemented by the bottom baffling made of C tile supported by the water tubes, so that the least distance from grates to tube heating surface is three times as long as in the mounting shown in figure 1. The bottom baffling, though it can not, on account of its construction, become as hot as the ignition arch, has slight chilling effect, and there is ample opportunity for complete combustion before the gases reach the first cooling surface.

Comparatively few chain-grate stokers were found under tubular boilers. An example of the usual setting is given in figure 4. Here, while the ignition arch is short and the shell of the boiler has a cooling effect, the average distance from the grates to the beginning of the tube heating surface is so long that smokeless combustion can be

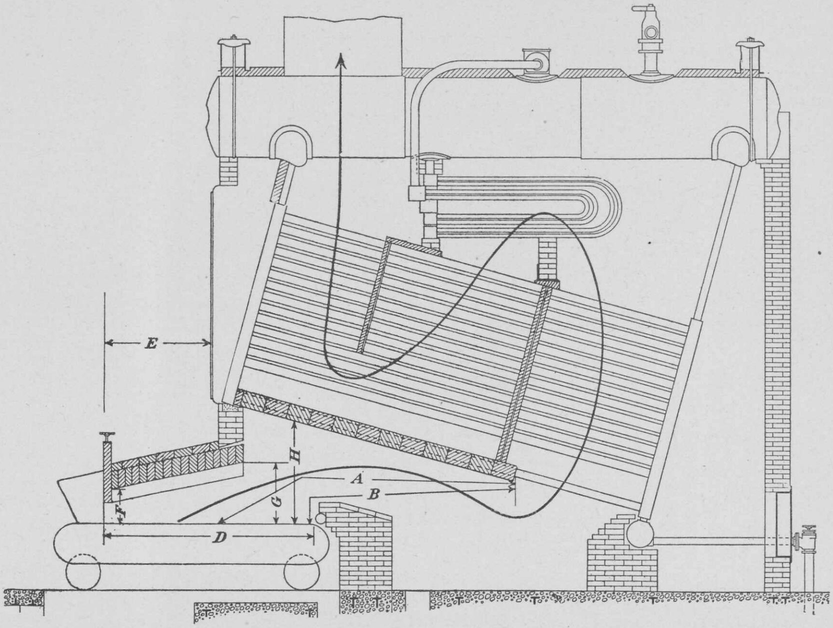

FIGURE 3.—Chain-grate stoker and Babcock & Wilcox boiler with uptake in front.

obtained with ordinary care in operation. In the journey from the grate to the rear of the boiler the cooling effect of the boiler shell, though not negligible, is much less than it is often thought to be, inasmuch as the area exposed is not more than that of eight or nine tubes.

DETAILED DESCRIPTION OF PLANTS.

In the course of the field investigation 57 plants, ranging from 300 to 9,600 rated boiler horsepower, at which chain grates were installed were visited. The detailed information collected regarding these plants is presented in Table 5 (pp. 19–32), but some of the more important facts to be gained from a study of that table are summarized here.

The coals used, all small sizes, came from five different States and the average depth of fire in burning them ranged from 4.5 to 6 inches.

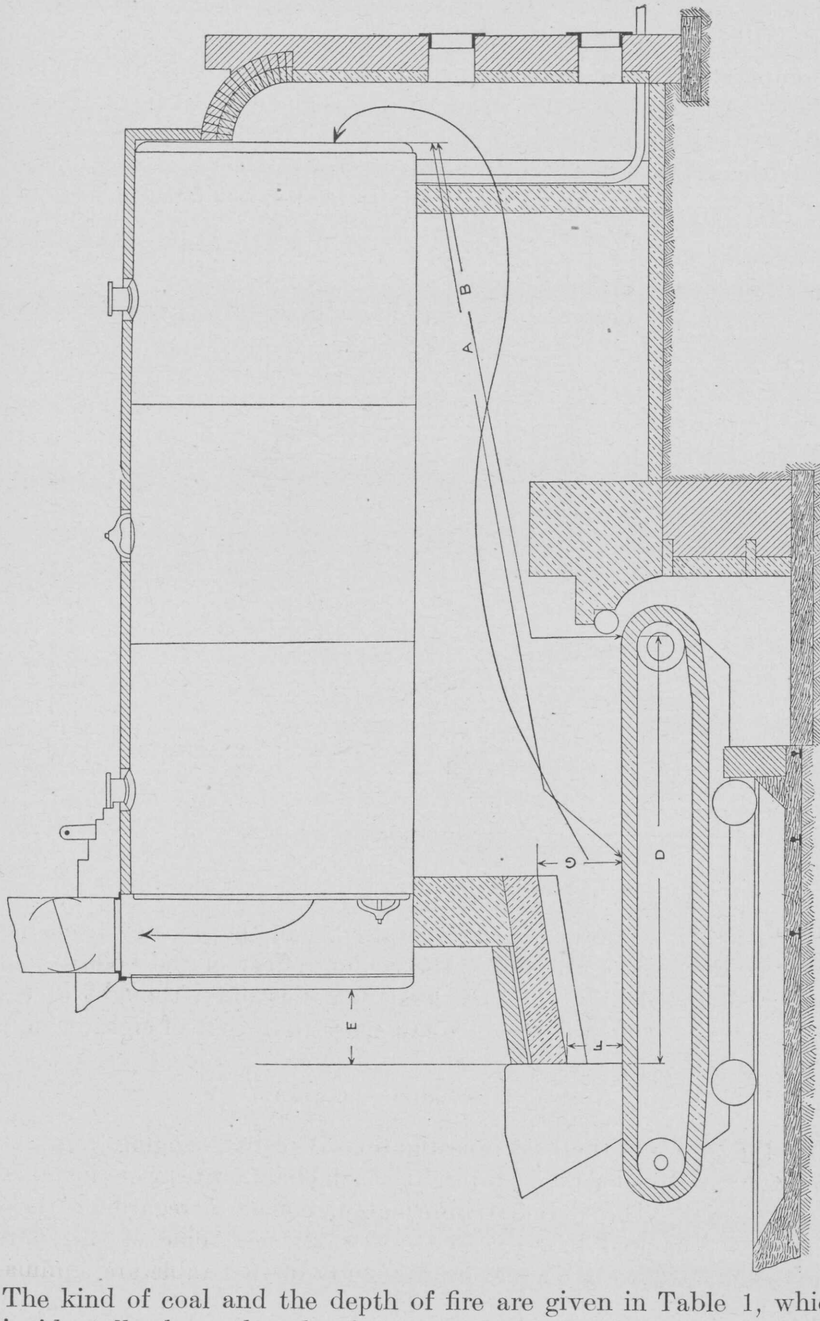

FIGURE 4.—Chain-grate stoker and return tubular boiler.

The kind of coal and the depth of fire are given in Table 1, which incidentally shows that the chain-grate stoker has been found to work remarkably well with Illinois coals.

TABLE 1.—*Kind of coal and depth of fire at plants with chain grates.*

Kind of coal.	Number of plants.[a]	Average depth of fire.	Kind of coal.	Number of plants.[a]	Average depth of fire.
		Inches.			*Inches.*
Illinois	21	5	Ohio	6	5
Indiana	8	5	Pennsylvania	6	4.5
Kentucky	8	4	Miscellaneous	10	6

[a] Two plants burned both Indiana and Illinois coal.

Forty of these plants maintained uniform loads; the remainder had to carry variable loads. At 18 per cent of the plants the stokers were under boiler units of 200 horsepower or less and at 69 per cent they were under units of 300 horsepower or less. The average boiler horsepower developed, the boiler being rated on 10 square feet of heating surface per horsepower, ranged from 23 to 158, the average being 93. The ratio of square feet of heating surface to square feet of grate surface varied from 33 to 1 to 88 to 1, the average ratio being 50 to 1.

The height of the ignition arch at the front of the furnace ranged from 0.9 to 1.1 feet, and the height above the grate at the rear of the arch from 1.3 to 2.2 feet. In 16 plants out of 46 the forward ends of the stokers were some distance in front of the boiler. The average height of the ignition arches above the grates is given in Table 2.

TABLE 2.—*Average height of arch at front and rear at plants with chain grates.*

Type of boiler.	At front of furnace.		At rear of furnace.	
	Average height of arch.	Number of plants at which measured.	Average height of arch.	Number of plants at which measured.
	Feet.		*Feet.*	
Aultman & Taylor	1.1	6	1.7	6
Babcock & Wilcox	1.1	13	1.5	13
Heine	1.1	6	1.6	5
Stirling	.9	16	1.5	14
Miscellaneous water-tube	1	3	1.3	3
Return tubular	1.1	5	2.2	6

The coal as received burned per square foot of grate per hour of average heavy load ranged from 11.4 to 39 pounds, the average being 23.3 pounds.

Table 3 presents in more impressive form some of the particulars recapitulated above. It was compiled to show that with chain-grate stokers installed under 10 types of boilers (five different makes of water-tube boilers are included under "Miscellaneous") which were run at about their full capacity, at no plant was there any serious emission of smoke, combustion being practically smokeless. As bearing on the proper length of travel of the burning gases for coals from different States, the least and average distances from grates to tube heating surface are given.

TABLE 3.—*Summary of various observations at plants with chain grates.*

Type of boiler.	Kind of coal.	Number of plants.	Furnace draft.	Coal burned per square foot of grate surface per hour, average heavy load.	Percentage of rated boiler horsepower developed, average heavy load.[a]	Distance from grates to tube heating surface.		Black smoke.
						Average.	Minimum.	
			Inch of water.	*Pounds.*		*Feet.*	*Feet.*	*Per ct.*
Aultman & Taylor.	Illinois, Ohio, and Pennsylvania.	7	0.23	19.4	83	5.2	3.2	4.4
Babcock & Wilcox.	Illinois, Kentucky, Ohio, and Pennsylvania.	12	.21	24.0	88	5.2	3.3	2.7
Heine	Illinois	7	.22	21.2	113	8.4	6.4	6.5
Stirling	Illinois, Indiana, Kentucky, and Ohio.	18	.19	23.5	94	7.0	4.9	5.4
Miscellaneous water-tube.	Indiana, Kentucky, and Pennsylvania.	5	.20	26.2	104	8.3	5.5	7.5
Return tubular	Illinois, Kentucky, Pennsylvania, and Indiana.	8	.15	24.9	108	19.0	14.7	2.8

[a] Boiler rated on 10 square feet of heating surface per horsepower.

The draft measurements at the plants with chain grates are summarized in Table 4.

TABLE 4.—*Summary of draft measurements at plants with chain grates.*

Type of boiler.	Measurement taken at—	Number of plants at which taken.	Average draft (inch of water).
Aultman & Taylor	Furnace	5	0.23
	Rear of boiler	6	.46
	Base of stack	3	.71
Babcock & Wilcox	Furnace	12	.21
	Rear of boiler	11	.34
	Base of stack	5	.57
Heine	Furnace	5	.22
	Rear of boiler	2	.58
	Base of stack	4	.77
Stirling	Furnace	18	.19
	Rear of boiler	17	.47
	Base of stack	7	.96
Miscellaneous water-tube	Furnace	6	.20
	Rear of boiler	4	.41
	Base of stack	2	.60
Return tubular	Furnace	8	.15
	Front tube sheet	4	.43
	Base of stack	3	.81

Average furnace draft, 54 plants, 0.19 inch of water; range, 0.07 to 0.45 inch. Average draft at rear of boiler, 40 plants, 0.43 inch of water; range, 0.11 to 0.94 inch. Average draft at front tube sheet, 4 plants, 0.43 inch of water; range, 0.25 to 0.61 inch. Average draft at base of stack, 24 plants, 0.77 inch of water; range, 0.26 to 1.30 inch. These figures show approximate average drafts as follows: Furnace, 0.20 inch of water; rear of boiler, 0.45 inch; base of stack, 0.80 inch. These results give a drop in draft through the boiler of 0.25 inch of water and a drop from boiler to stack of 0.35 inch.

Table 5.—*Details of observations at plants with chain grates.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
1	Illinois	Aultman & Taylor	700	Carterville	Illinois	No. 3		
2	Ohio	do	1,100	Pittsburg No. 8	Ohio	Slack	$2.00	6,188
3	do	do	1,000	Various coals		$\frac{3}{4}$-inch screenings	1.50	10,950
4	do	do	825	Pittsburg No. 8	Ohio	Slack	2.15	6,000
5	do	do	500	Bessemer	Pennsylvania	do	1.80	9,000
6	Illinois	Green	600	Various coals		1$\frac{1}{4}$-inch screenings	1.45	
7	do	Mansfield	600	do		do		
8	do	Green	1,440	Washed	Ladd, Ill	No. 5	1.55	
9	do	do	1,035		Carterville, Ill	Nos. 3 and 4 mixed	2.10	
10	Kentucky	do	500		Western Kentucky	Nut and slack		
11	do	do	655		do	do	1.58	
12	Ohio	Babcock & Wilcox	595	Gaylord	Belmont County, Ohio	$\frac{3}{4}$-inch screenings	1.40	3,720
13	do	do	450		Eastern Ohio	Nut and slack	2.05-2.35	2,500
14	Pennsylvania	do	3,600	Second pool	Monongahela River, Pa	1$\frac{1}{4}$-inch screenings		16,000
15	Ohio	do	2,184	Youghiogheny	Pennsylvania	Slack	1.75	23,360
16	do	Babcock & Wilcox; Green	1,200	Pittsburg	do	do	1.75	6,500
17	do	Babcock & Wilcox	500	Various coals		do	1.70	4,700
18	do	do	310	Morgan Run			1.60	2,500
19	do	do	300			Nut and slack	1.75	3,000
20	Illinois	Green	2,700		Indiana; Illinois	1$\frac{1}{4}$-inch screenings	1.35	
21	do	McKenzie	2,075		Williamson and Marion counties, Ill.	No. 3 nut	2.75	
22	do	McKenzie bar	1,000	Washed	Carterville, Ill	No. 3		
23	do	Green	750	do	Illinois	No. 4	3.00	
24	Missouri	American	600	Carterville, washed	do	Pea	1.80	1,800
25	Illinois	Green	1,260			1$\frac{1}{4}$-inch screenings	1.60	
26	do	do	1,800	Washed	Illinois	No. 4		
27	do	do	1,500		do	Nut and slack	2.30	
28	do	do	1,050		do	Screenings	1.20	
29	do	do	800		Indiana; Illinois	1$\frac{1}{4}$-inch screenings	1.35	
30	do	do	800		Illinois	2-inch screenings		
31	do	do	608	Duquoin, Springfield	do	1$\frac{1}{4}$-inch screenings	1.25	
32	do	do	600	Washed	Carterville, Ill	No. 4		
33	do	do	600	Duquoin; Springfield	Illinois	1$\frac{1}{4}$-inch screenings	1.25	
34	do	do	400	Washed	Carterville, Ill	No. 2	2.65	
35	Indiana	do	1,520		Indiana	Slack		
36	do	do	675		do	do		
37	do	do	495		do	Nut and slack		
38	do	American	201		Southern Indiana	do		
39	Kentucky	Green	620		Western Kentucky	Pea and slack		

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	State.	Kind of stoker.	Total builder's rated horsepower.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
40	Kentucky	Green	300		Eastern Kentucky	Nut and slack		
41	Ohio	McKenzie	3,400	Cambridge	Ohio	Pea and slack	$1.80	110,000
42	do	Green	1,170	Pittsburg No. 8	do	Slack	1.75	9,600
43	Illinois	do	9,600	Various coals				
44	Indiana	Babcock & Wilcox	1,000	Linton No. 4	Indiana	Nut, pea, and slack		
45	Kentucky	Green	924		Western Kentucky	Pea and slack		
46	do	do	400		do	do		
47	do	do	350		do	do		
48	Ohio	Aultman & Taylor	1,000	Youghiogheny	Pennsylvania	Slack	1.70	19,200
49	Illinois	Mansfield	1,584	Various coals		Screenings	1.50	
50	do	Green	1,400	Washed	Marion County, Ill	No. 3		
51	Missouri	do	750	do	Collinsville, Ill	Nos. 2, 3, and 4	1.90	4,400
52	do	do	500	do	Carterville, Ill	No. 4	1.75	
53	Illinois	S. and S	300	do	do	do	2.75	
54	Indiana	Green	300		Indiana	Nut and slack	1.60	
55	Kentucky	do	600		Western Kentucky	Pea and slack		
56	New York	McKenzie	4,000	Youghiogheny	Pennsylvania	$\frac{3}{4}$-inch screenings	2.10	55,000
57	Illinois	Green	400	Various coals		Screenings		

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Load.			Rating.								
				Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds)
				Heavy.		Light.						
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
1	Power and light	Uniform	Cold storage	24	16	......	......	24.5	......	71	71	5
2	Power, light, and heat	do	Office building	24	17	24	17	15	15	58	57	4.5
3	do	do	Factory	10	21	14	7	31	21	106	112	5
4	do	do	do	24	30	11	10.3	21	18.4	95	91	5
5	do	do	do	24	27	24	24	21.6	20.4	106	112	4
6	do	do	do	......	......	10	6	......	20.5	80	80	5
7	do	Variable	Brewery	24	24	24	......	14	......	66	66	5
8	Power	Uniform	Shops	9	40	9	40	30.4	30.4	135	148	5
9	Power and heat	Variable	Department store	10	32	10	7	35.3	28.7	125	125	5
10	Power, light, and heat	Uniform	Office building	5	3.5	9	3.1	26	19.4	106	112	5
11	Light and heat	Variable	County jail	24	32	24	13	20.4	15.7	93	81	5
12	Power, light, and heat	Uniform	Factory	10	7.5	10	7	18.5	17.9	53	50	5
13	do	do	do	10	7.3	10	3.9	26.2	23.4	72	68	4.5
14	do	do	Offices and factory	24	50	24	39	13.7	12.2	58	58	4
15	Power	do	Waterworks	24	58.6	24	58.6	16.4	16.4	74	80	4.5
16	Power and light	do	Factory	10	13.3	10	12	18.4	17.5	73	74	4.5
17	Power, light, and heat	do	do	10	10.4	10	9.2	15.5	14.6	61	83	5
18	do	do	do	24	18	10.5	4	31.6	29.8	105	108	4.5
19	Power and light	do	do	9	7.5	9	6	30	27	105	111	5
20	Power, light, and heat	Variable	Packing house	14	112	14	112	29.9	29.9	139	139	5
21	Power and light	Uniform	Department store	11	50	11	45	28	27	115	115	5
22	do	Variable	Refrigeration	24	25	24	20	21	19	83	83	5
23	Power and heat	Uniform	Factory and offices	8.5	20	8.5	16	21	20	130	130	5
24	Power and light	do	Factory	12	6	12	4.5	18.5	16.3	71	67	5
25	Power, light, and heat	Variable	do	10	35	10	20	39	31	137	167	5
26	do	do	Shops and car heating	10	15	10	28	24	23	114	100	5
27	do	Uniform	Factory	24	110	24	110	29.2	29.2	123	123	5
28	do	Variable	do	11	25	11	22	34	32	130	130	5
29	do	do	Packing house	14	38	14	38	28.7	28.7	136	136	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

Table 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Load.			Rating.								
				Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
30	Power, light, and heat	Uniform	Shops and car heating	24	50	24	20	19	17	104	104	5
31	do	do	Packing house	24	25	24	15	17	16	80	80	5
32	do	do	Office building	12	10	12	9	31	29	133	111	5
33	do	do	Packing house	24	25	24	15	16	15	70	70	5
34	do	do	Factory	12	10	12	6	19	15	80	80	5
35	do	Variable	Mill	10	60	10	45	32.2	28.2	158	158	5
36	do	do	Brewery	24	26	24	14	16.9	16.3	92	104	5
37	Light and heat	Uniform	Depot	24	18	12	2	22.6	16.4	92	91	5
38	Power, light, and heat	do	Mill	24	7.5	.....	.....	11.4	.....	62	62	5
39	Power and light	do	do	24	40	24	17	20.2	19.6	110	110	5
40	Power, light, and heat	Variable	Store building	11.5	3.5	20	5	16	14.5	81	81	5
41	Power and light	do	Commercial	24	116	24	116	.....	15	67	57	5
42	Power, light, and heat	Uniform	Mill	12	24	12	24	16.5	16.5	68	68	5
43	Power and light	Variable	Street railway	24	350	24	210	.....	20.8	.....	88	5
44	Power, light, and heat	do	Factory	10	22	10	18	30	27.3	106	117	5
45	do	do	do	24	65	24	58	26.5	25.1	145	120	5
46	do	Uniform	Mill	24	23	24	23	21.3	21.3	96	96	5
47	do	Variable	Factory	24	25	24	22	28.9	27.1	.....	119	5
48	do	Uniform	Shops	24	48	24	56	31.7	29.8	105	107	5
49	do	do	Pumping station	24	35	24	25	28	24	111	111	5
50	Power and light	do	Office building	.....	.....	10	14	21	21	90	80	5
51	do	do	Refrigeration	24	30	24	12	15.4	12.3	73	67	5
52	do	do	Factory	10	16.5	10	13.5	30.6	27.8	138	132	5
53	Power, light, and heat	do	Laundry	11.5	4.5	11.5	4	22	20.7	98	107	5
54	do	do	School building	20	7	12	4	19.4	19	143	93	5
55	Power and light	do	Ice plant	24	29.5	24	14.2	17.1	16.9	77	82	5
56	Power	do	Waterworks	24	151	24	151	24	24	80	93	4.5
57	do	do	Foundry and ironworks	.....	.....	10	11	.....	23.3	110	147	5

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Thickness of fire (inches).	Boilers.									
		Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage (pounds).
1	3	Aultman & Taylor water-tube	168 4″ tubes; 2 48″ x 20⅙′ drums	2	1	1	350	350	3,500	0	140
2	4.5	do		4	2	2	400 150	394 151	3,935 1,510	0	150
3	4–4.5	do	126 4″ x 18′ tubes	4	3	2	250	264	2,640	0	110
4	3–4	do	126 4″ x 18′ tubes	3	2	2	275	264	2,640	0	120
5	4	do	126 4″ x 18′ tubes	2	2	2	250	264	2,640		140
6	6–7	do	144 4″ x 18′ tubes, 2 36″ x 20.2′ drums	2	1	1	300	300	3,000	0	120
7	4–5	do	2 33″ drums	2	2	1	300	300	3,000	0	120
8	6	Babcock & Wilcox water-tube	126 4″ x 18′ tubes, 2 36″ drums	6	5	5	240	264	2,640	0	140
9	4–10	do	162 4″ tubes, 3 36″ x 20⅓′ drums	3	3	1	345	345	3,450	0	80–90
10	3.5–4	do	117 4″ x 18′ tubes, 2 36″ x 21′ drums	2	1	1	250	264	2,640	0	105
11	3–5	Babcock & Wilcox; Henry Vogt	Babcock & Wilcox, 63 4″ x 18′ tubes; 1 drum	4	4	3	135 250	125 200	1,250 2,000	0	100–110
12	4–4.5	Babcock & Wilcox water-tube	1–126 4″ x 18′ tubes, 2–72 4″ x 18′ drums	3	3	3	165 265	150 264	1,500 2,640	0	160
13	4–8	do	72 4″ x 18′ tubes	3	3	2	150	159	1,585	0	125
14	4–6	do	140 4″ x 18′ tubes	12	6	6	300	300	3,000	0	165
15	4–5	do	140 4″ x 18′ tubes	8	5	5	273	293	2,930	409	150
16	4–5	Babcock & Wilcox; Stirling water-tube.	192 4″ x 18′ tubes	3	2	2	400	400 410	4,000 4,100	0	130
17	3	Babcock & Wilcox water-tube	142 4″ x 18′ tubes	2	2	2	250	298	2,980	0	140
18	4–8	do	72 4″ x 18′ tubes	2	2	1	155	159	1,585	0	135
19	3–5	do	72 4″ x 18′ tubes	2	2	2	150	159	1,585	0	150
20	6–8	Heine; Stirling water-tube		8	7	7	300 350 400	300 350 400	3,000 3,500 4,000	0	140
21	3–6	Heine water-tube		5	4	4	375 500 350	375 500 350	3,750 5,000 3,500	0	150
22	5–7	do	138 3½″ x 18′ tubes, 1 48″ x 20¾′ drum	4	2	2	250	250	2,500	0	85–90
23	4	Mohr and Heine water-tube	Mohr, 140 3½″ x 18′ tubes; Heine, 138 3½″ x 18′ tubes.	3	3	2	250	250	2,500	0	80
24	4	Heine water-tube	138 3½″ x 20′ tubes	2	1	1	300	281	2,810	0	120
25	6	do	278 3½″ x 18′ tubes, 2 42″ drums	3	2	2	420	510	5,100	0	150–160
26	4–5	Stirling water-tube	223 3¼″ tubes, 3 42″ x 10⅒′ drums	6	2	4	300	264	2,640		160
27	6.5	do	192 3¼″ tubes, 3 42″ x 10′ drums	6	5	5	300	300	3,000	0	150

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Thickness of fire (inches).	Boilers.									
		Type.	Size.	Number installed.	Number used to carry—		Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage (pounds).
					Average heavy load.	Average light load.					
28	4	Stirling water-tube	340 3¼″ x 17½′ tubes, 3 42″ x 13′ drums	3	2	2	350	350	3,500	....	155
29	6–8	.....do	....	2	2	2	400	400	4,000	0	140
30	3	.....do	207 3¼″ tubes, 3 36″ x 10¾′ drums	4	4	2	200	200	2,000	0	100
31	4–6	.....do	272 3¼″ tubes, 3 36″ x 13¼′ drums	2	2	1	304	304	3,040	0	150
32	3–3.5	.....do	209 3¼″ tubes, 3 42″ x 11 3/10′ drums	2	1	1	300	250	2,500	0	80–100
33	4–6	.....do	181 3¼″ tubes, 3 36″ x 9¾′ drums	3	3	2	200	200	2,000	0	150
34	3–5	.....do	243 3¼″ tubes, 3 42″ x 13′ drums	1	1	1	400	400	4,000	0	100
35	4–4.5	.....do	....	5	5	5	300 320	300 320	3,000 3,200	0	150
36	4	.....do	162 3½″ tubes, 3 36″ drums	3	2	1; 2	225	235	2,350	0	120–125
37	4.5	.....do	....	3	2	1	165	164	1,640	0	125
38	5.5	.....do	192 3¼″ tubes, 3 36″ drums	1	1	1	201	201	2,010	0	115
39	3.5–4	.....do	....	2	2	1	310	310	3,100	0	150
40	4.5	.....do	....	2	1	1	150	150	1,500	0	150
41	4.5	Heine and Stirling water-tube	....	8	8	8	500 350	375 345	3,750 3,450	0	150
42	4.5–5	Stirling water-tube	....	4	4	4	327 258	328 259	3,277 2,587	0	160
43	7	.....do	240 3¼″ tubes, 3 40″ x 10′ drums	24	Variable.	Variable.	400	....	....	0	150
44	3–5	Cahall vertical water-tube	108 4″ x 22′ tubes	4	3	3	250	276	2,760	0	115
45	3	Erie water-tube	....	3	3	3	300	250	2,500	0	120–130
46	3.5–4	Henry Vogt water-tube	....	1	1	1	400	400	4,000	0	150
47	3	.....do	....	1	1	1	350	....	....	0	120–130
48	4	Cahall vertical water-tube	....	4	3	4	250	254	2,536	....	150
49	8	Cahall horizontal water-tube	126 4″ x 18′ tubes, 2 36″ x 23 3/10′ drums	6	*a* 2	2	264	264	2,640	0	185
50	5–6	Sederholm return tubular	220 3″–87″ x 16′ tubes, 4 30″ x 12′ drums	4	....	2	350	298	2,975	0	150
51	6	Bronson special fire-tube	102 3½″–72″ x 18′ tubes, 16 4″ water tubes	3	3	2	250	228	2,280	0	150
52	4	.....do	72″ x 20′–84 4″ tubes, 16 4″ water tubes	2	2	2	250	240	2,400	0	125
53	4–6	Return tubular	72″ x 18′, 72 4″ tubes	2	1	1	150	159	1,585	0	125
54	4–5	.....do	72″ x 18′, 27 6″ tubes	2	1	1	150	98	975	0	65–70
55	3.5	.....do	72″ x 18′, 72 4″ tubes	4	4	2	150	159	1,590	0	100
56	4	Return tubular and Bronson special fire-tube.	10 84″ x 18′, 176 3″, 6 90″ x 18′, 184 3″, and 13 4″.	16	12	12	250	275 311	2,750 3,110	0	130
57	7	Return tubular	72″ x 16′, 70 4″ tubes	4	....	3	100	133	1,325	0	100

a Usually.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Furnaces.										
	Number.	Kind.	Grate area per boiler (square feet).	Dimensions (feet).							
				Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch.		Height of arch at rear of furnace (H).
				Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
1	2	Plain	54.4	.....	.....	6.4	8.5	0	.....	.....	.....
2	4	....do	67, 28	5.5	2.5	a8, 4.0	a8.4, 7	0	1.2	1.5	.....
3	4	....do	45.5	4.0	2.5	6.0	7.7	0	1.25	1.5	.....
4	3	....do	59.5	6.0	4.0	7.0	8.5	0	.9	1.5	.....
5	2	....do	52	4.5	2.5	6.5	8.0	0	1.0	1.75	.....
6	2	....do	58.5	6.0	4.3	6.5	9.0	3.0	.09	2.6	.....
7	2	....do	72, 25	.....	.....	8.5	8.5	0	1.2	1.2	.....
8	6	....do	58.5	4.2	3.3	6.5	9.0	3.0	.9	1.5	.....
9	3	....do	63	6.5	4.0	7.0	9.0	0	1.2	1.2	.....
10	2	....do	54	5.25	3.8	6.0	9.0	2.25	.9	1.6	.....
11	4	....do	31.5, 36	b5.1, ——	b3.75, ——	b3.5, 4	9.0	b2.0, ——	b.8, ——	b1.75, ——	.....
12	3	....do	18, 45	5.0	2.5	c3.0, 7.5	6.0	0	1.25	1.5	.....
13	3	....do	18, 19.8	4.5	3.0	3.0	c6.0, 6.75	0	1.25	1.5	.....
14	12	....do	50.4	4.0	3.5	6.5	7.75	0	1.8	1.8	.....
15	8	....do	59.4	6.0	3.5	6.4	9.25	0	1.25	1.9	.....
16	3	....do	63.8, 81	b6, 8	3.5	b7.5, 9.0	b8.5, 9.0	0	b1.25, 75	b1.5, 1.25	.....
17	2	....do	67.3	6.0	3.5	8.4	8.0	0	.9	1.3	.....
18	2	....do	28, 25.3	5.5, 4.5	3.0, 2.0	3.5	8.0, 7.25	0	.4	1.6	.....
19	2	....do	28	5.0	3.5	4.0	7.0	0	1.3	1.6	.....
20	10	....do	72, 76.5, 94.5	c6.7, 4.3, 6.8	c4.0, 3.3, 4.1	c8.0, 8.5, 5.25	9.0	c0.8, 1.0, 0	.9	1.4	c3.6, —, 3.6
21	5	Tile roof	88, 93.5, 71.5	18.0	14.0	8.0, 8.5, 6.5	11.0	4.5	1.3	1.3	4.3
22	4	Partial tile roof	50	5.3	4.0	6.0	8.3	0	1.7	2.2	.....
23	3	Plain	76.5, 72	4.0, 16.0	3.25, 13.5	8.5, 8.0	9.0	2.3, ——	.8	1.5	.....
24	2	Tile roof	54	11.5	7.0	6.0	9.0	0	.....	.....	.....
25	3	....do	90	4.3	3.6	10.0	9.0	2.25	.9	1.5	.....
26	6	Plain	63	8.7	6.0	7.0	9.0	1.9	1.0	1.5	4.25
27	5	....do	63	7.3	5.6	7.0	9.0	0	.9	1.3	4.8
28	3	....do	67.5	7.3	5.0	7.5	9.0	0	.9	1.5	5.0
29	2	....do	94.5	.....	.....	5.25	9.0	.....	.....	.....	.....
30	4	....do	54	6.5	4.5	6.0	9.0	0	.9	1.4	.....
31	2	....do	67.5	6.7	4.5	7.5	9.0	.8	.9	1.4	.....

a First dimension applies to large boiler.
b First dimension applies to Babcock & Wilcox boiler.
c First dimension applies to small boiler.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Furnaces.										
	Number.	Kind.	Grate area per boiler (square feet).	Dimensions (feet).							
				Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch.		Height of arch at rear of furnace (H).
				Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
32	2	Plain	54	6.8	4.3	6.0	9.0	0	1.0	1.5	4.6
33	3	....do	45	6.7	4.7	5.0	9.0	.7	.9	1.4	4.9
34	1	....do	90	8.2	5.5	10.0	9.0	0	.9	1.5	5.0
35	5	....do	74.4	6.8	5.8	8.5	8.75	.75	.9	1.5	4.4
36	3	....do	68.9	6.25	4.6	7.7	9.0	0	.9	1.5	3.6
37	3	....do	33.2	6.0	4.4	4.0	8.3	0	.9	1.5	4.7
38	1	....do	56	6.5	4.5	6.2	9.0	0	....	....	....
39	2	....do	74.3	6.0	4.2	8.25	9.0	0	.9	1.5	3.6
40	2	....do	39.1	6.0	6.0	4.5	8.7	0	.8	1.6	4.2
41	8	....do	81	[a]3.0, 7.5	[a]2.5, 4.5	9.0	9.0	0	1.0	1.5	——, 3.5
42	4	....do	67.5, 54	8.5	4.0	[b]7.5, 6.0	9.0	0	.9	1.5	3.8
43	24	....do	84	8.0	5.7	9.3	9.0	0	.9	1.5	4.9
44	4	Dutch oven	49	10.0	6.0	6.3	7.75	10.5	....	....	....
45	3	Plain	68	4.1	3.9	8.0	8.5	2.0	.9	1.6	....
46	1	....do	90	....	....	10.0	9.0	0	....	....	....
47	1	....do	72	....	....	....	....	....	....	....	....
48	4	Dutch oven	42	10.5	6.5	6.5	6.5	11.0	.7	1.0	5.2
49	6	....do	51.6	8.5	5.5	6.4	8.0	4.0	1.3	1.3	3.6
50	4	Plain	67.5	17.5	13.0	7.5	9.0	0	1.0	1.75	....
51	3	Tile roof	54	7.5	3.5	6.0	9.0	0	....	....	....
52	2	....do	54	6.5	2.5	6.0	9.0	0	....	....	....
53	2	Plain	36	17.0	14.0	6.0	6.0	0	1.2	1.2	....
54	2	....do	36	5.0	4.1	4.0	9.0	0	.9	1.8	....
55	4	....do	36	18.0	13.5	4.0	9.0	0	....	....	....
56	16	Plain and tile roof	42	[c]21, 22	[c]16, 17	6.0	7.0	0	1.5	[c]2.3, 3.7	....
57	4	Plain	31.5	18.5	14.5	3.5	9.0	1.3	1.1	2.7	....

[a] First dimension applies to Heine boiler. [b] First dimension applies to large boiler. [c] First dimension applies to return tubular boiler.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for 1 hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
1	Chimney	0.26	0.40–0.48		0.82		Damper open, thin fire	4	225	0	2	34	8.2	Heavy.
2	....do....	.23–.27	.45–.73			0.85		1	60	0	0	55	1.7	Average.
3	....do....	.13–.15	.25			.60	Dampers open	1	60	0	0	43	6.3	Light.
4	....do....	.12–.23	.19–.30				Draft varied by thickness of fire.	1	600	0	0	60	0	Average.
5	....do....	.25–.27	.54–.63			.67		1	60	0	2	36	8.0	Do.
6	....do....	.30	.48–.58		.73		Dampers open; rear 2½′ of grate bare.	1	60	0	0	20	7.4	Light.
7	....do....		.55				Damper open; rear half of grate bare.	1	60	0	0	12	14.1	Heavy.
8	....do....	.15–.33	.35–.48		.47–.62		Dampers open	1	75	0	0		33.3	Average.
9	....do....	.40	.75		1.30		Dampers partly closed; thin fire.	1	60	0	0	60	0	Light.
10	....do....	.13	.24		.45		Dampers open; thin fire	1	60	0	0	37	9.8	Do.
11	....do....	.03–.11	.08–.14		.23		....do....	1	50	0	0	30	9.6	Do.
12	....do....	.09–.17	.14–.18			.32		1	600	0	0	58	.5	Do.
13	....do....	.18–.30	.25–.36				Damper open	1	60	0	0	40	1.7	Do.
14	....do....	.10–.20	.16–.33		.80			2	120	0	0	60	0	Do.
15	....do....	.18–.36			.36–.78	.97	Damper open	2	120	0	0	54	2.4	Average.
16	Induced	.19–.70	.45–1.10				Fan on full blast	1	60	0	0	58	.7	Light.
17	Chimney	.06–.07	.12–.15			.60	Damper partly closed	1	600	0	0	57	1.3	Average.
18	....do....	.12	.19–.21			.42		1	300	0	0	54	2.0	Heavy.
19	....do....	.17–.25	.28–.37			.52	Dampers open	1	600	0	0	54	3.0	Average.
20	Induced	.18–.32			Near stack 2.00		Dampers open; economizer in use.	1	60	0	0	60	0	Do.
21	Chimney	.21–.23	.74–.78				Damper open	1	61	0	3	27	10.2	Light.
22	....do....	.18			.60	.80	Dampers open	1	60	0	0	60	0	Heavy.
23	....do....	Very low.				.60	Dampers open; rear one-third of grates bare.	2	97	0	0	25	25.0	Average.
24	....do....	.24	.40			.63		1	60	0	0	48	5.7	Do.
25	....do....	.20	Combustion chamber, .31.		.92	1.04	Dampers one-half open; rear of grates bare.	1	60	0	0	45	3.8	Light.
26	....do....	.12	Lower, .40; upper, .50.		.68		Damper open; rear one-third of grates bare.	1	90	0	0	60	0	Average.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for 1 hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
27	Chimney..	0.18–0.32	Lower rear, 0.48–0.64.				Dampers open	2	122	0	0	45	5.3	Average.
28	....do.....	.17– .18	Lower rear, .38– .41.			.84	Dampers open; rear of grates bare.	1	60	0	0			Do.
29	....do.....	.17– .18	Lower rear, 33– .38.		.52		Damper open	1	60	0	0	60	0	Do.
30	....do.....	.04– .17	Lower rear, .16– .40.			.68	Thin fire; running conditions	(*a*)	(*b*)	0	0			Light.
31	....do.....	.28, .29	Lower, .48; upper, .90.				Dampers open	1	60	0	0	60	0	Average.
32	....do.....	.08– .10	Lower rear, .25		.85		Damper open; rear half of grate bare.	2	122	0	0	45	8.7	Do.
33	....do.....	.14– .17	Lower, .27– .28; upper, .48– .66				Dampers open	1	60	0	0	53	2.8	Do.
34	....do.....	.11	Lower, .32; upper, .63.		.72		Damper open; rear one-third of grates bare.	2	120	0	0	51	3.0	Heavy.
35	....do.....	.23– .32	Lower rear, .58			1.12	Dampers open	1	75	0	2	(*c*)	0–3.3	Light.
36	Induced...	.09– .15	Lower rear, .31– .33.				Dampers partly closed	2	45	0	0	60	0	Heavy.
37	Chimney..	.27	.56– .61		.97		Dampers open	2	120	0	0	51	4.1	Light.
38	....do.....	.36– .35	Lower rear, .56			.90	Damper open	1	35	0	0	56	1.7	Heavy.
39	....do.....	.11	Lower rear, .52			.78	....do	1	80	0	0	60	0	Average.
40	....do.....	.13	.47		.72		Damper open; thin fire	1	43	0	0	21	9.1	Do.
41	....do.....	.18			.70	1.10	Dampers open	(*a*)	(*b*)	0	0	30	9.0	Do.
42	....do.....	.14– .23	Lower rear, .80–1.08.			1.30	....do	1	600	0	0	53	3.3	Do.
43	....do.....	.19– .25	Lower rear, .65– .77.		.34– .90		....do	1	60	0	0	21	11.7	Do.
44	....do.....	.31– .44				.94	....do	1	40	0	0	60	0	Light.
45	....do.....	.11– .14	.58– .67				....do	(*a*)	(*b*)	0	0	60	0	Average.
46	....do.....	.09	.36		.70		....do	1	80	0	0	0	30.0	Do.
47	....do.....	.12	.30				Damper open	(*a*)	(*b*)	0	0			Do.
48	....do.....	.17– .26				26	....do	1	600	0	0	60	0	Do.

49	....do....	.25	.35	....	.80	....	Dampers open; rear one-third of grates bare.	1	60	0	0	60	0	Do.
50	....do....	.10-.13	Combustion chamber, .14-.26	....	1.20	....	Rear one-third of grates bare.	7	419	0	0	53	.9	Light.
51	....do....	.12	....	0.52	....	....	Damper open..............	1	60	0	0	53	3.0	Heavy.
52	....do....	.17	....	....	.86	....	....	1	60	0	0	57	1.0	Average.
53	....do....	.10	....	.25	....	.55	Damper open..............	1	60	0	0	60	0	Do.
54	Induced...	.20-.30	....	.45-.77	1.10-1.50	....	Average running conditions.	2	60	0	0	60	0	Light.
55	Chimney..	.12-.13	....	....	.56	....	Dampers open..............	2	140	0	0	60	0	Average.
56	Induced...	.10-.18	....	.20-.45	.62	1.25	....	1	60	0	0	58	.7	Do.
57	Chimney..	.18-.20	....	....	.55	.63	Dampers open..............	1	60	0	0	60	0	Light.

a Several. *b* Various lengths. *c* Variable.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Breeching.				Stack.			Ignition arch.		Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	Length (feet).	Style.	
1	5	....	....	0	125	*a* 5.4	23.0	4.5	Sprung..	Usually run with damper partly closed. Smokes considerably, 10 to 20 per cent black.
2	9	....	....	0	216	6.5	33.2	3.5	....	
3	4	....	....	1	150	8.0	50.25	....	....	Coal runs from 10 to 15 per cent ash. Plant has to run with damper nearly wide open to keep from making smoke.
4	10	....	....	0	175	6.0	28.3	....	....	Range of draft obtained by taking readings on both thin and heavy fires. An air injector on each boiler consisting of ½-inch steam jet passing through 2-inch pipe. When air injector is not in use, stack smoke varies from 20 to 40 per cent black.
5	10	....	....	1	125	*a* 5.0	19.6	3.5	....	Coal as fired runs about 2 per cent moisture and 6 to 9 per cent ash. Smokes considerably, 10 to 20 per cent black.
6	6	4 x 7	Near stack......	0	175	*a* 5.5	23.7	5.0	....	Usually burns Illinois screenings. Smokes considerably, 10 per cent black.
7	0	....	....	0	135	*a* 8.0	50.25	3.0	Sprung..	When the draft is not reduced below 0.20 inch inside stack damper, stack smokes, 10 to 20 per cent black. Reducing draft below 0.20 inch gives bad stack.
8	28	9 x 5½	Near stack......	0	185	8.0	50.25	....	....	Stack usually smokes, 20 to 30 per cent black.
9	22	6 x 12	.....do...........	0	275	8.0	50.25	6.5	Flat.....	Before present arch was installed ignition arch was 1.7 feet from grate at the rear and 3.5 feet long, and stack smoked badly at times.
10	16	....	....	1	116	*a* 2.5	4.9	4.0	...do.....	On heavy load stack smokes continuously, 40 to 50 per cent black.
11	17	....	....	3	85	3.8 x 3.8	14.7	4.0	Sprung..	On account of low stack draft, three boilers are used to carry load not heavy enough to keep stokers running continuously and stack smokes considerably, 10 per cent black.
12	13	....	....	1	110	*a* 4.5	15.9	3.0	....	Coal as fired runs about 13,000 B. t. u. per pound, 11.5 per cent ash, and 2 per cent moisture. When boilers run at 75 per cent or more of their rated capacity, stack smokes badly.
13	13	....	....	2	90	....	....	....	....	Stack is cleaner when burning nut coal than when burning slack.
14	0	0	....	0	200	11	95.0	3.5	....	Coal as fired runs about as follows: Moisture, 1.40 per cent; ash, 3.40 per cent; fixed carbon, 60 per cent; volatile matter, 35 per cent. Two similar stacks; six boilers for each. Stokers carry a thick fire over entire grate.
15	90	....	....	0	200	9.0	63.6	5.0	....	Coal as fired runs about 13,300 B. t. u. per pound.
16	3	....	....	2	95	5.0	19.6	3, 3.5	....	Babcock & Wilcox boiler and chain grate, 2 Stirling boilers and Green chain grate. First furnace dimensions apply to Babcock & Wilcox boiler and grate. Speed of induced-draft fan controlled by steam pressure.
17	0	....	....	0	110	....	....	3.0	....	
18	13	....	....	1	100	*a* 4.0	12.56	3.5	....	

19	9			1	108	*a* 4.0	12.56	3.0		
20	28			1	119	10	78.5	3.6		
21	12	7 x 9	Near stack	0	200	9.0	63.6			Boilers have C tile on lower row of tubes within 3 feet of rear water leg. Damper regulator on main damper. Stack smokes considerably, 10 to 20 per cent black.
22	0	4½ x 5½	do	0	150	7.0	38.5	4.0	Sprung	U tile on lower row of tubes. Secondary grates at rear of bar grate, 15 inches long by 6 feet wide; effort made to keep these well covered; area not included in grate area. Damper regulator connected to damper on each boiler. Stack is cleaner when burning No. 3 washed coal than when burning poorer grades.
23	6			1	150	3.25 x 6	19.5	Mohr, 4.0 Heine, 3.5		C tile on secondary lower row of tubes of Heine boilers; Mohr boilers baffled vertically. Stack smokes considerably, 10 to 20 per cent black.
24	11			2	115	*a* 4.0	12.56	3.5	Flat	C tile on lower row of tubes.
25	15	7 x 9	Near stack	0	200	9.0	63.6	4.0		Coal as fired runs 12 to 20 per cent ash. Boilers have 8 feet of C tile and 5 feet of U tile on lower row of tubes. Damper regulator on main damper is so connected that the dampers are never wide open.
26	4			1	225	9.0	63.6			This stack occasionally emitted smoke, 40 per cent black, for several minutes.
27	22	5½ x 11	Near stack	0	185	9.5	70.6			Coal as received runs about 12,000 B. t. u. per pound. All boilers are baffled alike. Boilers are run with dampers wide open; consequently boiler nearest stack runs above rating and boiler farthest from stack runs at rating or less.
28	8	4 x 8	do	0	150	6.0	28.3			Dry coal ranges from 12,500 to 13,000 B. t. u. per pound, with 5 to 14 per cent of ash. A very little smoke, 20 to 40 per cent black. Regulator on main damper. Coal is wet before firing to prevent waste into ash pit.
29	8			0	140	10.0	78.5			
30	0	0		0	110	4.0	12.56	3.5		Two similar stacks, each resting on rear of boilers. While this plant runs for long periods with a very good stack, it has been seen smoking many times; with furnace draft reduced to 0.04 inch water stack smokes continuously, 20 to 40 per cent black.
31	0	0		0	125	*a* 5.0	19.6	3.5		Coal is wet before firing to prevent waste into pit. Stack rests on rear of boilers.
32	3			0	130	2.5 x 2.5	6.3			Two similar stacks. Smoke noted in table due to nearly complete closure of damper.
33	30	*a* 5½	Near stack	1	125	*a* 5.5	23.7	3.5		Coal wet before firing to prevent waste into pit.
34	31	*a* 4	do	1	110	3.8 x 3.8	14.4			
35	0	0		0	135	4.0	12.56	3.6	Flat	Separate stack resting on rear of each boiler. Plant has variable load; sometimes dampers are nearly closed and stacks smoke badly, but usually little smoke for long intervals. Smoke observation taken when plant was running at about 118 per cent of rated capacity.
36	8			1	40	*a* 4.0	12.56	4.0	Sprung	Speed of induced draft fan controlled by steam pressure.
37	22	4 x 6	Near stack	0	136	*a* 6.0	28.3	3.5	Flat	Stack sometimes smokes badly. Observations were taken during light load and it is probable that dampers were not open enough to furnish sufficient air.
38	0	0		0	110	*a* 3.5	9.6	3.0	Sprung	Stack rests on rear of boiler. Steam pressure controlled by hand regulation of damper. Stack is clean except when furnace draft is reduced nearly to zero, when it smokes from 20 to 50 per cent black.
39	0	0		0	125	*a* 4.5	15.9	3.5	Flat	Two similar stacks, each resting on rear of boiler.
40	4			1	125	*a* 4.0	12.56	3.5	Sprung	Plant usually runs with dampers partly closed and stack then smokes about 10 per cent black.

a Diameter.

TABLE 5.—*Details of observations at plants with chain grates*—Continued.

No. of plant.	Breeching.				Stack.			Ignition arch.		Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	Length (feet).	Style.	
41	7	....	....	0	208	11	95.0	3.0	....	Coal as fired contains 11.50 per cent ash, 3.60 per cent moisture, and 33 per cent volatile matter, with 12,730 B. t. u. U tile on lower row of tubes of Heine boiler. Stack usually smokes 20 per cent black about half the time.
42	12	....	....	0	171	7.0	38.5	3.5	....	Usually run with dampers partly closed.
43	20	....	....	2	220	14	153.9	3.6	....	All flues underground.
44	0	0	....	0	90	3.0	7.06	3.0	Sprung..	Four similar stacks, each resting on top of boiler. Steam pressure controlled by automatic regulator, which varies speed of stoker engine and position of damper.
45	0	0	....	0	125	4.5	15.9	4.0	Flat....	Three similar stacks resting on rear of boilers. Coal is wet before firing.
46	12	....	....	2	125	*a* 4.5	15.9	5.0	...do....	Stack rests on rear of boiler; smokes continuously, from 30 to 60 per cent black.
47	12	....	....	1	125	*a* 4.5	15.9	2.8	....	Stack rests on rear of boiler; usually smokes from 10 to 20 per cent black. Coal is wet before firing.
48	0	....	....	0	90	3.2	7.85	1.3	....	Coal as fired runs about 12,400 B. t. u. per pound; 11 per cent ash; 5½ per cent moisture. Can not keep stacks clean with more than a 4-inch fire. Four similar stacks, each set on top of boiler.
49	15	8 x 10	Near stack......	0	203	9.0	63.6	....	....	
50	80	7½ x 5½	.....do..........	2	325	7.7	47	....	....	Draft readings not of much value; dampers on boilers out of service, not being closed.
51	24	5 x 3½	.....do..........	2	125	*a* 5.0	19.6	4.0	Flat.....	U tile on lower row of tubes for 10 feet from front of furnace. Plant has automatic regulator on main damper.
52	34	4 x 4	.....do..........	2	125	*a* 6.0	28.3	4.0	...do....	C tile on lower row of tubes for 9 feet from front of furnace.
53	18	*a* 4	.....do..........	1	125	*a* 4.5	23.7	4.0	Sprung..	Large combustion chambers. Bridge wall is built up to shell and has two openings, with total area of 6 square feet. Plant usually runs with dampers partly closed.
54	30	....	....	1	35	*a* 4.0	12.56	4.0	...do....	Fired occasionally through inspection door. Speed of induced dra fan controlled by the steam pressure.
55	0	....	....	0	110	*a* 5.0	19.6	4.0	...do....	Large combustion chambers.
56	50	....	....	2	250	11	95.0	3.3, 5.0	....	Coal as fired runs about 13,700 B. t. u. per pound. A considerable task to keep grates clean.
57	7	3¼ x 7	Near stack......	0	100	4.5 x 4.5	20.25	5.75	....	Boilers arched over top for gas passage.

a Diameter.

SUMMARY.

The chain-grate stoker was found in plants carrying uniform loads and in plants where loads were extremely variable. With a uniform load and a proper setting there should never be any smoke with this equipment, but when a variable load is carried a faulty method of operation may cause the emission of dense smoke. In a chain-grate plant having a variable load, with the fire carried up to the water back, a sudden release of load will require a reduction of draft. Too often the damper is nearly closed, so that the coal on the grate and the fresh coal fed to hold the fire are burned with a imited air supply, causing the stack to smoke badly.

Plants equipped with the chain grate can be made to carry a very variable load with good results by changing the thickness of the fire, the speed of the grate, and the position of the damper to suit the load. The draft should not be reduced below a certain value, which can be determined for each plant by gradually closing the damper and watching the stack. In a plant where the maximum variations of load are nearly the same, it might be necessary to vary only the speed of the grate and the position of the damper. The damper regulator is often the cause of a smoky stack, because it is usually set to choke off the entire draft, a condition which is never necessary.

Both the speed of a chain grate and the slope of the ignition arch are important. Too often the grate is run so fast that volatile matter is being driven from the coal as far back as the center of the grate; usually in this case there is not only a loss from incomplete combustion of the gases but also losses from unconsumed carbon in the ash and from injury to the grate. Live coals in the ash pit will not only warp a grate but gradually burn it up. The grate should not be run so fast that it will be hot when reentering the furnace. In one plant where a high draft was carried a sloping arch was removed and an arch built parallel to the grate. With the sloping arch the stack smoked, but with the flat arch it was entirely clean.

With chain-grate equipment a plant may run very inefficiently if the fire is carried only on the front half of the grate, as sometimes happens. When coal is burned in this way with a proper setting, it is because the fireman finds it the easiest way to carry a variable load and have a clean stack, demanding less of his attention in operation.

At some plants the boiler is forced by firing considerable coal through the inspection door. Although the desired result is accomplished by this practice, the plant becomes the equivalent of a hand-fired plant and the stack will invariably smoke badly.

FRONT-FEED STOKERS.

GENERAL DISCUSSION.

Inclined-grate stokers were patented years ago. As a result of the competition between different makers and the consequent improvement in details of construction, the present types have been evolved. They have been installed at many places and handle a great variety of coals. All those in extensive use have grates with mechanically

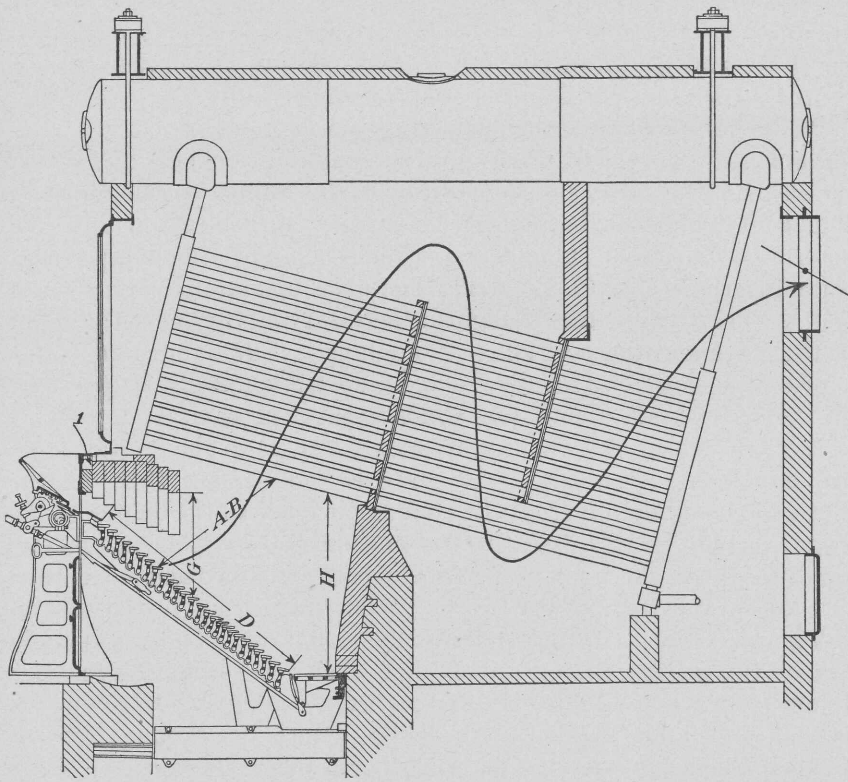

FIGURE 5.—Front-feed stoker and Babcock & Wilcox boiler, usual setting. 1, Air space; steam jets enter furnace at this point.

operated grate bars. From the difference in position of the hopper supplying the grates, these stokers are conveniently divided into two classes—front feed and side feed.

In the front-feed type the hopper is in front of the boiler, extending from side to side. Immediately back of it is sprung a coking arch, usually short. A reciprocating pusher feeds the coal to a dead plate beneath the front of the arch, where it begins to ignite. The construction and movement of the grate bars, which cause the burning coal to move down the grate, vary in different makes of this type.

These stokers can force a fire quickly and are often given severe treatment, but tests have shown that with the average setting, in

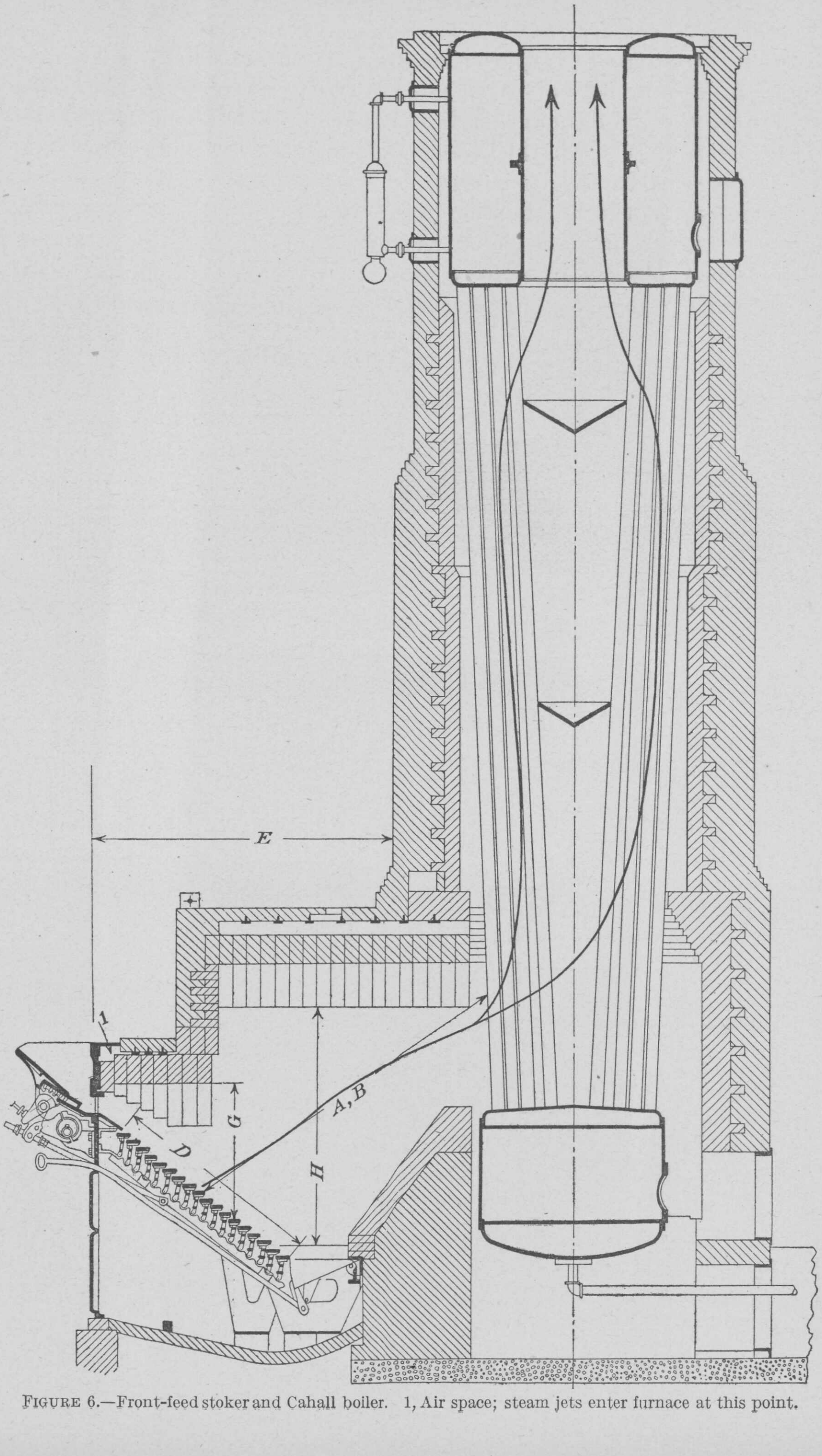

FIGURE 6.—Front-feed stoker and Cahall boiler. 1, Air space; steam jets enter furnace at this point.

which the grates are placed close to the heating surface, more than average attention is required to keep down smoke; consequently such stokers should be so set that when the fireman pushes green coal down the grate there is sufficient space for the combustion of the gases before they strike the tube heating surface. Failure to provide such space usually results in a smoky stack.

To intensify the combustion most stokers of this type are frequently set with an air space at the front of the ignition arch, through which steam jets enter the furnace. The accompanying illustrations show some boilers having stokers set in this manner. Figure 5

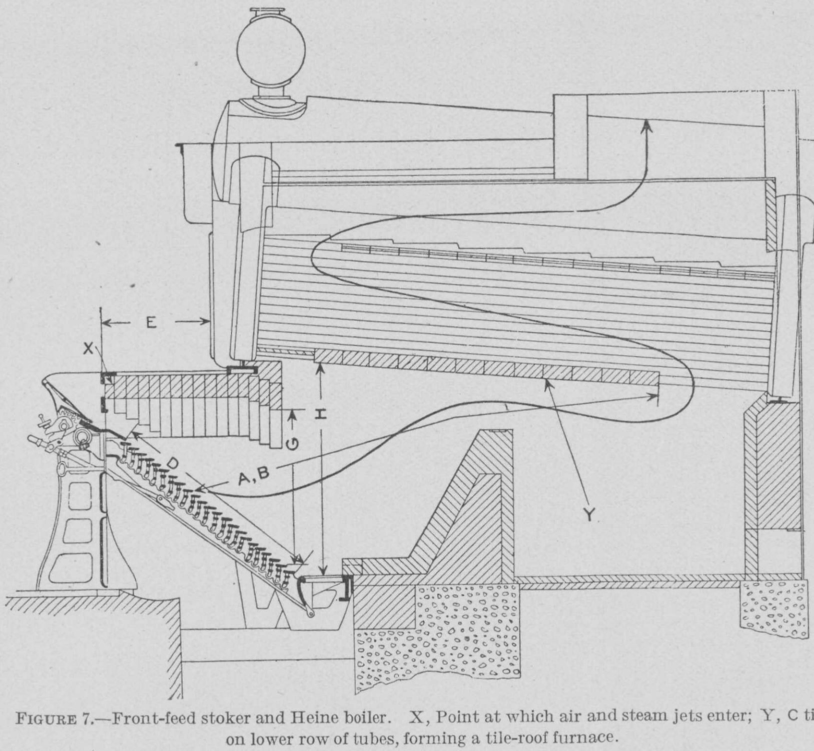

FIGURE 7.—Front-feed stoker and Heine boiler. X, Point at which air and steam jets enter; Y, C tile on lower row of tubes, forming a tile-roof furnace.

represents a Babcock & Wilcox boiler with stack at the rear and baffled so that the gases from the burning coal travel but a short distance before they strike the bottom water tubes.

Figure 6 shows a stoker of the same make as installed at a plant having Cahall water-tube boilers. Here the fire-brick arch back of the hopper covers a larger proportion of the length of the grate than in the setting illustrated by figure 5, and as the boilers are vertical the furnace is in a Dutch oven the arch of which covers the space between the ignition arch and the front tubes of the boiler. The travel of the gases to the first heating surface is much lengthened in this setting and ample space is provided for combustion when forcing the fire.

A Heine water-tube boiler, with uptake in the rear and a furnace fired by a stoker of the front-feed type, are shown in figure 7. In this installation the bottom baffling of tile on the water tubes lengthens the course taken by the gases in reaching the first heating surface. Ample space is provided for complete combustion when the boiler is carrying heavy loads.

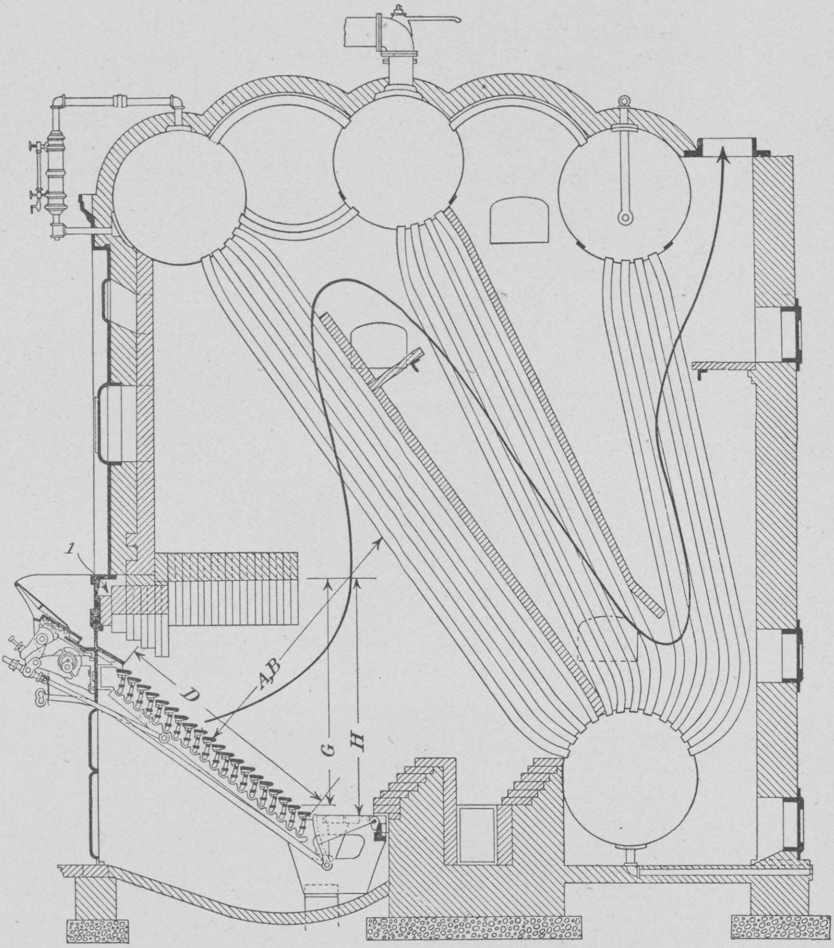

FIGURE 8.—Front-feed stoker and Stirling boiler. 1, Air space; steam jets enter furnace at this point.

Figure 8 shows the usual methods of placing a front overfeed stoker beneath the arch that is part of the regular setting of the Stirling boiler. Figure 9 represents a similar stoker, with longer ignition arch, under a return tubular boiler.

DETAILED DESCRIPTION OF PLANTS.

Detailed information was collected at 32 plants, ranging in size from 200 to 2,500 rated boiler horsepower, where front overfeed stokers were used. This information is presented in condensed form in Table 9 (pp. 40–47), in which the same order of particulars is followed as in Table 5. In Table 9 the grate area of the front overfeed stokers includes the area of both the sloping grates and the dump grates.

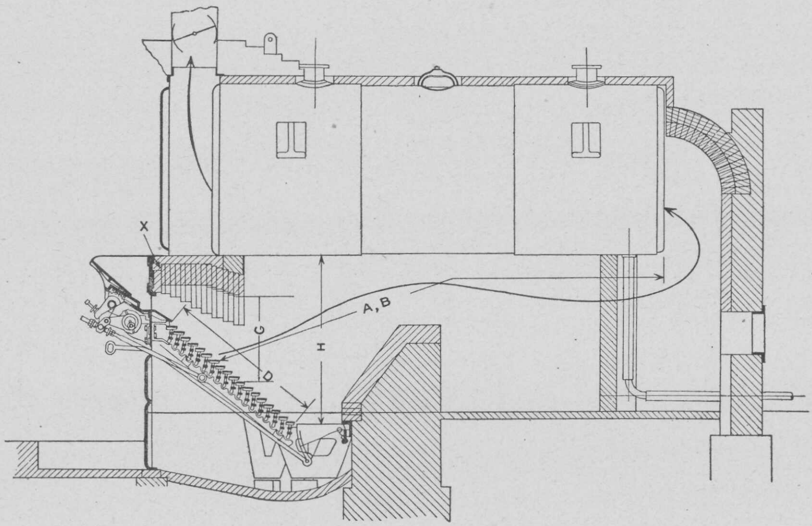

FIGURE 9.—Front-feed stoker and return tubular boiler. X, Point at which air and steam jets enter.

The different plants burned various sizes of coal, but at 11 plants the stokers were handling run of mine. The depth of fire ranged from 3.5 to 7 inches. The source of the coal and the depth of the fire are summarized in the following table:

TABLE 6.—*Kind of coal and depth of fire at plants with front overfeed stokers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	10	4	Pennsylvania	4	4.5
Indiana	3	4	Virginia	1	
Kentucky	2	3.5	West Virginia	2	5
Maryland	8	4	Miscellaneous	1	7
Ohio	1	5			

At 40 per cent of the plants the stokers were under boiler units of 200 horsepower or less, and at 4 plants the stokers were in a Dutch oven, this setting having been installed at two plants because the boilers were of a vertical water-tube type. At 6 of the plants visited the boilers had a variable load and at 2.6 a uniform load. The least ratio of heating surface to grate surface that was determined was 28.4 to 1 and the highest 58.3 to 1, the average being 40 to 1. The coal as received burned per square foot of grate surface per hour averaged 15.6 pounds; the smallest consumption of coal per square foot of grate surface per hour was 6.4 pounds, the largest 34.7 pounds.

The percentage of the rated boiler horsepower developed on mean heavy load (the boiler being rated on 10 square feet of heating surface per horsepower) averaged 84, the lowest and highest values being 55 and 111 per cent, respectively. The percentage of boiler horsepower developed by different makes of boilers, the coal consumption, and the least and average distances from the grate to the tube heating surface have been summarized for ready reference in Table 7.

TABLE 7.—*Summary of various observations at plants with front overfeed stokers.*

Type of boiler.	Kind of coal.	Number of plants.	Furnace draft.	Coal burned per square foot of grate surface per hour, average heavy load.	Percentage of rated boiler horsepower developed, average heavy load.[a]	Distance from grates to tube heating surface. Average.	Distance from grates to tube heating surface. Minimum.	Black smoke.
			Inch of water.	*Pounds.*		*Feet.*	*Feet.*	*Per ct.*
Babcock & Wilcox	Illinois, Maryland, Virginia and West Virginia.	9	0.31	16.8	87	6.3	5.8	7.5
Heine	Illinois, Kentucky, and West Virginia.	4	.22	12.4	81	5.0	5.0	14.1
Stirling	Illinois, Indiana, Maryland, and Pennsylvania.	5	.24	14.5	86	7.1	7.1	5.6
Miscellaneous water-tube.	Indiana, Kentucky, Maryland, and Pennsylvania.	7	.32	19.7	91	7.2	5.7	7.7
Return tubular	Illinois, Maryland, and Ohio.	7	.21	13.2	78	17.6	15.6	5.2

[a] Boiler rated on 10 square feet of heating surface per horsepower.

The average drafts, as determined at the furnace front, at the rear of the boiler, and at the base of the stack, are given in the following table:

TABLE 8.—*Summary of draft measurements at plants with front overfeed stokers.*

Type of boiler.	Measurement taken at—	Number of plants at which taken.	Average draft (inch of water).
Babcock & Wilcox	Furnace	8	0.31
	Rear of boiler	5	.36
	Base of stack	6	.87
Heine	Furnace	3	.22
	Rear of boiler	4	.48
	Base of stack	3	.76
Stirling	Furnace	5	.24
	Rear of boiler	4	.52
	Base of stack	4	.69
Return tubular	Furnace	7	.21
	Front tube sheet	4	.54
	Base of stack	3	.66
Miscellaneous types	Furnace	6	.32
	Rear of boiler	4	.43
	Base of stack	4	.76

Range of furnace draft, 29 plants, 0.09 to 0.62 inch; average, 0.26 inch. Range of draft at rear of boiler, water tube, 17 plants, 0.25 to 0.74 inch; average, 0.44 inch. Range of draft at base of stack, 20 plants, 0.38 to 1.30 inches; average, 0.76 inch. Average drop of draft from furnace to rear of boiler in water-tube boilers, 0.16 inch. Average drop from furnace to front tube sheet in return tubular boilers, 0.33 inch.

TABLE 9.—*Details of observations at plants with front overfeed stokers.*

No. of plant.	State.	Kind of stoker.	Total builders' rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
58	Illinois	Roney	1,200	Washed	Carterville, Ill	No. 5	$2.00	
59	do	do	300	do	Ladd, Ill	No. 2		
60	Pennsylvania	do	1,400	Georges Creek	Maryland	Run of mine		
61	Maryland	do	800	do	do	do		
62	do	do	800	do	do	do		
63	do	do	700	do	do	do		
64	do	do	750		Virginia	do		
65	Missouri	do	2,700	Various coals		Screenings		33,200
66	Ohio	do	600	Pocahontas	West Virginia	Nut and slack	2.25	2,600
67	Missouri	do	500	Various washed coals	Illinois	Slack	1.30	2,440
68	do	do	300	Belleville	do	do	1.40	1,445
69	Ohio	do	1,800	Laurel; Jellico	Kentucky	Nut and slack	2.00	
70	do	do	230	Pocahontas	West Virginia	Run of mine	2.70	900
71	Missouri	do	750	Belleville	Illinois	Screenings	1.15	
72	do	do	600	Stanton	do	Slack	1.00	1,300
73	do	do	500	Belleville	do	do	1.35	1,364
74	do	do	375	Washed	Carterville, Ill	No. 4	2.12	1,300
75	do	do	330	do	do	do	1.90	2,567
76	Maryland	do	500	Georges Creek	Maryland	Run of mine		
77	Ohio	do	480	Glen Run	Ohio	Slack		
78	Missouri	do	500	Washed	Collinsville, Ill	Pea	1.50	5,000
79	Indiana	do	260		Indiana	Nut and slack		
80	Maryland	do	700	Georges Creek	Maryland	Run of mine		
81	do	do	500	do	do	do		
82	Ohio	do	1,740	Pittsburg	Pennsylvania	Slack	1.30	30,000
83	Indiana	do	450		Indiana	Nut and slack		
84	do	do	300		do	do		
85	Kentucky	do	900		Kentucky	do		
86	Maryland	do	200	Georges Creek	Maryland	Run of mine		
87	Pennsylvania	do	2,800	River coal	Pittsburg, Pa	1¼-inch slack		
88	New York	Wilkinson	1,100	Rochester; Pittsburg	Pennsylvania	Various sizes	1.95–2.10	10,800
89	Maryland	Roney	800		do	Run of mine	2.79	

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Load.			Rating.								
				Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builders' rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
58	Power and heat	Uniform	Office building	24	60	24	20	26	26	111	111	5
59	Power, light, and heat	do	do	10	7.5	10	5.5	18.3	15.8	90	100	5
60	Power and heat	do	Factory	24	50	24	50	17.4	17.4	75	75	4
61	Power, light, and heat	do	Rolling mill	7.5	4.6	....	....	11	11	67	76	4
62	do	do	do	3.5	4.5	....	....	15.2	15.2	96	108	4
63	do	do	do	8	9	8	9	14.8	14.8	83	80	4
64	Power and heat	do	Office building	12	12	12	6	16.6	16.6	94	100	4
65	Power, light, and heat	Variable	Depot	24	125	24	50	14.5	13.1	78	78	5
66	do	Uniform	Office building	12	7.5	12	7.5	17.4	17.4	89	93	4.5
67	do	do	Mill	10	8.5	10	7.5	11.7	11	67	68	5
68	do	do	Factory	10	5.75	10	4	11.8	10	77	77	5
69	do	Variable	Brewery	24	71	24	39	13.3	11.2	77	66	5
70	do	Uniform	Office building	14	2.5	12	1.3	12.6	10.3	103	78	4
71	do	do	Factory	10	8	10	8	23.5	23.5	98	85	5
72	Power and light	do	Brick manufacture	12	4.3	12	4.3	6.4	6.4	55	48	5
73	Power, light, and heat	do	Factory	10	4	10	3.5	16.4	15.3	93	64	5
74	do	do	do	24	8.25	12	4.25	9.2	9.2	57	55	5
75	do	do	Bakery	10	5	10	5	13.3	13.3	93	91	5
76	do	do	Ice plant	11	6.5	11	6.5	13.3	13.3	91	120	4
77	Power and heat	do	Oil refinery	24	20	24	20	10.1	10.1	57	69	5
78	Power, light, and heat	Variable	Manufacturing	12	5.5	12	9	12.1	11	75	75	5
79	do	Uniform	Factory	10	6.5	10	6.5	17.3	17.3	100	100	5
80	do	do	Rolling mill	8	9	8	9	14.8	14.8	79	80	4
81	do	do	do	6.25	4.5	6.25	4.5	12.3	12.3	....	72	4
82	do	do	Salt works	24	82	24	82	15.8	15.8	88	88	4.5
83	do	do	Factory	10	11	10	11	20	20	98	98	5
84	do	do	Hospital	24	12	24	10	14.4	13.2	67	67	5
85	do	Variable	Office building	24	28	24	20	34.7	29.0	....	111	5
86	do	Uniform	Rolling mill	8	3.4	8	3.4	17.3	17.3	94	106	4
87	Power	Variable	do	24	100	....	....	....	14.4	104	100	4
88	Power, light, and heat	do	....	12	17	12	10.5	13	10.9	....	58	4.5
89	Power	Uniform	Pumping station	24	26	24	26	19	19	....	120	4.5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builders' rated horse-power.	Horse-power, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
58	3 -4	8 times in 24 hours	Babcock & Wilcox water-tube.	140 4″ x 18′ tubes, 2 36″ drums	4	3	1	300	300	3,000	0	165
59	2.5-3	2 to 3 times in 10 hours.	Standard; Babcock & Wilcox.	80 4″ x 18′ tubes	2	2	2	150	167	1,670	0	125
60	3 -4	....	Babcock & Wilcox water-tube.	168 4″ x 18′ tubes, 2 42″ x $20\frac{3}{16}$′ drums.	4	4	4	350	350	3,500	0	150
61	....	....	....do	108 4″ x 18′ tubes, 2 36″ x 18′ drums.	4	2	....	200	226	2,260	0	140
62	....	....	....do	108 4″ x 18′ tubes, 2 36″ x 18′ drums.	4	3	....	200	226	2,260	0	100, 140
63	....	....	....do	162 4″ x 18′ tubes	2	2	2	350	340	3,400	(*a*)	140
64	....	2 times in 24 hours	....do	126 4″ x 18′ tubes, 2 30″ drums	3	2	1	250	264	2,640	0	60
65	7	....	....do	126 4″ x 18′ tubes	10	10	5	270	266	2,660	0	160
66	6	4 times in 24 hours	....do	168 4″ x 16′ tubes, 2 30″ x 16′ drums.	2	1	1	300	313	3,130	0	140
67	3	3 times in 12 hours	Heine water-tube	138 3½″ x 18′ tubes	2	2	2	250	253	2,530	0	140
68	5	5 times in 10 hours	O'Brien and Heine water-tube.	85 3½″ x 18′ tubes, 78 3½ x 18′ drums.	2	2	2	175, 125	156, 143	1,560, 1,430	0	140
69	3.5	Variable	Heine water-tube	140 3½″ x 18′ tubes	6	6	5	300	256	2,560	0	110
70	3 -4	Once in 14 hours	....do	53 3½″ x 16′ tubes	2	1	1	115	87	865	0	85
71	2	2 times in 10 hours	Bronson special fire-tube.	84″ x 18′, 150 3½″, 18 4″ x 18′ water tubes.	2	1	1	375	325	3,250	0	140
72	2.5	2 times in 12 hours	Return tubular	60″ x 16′, 44 4″ tubes	6	3	3	100	87	870	0	110
73	4	3 times in 10 hours	....do	72″ x 20′, 70 4″ tubes	2	1	1	250	172	1,725	0	145
74	5	3 times in 12 hours	....do	66″ x 18′, 54 4″ tubes	3	2	2	125	120	1,200	0	130
75	5	2 times in 10 hours	....do	66″ x 16′, 54 4″ tubes	3	2	2	110	107	1,065	0	110
76	....	....	....do	72″ x 18′, 74 4″ tubes	4	2	2	125	164	1,640	0	85
77	4 -5	4 times in 24 hours	....do	4 60″ x 16′, 46 4″, 2 60″ x 16′, 54 4″.	6	6	6	80	107, 93	1,065, 932	0	75-80
78	4	2 times in 12 hours	Stirling water-tube	192 3¼″ tubes	2	1	2	250	250	2,500	0	125
79	3 -4	2 times in 10 hours	....do	198 3½″ tubes, 3 36″ drums	1	1	1	260	260	2,600	0	120
80	....	....	....do	259 3¼″ tubes, 2 42″ x $12\frac{3}{16}$′ drums.	2	2	2	350	354	3,540	(*b*)	140
81	....	....	....do	....	1	1	1	500	....	....	0	140
82	....	....	....do	....	5	5	5	230, 525	230, 521	2,300, 5,208	0	125

83	3 -4	2 times in 10 hours....	Wickes vertical water-tube.	112 4″ tubes....................	2	2	2	225	225	2,250	0	120
84	3 -4	4 times in 24 hours....	Atlas water-tube......	63 4″ x 18′ tubes...............	3	2	2	150	150	1,500	0	100
85	3	....	Henry Vogt water-tube.	....	3	2	1	300	....	....	0	125
86	....	....	Cahall vertical water-tube.	108 4″ x 18′ tubes..............	1	1	1	200	226	2,260	0	100
87	4 -6	2 to 3 times in 24 hours.	Rust water-tube......	....	8	6	5	350	335	3,350	0	150
88	4	4 times in 24 hours....	Standard water-tube..	....	4	4	4	250, 350	—, 268	——, 2,680	0	175
89	....	.....do..................	National water-tube...	....	4	2	2	200	....	....	0	140

[a] 125° F. at boiler.

[b] 175° F. at boiler.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Furnaces.										
	Number.	Kind.	Grate area per boiler (square feet).	Dimensions (feet).							
				Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch.		Height of arch at rear of furnace (H).
				Average (A).	Minimum (B).				At front (F).	At rear (G).	
58	4	Plain	64		5			2			
59	2	Dutch oven	42.5, 39.5	9.5	7	5.5. 5	6	9			4
60	4	Plain	60			8	7.5	0			
61	4	....do	56.3	5.5	5.5	7.5	7.5	0		3.2	
62	4	....do	57	5.5	5.5	7.5	7.5	0		3.2	
63	2	....do	76	5.5	5.5	9	8.5	0			
64	3	....do	60	6	6	8	7.5	0			
65	10	....do	72			8	9				
66	2	....do	72	5.5	5.5	8	9	0			
67	2	Tile roof	72.25			8.5	8.5	0			
68	2	Plain	55.25, 42.25			6.5	[a]8.5, 6.5				
69	6	....do	73	6	6	4.3	8.5	0			
70	2	....do	28.6	4	4	4.4	6.5	0			
71	2	Tile roof	68	8	5.5	8	8.5	0			
72	6	Plain	37.5	15	13	5	7.5	0			
73	2	....do	48	18.5	15.5	5.5	8.5	0			
74	3	....do	37.5			5	7.5				
75	3	....do	37.5			5	7.5				
76	4	....do	45	18	17	6	7.3	0			6.5
77	6	....do	27.5	19	17	5	5.6	0			
78	2	....do	76			8	9.5				
79	1	....do	75	7	7	8.3	9	0			6.8
80	2	....do	76	7.25	7.25	9	8.5	0			6.75
81	2	....do	117	7.25	7.25	6.5	9	0			
82	5	....do	76, 104.5	[b]6.5, 7.5	[b]6, 7	[b]8, 11	9.5	0			[b]7.25, 8.5
83	2	Dutch oven	55			5.5	10	6.75			
84	3	Plain	34.64			4.3	8	0			
85	3	....do	48			6	8	0			
86	1	Dutch oven	49	10.5	8			6			
87	8	....do	83	7	5	10	7	9.5			5
88	4	Plain	52.5, 59.5	4	4	8.5, 7.5	7	0	0.3		
89	4	....do	57								

[a] First dimension applies to O'Brien boiler.

[b] First dimension appli es to small boiler.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for 1 hour (minutes).			Average percentage of black smoke.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
58	Chimney..	0.30-0.33	0.64	....	1.14	....	Damper and poke-hole doors open.	5	333	0	0	50	4.4	Average.
59	...do......	.12- .24	.36	....	.52	....	Dampers open..........	1	60	0	0	56	.6	Light.
60	...do......	.18- .25	....	....	.70	....	.....do..........	2	59	0	2	50	3.9	Average.
61	...do......	.19- .21	.25	....	.32	0.65	.....do..........	1	93	0	7	48	7.4	
62	...do......	.17- .22	0.25- .32	....	.32	.70	.....do..........	1	93	2	9	25	16.5	
63	...do......	.38- .46	....	....	....	.60	.....do..........	1	93	0	2	52	3.4	
64	...do......	.50- .57	....	....	1.10	1.25	.....do..........	2	195	0	0	0	5	Do.
65	...do......	.25- .50	....	....	.80- .90	1.10	....	1	60	0	0	0	19	Light.
66	...do......	....	.25	....	....	.90	Damper half open......	(a)	(b)	0	0	....	....	Average.
67	...do......	.20	.44	....	....	.64	....	1	60	0	0	52	3.7	Do.
68	...do......	.25	.50	....	....	.54	....	1	60	0	0	0	10.7	Light.
69	...do......	.18- .22	.35- .40	....	.40- .45	1.10	Damper open..........	2	120	0	12	0	28	Do.
70	...do......	....	.60	c 0.40	.90	....	.....do..........	(a)	(b)	0	0	....	....	Heavy.
71	...do......	.30	....	.60	....	.70	....	1	60	0	0	54	2.7	Average.
72	...do......	.16	....	.38	....	....	....	1	60	0	0	0	19.2	Do.
73	...do......	.30	....	.44	....	....	....	1	60	0	0	55	4.2	Do.
74	Chimney; induced.	.09	....	....	....	.47	Fan not running.......	1	60	0	0	54	10	Do.
75	Chimney..	.20	....	....	....	.80	Damper open..........	1	60	0	0	60	0	Do.
76	...do......	.21- .25	....	....	.55	....	.....do..........	1	120	0	0	60	0	Do.
77	Induced...	.05- .07	....	.15- .17	.48- .95	....	....	1	60	0	0	60	0	Do.
78	Chimney..	.16	.64	....	....	.64	....	1	60	0	3	28	16.6	Light.
79	...do......	.25	Lower rear, .47	....	.64	....	Dampers open........	1	62	0	0	55	.1	Average.
80	...do......	.21- .33	Lower rear, .41- .48	....	....	.55	.....do..........	1	93	0	4	55	2.8	
81	...do......	.28	{Lower, .45 {Upper, .60	}	....	.65	Damper open..........	1	93	0	2	52	3.1	
82	...do......	.10- .40	Upper rear, .50- .60	....	....	.80-1.0	....	1	600	0	2.5	51	5.5	Do.
83	...do......	.20	Lower rear, .23	....	.71	....	Dampers open..........	1	62	0	6	40	10	Do.
84	...do......	.20- .25	.39- .41	....	....	.55	.....do..........	2	80	0	0	(d)	17.1	Light.
85	...do......	.26	.74	....	1.15	....	.....do..........	2	170	3	8	34	18	Do.
86	...do......	.28	Lower rear, .30	....	....	.38	.....do..........	1	93	1	2	59	2.5	Average.
87	...do......	.26- .40	....	....	....	.75- .85	....	1	60	0	0	59	.3	Heavy.
88	...do......	....	....	....	....	....	....	1	60	0	0	43	6.3	Light.
89	...do......	.58- .66	....	....	1.10	1.30	Dampers open..........	1	60	0	0	60	0	Average.

a Several. b Various lengths. c Front water leg. d Variable.

TABLE 9.—*Details of observations at plants with front overfeed stokers*—Continued.

No. of plant.	Breeching.				Stack.			Length of coking arch (feet).	Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boiler and stack.	Height (feet).	Size (feet).	Area (square feet).		
58	25	5 x 5	Near boiler	0	265	*a* 6	28.3	2.4	Bar never inserted through poke holes in front of furnaces. Four ⅛-inch steam jets on each boiler run continuously. Stack sometimes smoked badly for several minutes. Always run with poke-hole doors open.
59	10			2	121	2 x 7.5	15		Fire never poked through poke holes. Two ⅛-inch steam jets on each boiler used continuously. Run with poke-hole doors open.
60	5			0	150	*a* 6	28.3		Steam jets across front of furnace used continuously.
61	0			0	150	*a* 6	28.3	3	
62	0			0	150	*a* 6	28.3	3	Coal runs about 12 per cent ash.
63	5			0	125	*a* 6	28.3	3	
64	6			0	220	*a* 5	19.6	2.8	Fire poked through poke holes very carefully. Stack smokes nearly continuously, 5 per cent black. Automatic regulator on main damper.
65	30	7 x 17.5	Near stack	0	200	*a* 12	113.1	2.2	Steam jets run continuously. Stack smokes steadily from 10 to 40 per cent black.
66	8.5			1	260	*a* 4	12.56	3	Steam jets used part of time.
67	12	3.5 x 4	Near stack	0	90	*a* 4.3	14.7	3	Steam jets run continuously.
68	40	5 x 3.5	do	1	140	*a* 5	19.6		C tile on lower row of tubes. Steam jets run continuously. Smoked steadily, 10 to 20 per cent black. Some refuse burned.
69	3			1	164	*a* 5	19.6	3	V tile on lower row of tubes. Stack smoked continuously, 10 to 40 per cent black.
70	55	*a* 5	Near stack	4	175	*a* 3.5	9.7		V tile on lower row of tubes.
71	12			1	125	*a* 7	38.5	4	Steam jets used continuously.
72	0	0		0	78	*a* 3	7.06	2	Steam jets run continuously. Three similar stacks, two boilers per stack, resting on front of boilers. Stacks smoke continuously, 10 to 40 per cent black.
73	17			2	128	*a* 5	19.6		Steam jets run continuously.
74	45			3	125	3 x 2	6		Induced draft used on heavy load. Regular steam jets installed, besides two more steam jets entering through front of furnace, all run continuously. Some refuse burned.
75	20	4.5 x 3.5	Near stack	1	120	4.5 x 4.5	20.25	2.5	Steam jets run continuously.
76	2			0				2.7	Steam jets used.
77	19			3	30	*a* 5	19.6		Four $\frac{3}{32}$-inch steam jets to each boiler used continuously. Some smoke in cleaning fire, usually about 20 per cent black.
78	0	0		0	100	*a* 4	12.56		Steam jets run continuously.
79	6			0	105	*a* 5	19.6		Four steam jets run continuously.
80	0	0		0	96	*a* 4	12.56		Two similar stacks resting on rear of boilers.

81	0	0	....	0	96	*a* 4	12.56	1.75	Stack rests on rear of boilers.
82	0	82	....	0	120 110	*a* 5 *a* 3.3	19.6 8.8	....	Three boilers have four $\frac{1}{8}$-inch jets and two boilers six $\frac{1}{8}$-inch jets. Separate stack resting on the rear of each boiler; three 110-foot stacks and two 120-foot stacks.
83	6	....	....	0	105	*a* 5	19.6	....	Three steam jets on each boiler run continuously.
84	9	....	....	1	130	*a* 5.5	23.7	3	Two steam jets per boiler run continuously. Automatic regulator on main damper. Stacks smoke from 20 to 50 per cent black when regulator closes damper.
85	40	....	....	0	195	*a* 5	19.6	2.5	Six $\frac{1}{16}$-inch steam jets on each boiler run continuously.
86	0	0	....	0	50	*a* 4	12.56	....	Coal runs about 12 per cent ash. Stack rests on top of boiler. This stack was seen to smoke three times in a 93-minute observation for only one-half minute each time.
87	8	....	....	0	120	*a* 4	12.56	2.75	Coal as fired runs about 13,500 B. t. u. per pound. Five $\frac{1}{8}$-inch steam jets across front of furnace run continuously. Eight similar stacks.
88	11	....	....	0	130	5 x 5	25	3	Twenty-three and twenty-six $\frac{1}{16}$-inch steam jets across front of furnace; are hand operated and do not run continuously.
89	10	....	....	1	150	*a* 6	28.3	....	Three $\frac{1}{8}$-inch steam jets in furnace and fifteen $\frac{1}{8}$-inch steam jets above the first gas passage, all run continuously.

a Diameter.

SUMMARY.

A review of the remarks in the preceding table shows that with the front overfeed type of mechanical stoker, success in smoke abatement has been attained by one of three methods—the continuous use of steam jets, a generous admission of air, or careful operation.

SIDE-FEED STOKERS.

GENERAL DISCUSSION.

Like the front feed, the side-feed stoker has been in use for many years, the first American patent for this type having been taken out in 1878. Several firms now make such stokers, which differ chiefly in the manner of feeding coal and getting rid of clinkers and ash. In all the coal is fed from two magazines, one at each side of the boiler. At the bottom of each magazine is a flat built-up iron and steel plate called the coking plate; beneath this is an air duct and on it rests the coal-feeding mechanism. Over this feeding device is a heavy casting, the arch plate, on which rests a fire-brick arch extending over the whole grate area and having along the upper side an air duct connected with the fire space by small openings in the skew-backs supporting the arch. These openings are designed to admit hot air above the coal at a point where the volatile hydrocarbons are given off. The movable grate bars and a clinker-breaking device at the bottom of the V-shaped space between the grates are actuated by a small engine that forms part of the equipment.

Stokers of the side overfeed type are characterized by large coking space per foot of grate area and an ample combustion chamber. They have been installed at both large and small plants, and are successfully carrying both uniform and variable loads. In the field investigation here reported no other type of stoker was found doing as well under so great a variety of conditions. Its chief defect seems to lie in the devices for getting rid of the ash. Though supposedly automatic, they often require the service of a fireman. This introduces an element of varying value in the operation of the plant.

The two makes of this stoker that are most used formerly differed in arch construction, one having only side arches over the coking plates. As now installed, the arch in both makes extends over the grate area and the two styles differ merely in the devices for distributing coal to the grate and for getting rid of refuse. One employs for coal distribution a shaft rotating through a small arc to move stoker boxes on the coking plates; as the boxes work forward, they push coal toward the edge of the plates. Between the lower ends of the grates and supported by a bearing shaft is a hollow iron bar with projections on its surface; this bar, when rotated, grinds up the clinker. The other make feeds the coal by a screw and has heavy iron disks actuated by a reciprocating bar for crushing clinker. Both these stokers are frequently set in Dutch ovens.

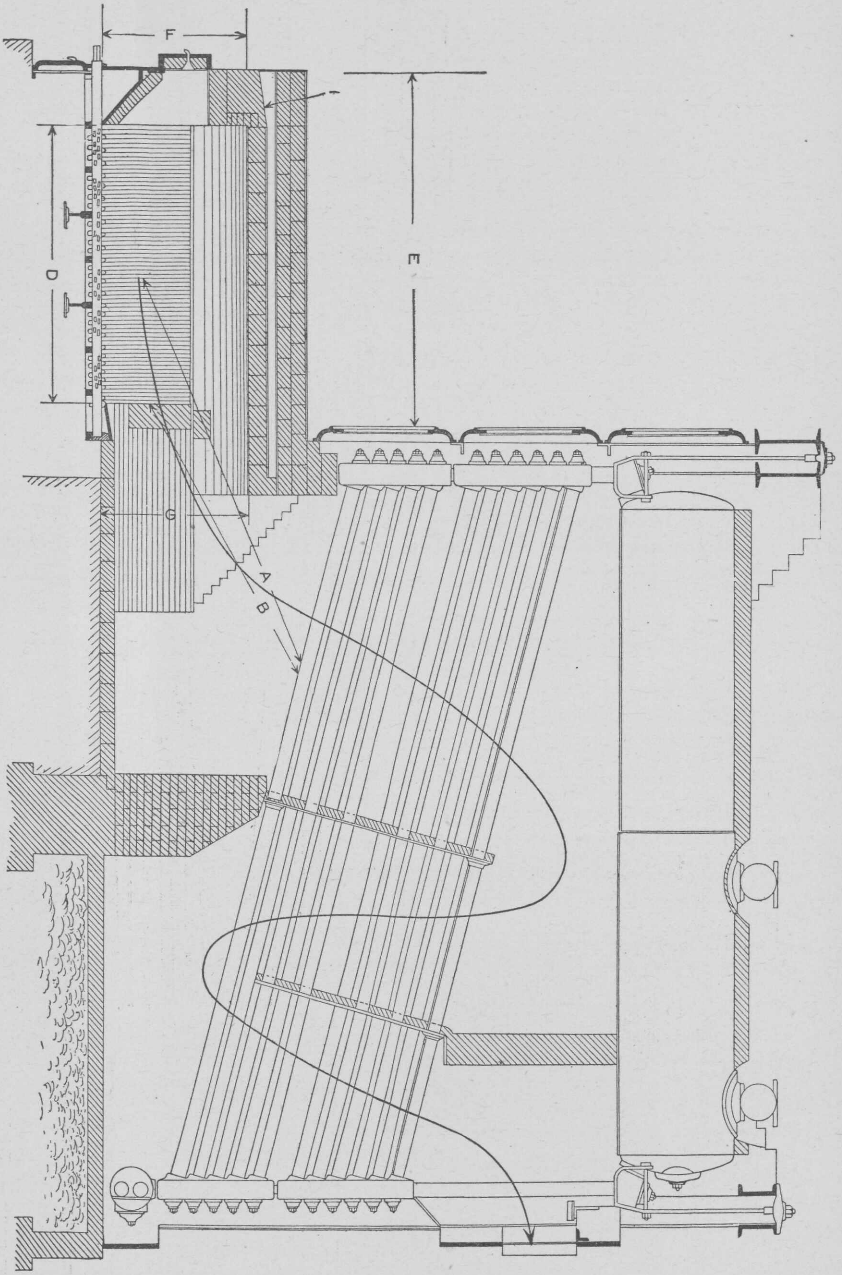

FIGURE 10.—Side-feed stoker in Dutch oven and Babcock & Wilcox boiler.

Figure 10 shows the stoker first mentioned in a Dutch oven having a chamber above the arch for heating the air admitted over the coal,

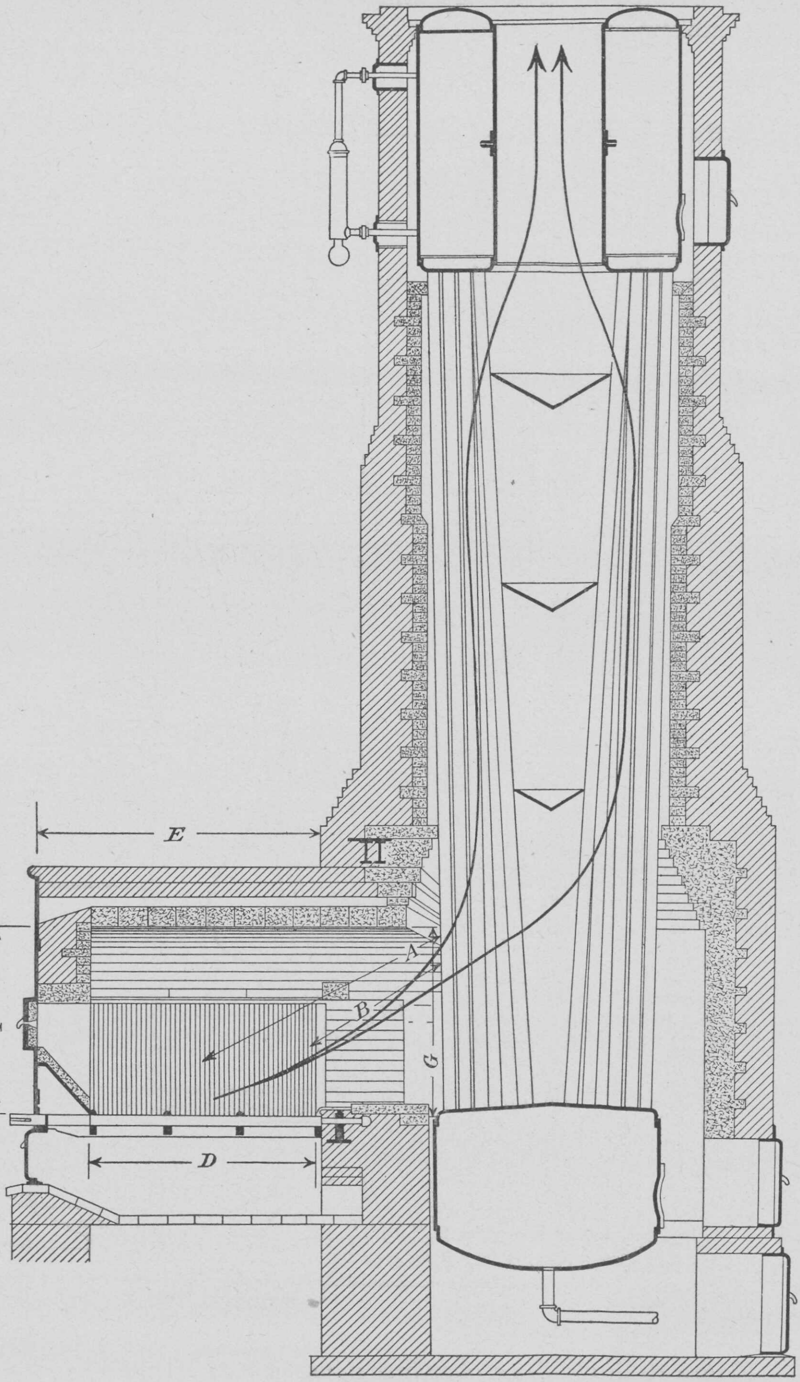

FIGURE 11.—Side-feed stoker in Dutch oven and Cahall boiler.

as set at a battery of Babcock & Wilcox boilers. This setting, with its ample combustion chamber and fairly long travel from the grates

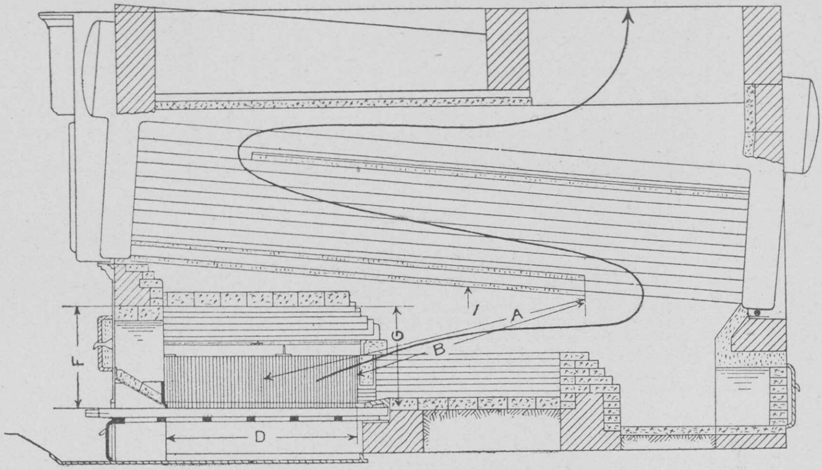

FIGURE 12.—Side-feed stoker and Heine boiler. 1, C tile on lower row of tubes, forming a tile-roof furnace

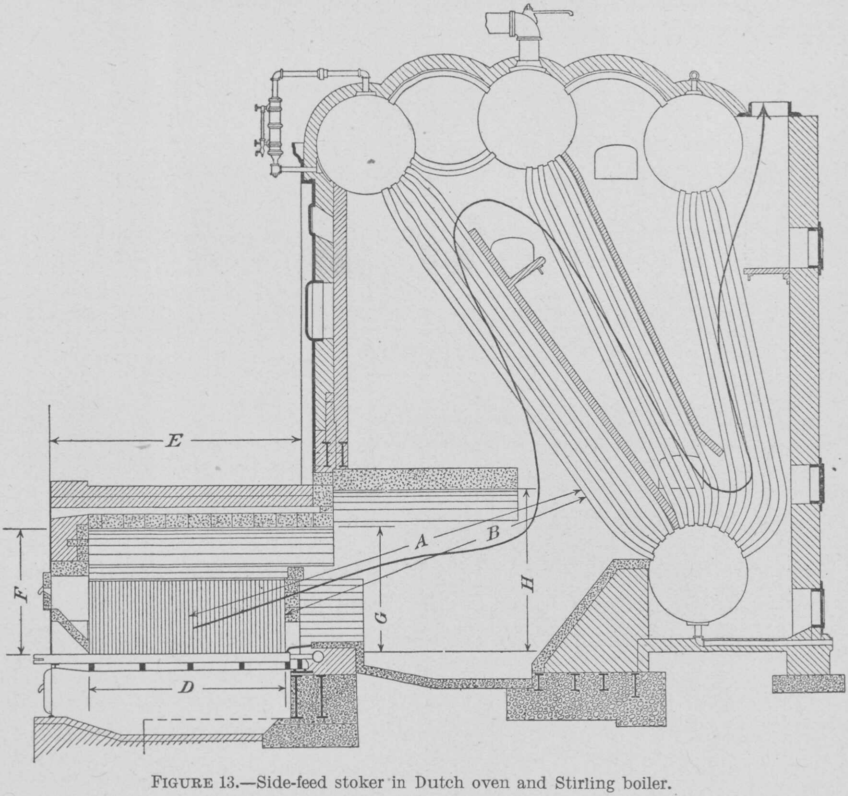

FIGURE 13.—Side-feed stoker in Dutch oven and Stirling boiler.

to the tube heating surface, allows nearly perfect combustion of the hydrocarbons from the bed of coal.

The other make of stoker as installed under a Cahall boiler is shown in figure 11. As the boiler is vertical, the stoker is placed in a Dutch oven. In this setting also, the combustion chamber is large enough to permit thorough mixing of the gases from the burning coal and a moderately long travel from the grates to the first row of water tubes.

A side-feed stoker set in a Dutch oven under a Heine boiler is shown in figure 12. The ignition arch extends over the grates, and by baffling the bottom row of tubes the space between the back of the

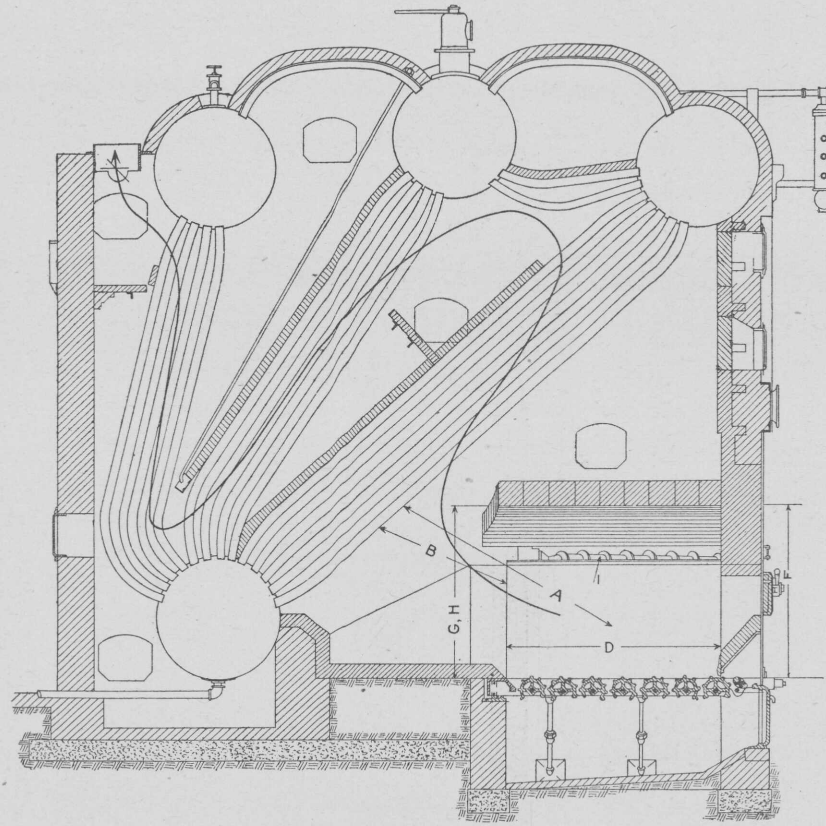

FIGURE 14.—Side-feed stoker and Stirling boiler. 1, Continuous screw for distributing coal.

arch and the rear end of the baffling becomes a tile-roofed furnace. The gases are given a long journey from fire to heating surface, and the construction insures a smokeless fire under heavy loads and forced feed.

The chief difference in the two patterns of side-feed stokers under discussion are shown in the accompanying illustration of these stokers under Stirling boilers. Figure 13 shows the stoker first mentioned set in a Dutch oven. The feeding device is not shown, but the rotating clinker bar is. In figure 14 the screw for feeding coal and the

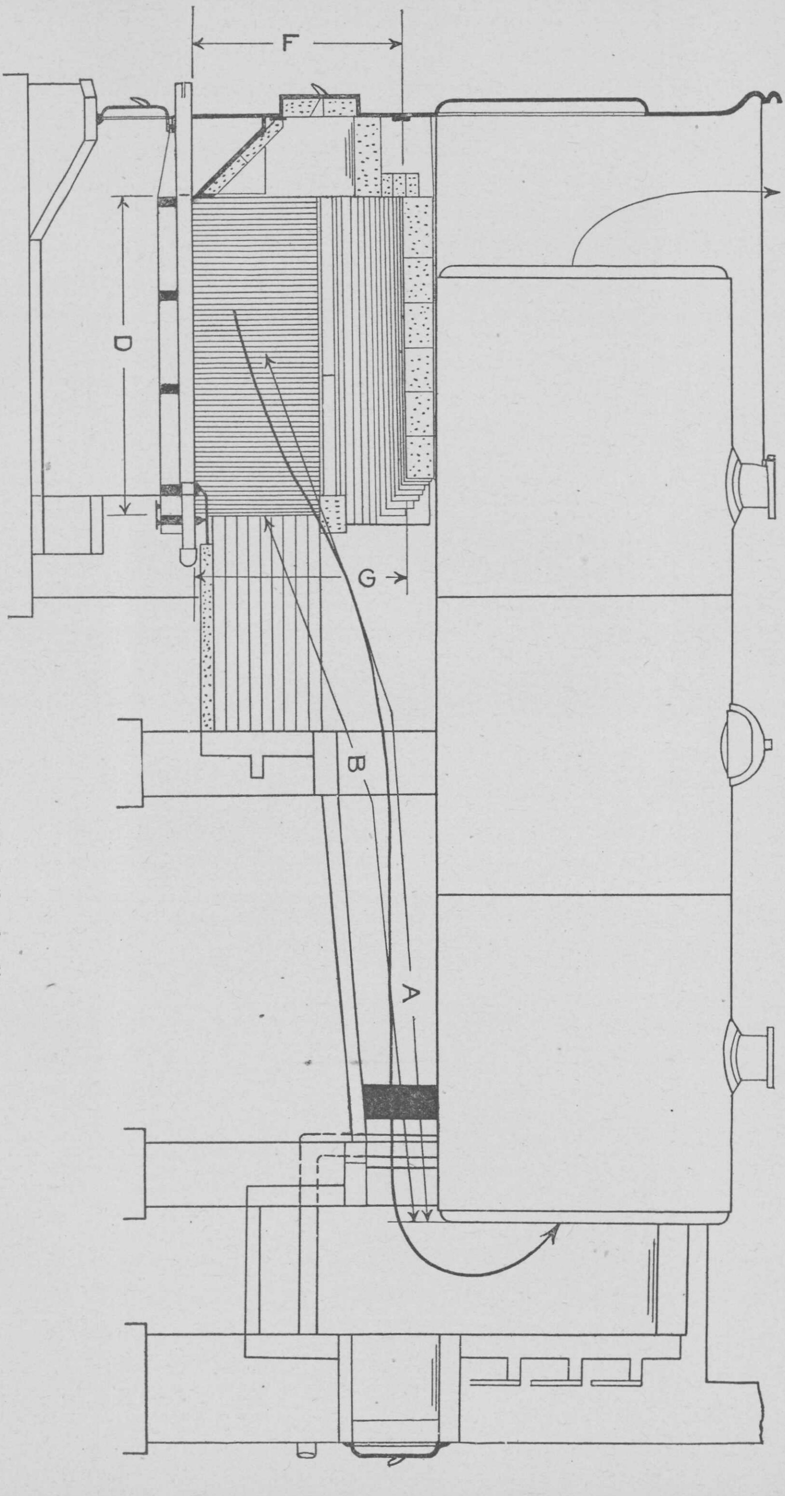

FIGURE 15.—Side-feed stoker and return tubular boiler, elevation.

device for crushing clinker, the special features of the other make of stoker, are evident. One stoker is set in a Dutch oven; the other is placed beneath the arch that is a characteristic feature of the Stirling boiler. Both installations exhibit a meritorious feature of the side-feed stoker—the large combustion space over the grates.

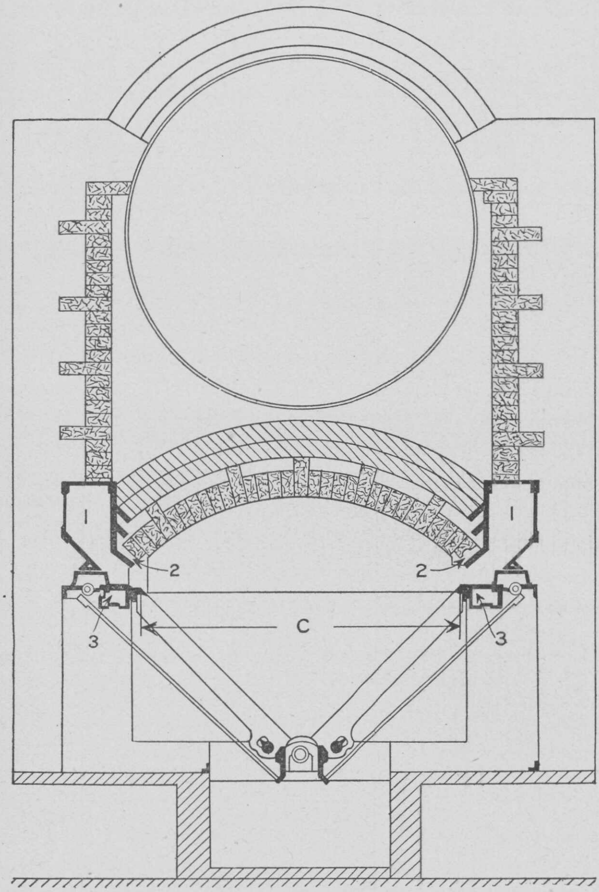

FIGURE 16.—Side-feed stoker and return tubular boiler, cross section. 1, Coal magazines; 2, hot-air ducts; 3, air-admission openings under coking plates.

The fact that a large number of the plants visited have a side-feed stoker under a return tubular boiler indicates that this type has given satisfaction when used with tubular boilers. Details of a sample installation, showing the particular features of the side-feed type that have been mentioned in this discussion, are presented in figures 15 and 16, which represent sections through the stoker and boiler. Figure 15 shows the high arch over the grates and the long distance from grates to tube heating surface. The situation of the coal magazines, of the hot-air ducts above the arch, and of the air passages under the coking plates, as well as the ample size of the combustion chamber, are made plain by figure 16.

DETAILED DESCRIPTION OF PLANTS.

In all, 76 plants with side-feed stokers were visited; at 44 the stokers were installed under return tubular boilers, at 30 under water-tube boilers, and at 2 under boilers of both types. The plants ranged in size from 50 to 6,750 horsepower. The coal used came from Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia, and ranged from slack to run of mine. Eleven plants were burning slack. The other 65 used small nut or nut and slack.

Plants with water-tube boilers.—At the 30 plants where stokers of this type were installed under water-tube boilers alone the kind of coal used and the depth of fire were as follows:

TABLE 10.—*Kind of coal and depth of fire at plants with side overfeed stokers under water-tube boilers.*

Kind of coal.	Number of plants.[a]	Average depth of fire.	Kind of coal.	Number of plants.[a]	Average depth of fire.
		Inches.			*Inches.*
Illinois	6	5	Pennsylvania	7	5
Indiana	1	6	West Virginia	4	5
Kentucky	1	7	Miscellaneous	5	6
Ohio	7	5			

[a] One plant used both Ohio and Pennsylvania coal.

At 35 per cent of the plants with side-feed stokers under water-tube boilers the boiler units were 200 horsepower or less. The coal as received burned per square foot of grate per hour ranged from 10 to 41 pounds. The percentage of the rated horsepower developed on average heavy load (the boiler being rated on the basis of 10 square feet of heating surface per horsepower) ranged from 37 to 189. These and other details are summarized in the subjoined table.

TABLE 11.—*Summary of various observations at plants with side overfeed stokers under water-tube boilers.*

Type of boiler.	Kind of coal.	Number of plants.	Furnace draft (inch of water).	Coal burned per square foot of grate surface per hour, average heavy load.	Boiler horsepower developed, average heavy load. ([a])	Distance from grate to tube-heating surface. Average.	Distance from grate to tube-heating surface. Minimum.	Distance from front of furnace to front of boiler.	Black smoke.
				Pounds.		*Feet.*	*Feet.*	*Feet.*	*Per ct.*
Babcock & Wilcox.	Illinois, Ohio, and West Virginia.	8	0.24	22.6	91	8.5	5.7	([b]) 6.9	5.2
Stirling	Illinois, Ohio, Pennsylvania, and West Virginia.	9	.36	23.1	85	9.4	6.5	4.1	2.8
Miscellaneous water tube.	Illinois, Indiana, Kentucky, Ohio, and Pennsylvania.	15	.22	23.7	81	7.9	5.5	([c]) 4.1	6.0

[a] Boiler rated on 10 square feet of heating surface per horsepower.
[b] From 7 plants.
[c] From 13 plants.

The average ratio of heating surface to grate surface at these plants was 59.1 to 1, the range being from 33 to 1 to 72 to 1. The grate area of this type of stoker was taken to be equal to the distance between the coking plates multiplied by the distance from the front of the furnace to the rear of the grates.

Natural draft, supplied by a chimney, was used at most of the plants. The furnace draft varied from 0.10 to 0.35 inch of water, but most of the readings were between 0.15 and 0.25 inch. The draft measurements are summarized below:

TABLE 12.—*Summary of draft measurements at plants with side overfeed stockers under water-tube boilers.*

Type of boiler.	Measurement taken at—	Number of plants at which taken.	Average draft (inch of water).
Babcock & Wilcox	Furnace	7	0.24
	Rear of boiler	7	.43
	Base of stack	2	.58
Stirling	Furnace	8	.36
	Rear of boiler	7	.47
	Base of stack	5	.81
Miscellaneous water tube	Furnace	12	.22
	Rear of boiler	7	.51
	Base of stack	8	.67

Furnace draft, 27 plants, 0. 10 to 0. 53 inch water; average 0. 27 inch. Draft at rear of boiler, 21 plants, 0. 18 to 0. 90 inch; average, 0. 47 inch. Draft at base of stack, 15 plants, 0. 18 to 1. 10 inches; average, 0. 71 inch. The approximate average drafts were as follows: Furnace, 0. 25 inch; rear of boiler, 0. 50 inch; base of stack, 0. 75 inch. These figures show a draft drop of 0. 25 inch of water through the furnace and of 0. 25 inch from boiler to stack.

Details of the observations at plants with side-feed stokers under water-tube boilers are given in Table 13.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
90	Illinois	Murphy	5,040		Green County, Ill	Screenings		
91	do	do	500	Washed	Williamson County, Ill	Nos. 2 and 4	$2.85–$3.00	
92	Michigan	do	500	Hocking Valley	Ohio	Slack	1.50	6,000
93	Ohio	do	200	Massillon	do	$\frac{3}{4}$-inch to 1-inch screenings.	1.80	1,455
94	Pennsylvania	do	1,200		West Virginia	Run of mine	2.80	
95	Ohio	do	500	New River	do	Nut and slack		
96	Pennsylvania	do	458			Run of mine	3.00	
97	Illinois	do	2,000	Washed	Carterville, Ill	Nos. 2 to 5	2.45	12,000–15,000
98	do	do	400	do	do	No. 3	2.15	
99	Ohio	do	1,200	Various coals	Ohio	Pea and slack	1.90	6,000
100	do	do	500	Youghiogheny	do	1-inch nut	1.90	
101	do	do	413	do	do	No. 1 nut	1.90	
102	do	do	1,200	Pittsburg	Pennsylvania	Slack	1.52	6,220
103	Pennsylvania	do	306	Westmoreland gas slack	do	do	2.80	
104	Ohio	do	600	Kanawha	West Virginia	Nut and slack	1.75	
105	do	do	200	do	do	do	1.75	
106	do	Detroit	400			do	2.00	2,400
107	Illinois	Murphy	600	Washed	Carterville, Ill	No. 4	2.70	
108	do	do	1,000	do	do	No. 3	2.90	
109	Indiana	do	250	Linton No. 4	Indiana	Nut and slack	2.55	
110	Kentucky	Detroit	400	Straight Creek	Kentucky	do		
111	Ohio	Murphy	1,320	Various coals	Ohio; Pennsylvania	$\frac{3}{4}$-inch screenings	1.50–1.65	
112	do	do	1,200	Pittsburg No. 8	Dillonvale, Ohio	Pea and slack	1.80	
113	do	do	350	Youghiogheny	Pennsylvania	1-inch nut	1.90	
114	Pennsylvania	do	200	Lincoln gas slack	do	Nut and slack	3.50	
115	Ohio	do	1,200	Youghiogheny	do	Nut	2.50	7,300
116	Kentucky	Model	300	Pittsburg	do	Nut and slack		
117	Pennsylvania	Murphy	600			Run of mine; slack		1,880
118	New York	do	6,750	Various coals		$1\frac{1}{4}$-inch screenings	1.93	38,570
119	Michigan	Detroit	300	do		Nut and slack	1.92	1,500

Table 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Load.			Rating.								
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
90	Power and heat	Variable	Street railway	24	150–200	24	100–130	23.8	22.8	114	114	5
91	Power, light, and heat	do	Printing office	24	12	24	8	29	24	106	80	5
92	do	Uniform	Factory	24	19	24	19	31.7	31.7	106	106	5
93	do	do	do	10	4.7	10	4.7	22.4	22.4	104	118	4
94	Power	do	Ice plant	24	60	24	25	22.3	20.5	98	104	4
95	Power, light, and heat	do	Lead works	10	2.6	14	2.4	12.4	10.2	44	46	4.5
96	do	Variable	Factory	10.25	6.5			16.3		65	69	4
97	Power and heat	Uniform	Department stores	11	70	12	6	24.7		145	145	5
98	Power, light, and heat	Variable	Factory	9	6	9	4	34	29		133	5
99	Power and light	Uniform	Municipal waterworks	14	15.3	18	10.4	14.6	13.1	50	54	4.5
100	Power, light, and heat	do	Factory	10	7.3	10	7.3	17.4	17.4	68	59	5
101	do	do	do	10	7	10	7	21.9	21.9	68	68	5
102	do	do	do	10.5	15.5	10.5	14	20.6	19.5	73	73	4.5
103	Power and light	do	Refrigeration	24	10	24	8	17	15.3	68	68	4
104	do	do	Union depot	5	6	19	11	33.3	24.5		120	5
105	Power and heat	do	Depot	24	7			12.2			65	4.5
106	Power and light	do	Office building	11	6.75	11	6.75	35	35	123	123	5
107	Power, light, and heat	Variable	Hotel	24	20	24	8	26	18	111	111	5
108	Power and heat	Uniform	Office building	12	14	12	12	33	32	109	80	5
109	Power, light, and heat	do	Hotel	14	7.75			18.5			88	5
110	do	Variable	Brewery	24	11.5			37.4			96	5
111	do	do	Factory	12	24	12	17	14	12	62	62	5
112	do	Uniform	Shops	10	19	10	19	26.4	26.4	90	95	5
113	do	do	Factory	10	8.7	10	8.7	17.4	17.4		100	5
114	do	Variable	Store building	10.5	3.5			16.7	16.7	69	86	4
115	do	Uniform	Hotel	24	20	24	20		14	46	46	4.5
116	do	do	Refrigeration	24	8.8			27.7			98	5
117	do	do	Factory	11	7			17.2		78	71	4
118	Power and light	do		8	80	8	80	30	30	104	92	4
119	Power and heat	do		10.5	5	10.5	5	20.5	20.5	63	63	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builders' rated horsepower.	Horsepower.[a]	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
90	6	Continuous	Babcock & Wilcox	198 4″ tubes, 3 36″ x 20¼′ drums	12	(b)	(b)	420	420	4, 200	0	160
91	3. 5–4	Variable	do	90 4″ x 18′ tubes, 2 30″ drums.	2	1	1	250	189	1, 890	0	140
92	...	Continuous	do	Small boiler, 72 4″ x 18′ tubes.	3	2	2	200, 150	200, 150	2, 000, 1, 500	0	130
93	4	do	do	108 4″ x 18′ tubes	1	1	1	200	227	2, 265	0	100
94	3–6	do	do	154 4″ x 18′ tubes, 1 42″ x 20⅓′ drum.	4	4	2	300	318	3, 180	0	145
95	4–6	do	do	126 4″ x 18′ tubes	2	1	1	250	264	2, 640	0	95
96	(b)	do	do	1–126 4″ x 18′ tubes, 1–108 4″ x 18′.	2	2	...	250, 208	264, 226	2, 640, 2, 260	0	85
97	6–8	do	Stirling	2–181 3¼″ tubes, 3–403 3¼″ tubes	5	4	1	250, 500	250, 500	2, 500, 5, 000	0	100
98	4–6	do	do	181 3½″ tubes, 3 36″ drums	2	1	1	200	...	...	0	150
99	...	do	do	...	4	3	2	300	322	3, 223	0	145
100	5–6	do	do	...	2	2	2	250	214	2, 135	0	100
101	5–6	do	do	...	1	1	1	413	413	4, 130	0	100
102	4	do	do	...	4	3	3	300	300	3, 000	0	150
103	6	do	do	168 3¼″ tubes	1	1	1	306	305	3, 050	0	130
104	4–6	do	do	192 3½″ tubes	3	2	2	200	...	...	0	110
105	4–6	do	do	96 3¼″ tubes	2	2	...	100	...	...	0	100
106	4	do	do	176 3¼″ tubes	2	1	1	200	200	2, 000	0	115
107	3–4	do	Aultman & Taylor	144 4″ x 18′ tubes, 2 36″ drums.	2	1	1	300	300	3, 000	0	150
108	3–6	Variable	Heine	113 3½″ x 16′ tubes, 2 30″ x 16′ drums.	4	2. 5	2	250	184	1, 840	0	100
109	6	Continuous	Erie City	...	2	2	2	125	...	...	0	115
110	6–8	do	Henry Vogt	...	2	1	...	200	...	...	0	105–120
111	...	do	Heine; Stirling	...	6	6	6	140, 380	140, 380	1, 402, 3, 795	0	110
112	5	do	McNaull	100 4″ x 17′ tubes	6	4	4	200	210	2, 095	0	200
113	5–6	do	Hazelton	...	1	1	1	350	...	...	0	100
114	4–6	do	National	72 4″ x 14′ tubes	2	2	2	100	120	1, 200	0	100
115	...	2 times in 12 hours	Aultman & Taylor	...	3	2	2	400	402	4, 022	582	150
116	4–5	Continuous	Henry Vogt	...	2	1	1	150	...	...	0	100
117	4–6	do	Heine; Edgemoor	2–67 3½″ x 18′ tubes, 1–138 4″ x 18′ drums.	3	2	1,2	150, 300	110, 300	1, 100, 3, 000	0	110–115
118	6–10	Once in 8 hours	Standard	192 4″ x 18′ tubes	15	12	12	450	402	4, 020	0	110
119	...	Continuous	Atlas	...	2	2	2	150	150	1, 500	0	110

[a] Boiler rated on 10 square feet of heating surface per horsepower.

[b] Variable.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Furnaces.									
			Dimensions (feet).							
	Number.	Grate area per boiler (square feet).	Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch or heating surface.		Height of arch at rear of furnace (H).
			Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
90	24	70	10	6.5	5	7	9	3.9	....	3.9
91	2	35	9	5.5	5	7	8.8	3.75	3.75	....
92	3	36,25	8,8.5	5.5	5,6	5,6	4	4	4	....
93	1	42	9.5	6.5	7	6	6.6	5	5	....
94	4	56	8.5	5.5	8	7	7.2	6.1	6.1	....
95	2	42	8	6	7	6	6.5	4.8	....	4.8
96	2	42,36	a 8,7	a 5.5,4.5	6	a 6,7	6	4.4	4.4	....
97	8	38.5,77	14	10.5	5.6	7	9	4.5	4.5	....
98	2	39	7.5	4.5	6.5	6	2	5	5	....
99	8	50	11	9	5	5	6.6	4.5	4.5	5.5
100	2	42	7	3.5	7	6	0	5	5	5
101	1	64	7	3.5	8	8	2	6.5	6.5	6.5
102	4	48	8	5	8	6	3	6	6	6
103	1	49	14.5	11	7	7	7.5	5.25	5.25	....
104	3	36	8.5	6	6	6	4.5	4.8	....	4.8
105	2	24	9.5	6.5	4	6	4.5	3.5	....	3.5
106	2	35	5.5	3.5	6.75	5.25	0	4.8	....	4.8
107	2	49	20	16.5	7	7	9	5.25	5.25	....
108	8	30	9	6.5	3	5	0	2.75	....	2.75
109	2	30	....	....	5	6	1.25	....	....	....
110	2	25.7	....	....	4.7	5.5	0	....	....	....
111	8	42,63	b 9,6.5	b 7,3	b 6,7	b 7,4.5	0	b —,3.3	b —,3.3	....
112	6	36	9	6	6	6	6	5	5	....
113	4	100	8	....	5	5	....	....	....	....
114	2	20	7	4.75	4	5	5.3	3.25	3.25	....
115	3	59.5	10.5	7.5	7	8.5	9	6.5	6.5	....
116	2	26.5	....	....	4.4	6	0	....	....	....
117	3	25,49	b 7.5,8	5.5	b 5,7	b 5,7	0	3.9	3.9	....
118	15	56	9	6	8	7	8.5	6	6	....
119	2	23.2	3.5	3	5.25	4.4	0	5.5	5.5	....

a First dimension applies to small boiler.

b First dimension applies to Heine boiler.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Draft.						Smoke records.						
	Kind.	Readings (inches of water).				Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke.	Load during observations.
		Furnace.	Rear of boiler.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
90	Chimney..	0.18–0.27	0.44–0.54	....	....	Dampers open....................	3	160	0.5	0	0	14.1	Average.
91	...do.....	.18	.50	....	....	Ash-pit doors open, dust doors cracked.	1	60	0	0	48	3.3	Light.
92	...do......	.17– .19	.31– .40	....	0.56	Dust-pit doors open..............	1	60	0	2	56	2.2	Average.
93	...do......	.09– .12	.16– .19	0.29–0.31	....	....	1	300	0	1	56	1.7	Do.
94	...do......	.25– .30	.44– .45	.70– .75	....	Ash and dust-pit doors open; damper partly closed.	1	60	0	0	56	.8	Light.
95	...do......	.37	.50	....	....	Damper and ash-pit doors open....	(*a*)	(*b*)	0	0	....	....	Do.
96	...do......	.37, .42	.55, .58	....	.60	Dampers open; ash-pit doors cracked.	2	80	0	1	27	9.1	Heavy.
97	...do......	.20	Lower rear, .35	....	.75	Door in stack open..............	3	183	0	0	44	3.5	Light.
98	...do......	....	....	....	....	....	1	77	0	2	50	4.9	Do.
99	...do......	.18– .24	.32– .38	.22– .34	.54	Dampers open	1	45	0	0	57	.9	Average.
100	...do......	.18– .28	Lower rear, .56– .64	....	....	....	2	120	0	2	49	5	Do.
101	...do......	.18– .36	Lower rear, .34– .58	....	.76	....	2	120	0	1	56	1.8	Do.
102	...do......	.11– .18	Lower rear, .40– .60	....	.90	....	1	60	0	0.5	53	2.5	Do.
103	...do......	.53	Lower rear, .60	.90	....	Damper open.....................	1	46	0	0	57	1.3	Heavy.
104	...do......	.15	....	.75	....	.....do.........................	(*a*)	(*b*)	0	0	....	....	Light.
105	...do......	.10	....	.45– .50	....	.....do.........................	(*a*)	(*b*)	0	0	....	....	Heavy.
106	...do......	....	Lower rear, .45	.90	1.10	Dampers open; thin fire..........	(*a*)	(*b*)	....	....	....	....	Average.
107	...do......	.12	....	.43	....	Damper open.....................	3	211	0	0	60	0	Do.
108	...do......	.08– .17	.90	1.26	....	Dampers open....................	5	333	0	0	56	1.4	Do.
109	...do......	....	....	....	....	....	1	60	0	0	....	12.7	Light.
110	...do......	.34	.39– .45	.64	....	Damper and ash-pit doors open...	2	115	0	4	48	12.5	Heavy.
111	...do......	.12– .30	....	.65– .74	....	....	1	60	0	0	44	7.7	Average.
112	...do......	.14– .25	....	.26– .34	.55–.60	Dampers open....................	1	60	0	.5	55	2.5	Do.
113	...do......	.12– .15	....	....	.18	....	2	120	0	0	60	0	Do.
114	...do......	.13– .15	....	....	.65	Dampers partly closed............	1	30	0	0	30	7.7	Heavy.
115	...do......	.30– .48	.53– .67	....	1.10	Ash-pit doors open...............	1	600	0	0	49	5.7	Average.
116	...do......	.18	.43	....	.70	Damper partly closed.............	1	110	1	1	43	7	Heavy.
117	...do......	.20– .30	.30– .40	....	.65	Dampers open; heavy fire.........	1	60	0	0	35	7.2	Light.
118	...do......	.20– .29	.25– .56	....	.92–1	....	1	60	0	0	39	8.3	Average.
119	...do......	.22– .26	.39– .49	....	.56	....	1	30	0	0	30	5	Do.

a Several. *b* Various lengths.

TABLE 13.—*Details of observations at plants with side overfeed stokers under water-tube boilers*—Continued.

No. of plant.	Breeching. Length from stack to nearest boiler (feet).	Breeching. Size (feet).	Breeching. Place at which measurement was taken.	Breeching. Number of elbows between boilers and stack.	Stack. Height (feet).	Stack. Size (feet).	Stack. Area (square feet).	Remarks.
90	4	....	....	0	203	a 16	201	Coal as received contains 16 to 20 per cent ash; 11,000 to 11,500 B. t. u. per pound. Steam pressure regulated by opening and closing ash-pit doors. Plant runs in connection with storage batteries which are used to assist in carrying peak loads. Stack smoked considerably, 10 to 20 per cent black.
91	5	....	....	1	110	a 5	19. 6	
92	0	0	....	0	105	4 x 4	16	
93	50	....	....	4	71	3 x 3	9	
94	35	....	....	0	150	a 12	113. 5	Automatic regulator on main damper in breeching. Stack reported bad at times on heavy load.
95	26	....	....	1	165	a 5. 5	23. 7	
96	3	....	....	1	122	a 5. 5	23. 7	Automatic regulator on main damper.
97	40	....	....	1	305	b 13 x 6	70. 3	One 250-horsepower boiler carries the light load; three 500-horsepower and one 250-horsepower the heavy load. Try to carry draft of about 0.25 inch water in furnace. Run with dust-pit doors three-quarters open and ash-pit doors half open.
98	12	4 x 4. 5	Near stack........	0	125	a 5	19. 6	Coal as received contains about 12,000 B. t. u. per pound and 7 per cent ash. Furnace too large for light load. On light load run with damper half closed, ash-pit and dust-pit doors closed, furnace door three-quarters closed. No draft readings taken on account of these conditions.
99	9	....	....	1	140	6 x 6	36	Wet coal banks on grates and has to be poked down, producing smoke.
100	0	0	....	0	108	a 2. 5	4. 9	Two similar stacks, resting on rear of boilers. Smoke average is from both stacks.
101	0	0	....	0	100	a 3	. 06	Stacks rest on rear of boilers.
102	15	....	....	0	152	a 6. 5	33. 2	Smoke observation taken when carrying furnace draft of 0.15 inch water. With furnace draft reduced to 0.07 inch stack smoked continuously, 20 to 40 per cent black.
103	35	....	....	1	150	a 8	50. 24	Automatic regulator attached to main damper.
104	3	....	....	0	125	a 4	12. 56	Smoke observations include some readings 10 and 20 per cent black. Total length of Murphy and Stirling arch, 9 feet.
105	10	....	....	0	80	2 x 2	4	Draft assisted by ½-inch steam pipe entering breeching. Smoke observations include some readings 10 and 20 per cent black. Total length of Murphy and Stirling arch, 10 feet.
106	11	....	....	0	252	a 4	12. 56	Smoke observations include a great many readings 20 per cent black and several 60, 80, and 100 per cent black. Stoker does not distribute the coal evenly along grate, and fire has to be poked down.
107	20	4 x 4	Near stack........	1	127	a 6	28. 3	Coal as received runs about 12,000 B. t. u. per pound. A gas-mixing pier is in combustion chamber, also 16-inch projections built on bridge wall to deflect gases inward. Gases cross the tubes four times. Very hot fire.
108	11	10 x 4	.....do............	0	305	a 7	38. 5	Coal as received runs about 12,000 B. t. u. per pound. Arch 5 feet 9 inches long. C tile on lower row of tubes. Run with ash-pit doors open.

109	18	....	....	1	125	a 4	12.56	
110	18	....	....	0	....	....	....	Fired occasionally through furnace door.
111	5	....	....	1	125	a 6.5	33.2	Coal as received runs about 12,700 B. t. u. per pound and 10 to 14 per cent ash. One stoker per Heine boiler; two stokers per Stirling boiler. U tile on lower row of tubes of Heine boiler. About half as much coal burned per furnace under Stirling boilers as under Heine boilers. Stirling boilers have poor draft.
112	22	....	....	2	110	a 7.1	40	Boiler baffled vertically.
113	0	0	....	0	66	a 4	12.56	Stacks rest on top of boiler.
114	8	....	....	0	125	a 5	19.6	Automatic regulator attached to main damper.
115	11	....	....	0	175	a 7	38.5	
116	2	....	....	1	105	a 3.5	9.6	Stack smokes sometimes from 20 to 30 per cent black for ten to fifteen minutes.
117	5	....	....	0	120	a 5	19.6	Either the two small boilers or the large one will carry the light load. Edgemoor boiler is baffled like Heine. U tile on lower row of tubes. Automatic regulator on main damper.
118	0	....	....	2	250	a 16	201	Fires sliced often. Rubbish burned also at this plant.
119	12	....	....	1	95	3.3 x 3.3	11.1	Smoked considerably, 10 per cent black.

a Diameter. b Ellipse.

Plants with return tubular boilers.—Side overfeed stokers were installed under return tubular boilers at 48 plants, with rated boiler capacity varying from 50 to 180 horsepower. At two of these plants the stokers were set in a Dutch oven. The kinds of coal burned and the thickness of fire were as follows:

TABLE 14.—*Kind of coal and depth of fire at plants, with side overfeed stokers under return tubular boilers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	7	5	Pennsylvania	11	5
Indiana	3	4	West Virginia	8	6
Kentucky	5	4	Miscellaneous	8	5
Ohio	6	5			

Other details given in Table 15 regarding the setting and operation of side-feed stokers at these plants may be briefly summarized thus:

Draft through fire, 0.17 inch; coal as received burned per square feet of grate surface per hour, average heavy load, 20.6 pounds; percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 90; average distance from grates to tube heating surface, 14.5 feet; average vertical distance from clinker grinder to coking arch, 3.75 feet; per cent of black smoke, 5.6. Approximate draft averages gave a furnace draft of 0.15 inch and a drop through the boiler of 0.25 inch. The drop from the boiler to the stack averaged 0.20 inch.

Details of the observations at plants with side-feed stokers under return tubular boilers are given in Table 15

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
120	Illinois	Murphy	1,080	Washed	Marion County, Ill	No. 2	$2.90	
121	....do	....do	640		Illinois; Indiana	Screenings	1.80–2.35	
122	....do	....do	360	Steam nut	Benton, Ill	Through a 3-inch screen	2.35	
123	....do	....do	320	Carterville	Illinois	Nos. 2 and 3, mixed		
124	....do	....do	250	Carterville, washed	....do	No. 3	2.15	
125	....do	....do	240		....do	No. 3 nut and screenings.		
126	....do	....do	176	Carterville, washed	....do	No. 3	2.80	
127	Indiana	....do	400	Linton	Indiana	No. 4	2.35	
128	....do	Detroit	195		....do	Nut and slack		
129	Kentucky	....do	600		Western Kentucky	Pea and slack		
130	....do	....do	450		....do	....do		
131	....do	....do	300		....do	Nut and slack		
132	....do	....do	150		....do	Pea and slack		
133	Ohio	Murphy	100	Laurel; Jellico	Kentucky	Nut and slack	2.00	
134	....do	....do	600	Pittsburg No. 8	Dillonvale, Ohio	Pea and slack	2.00	
135	....do	....do	600	....do	Ohio	Slack	2.05	7,300
136	....do	....do	500	....do	....do	....do	2.35	5,500
137	....do	....do	450	....do	Dillonvale, Ohio	Pea and slack	2.00	5,100
138	....do	....do	300	Youghiogheny	Ohio	1-inch nut	1.90	
139	New York	....do	874	Pittsburg	Elk County, Pa	Slack	2.40	6,000
140	Kentucky	Detroit	600		Pittsburg, Pa	Nut and slack		
141	Pennsylvania	Murphy	405	Clearfield	Pennsylvania	Run of mine	2.80	
142	Ohio	....do	360	Pittsburg	....do	Nut and slack	1.87	
143	....do	....do	320	....do	....do	....do		
144	Pennsylvania	....do	300	Westmoreland gas slack	....do	Slack	3.00	
145	Ohio	Detroit	300	Pittsburg	....do	....do	1.80	1,200
146	New York	Murphy	300	Rochester; Pittsburg; Reynoldsville.	....do	1¼-inch nut	2.55	2,100
147	Ohio	....do	200	Pittsburg	....do	Nut and slack		
148	Pennsylvania	....do	150		....do	....do		
149	Ohio	....do	50	Pittsburg	....do	....do		
150	....do	....do	1,000	Kanawha	West Virginia	....do	2.00	
151	....do	....do	790	....do	....do	....do	2.00	
152	....do	....do	750	....do	....do	....do	1.69	
153	Pennsylvania	....do	445	Gas slack	....do	Slack	2.55	
154	Michigan	Detroit	350	Pittsburg No. 8; Thacker.	Ohio; West Virginia	Nut and slack	2.60	2,560
155	Ohio	Murphy	300	Kanawha	West Virginia	....do	1.90	2,730
156	Michigan	Detroit	250	Red Jacket	....do	....do	2.70	900

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
157	Kentucky	Detroit	140		West Virginia	Run of mine; pea and slack.		
158	Pennsylvania	Murphy	1,000	Gas slack			$3.05	
159	do	do	450			Run of mine		
160	Ohio	do	250			Nut and slack	1.90	
161	Michigan	do	200	Various coals		Slack	2.00	
162	Pennsylvania	do	180			Run of mine		
163	do	do	179			Slack	3.30	
164	Ohio	Detroit	150	Cedar Point		Nut and slack	1.70	
165	do	Murphy	150	Various coals		Slack	1.85	1,200

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Load. Requirement.	Load. Nature.	Load. Character.	Rating. Average load. Heavy. Hours per day load is on plant.	Heavy. Coal burned per day (short tons).	Light. Hours per day load is on plant.	Light. Coal burned per day (short tons).	Coal burned per square foot of grate per hour (pounds). Average heavy load.	Coal burned per square foot of grate per hour (pounds). Average load.	Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
120	Power, light, and heat	Uniform	Department store	11	33	11	39	26	25	110	143	5
121	....do	Variable	Office building	18	16	18	13	21	19	95	77	5
122	....do	Uniform	Hotel	18	10	18	8	31	28	134	123	5
123	....do	Variable	....do	24	14	24	12.5	24.3	23	124	146	5
124	....do	....do	Factory	9	7	9	6	23.5	21.9	106	123	5
125	....do	Uniform	Office building	17	6	17	6	17.7	17.7	75	88	5
126	....do	....do	....do	18	8	12	5	29.6	28.6	189	214	5
127	....do	....do	Store building	9.5	11	9.5	9.5	23.2	21.6	95	116	5
128	....do	....do	School building	24	10	16	4.5	17.4	17.4	109	81	5
129	....do	....do	Ice plant	24	20	24	16	37	33.3	83	83	5
130	Power and light	....do	....do	24	20	24	18	41.3	39	105	111	5
131	Power and heat	....do	Factory	10	3	10	3	33.3	33.3	75	80	5
132	....do	....do	Pottery	11	1.6	11	1.6	10	10	37	39	5
133	Power, light, and heat	....do	Printing office	9.5	2.5	9.5	1.4	21	17.8	85	105	5
134	....do	....do	Office building	14	8	....	....	17.3	....	71	85	4.5
135	....do	....do	Store and office building	17	11.6	17	9.2	19	15.5	61	68	5
136	....do	....do	Office building	12	10	12	9	25.3	24	104	89	5
137	....do	....do	....do	12	8	12	8	14.8	14.8	64	66	4
138	....do	....do	Factory	10	4.4	10	4.4	17.6	17.6	72	88	5
139	Power	....do	Refrigeration	12	15	....	....	20	....	107	107	4
140	Power and light	Variable	Apartment house	24	10.3	24	9	17.4	16.3	58	57	5
141	Power, light, and heat	Uniform	Factory	11	6.7	....	....	13	....	65	75	4
142	....do	Variable	Office building	18	7	18	4.5	15.6	12.8	64	65	5
143	....do	....do	Brewery	12	10	24	16	16.7	15	....	104	5
144	Power and heat	Uniform	Mill	11	10	11	7.8	27.6	24.5	182	152	4
145	Power and light	....do	Factory	10	5.5	10	5.5	14.7	14.7	94	82	4.5
146	Power, light, and heat	....do	Hotel	24	6	24	6	14	14	79	83	4
147	....do	Variable	Brewery	12	5.5	24	9	14	12.7	....	93	5
148	Power	Uniform	Factory	10	2.8	10	2.2	14	12.5	73	93	4

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.								
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
149	Heat	Variable	Dye works	11	2	11	1	16.2	12	119	146	5
150	Heat and light	do	Brewery	11	12.9	11	9.1	15.9	14.8	64	84	4.5
151	Power, light, and heat	Uniform	Department store	10	9	10	6	19	16.4	71	62	5
152	do	do	Office building	16	8	16	4	20	20	72	67	5
153	Power and heat	do	Factory	10	13.4	10	10	25.5	22.7	138	147	5
154	Power, light, and heat	do	Hotel	13	4.5	13	4.5	23.5	23.5	86	88	4.5
155	do	do	Mill	24	8.5	24	8.5	14.2	14.2	47	53	4.5
156	do	do	Office building	10	2.6	10	2	23.6	20.9	84	92	4.5
157	do	do	do	24	2	....	....	12.4	....	42	60	5
158	do	do	Factory	12	28	12	20	28	24	131	117	4
159	Power	do	Ice plant	24	30	24	22.5	25.3	22.1	92	139	4
160	Power, light, and heat	do	Factory	14.5	3.5	10	6	20.7	20.4	79	96	5
161	Power and heat	do	do	24	6.7	10	1.6	11.2	....	40	62	4.5
162	do	do	Mill	10.5	3.4	10.5	3.4	14.4	14.4	67	80	4.5
163	do	do	do	9.5	3	9.5	3	15.8	15.8	73	88	4
164	Power, light, and heat	do	Library	13.5	5	13.5	3	25.1	23	81	99	5
165	do	Variable	Shops	10	4	10	4	22.2	22.2	89	107	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Stoking. Thickness of fire (inches).	Stoking. Frequency of cleaning fire.	Boilers. Type	Boilers. Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horse-power.	Horse-power boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
120	4	3 times in 24 hours	Return tubular	72″ x 20′, 56 4½″ tubes	9	7	9	120	155	1,550	0	100
121	3–4	Continuous	do	1 48″ x 14′, 32 3½″ tubes; 6 48″ x 16′, 32 3½″ tubes; 2 42″ x 16′, 28 3½″ tubes.	9	7	5	60, 65, 75	49, 55	490, 550	0	100
122	3–6	do	do	66″ x 16′, 42 4″ tubes	4	2	2	90	83	830	0	120
123	4–5	3 to 4 times in 24 hours.	do	60″ x 16′, 48 4″ tubes	4	2	2	80	94	940	0	90
124	6	Continuous	do	78″ x 19′, 84 3″ tubes	2	2	2	125	147	1,470	0	110
125	3–4	do	do	54″ x 16′, 48 4″ tubes	3	2	2	80	94	940	0	85
126	5	do	do	1 66″ x 16′, 54 4″ tubes; 1 60″ x 18′, 42 4″ tubes.	2	1	1	93, 83	106, 94	1,060, 935	0	85, 90
127	4	do	do.	3 66″ x 16′, 64 4″ tubes; 1 66″ x 14′, 72 3½″ tubes.	4	4	4	100	126, 109	1,260, 1,085	0	80
128	3	do	do	60″ x 20′, 5 12″ tubes	3	3	2	65	51	505	0	70
129	4	do	do	78″ x 18′, 90 4″ tubes	3	2	2	200	200	2,000	0	100
130	3	do	do	72″ x 18′, 72 4″ tubes	3	2	2	150	159	1,590	0	105
131	4	do	do	72″ x 18′, 72 4″ tubes	2	1	1	150	159	1,590	0	90
132	4–6	do	do	60″ x 18′, 72 4″ tubes	1	1	1	150	159	1,590	0	80
133	5	3 times in 10 hours	do	66″ x 18′, 56 4″ tubes	1	1	1	100	124	1,240	0	80
134	....	Continuous	do	72″ x 18′, 92 3½″ tubes	4	2	....	150	178	1,785	0	100
135	4	Once in 17 hours	do	78″ x 20′, 84 4″ tubes	3	2	2	200	225	2,250	0	120
136	4	Continuous	do	60″ x 18′, 48 4″ tubes	4	3	3	125	107	1,065	0	110
137	5	do	do	3 60″ x 16′, 48 4″ tubes; 1 72″ x 18′, 90 3½″ tubes.	4	4	4	100, 150	95, 176	950, 1,760	0	90–100
138	5–6	do	do	66″ x 18′, 54 4′ tubes	3	2	2	100	122	1,220	0	100
139	4–5	do	{2 return tubular {3 Babcock & Wilcox	2 60″ x 18′, 72 4″ tubes; 1 90 4″ x 16′ tubes; 1 108 4″ x 16′ tubes; 1 120 4″ x 16′ tubes.	5	3	....	{125, 200 {224	158, 168 201, 224	1,580, 1,675 2,010, 2,235	0	160
140	4	do	Return tubular	72″ x 18′, 70 4″ tubes	4	2	2	150	147	1,470	0	100
141	4–6	do	do	3 60″ x 18′, 36 4½″ tubes; 1 72″ x 18′, 60 4½″ tubes.	4	4	....	85, 150	108, 146	1,080, 1,460	0	100
142	6–7	3 times in 24 hours	do	60″ x 18′, 48 4″ tubes	3	2	2	120	122	1,220	0	95
143	4	Continuous	do	62″ x 16′	4	4	4	80	....	....	0	90
144	4–6	do	do	72″ x 18′, 45 5″ tubes	2	2	2	150	125	1,250	0	120
145	3–5	do	do	60″ x 16′, 44 4″ tubes	3	3	3	100	87	870	0	100

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Stoking.		Boilers.									
	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry—		Builder's rated horse-power.	Horse-power boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
						Average heavy load.	Average light load.					
146	6	Continuous	Return tubular	72″ x 16′, 92 3½″ tubes	2	1	1	150	159	1,585	0	90
147	4	....do	....do	72″ x 18′	2	2	2	100	....	....	0	90
148	3–4	....do	....do	60″ x 16′, 36 4½″ tubes	2	2	2	75	96	960	0	65
149	(*a*)	3 to 4 times in 11 hours	....do	60″ x 16′, 18 6″ tubes	1	1	1	50	61	610	0	45
150	8–10	5 times in 24 hours	....do	4 72″ x 16′, 84 4″ tubes; 4 72″ x 16′, 72 4″ tubes.	8	5	4	125	175, 155	1,750, 1,550	0	85
151	6–8	Once in ten hours	Return tubular; Heine water-tube.	1 72″ x 18′, 70 4″ tubes; 1 113 3½″ x 16′; 2 87 3½″ x 16′.	4	4	2	{140, 200, 250	166, 142 184	1,560, 1,420, 1,840	} 0	110
152	6	6 times in 24 hours	Return tubular	72″ x 16′, 70 4″ tubes	5	2	1	150	138	1,380	0	80
153	3–4	Continuous	....do	4 60″ x 16′, 44 4″ tubes; 1 72″ x 18′, 45 5″ tubes.	5	4	4	80, 125	87, 127	870, 1,270	0	80
154	....	....do	....do	78″ x 18′, 82 4″ tubes	2	1	1	175	180	1,800	0	110
155	3–5	....do	....do	1 72″ x 18′, 72 4″ tubes; 1 72″ x 18′, 92 3½″ tubes.	2	2	2	150	158, 179	1,576, 1,785	0	100
156	4–5	....do	....do	72″ x 16′, 70 4″ tubes	2	1	1	125	137	1,372	0	80
157	5–6	....do	....do	54″ x 18′, 36 4″ tubes	2	1	1	70	80	800	0	80
158	6	....do	....do	2 72″ x 20′, 60 4″ tubes; 3 72″ x 20′, 60 4½″ tubes.	5	5	5	200	168, 184	1,680, 1,835	0	115
159	4	....do	....do	78″ x 20′, 86 4″ tubes	3	3	3	150	226	2,260	0	95
160	4	....do	....do	1 72″ x 18′, 94 4″ tubes; 1 60″ x 16′, 47 4″ tubes.	2	2	2	150, 100	209, 93	2,085, 930	0	95
161	....	....do	....do	72″ x 16′, 84 3½″ tubes	2	2	1	100	158	1,575	0	105
162	6	....do	....do	60″ x 18′, 36 4½″ tubes	2	2	2	90	108	1,080	0	100
163	6	....do	....do	1 72″ x 18′, 45 5″ tubes; 1 54″ x 14′, 42 3½″ tubes.	2	2	2	123, 56	144, 74	1,440, 735	0	90
164	4–6	....do	....do	60″ x 16′, 46 4″ tubes	2	2	1	75	91	910	0	85
165	4	2 times in 10 hours	....do	72″ x 18′, 74 4″ tubes	1	1	1	150	180	1,802	0	100

a Variable.

Table 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Furnaces.									
	Number.	Grate area per boiler (square feet).	Dimensions (feet).							
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch or heating surface.		Height of arch at rear of furnace (H).
			Average (A).	Minimum. (B).				At front of furnace (F).	At rear of furnace (G).	
120	9	33	21	18	5.5	6	0	4	4	...
121	9	14	16, 18	14, 16	3.5	4	0	2.7	2.7	...
122	4	18	16	14	4.5	4	0	3.5	3.5	...
123	4	24	17	14	4	6	0	3	3	...
124	2	33	17.5	14.5	5.5	6	0	4.5	4.5	...
125	3	20	16	13.5	4	5	0	3	3	...
126	2	30	15, 17	12, 14	5	6	0	2.25	2.25	...
127	4	25	15.5, 13.5	13, 11	5	5	0	4	4	...
128	3	16	20	18	4	4	0	...	...	...
129	3	22.5	18	15.5	5	4.5	0	...	...	...
130	3	20.3	18	15.5	4.5	4.5	0	...	...	...
131	2	21.8	18	16	4.7	4.6	0	...	...	...
132	1	29.3	18	15	5.3	5.5	0	...	...	...
133	1	25	17	15	5	5	0	4	...	4
134	4	33	17.5	14.5	5.5	6	0	3.75	3.75	...
135	2	36	19.5	17	6	6	0	4.3	4.3	...
136	4	22	17.5	15.5	5.5	5	0	4	4	...
137	4	20, 30	15, 17	13, 14.5	4, 5	5, 6	0	3.2, 3.5	3.2, 3.5	...
138	3	25	17.5	15.5	5	5	0	4	4	...
139	5	36, 45	15, 8	12.5, 5	6	6, 7.5	0, 6	4, 4.25	4, 4.25	...
140	4	24.75	18	15.5	5.5	4.5	0	...	...	...
141	4	22.5, 27	18	15.5, 15	4.5	5, 6	0	3.5, 4	3.5, 4	...
142	3	25	17	15	5	5	0	3.4	...	3.4
143	4	25	15	13	5	5	0	3.4	3.4	...
144	2	33	17.5	14.5	5.5	6	0	4	4	...
145	3	25	15.5	13.5	5	5	0	3.1	3.1	...
146	2	36	15	12	6	6	0	3.5	3.5	...
147	2	33	17	14	5.5	6	0	4	...	4
148	2	20	15.5	13	4	5	0	3.2	3.2	...
149	1	22.5	15.5	13.5	4.5	5	0	3.75	...	3.75
150	8	33, 27.5	16, 13	15.5, 12	5.6	6, 5	0	3.8	3.8	...

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Furnaces.									
	Number.	Grate area per boiler (square feet).	Dimensions (feet).							
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance from grates to coking arch or heating surface.		Height of arch at rear of furnace (H).
			Average (A).	Minimum (B).				At front of furnace (F).	At rear of furnace (G).	
151	4	30-39, 33	6, 6, 16	4.5, 4.5, 13.5	6, 6, 5.5	5, 6.5, 6	0	4.25, 4.25, 4		4.25, 4.25, 4
152	5	25	15.5	13	5	5	0	4		4
153	5	25, 30	16, 18	13.5, 15	5	5, 6	0	4	4	
154	2	29.4	17	15	5.7	5.25	0	4.3		
155	2	25	17.5	15.5	5	5	0	4	4	
156	2	22	16	14	4.4	5	0	3.8		
157	2	13.5	18	16	3	4.5	0			
158	5	30, 36	26, 26.5	23.5	6	5, 6	6.5	4.3	4.3	
159	3	33	19.5	16.5	5.5	6	0	4.4	4.4	
160	2	33, 25	17, 16	14	5.5, 5	6, 5	0	4.2, 4		4.2, 4
161	2	25	15	13	5	5	0			
162	2	22.5	18.5	16	4.5	5	0	3.5	3.5	
163	2	25, 15	20.5	19, 18	5	3, 5	4.5	3.9	3.9	
164	2	17.7	15	13	4	4.4	0	2.2		
165	1	36	17	15	6	6	0	4.5	4.5	

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
120	Chimney..	0.08–0.12	a 0.22		0.31–0.68		Furnace doors cracked; pit doors and dampers open.	4	237	0	0	32	5.6	Average.
121	...do.....	.08– .12		0.38–0.48	.52– .68		Dust pit and dampers open	1	61	0	0	57	1	Light.
122	...do.....	.08– .12			.85		Dampers and ash-pit doors open; thin fire.	2	90	1	1	30	12.1	Do.
123	...do.....	.07– .08		.34– .35	.58		Dampers and ash-pit doors open.	2	90	1	1	48	15.3	Average.
124	...do.....	.30			.46		Dampers partly closed; thin fire; dust doors three-fourths open.	1	60	2	3	22	16.2	Light.
125	...do.....	.10 –.12		.46– .48			Dampers and pit doors open.	1	40	0	0			Average.
126	...do.....	.22			.46		Damper and ash-pit doors open.	1	30	0	0	44	2.7	Do.
127	...do.....	.11– .14				0.64	Dampers open; ash and dust-pit doors closed.	2	90	2	4	42	17.7	Light.
128	...do.....	.16– .18			.28		Dampers and pit doors open; thin fire.	1	30	0	0	37	7	Do.
129	...do.....	.36		.63– .65			Dampers open	1	40	0	0	0	20	Average.
130	...do.....	.10– .13			.46– .48		Dampers open; thin fire	1	55	0	0	0	30	Do.
131	...do.....	.25		.37		.48–.52	Damper open	1	60	0	0	50	1.4	Do.
132	...do.....	.09			.36		...do	1	60	0	1	57	1.7	Do.
133	...do.....	.18			.35		Damper and ash pit doors open.	2	60	0	0	60	0	Heavy.
134	...do.....	.20– .27			.50– .65	1.10		(b)	(c)	0	0	57	1.5	Light.
135	...do.....	.28– .37		.52– .70			Damper open; thin fire	1	240	0	0	59	.3	Average.
136	...do.....	.07– .11		.41	.92			1	240	0	0	57	1.2	Do.
137	...do.....	.10– .16		.38– .45	.84	.90		(b)	(c)	0	0	0	10	Do.
138	...do.....	.06– .08		.09– .19				2	120	0	0	60	0	Do.
139	...do.....	.09– .15	.12– .22				Ash-pit doors open	1	60	0	0	58	.7	Heavy.
140	...do.....	.33– .34			.42		Dampers open; ash-pit doors cracked.	2	170	2	4	49	9.2	Average.
141	...do.....	.23– .24			.55		Dampers open	1	30	0	0	58	0	Heavy.
142	...do.....	.10– .12			.37	.50	...do	(b)	(c)	0	0	60	0	Light.

a Combustion chamber. b Several. c Various lengths.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
143	Chimney	0.12–0.14				0.58	Ash-pit doors and dampers open.	2	60	0	0			Light.
144	...do	.12– .15				.60–.65	Average conditions; dampers partly closed.	1	57	2	4	50	10	Heavy.
145	...do	.10– .15		0.20–0.27				1	60	0	1	53	3.7	Average.
146	...do	.08		.16		.47		1	60	0	0	60	0	Do.
147	...do	.16– .18	a 0.36–0.40				Ash-pit doors and damper open.	2	60	0	0			Light.
148	...do	.08– .16					Damper and dust-pit doors open.	2	60	0	2	55	1.7	Average.
149	...do	.10				.40	Damper open; thin fire	(b)	(c)	0	0			Light.
150	...do	.12	d .20		0.67–0.75	.90	Dampers partly closed	(b)	(c)	0	0	55		Do.
151	...do	.10– .12	.25		.30– .55		Dampers open	(b)	(c)	0	0			Heavy.
152	...do				.85		...do	(b)	(c)	0	0			Do.
153	...do	.10– .16			.32	.55	Dampers open; thin fire; ash-pit doors cracked.	1	30	0	3.5	44	12	Average.
154	...do	.17		.32		.56		1	60	0	2	53	4.7	Do.
155	...do	.24– .29			.38– .40	.65		1	60	0	0	60	0	Do.
156	...do	.17– .20		.33		.54		1	60	0	1	57	2	Heavy.
157	...do	.18			.50		Damper and ash-pit doors open.	1	110	2	2	53	6.2	Average.
158	...do	.35– .40	d .45		.85– .95		Dampers open	2	55	0	0	59	0	Do.
159	...do	.13– .15			.42– .45	.62	Thin fire; dampers partly closed.	2	65	0	0	55	3	Light.
160	...do	.10– .32				.75	Dampers open	(b)	(c)	0	0			Do.
161	...do	.16– .19		.30		.55		(b)	(c)	0	0	55	2	Heavy.
162	...do	.25– .27			.53		Damper open	1	40	0	0	58	1	Average.
163	...do	.12– .15			.45		Damper partly closed	1	57	0	1			Do.
164	...do	.27– .30			.47– .50	.47–.50	Dampers and ash-pit doors open.	(b)	(c)	0	0			Light.
165	...do	.22		.43	.60	.76	Thin fire	1	300	0	0	56	1.7	Average.

a Upper rear. b Several. c Various lengths. d Combustion chamber.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
120	16	6 x 5	Near stack	1	185	*a* 10	78.5	
121	15			1	230	6 x 6	36	
122	30	4 x 4	Near stack	1	160	4 x 4	16	Smokes considerably. 10 to 20 per cent black.
123	0			1	150	*a* 5.3	22.2	
124	47	4 x 3.5	Near stack	1	125	5 x 5	25	Shavings fed continuously through openings over the furnace doors. Automatic regulator on main damper. Stack smokes considerably, 10 to 40 per cent black.
125	48	3.5 x 4	45′ from stack	1	180	*a* 3.5	9.6	
126	0.15			1, 2	100, 90	*a* 3, 2.2x2.7	7.06, 5.8	Plant has damper regulator but it is not used; when it is in service there is difficulty in keeping smoke down. Trouble in carrying load and keeping down smoke when coal smaller than No. 3 is burned. Plant often runs with furnace door open.
127	15			1	90	3.7 x 3.7	13.4	
128	15			1	90			Smoke due to poking fire. Coal not equally distributed along grates.
129	9			1	120	*a* 5	19.6	Smokes continuously, 20 per cent black.
130	3			0	100	*a* 4.3	14.7	Smokes continuously, 30 per cent black.
131	11			0	100	*a* 4.3	14.76	
132	11			0	53	*a* 2.5	4.9	
133	28			1	85	4 x 4	16	Plant has automatic regulator on stack damper.
134	12			0	220	*a* 4.3	15.7	
135	18			1	220	*a* 6.5	33.2	Boilers arched over top for gas passage.
136	40			1	135	*a* 5	19.6	
137	20			1	140	3.5 x 3.5	12.3	Smokes continuously, 10 per cent black.
138	2			2	88	*a* 4.6	16.5	Boilers arched over top for gas passage.
139	7			0	138	*a* 6.5	33.2	
140	6			2	150	*a* 4.5	15.9	
141	8			1	100	*a* 5	19.6	Boilers arched over top for gas passage. Automatic regulator attached to main damper.
142	6			1	175			Boilers arched over top for gas passage.
143	0	0		0	100	*a* 6	28.3	Readings include some 10 and 20 per cent black smoke. Boilers arched over top for gas passage.
144	26			1	100	4 x 4	16	
145	15			1	90			Fires have to be poked frequently to keep grates covered.
146	50			3	120	*a* 3	7.06	
147	0	0		0	100	*a* 5	19.6	Stack rests on rear of boilers. Readings include some 10 and 20 per cent black smoke. Boilers arched over top for gas passage.
148	3			0	115	*a* 3	7.06	Boilers arched over top for gas passage. With ash-pit doors closed, draft in furnace varied from 0.17 to 0.32 inch water.

a Diameter.

TABLE 15.—*Details of observations at plants with side overfeed stokers under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
149	5	....	....	0	100	3 x 3	9	Smoke observations include some 10 and 20 per cent black readings.
150	4	....	....	0	165	*a* 5	19.6	Boilers arched over top for gas passage. Very clean stack; observations include a few 10 per cent black readings.
151	17	....	....	3	158	4 x 5	20	None of the observations showed more than 20 per cent black smoke.
152	4	....	....	0	150	*a* 5	19.6	Observations include several 20 and 40 per cent black readings.
153	4	....	....	1	103	*a* 4	12.56	Coal does not work down grates properly and fire is poked vigorously every eight to fifteen minutes, causing two to three and one-half minutes of smoke each time.
154	28	....	....	1	100	2.7x 4	10.7	Stack generally good. Trouble sometimes with coal feed.
155	9	....	....	0	100	*a* 4	12.56	Observations have been taken that are not as good as record given. Automatic regulator attached to main damper.
156	23	....	....	2	110	2 x 3.4	6.7	
157	8	....	....	0	149	*a* 2.5	4.9	One side of each stoker flanked with fire brick.
158	6	....	....	0	160	*a* 6	28.3	Boilers arched over top for gas passage.
159	4	....	....	2	150	*a* 6	28.3	Do.
160	5	....	....	2	120	*a* 3.2	7.85	A ¼-inch steam jet entering the furnace through a 1-inch opening in door runs continuously. Observations include some 10 and 20 per cent black readings. Automatic regulator on main damper.
161	15	....	....	1	100	*a* 4	12.56	Boiler arched over top for gas passage.
162	6	....	....	0	90	....	....	
163	3	....	....	1	90	*a* 3.5	9.6	Usually a very good stack. Damper controlled by automatic regulator. Boilers arched over top for gas passage.
164	18	....	....	0	100	*a* 2.5	4.9	Stack smokes occasionally, 10, 20, and 40 per cent black.
165	0	....	....	0	100	4 x 4	16	Boilers arched over top for gas passage.

a Diameter.

SUMMARY.

The importance of installing the side-feed stoker with an arch over the entire grate can not be too strongly urged. At nearly every plant observed where this stoker had been installed with a short ignition arch only, trouble was experienced in keeping down smoke.

Some of the stacks having this stoker under them smoked badly because the fireman took advantage of the opening into the furnace and fired a part of the coal by hand.

There was some trouble in maintaining a uniform feed of coal at a few of the plants visited. This seemed to happen when very fine coal was supplied. With this stoker as ordinarily set, a banked fire can be maintained and the boiler thrown into service with only a small amount of smoke. The stoker has the valuable feature of a large coking plate area.

UNDERFEED STOKERS.

GENERAL DISCUSSION.

Stokers of the underfeed type differ radically from those described in the preceding pages. The fresh coal is forced into a horizontal retort, beneath that which has already ignited, and burns in a long heap that forms in the middle of the furnace. The unburned refuse is largely fused to a clinker, which slides down the sides of the heap and is hooked out by hand through the front of the furnace. The method of burning compels the use of mechanical draft, a fan being employed to force air through openings in tuyère blocks along the sides of the retort, at the level where the volatile hydrocarbons from the heap of burning coal are given off. Two makes of this stoker that have been put to the test of use under average power-plant conditions differ chiefly in the feeding mechanism and the device for handling the partly burned coal after it leaves the retort. In one pattern the coal is forced in continuously by a cone-shaped screw driven by a small steam engine, and the partly burned coal falls on a flat grate through which air is drawn by a chimney. In the other pattern the coal is pushed beneath the burning heap in large charges, and the partly burned coal that rolls down the sides of the heap falls on a dead plate, where combustion is completed by the excess air that enters through tuyère openings. This method of burning coal has proved to be the better, and the plan of using air from the tuyères for complete combustion has been generally adopted as correct. The newer models of underfeed stokers are always installed with automatic control for coal and air.

In all underfeed stokers the air and the distilled gases are intimately mixed and intensely heated by rising through the incandescent coal, so that combustion is complete within a very short distance from the

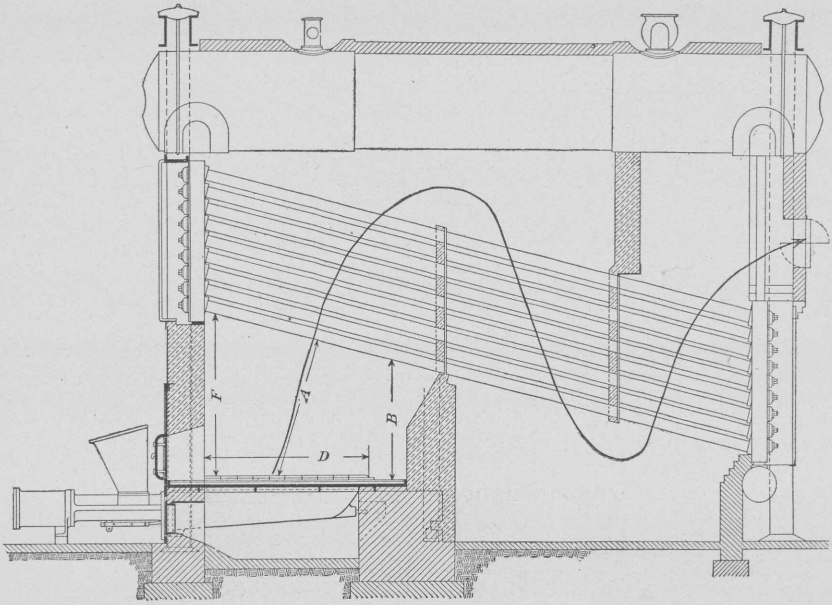

FIGURE 17.—Underfeed stoker and Babcock & Wilcox boiler.

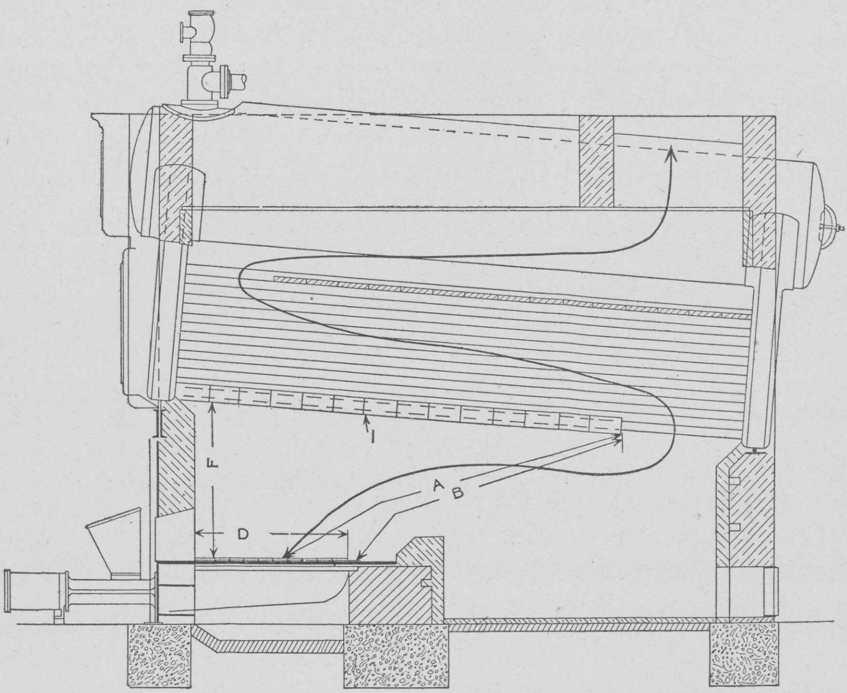

FIGURE 18.—Underfeed stoker and Heine boiler. 1, C tile on lower row of tubes, forming a tile-roof furnace.

retort. Hence the combustion space required over the fuel bed is less than with any other type. By reason of its compactness and the small combustion space it demands, the underfeed stoker sometimes gives good results when installed in the 36-inch corrugated flue of an internally fired boiler.

The customary method of placing this stoker under a Babcock & Wilcox boiler with uptake in the rear is shown by figure 17. In the setting of the Heine boiler (fig. 18) the C tile on the lower stow of water tubes make a tile roof for the furnace. This increases the travel of the gases from the fire and permits complete combustion of the

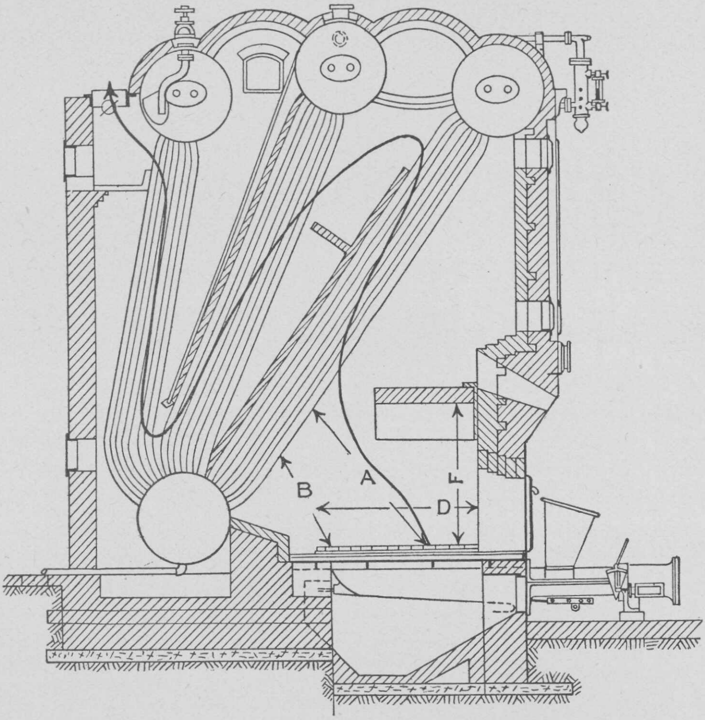

FIGURE 19.—Underfeed stoker and Stirling boiler.

carbon before the gases are chilled by contact with the tubes. In the regular setting of the Stirling boiler (fig. 19) the stoker is placed under the fire-brick arch. The construction of one of the makes of underfeed stokers is shown by figure 20, an elevation of a stoker under a return tubular boiler; figure 21, a cross section through boiler and stoker; figure 22, a plan of the stoker.

Attention has been called to the compactness of the underfeed stoker and the small amount of space required above the grate. An illustration showing such a stoker set in the corrugated flue of a Scotch boiler is given in figure 23.

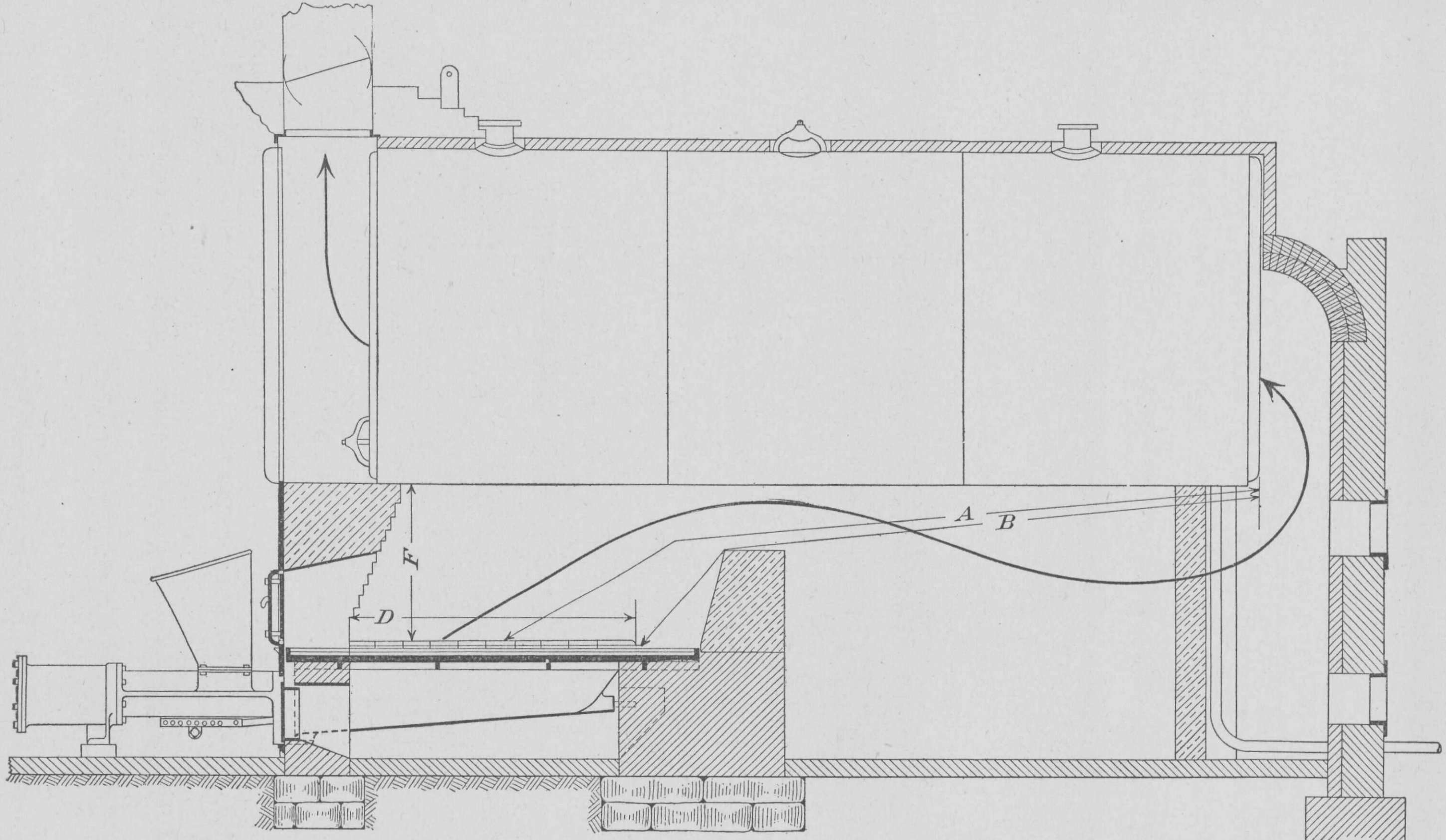

FIGURE 20.—Underfeed stoker and return tubular boiler, elevation

Having the advantage of positive draft, the underfeed stoker allows a plant to be run without regard to weather conditions that may make the attainment of high draft by a stack impossible. The effects of weather changes on furnace draft are considerable and are very noticeable at plants which require all the available draft to carry their loads. Another valuable feature of this stoker is the ease and economy with which a variable load may be carried. The change from heavy to

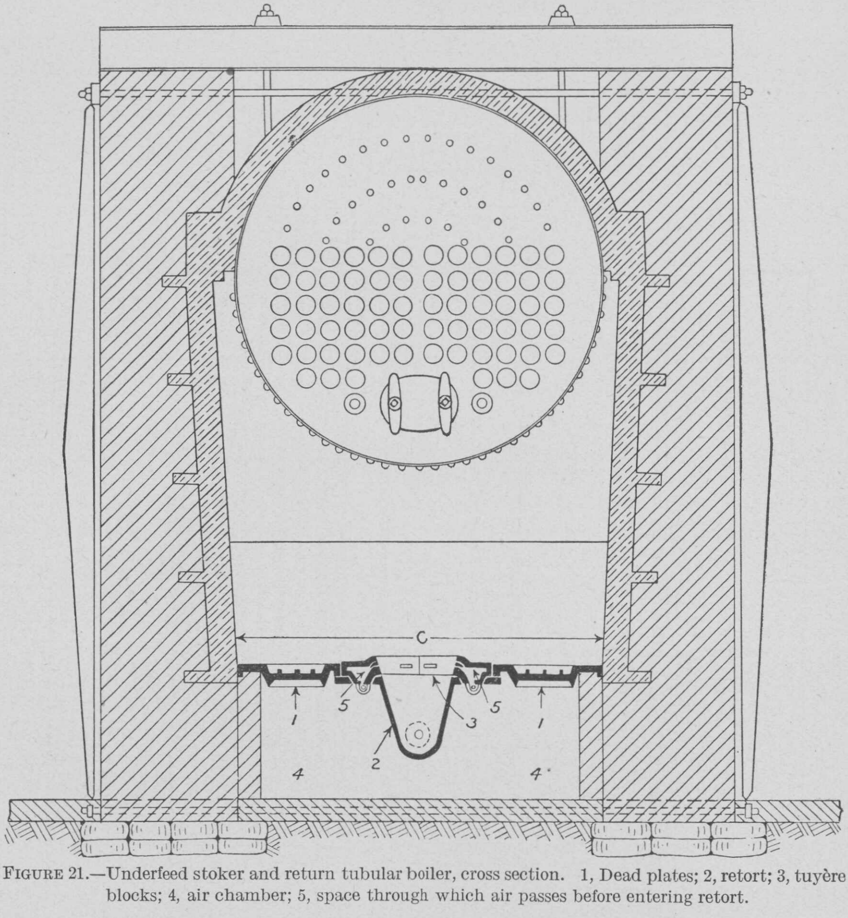

FIGURE 21.—Underfeed stoker and return tubular boiler, cross section. 1, Dead plates; 2, retort; 3, tuyère blocks; 4, air chamber; 5, space through which air passes before entering retort.

light coal charges or vice versa can be made without loss, because when the fuel supply is altered the air supply is at once regulated to the amount of coal being burned.

It sometimes happens that, to meet the competition of other types, a single underfeed stoker is installed under a boiler unit as large as 200 horsepower. It is easy to show that such overloading of a stoker is not good business economy, particularly in localities where poor coal is supplied. On the assumption of an average ratio of heating surface to grate surface of 50 to 1, a 200-horsepower boiler should have 40 square feet of grate. Now while it is possible to burn, say 30 pounds of average coal per square foot of grate surface per hour, or 1,200 pounds of coal per hour for a 200-horsepower boiler, it is not

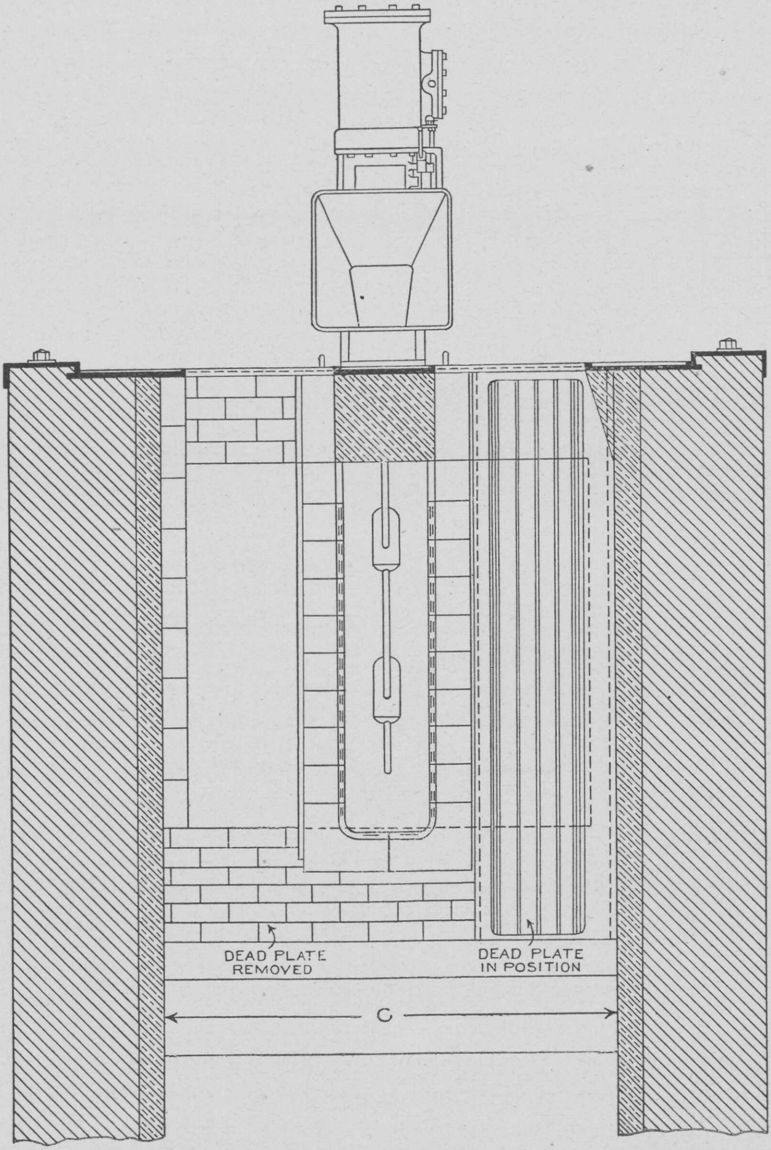

FIGURE 22.—Plan of underfeed stoker.

considered good practice to try to burn over 700 to 800 pounds of coal per stoker per hour with an underfeed stoker, as heavier feeding gives questionable results. The consequence of trying to feed 1,200 pounds of dirty coal per hour with one stoker of this type is evident.

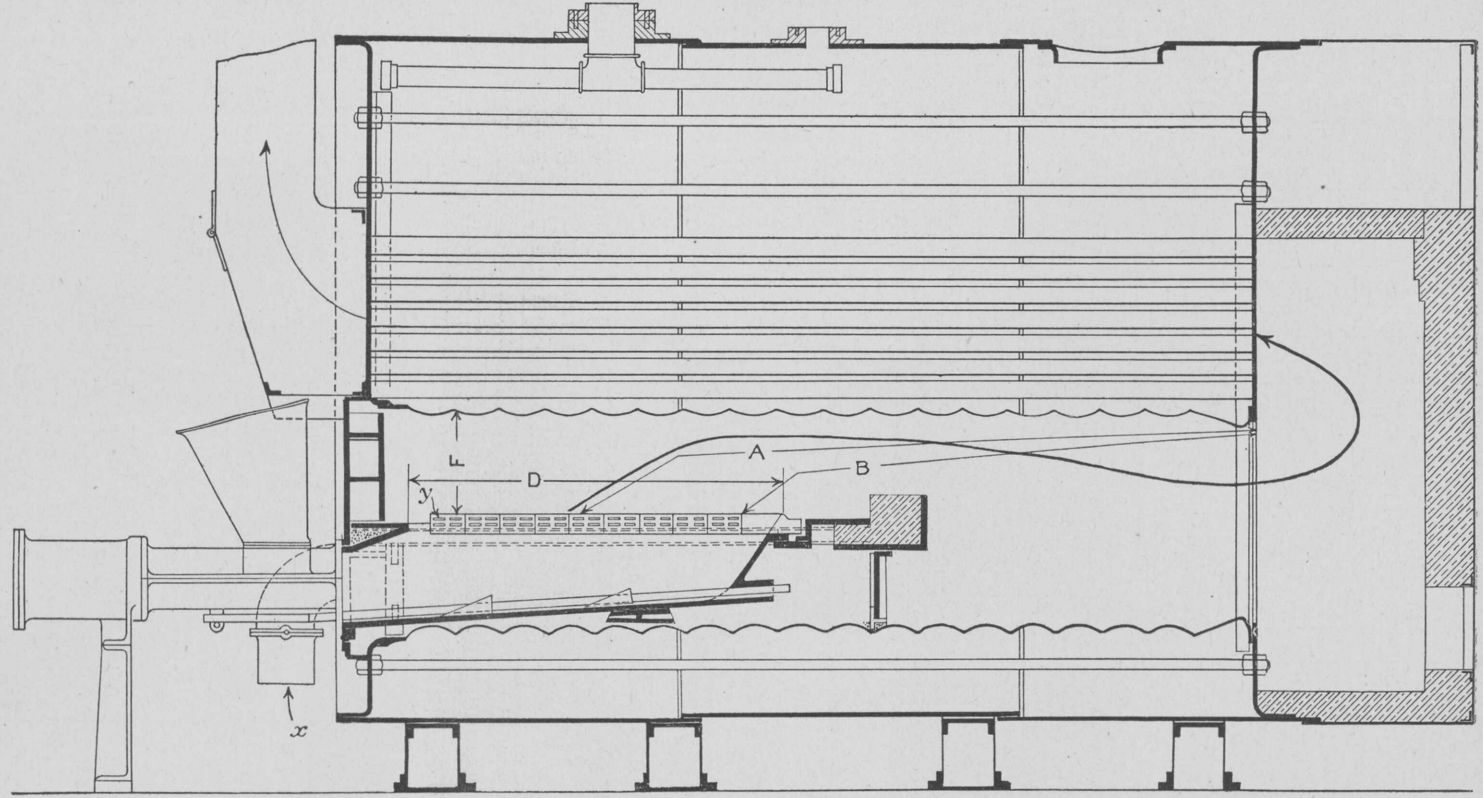

FIGURE 23.—Underfeed stoker and Scotch marine boiler. *x*, Pipe through which air is admitted under retort; *y*, air-admission openings in tuyère blocks.

It is the general opinion that it is harder to keep down smoke at the small hand-fired return tubular boiler plant than anywhere else, but the underfeed stoker has replaced many hand-fired furnaces at such plants. The only variable element in the operation of this stoker, once it is correctly installed, is the cleaning of fires, but if the fireman is careful to burn down the fires before breaking them up there will be no necessity of making smoke.

DETAILED DESCRIPTION OF PLANTS.

The underfeed type of stoker was found at 48 different plants in eight different States, the size of the plants ranging from 75 to 3,500 rated boiler horsepower. These plants burned coal from Illinois, Indiana, Kentucky, Ohio, Pennsylvania, and West Virginia, the cost of which ranged from $1.03 to $2.75 per ton, the conditions at the different plants varying widely. The size of the boiler units ranged from 50 to 500 horsepower; at 33 plants the units were 200 horsepower or less, and with two exceptions one stoker per boiler was installed at these plants. All but five of the plants had automatic regulators for coal or air. But two of these stokers were set in a Dutch oven; this setting was used because the boilers were of the vertical type.

Plants with water-tube boilers.—Underfeed stokers were found under water-tube boilers at 22 plants, at 4 of which the fuel was run-of-mine coal. At 13 plants the load carried was uniform, and at 9 it was variable. The thickness of fire ranged from 8 to 18 inches. The kind of coal burned is stated in the following summary:

Kind of coal burned at plants with underfeed stokers under water-tube boilers.

	Number of plants.[a]
Illinois	5
Indiana	1
Kentucky	1
Ohio	7
Pennsylvania	8
West Virginia	1

Some averages of the observations at these plants are given below:

Difference of draft between ash pit and furnace, 3 inches of water.

Coal as received burned per stoker per hour, average heavy load, 560 pounds; extremes, 330 and 1,060 pounds.

Percentage of rated boiler horsepower developed average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 92; extremes, 58 and 146.

Average distance from grate to heating surface (dead plates to shell), 4.9 feet; extremes, 3 and 7.5 feet.

[a] One plant burned both Ohio and Pennsylvania coal.

Least distance from grate to heating surface (dead plates to shell), 3.8 feet; extremes, 2 and 5.3 feet.

Smoke, black, 2.4 per cent.

Average draft conditions: Pressure in ash pit, 17 plants, 2.45 inches of water; range, 1 to 4 inches. Draft in furnace, 19 plants, 0.33 inch; range, 0.01 to 1 inch. Draft in rear of boiler, 13 plants, 0.48 inch; range, 0.17 to 1.07 inches. Draft at base of stack, 11 plants, 0.80 inch; range, 0.24 to 1.50 inches. The approximate pressure and drafts deduced from these readings are as follows: Pressure in ash pit, 2.50 inches of water; draft in furnace, 0.35 inch; draft at rear of boiler, 0.50 inch; draft at base of stack, 0.80 inch. This gives a drop of about 3 inches through the fuel bed, of about 0.15 inch through the boiler, and of 0.30 inch from the boiler to the stack.

Details of the observations at plants with underfeed stokers under water-tube boilers are given in Table 16.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers.*

No of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
166	Missouri	Jones	3,500	Various coals	Illinois	Various sizes	$1.03	
167	....do	....do	2,000	....do	....do	....do	1.03	
168	....do	....do	2,000	....do	....do	....do	1.03	
169	Illinois	....do	1,875	Screenings	....do	1 to 1½ inches		
170	....do	....do	400	Washed nut	Marion County, Ill	No. 1 nut		
171	Indiana	....do	230		Indiana	Nut and slack		
172	....do	American	728	Straight Creek	Kentucky	....do		
173	Ohio	Jones	909	Coshocton	Ohio	Slack	2.00	6,000
174	....do	....do	600	Hocking Valley	....do	1-inch screenings	1.80	
175	Michigan	....do	300	Cambridge	....do	Slack	1.65–1.70	
176	....do	....do	300	....do	....do	....do	1.65–1.75	
177	Ohio	....do	200	Pittsburg No. 8	....do	1-inch nut	2.40	1,400
178	....do	....do	200	Hocking Valley	....do	Pea and slack	1.80	4,800
179	Pennsylvania	....do	1,400	Clearfield	Pennsylvania	Run of mine		
180	Ohio	....do	800	Pittsburg nut and slack	....do	Through 1½-inch screen	1.80	
181	Pennsylvania	....do	720	Pittsburg second pool	....do	Slack	1.30	5,200
182	Ohio	American	700	Various coals	Ohio and Pennsylvania	¾-inch screenings	1.50–1.65	
183	Pennsylvania	Jones	600	Nanty Glo	Pennsylvania	Run of mine	3.05	
184	New York	....do	320	Youghiogheny	....do	Slack and run of mine	2.35–2.50	6,900
185	....do	....do	300	Rochester and Pittsburg; Reynoldsville.	....do	Slack	2.35	1,500
186	Pennsylvania	....do	276	Pittsburg	....do	Run of mine	2.75	
187	Michigan	....do	275	Thacker	West Virginia	Slack	2.50	1,500

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Load.			Rating.							
				Average load.							
				Heavy.		Light.					
	Requirement.	Nature.	Character.	Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Coal burned per stoker per hour, average heavy load (pounds).	Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
166	Power	Variable	Street railway	20	111	20	111	528	76	64	5
167	....do	....do	....do	20	64	20	64	533	76	64	5
168	....do	....do	....do	20	64	20	64	533	76	64	5
169	Power and light	....do	Office building	8	22	8	18	450	79	80	5
170	....do	Uniform	Refrigeration	24	10	24	12	420	81	83	5
171	Power, light, and heat	Variable	Bakery	....	....	24	5	416	83	72	5
172	....do	Uniform	Factory	9.5	10	9.5	13	1,060	130	130	5
173	....do	....do	Store building	10	12	10	15	600	92	79	5
174	....do	....do	....do	10	8	10	8	400	59	59	4.5
175	....do	....do	Factory	10	4.5	10	3.3	450	59	60	5
176	....do	....do	....do	10	4.5	10	3.3	450	59	60	5
177	Light and heat	....do	Office buildings	24	6	12	1.3	250	78	63	4
178	....do	Variable	Commercial	24	12	24	9	500	91	100	5
179	Power and heat	Uniform	....do	24	60	24	20	625	112	90	4
180	Power, light, and heat	Variable	Factory	10	10.4	....	....	1,040	115	115	4.5
181	....do	....do	Office building	16	10	....	....	625	58	58	4
182	....do	Uniform	Factory	12	17	12	17	710	95	81	5
183	Power and heat	Variable	....do	9	15	9	8	830	139	139	4
184	Power, light, and heat	Uniform	Hotel	24	19	24	19	527	146	165	4
185	....do	....do	Organization building	24	7.9	16	4	330	68	60	3.6
186	Power	....do	Factory	10	7	10	7	700	146	127	4
187	Power and heat	....do	Office building	10	3.5	10	3.5	350	78	78	4.5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

Table 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Stoking.			Boilers.									
	Method.	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
166	Automatic	14	5 times in 20 hours.	O'Brien	228 3½″ x 18′ tubes	7	7	7	500	418	4,180	0	160
167	do	14	do	do	do	4	4	4	500	418	4,180	0	160
168	do	14	do	do	do	4	4	4	500	418	4,180	0	160
169	do	Variable.	3 times in 24 hours.	Stirling	286 3¼″ tubes, 3 36″ x 14′ drums	5	4	3	375	378	3,780	0	150
170	do		6 times in 24 hours.	Scotch marine.	142 4″ x 12′, 10′ shell	2	1	2	200	205	2,050	0	140–145
171	do		4 times in 24 hours.	Babcock & Wilcox.	54 4″ x 16′ tubes, 1 36″ drum	2		1	115	100	1,000	0	80–90
172	do		Once in 9 hours	Stirling	Two, 176 3½″ tubes; one, 280 3½″ tubes—3 36″ drums each.	3	2	1, 2	200, 328	200, 328	2,000, 3,280	0	115
173	do		4 times in 24 hours.	do		3	2	3	303	262	2,618	1,345	150
174	do	Variable.	Once every 4 hours	Park		2	2	2	300	304	3,035		100–120
175	do	12–15	2 times in 10 hours.	Wickes vertical.		1	1	1	300	307	3,065	0	150
176	do	12–15	do	do		1	1	1	300	307	3,065	0	150
177	do			Scotch marine.	56 3½″ x 12½′ tubes	2	2	1	100	80	800	0	100
178	do	12–15	2 times in 8 hours.	McNaull	128 4″ x 15′ tubes	1	1	1	200	220	2,200	0	95–120
179	do		2 to 3 times in 24 hours.	Edgemoor	131 4″ x 18′ tubes, 3 35″ x 20′ drums.	4	4	3	350	280	2,800	0	85
180	do	Variable.	2 times in 10 hours.	Atlas	140 4″ x 18′ tubes between water legs.	2	1	1	400	401	4,013	(*a*)	120
181	do	15–18	Once in 8 hours	Gill	96 4″ x 16′ tubes	4	3		180	180	1,800	0	120
182	do			Stirling		2	2	2	350	300	3,000	0	110
183	do		3 times in 9 hours.	Babcock & Wilcox.	144 4″ x 18′ tubes, 1 42″ drum.	2	2	2	300	300	3,000	0	125
184	do	15	3 to 6 times in 24 hours.	do	48 4″ x 16′ tubes	4	3	3	80	90	900	0	90
185	do	8–15	3 to 4 times in 24 hours.	National	72 4″ x 16′ tubes	2	2		150	135	1,345	0	100
186	do		2 times in 10 hours.	Babcock & Wilcox.	64 4″ x 16′ tubes, 1 36″ drum	2	2	2	138	120	1,200	0	110
187	Hand-operated.	12–15	1 to 2 times in 10 hours.	Wood horizontal.		3	2	2	100, 75	2–100 1– 75	1,000, 750	0	125

a 10° to 24° F. superheat.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Furnaces.							
	Kind.	Number of stokers per boiler.	Dimensions (feet).					
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to coking arch or heating surface (F).
			Average (A).	Minimum (B).				
166	Plain	3	4.5	4	11	6.3	0	5
167	do	3	4.5	4	11	6.3	0	5
168	do	3	4.5	4	11	6.3	0	5
169	do	3	7.5	5.3	12.2	6.3	0	4.5
170	Corrugated flue	2	10	7	3	7.5	0	1.4
171	Plain	1	4.5	3.8	3.8	6.3	0	5
172	do	(a)					0	3.2
173	do	2	7.5	4.5	8.5	6.3	0	4
174	do	2	5	4	8.75	6.3	0	5
175	Dutch oven	2	6	3	8	6.3	9	5.25
176	do	2	6	3	8	6.3	9	5.25
177	Corrugated flue	1	11	8	3.2	6.3	0	1.5
178	Plain	2	4.3	4	8.5	6.3	0	4.3
179	do	2	4.75	4.5	9.5	6.3	0	5
180	do	2	4.8	4.8	8.8	6.3	0	5
181	do	1	3.5	3		6.3	0	3.5
182	do	2	7	4		6.3	0	4.5
183	do	2	4	3.5	9.7	6.3	0	4.8
184	do	1	3.5	3	4	6.3	0	4
185	do	1	3.5	3	5	6.3	0	3.5
186	do	1	4	3.5	5	6.3	0	4.5
187	do	1	3	2	4	6.3	0	2.5

a Two on 328 horsepower; one on 200 horsepower.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Kind.	Draft and pressure. Readings (inches of water). Pressure in ash pit.	Draft. Furnace.	Draft. Rear of boiler.	Draft. Front tube sheet.	Draft. Breeching.	Draft. Base of stack.	Conditions under which readings were taken.	Smoke records. Number of observations.	Total length of observations (minutes).	Average for one hour (minutes). 100 to 80 per cent black.	Average for one hour (minutes). 80 to 60 per cent black.	Average for one hour (minutes). Stack clean.	Average percentage of black smoke from observations.	Load during observations.
166	Chimney and forced.	3.6	0.28	0.48					1	60	0	0	56	1.3	Average.
167	.....do	2.8	.33	.53					1	60	0	0	56	1.3	Do.
168	.....do	3	.34	.54					1	60	0	0	56	1.3	Do.
169	.....do		0.86–1.02	[a] .98–1.16			1.50	Dampers open, fan running at maximum speed.	9	501	0	0	40	10.3	Do.
170	Induced and forced	0.90–1.13	.35		0.70				1	60	0	0	57	1.1	Light.
171	Chimney and forced.	2.25	.32	.39				Average conditions; damper partly closed.	2	80	0	0	([c])	4.8	Do.
172	.....do		.32–.35	[a] .40–.42		0.61		Average conditions; ash pit doors cracked.	1	50	2	0	53	5.8	Do.
173	.....do	2	.20–.30	[b] .33–.40		.50			1	600	0	0	60	0	Average.
174	.....do	1	.48			0.52–.56	.57	Average running conditions.	1	60	0	0	60	0	Do.
175	.....do	2	.20	[a] .28			.70		1	60	0	0	59	.3	Do.
176	.....do	2	.23	[a] .50			.64		1	60	0	0	60	.3	Heavy.
177	.....do	.25	.17–.25		.70		.88		1	600	0	0	60	0	Average.
178	.....do	4	.32			.90	1	Damper open.	1	60	0	.5	58	1.9	Do.
179	.....do	2.1	.25–.55	.55–.78				Dampers wide open	1	40	0	0	48	5	Heavy.
180	.....do	2.3				.80		Damper open; fan running at average speed.	([d])		0	0			Do.
181	.....do	2–3	.43–.66						1	60	0	0	60	0	Light.
182	.....do	1.5	.44	[a] .60			.92		1	60	0	2	49	6.7	Average.
183	.....do	3–3.2	.10–.17	.34–.44			.9–1	Damper one-half open; furnace doors cracked 3 inches.	1	90	0	0	60	0	Light.
184	.....do	2	.28–.50				1		1	120	0	0	50	3.2	Average.
185	.....do	2	.12	.19			.24		1	60	0	0	59	.4	Heavy.
186	.....do	3.5	.15				.40		2	58	10	.5	55	4.3	Average.
187	.....do		0–.02	.14–.19			.90		1	60	0	1	55	3.1	Do.

[a] Lower rear boiler. [b] Upper rear boiler. [c] See remarks. [d] Several.

TABLE 16.—*Details of observations at plants with underfeed stokers under water-tube boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
166	0	....	....	0	80	[a] 4.5	15.9	Seven stacks, each on rear of boiler.
167	8	4 x 4	Near stack........	0	158	[a] 6.4	32.3	
168	0	....	....	0	80	[a] 6	28.3	Two stacks, each on rear of boiler.
169	32	[b] 70	50 feet from stack..	2	330	[a] 8	50.25	Coal varies from 11,000 to 12,000 B. t. u. per pound of dry coal; coal as received contains 10 to 12 per cent moisture, 11 to 17 per cent ash.
170	28	....	....	1	37	[a] 4	12.56	
171	4	....	....	1	85	3.3 x 3.3	11.1	With damper partly closed, as soon as fires begin to get dirty 20 to 30 per cent black smoke produced for about twenty seconds every time coal is fed. One observation taken while cleaning fire. Some smoke when coal is wet and usually while cleaning fire.
172	30	....	....	1	123	[a] 6.2	29.86	
173	80	....	....	2	165	[a] 5	19.6	Coal as fired runs about 12,800 B. t. u.; ash, 12 per cent; moisture, 3.5 per cent.
174	0	....	....	0	120	6 x 6	36	Stack on rear of boiler.
175	8	....	....	2	80	4 x 4	16	Stack smokes about 20 per cent black for about one minute when cleaning fires.
176	3	....	....	0	80	[a] 3.8	11.6	Do.
177	8	....	....	2	200	2.5 x 2.5	6.3	
178	15	....	....	1	162	[a] 6	28.3	Boiler baffled vertically.
179	23	....	....	8	150	6 x 6	36	Boilers baffled vertically, four passes. Four separate flues join main breeching. Stack smokes 10 to 40 per cent black for about half a minute every two or three minutes.
180	24	....	....	1	135	[a] 6	28.3	Observations include some 10 and 20 per cent black readings.
181	28	....	....	1	200	[a] 5	19 6	
182	10	....	....	0	125	[a] 6	28.3	Coal as received runs about 12,700 B. t. u. and 10 to 14 per cent ash.
183	0	....	....	0	120	[a] 4	12.56	Coal runs about 8 per cent ash. Stack rests on rear of boilers. Get best results when running at about rated capacity.
184	25	....	....	1	145	[a] 5	19.6	Boiler baffled vertically with top half of first baffle removed.
185	105	....	....	2	150	[a] 3	7.06	Coal as received runs about 13,600 B. t. u. and 10 per cent ash.
186	3	....	....	2	58	[a] 3	7.06	Cleaned fire during part of observations. Plant has burned 1,000 pounds of coal per stoker per hour, but made considerable smoke.
187	65	....	....	4	175	[a] 6	28.3	

[a] Diameter. [b] Square feet.

Plants with return tubular boilers.—Underfeed stokers were installed under return tubular boilers at 26 plants. The fires carried ranged in thickness from 12 to 18 inches. Four of the plants burned run-of-mine coal. Seventeen carried a uniform load, and 9 a variable load. The kinds of coal burned were as follows:

Kind of coal burned at plants with underfeed stokers under return tubular boilers.

	Number of plants.[a]
Illinois	1
Indiana	4
Kentucky	1
Ohio	3
Pennsylvania	8
West Virginia	4
Miscellaneous	7

Various particulars regarding these plants are condensed in the following statement:

Coal as received burned per stoker per hour, average heavy load, 513 pounds; range, 225 to 750 pounds.

Percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 74; range, 57 to 135.

Average distance from grates to shell, 2.8 feet; range, 2 to 3.75 feet.

Smoke, black, 2.6 per cent.

Approximate average pressure in ash pit, 1.75 inches.

Approximate average draft in furnace, 0.20 inch; at front tube sheets, 0.30 inch; at base of stack, 0.50 inch. This gives an average drop of 2 inches between the ash pit and the furnace, 0.10 inch through the boiler, and 0.20 inch from the boiler to the stack.

Details of the observations at plants with underfeed stokers under return tubular boilers are given in Table 17.

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[a] Two plants burned both Ohio and West Virginia coal.

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers.*

No. of plant.	State.	Kind of stoker.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
188	Illinois	Jones	200	Washed	Williamson County, Ill.	No. 4		
189	do	do	3,500		Indiana	Screenings		
190	Indiana	do	700	Various coals	do	Run of mine, nut, and slack.	$1.30–$1.60	
191	do	do	165		do	Nut and slack		
192	do	do	125		do	do		
193	Kentucky	American	100		Western Kentucky	Pea and slack		
194	Ohio	Jones	530	Goshen	Ohio	Slack	1.90	5,030
195	Michigan	do	300	Various coals	Ohio; West Virginia	Slack and run of mine	2.00– 2.15	
196	Ohio	do	200	Kanawha	West Virginia	Run of mine	2.30	2,600
197	Michigan	do	200	Various coals	Ohio; West Virginia	Pea and slack	2.05	1,300
198	Indiana	do	150		West Virginia	Slack		
199	New York	do	1,104	Shawmut	Pennsylvania	do	2.00	
200	do	do	860		do	Screenings		7,000
201	do	do	800	Rochester; Pittsburg	do		2.45	
202	do	do	736	Shawmut	do	Slack	2.00	
203	Ohio	do	625	Youghiogheny	do	do	1.70	7,500
204	New York	do	500	Shawmut	do	do	2.00	
205	do	do	260	do	do	do	1.95	2,880
206	Kentucky	American	150		do	Nut and slack		
207	Ohio	Jones	575	Various coals		Slack	1.85	
208	do	do	500	do		1-inch screenings	1.51	
209	do	do	500	do		Nut and slack	1.51	
210	do	do	375	do		1-inch screenings	1.51	
211	do	do	300	do		Pea and slack	1.70	2,000
212	Pennsylvania	do	250			Run of mine	3.00	
213	Illinois	do	75	Various coals				

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.							
	Requirement.	Nature.	Character.	Average load.				Coal burned per stoker per hour, average heavy load (pounds).	Percentage of boiler horsepower developed on average heavy load. [a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horse power per hour (pounds).
				Heavy.		Light.					
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).				
188	Power and heat	Variable	Factory	8	4.5	8	4	560	135	112	5
189	Light and heat	....do	School buildings	17	54	17	13.5	582	57	73	5
190	Power, light, and heat	Uniform	Factory	10	15	10	15	500	79	100	5
191	....do	Variable	Store building	11	3.5	11	3.5	320	70	77	5
192	....do	Uniform	Laundry	11	4	11	3.3	728	88	116	5
193	....do	Variable	Organization building	18	4	18	2.8	225	70	89	5
194	....do	Uniform	Brewery	24	15.4	24	12.6	427	50	68	5
195	....do	....do	Factory	10	5	10	5	500	58	74	4.5
196	....do	Variable	Glass works	12	9	....	....	750	100	167	4.5
197	....do	Uniform	Printing office	10	3.6	10	2.3	360	58	72	5
198	....do	....do	Factory	14	3.5	14	3.5	500	104	148	4.5
199	Heat	Variable	Oil refinery	24	51	24	51	706	69	96	4
200	Power, light, and heat	Uniform	....	24	24	24	18	500	55	58	4
201	....do	....do	Office building	14	13	14	4	620	66	79	4
202	Power and heat	Variable	Oil refinery	24	35	24	35	730	70	100	4
203	Power, light, and heat	Uniform	Salt works	12	13.6	12	11.4	565	70	100	4.5
204	Power and light	....do	Oil refinery	10	11.7	10	11.7	585	102	117	4
205	Power	....do	Refrigeration	12	4	24	10	330	....	92	4
206	Power, light, and heat	Variable	Hospital	24	4	24	2.4	335	63	89	5
207	....do	Uniform	Refrigeration	24	22.3	24	17.8	620	76	88	5
208	Heat	....do	Commercial	24	26	....	....	545	80	87	5
209	....do	....do	....do	24	20	....	....	416	61	67	5
210	....do	....do	....do	24	19	....	....	535	80	87	5
211	Power, light, and heat	....do	Laundry	12	5.5	12	5.5	460	65	68	4.5
212	Power	....do	Refrigeration	24	14.5	24	13.4	600	104	121	4
213	Power and heat	Variable	Machine shop	9	1.5	9	1.25	340	68	91	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Stoking.			Boilers.								
	Method.	Thickness of fire (inches).	Frequency of cleaning fire.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
188	Automatic		1 to 2 times in 8 hours	60″ x 16′, 42 41″ tubes	2	2	2	100	83	830	0	110
189	do		Once in 8 hours	72″ x 18′, 135 3″ tubes	20	10	3	175	223	2,225	0	
190	do		4 times in 10 hours	66″ x 16′, 64 4″ tubes	7	6	6	100	126	1,260	0	90
191	do		2 times in 11 hours	1 60″ x 14′, 60 3″ tubes; 1 60″ x 16′, 52 4″ tubes.	2	2	2	80,85	78,103	775,1,030	0	85-90
192	do		do	72″ x 16′, 84 4″ tubes	1	1	1	125	165	1,650	0	80
193	do			48″ x 16′, 36 3½″ tubes	2	2	2	50	63	625	0	80
194	do	12-15		2 72″ x 16′, 72 4″ tubes; 2 78″ x 18′, 84 4″ tubes.	4	3	3	115,150	156,200	1,560,2,000	0	85
195	Hand operated	15	2 times in 10 hours	72″ x 18′, 100 3½″ tubes	2	2	2	150	194	1,940	0	100
196	Automatic	12-15	4 times in 24 hours	72″ x 16′, 84 4″ tubes	2	2		100	166	1,655	4	90-100
197	do		Once in 10 hours	60″ x 16′, 72 3½″ tubes	2	2	1	100	124	1,240	0	80
198	do		Once in 14 hours	1 66″ x 18′, 54 4″ tubes; 1 66″ x 16″, 54 4″ tubes.	2	1	1	75	120,107	1,200,1,065	0	100
199	do	15-18	4 to 6 times in 24 hours	78″ x 18′, 154 3″ tubes	6	6	6	184	257	2,565	0	95
200	do	12-16	4 times in 24 hours	84″ x 18′, 104 4″ tubes	4	4	4	215	229	2,290	0	125
201	do	12-15	3 to 4 times in 24 hours	78″ x 18′, 104 4″ tubes	4	3	1	200	231	2,310	0	125
202	do	15-18	4 to 6 times in 24 hours	78″ x 18′, 154 3″ tubes	4	4	4	184	257	2,565	0	95
203	do		6 times in 12 hours	4 72″ x 17′, 100 3½″ tubes; 1 72″ x 15′, 94 4″ tubes.	5	4	4	125	183,174	1,830,1,740	0	115
204	do	15-18	Every 4 to 6 hours	72″ x 16′, 72 4″ tubes	4	4	4	125	144	1,440	0	80
205	do	15	3 times in 24 hours	18′ long	3	2	3	2 80, 1 100			0	100
206	do			60″ x 18′, 48 4″ tubes	2	1	1	75	106	1,060	0	60-80
207	do	12-18	4 to 6 times in 24 hours	3 72″ x 18′, 72 4″ tubes; 1 60″ x 18′, 54 4″ tubes.	4	3	3	3 150, 1 125	3 177, 1 134	1,770,1,340	0	90
208	Hand operated	12	6 times in 24 hours	1 72″ x 16′, 72 4″ tubes; 2 72″ x 16′, 90 3″ tubes; 1 72″ x 16′, 92 3″ tubes.	4	4		125	142,134,136	1,420,1,335, 1,360	0	60-75
209	do	12-15	8 times in 24 hours	72″ x 16′, 92 3″ tubes	4	4		125	136	1,360	0	90-100
210	do	12	6 times in 24 hours	do	3	3		125	136	1,360	0	60-75
211	Automatic	15-18	2 times in 12 hours	72″ x 18′, 70 4″ tubes	2	2	2	150	156	1,550	0	100
212	do		7 times in 24 hours	72″ x 20′, 47 5″ tubes	2	2	2	125	145	1,450	0	90
213	do		2 times in 9 hours	60″ x 18′, 44 4″ tubes	1	1	1	75	92	920	0	100

Table 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Furnaces.							
	Kind.	Number of stokers per boiler.	Dimensions (feet).					
			Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to heating surface (F).
			Average (A).	Minimum (B).				
188	Plain	1	15.5	12.5	5	6.3	0	3
189	.....do	1	15.5	12.5	6	6.3	0	3
190	.....do	1	15	12	5.5	6.3	0	3
191	.....do	1	13, 15	10, 12	5	6.3	0	2.5
192	.....do	1	15	12	6	6.3	0	2.75
193	.....do	1	16	13	4	6	0	....
194	.....do	1	15, 17	12, 14	6, 6.5	6.3	0	2.5
195	.....do	1	16.5	14	6	6.3	0	2.5
196	.....do	1	15	12	6	6.3	0	3
197	.....do	1	15	12.5	5	6.3	0	3
198	.....do	1	17, 15	14, 12	5.5	6.3	0	3
199	.....do	1	17	14.5	6.5	6.3	0	3
200	.....do	1	17	14	7	6.3	0	3.25
201	.....do	1	17	14.5	6.3	6.3	0	3
202	.....do	1	17	14.5	6.5	6.3	0	3
203	.....do	1	16, 13	13.5, 12.5	6	6.3	0	3
204	.....do	1	15	12.5	6	6.3	0	3
205	.....do	1	17	14	6	6.3	0	2.5
206	.....do	1	18	15	5	6	0	....
207	.....do	1	17	14.5	7.5	6.3	0	3.75
208	Dutch oven	1	19.5	16.5	6	6.3	4.5	2
209	Plain	1	20	17	6	6.3	4	2.3
210	Plain and Dutch oven	1	14.5, 19.5	11.5, 16.5	6	6.3	0, 4.5	2.5, 2
211	Plain	1	17	14	6	6.3	0	3
212	.....do	1	19	16	6.2	6.3	0	3
213	.....do	1	16.5	14.5	5	6.3	0	3

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TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Draft and pressure.								Smoke records.						
	Kind.	Readings (inches of water).						Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Pressure in ash pit.	Draft.												
			Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
188	Chimney and forced.		0.12–0.14			[a] 0.52		Average conditions; dampers open.	1	60	1	2	47	7.7	Average.
189	do	2.5 –3					0.60	Dampers wide open.	1	60	0	0	58	.6	Light.
190	do	1.35, 1.75	.04– .20				.40	Average conditions; dampers open.	1	62	0	0	46	12.7	Average.
191	do	1.40, 1.50	.29– .30		0.40			do	1	60	6	0	49	13.8	Do.
192	do	2.55	.36				.56	do	1	60	0	0	47	3.1	Light.
193	do	1.25	.13– .20			.27		Fan running at maximum speed.	1	40	0	0	47	3.0	Do.
194	do	1.5	.20– .46			0.28–.46	.70		1	600	0	0	58	.5	Average.
195	do		.21– .22		.40		.50		1	60	0	0	56	2	Do.
196	do	.75	.22– .28		0.26– .36		.54		1	60	0	0	60	0	Heavy.
197	do	1.45	.28– .29		.32– .37				([b])	([c])	0	0	60	0	Do.
198	do	1.70	.39– .41				.90	Average conditions; damper open.	1	60	0.5	1	55	3.7	Average.
199	do	2	.10– .13		.17– .24		.30		1	60	0	0	53	1	Do.
200	do	2.5 –3	+.28 to –.06		+.30 to –.04		.54		1	60	0	0	50	1.7	Light.
201	do	1.5	.50		.50		.50		1	60	0	0	60	0	Average.
202	do	1.5	.16– .24		.25– .28				1	60	0	0	58	.7	Do.
203	do	1	+.04 to –.02		+.12 to –.04	.54			1	300	0	0	59	.5	Do.
204	do	2	.06– .16		.11– .25		0.13–.30		1	60	0	0	58	.7	Do.
205	do	1.25–1.50	.15– .18		.17– .18		.35		1	60	0	0	59	.3	Heavy.
206	do	.90–1.10	.12			.30	.40	Damper open.	2	55	0	0	54	2.1	Light.
207	do	2.25	.10– .15			.34	.40		1	600	0	0	57	2.1	Average.
208	do		.02– .12			.10–.22	.44		([b])	([c])	0	0	([d])		Heavy.
209	do	.5	.08– .13		.11– .20				1	60	0	2	55	3.7	Do.
210	do	1.6–2.1	0– .08			.16–.22			([b])	([c])	0	0	([d])		Do.
211	do	1.4	.46– .55		.46– .55		.65		1	60	0	0	60	0	Average.
212	do	2.5–2.75	.17			.30	.37	One boiler in service; damper open.	2	61	0	0	55	1	Do.
213	do								1	60	0	0	60	0	Do.

[a] Near stack. [b] Several. [c] Various lengths. [d] See remarks.

TABLE 17.—*Details of observations at plants with underfeed stokers under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
188	15	3.5 x 3.5	Near stack	0	110	[a] 3.25	10.5	
189	15			2	200	[a] 8	50.3	
190	0			0	85	[a] 5.5	23.7	Observations include a cleaning of fires.
191	8			1	140	[a] 3.1	7.45	Distance to heating surface 2.5 feet.
192	0			0	65	[a] 3	7.07	
193	5			1	80			Large combustion chamber. Fan running at maximum speed when pressure in ash pit was measured. Stokers not run continuously on light load.
194	9			1	95	[a] 5.5	23.8	Boilers arched over top for gas passage.
195	24			1	80	[a] 3.5	9.6	
196	17			0	80	[a] 4.25	14.1	Some smoke when cleaning fires, usually about two minutes of 60 per cent black.
197	31			2	97	4 x 4	16	
198	30			1	130	[a] 3.5	9.6	Large combustion chamber.
199	6			0	100	7.5 x 7.5	56.25	Boilers arched over top for gas passage.
200	70			3	150	[a] 6	28.3	Cleaned fire during smoke observations.
201	13			0	200	[a] 4	12.56	
202	5			0	70	5 x 5	25	Boilers arched over top for gas passage.
203	32			1	90	[a] 6.5	33.2	
204	5			2	65	3 x 3	9	Two similar stacks.
205	6			0	75	3 x 3	9	
206	16			1	100	5 x 5	25	Coal not well burned and refuse usually refired. Stoker not run continuously on light load. Fire sometimes requires poking; then stack is not so good as recorded observation. Stack rests on front of boiler. Coal nearly all slack.
207	13			1	125	[a] 4.5	15.9	Boilers arched over top for gas passage.
208	0			0	100	[a] 4	12.56	No smoke except when cleaning fires; then each furnace gives off 60 per cent black (or lower) smoke for about half a minute.
209	16			1	75	[a] 4	12.56	
210	9			1	75	[a] 4	12.56	Do.
211	45			2	120	5 x 5	25	Each furnace gives off about 40 per cent black (and lower) smoke for about one minute.
212	0			1	75	[a] 3.3	8.7	
213	2			1	55	2.5 x 2.5	5	Burned 728 pounds coal per stoker per hour. Distance to heating surface, 2.75 feet. Some smoke when cleaning fire.

[a] Diameter.

SUMMARY.

The underfeed stoker affords a means of increasing both the economy and capacity of plants which by gradual growth have added so many boilers to a single stack that the draft capacity of the stack has been exceeded, and natural draft does not supply the necessary amount of air to permit the required amount of coal to be burned with high efficiency.

A very much smaller stack will suffice with the underfeed stoker than with some other devices, as it is only necessary to have enough stack draft to carry away the gases of combustion, all the air necessary for burning the coal being forced through the fire.

It will be seen that this stoker is meeting with most success in districts where low-ash coal is used.

The notes show that the greatest difficulty in keeping down smoke came when cleaning fires, but in general at the plants visited there was little trouble on this account.

In this stoker the ash accumulates at either side of the retort. The furnace temperature is so high that most of the ash fuses and is pulled out of the furnace in large pieces. Both for this reason and to permit complete combustion of the fuel it is advisable to have the dead plate on which the clinkers accumulate of sufficient width to permit cleaning fires without breaking up the fuel bed.

SMOKE PREVENTION AT BOILER PLANTS WITH GREAT VARIATIONS OF LOAD.

The data already presented show that bitumnious coals high in volatile matter can be burned without smoke. Smokeless combustion at large plants carrying loads that fluctuate widely, where boilers over banked fires must be put in service quickly and fires forced to the capacity of the units, is no less possible. The accompanying load diagram (fig. 24) shows the variations in boiler horsepower in service and in power output at a plant of about 10,000 horsepower. The sudden increase in output and in boilers in service between 5.30 and 8.30 a. m. and the heavy peak load in the early evening are strikingly brought out. Yet the stacks at this plant, though frequently watched at the time of peak load, were quite clean. No better demonstration than this of what can be done by proper equipment, efficient labor, and intelligent supervision could be given.

HAND-FIRED FURNACES.

GENERAL STATEMENT.

None of the problems of combustion have received more experimental treatment than the burning of coal in hand-fired furnaces. Hundreds of devices for smokeless combustion have been patented, but almost without exception they have proved failures. This record may be explained by the fact that many of the patentees have been unfamiliar with all the difficulties to be overcome, or have begun at the wrong end. Numerous patents cover such processes as causing the waste gases to reenter the furnace, and schemes for collecting and burning the soot are legion. So many manufacturers who have been looking for some cheap addition to a poorly constructed furnace

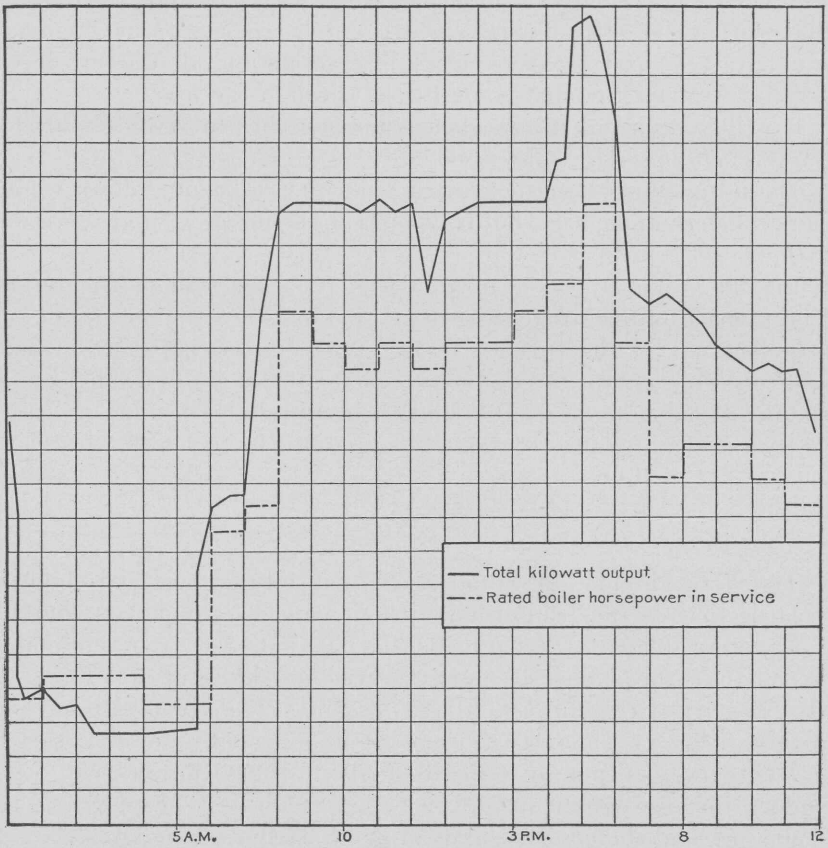


FIGURE 24.—Load and boiler-service chart of large power plant with mechanical stokers. The total rated boiler horsepower used to supply the demand for power varied from about 2,000 to 12,000. This plant is absolutely smokeless.

to make it smokeless have experienced inevitable failure that the work of educating the public to rid cities of the smoke nuisance has been hard, long, and only partly successful.

The total number of steam plants having boilers fired by hand is far greater than the total of plants with mechanical stokers, but if the comparison is based on total horsepower developed the figures show less difference. Particularly is this true in sections of the Middle West, where mechanical stokers are generally used at large plants.

As a general rule hand-fired plants do not have proper furnaces, and methods of operation are far from conducive to good combustion. Coal is usually fired in large quantities, and little opportunity is given for the air and gases to mix before the heating surface is reached and combustion is arrested. In all the hand-fired plants visited success in smoke prevention has been obtained chiefly by careful firing. The coal was thrown on often in small quantities; the fire was kept clean, enough ash to prevent the passage of air through the fire never being allowed to collect on the grate; and more air was supplied at firing than after the volatile matter had been distilled. Even with such precautions the plants might have made objectionable smoke at times but for the fact that usually some method was employed for mixing the gases and air before they reached the heating surface.

COKING FURNACE.

One pattern of furnace that requires less attention from the fireman and less care in operating than the usual hand-fired types was found at several plants. This is known as the coking furnace, which in its earliest form was the invention of James Watt. With this furnace large charges of coal may be fired at one time. The coal is shoveled or fed from magazines to a dead plate at the mouth of the furnace, where the volatile compounds distill, and the coal is later pushed back. Unfortunately, in the model of this furnace generally used the magazines are open after the coal on the dead plate has burned down, so that the coal is consumed with a large excess of air.

STEAM JETS.

A clean stack with hand firing is not as good evidence of efficient operation as it is with almost any type of mechanical stoker, because of the special devices used with hand-fired boilers to prevent smoke. Steam jets are the most common of such devices. Usually they are not automatic, and at many plants they are allowed to run longer than is necessary or else are not used at all. Any steam jet that will so mix the gases and air at the times of greatest need, when coal is fired, as to prevent smoke will, if allowed to run continuously, probably waste more of the energy in the coal than it will save. At the same time a steam and air admission device allows a regulation which, if properly made, will keep a stack clean and save coal.

The steam jet is found in an improperly designed furnace or in one where the air supply is too small. It is an expensive device, all conditions being considered. The only purpose it can serve is to mix the air and gases intimately and prevent the combustible gases from coming too quickly into contact with the heating surface. The claims sometimes made that the use of a steam jet will increase the thermal value of the fuel are erroneous.

It takes the same amount of heat to dissociate a pound of steam into hydrogen and oxygen as is given off when a pound of steam is formed by the union of hydrogen and oxygen. Moreover, the fact must not be overlooked that to burn hydrogen in the average furnace is extremely difficult, and therefore if some steam were dissociated by a jet it is probable that part of the hydrogen would escape to the stack unburned. The same quantity of oxygen that is formed by the dissociation of a pound of steam would be required to burn enough hydrogen to form another pound of steam, therefore there would be no oxygen available from dissociation to burn the coal.

In a water-gas plant, sometimes cited by makers of steam-jet attachments, the heat required to dissociate the steam is supplied by the coke and is later utilized when the gas is burned. The process is as follows: Air is blown through the fuel bed until combustion is fairly well started. The air is then shut off and steam is blown through; this is dissociated, the fuel loses its heat and if the operation continues too long the fire goes out; but after a certain length of time the steam is turned off and air is passed through until the fuel bed is in condition to give up more heat. Then steam is turned on again and the process repeated. After several hours of operation several thousand cubic feet of gas have been formed from the union of the dissociated oxygen of the steam with the glowing carbon of the coke, but there has been no gain in thermal units.

Another fact to be remembered in using steam jets is that all steam entering the furnace must be heated to stack temperature, and the heat required for this is supplied from the coal.

As most air is required in a furnace at the moment of firing fresh coal, and the requirement diminishes as the volatile matter in the coal is distilled, steam jets need close regulation for good economy. To make this regulation independent of the fireman several devices for automatically turning the steam on and off have been patented. Figure 25 illustrates one of these devices at a furnace under a water-tube boiler, and figure 26 gives a section through a return tubular boiler with similar equipment. Opening the furnace door turns on the steam, and a dash pot suitably connected shuts off the jets after a short interval.

MIXING DEVICES.

There is no question as to the value of mixing the air and gases in a hand-fired furnace, and if the mixing could be done by some effective arrangement of fire-brick piers the losses resulting from the use of steam jets would be avoided, but to build arches and piers that will stand the intense heat from intimate mixing and combustion has proved a difficult matter. Moreover, the piers and arches take up room and diminishing the space in a furnace will usually reduce the available furnace draft, so that less coal can be burned even though there is more perfect combustion. The easiest and most nearly perfect solution of the problem is a mechanical stoker properly set under the boiler.

DETAILED DESCRIPTION OF PLANTS.

During the field investigations 71 hand-fired plants run without the emission of dense smoke were visited. The types of boilers installed at these plants were as follows: Return tubular, 44; water-tube, 22;

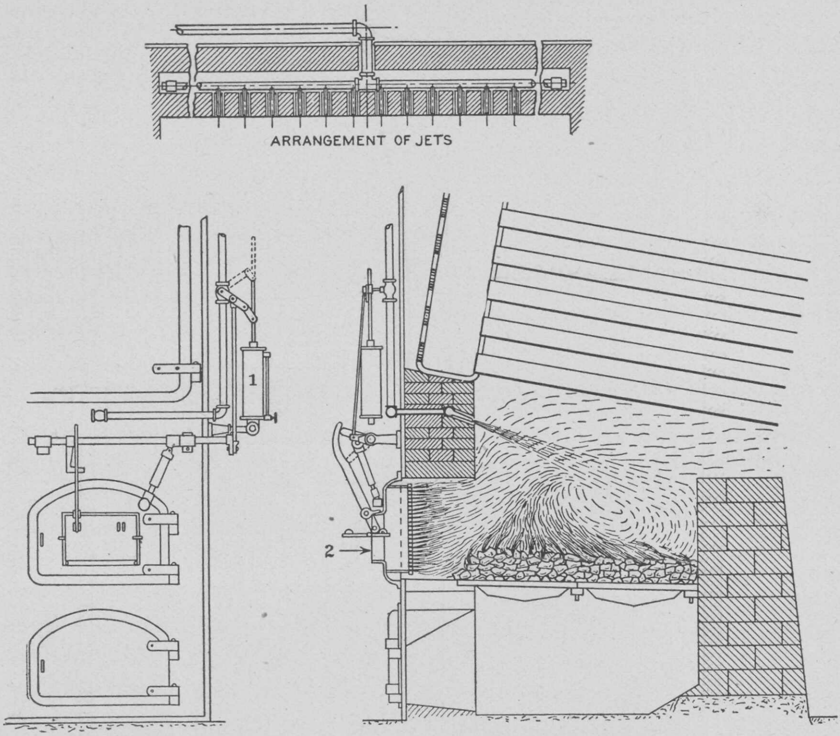


FIGURE 25.—Automatic steam and air admission device and water-tube boiler. 1, Dash pot used to control length of time steam jets are in operation; 2, air admission through furnace doors.

Scotch marine, 5. Tables 20 to 25 give all the essential data that could be collected regarding these plants.

Plants with water-tube and Scotch marine boilers.—Hand-fired furnaces operated under water-tube or Scotch marine boilers were found at 27 plants. These furnaces were of the following patterns: Plain, Dutch oven, Burke, Dorrance, down-draft, Puddington, and twin arch. Brief descriptions of three of these, including the down-draft pattern, are appended, and some of the others are described in the discussion of hand-fired furnaces with return tubular boilers (pp. 117–124).

One of these furnaces is virtually a Dutch oven with a long, rearward-sloping arch that entirely covers the grate and projects into

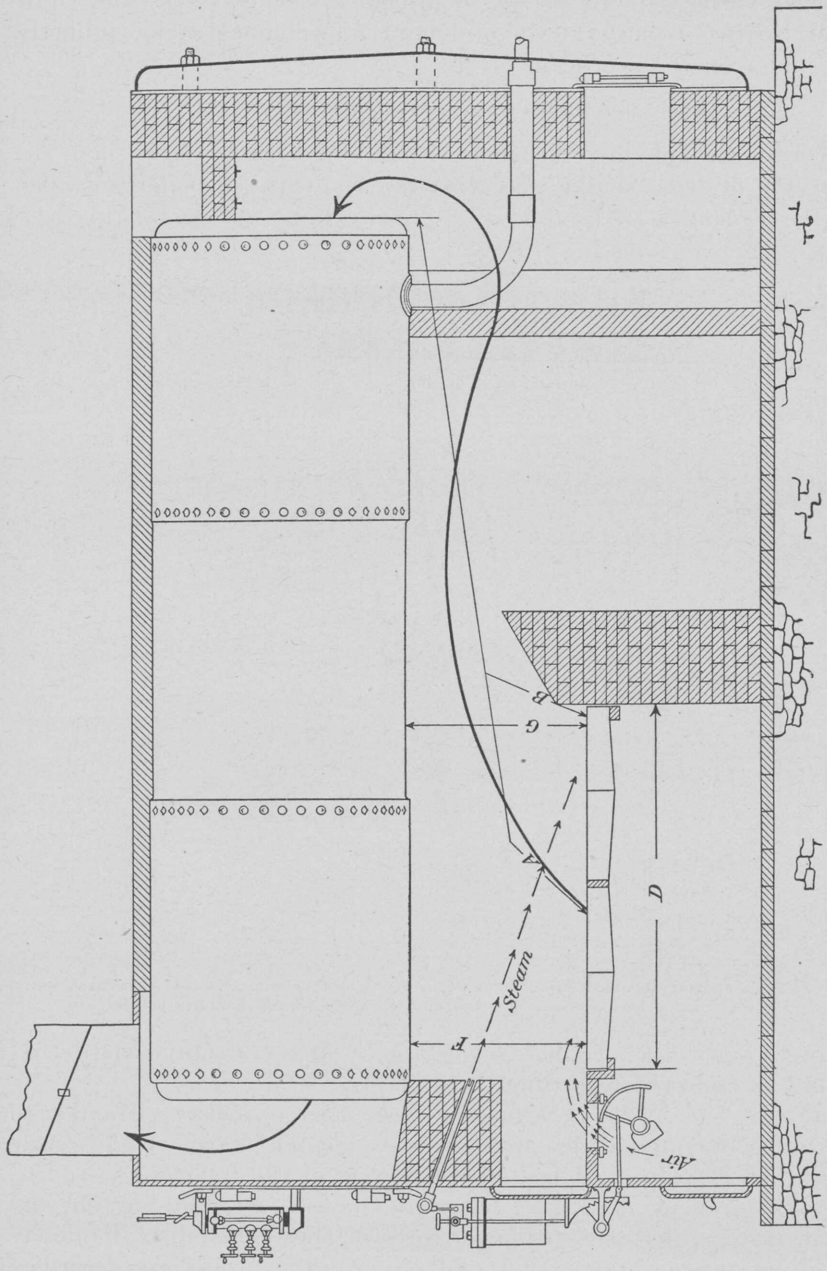


FIGURE 26.—Automatic steam and air admission device and return tubular boiler.

the space back of the bridge wall. The grate also has a rearward slope. The accompanying illustration (fig. 27) of one of these furnaces under a Babcock & Wilcox boiler shows how the travel of the burning gases is lengthened.

The distinguishing feature of the down-draft furnace is an upper grate, which may be formed of tubes through which water circulates,

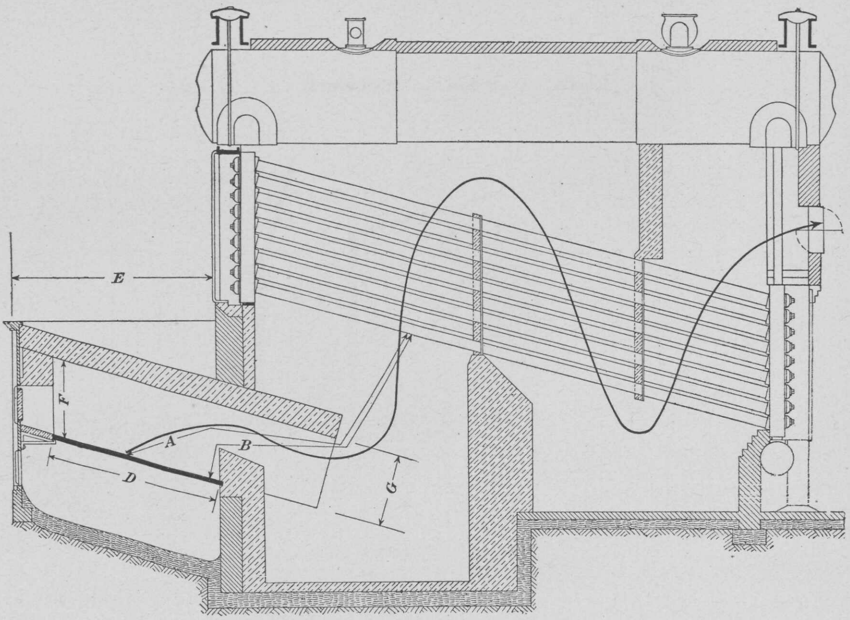


FIGURE 27.—A hand-fired furnace and Babcock & Wilcox boiler.

connected to headers and supported by lugs. The fresh coal is thrown on this grate, whence, after partial burning, it falls to a grate of ordinary construction a foot or more below, where combustion is com-

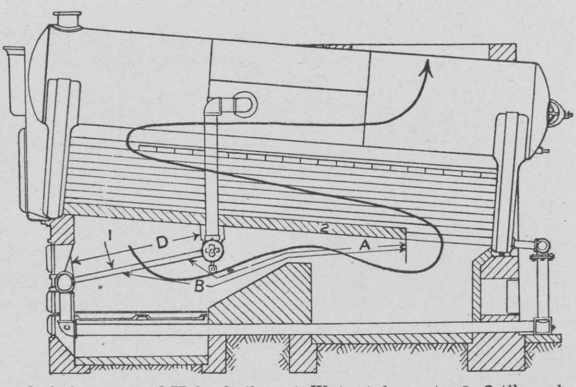


FIGURE 28.—Down-draft furnace and Heine boiler. 1, Water-tube grate; 2, C tile on lower row of tubes, forming a tile-roof furnace.

pleted by the excess of air drawn through the upper and lower grates. The air and the distilled gases from the fresh coal are heated and intimately mixed in passing through the fuel bed, facilitating combustion in the space between the grates. One of these furnaces under a horizontally baffled Heine boiler is represented in figure 28.

The third furnace has back of the bridge a fire-brick wall with two arched openings at its base separated by a projecting angle. The

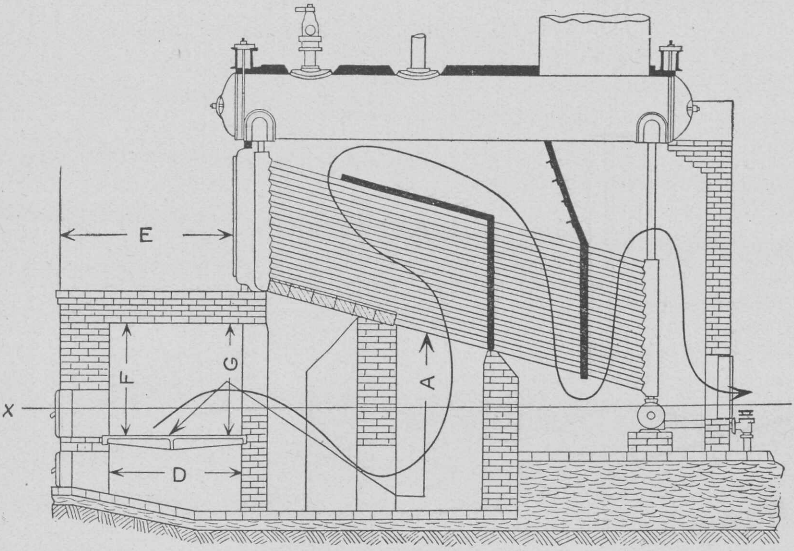


FIGURE 29.—A hand-fired furnace and Babcock & Wilcox boiler, elevation. *X–X'*, Line of sectional plan, figure 30.

long minimum distance from grate to first tube heating surface is shown by figure 29. The plan of the furnace (fig. 30) and the cross section (fig. 31) show the construction of the mixing wall.

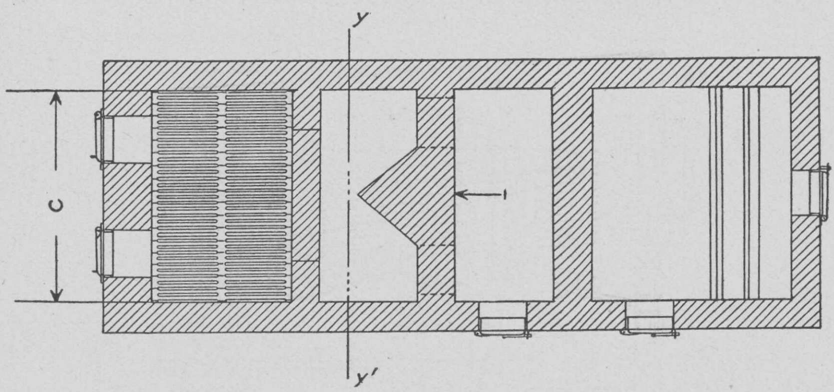


FIGURE 30.—A hand-fired furnace, plan along line *X–X'*, figure 29. *y–y'*, Line of cross section, figure 31.

These 27 plants ranged in size from 75 to 1,500 horsepower. Seven were equipped with steam-jet devices. Ten had a variable load and 17 a uniform load. At 9 plants the coal supplied was either run-of-mine, egg, or lump. The coal as fired burned per square foot of grate surface per hour varied from 10.8 to 40.4 pounds and averaged 23.9 pounds. The average ratio of heating surface to grate surface was 49.6 to 1, the lowest being 26 to 1 and the highest 73 to 1. Thirty-five per cent of the furnaces were installed under boiler units of 150 horsepower or less and 50 per cent under units of 200 horsepower or less. Forty-four per cent of the plants had either rocking or dumping grates. All plants except one with induced and one with forced draft ran on natural draft. Thirteen of the plants were fired by the spreading method, 8 by the alternate method, and 3 by the coking method. The kind of coal used and the average depth of fire are summarized in the following table:

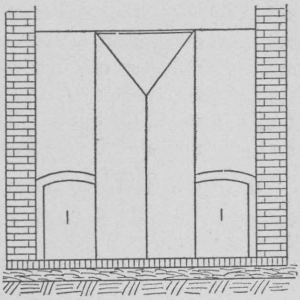


FIGURE 31.—A hand-fired furnace, cross section along line $y-y'$, figure 30. 1, Openings in mixing structures.

TABLE 18.—*Kind of coal and depth of fire at plants with hand-fired furnaces under water-tube and Scotch marine boilers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	14	7	Pennsylvania	1	11
Indiana	2	8	West Virginia	4	7
Maryland	2	15	Miscellaneous	3	8
Ohio	1	4			

Details regarding type of furnace, kind of coal, amount consumed, draft, furnace setting, etc., are summarized below:

TABLE 19.—*Summary of various observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers.*

Type of boiler.	Kind of furnace and number of plants.[a]	Kind of coal.	Furnace draft.	Coal burned per square foot of grate surface per hour, average heavy load.	Percentage of rated boiler horsepower developed, average heavy load.[b]	Distance from grates to tube-heating surface.		Distance from front of furnace to front of boiler	Vertical distance from grate to arch or heating surface.	Black smoke.
						Average.	Minimum.			
			Inch water.	Lbs.		Ft.	Ft.	Ft.	Ft.	P.ct.
Babcock & Wilcox.	Dutch oven 2, plain 1, twin arch 1.	Illinois and West Virginia.	0.24	20.5	107	11	8	4.8	3.1	4.5
Heine	Dorrance 1, Hawley 3, Puddington 1.	Illinois, Maryland, Ohio, and West Virginia.	.41	30.5	103	8.6	6.2	0.	2.6	4.3
Scotch marine	Burke 2, Hawley 1, plain 2.	Illinois and Indiana.	.21	19.7	84	4.2	3.0	4.3	1.7	4.0
Miscellaneous	Dorrance 3, Dutch oven 1, Hawley 3, plain 4, Burke 2, twin arch 1.	Illinois, Indiana, Maryland, Pennsylvania, and West Virginia.	.30	24.5	104	9.4	7.2	2.9	2.9	4.5

[a] One plant has both Hawley and plain furnaces.
[b] Boiler rated on 10 square feet of heating surface per horsepower.

The draft observations may be briefly summarized thus:

Average furnace draft, 25 plants, 0.29 inch of water; least, 0.07 inch; most, 0.60 inch. Average draft at rear of boiler, 11 plants, 0.54 inch, least, 0.32 inch; most, 0.70 inch. Average draft at base of stack, 19 plants, 0.75 inch, least, 0.50 inch; most, 1 inch. From these readings were deduced the following approximate draft averages: Approximate average draft in furnace, 0.30 inch of water; at rear of boiler, 0.55 inch, at base of stack, 0.75 inch. This gives an average drop of 0.25 inch of water through the boiler and of 0.20 inch from the boiler to the base of the stack.

Details of the observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers are given in Table 20.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers.*

No. of plant.	State.	Device used to facilitate combustion.	Total builder s rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
214	Illinois	None	450	Washed	Carterville, Ill	No. 5	$2.10	
215	Ohio	Steam jet	825	New River	West Virginia	Slack		
216	do	do	100			Nut and slack		
217	New York	None	80			Slack		1,400
218	Illinois	do	900	Washed	Carterville, Ill	Nos. 4 and 5		
219	Maryland	Steam jet	424	Somerset big vein	Maryland	Run of mine	2.80	1,940
220	Ohio	Air admission	325	Massillon	Ohio	Slack	2.00	5,000
221	do	None	500	New River	West Virginia	Nut and slack	2.50	
222	do	Steam jet	200	Pocahontas	do	Screened lump	3.60	
223	Illinois	None	750	Washed	Illinois	Nut and pea		
224	do	do	711	do	Carterville, Ill	Nos. 2 and 5		
225	do	do	200		do	No. 2		
226	do	do	1,500	Miami lump	Indiana	1-inch screenings	2.25	
227	Michigan	do	500	Red jacket		Run of mine	2.85	1,550
228	Illinois	do	900	Washed	Carterville, Ill	Nos. 4 and 5	$2.60–2.65	
229	Missouri	Steam jet	900	Staunton	Illinois	Lump	2.05	6,420
230	Illinois	None	600		do	1¼-inch screenings	1.80	
231	do	do	540	Washed	do	No. 4	2.65	
232	Missouri	do	500	Staunton	do	Lump	2.05	
233	Illinois	do	450		do	1-inch nut		
234	do	do	450		do	3-inch screenings	2.60	
235	do	do	856	Majestic	Near Carterville, Ill	No. 1 nut		
236	do	do	200	Buckhorn	do	Egg	2.85	
237	do	do	75	Block	Indiana	Run of mine	3.60	
238	Maryland	Steam jet	765	Georges Creek	Maryland	do	3.02	
239	New York	None	600		Pennsylvania	Slack	2.00–2.40	9,800
240	Ohio	Steam jet	150		West Virginia	Run of mine	2.00	

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Load.			Rating.								
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
214	Power, light, and heat	Variable	Offices and manufacturing	10	11	10	9	30.6	27.8	140	147	5
215	Power and light	Uniform	Office building	12	10	12	10	17.1	17.1	74	68	4.5
216	Power	do	Factory	9.5	1.9	....	....	17.4	....	71	80	5
217	Power, light, and heat	do	Transfer company	12	2	12	1	16.7	12.5	143	186	4.5
218	do	do	Hotel	24	19	24	16	35	32.1	100	106	5
219	Power and heat	do	Post-office	12	6.2	12	4.8	18.3	16.3	115	109	4.5
220	Power and light	Variable	Commercial	17	15	17	7.4	36.8	27.5	95	109	5
221	do	Uniform	Office building	12	7.5	....	....	32	....	140	125	4
222	Power, light, and heat	do	Post-office	17	4.3	17	3.5	....	....	63	63	4
223	do	Variable	Offices and theater	24	20	24	8	17	16	90	66	5
224	do	do	Hotel	24	22	24	15.5	25.5	21.5	97	80	5
225	do	do	Store building	11	3.5	14	3.25	14	10	81	64	5
226	do	Uniform	Waterworks	24	60	24	60	31	31	100	132	5
227	do	do	Laundry	12	4.9	12	3.7	10.8	9.5	50	36	4.5
228	Power and light	do	Office building	8	12.5	24	20	33.9	26	93	104	5
229	Power, light, and heat	do	Commercial	17	12	....	....	12.9	....	57	47	5
230	Light and heat	Variable	Brewery	24	12	24	15	16.2	13.4	76	80	5
231	Power and heat	Uniform	Office building	10	5	10	3	31	25	111	111	5
232	Power, light, and heat	do	Factory	10	8.8	10	6	34	28.5	170	141	5
233	do	Variable	Office building	16.5	6	10	3	29	27	97	97	5
234	do	Uniform	Hotel	18	16	18	16	32	32	112	118	5
235	do	Variable	Office building	11	18	11	8	40.4	40	160	153	5
236	Power and heat	Uniform	do	12	6.5	12	5	20	18	108	108	5
237	Power, light, and heat	Variable	Printing office	10	3	10	2	28	24	....	160	5
238	do	do	Hotel	17	14	17	14	14.2	14.2	....	79	4.5
239	do	Uniform	Office building	17	20	17	17	14.7	13.3	60	79	5
240	do	do	Store building	11	2.5	11	2.5	12.7	12.7	....	61	5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Stoking.					Boilers.									
	Method of firing.	Frequency of firing (minutes).	Coal fired at each firing per boiler (pounds).	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horsepower.	Horsepower.[a]	Heating surface (square feet).	Superheating surface.	Steam pressure at gage.
214	Alternate	([b])	75–90	10–12	Once in 10 hours	Babcock & Wilcox water-tube.	84 4″ x 16′ tubes	3	2	2	150	157	1,570	0	165
215	do	15	65	8–10	.....	do	120 4″ x 18′ tubes	3	2	2	275	252	2,520	0	150
216	Spreading	7–12	60–90	4–6	.....	do	54 4″ x 18′ tubes	1	1	1	100	113	1,130	0	90
217	.....	.....	.....	6–8	.....	do	32 4″ x 14′ tubes	2	1	1	40	52	520	0	80
218	Alternate	([b])	45	6–8	3 times in 24 hours.	Heine water-tube.	170 3½″ x 18′ tubes, 2 36″ drums.	3	1	1	300	319	3,185	0	150
219	Spreading	([b])	250–400	([b])	2 to 3 times in 12 hours.	do	54 3½″ x 18′ tubes, 1 36″ drum.	4	2	2	106	100	1,000	0	120
220	do	15	150–180	3–4	3 to 4 times in 17 hours.	do	176 4″ x 18′ tubes	1	1	1	325	370	3,700	0	105
221	do	([b])	([b])	6–8	.....	do	116 3½″ x 19′ tubes, 1 40″ drum.	2	1	1	250	224	2,240	0	150
222	do	20	270–370	.....	Once in 24 hours	do	58 3½″ x 18′ tubes	2	2	2	100	100	1,000	0	120
223	Coking	([b])	([b])	([b])	3 times in 24 hours	Scotch marine	84 4″ tubes, 9 3/10′ x 18′ shell.	3	2	1	250	175	1,750	0	100–110
224	Spreading	([b])	60	6–8	do	Inverted Scotch marine.	94 3″ tubes, 94″ shell.	3	2	2	237	190	1,900	0	145
225	Coking	([b])	([b])	([b])	Once in 11 hours	Scotch marine	44 3½″ x 15′ tubes, 78″ shell.	2	2	2	100	75	746	0	90–100
226	Spreading	18–25	350–400	8	6 times in 24 hours.	do	138 4″ x 12′ tubes, 10′ shell.	6	4	4	250	190	1,900	0	130
227	do	12	.....	5–6	Once in 12 hours	do	2 38″ flues, 2 42″ flues.	2	2	2	200, 300	142, 225	1,423, 2,250	0	100
228	Alternate	4–6	50–70	6	Once in 8 hours	Cahall horizontal water-tube.	160 4″ x 18′, 2 42″ drums.	3	2	2	300	335	3,350	0	135
229	Spreading	15–30	150	10	2 times in 12 hours.	O'Brien water-tube.	140 x 18′ tubes	3	2	1	300	250	2,500	0	140
230	do	([b])	400–500	[c]8	3 times in 24 hours.	Cahall horizontal water-tube.	162 4″ x 18′, 126 4″ x 18′.	2	1	2	250, 350	264, 340	2,640, 3,400	0	120
231	Alternate	5–7	40–60	6–8	Once in 8 hours	Detroit water-tube	96 4″ tubes, 1 30″ drum.	3	1	1	180	180	1,800	0	125

[a] Boiler rated on 10 square feet of heating surface per horsepower. [b] Variable. [c] On top grate.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Stoking.					Boilers.									
	Method of firing.	Frequency of firing (minutes).	Coal fired at each firing per boiler (pounds.)	Thickness of fire (inches).	Frequency of cleaning fire.	Type.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horse-power.	Horse-power.	Heating surface (square feet).	Superheating surface.	Steam pressure at gage.
232	Spreading...	20	100	11	2 times in 10 hours.	O'Brien water-tube.	113 3½″ x 18′ tubes.	2	1	2	250	207	2,070	0	140
233	Alternate...	(a)	30-35	3-4	.....do............	Aultman & Taylor water-tube.	72 4″ x 18′ tubes, 1 36″ drum	3	1	1	150	150	1,500	0	90-110
234	.....do.......	10-15	60-75	4-5	3 times in 24 hours.	Detroit water-tube	110 3½″ x 14′ tubes.	3	2	2	150	158	1,575	0	120
235	.....do.......	(a)	45	3	.....do............	Aultman & Taylor water-tube.	2 36″ drums.......	4	2	1	200, 228	188, 226	1,875, 2,260	0	125
236	Coking......	(a)	(a)	....	1 to 2 times in 12 hours.	Standard water-tube.	54 4″ x 16′ tubes, 36″ drums.	2	2	2	100	100	1,000	0	120
237	.....do.......	(a)	(a)	(a)	Once in 10 hours..	Stirling water-tube	....	1	1	1	75	....	....	0	100
238	Spreading...	8-12	120-150	14-16	2 times in 24 hours.	Edgemoor water-tube.	....	3	2	2	300, 165	....	....	0	150
239	....	7	120-150	9-12	3 times in 24 hours.	Geary water-tube.	140 4″ x 16′ tubes..	4	3	3	200	260	2,600	0	135
240	Spreading...	10	50-90	5-6	2 times in 11 hours.	Stirling water-tube	144 3¼″ tubes......	1	1	1	150	....	....	0	100

a Variable.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Furnaces.									
	Number.	Kind of furnace.	Kind of grate.	Grate area per boiler [a] (square feet).	Dimensions (feet).					
					Distance from grates to tube-heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to coking arch or heating surface (F).
					Average (A).	Minimum (B).				
214	3	Twin arch	Shaking	36	17	14	3	6	5	2.3
215	3	Dutch oven	Flat	48.75	8.5	5.5	7.5	6.5	7	4.5
216	1	Plain	Rocking	23	....	....	3.8	6	0	....
217	2	Dutch oven	Flat; hollow	20	7.5	4.5	3.3	6	7	2.5
218	6	Dorrance	Rocking	45.6	10	7	4	5.7	0	2.2
219	4	Hawley	Water-tube and flat	28.2	12	9	4.8	5.8	0	....
220	1	Puddington	Flat	48	3	2.5	8	6	0	3
221	2	Hawley	Water-tube and flat	39	9	6	6.5	6	0	
222	2	....do	....do	....	9	6.5	....	....	0	....
223	3	Burke	Rocking	48	8.5	5.5	8	6	7.75	....
224	6	Corrugated flue	Flat	36	1.5	1.5	3	6	0	1.5
225	2	Burke	Rocking	23.6	7.5	5.5	5.25	4.5	6.25	....
226	12	Hawley, down draft	Water-tube and flat	40	4	2	8	5	7.75	....
227	4	Corrugated flue	Flat	38	[b]1.6, 2	[b]1.6, 2	[b]3.2, 3.5	[b]6, 5.6	0	[b]1.6, 2
228	6	Dorrance	Rocking	46	12.5	9.5	4	5.75	6.5	2.5
229	2 1	Hawley Plain	Water-tube and flat	55	....	....	10	5.5	....	....
230	2	Hawley	....do	59, 61.5	....	....	....	....	....	....
231	3	Dutch oven and tile roof	Shaking	33.25	17	13.5	4.75	7	3.3	2.6
232	2	Hawley	Water-tube and flat	52	....	....	8	6.5	0	....
233	3	Dorrance	Shaking	25	11	9	5	5	6.3	2.3
234	3	Twin arch	....do	27.5	9	6.5	2.5	5.5	0	2.2
235	4	Dorrance	....do	36, 47	11.5	8	[b]5, 8, 6.7	6.2	6.5	[b]3, 3.3
236	2	Burke	....do	27	9	6.5	6	4.5	4.5	2
237	1	....do	Rocking	21.3	11.5	9.5	4.75	4.5	5	....
238	3	Plain	Flat	75, 41.25	4.5	4.5	[c]10, 5.5	7.5	0	5.5
239	4	....do	McClave flat	53.5	2.5	2	8.9	6	0	2.5
240	1	....do	Flat	35.75	5	3	6.5	5.5	0	3

[a] In down-draft furnaces, area of upper grate only. [b] First dimension applies to small boiler. [c] First dimension applies to large boiler.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
214	Chimney....	0.38	0.46–0.50	....	0.72	0.78	Damper open, door in base of stack cracked.	2	128	0	0	54	3.4	Light.
215	.....do......	....	....	....	.75	....	Damper partly closed........	(a)	(b)	0	0	....	....	Average.
216	.....do......	.18	....	....	....	.55	Damper open, ash-pit doors three-quarters closed.	(a)	(b)	0	0	55	....	Heavy.
217	.....do......	.16	.32	....	....	.55	....	1	60	0	0	49	5.7	Light.
218	.....do......	0.50– .53	.78	....	1.46	....	Damper open..........	4	262	2	1	52	5.3	Do.
219	.....do......	.26– .38	....	....	0.56– .84	....	Damper partly closed........	(a)	(b)	0	0	....	....	Heavy.
220	.....do......	.16	....	....	....	.51	....	1	60	0	0	52	3.3	
221	.....do......	.50	....	....	1.45	....	Damper and ash-pit doors open.	(a)	(b)	0	....	....	....	Do.
222	.....do......	.55	....	....	.95	....	Dampers open..........	(a)	(b)	0	0	....	....	Do.
223	.....do......	.16	....	....	....	1	Door at base of stack open...	8	515	0	3	50	5	Light.
224	.....do......	.22– .48	....	....	.96	....	Dampers open..........	4	272	0	0	52	3.1	Do.
225	.....do......	.04– .09	.43	....	.74	....	Damper and ash-pit doors open.	1	60	0	0	60	0	Do.
226	.....do......	.25– .40	....	....	.56– .64	....	Dampers open; ash-pit doors cracked.	1	60	1	3	47	7.9	Average.
227	.....do......	.11– .17	....	0.37–0.40	....	.50	....	1	60	0	0	54	4.2	Heavy.
228	.....do......	.27	.68	....	....	.90	Damper open..........	3	211	0	0	51	.3	Do.
229	.....do......	.29	.54	....	....	....	....	1	60	0	0	49	5	Do.
230	.....do......	....	....	....	....	0.75– .85	Dampers partly closed......	2	114	0	2	40	6	Light.
231	.....do......	.23	....	....	....	.85	Door in base of stack open..	7	399	8	5	44	12.6	Do.
232	.....do......	.54	.60	....	....	....	Ash-pit doors open..........	1	60	0	0	36	6.5	Do.
233	.....do......	.36	.66	....	.94	....	Damper half open..........	2	150	0	0	60	0	Do.
234	.....do......	.12	.47	....	....	.76	Dampers and ash-pit doors open.	4	187	0	0	60	0	Average.
235	.....do......	.24– .25	.56	....	....	.78	Dampers open..........	4	272	0	0	56	4.2	Light.
236	.....do......	.11– .12	.46– .47	....	.76	....	.....do..........	3	183	0	0	54	2.4	Do.
237	Induced.....	.09	(c) .45	....	....	....	Fan running at average speed.	1	60	0	0	60	0	Do.
238	Chimney....	.60	....	....	.90	....	Dampers open..........	1	....	....	....	....	....	Average.
239	Forced......	.22– .44	.32– .45	....	.92	1	Fan blast in ash pit........	1	120	0	0	30	11.8	Light.
240	Chimney....	.35	....	....	.60	....	Damper open..........	(a)	(b)	0	0	50	3	Average.

[a] Several. [b] Various lengths. [c] Upper rear boiler.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
214	8	5 x 3	Near boiler........	2	130	[a]4	12.56	Small combustion chambers. Furnace doors cracked for short time after each firing. Must run with dampers wide open to keep clean stack.
215	11	3.5 x 6	Near stack........	0	270	[a]4.4	14.7	Two boilers equipped with automatic steam jets and air admissions. Stack good with these two boilers in service. Smoke observations include some 10, 20, and 40 per cent black readings. Each furnace equipped with eight $\frac{1}{8}$-inch steam jets.
216	0	....	....	0	90	....	....	Draft in front of furnace increased about 0.07 inch of water with steam jets on. Automatic steam and air admission; six $\frac{1}{8}$-inch steam jets across front of furnace. Success due to careful operation. Stack smokes from 10 to 20 per cent black for one-half to one minute at each firing. During firing ash-pit doors closed, but opened as soon as furnace doors closed. Some shavings burned. Device in service about two minutes.
217	10	....	....	0	100	3 x 3	9	Forced draft through hollow grate bars. Half anthracite and bituminous coal usually burned, to keep smoke down. Some straw refuse burned.
218	32	4.6 x 6	....	1	235	[a]6	28.3	U tile on lower row of tubes. Total length of arch over furnace 11.25 feet.
219	22	....	....	2	108	[a]3	7.06	U tile on lower row of tubes to a point within 3 feet of rear water leg. Heating surface figures do not include heating surface of water-tube grates. Fire-brick checker work at rear of lower grate. Two boilers have 14 $\frac{1}{8}$-inch steam jets entering through rear water leg; two boilers have 21 steam jets. Jets not automatic but turned on before firing and left on two to three minutes after firing. Ash-pit doors opened during firing. Two similar stacks. Stacks smoked 20 per cent black for short time at long intervals. Coal wet before firing. Dry coal contains about 15,000 B. t. u. per pound; moisture plus ash in coal as received, 5 per cent.
220	0	0	....	0	100	[a]4.25	14.2	U tile on lower row of tubes. Three 3 by 24 inch air openings through front of furnace, also two 10 by 16 inch air openings leading from back of boiler through ash pit to front. Combustion assisted by steam-oil-gas jets. All jets and air admissions automatically operated. Stack on rear of boiler.
221	40	....	....	1	255	[a]4	12.56	U tile on lower row of tubes to a point within 3 feet of rear water leg. Fire occasionally on lower grate, which causes 40 and 60 per cent black smoke from stack for one-half to one minute.
222	12	....	....	1	152	[a]4.5	15.9	U tile on lower row of tubes to a point within 3 feet of rear water leg. 24$\frac{1}{8}$-inch steam jets pass through stay-bolt holes in rear water leg, not automatic; in use during firing and shortly after. Smoke observations include several 10, 20, and 40 per cent black readings. Automatic regulator on main damper.
223	28	4 x 6	Near stack........	1	306	[a]5.5	23.7	Coal as fired runs moisture 16.5 per cent; ash, 9 per cent; B. t. u. per pound, 10,800.

[a] Diameter.

TABLE 20.—*Details of observations at plants with hand-fired furnaces under water-tube and Scotch marine boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
224	10	4 x 7	Near stack........	1	250	[a] 4 x 6	20.56	Furnace doors cracked after each firing. Grates have 55 per cent air space. Plant usually runs with dampers partly closed. Alternate doors fired, spreading method.
225	25	[b] 3	.....do............	2	135	4 x 1.9	7.6	Furnace draft on this type of furnace varies greatly as coal magazine is or is not kept filled. Occasionally, 40 and 60 per cent black smoke at first firing after cleaning fires.
226	7	1 3.5x11 1 3.5x 6	....	2	....	....	....	Water-tube grates have two rows of tubes staggered. Ash-pit doors kept cracked.
227	20	....	....	3	80	[b] 4.2	13.6	Air admission at bridge wall and patent air-admission doors.
228	18	3.5 x 9	Near stack........	1	260	[b] 5	19.6	Total length of arch over grates, 9.7 feet. Boilers baffled vertically.
229	15	3 x 6	.....do............	0	200	[b] 4.5	15.9	Boilers baffled horizontally. Steam jets in furnace and brick checkerwork in combustion chamber on boiler with plain grates.
230	17	4 x 6	.....do............	1	150	[b] 5.5	23.7	Staggered water-tube grates. Dampers kept partly closed to carry about 0.5 inch of water in first pass. Brick arches built on bridge wall. Stack occasionally smoked badly when fire was cleaned. Usually run with ash-pit doors closed. Figures for heating surface do not include area of water-tube grates. Considerable 10 per cent black smoke.
231	12	....	....	1	279	[b] 5.5	23.8	Fired by spreading method, using alternate doors. Large combustion chambers. Lower row of tubes covered with C tile leaving 5-foot gas passage at rear of boilers. Furnace doors cracked after each firing. Damper regulator.
232	3	....	....	0	110	[b] 4	12.56	Figures for heating surface do not include area of water-tube grates. Some rubbish burned.
233	50	3 x 5	Near stack........	1	200	4 x 4	16	Large combustion chambers. Draft of 0.80 inch of water in last pass with damper wide open.
234	7	....	....	1	225	[b] 4.7	17.1	Detroit water-tube boiler is of Heine type.
235	70	3 x 8	Near stack........	1	165	9 x 9	81	Spreading method of firing; fire alternate doors.
236	12	2.5 x 3	.....do............	1	210	[b] 4	12.56	
237	18	....	....	1	125	[b] 2.1	3.4	
238	9	....	....	1	....	....	....	Automatic steam and air admission device. Large boiler has 27 $\frac{1}{8}$-inch steam jets across front of furnace; small boiler has 14 $\frac{1}{8}$-inch jets. Device automatically opens and closes air-admission openings in furnace doors; is on during firing and one to two minutes later. Very small amount of black smoke for one-half to one minute at each firing.
239	15	....	....	1	140	[b] 5	19.6	Coal burned, 3 parts anthracite and 2 parts bituminous. Boilers baffled vertically. Stack smokes 20 per cent black about half the time. Using all bituminous coal makes offensive smoke.
240	10	....	....	1	125	3.2 x 3.1	10	Thickest fire in front of furnace. Steam and air admission device runs continuously. Twenty $\frac{1}{64}$-inch jets for superheated steam enter furnace.

[a] Oval.

[b] Diameter.

Plants with return tubular boilers.—The size of the 44 plants having hand-fired furnaces under return tubular boilers varied widely, the smallest being 50 horsepower and the largest 1,000 horsepower. At 45 per cent of these plants run-of-mine, egg, or lump coal was burned. The cost of coal at 31 plants averaged $2.49 per ton, ranging from $1.60 to $4.10. Uniform loads were carried by 34 plants and varied loads by 10. On the average 90 per cent of the rated boiler horsepower (boiler rated on 10 square feet of heating surface per horsepower) was developed on mean heavy load. The furnaces in use at the different plants included 10 types, as follows:

Furnaces used at plants with hand-fired furnaces under return tubular boilers.

	Number of plants.
Dorrance (with Dutch oven)	1
Down-draft	10
McMillan	5
Twin arch	1
Wooley	1
Burke (western, with Dutch oven)	2
Burke (eastern)	1
Plain	21
Cornell economizer	1
Puddington	1

Of these furnaces, 20 had steam-jet attachments. Eleven were equipped with either rocking or dumping grates. At 33 plants either the spreading or the alternate method of firing was used; 5 plants used the coking method.

The average length of travel of the gases to the tube heating surface and the height of the combustion chamber are indicated by the following figures:

Average distance from grates to tube heating surface, 44 plants, 16.6 feet; shortest, 13 feet; longest, 24 feet. Average least distance from grates to tube heating surface, 44 plants, 14.2 feet; shortest, 11 feet; longest, 22 feet. Average vertical distance from grates to shell, 31 plants, 2.3 feet; shortest, 1.5 feet; longest, 5 feet. Average ratio of heating surface to grate surface, 44 plants, 45 to 1; lowest, 26 to 1; highest, 67 to 1.

The draft readings taken at these plants may be summarized as follows:

Average furnace draft, 39 plants, 0.23 inch of water; range, 0.03 to 0.55 inch. Average draft at front tube sheet, 15 plants, 0.41 inch; range, 0.27 to 0.68 inch. Average draft in breeching, 25 plants, 0.51 inch; range, 0.22 to 1.42 inches. Average draft at base of stack, 16 plants, 0.66 inch; range, 0.35 to 1.10 inches.

The following approximate draft averages were deduced from the above: Furnace, 0.25 inch of water; front tube sheet, 0.40 inch; breeching 0.50 inch; base of stack, 0.70 inch. Approximate average drop through the boiler, 0.15 inch.

For convenience the furnaces and devices in use at these plants are discussed in three groups—down-draft furnaces, steam jets, and miscellaneous furnaces and devices.

The essential features of the down-draft furnace are described in the account of hand-fired furnaces under water-tube boilers. Its setting and operation at the 10 return tubular boiler plants where it was found in use are taken up here. All the down-draft furnaces at these plants were set under units of 150 horsepower or less, and none were set in a Dutch oven. Nine of the plants carried a uniform load. At 4 of the plants the coal fired was run-of-mine, nut, or egg. The average cost of coal at 6 of them was $2.68 per ton. At all 10 plants firing was by the spreading method. The kinds of coal burned and the average depth of fire carried were as follows:

TABLE 21.—*Kind of coal and depth of fire at plants with down-draft furnaces under return tubular boilers.*

Kind of coal burned.	Number of plants.	Average depth of fire.	Kind of coal burned.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Illinois	1	7	Pennsylvania	2	10
Kentucky	4	8.5	West Virginia	2	11
Ohio	1	9			

The draft, coal consumption, percentage of rated boiler horsepower developed, distance from grates to tube heating surface, and smoke observations show the following averages:

Draft through fire, 0.30 inch of water; range, 0.03 to 0.36 inch.

Coal as received burned per square foot of grate surface per hour, average heavy load, 20 pounds; least, 13.3 pounds; most, 24.4 pounds.

Percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 96; range, 58 to 157.

Average distance from grates to tube heating surface, 17.1 feet. Least distance from grates to tube heating surface, 14.7 feet.

Smoke emitted, 5.6 per cent black.

The plants visited that had steam jets in the furnaces numbered 20, one of which is included also in the group with down-draft furnaces. At all of them the furnaces were run under boiler units of 150 horsepower or less. The coal burned came from eight States. At 10 plants the size of coal was lump or run-of-mine; the cost ranged from $1.50 to $4.10 per ton, the average being $2.32. Eighteen plants carried fairly uniform loads. Nineteen had furnaces with flat grates. The kinds of coal and the thicknesses of fire carried are shown below.

TABLE 22.—*Kind of coal and depth of fire at plants with steam jets in furnaces under return tubular boilers.*

Kind of coal.	Number of plants.	Average depth of fire.	Kind of coal.	Number of plants.	Average depth of fire.
		Inches.			*Inches.*
Indiana	2	4.5	Tennessee	1	9
Maryland	1	15	West Virginia	5	8.5
Ohio	3	6	Miscellaneous	5	7
Pennsylvania	3	7.3			

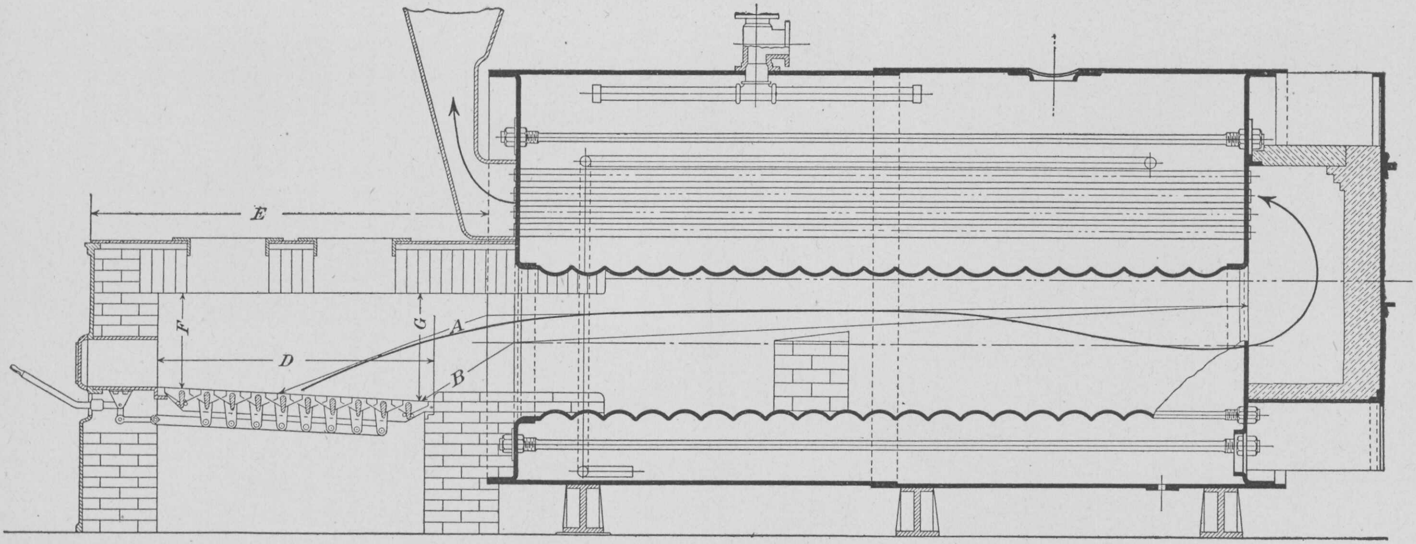


FIGURE 32.—A hand-fired furnace and Scotch marine boiler, elevation.

The draft through the fire, the coal consumption, the furnace setting, and the smoke given off were noted at only 20 plants. The average of the measurements were as follows:

Draft through fire, 0.23 inch of water; range, 0.15 to 0.37 inch.

Coal as received burned per square foot of grate surface per hour, average heavy load, 17.6 pounds; least, 11.2 pounds; most, 25.3 pounds.

Percentage of rated boiler horsepower developed, average heavy load (boiler rated on 10 square feet of heating surface per horsepower), 78; range, 46 to 174.

Average distance from grate to tube heating surface, 15.9 feet. Least distance from grate to tube heating surface, 13.7 feet. Vertical distance, grate to shell, 2.2 feet.

Smoke emitted, 4.2 per cent black.

The miscellaneous group includes all the hand-fired furnaces under return tubular boilers not already described. Three of these furnaces with their distinctive features are briefly described below. Three

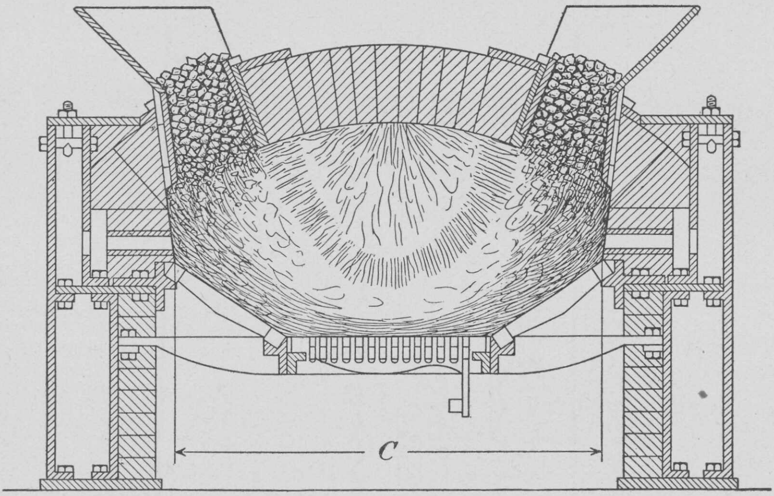


FIGURE 33.—A hand-fired furnace, cross section.

others, including the down-draft, are described in the account of hand-fired furnaces under water-tube boilers (pp. 104–106).

In the first furnace the coal is fired from side hoppers in the furnace wall to a combustion chamber, virtually a Dutch oven, having short sloping grates at the sides with a wide rocking grate between them. The furnace is thus practically a hand-fired side-feed stoker. The Dutch oven construction gives a hot combustion chamber and lengthens the travel of the burning gases. An elevation and a cross section of such a furnace placed in front of a Scotch boiler are presented in figures 32 and 33.

Another furnace having distinctive features intended to insure complete combustion and prevent smoke is shown on page 121. In this pattern (see fig. 34) the furnace gases pass through circular openings in the bridge wall. Immediately beneath these openings are small rectangular holes by which air that comes through a passage in the bridge enters the furnace. The object of this construction is to admit air in such a way that any unconsumed carbon in the gases

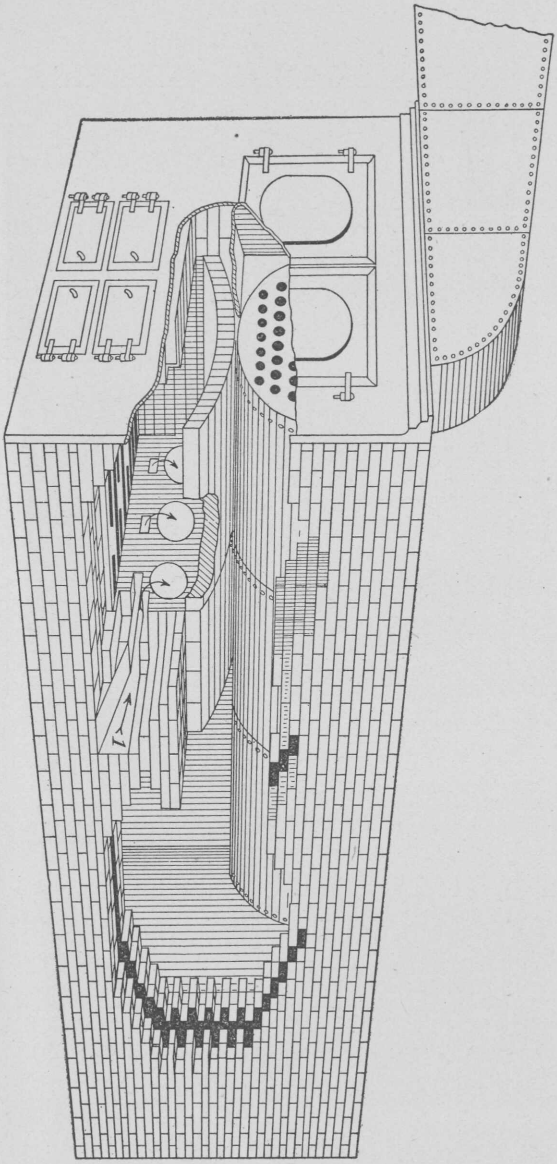


FIGURE 34.—A hand-fired furnace and return tubular boiler. 1, Air admission in bridge wall.

will be brought into contact with the necessary air for burning it without cooling the combustion space.

Another furnace intended to effect smokeless combustion by special fire-brick piers and arches in the combustion space is shown in figures 35–37. Its characteristic features are two furnaces, each with

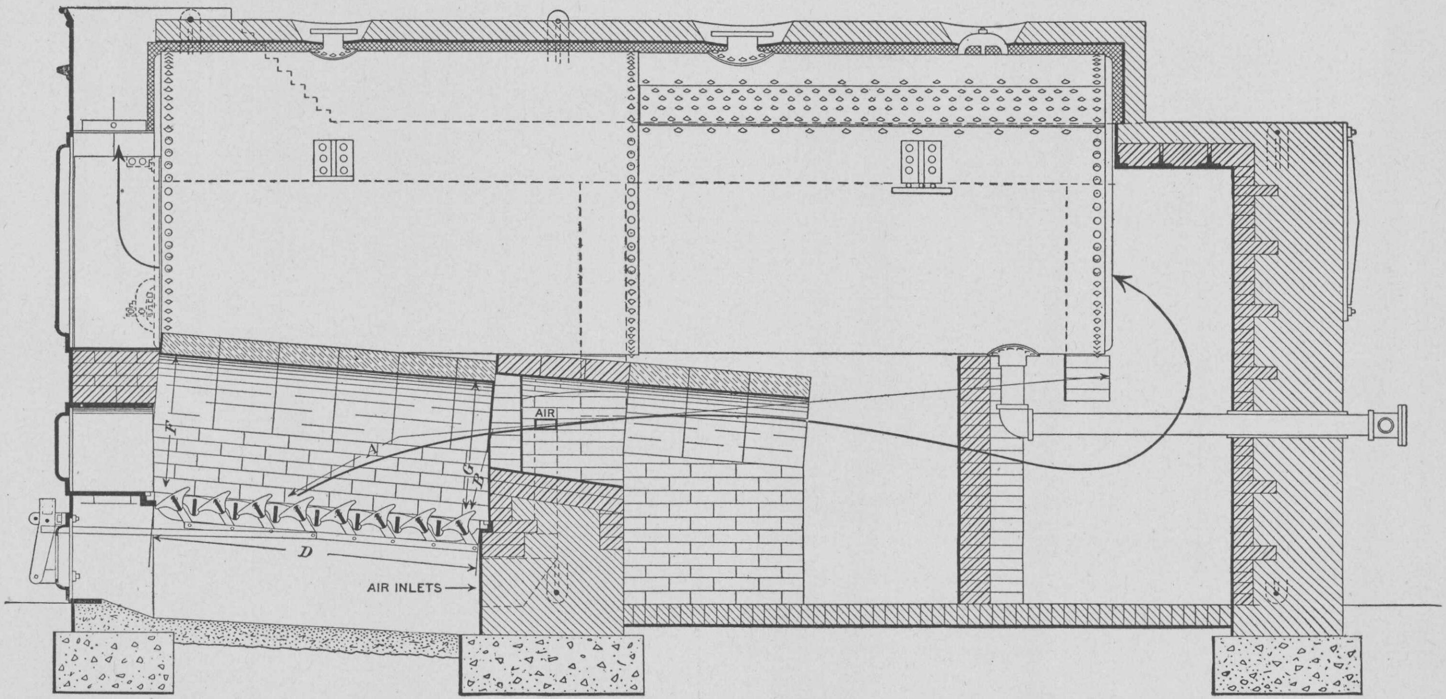


FIGURE 35.—A hand-fired furnace and return tubular boiler, elevation.

an arch extending the entire length of the grate, virtually making small Dutch ovens; a wide-arched passage, in which are openings for

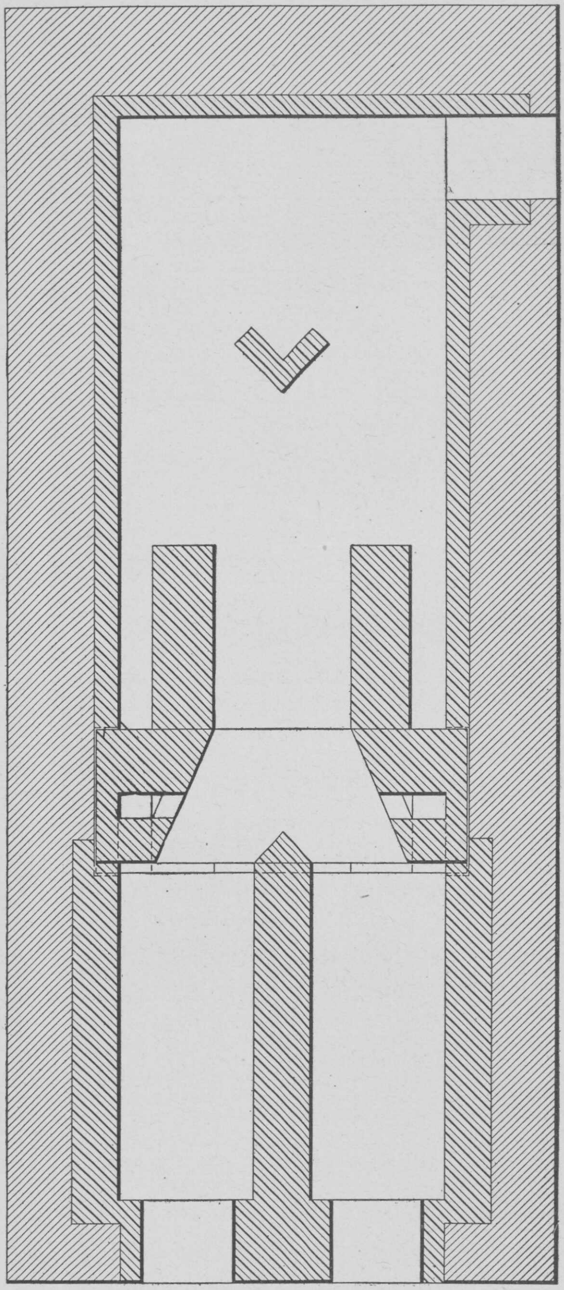


FIGURE 36.—A hand-fired furnace, plan.

air admission, in the wall back of the grates; and another arched passage of greater height back of this. This construction gives a long, irregular combustion space, evidently intended to permit thorough mixing of gas and air. Figure 35 is an elevation of the furnace as usually installed under a return tubular boiler; figure 36 is a horizontal plan, and figure 37 a cross section.

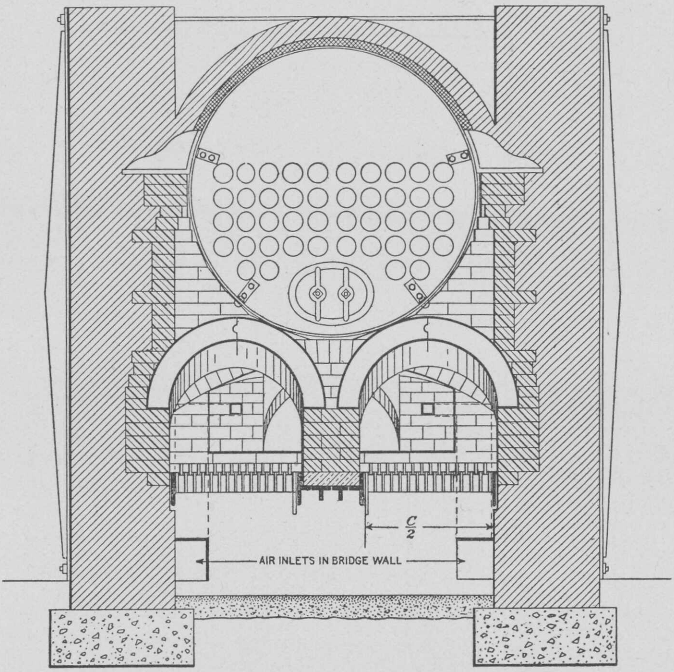


FIGURE 37.—A hand-fired furnace and return tubular boiler, cross section.

The observations on seven different styles of furnaces were averaged to obtain the figures given in the tables below. All of these furnaces were installed under boiler units of 150 horsepower or less. Nine were equipped with either rocking or dumping grates.

The coals burned and the thicknesses of fire carried at the 15 plants classed as miscellaneous were as follows:

TABLE 23.—*Kind of coal and depth of fire at plants with miscellaneous hand-fired furnaces under return tubular boilers.*

Number of plants.	Kind of coal.	Average depth of fire.
		Inches.
8	Illinois	6
2	Indiana	4
1	Pennsylvania	....
4	West Virginia	7.7

The average draft through the fire and the average coal consumption were as follows:

TABLE 24.—*Average draft and coal consumption at plants with miscellaneous hand-fired furnaces under return tubular boilers.*

Kind of furnace.	Number of furnaces.	Furnace draft.	Coal as received burned per square foot of grate surface per hour, average heavy load.
		Inch of water.	*Pounds.*
McMillan	5	0.14	22
Dorrance	1	.23	47
Twin arch	1	.27	....
Wooley	1	.21	16
Burke	2	.11	18
Puddington	1	.12	13.2
Plain	4	.28	14.6

The averages of various items are as follows:

Coal as received burned per square feet of grate per hour, average heavy load, 21.8 pounds.

Percentage rated boiler horsepower developed, averaged heavy load (boiler rated on 10 square feet of heating surface per horsepower), 91.7; lowest, 53; highest, 184.

Average distance from grate to tube heating surface, 16.3 feet. Least distance from grate to tube heating surface, 14.1 feet. Vertical distance, grate to shell or arch, 2.1 feet.

Smoke, 6 per cent black.

Details of the observations at all the plants with hand-fired furnaces under return tubular boilers are given in Table 25.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers.*

No. of plant.	State.	Device used to facilitate combustion.	Total builder's rated horse-power.	Coal.				
				Commercial name.	Where mined.	Size.	Cost per short ton, delivered.	Short tons burned per year.
241	Illinois	None	300		Carterville, Ill	3-inch egg	$3.10	
242	Kentucky	do	600		Western Kentucky	Nut and slack		
243	do	do	300		do	Nut, pea, and slack	1.65	
244	do	do	160		do	Pea and slack		
245	do	do	120		do	Nut and slack		
246	Michigan	do	300	Pittsburg No. 8	Ohio	Run-of-mine	2.25	1,070
247	New York	do	500	Rochester; Pittsburg; Reynoldsville.	Pennsylvania	Slack	2.45	3,100
248	Kentucky	do	160		Pittsburg, Pa	Nut and slack		
249	Ohio	Steam jet	400	Pocahontas	West Virginia	Screened lump	3.60	
250	Pennsylvania	None	300		Powellton, W. Va	Run-of-mine	3.02	
251	Ohio	Steam jet	150	Logan block	Indiana	Nut and slack	1.90	
252	Indiana	do	100		do	$\frac{3}{4}$ to 1 inch nut		
253	Maryland	do	130	Georges Creek	Maryland	Run-of-mine		
254	Ohio	do	320	Massillon	Ohio	Slack	1.60	3,200
255	do	do	230	Pittsburg	do	Run-of-mine		
256	do	do	88	do	do	do		
257	New York	do	1,000	Rochester; Pittsburg	Pennsylvania	Lump	$2.65–2.80	12,000
258	Ohio	do	250	Pittsburg	do	Nut and slack	1.90	
259	do	do	170	Jellico	Tennessee	do	2.00	600
260	do	do	500	Kanawha	West Virginia	do	1.70	
261	do	do	450	do	do	do	2.10	
262	Illinois	do	350	Pocahontas	do	Run-of-mine	4.10	
263	Ohio	None	240	do	do	do	2.70	800
264	do	Steam jet	150	Thacker	do	do	2.40	
265	do	None	100	Kanawha	do	Nut and slack	1.90	
266	do	do	90	Pocahontas	do	Slack	2.25	
267	do	do	86	do	do	Run-of-mine		
268	do	Steam jet	411	Various coals		do	1.80–2.10	2,070
269	do	do	300			Nut and slack		
270	do	do	144	Various coals		Run-of-mine	2.60–2.85	600
271	do	do	100			Nut and slack		
272	do	do	87			do	1.80	
273	Illinois	None	250		Carterville, Ill	No. 2	2.85	
274	do	do	250		do	Lump		
275	do	do	166		Illinois	Large lump		
276	do	do	240		Indiana	3 to 6 inch egg	3.15	
277	do	do	116	Block	do		3.90	

278	do	do	580	Washed	Carterville, Ill	No. 4	2.90	
279	do	Air admission	240	do	do	No. 5		
280	do	None	180	do	do	do		
281	do	do	160		do	Run-of-mine		
282	do	do	50		do	4 to 6 inch egg	2.85	
283	Ohio	do	500	Pittsburg	Pennsylvania	$\frac{3}{4}$-inch screenings	1.80	4,800
284	New York	Steam jet	160	Reynoldsville	do	Run-of-mine	2.50	700

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Load.			Rating.									
	Requirement.	Nature.	Character.	Average load.				Coal burned per square foot of grate per hour (pounds).		Percentage of boiler horsepower developed on average heavy load.[a]	Percentage of builder's rated horsepower developed on average heavy load.	Assumed amount of coal burned per horsepower per hour (pounds).
				Heavy.		Light.						
				Hours per day load is on plant.	Coal burned per day (short tons).	Hours per day load is on plant.	Coal burned per day (short tons).	Average heavy load.	Average load.			
241	Power, light, and heat	Uniform	Hospital	24	14	24	7	20	20	84	92	5
242	do	Variable	Manufacturing	24	16	24	7	13.3	12.5	58	45	5
243	do	Uniform	Post-office	24	15	15	6.7	22.1	21.3	112	119	5
244	Power and light	do	Office building	16	3.25	16	2	17.7	14.3	86	102	5
245	do	do	do	19	3.2	19	2.4	20	17.5	114	112	5
246	do	do	Factory	10	3.6	10	3.4	24.4	23.7	112	96	5
247	Power, light, and heat	do	Office building	17	12.5	17	8	19.6	16.1	84	98	4
248	Power and heat	do	Factory	10	5.25	10	5.25	24	24	157	131	5
249	Power, light, and heat	do	Post-office	17	4.3	17	3.5			60	63	4
250	do	do	do	13	10	13	5.5	19.2	16.6	93	128	4
251	do	do	Bakery	18	2.5	24	2.5	11.2	9.8	46	75	5
252	do	do	Laundry	10	3	10	2.5	22.5	20.5	113	120	5
253	Power and heat	do	Offices and factory	12	2	12	1.4	16	13.7	92	111	5
254	Power, light, and heat	do	Shops	9.5	8	9.5	6.5	18.7	16.9	78	105	5
255	do	do	Factory	10	2.4	10	2	16	14.7	70	84	5
256	do	do	do	10	2.4	10	2	16	14.7	81	109	5
257	Heat	Variable	Manufacturing	18	33	6	7	14.5	12	66	84	5
258	Power, light, and heat	do	Brewery	24	8	24	5	22.2	18.1	85	107	5
259	Power and heat	Uniform	Office building	10	2	10	2	22.2	22.2	174	94	5
260	Power, light, and heat	Variable	Brewery	7	6	17	9	25.3	20.5	61	69	5
261	Heat	Uniform	School buildings	12	6			16.7		56	67	5
262	Power, light, and heat	Variable	Office building	19	5	19	3.5	16	14		77	5
263	do	Uniform	do	14	3	14	1.5	17.3	13	89	89	4
264	do	do	Factory	10	3.25	10	2.25	22.5	19.4	99	120	5
265	do	do		10.5	1.5	10.5	1	14.1	11.5	48	57	5
266	Power and heat	do		10	1.5	10	1.2	15	13.5	70	74	4.5
267	do	do	Factory	10.5	1.25	10.5	1	12	10.8	53	56	5
268	do	do	Mill	12	6	12	6	14	14	61	73	5
269	Power, light, and heat	do	Factory	10	8.5	10	8.5	18.9	18.9	91	113	5
270	Power and heat	do	Store building	11	1.8	11	1.8	20.4	20.4	62	91	5

271	Power and light	do	Shops	10	2.5	10	2.5	18.2	18.2	83	100	5
272	Power and heat	do		10	1.5	10	.75	16.7	12.6	65	69	5
273	Power, light, and heat	Variable	Factory	9	3	9	2.75	22	21	84	107	5
274	do	do	Manufacturing	10	7	10	6.5	23	22	88	112	5
275	do	Uniform	Factory	8	3	8	2.5	30	28	176	181	5
276	Power and light	do	Manufacturing	10	4	10	3	19	16.5	89	100	5
277	Power and heat	Variable	Factory	10	3.5	8.5	.75	16	12	95	121	5
278	do	Uniform	Office building	12	26	12	26	47	47	184	150	5
279	do	do	do			10	3		11	70	75	5
280	Power, light, and heat	Variable	Factory	15	6	15	3	16	12	92	133	5
281	Power and heat	Uniform	Office building	18	5	18	3.5	19.4	17	76	100	5
282	do	do	Factory			9	1.5		16.5	106	134	5
283	Power, light, and heat	Variable	Shops	24	13.3	24	13.3	13.2	13.2	56	66	4.5
284	Heat	Uniform	Distilling	5	1.4	5	.6	21.6	18.6	102	156	4.5

[a] Boiler rated on 10 square feet of heating surface per horsepower.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Stoking.					Boilers.								
	Method of firing.	Frequency of firing (minutes).	Coal fired at each firing per boiler (pounds).	Thickness of fire (inches).	Frequency of cleaning fire.	Size.	Number installed.	Number used to carry— Average heavy load.	Number used to carry— Average light load.	Builder's rated horsepower.	Horsepower, boiler rated on 10 square feet of heating surface.	Heating surface (square feet).	Superheating surface (square feet).	Steam pressure at gage.
241	Spreading	20	200	6–8	3 times in 24 hours	72″ x 18′, 62 4″ tubes	2	2	1	150	138	1,380	0	80
242	do	Var.	Var.	7–9		72″ x 22′, 26 6″ tubes	4	4	2	150	115	1,150	0	100
243	do	Var.	Var.	8	3 times in 24 hours	54″ x 17′, 44 3½″ tubes	4	3	2	75	80	800	0	80
244	do	Var.	Var.	8–10	2 times in 16 hours	60″ x 16′, 48 4″ tubes	2	1	1	80	95	950	0	100
245	do	Var.	Var.	8–10	2 times in 19 hours	50″ x 16′, 34 3½″ tubes	2	1	1	60	59	585	0	90–100
246	do	8–10	90–110	*a* 8–10	2 times in 10 hours	66″ x 18′, 58 4″ tubes	2	1	1	150	129	1,285	0	110
247		Var.	Var.	*a* 10–12	2 times in 24 hours	72″ x 16′, 66 4″ tubes	4	3	3	125	145	1,450	0	100
248	Spreading	Var.	Var.	8–10	2 times in 10 hours	66″ x 16′, 34 4″ tubes	2	2	2	80	67	670	0	90
249	do	20	270–370		Once in 24 hours	60″ x 18′, 54 3½″ tubes	4	2	2	100	106	1,060	0	120
250	do	Var.	120–150	10–12	3 times in 24 hours	48″ x 18′, 48 3½″ tubes	4	4	3	75	104	1,040	0	105
251	do	15–17	50–75	6	2 times in 24 hours	60″ x 18′, 54 4″ tubes	2	1	1	75	120	1,200	0	85
252	do	5–10	30–50	3		66″ x 16′, 54 4″ tubes	1	1	1	100	106	1,060	0	85
253	do	20–40	80	14–16	Once in 12 hours	50″ x 14′, 56 2½″; 50″ x 16′, 56 2½″	2	1	1	60, 70	72, 82	720, 820	0	80
254	Coking	10	60	4–5	2 times in 10 hours	60″ x 16′, 47 4″ tubes	4	4	4	80	108	1,075	0	90
255		12–18	90–150	6	do	72″ x 16′, 70 4″ tubes	2	1	1	115	138	1,380	0	80
256		12–18	90–150	6	do	62″ x 16′, 53 4″ tubes	1	1	1	88	105	1,050	0	80
257	Spreading	10–20	150–180	6–8	2 times in 24 hours	72″ x 16′, 92 3½″ tubes	8	6–8	6	125	159	1,585	0	90
258	do	Var.	60–80	6–8	3 times in 24 hours	72″ x 18′, 70 4″ tubes	2	1	1	125	156	1,560	0	95
259	Coking	12–20	75–90	8–10	2 times in 10 hours	54″ x 20′, 4 8½″ and 2 10″ tubes	2	1	1	85	46	465	0	85
260	Alternate	7–10	40–50	4–10	Once in 8 hours	72″ x 18′, 64 4″ tubes	5	4	4	125	142	1,420	0	85
261	Spreading	10	75–90	8	Once in 12 hours	80 4″ x 18′ tubes	3	2		150	178	1,780	0	80
262	do	Var.	Var.	12–14	do		3	1	1	80–135			0	95–100
263	Coking	Var.	60	Var.		66″ x 18′, 54 4″ tubes	2	1	1	120	120	1,200	0	100
264	Spreading	12–15	60–80	6	Once in 10 hours	60″ x 14′, 46 4″ tubes	2	2	1	75	91	910	0	75
265	do	7–12	40–60	6–8	do	60″ x 18′, 54 4″ tubes	1	1	1	100	120	1,200	0	80
266	do	12–15	60	6	do	60″ x 16′, 48 4″ tubes	1	1	1	90	95	950	0	90
267		15–20	40–60	10	do	58″ x 16′, 46 4″ tubes	1	1	1	86	91	910	0	80
268		15–20	100–140	6	2 times in 12 hours	76″ x 18′, 74 4″ tubes	3	2	2	137	164	1,640	0	100
269	Spreading	15–20	40–60	7–8	2 times in 10 hours	60″ x 16′, 54 3½″ tubes	4	4	4	75	93	930	0	105
270		10–15	50–60	6	1 to 2 times in 11 hours	60″ x 16′, 72 3″ tubes	2	1	1	72	107	1,065	0	75
271	Alternate	3–8	50–70	5–6	2 times in 10 hours	66″ x 18′, 54 4″ tubes	1	1	1	87	120	1,200	0	80
272		8–10	40–50	7–8	Once in 10 hours	60″ x 16′, 54 3½″ tubes	1	1	1	100	92	920	0	80

273	Spreading...	Var.	100–120	4	Once in 9 hours........	72″ x 18′, 70 4″ tubes.............	2	1	1	125	159	1,590	0	125
274	.....do.......	2–5	80–100	4–10	4 times in 24 hours.....	.....do............................	2	2	2	125	159	1,590	0	115
275	.....do.......	10–12	60–90	6	2 times in 8 hours......	60″ x 16′, 46 4″ tubes.............	2	1	1	83	85	850	0	80
276	.....do.......	10–15	120–180	3–5	2 times in 10 hours.....	54″ x 16′, 52 3½″ tubes............	3	2	2	80	90	900	0	70
277	Alternate....	Var.	30–60	4	1 to 2 times in 10 hours.	60″ x 16′, 37 4″ tubes.............	2	2	1	58	74	740	0	80
278	Spreading...	4–5	70–75	5–6	6 times in 24 hours.....	60″ x 18′, 48 3½″; 13 4″ water tubes.	4	4	4	145	118	1,180	0	125
279	Alternate....	12–15	60–70	6–8	....	60″ x 16′, 44 4″ tubes.............	3	2	2	80	87	870	0	100
280	.....do.......	Var.	30–60	5–6	1 to 2 times in 15 hours.	.....do............................	3	2	2	60	87	870	0	125
281	Coking.......	Var.	Var.	Var.	1 to 2 times in 18 hours.	60″ x 18′, 46 4″ tubes.............	2	2	1	80	102	1,020	0	160
282	.....do.......	Var.	Var.	Var.	Once in 9 hours........	52″ x 16′, 32 4″ tubes.............	1	1	1	50	63	625	0	110
283	Spreading...	Var.	100–120	....	....	72 4″ x 16′ tubes; 144 4″ x 18′ tubes	3	2	2	125,250	142,302	{ 1,420 3,020 }	0	90
284	.....do.......	7–8	45–90	8	Once in 5 hours........	66″ x 14′, 94 3″ tubes.............	2	1	1	80	122	1,220	0	90

a On top grate.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Furnaces.								
	Number.	Kind of furnace.	Kind of grate.	Grate area per boiler (square feet).[a]	Dimensions.				
					Distance from grates to tube heating surface.		Width of furnace (C).	Length of furnace (D).	Distance from front of furnace to front of boiler (E).	Vertical distance at front of furnace from grates to coking arch or heating surface (F).
					Average (A).	Minimum (B).				
241	2	Hawley	Water-tube and flat	30	17	14.5	6	5	0	....
242	4	....do	....do	25	22	20	6	4.2	0	....
243	4	....do	....do	20.2	17	15	4.5	4.5	0	....
244	2	....do	....do	23	16	13.5	5	4.6	0	....
245	2	....do	....do	16.7	16	14	4.2	4	0	....
246	2	Down-draft	....do	29.5	17	14	4.5	6.5	0	4
247	4	Hawley	....do	25	15	12	5	5	0	5
248	2	....do	....do	22.4	16	14	5.6	4	0	....
249	4	....do	....do	....	17	14.5	....	....	0	....
250	4	....do	....do	20	17.5	15.5	4	5	0	....
251	2	Plain	Flat	25	17	14.5	5	5	0	2.2
252	1	....do	Rocking	26.7	16	13.5	5.1	5.25	0	2.2
253	2	....do	Flat	21, 23	[b] 13.5, 15.5	[b] 11, 12.5	4.2	[b] 5, 5.5	0	2
254	4	Burke	Flat and dumping	22.5	15	13	4.5	5	0	2.5
255	2	Plain	Flat	30	16.5	14	6	5	0	2.4
256	1	....do	....do	30	16.5	14	6	5	0	2.4
257	8	....do	....do	36	15	12	6	6	0	2.5
258	2	....do	....do	30	16.5	14	6	5	0	1.7
259	2	....do	....do	18	19	17	4.5	4	0	....
260	5	....do	....do	27	17	15	6	4.5	0	2.1
261	3	....do	....do	30	17	15	6	5	0	2.5
262	3	....do	....do	25, 33	....	....	[b] 5, 6	[b] 5, 5.5	0	2.5
263	2	....do	....do	24.75	17.5	15.5	5.5	4.5	0	2.3
264	2	....do	....do	20	13	11	5	4	0	2.5
265	1	....do	....do	20.25	17	15	4.5	4.5	0	2.2
266	1	....do	....do	20	15.5	13.5	5	4	0	2.3
267	1	....do	....do	20	15	13	5	4	0	1.75
268	3	....do	....do	36	16.5	14	6	6	0	2.5
269	4	....do	....do	22.5	15	13	5	4.5	0	1.7

270	2	.....do	.....do	16	15	13	4	4	0	2.5
271	1	.....do	.....do	27.5	16.5	14	5.5	5	0	....
272	1	.....do	.....do	18	15	13	4.5	4	0	1.75
273	2	McMillan smokeless	Rocking	30	17.5	15	6	5	0	1.5
274	2	.....do	Shaking	30	17.5	14.3	6	5	0	1.8
275	2	.....do	Rocking	25	15.5	13	5	5	0	1.7
276	3	.....do	Shaking	21	15.5	13	4.5	4.7	0	1.7
277	2	.....do	Flat	22.5	17.5	15.5	5	4.5	0	1.6
278	4	Dorrance	Shaking	23	24	22	5.1	4.5	7.7	2.25
279	3	Twin arch	Rocking	28	15	12	2.3	6	0	2
280	3	Woolley	Shaking	25	16	13.5	5	5	0	2.1
281	2	Burke	Rocking	19	20	18	4.75	4	5	....
282	1	.....do	.....do	20.25	21	19	5.1	4	5	....
283	3	Puddington	Flat	42	[c] 3.5, 14	[c] 3, 11	6	7	0	[c] 2.5, 4
284	1	Plain with Cornell economizer	.....do	25	13	11	5.5	4.7	0	2

[a] In down-draft furnaces; area of upper grate only.

[b] First dimension applies to small boiler.

[c] First dimension applies to tubular boiler.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Draft.							Smoke records.						
	Kind.	Readings (inches of water).					Conditions under which readings were taken.	Number of observations.	Total length of observations (minutes).	Average for one hour (minutes).			Average percentage of black smoke from observations.	Load during observations.
		Furnace.	Rear of boiler.	Front tube sheet.	Breeching.	Base of stack.				100 to 80 per cent black.	80 to 60 per cent black.	Stack clean.		
241	Chimney	0.25					Damper open, ash-pit doors cracked.	1	50	1	2	35	11.7	Average.
242	....do	0.20–.39			0.53		Dampers and ash-pit doors open.	1	60	0	0	48	3.3	Light.
243	....do	.22			.40	0.46	Dampers open, ash-pit doors closed.	1	110	0	1	36	6.4	Average.
244	....do	.55			.57		Ash-pit doors closed, damper open.	2	94	0	0	58	.7	Light.
245	....do	.32			.47		Damper open, ash-pit doors closed.	1	60	0	1.5	58	1.5	Do.
246	....do	.03		0.60		.60	Lower furnace doors cracked	1	60	0	4	54	5	Average.
247	....do	.24–.34		.42–.55		.67		1	60	0	0	58	.7	Light.
248	....do	.21–.51			.55		Damper open, ash-pit doors cracked.	2	77	0	0	55	3	Average.
249	....do	.30–.35		.45–.50	.85		Dampers open	4	295	0	0	0	21	Heavy.
250	....do	.22–.44			.60	.65	....do	1	75	0	0	50	3	Do.
251	....do	.19			.28		Damper open, thick fire	(a)	(b)	0	0			Do.
252	....do	.20		.27	.31		Damper open	2	45	0	0	53	5.5	Light.
253	....do	.25			.48		....do	1		0	0			Heavy.
254	....do	.18–.27		.36–.38		.45		1	60	0	0	58	.7	
255	....do	.30		.35				1	60	0	0	57	1.3	Average.
256	....do	.23		.30				1	60	0	0	57	1.3	
257	....do	.14–.18		.25–.30				1	60	0	0	42	7.9	Light.
258	....do	.28–.30			.40		Damper open	(a)	(b)	0	0			Heavy.
259	....do				.35	.70	....do	(a)	(b)	0	0			Average.
260	....do			.40	0.35–.60	.65	Dampers open	(a)	(b)	0	0			Heavy.
261	....do					0.75–1	Damper open	(a)	(b)	0	0			Do.
262	....do							1	60	0	0	59	.1	Light.
263	....do					.85	Damper open, thin fire	(a)	(b)	0	0			Heavy.
264	....do	.15			.45		Damper open, ash-pit doors two-thirds closed.	(a)	(b)	0	0			Do.
265	....do	.37			.60		Damper open	(a)	(b)	0	0			Do.
266	....do	.30			.50		....do	(a)	(b)	0	0			Do.
267	....do	.18			.43		....do	(a)	(b)	0	0			Do.

268	do.	.13–.27		.28–.29		.70		1	60	0	3	45	9.3	Average.
269	do.	.20			.42–.45		Dampers open	(a)	(b)	0	0			Do.
270	do.	.27–.32		.45				1	60	0	0	55	2.3	Do.
271	do.	.15				.35	Damper open, ash-pit doors partly closed.	(a)	(b)	0	0	50	5.6	Do.
272	do.	.17–.20			.40	.52	Damper open	(a)	(b)	0				Heavy.
273	do.	.17		.35			Dampers open	2	65					Average.
274	do.	.12–.17				.62	Damper and ash-pit doors open.	1	54	0	2	33	10.7	Do.
275	do.	.20–.22			.44		Damper open	1	60	2	2	39	9.6	Light.
276	do.	.11			.47–.56		Damper and ash-pit doors open.	1	60	0	3.5	38	9.8	Average.
277	do.	.06			.22		Damper open, banked fire	1	60	0	5	35	11.6	Light.
278	do.	.17–.28	[c]0.33–.48		1.34–1.50		Dampers and ash-pit doors open.	2	395	0	0	57, 54	2.5, .7	Heavy.
279	do.	.27				1.10	Damper open	3	127	0	6	50	3.8	
280	do.	.20–.22		.44–.46	.64		do	1	60	0	3.5	48	6.3	Light.
281	do.	.14		.68		.82	do	1	60	0	0	57	2.5	Heavy.
282	do.	.08			.45		do	1	60	0	.5	54	3.4	Light.
283	do.	.10–.13	.32–.34					1	30	0	0	(d)	5	Heavy.
284	do.	.24–.33		.35		.47	Device in use during readings	1	60	0	0			

[a] Several. [b] Various lengths. [c] Combustion chamber. [d] 56 water tube, 46 tubular.

Table 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
241	27	3 x 4	Near stack	0	100	4.5 x 6	27	Heating surface in water-tube grates not figured in heating surface. Water-tube grate, single row of tubes. Considerable, 10 to 20 per cent, black smoke from stack.
242	5			0	100	a 5	19.6	Large combustion chambers. Stack occasionally not as good as recorded observations.
243	55	2.2 x 4	Near stack	3	105	3 x 4	12	Coal as fired runs 12,500 B. t. u.; ash, 15 per cent; moisture, 5 per cent. Figures for heating surface do not include heating surface in water-tube grates. Stack occasionally not as good as recorded observations. Automatic regulator on main damper.
244	30			2	95	a 1.8	2.64	Heating-surface figures do not include heating surface in water-tube grates. Large combustion chambers.
245	20			1	130			Large combustion chambers.
246	0	0		0	105	a 4	12.56	Five-inch fire on secondary grates. Heating-surface figures do not include heating surface in water-tube grates. Stack on front of boiler. Stack smokes 60 to 80 per cent black about one-half minute at every firing.
247	10			0	112	3 x 4	12	Three- to 4-inch fire on secondary grates. Boilers arched over the top for gas passage.
248	22			1	115	a 4	12.56	Large combustion chambers.
249	10			3	152	a 4.5	15.9	Twenty $\frac{1}{8}$-inch steam jets at base of bridge wall in combustion chamber; not automatic; turned on before firing and left on for three to four minutes after. Considerable, 10, 20, and 40 per cent black smoke from stack. Automatic regulator on main damper.
250	65			1		a 4	12.56	Coal breaks up easily, and nearly all slack as fired. Heating-surface figures do not include heating surface in water-tube grate. Boilers arched over top for gas passage. Eight- to 10-inch fire on secondary grate.
251	17			2	90	a 3	7.06	Steam jets and air admission, 7$\frac{1}{8}$-inch jets across front of furnace. Device in service about two and one-half minutes at each firing. Stack smokes at each firing 40 per cent black or less for one to two minutes. 9 by 4 inch air opening in each dead plate.
252	9			0	50	2.7x2.7	5.65	Six $\frac{1}{8}$-inch steam jets enter through front of furnace, automatic with opening of furnace doors. Average firing produces about 40 to 50 per cent black smoke, for one-half to three-fourths of a minute.
253	8			0				Boilers arched over top for gas passages. 16 to 17 $\frac{1}{8}$-inch steam jets in combustion chamber at base of bridge wall; not automatic; turned on before firing and allowed to run from three to four minutes.
254	4			4	100	a 4	12.56	Two coking ovens per boiler; also four $\frac{1}{16}$-inch steam jets in bridge wall which draw heated air into furnace. Air taken in over the fire and through ash-pit doors. Boilers arched over the top for gas passage.
255	21			1	85	a 3.75	11.1	Arch sprung across combustion chamber just at rear of boiler. Twelve $\frac{3}{32}$-inch steam jets across front of each furnace, automatic with two 6 by 10 inch air inlets in each door. Smoke preventer in operation five or six minutes at each firing.

256	7	....	....	1	85	a 3.75	11.1	Arch sprung under rear of boiler makes gas passage longer and aids in mixing and distributing gases. Smoke preventer in operation five or six minutes at each firing. Nine 3/32-inch steam jets across front of furnace, automatic with two 6 by 10 inch air inlets in each furnace door.
257	15	....	....	1	85	a 4	12.56	Two steam jets, each with six 3/16-inch openings, not automatic, enter front of each furnace. Patent air-admission door. Three similar stacks. Considerable, 20 per cent, black smoke. Success due to careful operation and firing.
258	3	....	....	0	....	....	....	Automatic steam and air admission device. Seven 1/8-inch steam jets across front of furnace. At average firing stack smokes 30 per cent black and less for one and one-half to two minutes. Device in service about two and one-half minutes at each firing.
259	24	....	....	2	125	a 2.5	7.06	Four 5/64-inch steam jets across front of furnace; not automatic. At average firing stack smokes 20 per cent black and less for one to one and one-half minutes.
260	3	....	....	1	125	a 6	28.3	Four 1/8-inch steam jets; not automatic. Two arches, one in front and one behind bridge wall. Smokes about 40 per cent black and less at each firing for one and one-half to two minutes. Fire carried about 2 feet back from furnace doors. Two 2 by 4 inch air openings in each coking plate; also a 1½ by 24 inch opening always open for air admission. Steam jets turned on before firing and kept on from three to five minutes. Jets entering furnace pass through air-admission pipes.
261	53	....	....	1	140	a 5	19.6	Automatic steam and air admission device. Eight 1/8-inch steam jets across front of furnace. During average firing stack smokes from 20 to 40 per cent black for one-half to one minute. Air openings 1 by 6 inches in each dead plate.
262	6	....	....	1	160	a 5.5	23.8	Large combustion chambers. Four 1/16-inch steam jets across front of furnace; not automatic; jets used during and shortly after firing. Smoke kept down by careful operation.
263	7	....	....	1	165	3 x 3	9	Retorts in bridge wall for gases to pass through. Less than 20 per cent black smoke for about one minute when firing. About 50 per cent air space in grate. Furnace not very hot. Lumps of coal 8 to 10 inches in diameter fired.
264	20	....	....	1	75	2.3 x 2.3	5.4	Automatic steam and air admission device. Seven 1/8-inch steam jets across front of furnace. At each firing stack smokes 40 per cent black and less for three to four minutes. 5 by 12 inch air opening in each coking plate. Lumps of coal 8 inches in diameter fired.
265	9	....	....	1	....	....	....	Smoke observations include some 10, 20, and 40 per cent black readings.
266	0	0	....	0	80	....	....	Coal cokes badly, and fire requires frequent poking. Stack rests on boiler. At each firing stack smokes 60 per cent black and less for about one minute.
267	9	....	....	1	....	....	....	Lumps of coal up to 6 inches in diameter fired. Smoke observations include some 10, 20, and 40 per cent black readings.
268	12	....	....	1	110	a 4	12.56	Automatic steam jets and air admission; eight 1/8-inch steam jets across front of furnace, also an 8 by 20 inch air opening in each dead plate.
269	14	....	....	1	....	....	....	Automatic steam jets and air admission. Six 1/16-inch steam jets across front of furnace. Four similar stacks. During average firing stacks smoke from 60 to 20 per cent black for three-fourths to one minute.
270	42	....	....	3	125	a 3	7.06	Six 1/16-inch steam jets across front of furnace. One steam jet at either side of furnace, not automatic; also a patent furnace door for air admission, not automatic. Success due to careful firing and operation.
271	15	....	....	0	75	2.5x2.5	6.25	Steam jets and air admission device run continuously. Twenty 1/64-inch steam jets enter furnace.
272	23	....	....	2	68	3.5x3.5	12.25	Automatic steam jets and air admission. At each firing stack smokes about one minute, 40 to 60 per cent black and one to one and one-half minutes 20 to 40 per cent black. Seven 1/16-inch steam jets and two 1/8-inch steam jets across front of furnace. Device in service from three to five minutes.

a Diameter.

TABLE 25.—*Details of observations at plants with hand-fired furnaces under return tubular boilers*—Continued.

No. of plant.	Breeching.				Stack.			Remarks.
	Length from stack to nearest boiler (feet).	Size (feet).	Place at which measurement was taken.	Number of elbows between boilers and stack.	Height (feet).	Size (feet).	Area (square feet).	
273	6	3.5 x 3.5	Near stack	1	97	3.5x3.5	12.25	One mixing pier on bridge wall, 18 inches wide. Furnace doors perforated but plant usually run with one furnace door three-fourths open. Water in ash pit to cool grates. Success due to careful operation, light firing, and cracking of furnace doors after firing.
274	34	3.5 x 4.5	do	1	105			Mixing pier on bridge wall 18 by 24 inches. Perforated furnace doors.
275	20	3 x 3	do	1	100			Large combustion chambers. Mixing pier on bridge wall. Some refuse burned. Patent furnace doors for air admission.
276	3			1	120	3 x 3	9	Large combustion chambers. Three retorts in bridge wall. Considerable wood burned. Perforated furnace doors for air admission. Stack smokes from 10 to 60 per cent black.
277	25			1	60	*a* 5	19.6	Fire thick, practically banked, on light load One mixing pier on bridge wall. Perforated furnace doors.
278				1, 2	235	*a* 5.3 5.5x4.5	22.3 24.7	Coal as fired runs about 12,000 B. t. u. per pound. Always one furnace door on each boiler open when running.
279	12			1	235	*b* 5x3	7.8	Two 4 by 6 inch openings in rear of bridge wall for air admission. Ash pit kept filled with water.
280	12			1	110	6 x 6	36	Side grates not included in grate area. Side grates for air admission; mixing structures in combustion chamber.
281	23			1	190	*a* 3.5	9.6	Large combustion chambers. Some of the coal very fine and cakes, so magazines are not kept filled; probably necessary to break up fire to keep magazines full. With magazines not full considerable air enters.
282	22	2.5 x 2.8	Near stack	2	65	2.2x2.2	4.8	Large combustion chambers.
283	0	0		0	85, 125	*a* 3, *a* 3.5	7.07, 9.6	One large and one small boiler always carry load. Automatic steam and air admission in furnace; mixing structure in combustion chamber. Three stacks resting on boilers. Automatic steam jets, in use at each firing for three to four minutes.
284	30			1	80	*a* 3.75	11.1	Forty 1/16-inch openings across front of furnace for superheated steam. Stack smokes 10 per cent black for one-half minute at each firing.

a Diameter.

b Oval.

SUMMARY.

The remarks in Tables 20 and 25 show that in many of the hand-fired furnaces an attempt was made to lengthen the travel of the gases from the grates to the heating surface. The design of some furnaces showed recognition of the value of mixing the air and the gases, and arches, retorts, piers, or steam jets were used to accomplish this end. Where steam jets were used they were usually installed so as to be automatically thrown in and out of service.

The regulation of air admission was accomplished at some plants by cracking the furnace door after firing, at others by taking air through the dead plates or through openings in patent furnace doors. These openings in the dead plates and furnace doors were usually automatic with the opening of the doors and were slowly closed by a weight and dash pot. This arrangement allowed the most air to enter the furnace at the required time.

All hand-fired furnaces which will burn coal without objectionable smoke approach the theory of the mechanical stoker, but owing to the variability introduced by the personal element, they can not under average conditions give as good results.

SMOKE OBSERVATIONS AT GEOLOGICAL SURVEY FUEL-TESTING PLANTS.

TESTS AT NORFOLK, VA.

The boiler plant at Norfolk was equipped with two furnaces—one fired by hand, the other by a mechanical stoker. The hand-fired furnace had plain grates and mixing structures in the combustion chamber. The mechanical stoker was of the underfeed type. Figure 38 shows the elevation and plan of the boiler setting; figure 39 gives a cross section of the setting and the plan of the bridge wall. All of the coal used in the tests was of the same general grade; it coked and was low in volatile matter. An expert fireman was employed. Each test lasted about eight hours.

HAND-FIRED TESTS.

The hand-fired furnace was set under a Heine boiler which had C tile on the lowest row of tubes. The tile-roof furnace thus formed, in combination with the mixing structures, proved to be a good design for burning coal low in volatile matter. With this boiler six tests were made, a number too small to permit the drawing of any very definite conclusions. The plant developed from 78 to 155 per cent of the builder's rated capacity and made very little smoke; on no test did the smoke average 10 per cent black. The boiler efficiency on the six tests averaged 66.90 per cent, varying from 65 to 69. The dry coal burned per square foot of grate per hour ranged from 13.7 to 27.6 pounds.

The tests showed that the percentage of volatile matter in the combustible is an element always to be considered. Even with

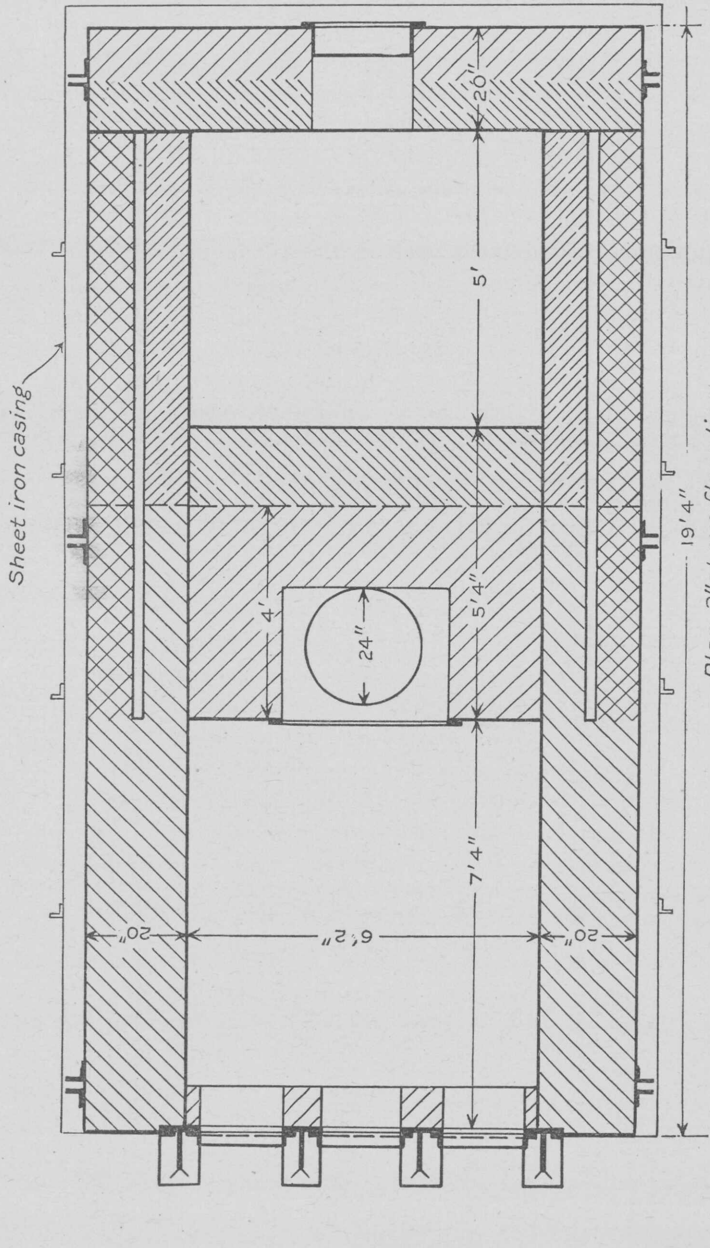
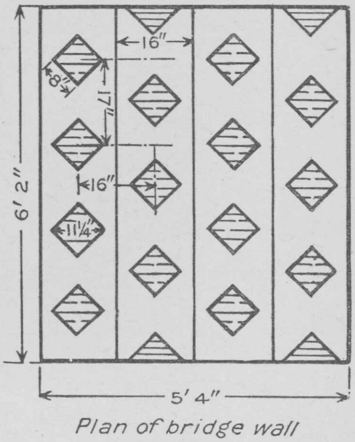


FIGURE 33.—Elevation and plan of setting of hand-fired Heine boiler at Norfolk, Va.

small variations the percentage of efficiency follows it closely. High volatile matter gives low efficiency, and vice versa.

The highest efficiency was obtained when the plant was run at low capacity. The most carbon monoxide was found in the flue gas and the greatest unaccounted for loss in the heat balance when the plant was run at high capacity, showing that forcing the furnace decreased the efficiency. The smoke determinations do not seem to harmonize with some of the expected relations; but these readings vary a great deal and are not as reliable as some of the other items. In determining efficiency it must not be overlooked that incomplete combustion is not the only varying element. In all six tests the percentage of black smoke was so small that a variation in



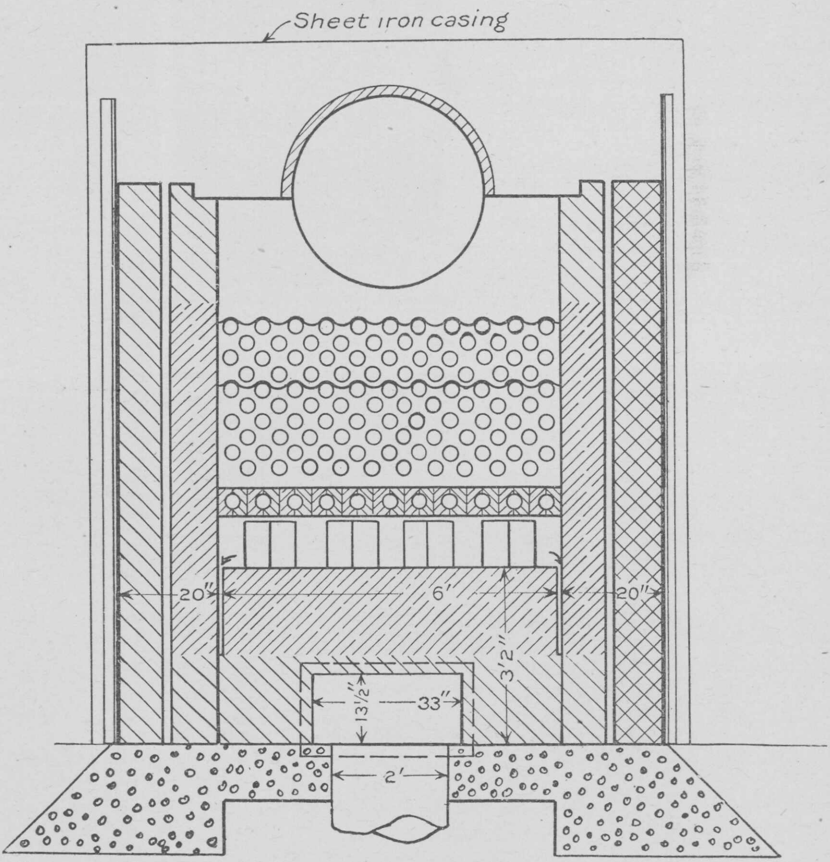


FIGURE 39.—Cross section of setting of hand-fired Heine boiler at Norfolk, Va., and plan of bridge wall.

temperature could make the smoke determination and the efficiency noncomparable.

Five tables compiled from the data collected during these tests are given below:

TABLE 26.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of boiler efficiency 72*.*

Efficiency 72* (per cent).[a]	Black smoke (per cent).	Combustion-chamber temperature (°F.).	Volatile matter in combustible (per (cent).	Percentage of builder's rated capacity developed.	CO_2 in flue gas (per cent).
64.91	5.5	2,192	20.36	81.0	6.26
64.93	6.2	2,523	19.31	129.5	
66.29	5.6	2,442	19.97	154.8	6.73
67.69	8.2	2,678	17.05	102.2	10.93
68.61	8.6	2,264	16.78	78.3	6.96
68.94	8.4	2,016	16.48	80.6	7.04

[a] Efficiency 72* figured from pounds of combustible ascending from the grate, the ash being determined by analysis of the dry coal.

TABLE 27.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of unaccounted for loss in heat balance.*

Unaccounted for (per cent).	CO_2 in flue gas (per cent).	CO in flue gas (per cent).	Percentage of builder's rated capacity developed.	Loss up stack (per cent).	Black smoke (per cent).
5.02	6.73	0	154.8	23.67	5.6
9.42	7.04	0	80.6	18.14	8.4
9.86	6.26	0	81.0	21.51	5.5
11.02	6.96	.06	78.3	16.43	8.6
13.05	10.93	.09	102.2	14.97	8.2

TABLE 28.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of black smoke.*

Black smoke (per cent).	Combustion-chamber temperature (° F.).	Efficiency 72* (per cent).	Volatile matter in combustible (per cent).	Percentage of builder's rated capacity developed.	CO_2 in flue gas (per cent).
5.5	2,192	64.91	20.36	81.0	6.26
5.6	2,442	66.29	19.97	154.8	6.73
6.2	2,523	64.93	19.31	129.5	
8.2	2,678	67.69	17.05	102.2	10.93
8.4	2,016	68.94	16.48	80.6	7.04
8.6	2,264	68.61	16.78	78.3	6.96

TABLE 29.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of combustion-chamber temperature.*

Combustion-chamber temperature (° F.).	Efficiency 72* (per cent).	Percentage of builder's rated capacity developed.	Black smoke (per cent).
2,016	68.94	80.6	8.4
2,192	64.91	81.0	5.5
2,264	68.61	78.3	8.6
2,442	66.29	154.8	5.6
2,523	64.93	129.5	6.2
2,678	67.69	102.2	8.2

TABLE 30.—*Results of hand-fired smoke tests at Norfolk, Va., on basis of CO_2 in flue gas.*

CO_2 in flue gas (per cent).	Combustion-chamber temperature (° F.).	Efficiency 72* (per cent).	Volatile matter in combustible (per cent).	Black smoke (per cent).	Pounds of air per pound of combustible.
6.26	2,192	64.91	20.36	5.5	34.96
6.73	2,442	66.29	19.97	5.6	32.74
6.96	2,264	68.61	16.78	8.6	31.81
7.04	2,016	68.94	16.48	8.4	31.74
10.93	2,678	67.69	17.05	8.2	20.64

TESTS WITH MECHANICAL STOKER.

At the same plant 23 tests were made with an underfeed stoker under a Heine boiler. The boiler was baffled so as to form a tile-roofed furnace. It contained 2,031 square feet of heating surface and was rated by its builders at 210 horsepower. The boiler efficiency 72* averaged 67.4 per cent and varied from 61.83 to 73.71 per cent. On arranging the test data and calculated results on the basis of efficiency it was shown that there was no general relation between efficiency and any other item. The combustion on all the tests was nearly perfect, the highest average percentage of black smoke being 5.3. The percentage of rated capacity developed ranged from 53.8 to 175. The average percentage of CO_2 in the flue gases ranged from 5.97 to 11.61. The average combustion-chamber temperatures varied between 1,792° and 2,575° F.

The results of these tests are shown in Table 31 on the basis of black smoke observed, and in Table 32 on the basis of dry coal burned per hour.

TABLE 31.—*Results of smoke tests with underfeed stoker at Norfolk, Va., on basis of black smoke.*

Black smoke (per cent).	CO_2 in flue gas (per cent.)	CO in flue gas (per cent).	Percentage of builder's rated capacity developed.	Combustion-chamber temperature (° F.).
0	6.81	0	54.8	1,792
0	9.01	0	74.8	1,978
0	7.38	0	70.7	2,014
.5	7.88	0	75.8	2,192
.8	7.99	0	57.7	1,920
.8	8.58	0	93.0	2,070
.9	10.00	0	94.9	2,196
1.0	5.97	0	83.1	2,136
1.1	7.66	0	58.9	2,053
1.1	9.58	0	73.5	2,133
1.2	9.58	0	71.4	2,003
1.3	7.55	0	131.5	2,381
1.8	8.76	0	124.7	2,311
1.9	7.62	0	56.4	2,016
2.0	9.61	.06	106.3	2,205
2.2	8.58	.06	105.0	2,192
2.2	10.74	.04	126.0	2,352
2.3	6.85	.10	124.0	2,296
3.4	9.49	.04	91.9	2,336
3.9	10.74	.03	115.3	2,298
3.9	11.61	.11	175.0	2,575
5.3	11.25	.16	127.9	2,347

TABLE 32.—*Results of smoke tests with underfeed stoker at Norfolk, Va., on basis of dry coal burned per hour.*

Dry coal burned per hour (pounds).	Black smoke (per cent).	Efficiency 72* (per cent).	CO_2 in flue gas (per cent).	CO in flue gas (per cent).	Combustion-chamber temperature (° F.).
376	0	69.58	6.81	0	1,792
396	.08	67.60	7.99	0	1,920
414	1.1	66.52	7.66	0	2,053
421	1.9	65.04	7.62	0	2,016
469	1.1	73.71	9.58	0	2,133
482	1.2	68.62	9.58	0	2,003
489	0	68.44	7.38	0	2,014
497	0	70.01	9.01	0	1,978
531	.5	66.62	7.88	0	2,192
570	1.0	68.47	5.97	0	2,136
636	.9	69.41	10.00	0	2,196
682	.8	63.44	8.58	0	2,070
711	2.2	69.62	8.58	.06	2,192
735	3.4	68.98	9.49	.04	2,336
813	2.0	63.91	9.61	.06	2,205
872	2.2	68.00	10.74	.04	2,352
879	3.9	63.90	10.74	.03	2,298
887	2.9	65.97	10.76	0	....
894	1.3	69.13	7.55	0	2,381
901	2.3	64.51	6.85	.10	2,296
921	5.3	68.59	11.25	.16	2,347
938	1.8	61.83	8.76	0	2,311
1,209	3.9	68.11	11.61	.11	2,575

It will be noted that, as has been pointed out by Breckenridge,[a] a high percentage of CO_2 is not necessarily an indication of high economy. When the air supply is reduced, the furnace temperature, CO_2, CO, and smoke are all increased after a certain capacity is reached.

Theoretically, better results should be obtained with only enough air to supply the necessary oxygen, but in practice with most equipments there is a limit to the capacity of the furnace for burning the volatile matter in the coal, and the limited supply of air results in incomplete combustion, which more than offsets the effects of high furnace temperature and high CO_2.

The following general relations have been deduced from a study of the data collected: When the percentage of black smoke was the highest, the CO_2 and the CO in the flue gases, the capacity, and the combustion-chamber temperature were highest, and vice versa; there was no definite relation with boiler efficiency: This may be taken to mean that a stoker properly installed can be operated under wide variations in capacity with different conditions of operation, and yet run smokelessly and with high efficiency.

TESTS AT ST. LOUIS, MO.

The plant at St. Louis had two hand-fired Heine boilers; one furnace had a flat grate, the other a rocking grate. Either natural draft or forced draft supplied by a fan could be used. The bottom row of

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

water tubes in each boiler was incased in tile, forming tile-roof furnaces. In most of the tests these furnaces contained some sort of structure to mix the air and the gases from the fire, and thus hasten combustion. An expert fireman working under the direction of a competent engineer was employed in all tests.

The following tables and deductions are compiled from tests made at this plant and supplement the observations in the field and at Norfolk, as they throw light on several points which have heretofore been little considered or at least not fully determined. All the tables have a bearing on the problem of smoke prevention and they are presented because they may be of assistance in its solution.

Table 33 shows the results of six tests made to determine the best method of hand firing a high-volatile Illinois coal, nut size, using natural draft. The proximate analysis of the coal as fired showed the following: Volatile matter, about 36 per cent; ash, about 10 per cent; moisture, about 13 per cent; British thermal units average, 10,948.

Four different methods of firing were used—ribbon (firing alternately in narrow strips across the full length of the grate), coking, alternate, and spreading. In every test a reasonably thin fire was carried, from 2 to 3 inches of incandescent fuel above the clinker. When firing by the spreading method three shovelfuls of coal were thrown on the back of the grate and two on the front. When firing by the ribbon method the fire doors were kept cracked.

The average of tests 500 and 504 was taken as representative of the alternate method of firing. On test 500 the furnace doors were closed tightly after each firing; on test 504 they were kept cracked. This cracking of the furnace doors, while it caused a slight reduction in smoke compared with test 500, proved to be wasteful because the combustion space was not constructed so as to make the excess air of value in hastening combustion. A compromise method, cracking the doors for a short time after firing and then closing them, ought to give as good if not better results for alternate firing than those shown in the table.

The ribbon method of firing, where the coal was fired most frequently with the smallest amount per firing, gave the highest efficiency and practically no smoke. The usual spreading method of firing gave the lowest efficiency and caused the most smoke. The results with the alternate and the coking methods showed that one was about as good as the other.

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TABLE 33.—*Results of comparative tests on Illinois coal to determine best method of firing.*

No. of test.	Kind of draft.	Method of firing.	Efficiency 72*.	Black smoke.	Average interval between firings.	Coal per firing.	Percentage of rated capacity developed.	Observation of stack for one hour.
			Per ct.	*Per ct.*	*Minutes.*	*Pounds.*		
503	Natural...	Ribbon.....	62.22	5.0	2.3	50	106.7	Twenty per cent black smoke 15 minutes; clean 45 minutes.
502	.....do.....	Coking......	60.49	15.0	7.4	140	95.0	Twenty per cent black smoke 48 minutes, very seldom as high as 40 per cent; clean 12 minutes.
a 500 *a* 504	....do.....	Alternate...	59.87	15.8	3.5	70	106.5	One hundred per cent black smoke 4½ minutes, 80 per cent 4½ minutes, 60 per cent 3 minutes, 40 per cent 1½ minutes, 20 per cent 6 minutes; clean 41 minutes. Forty per cent black smoke 6 minutes, 20 per cent 24 minutes; clean 30 minutes.
501	.....do.....	Spreading ..	57.56	32.0	9.3	170	92.7	One hundred per cent black smoke 15 minutes, 80 per cent 1½ minutes, 60 per cent 1½ minutes, 40 per cent 4½ minutes, 20 per cent 6 minutes; clean 32 minutes.
505	Forced....	Alternate...	60.20	14.9	3.4	85	131.6	Sixty per cent black smoke 4½ minutes, 40 per cent 3 minutes, 20 per cent 24 minutes; clean 29 minutes.

a Average.

Table 34 is instructive because it shows the possibility of utilizing high-ash coals. Although the grate area was too small to obtain the rated capacity of the boiler, steam was produced at a reasonable efficiency. Owing to the distribution of the combustible in the coal as fired and to the low rate of the combustion, no smoke was produced.

TABLE 34.—*Results of tests on high-ash coals.*

No. of test.	Field designation of fuel.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Ash in coal.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry flue gas.	Moisture in coal.
			Per ct.	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
451	Argentina No. 1.....	Forced..	60	39.32	50.16	34.20	51.01	0	0.15	6.94
458	Argentina No. 1 (washed).	....do....	48	34.41	31.33	52.90	57.82	0	.26	16.48
479	Washery refuse......	....do....	69	36.35	41.82	72.60	57.08	0	.40	10.83
	Average.......	....	59	36.69	41.10	53.23	55.30	0	.27	11.42

Tables 35 and 36 were compiled to show the effect of size of coal on efficiency developed and smoke produced. All coal used in the tests summarized in Table 35 had an average diameter of over 1 inch; that used in the tests summarized in Table 36 had an average diameter of less than one-half inch.

TABLE 35.—*Results of tests with coals having an average diameter of over 1 inch.*

Field designation of coal.	No. of test.	Average diameter of coal	Efficiency. 72*.	Black smoke.	Percentage of rated capacity developed.	Pounds of air per pound of combustible.
		Inches.	*Per cent.*	*Per cent.*		
Alabama:						
No. 2 B	383	1.12	65.83	30.0	93.9	23.73
Do	382					
Illinois:						
No. 19 B	175					
Do	205					
No. 22 A	324					
Do	325					
No. 24 B	337					
No. 25	338					
Do	339	1.97	65.13	19.7	97.8	20.33
No. 26	341					
Do	342					
No. 27	353					
No. 28 C	452					
No. 29 B	461					
No. 34 B	509					
Indiana:						
No. 13	432					
No. 14	431					
Do	430	1.27	66.82	12.0	90.3	20.55
No. 15	428					
No. 17	441					
Kentucky:						
No. 5	276					
No. 6	271	1.14	67.27	19.4	96.2	19.74
Do	270					
Ohio:						
No. 4	254					
No. 5	186					
No. 7	269					
No. 8	287	1.29	66.20	25.1	99.6	19.26
No. 9 A	249					
No. 10	469					
No. 11	474					
Do	475					
Pennsylvania:						
No. 5	286					
No. 5 (washed)	194	1.29	66.90	23.8	99.6	19.67
Do	195					
No. 19	498					
Tennessee:						
No. 1	344					
Do	345					
Do	346					
No. 2	369	1.58	66.26	24.1	106.6	21.38
No. 3	350					
Do	349					
No. 4	356					
No. 7 A	372					
Virginia:						
No. 2	247	1.03	66.90	41.4	95.9	17.63
No. 2 (washed)	260					
West Virginia:						
No. 16 A	304					
No. 21 (washed)	274	1.20	68.59	12.8	109.3	19.89
No. 22 B	438					
No. 23 A	439					
Wyoming:						
No. 2 B	196					
Do	213	1.22	61.72	18.6	83.6	20.61
No. 3	212					
Do	211					

TABLE 36.—*Results of tests with coals having an average diameter of less than one-half inch.*

Field designation of coal.	No. of test.	Average diameter.	Efficiency 72*.	Black smoke.	Percentage of rated capacity developed.	Pounds of air per pound of combustible.
		Inches.	*Per cent.*	*Per cent.*		
Alabama:						
No. 4	377	0.39	67.25	8.5	91.4	26.53
No. 5	478					
Do	480					
Arkansas:						
No. 7 A	293	.37	67.20	0	79.3	26.50
Do	294					
Illinois: [a]						
No. 19 A	160	.36	66.40	13.5	90.3	19.27
Do	161					
Do	163					
Do	170					
Do	171					
Indiana: No. 4 [b]	166	.45	66.38	2.0	74.7	23.64
Indian Territory: No. 9	449	.35	65.20	3.0	97.0	23.77
Maryland: No. 1	222	.34	65.28	8.2	80.1	21.45
New Mexico: No. 4 B	395	.39	65.12	18.0	100.6	25.13
Pennsylvania:						
No. 8	242	.36	66.87	3.6	87.5	23.14
Do	239					
Do	238					
Do	237					
Do	236					
No. 15	472					
Do	473					
No. 16	471					
No. 17	506					
Tennessee: No. 9 A	365	.44	64.24	12.0	98.8	24.93
Virginia: No. 6	507	.46	63.39	3.0	101.8	25.84
West Virginia:						
No. 13	180	.46	68.93	9.8	86.9	22.18
No. 17	225					
No. 19	289					
Do	285					
No. 22 A	447					
Do	446					

[a] Test 129 omitted, no smoke having been recorded.
[b] Tests 164 and 176 omitted, clinker having caused trouble.

These two tables show that both large and small sizes of coal from the same State were burned. All tests in which owing to some factor, such as trouble with clinker, the air distribution was not due to the size of the coal were omitted in compiling results. Table 37 gives a comparison of the average results of Tables 35 and 36. It shows that with either large or small coal about the same efficiency resulted. Unfortunately for direct comparison the large coals burned more readily and produced higher capacities than the small in nearly every test; also with the large coal less air was used per pound of combustible. Nearly all the small coals burned with little smoke, while all the larger sizes caused considerable black smoke.

TABLE 37.—*Comparison of average results of tests with small and large sizes of coal.*

Number of tests.	Average diameter.	Efficiency 72*.	Black smoke.	Percentage of rated capacity developed.	Pounds of air per pound of combustible.
	Inches.	*Per cent.*	*Per cent.*		
31	0.39	66.88	7.4	88.6	23.07
53	1.46	65.97	21.3	98.3	20.28

Table 38 is of especial interest, for it shows that lignites, peat, and subbituminous coals with 47 to 67 per cent of volatile matter in the combustible can be hand-fired with the production of only a small amount of smoke. The average indicates that the boiler was run up to the rating at an efficiency of about 60 per cent. The smoke averaged less than 10 per cent black.

TABLE 38.—*Results of tests on lignites, peat, and subbituminous coals.*

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry flue gases.	Unaccounted for in heat balance.
			Per ct.	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*
Arkansas No. 10	340	Forced	0	53.77	104.0	60.25	0	0.34	....
Florida No. 1 (briquets)	386	Natural	29	67.24	113.2	58.19	13	.10	9.34
Montana No. 2	470	...do...	0	42.07	113.2	68.11	18	.02	6.00
Montana No. 3	477	...do...	58	41.76	115.2	65.78	12.5	.07	8.65
North Dakota No. 3	206	Forced	57	56.71	90.7	57.46	0	0	13.32
Texas No. 4	291	...do...	0	54.88	89.1	61.37	0	0	6.88
	298	...do...	0	55.14	104.1	52.01	12	0	17.59
	303	...do...	28	53.07	96.4	53.05	14	.24	14.84
Washington No. 1 B	290	Natural	0	47.99	81.8	65.04	10	.07	8.89
Wyoming No. 6	400	...do...	14	47.19	93.1	57.84	3.5	.04	16.22
Average	....	....	18.6	51.98	100.1	59.91	8.3	.08	11.30

Tables 39 to 41 supplement one another. Table 39 gives the average results of tests which showed a high percentage of black smoke; Table 40 gives the coals used in these tests and contains some remarks explanatory of the high percentage of smoke in particular tests; and Table 41 gives the results of tests with coal which made little smoke.

A comparison of Tables 40 and 41 shows that the coals which smoked the worst clinkered the most. The smoky coals also had higher percentages of volatile matter in the combustible, were burned at higher capacities, and gave a lower efficiency than the less smoky coals.

Among the comparatively smokeless tests were two on Utah coal and two on Missouri coal in which, for some unaccountable reason, the coals burned with a low efficiency; with these four tests omitted from the average, the low-smoke tests gave an average efficiency of 66.93 per cent, with a percentage of builder's rated capacity developed of 96.6. The high-smoke tests gave an average efficiency of 64.32 per cent, with a percentage of rated capacity developed of 99.2, showing a good percentage in efficiency in favor of the low-smoke tests. There are many briquet tests included in Table 41, and Table 42 shows that as a general rule the briquets made very little smoke. The other tests which gave low percentage of smoke were made with coals low in volatile matter, or slow burning, or else some means besides the automatic operation of the air-admission doors was employed to supply more air.

TABLE 39.—*Results of tests showing 35 per cent or over of black smoke.*

[Tests using natural draft, 34; forced draft, 5.]

	Average.	Range.
Clinker in refuse .... per cent..	49.9	0 to 67
Volatile matter in combustible .... do....	42.88	36.38 to 51.58
Percentage of rated capacity developed	99.2	84.4 to 129.9
Efficiency 72* .... per cent..	64.32	56.64 to 69.36
Black smoke .... do....	41.8	35.0 to 54.8
CO in dry chimney gases .... do....	.28	.07 to .73
Unaccounted for in heat balance .... do....	12.55	5.71 to 19.03

TABLE 40.—*Coal giving over 35 per cent black smoke.*

Field designation of fuel.	No. of test.	Remarks.
Illinois:		
No. 7 E	516	Forced draft; automatic air admission not operated.
No. 13 (washed)	144	Automatic air admission operated.
No. 15 (washed)	152	Clinker removed with difficulty; automatic air admission operated.
No. 16	150	Automatic air admission operated.
Indiana:		
No. 5	153	Heavy clinker formed on grate; automatic air admission operated.
No. 6 (washed)	159	Automatic air admission operated.
No. 7 A	158	Do.
No. 8 (washed)	184	Do.
No. 9 A	168	Do.
Nos. 9 A and 9 B (briquets)	334	Do.
No. 10	167	Do.
No. 10 (washed)	177	Do.
Kansas: No. 6 (washed)	323	Do.
Missouri: No. 7 (washed)	332	Forced draft; clinker solid; automatic air admission not operated; maximum-capacity test.
Ohio:		
No. 3	203	Automatic air admission operated.
No. 4	202	Clinker adhered to grate; automatic air admission operated.
No. 4 (washed)	220	Automatic air admission operated; coal caked badly.
Do	219	Clinker fused into grate; automatic air admission operated.
No. 5	190	Automatic air admission operated.
Do	186	Do.
No. 7	269	Clinker adhered to grate; automatic air admission operated.
No. 9 A	246	Automatic air admission operated.
No. 9 B (washed)	241	Do.
No. 9 B (washed and dried)	243	Do.
Pennsylvania:		
No. 5 (washed)	195	
No. 6	217	Do.
Tennessee: No. 2	367	Maximum-capacity test; doors cracked after each firing; combustion wall down during test.
Virginia:		
No. 2	251	Automatic air admission operated.
Do	247	Do.
No. 2 (washed)	260	Do.
No. 4	240	Clinker fused into grate; automatic air admission operated.
West Virginia:		
No. 15	216	Forced draft; automatic air admission operated.
Do	215	Automatic air admission operated.
No. 21 (washed)	267	Do.
Wyoming: No. 2 B	213	Forced draft; maximum-capacity test; automatic air admission not operated.

TABLE 41.—*Results of tests showing less than 6 per cent black smoke.*

Field designation of fuel.	No. of test.	Clinker in refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as received.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alabama:											
No. 2 B (briquets)	410										
No. 3	390										
No. 4	378	39	35.13	16.18	4.22	93.0	66.88	2.3	0.10	....	Some of these coals caked in fire; they burned with both long and short flame; automatic air admission operated only on test 378. Furnace doors cracked after each firing on test 390.
No. 4 (briquets)	413										
No. 5	478, 480										
Arkansas:											
No. 7 A	293, 294										
No. 8	297	45	15.16	10.98	5.21	85.2	66.17	0	.15	8.18	Coals slow burning; automatic air admission not operated.
No. 8 (washed)	308, 309										
Georgia: No. 1	481	65	21.21	17.77	3.11	111.8	70.31	2.5	.08	6.19	Coal burned freely; automatic air admission not operated.
Illinois:											
No. 6 B (briquets)	313										
No. 9 C (briquets)	492, 497										
No. 11 C (briquets)	312										
No. 12 B (briquets)	463										
No. 19 C	420, 423										
No. 19 D	424, 425										
No. 20	292										
No. 21	316										
No. 21 (briquets)	318										
No. 23 A (washed)	317	49	42.01	13.41	11.94	92.6	64.58	1.7	.06	8.57	Coals free burning; automatic air admission operated only on the coal tests. On test 503 furnace doors were cracked continuously; on tests 420, 424, and 425 the furnace doors were cracked for a short interval after each firing.
No. 25	338, 339										
No. 26	342										
No. 28 A (washed; briquets)	459										
No. 28 B (briquets)	457										
No. 29 B (washed; briquets)	465										
No. 30 (washed; briquets)	511										
No. 31 (briquets)	489, 491										
No. 33 (briquets)	513										
Collinsville	503										
Indiana:											
No. 4	166										
No. 7 A (briquets)	288										
No. 15	429	41	43.28	14.04	11.49	83.4	65.34	2.7	.11	8.80	Automatic air admission operated on all the coal tests.
No. 16	427										
No. 19 (briquets)	464										

TABLE 41.—*Results of tests showing less than 6 per cent black smoke*—Continued.

Field designation of fuel.	No. of test.	Clinker in refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as received.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Indian Territory:											
No. 2 B (briquets)	453										
No. 9	449	....	37.14	7.64	3.50	101.4	67.54	2.5	.09	7.77	Coal burned with short flame; automatic air admission not operated.
No. 9 (briquets)	450										
Kansas:											
No. 2 B (briquets)	487, 488	46	39.02	16.50	7.24	96.7	65.88	1.3	.03	8.42	Burned with short flame; automatic air admission not operated.
No. 2 B (washed; briquets)	495										
Maryland:											
No. 1 (washed)	231										
No. 2	490	35	19.42	9.16	4.29	110.3	68.76	1.6	.05	9.46	Coal burned slowly; automatic air admission operated on one of the coal tests.
No. 2 (briquets)	493										
Missouri:											
No. 5	320										
No. 10 (briquets)	486	....	45.11	18.92	8.38	93.4	60.50	1.3	.01	15.63	Coal caked in fire; automatic air admission operated.
New Mexico: No. 3 B	389	0	40.94	17.87	3.01	98.5	68.45	0	....	....	Free-burning coal; long flaming; furnace doors cracked after each firing.
Pennsylvania:											
No. 8	236, 237										
No. 15	472, 473										
No. 15 (briquets)	467										
No. 16 (briquets)	468										
No. 18 (briquets)	499, 515										
No. 19	498	40	25.30	8.86	3.75	101.8	65.72	1.7	.08	9.23	Coal caked and burned with short flame; automatic air admission not operated.
No. 19 (briquets)	508										
No. 20 (briquets)	514										
No. 20 (washed; briquets)	512										
No. 22 (briquets)	510										
Tennessee:											
No. 1 (washed; briquets)	409										
No. 5	352										
No. 6	379, 381										
No. 8 (washed)	388	47	37.34	13.40	3.32	96.2	66.79	0	.05	8.11	Test 352, coal burned rapidly; automatic air admission operated. Tests 379 and 381, coal caked in fire; burned with short to medium flame; automatic air admission operated. Test 388, furnace doors cracked after each firing.
No. 9 B (washed; briquets)	393										
No. 10 (washed; briquets)	407, 408										
Utah: No. 2 (briquets)	402, 404	0	47.44	6.99	10.78	74.8	56.21	0	0	4.58	Short flame; automatic air admission not operated.

Virginia:											
No. 5 A	476	49	20.57	14.96	4.51	120.6	66.35	1.5	.10	7.67	Automatic air admission not operated.
No. 5 B (briquets)	494										
No. 6	507										
Washington: No. 2 (briquets)	412	26	43.34	11.36	2.66	99.3	66.06	0	.06	....	Do.
West Virginia: No. 19	285, 289	52	24.71	6.80	2.76	80.7	70.71	0	.02	6.69	Coal burned slowly; caked; automatic air admission not operated.
Wyoming:											
No. 2 B	210	30	50.21	20.33	12.34	77.7	64.34	0	.08	10.52	Coal burned with short flame; automatic air admission operated.
No. 3	211										
Average by States	....	38	34.51	13.25	6.03	95.1 [a] 96.6	65.93 [a] 66.93	1.1	.07	8.56	
Average of 84 tests	....	43	34.85	12.07	7.22	94.8 [a] 95.4	65.61 [a] 65.97	1.4	.07	8.64	

[a] Tests on Missouri and Utah fuels omitted.

TABLE 42.—*Results of tests on briquetted coals.*

Field designation of coal.	Size of briquets.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.
Alabama:				*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 2 B	Large and small	410	Natural	23.5	37.64	100.5	67.24	2.5	0.05	....
No. 4	do	413								
Illinois:										
No. 6 B	Large	313								
No. 9 C	do	492, 497								
No. 11 C	do	312								
No. 12 B	Small	463								
No. 21	Large	318								
No. 23 B	do	321, 322								
No. 28 A (washed)	Large and small	459	12 natural, 4 forced	45.5	42.68	97.4	64.08	4.9	.08	9.04
No. 28 B	do	457								
No. 29 A (washed)	do	465								
No. 29 B	Small	466								
No. 30 (washed)	Large	511								
No. 31	Large and small	489, 491								
No. 33	Large	513								
Indiana:										
No. 7 A	do	288	Natural	35.0	44.40	88.2	65.30	2.8	.05	8.19
No. 19	Small	464								
Indian Territory:										
No. 2 B (lump)	Large and small	455								
No. 2 B (slack)	Small	453								
No. 2 B (washed, slack)	Large	456	do	29.8	35.68	100.7	65.19	5.6	.13	9.72
No. 8 (washed)	Small	437								
No. 9	do	450								
Kansas:										
No. 2 B	Large	487								
Do	Small	488	do	45.7	39.02	96.7	65.88	1.3	.03	8.42
No. 2 B (washed)	Large	495								
Maryland: No. 2	do	493	do	56.0	22.99	121.2	69.18	0	.02	8.42
Missouri: No. 10	Large and small	486	do	....	46.20	92.0	56.13	2.5	.02	20.09
Pennsylvania:										
No. 6	Large	333								
No. 15	Small	467								
No. 16	Large and small	468								
No. 18	Small	499								
Do	Large	515	8 natural, 1 forced	39.4	28.56	109.2	65.90	2.8	.11	8.81
No. 19	do	508								
No. 20 (washed)	do	512								
No. 20	Small	514								
No. 22	Large	510								

Tennessee:										
No. 1 (washed)	do	409	Natural	35.5	38.71	101.6	67.10	1.8	.01	5.50
No. 4	Large and small	405								
No. 7 B (washed)	Large	406								
No. 9 B (washed)	do	393								
No. 10 (washed)	do	407								
Do	Small	408								
Virginia: No. 5 B	Large and small	494	do	46.0	19.39	100.4	68.52	0	.10	6.20
Washington: No. 2	do	412	do	26.0	43.34	99.3	66.06	0	.06	
Average (by States)				38.2	36.20	100.6	65.51	2.2	.06	9.37
Average of 47 tests				39.7	37.50	100.7	65.37	3.4	.07	8.68

Table 42 is a compilation of results from all tests made on briquets at the St. Louis fuel-testing plant. The briquets all had a pitch binder and gave off little or no smoke, showing that the tile-roofed furnace used is satisfactory for burning such briquets. The volatile matter in the combustible varied from 23 to 46 per cent and averaged about 38 per cent. The smokeless combustion of coals so high in volatile shows that briquetting has an appreciable effect on burning, especially in the furnaces of steam boilers at the rates of combustion common in stationary practice. The average percentage of the rated capacity developed on these tests was 100.6.

Table 43 is compiled from results of tests made on raw coals and the same coals washed. All the coals were washed at the fuel-testing plant, and the reductions or additions in moisture, ash, and sulphur are of interest. Most of the washed coal either burned freely (was non-coking) or seemed to burn more rapidly than the raw coal. In fact, the average percentage of rated capacity developed was considerably greater with the washed than with the unwashed coal. This result does not indicate that the combustion chamber was more effective in one case than in the other, for the table shows that the washed coals burned with lower efficiency and made more smoke.

The average results show that the washed coals developed 96.6 per cent of the rated capacity, with an efficiency of 64.82 per cent, and the unwashed coals 89.9 per cent of the rated capacity, with an efficiency of 66.95 per cent. This difference in efficiency in favor of raw coal is more consistent and greater with the poorer coals than with the best.

The table emphasizes the difficulty of burning wet coal in any but a properly designed furnace. However, with a good furnace washing should be of advantage, as the washed coal burns more rapidly than the unwashed.

Table 44 is compiled from the results of tests made on the same coals raw and briquetted, natural draft being used in every test but one. It shows that the briquets usually burned with 1 to 3 per cent greater efficiency, developed higher capacity, and were consumed much more completely than the raw coal. Briquetting thus offers to hand-fired plants a means of developing high capacity. The plant can be run practically without smoke and obtain good efficiency by the use of briquets.

Table 45 is a comparison of results of tests made on the same coals burned with natural and with forced draft. Whenever forced draft was used the attempt was made to attain high capacity. Usually this was accomplished at the expense of efficiency. In the tests with forced draft the average percentage of black smoke was about double that in those with natural draft. The combustion space not being designed for high rates of combustion, an average variation in capacity of 92.6 to 108.4 caused an average drop in efficiency from 64.31 to 60.94. This table demonstrates that forced draft supplied through the average grate and fuel bed will neither intimately mix the air and gases nor allow coal to be burned at high and low rates of combustion with equal efficiency.

Table 46 is a comparison of results of tests of the same coals burned on flat and on rocking grates. In all the tests but one higher efficiency (from 1 to 5 per cent, with an average of 2) was obtained with the rocking grate. The average difference in proportion of rated capacity developed was about 2 per cent and was in favor of the flat grate. However, as the rocking grate had an area of 36.4 square feet and the flat grate of 40.55 square feet, it is evident that the rate of combustion per square foot of grate area was at least equal on the rocking grate to that on the flat grate, or perhaps slightly greater, but as the total weight of coal burned on the flat grates was greater it involved an increased tax on the efficiency of the combustion space. The average figures for over-all efficiency of the plant show that more coal was lost in the ash pit with the rocking grate than with the flat grate, but this loss did not counterbalance the efficiency, which still shows a gain of a little more than 1.50 per cent in favor of the rocking grate.

The ash in the dry coal varied from 5.39 to 23.16 per cent and the sulphur from 0.58 to 4.78 per cent. In the sole test in which the rocking grate failed to show better results the dry coal contained about 4.50 per cent of sulphur. With both flat and rocking grates the sulphur caused trouble. The clinker fused to the grate bars so that the rocking grate as constructed was practically inoperative and was actually used as a flat grate. However, as more difficulty was experienced in getting the clinker off the rocking grate, the time of cleaning and inefficient operation was longer with that grate and the tests showed less efficiency, but as most plants would not have a rocking grate to burn coal so high in sulphur, this point is unimportant. In practice about 2 per cent of sulphur is assumed to be the maximum content desirable for a coal to be burned on rocking grates, but this limit may be exceeded if experience shows that the sulphur is in organic form or that the sulphur and ash combined have no ill effects. The high sulphur and ash in the Wyoming coal did not cause trouble; in fact, the test was exceptional, for the coal did not clinker at all.

The black smoke was about 5 per cent less in the rocking-grate tests than in those with the flat grate. While this reduction is small the gain in efficiency with the rocking grate shows the advantage of having some means of keeping the fire clean. Such a grate would be of value in hand-fired plants for decreasing smoke and increasing the efficiency of operation.

TABLE 43.—*Comparison of results of tests on washed and raw coals.*

Field designation of coal.	No. of test.	Description of coal.	Moisture in coal as fired.	Ash in coal as fired.	Sulphur in coal as fired.	Sulphur in dry coal.	Ash in dry coal.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72 *.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
Illinois:			*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
No. 20	301	Washed	16.51	10.45	3.25	3.89	12.51	45	44.04	99.3	63.71	32.5	0.16	9.23	Coal free burning; automatic air admission not operated.
	292	Raw	14.52	15.49	4.32	5.05	18.12	55	45.69	66.3	66.51	0	.02	6.96	Automatic air admission operated.
No. 22 A	328	Washed	14.35	8.22	3.75	4.38	9.60	53	47.60	121.8	61.88	27.0	0	14.14	Coal free burning; automatic air admission operated.
	325	Raw	10.53	13.80	6.07	6.78	15.43	60	47.09	101.0	66.09	25.6	.16	9.07	Automatic air admission operated.
No. 23 A	317	Washed	14.64	8.88	3.23	3.78	10.40	50	46.71	90.4	62.97	0	0	10.80	Coal free burning; automatic air admission operated.
	306	Raw	14.49	13.45	4.62	5.40	15.73	66	44.92	84.3	68.31	15.5	.05	7.45	Do.
Indiana:															
No. 4	154	Washed	14.80	7.19	2.12	2.49	8.44	44	42.43	95.3	64.96	19.2	.18	12.02	Coal burned rapidly; caked; automatic air admission operated.
	165	Raw	13.82	17.26	2.43	2.82	20.03	53	42.25	88.9	70.13	16.1	.09	7.76	Coal caked; automatic air admission operated.
No. 6	159	Washed	11.27	9.63	3.57	4.02	10.85	51	47.92	96.7	60.37	43.4	.60	17.79	Coal burned rapidly; caked; automatic air admission operated.
	157	Raw	10.51	12.76	4.55	5.08	14.26	53	45.35	84.9	64.36	18.6	.23	9.40	Coal burned slowly; caked; automatic air admission operated.
No. 8	184	Washed	11.87	9.29	2.87	3.26	10.54	50	47.15	97.0	65.60	44.8	.25	10.26	Coal burned freely; automatic air admission operated.
	185	Raw	10.12	12.89	3.54	3.94	14.34	54	46.17	89.0	63.11	19.4	.17	12.65	Automatic air admission operated.
No. 10	177	Washed	10.98	6.24	3.50	3.93	7.01	51	49.69	105.3	58.72	46.6	.53	18.34	Coal burned freely; automatic air admission operated.
	167	Raw	10.60	10.16	4.21	4.71	11.36	49	47.83	99.4	66.60	36.6	.24	12.51	Coal burned rapidly; caked; automatic air admission operated.
No. 12	310	Washed	12.87	7.94	3.02	3.47	9.11	26	45.27	97.8	68.06	16.0	.14	15.83	Coal burned freely; automatic air admission operated.
	300	Raw	12.41	13.86	4.21	4.81	15.82	30	46.28	103.9	67.15	31.4	.08	6.00	Coal burned freely; automatic air admission not operated.
Kansas: No. 6	323	Washed	11.71	10.45	2.64	2.99	11.83	57	38.84	106.6	64.31	38.3	.30	13.71	Coal burned freely; automatic air admission operated.
	311	Raw	8.28	15.53	3.42	3.73	16.93	56	39.81	82.2	64.28	7.0	.09	10.59	Automatic air admission operated.

Maryland: No. 1	232	Washed	3.43	10.13	1.10	1.14	10.48	22	16.29	93.2	67.64	7.5	.08	12.86	Automatic air admission not operated.
	222	Raw	1.84	12.52	1.52	1.55	12.76	38	16.38	80.1	65.28	8.2	.10	12.63	Coal burned slowly; caked; automatic air admission not operated.
New Mexico:															
No. 3 B	392	Washed	4.77	12.23	.71	.75	12.85	0	39.88	119.2	65.48	26.0	.12	7.30	Coal burned quickly; caked; furnace door cracked after each firing.
	391	Raw	2.47	16.91	.67	.69	17.34	0	40.92	114.8	69.18	24.5	....	....	Coal burned quickly; furnace door cracked after each firing.
No. 4 A	398	Washed	3.86	11.40	.63	.66	11.86	0	40.19	108.1	65.83	21.0	.12	9.34	Coal burned freely; automatic air admission not operated.
	397	Raw	2.30	14.58	.60	.61	14.92	0	41.61	103.9	63.86	16.5	.12	9.69	Do.
Ohio:															
No. 2	197	Washed	8.99	7.74	3.15	3.46	8.50	50	45.29	84.4	62.54	32.2	.15	15.17	Coal burned freely; clinker fused into grate; automatic air admission operated.
	193	Raw	8.86	13.81	4.37	4.79	15.15	42	45.27	80.3	64.33	27.6	.11	14.82	Clinker fused into grate; automatic air admission operated.
No. 4	220	Washed	4.30	6.69	2.97	3.10	6.99	34	43.66	93.2	63.19	39.2	.17	16.02	Coal caked in fire; automatic air admission operated.
	201	Raw	3.73	9.73	2.65	2.75	10.11	51	42.44	93.2	66.14	25.8	.14	13.35	Coal burned freely; automatic air admission operated; clinker adhered to grate.
No. 6	253	Washed	3.26	6.88	3.01	3.11	7.11	60	43.11	79.4	64.08	23.2	.23	9.85	Clinker adhered to grate; automatic air admission operated.
	284	Raw	3.71	12.07	3.77	3.91	12.54	52	43.43	81.3	69.01	13.1	.13	4.12	Coal burned freely; automatic air admission not operated.
No. 9 B	241	Washed	7.92	7.08	2.86	3.11	7.69	56	45.39	92.7	67.13	39.6	.07	9.85	Coal burned freely; automatic air admission operated.
	224	Raw	7.84	14.89	3.27	3.55	16.16	48	45.61	87.8	66.61	22.4	.05	11.14	Coal caked; automatic air admission operated.
Pennsylvania:															
No. 5	195	Washed	2.97	4.73	.94	.97	4.88	40	38.04	96.9	65.33	43.8	.44	15.11	
	286	Raw	4.11	7.95	1.01	1.05	8.29	45	36.97	95.9	71.97	15.1	.21	4.59	Coal free burning; automatic air admission not operated.
No. 7	199	Washed	4.80	10.94	1.62	1.70	11.50	33	26.87	88.6	67.24	10.8	.04	12.71	Coal caked; automatic air-admission operated.
	307	Raw	5.80	13.63	2.22	2.36	14.47	0	27.04	85.0	68.51	8.0	.04	6.40	Coal burned slowly; automatic air admission operated.
Tennessee: Nos. 8 A and 8 B.	388	Washed	2.83	10.23	2.92	3.00	10.53	51	39.91	106.1	67.17	0	....	....	Coal burned quickly; caked; furnace door cracked after each firing.
	384	Raw	2.40	14.87	5.28	5.41	15.24	57	39.42	72.8	65.37	10.5	0	15.24	Coal caked; automatic air admission operated; clinker adhered to grate.
Virginia: No. 2	260	Washed	3.34	4.48	.85	.88	4.63	40	39.21	87.7	65.94	40.8	.19	13.71	Coal burned freely; automatic air admission operated.
	256	Raw	4.22	6.19	.82	.86	6.46	47	37.37	87.6	65.93	32.8	.26	11.69	Coal caked in fire; automatic air admission operated.

TABLE 43.—*Comparison of results of tests on washed and raw coals*—Continued.

Field designation of coal.	No. of test.	Description of coal.	Moisture in coal as fired.	Ash in coal as fired.	Sulphur in coal as fired.	Sulphur in dry coal.	Ash in dry coal.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72 *.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
West Virginia:			*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	
No. 17	230	Washed	4.35	6.17	1.36	1.42	6.45	48	31.68	89.0	67.94	23.8	.02	11.91	Coal burned slowly; automatic air admission operated.
	226	Raw	4.10	7.40	1.21	1.26	7.72	34	31.55	87.6	67.81	7.8	.06	9.37	Coal caked; automatic air admission operated.
No. 20	266	Washed	3.14	5.53	1.10	1.14	5.71	45	36.57	86.7	66.18	21.8	.06	11.73	Automatic air admission operated.
	273	Raw	2.89	8.43	1.50	1.54	8.68	34	35.80	83.6	70.07	12.2	.07	6.04	Coal burned freely; automatic air admission operated.
No. 21	267	Washed	4.24	3.67	1.07	1.12	3.83	52	39.59	95.4	66.81	36.0	.08	9.48	Do.
	296	Raw	3.42	6.12	1.22	1.26	6.34	47	37.87	101.8	69.45	13.5	.26	8.60	Do.
No. 22 A	454	Washed	5.24	6.10	.90	.95	6.44	25	37.98	110.3	65.95	20.0	.25	9.96	Coal caked; automatic air admission operated.
	447	Raw	5.55	13.47	1.04	1.10	14.26	33	36.61	99.1	68.40	13.0	.04	6.71	Do.
No. 23 B	444	Washed	4.06	4.80	.95	.99	5.00	30	39.17	88.0	62.84	8.5	.16	10.66	Coal caked; clinker adhered to grate; automatic air admission operated.
	445	Raw	2.44	10.59	1.40	1.43	10.85	41	38.29	95.9	67.93	27.0	.05	6.97	Coal burned quickly; caked; clinker adhered to grate; automatic air admission operated.
Wyoming: No. 3	223	Washed	19.08	6.78	4.26	5.26	8.38	53	49.34	81.0	63.34	21.0	.30	12.26	Coal burned freely; automatic air admission not operated; clinker adhered slightly to grate.
	212	Raw	13.60	16.21	7.90	9.14	18.76	58	51.46	88.2	64.08	22.7	.13	11.60	Clinker adhered slightly to grate; automatic air admission not operated.
Average		Washed	8.06	7.84	2.24	2.50	8.58	41	40.82	96.6	64.82	26.3	.19	12.40	
		Raw	7.48	12.48	2.99	3.29	13.54	42	40.50	89.9	66.95	18.1	.12	9.41	

TABLE 44.—*Comparison of results of tests on raw and briquetted coals.*

Field designation of coal.	Condition of fuel as fired.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gas.	Unaccounted for in heat balance.	Remarks.
Alabama:				*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
No. 2 B	Large and small briquets	410	Natural	0	38.94	91.4	69.52	0	0.02	....	Briquet broken before firing.
	Raw	382	...do	53	38.87	108.6	65.44	30.0	.15	13.63	
No. 4	Large and small briquets	413	...do	47	36.33	109.5	64.95	5.0	.07	....	Do.
	Raw	375	...do	54	35.41	106.9	66.38	11.5	.05	9.97	Furnace doors cracked for an interval after each firing.
Illinois:											
No. 21	Large briquets	318	Forced	47	41.83	115.3	64.00	0	.02	11.01	Briquets broken before firing.
	Raw	316	Natural	62	42.35	89.3	64.35	0	0	9.61	
No. 29 B	Small briquets	466	...do	38	45.79	109.2	66.91	13.0	.04	8.03	
	Raw	461	...do	64	45.66	104.2	64.37	7.0	.06	9.80	
Indiana: No. 7 A	Large briquets	288	...do	37	42.84	84.5	66.08	0	.07	6.77	Do.
	Raw	158	...do	54	47.33	96.9	64.71	45.4	.49	14.84	Coal caked in fire.
Indian Territory:											
No. 2 B	Small briquets from slack coal.	453	...do	34	39.88	105.1	69.66	4.5	.06	6.02	
	Raw	418	...do	48	40.81	95.0	68.38	15.5	.09	8.91	
No. 9	Small briquets	450	...do	....	19.23	102.2	67.77	0	.05	8.53	
	Raw	449	...do	26	15.17	97.0	65.20	3.0	.17	8.77	Clinker adhered to grate.
Maryland: No. 2	Large briquets	493	...do	56	22.99	121.2	69.18	0	.02	8.42	Briquets fired whole.
	Raw	490	...do	32	18.96	113.9	65.54	4.8	.10	8.69	
Pennsylvania:											
No. 6	Large briquets	333	...do	43	39.45	105.9	65.64	15.5	.20	5.83	Briquets broken before firing; test too short for reliable results.
	Raw	217	...do	54	38.59	97.1	66.39	37.8	.30	11.04	Coal caked in fire.
No. 15	Small briquets	467	...do	39	26.53	99.0	70.08	5.5	.03	7.89	
	Raw	473	...do	44	19.92	91.2	66.46	4.5	.08	7.85	Do.
No. 16	Large and small briquets	468	...do	41	27.43	105.7	68.22	4.0	.04	10.05	Briquets fired whole.
	Raw	471	...do	40	24.24	98.9	69.29	8.0	.02	7.48	Coal caked in fire.
No. 19	Large briquets	508	...do	34	37.77	113.7	67.23	0	.02	7.07	Briquets fired whole.
	Raw	498	...do	46	35.57	106.8	65.84	4.5	.04	8.65	
Tennessee:											
No. 1	Large briquets (washed)	409	...do	26	40.56	110.3	68.06	0	0	....	Briquets broken before firing.
	Small briquets (washed)	411	...do	0	40.31	134.7	70.26	17.0	.10	4.45	Test too short for reliable results.
	Raw	345	...do	44	39.87	111.7	66.09	14.0	.09	....	
	....do	346	...do	53	38.83	109.5	67.96	16.5	.05	....	

TABLE 44.—*Comparison of results of tests on raw and briquetted coals*—Continued.

Field designation of coal.	Condition of fuel as fired.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gas.	Unaccounted for in heat balance.	Remarks.
Tennessee—Continued.				*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
No. 4	Large and small briquets	405	...do	25	39.92	105.3	69.00	11.0	0	....	Briquets broken before firing.
	Raw	355	...do	38	38.44	110.8	67.05	23.5	.27	7.97	Smoked badly for short interval after firing.
Washington: No. 2	Large and small briquets	412	...do	26	43.34	99.3	66.06	0	.06	....	Briquets fired whole.
	Raw	359	...do	61	43.14	97.4	66.65	33.5	.23	6.41	Cracked furnace door for a short interval after each firing.
Average results	Briquetted coal	....	....	32.8	36.44	107.0	67.66	4.7	.05	7.64	
	Raw coal	....	....	48.3	35.19	102.2	66.25	16.2	.14	9.54	

TABLE 45.—*Comparison of results of tests of the same fuels when using natural and forced drafts.*

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry flue gases.	Unaccounted for in heat balance.
			Per cent.	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Arkansas:									
No. 7 A	294	Forced	57	19.07	85.7	65.07	0	0.02	9.84
	293	Natural	52	19.07	72.8	69.32	0	.11	7.48
No. 8 (washed)	309	Forced	28	12.51	106.3	62.92	0	.57	11.13
	308	Natural	36	13.03	80.9	67.64	0	.03	6.46
Illinois:									
Collinsville	505	Forced	57	45.87	131.6	60.20	14.9	.10	10.58
	500	Natural	55	45.91	112.1	62.53	19.7	.11	5.68
No. 9 C (briquets)	492	Forced	51	45.28	98.2	62.97	4.3	.06	8.85
	497	Natural	36	42.06	85.9	63.37	0	.05	7.03
No. 23 B (briquets)	322	Forced	62	46.61	106.6	58.22	17.0	.14	17.43
	321	Natural	62	46.61	106.0	58.93	22.0	.02	17.05
Missouri, No. 7 (washed)	332	Forced	61	44.48	129.4	56.64	42.5	.17	13.63
	330	Natural	55	45.40	115.0	62.03	27.5	0	13.49
Pennsylvania, No. 17	506	Forced	56	32.54	98.0	63.46	9.0	.04	8.30
	496	Natural	51	33.75	101.0	67.15	7.0	.03	6.63
Tennessee, No. 8	385	Forced	55	39.85	86.5	63.33	28.0	.05	14.80
	384	Natural	57	39.42	72.8	65.37	10.5	0	15.24
West Virginia:									
No. 5 A	482	Forced	62	14.75	147.7	60.23	20.5	.20	15.45
	476	Natural	51	15.18	99.7	67.13	1.5	.16	8.68
No. 15	216	Forced	49	42.92	103.0	60.30	54.6	.45	18.22
	215	Natural	46	42.71	84.4	62.91	46.2	.26	15.31
Wyoming, No. 2 B	213	Forced	0	51.58	99.9	56.98	42.0	.53	19.03
	210	Natural	0	50.01	88.3	61.06	0	.06	16.16
Average of 11 tests		Forced	48.9	35.9	108.4	60.94	21.2	.21	13.39
		Natural	45.5	35.7	92.6	64.41	12.2	.08	10.84

TABLE 46.—*Comparison of results of tests on the same coals with flat and rocking grates.*

Field designation of coal.	No. of test.	Kind of grate.	Clinker in refuse.	Volatile matter in combustible.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Sulphur in dry coal.	Ash in dry coal.	Efficiency of boiler and grate.
Illinois:			*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
No. 13 (washed)	145	Rocking	45	38.17	94.7	69.15	28.0	0.34	12.52	1.50	8.03	67.93
	144	Flat	47	39.38	103.8	67.33	36.0	.36	12.05	1.44	8.37	66.12
No. 19 A	171	Rocking	45	35.38	90.6	69.09	13.0	.14	9.81	.58	10.28	67.06
	161	Flat	58	35.53	87.6	68.27	13.0	.13	11.65	.58	10.25	65.82
No. 19 B	205	Rocking	41	36.74	94.9	71.27	28.8	.10	7.37	.61	11.41	68.86
	175	Flat	10	37.65	104.7	69.26	32.0	.21	9.69	.53	11.43	67.50
Indiana:												
No. 4	166	Rocking	44	42.85	74.7	66.38	2.0	.28	8.53	2.96	18.49	62.60
	151	Flat	58	44.15	80.8	64.37	12.8	.19	9.57	2.94	16.57	62.41
No. 7 B	*a* 164	Rocking	43	47.79	75.5	60.89	15.2	.08	19.61	4.39	11.44	59.49
	a 176	Flat	42	48.25	78.6	62.18	16.0	.04	13.21	4.60	12.19	60.94
Kentucky: No. 1 C	263	Rocking	49	38.68	78.9	68.44	13.6	.13	6.26	1.03	6.62	66.38
	265	Flat	51	37.98	77.2	65.95	12.0	.12	7.75	1.02	6.82	64.88
Ohio: No. 4	201	Rocking	51	42.44	93.2	66.14	25.8	.14	13.35	2.75	10.11	64.17
	188	Flat	53	42.87	95.0	63.97	33.6	.27	14.25	3.80	10.45	62.26
Virginia: No. 2	256	Rocking	47	37.37	87.6	65.93	32.8	.26	11.69	.86	6.46	64.48
	251	Flat	55	37.43	95.6	65.91	44.4	.04	11.80	.85	6.70	65.24
West Virginia:												
No. 15	214	Rocking	46	42.38	75.2	68.54	32.8	.10	12.21	3.07	8.18	62.76
	215	Flat	46	42.71	84.4	62.91	46.2	.26	15.31	2.84	7.86	61.13
No. 19	285	Rocking	56	22.62	81.8	70.76	0	.04	6.04	.94	6.70	69.04
	289	Flat	48	22.81	79.6	70.65	0	0	7.34	1.07	6.90	68.00
No. 20 (washed)	264	Rocking	33	36.07	90.5	70.23	26.0	.05	8.34	1.10	5.39	69.26
	266	Flat	45	36.57	86.7	66.18	21.8	.06	11.73	1.14	5.71	65.47
Wyoming: No. 2 B	210	Rocking	0	50.01	88.3	61.06	0	.06	16.16	4.37	20.98	58.66
	196	Flat	0	50.05	79.3	58.20	9.6	.11	14.75	4.78	23.16	55.61
Average results of 12 tests		Rocking	41.7	37.54	85.5	67.32	18.2	.14	10.99	2.01	10.34	65.06
		Flat	42.8	37.95	87.8	65.43	23.1	.17	17.40	2.13	10.53	63.78

a Clinker fused into grate and was removed with difficulty.

TABLE 47.—*Comparison of results of tests on the same coals showing the variation in boiler efficiency 72* as the percentage of black smoke increases.*

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in ash and refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Alabama: No. 3	390	Natural	43	36.75	21.42	2.93	92.7	67.43	0	....	....	Coal burned freely; furnace doors left open short time after firing.
	394	do	52	37.59	18.97	2.88	94.8	65.62	16.5	0.09	6.35	Automatic air admission not operated; coal high in slack; caked.
No. 4	378	do	54	35.24	13.97	5.27	77.4	65.61	0	0	11.89	Automatic air admission operated; coal burned rapidly; caked.
	376	do	44	34.83	15.02	4.84	83.2	65.82	6.5	.08	10.08	Furnace doors left open short interval after each firing; coal caked in fire.
	375	do	54	35.41	10.92	4.04	106.9	66.38	11.5	.05	9.97	Furnace doors left open short interval after each firing.
Indiana: No. 4	166	do	44	42.85	18.49	14.79	74.7	66.38	2.0	.28	8.53	Automatic air admission operated.
	165	do	53	42.25	20.03	13.82	88.9	70.13	16.1	.09	7.76	Coal caked; automatic air admission operated.
No. 15	429	do	41	41.16	9.44	12.83	87.9	64.43	0	.09	9.46	Automatic air admission operated.
	428	do	53	40.12	10.16	13.05	95.6	64.31	11.5	.13	8.92	Coal burned rapidly; automatic air admission operated.
No. 16	427	do	50	43.59	14.21	10.09	78.6	65.32	6.0	.09	9.64	Automatic air admission operated.
	426	do	53	44.89	13.75	9.09	89.1	66.30	16.5	.09	9.43	Do.
Indian Territory: No. 2 B (briquets).	453	do	34	39.88	8.59	3.29	105.1	69.66	4.5	.06	6.02	Small briquets; burned quickly; clinker adhered to grate; automatic air admission used for short period.
	455	do	26	40.16	8.28	2.70	93.5	60.41	8.0	.34	13.59	Both round and square briquets; automatic air admission operated on part of test; clinker adhered to grate.
Maryland: No. 1 (washed)	231	do	17	16.31	11.12	3.70	95.9	68.56	0	.04	11.28	Volatile matter burned off quickly; automatic air admission on only short time after firing.
	232	do	22	16.29	10.48	3.43	93.2	67.64	7.5	.08	12.86	Automatic air admission not operated.
Missouri: No. 5	320	do	63	44.03	18.36	12.24	94.7	64.87	0	0	11.17	Coal burned quickly; caked; automatic air admission operated.
	319	do	61	44.16	17.76	13.37	78.1	63.28	7.2	.04	9.58	Automatic air admission operated; coal caked.

TABLE 47.—*Comparison of results of tests on the same coals showing the variation in boiler efficiency 72* as the percentage of black smoke increases*—Continued.

Field designation of fuel.	No. of test.	Kind of draft.	Clinker in ash and refuse.	Volatile matter in combustible.	Ash in dry coal.	Moisture in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	CO in dry chimney gases.	Unaccounted for in heat balance.	Remarks.
			Per cent.	*Per cent.*	*Per cent.*	*Per cent.*		*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	
Tennessee: No. 5	352	Natural	47	39.72	10.34	5.59	95.4	65.62	0	0.21	9.86	Coal burned rapidly; automatic air admission operated.
	358	do	42	39.11	9.98	6.73	115.5	66.83	14.5	.10	7.91	Automatic air admission operated; coal burned freely.
	357	do	46	39.37	9.41	5.82	111.2	62.73	16.5	.18	10.31	Do.
Virginia: No. 5 A	476	Natural and forced.	51	15.18	19.50	4.73	99.7	67.13	1.5	.16	8.68	Automatic air admission not operated; forced draft used for 2 hours.
	482	Forced	62	14.75	18.22	4.60	147.7	60.23	20.5	.20	15.45	Coal burned rapidly; automatic air admission not operated.
Wyoming: No. 2 B	210	Natural	0	50.01	20.98	9.55	88.3	61.06	0	.06	16.16	Coal burned freely; automatic air admission operated.
	213	Forced	0	51.58	23.57	8.94	99.9	56.98	42.0	.53	19.03	Maximum capacity test; automatic air admission not operated.
No. 3	211	Natural	60	50.40	19.67	15.12	67.0	67.62	0	.10	4.88	Clinker adhered to grate; automatic air admission operated.
	212	Natural and forced.	58	51.46	18.76	13.60	88.2	64.08	22.7	.13	11.60	Clinker adhered to grate; automatic air admission not operated.

Table 47, compiled from the results of tests made on the same coals, shows the variation in boiler efficiency as the smoke increases. The tests of each coal compared were made with the same boiler and same grate. All the tests but two were made with natural draft; but inasmuch as the use of forced draft only increased the rate of combustion, as was shown by Table 45, the tests are comparable both as to efficiency and smoke.

In general the results show that as the percentage of rated capacity developed increased the percentage of black smoke increased and the efficiency decreased. This proves that the combustion space was not efficient over a wide range of working conditions, but there was a limit for rate of combustion for each kind of coal, above which efficient operation was impossible. The table also demonstrates that with hand-fired furnaces the combustion space to be most efficient must have some means of mixing the air and gases. The results with Maryland and Indian Territory coals show that the most smoke was made on the tests showing low capacity. Methods of operation may account for this efficiency variation, as with the Maryland coal the automatic air admission was used on the high-capacity test and not on the low. The discordant results in the tests of Indiana coals are probably due to the variation in air admission. The beneficial effect of the automatic air admission in reducing the smoke and increasing efficiency is noticeable in several tests.

The three tests on Alabama coal were run at about equal efficiency over a wide range of capacity, but as the methods of operating were dissimilar these apparent discrepancies could easily result.

High smoke values gave high unaccounted for values in the heat balance. Usually the percentage of CO in the flue gas was much greater when the smoke was high, showing a cause for the decreasing efficiency and increasing visible evidence of loss noted with high rates of combustion.

COMPARISON OF METHODS OF SUPPLYING AIR FOR COMBUSTION.

METHODS COMPARED.

As supplementing the data already presented to show the results obtained in tests at the fuel-testing plants, a number of tables have been compiled to show the relative value of different methods of supplying air for combustion. The following methods are compared: (1) Air supplied continuously by means of openings in grates; (2) air taken continuously through the grates and an extra amount supplied automatically at times of greatest distillation of volatile matter; (3) air taken continuously through the grates and more supplied at times of firing by cracking the furnace doors. All full-length St. Louis tests (except the briquet tests) and the hand-fired Norfolk tests have been used in this compilation.

RELATION OF EFFICIENCY TO CAPACITY WITH AIR ADMITTED THROUGH GRATES AND BY AUTOMATIC DEVICES.

To permit fair comparison of the boiler efficiency and rated capacity developed, tests were selected on which the same kind of coal was used and the same method of supplying air for combustion. These tests include two series, one in which the automatic air-admission device for the furnace was not operated and another in which it was. The results of the first series are given in the following table:

TABLE 48.—*Relation of efficiency to capacity, automatic air-admission device not operated.*

Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.	Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.
		Per cent.			*Per cent.*
Arkansas	106.3	62.92	Virginia	101.8	63.39
Do	85.7	65.07	Do	99.7	67.13
Do	85.0	65.90	Do	92.3	68.25
Do	80.9	67.64	Do	81.6	65.77
Do	72.8	69.32	Wyoming	99.9	56.98
New Mexico	108.2	67.19	Do	95.2	59.63
Do	108.1	65.83	Do	93.1	57.84
Do	103.9	63.86	Do	88.2	64.08
Virginia	147.7	60.23	Do	81.0	63.34

The above table shows that, in general, when the air was supplied by means of the air spaces in the grates the boiler efficiency was highest at the lowest capacities and decreased as the capacity increased.

Data from the second series of selected tests are presented in Table 49.

TABLE 49.—*Relation of efficiency to capacity, automatic air-admission device operated.*

Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.	Kind of coal.	Percentage of rated capacity developed.	Efficiency 72*.
		Per cent.			*Per cent.*
Maryland	113.9	68.54	Wyoming	88.3	61.06
Do	93.2	67.64	Do	79.3	58.20
Do	80.1	65.28	Do	67.0	67.62

This table shows that the automatic air admission is not always of equal value. With the Maryland coal too much air was supplied at the capacity of 80.1 per cent, for even at the highest capacity given neither the greatest possible reduction of air supply nor the highest efficiency had been reached. With the Wyoming coal not enough air was supplied at 88.3 per cent capacity to maintain the same efficiency as at 67 per cent.

COMPARISON OF RESULTS FROM DIFFERENT COALS WITH VARIED AIR ADMISSION.

In Table 50 the volatile matter in the coal as received, the percentage of rated capacity developed, the efficiency 72*, and the smoke readings have been averaged for the coals from each State according to the method of supplying air for combustion. The data show that no unvarying rule can be formulated to cover all coals, but in general a higher capacity and a higher efficiency resulted when additional air was supplied at times of firing. Many of the smoke averages do not fall as might be expected.

TABLE 50.—*Relation of air admission to results when burning different coals.*

Kind of coal.	Method of supplying air.	Number of tests.	Volatile matter in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.
			Per cent.		*Per cent.*	*Per ct.*
Alabama	Automatic air admission off	5	27.3	95.5	66.56	14.4
	Automatic air admission on	2	29.7	78.3	65.92	0
	Furnace doors cracked after firing.	4	28.1	98.8	66.88	8.0
Arkansas	Automatic air admission off	6	15.0	89.1	65.18	0
Illinois	....do	32	32.5	91.7	58.56	24.7
	Automatic air admission on	40	32.2	91.9	66.05	18.3
	Furnace doors cracked after firing.	11	31.6	92.7	65.04	5.4
Indiana	Automatic air admission off	1	34.1	103.9	67.15	31.4
	Automatic air admission on	35	34.8	90.1	65.13	21.9
	Furnace doors cracked after firing.	1	33.5	93.1	65.36	28.2
Indian Territory	Automatic air admission off	1	13.6	97.0	65.20	3.0
	Furnace doors cracked after firing.	1	35.4	90.5	68.10	19.5
West Virginia (Jamestown)	Automatic air admission off	2	16.9	128.5	66.99	6.9
	Automatic air admission on	2	17.1	80.8	66.93	7.0
	Furnace doors cracked after firing.	1	15.3	78.3	68.61	8.6
Kansas	Automatic air admission on	13	33.1	92.2	66.47	20.1
	Furnace doors cracked after firing.	1	33.7	68.4	67.08	....
Maryland	Automatic air admission off	3	15.0	95.7	67.15	6.8
	Automatic air admission on	1	14.0	95.9	68.56	0
Missouri	Automatic air admission off	1	32.0	129.4	56.64	42.5
	Automatic air admission on	6	32.5	97.7	63.12	12.8
Montana	Automatic air admission off	2	31.7	114.3	66.95	15.3
New Mexico	....do	3	33.8	106.7	65.63	17.3
	Furnace doors cracked after firing.	4	32.6	107.9	67.08	17.8
Ohio	Automatic air admission off	1	36.6	81.3	69.01	13.1
	Automatic air admission on	24	36.6	92.1	65.69	33.1
	Furnace doors cracked after firing.	2	39.0	118.4	68.02	13.0
Pennsylvania	Automatic air admission off	12	22.7	91.4	67.43	6.2
	Automatic air admission on	10	31.2	93.5	67.67	23.7
Tennessee	Automatic air admission off	4	32.8	89.8	65.71	20.1
	Automatic air admission on	12	32.1	103.0	66.02	14.2
	Furnace doors cracked after firing.	7	33.0	110.2	65.16	21.9
Texas	Automatic air admission off	2	30.6	96.6	56.69	6.0
Virginia	....do	5	22.5	104.6	64.95	10.4
	Automatic air admission on	9	34.7	92.3	66.77	34.2
Washington	Automatic air admission off	1	35.6	108.4	63.98	17.0
	Automatic air admission on	1	34.5	81.8	65.04	10.0
	Furnace doors cracked after firing.	1	36.5	97.4	66.65	33.5
West Virginia	Automatic air admission off	2	20.6	80.7	70.71	0
	Automatic air admission on	27	32.7	93.8	67.59	21.5
	Furnace doors cracked after firing.	2	34.3	103.9	69.10	16.0
Wyoming	Automatic air admission off	5	37.0	91.5	60.37	21.6
	Automatic air admission on	3	35.0	78.2	62.29	3.2

RELATION OF EFFICIENCY TO CAPACITY WITH VARIED AIR ADMISSION.

Table 51 gives averages for all tests made with automatic air admission not operated, automatic air admission operated, and furnace doors cracked, not classified according to States.

TABLE 51.—*Relations of air supply to averages of results.*

Method of supplying air.	Number of tests.	Volatile matter in coal as fired.	Percentage of rated capacity developed.	Efficiency 72*.	Black smoke.	
					Amount.	Number of tests.
		Per cent.		*Per cent.*	*Per cent.*	
Automatic air admission off	88	28.0	93.8	62.95	11.8	59
Automatic air admission on	185	33.2	92.9	66.06	21.6	162
Furnace doors cracked	35	31.2	99.7	66.21	15.4	28

The subjoined list shows the names of the coals which fell in the final grouping of Table 51:

AUTOMATIC AIR ADMISSION NOT OPERATED.

Indian Territory.
Arkansas.
Maryland.
West Virginia (Jamestown).
West Virginia.
Virginia.
Pennsylvania.
Alabama.
Texas.
Illinois.
Missouri.
Montana.
Tennessee.
Indiana.
New Mexico.
Washington.
Ohio.
Wyoming.

AUTOMATIC AIR ADMISSION OPERATED.

Maryland.
West Virginia (Jamestown).
Alabama.
Pennsylvania.
Illinois.
Missouri.
Tennessee.
West Virginia.
Kansas.
Indiana.
Virginia.
Washington.
Wyoming.
Ohio.

FURNACE DOORS CRACKED.

West Virginia (Jamestown).
Alabama.
Illinois.
New Mexico.
Indiana.
Kansas.
Tennessee.
West Virginia.
Indian Territory.
Washington.
Ohio.

Tables 52 to 54 give averaged results showing the relation of efficiency to capacity under the three methods of air admission when high-volatile coals are burned, all the tests on low-volatile coals being excluded.

TABLE 52.—*Relation of efficiency to capacity, automatic air admission not operated.*

Percentage of rated capacity developed.	Efficiency 72*.	Percentage of rated capacity developed.	Efficiency 72*.
	Per cent.		*Per cent.*
108.4	63.98	96.6	56.69
106.3	61.97	95.5	66.56
105.3	66.39	86.4	64.69
98.0	66.19	80.7	70.71

Table 52 shows that the highest efficiency was obtained with the lowest capacity and that the efficiency decreased as the capacity increased.

TABLE 53.—*Relation of efficiency to capacity, automatic air admission operated.*

Percentage of rated capacity developed.	Efficiency 72*.	Percentage of rated capacity developed.	Efficiency 72*.
	Per cent.		*Per cent.*
96.6	65.70	88.1	65.65
93.5	67.67	78.3	65.92
92.2	66.47	78.2	62.29
92.1	65.69		

Table 53 shows that the lowest efficiency was obtained when running at the lowest capacity and that the efficiency increased as the capacity increased.

TABLE 54.—*Relation of efficiency to capacity, furnace doors cracked after each firing.*

Percentage of rated capacity developed.	Efficiency 72*.	Percentage of rated capacity developed.	Efficiency 72*.
	Per cent.		*Per cent.*
118.4	68.02	97.4	66.65
107.9	67.08	92.7	65.04
103.9	69.10	90.6	65.87
98.8	66.88	90.5	68.10

Table 54 shows that the highest efficiencies were obtained when running at high capacity and that with one exception, the reverse was true. Supplying air by cracking the door, while it results in high efficiency, is more liable to furnish a variable supply than an automatic device, as it introduces the personal element.

With the furnace door cracked after firing, the lowest efficiency was 65 per cent. With the automatic air admission operated, the lowest efficiency was 62.3 per cent. With the automatic air admission not operated, the lowest efficiency was 56.7 per cent.

CONCLUSIONS.

Air supply should be regulated to suit the combustion of different kinds of coal.

With the same coal burned in the same furnace, a proper amount of air supplied at times of greatest distillation of volatile matter will aid in obtaining higher capacity and higher efficiency than can be had without such regulation.

When air is supplied in the same manner to the same coal in the same furnace, the efficiency is practically determined by the rate of combustion.

On the average, cracking the furnace door resulted in highest capacities with the highest efficiencies, from which it would seem that in general not enough air was supplied by the automatic air-admission openings.

Air should be supplied automatically to the furnace, as this overcomes in a measure the personal element.

In the average furnace the gases and air are not mixed thoroughly and it is possible, especially by cracking the furnace doors, to admit large amounts of air into the furnace and reduce the visible products of incomplete combustion at the expense of efficiency. (See tests of Illinois coal in Table 50.)

INFLUENCE OF VOLATILE MATTER IN FUEL ON THE SMOKE PROBLEM.

From a study of the tables giving the results of the tests made under Heine boilers, it appears that in all tests coal with low volatile matter was burned most efficiently and with the least smoke. High-volatile coals are more difficult to burn without loss than low-volatile coals, but the difficulty is not directly proportional to the percentage of volatile matter. Some coals with less than 30 per cent of volatile matter give off more smoke than others having 40 per cent. Observations of the behavior of coals when thrown into the furnace indicated that some coals gave off their volatile matter at lower temperatures than others, and that there was a difference in the nature of the volatile matter.

This phase of the composition of coals is now undergoing laboratory investigation under the direction of N. W. Lord. When these investigations are completed valuable data will be at the command of engineers who are called on to design furnaces for burning coal. Horace C. Porter, who is conducting the experiments, has furnished the following preliminary statement, which shows that among the coals tested there is a wide difference in the character of the volatile matter:

TABLE 55.—*Results of heating 10 grams of air-dried coal ten minutes.*

Kind of coal.	Highest temperature in coal in retort.	Tar.[a]	Water.	Gas.	Gas composition (calculated to undiluted gas).						
					CO_2.	Illuminants.[a]	CO.	CH_4.	C_2H_6.[a] [b]	H_2.	N_2.
At heating temperature of 500° C.	° *C.*	*P. ct.*	*P. ct.*	*C.c.*							
Connellsville, Pa	335	......	......	8	30.0	0	6.5	6.5	7.0	0	[c] 50.0
Zeigler, Ill	325	......	......	90	14.8	0	5.3	8.0	......	0	[c] 71.9
At heating temperature of 600° C.											
Connellsville, Pa	441	4.9	3.2	190	6.3	8.2	5.9	36.9	23.7	2.0	[c] 17.0
Zeigler, Ill	440	6.8	13.0	173	15.7	7.0	14.4	19.0	22.2	2.8	[c] 18.9

[a] Smoke-forming matter.
[b] Includes all higher paraffin calculated as C_2H_6.
[c] Includes small amount of air.

TABLE 55.—*Results of heating 10 grams of air-dried coal ten minutes*—Continued.

Kind of coal.	Highest temperature in coal in retort.	Tar.	Water.	Gas.	Gas composition (calculated to undiluted gas.)						
					CO_2.	Illuminants.	CO.	CH_4.	C_2H_6.	H_2.	N_2.
At heating temperature of 700° C.	° *C.*	*P. ct.*	*P. ct.*	*C. c.*							
Connellsville, Pa	562	11.0	3.5	583	3.0	7.2	5.4	44.1	17.7	13.5	9.1
Zeigler, Ill	545	7.8	14.0	471	8.5	5.1	13.7	59.6	0	1.1	12.0
Sheridan, Wyo	580	8.2	18.5	1,020	28.8	3.7	20.0	18.6	6.8	15.1	7.0
Pocahontas, W. Va	599	4.2	1.9	675	1.9	4.4	3.9	44.4	16.1	28.5	.8
At heating temperature of 800° C.											
Connellsville, Pa	687	12.6	4.5	1,375	1.5	5.5	6.9	24.9	12.1	33.1	[a] 16.0
Zeigler, Ill	680	9.3	13.9	1,251	3.8	3.8	16.0	27.7	6.1	33.7	[a] 8.9
Sheridan, Wyo	....	7.9	19.1	1,780	19.8	2.7	21.4	14.1	4.0	30.0	8.0
Pocahontas, W. Va	....	6.5	2.4	1,590	1.2	3.4	4.8	24.4	11.6	43.2	11.4

[a] Includes small amount of air.

The differences in the ease with which various coals give off their smoke-producing constituents are strikingly shown by the accompanying diagram (fig. 40), in which all these volatile substances are grouped, the total percentages given off being represented by the vertical scale and the temperatures by the horizontal scale. The behavior of the Illinois coal at temperatures between 600 and 700° C. contrasts strongly with the progressive distillation of Connellsville coal, and the decline in production of volatile compounds at temperatures over 700° shown by Wyoming coal is notably different from the even increases shown by Illinois, Pocahontas, and Connellsville coals.

HORSEPOWER FROM DIFFERENT COALS.

The facts presented in Table 56 were obtained by averaging more than 200 tests on coals and lignites from 17 different States. All these fuels were hand fired under a Heine boiler. The furnace was set with flat grates, which were 26 inches from the U tile on the lower row of tubes, measured at about the center of the grate. Natural draft was used in nearly all the tests. The damper was usually set so as to get a draft of about 0.6 inch of water in the hood, this giving from 0.12 to 0.30 inch in the furnace, varying with the coal and the condition of the fire. On the assumption that the boilers at the average good plant are run at approximately the same efficiency as those at the government testing plant, the figures given in Table 56 for coal per boiler horsepower per hour may be used as a basis for an approximate determination of the total boiler horsepower at any plant by dividing the amount of coal used per hour by the figures in the table opposite the State from which the coal is supplied. For

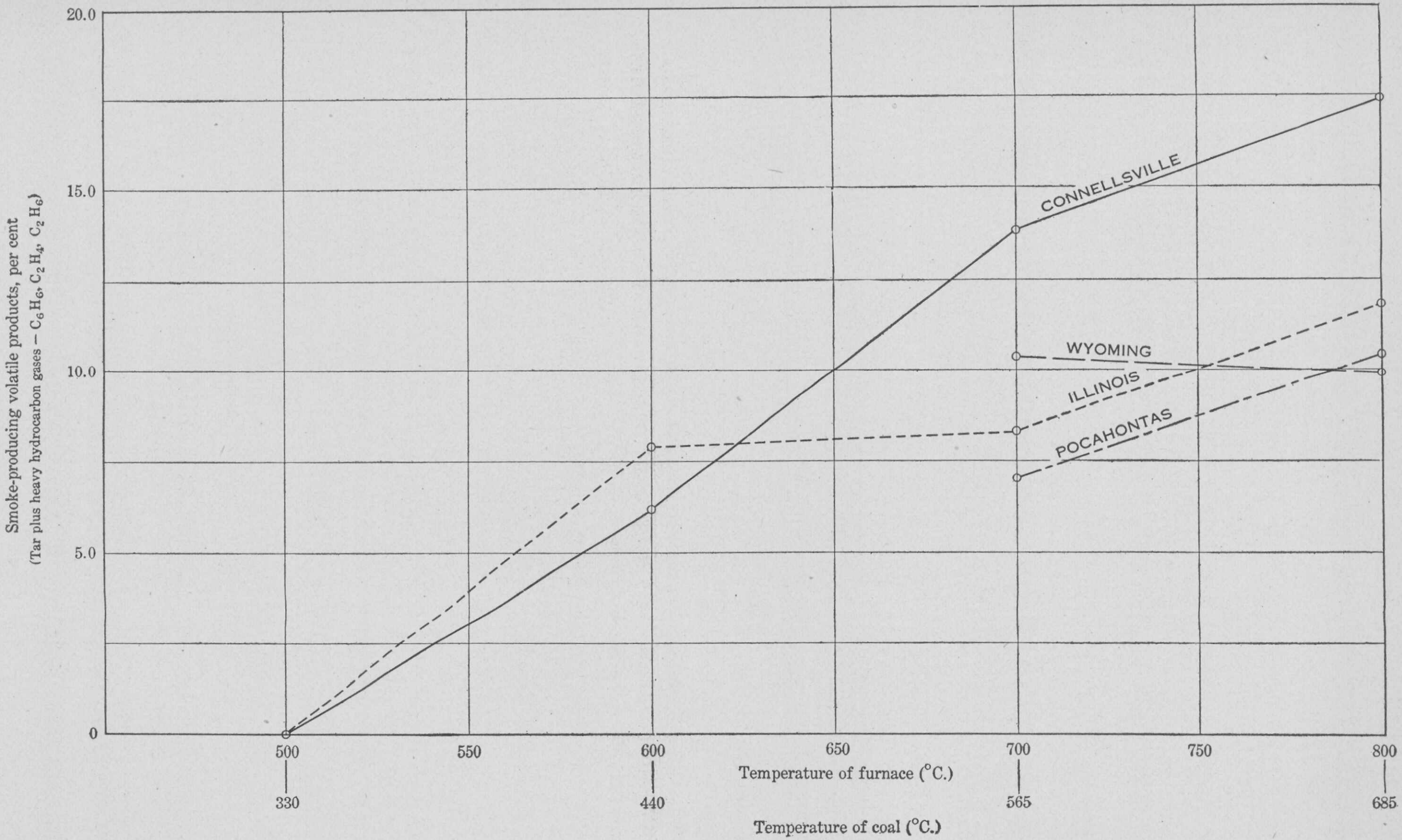

FIGURE 40.—Proportion of smoke-producing compounds given off at different temperatures by several coals.

instance, a consumption of 460 pounds of best Illinois coal per hour indicates that the total boiler horsepower developed would be about 100.

TABLE 56.—*Efficiency 72* and coal burned per boiler horsepower per hour.*

State.	Number of tests averaged.	Efficiency, 72*.	Coal burned per boiler horsepower per hour.	State.	Number of tests averaged.	Efficiency, 72*.	Coal burned per boiler horsepower per hour.
		Per cent.	*Pounds.*			*Per cent.*	*Pounds.*
Alabama	3	66	4.2	Kentucky	13	65	4.0
Arkansas	4	67	3.9	Maryland	3	66	3.8
Colorado (lignite)	1	61	6.0	Missouri	7	63	5.1
Illinois (best coal)	23	66	4.6	New Mexico	2	60	5.5
Illinois (fair and poor coal)	21	61	5.0	Ohio	26	64	4.2
				Pennsylvania	21	67	3.6
Indiana	27	63	4.7	Virginia	12	65	3.7
Indian Territory	4	64	4.5	West Virginia	36	67	3.6
Iowa	5	61	5.5	Wyoming (lignite)	8	59	6.1
Kansas	8	63	4.4				

CENTRAL HEATING STATIONS.

The possibility of reducing smoke in cities by the use of central heating plants was taken up as part of the general study of the smoke problem. There is no doubt that in winter the small heating plants, both in residences and in store buildings, contribute largely to the smoke nuisance. This is because the small plant is poorly designed for burning any but low-volatile fuels. When an attempt is made to burn the cheaper coals, such as large stations utilize, dense black smoke results, often lasting for several minutes after each coaling. Moreover, the plant is not large enough to warrant careful operation and the coal is fired in large quantities and at long intervals. To obviate the difficulties of combustion high-priced coal is burned, this being especially true in congested areas. It is evident that if for the heating plants of several buildings could be substituted a central station where a power-plant boiler of standard type could be installed, a correct furnace constructed, cheap fuel utilized, and the plant operated intelligently, much of the nuisance and discomfort from the small plants would be overcome.

The central heating plant is not a new thing; in fact some of the plants have been in operation for twenty to twenty-five years. Development in this direction has been very slow, however, until within the last five or six years, when the idea has received renewed attention.

The data presented in Table 57 were obtained by sending a circular letter to each of the central heating plants supposed to be in operation in the United States—150 in all. Of these, 77 responded, 57 giving the information as tabulated; twenty stated that they were out of business or inactive. The location of the 130 is given in the statement below. The tabulated statistics may be taken as fairly representative of central heating plant conditions. It will be noted that the plants are most numerous in the States where coal is relatively cheap.

Location and number of central heating plants.

	Number of plants.		Number of plants.
Arkansas	1	Montana	1
Colorado	2	Missouri	4
Connecticut	1	New Hampshire	1
Georgia	1	New York	10
Idaho	1	North Dakota	2
Illinois	24	Ohio	24
Indiana	17	Pennsylvania	25
Kansas	1	Rhode Island	1
Massachusetts	2	Texas	1
Michigan	3	Washington	1
Minnesota	3	Wisconsin	4

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TABLE 57.—*Details of operation of central heating plants.*

No.	Location of plant.	Purpose of plant.	Heating system.	Boilers.		Style of furnace.	Fuel.		Horsepower of engine.
				Character.	Horsepower.		Kind.	Cost per short ton.	
1	Colorado	Heat	Steam	Fire tube Water tube	1,500 2,200	Common	Lignite slack	$1.33	0
2	Illinois	Light, heat, and power	do	Water tube	4,200	Dutch oven	Bituminous slack	1.00	4,000
3	do	do	do	do	2,520	3 Green; 2 common	Bituminous screenings	1.50	3,150
4	do	do	do	do	1,800	Chain grates; Roney stokers.	Bituminous pea and screenings	1.38	360
5	do	do	do	Fire and water tube.	1,350	Common and chain grates	Bituminous screenings	1.85	1,700
6	do	do	do	Fire tube	600	Common	Run of mine and lump	1.30	400
7	do	Light and heat	do	do	450	do	Bituminous run of mine	1.70	120
8	do	Light, heat, and power	Steam and hot water.	Water tube	2,970	Chain grates	Bituminous screenings	.90	4,100
9	do	do	do	do	2,800	do	Run of mine and screenings		3,200
10	do	do	Hot water	do	1,100	Common	Bituminous screenings	1.20	1,250
11	do	do	do	do	400	do	Bituminous ¾-inch screenings	1.47	375
12	Indiana	do	do	do	1,800	Detroit and Roney stokers	Bituminous screenings	2.50	
13	do	Light and heat	do	do	1,720	Common	Bituminous slack	1.35	2,500
14	do	Light, heat, and power	do	do	1,000	do	Run of mine; screenings	1.75	570
15	do	do	do	Fire tube	400	do	Bituminous run of mine	1.12	
16	do	Light and heat	do	Water tube	800	1 common; 2 Roney stokers.	Bituminous	2.61	515
17	do	Light, heat, and power	do	Fire and water tube.	800	Common	Bituminous slack	2.20	880
18	Iowa	Light and heat	do	Water tube	800		Nut and run of mine	1.70	425
19	do	do	do	Fire tube	400	Common	Run of mine, nut steaming	3.00; 2.12	150
20	do	Light, heat, and power	do	do	300		Bituminous lump	1.95	250
21	do	Light and heat	Steam	Water tube	2,150	2 chain grates; 7 common	Bituminous screenings	1.70	2,800
22	Michigan	Light, heat, and power	do	Fire tube	600	Morrison suspension	Bituminous slack	2.90	400
23	Minnesota	do	do	Water tube	725	Common	⅔ anthracite, ⅓ bituminous	3.75	700
24	Missouri	do	do	Fire tube	900	Down draft	Bituminous lump	1.67	405
25	do	do	do	Water tube	900	2 down draft; 1 common	do	2.05	1,264
26	do	Heat	do	do	750	Common	Bituminous slack	1.75	0
27	do	Light, heat, and power	do	Fire tube	450	Down draft	Bituminous pea and nut	1.80	280
28	do	do	do	Fire and water tube.	400	do	Bituminous lump	2.10	200
29	Montana	Light and heat	do	Water tube	1,500	American stoker	Bituminous slack	4.60	250
30	New York	Power and heat	do	do	16,000	Common	Anthracite	2.23	0
31	do	Heat	do	do	11,000	do	do	2.23	0
32	do	Light, heat, and power	do	do	2,368	do	Buckwheat	2.13	1,475
33	do	Light and heat	do	do	1,600	Murphy stoker	Bituminous	2.50	705
34	do	Heat	do	Fire tube	700		¾ anthracite, ¼ bituminous	1.74; 2.90	0
35	do	Power and heat	do	do	405	Murphy stoker	Screened nut	2.60	430
36	North Dakota.	Light, heat, and power	do	Water tube	1,000	Common	⅔ anthracite, ⅓ bituminous	4.00	1,500
37	do	do	do	Fire tube	600		Lignite	2.00	600

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Purpose of plant.	Heating system.	Boilers.		Style of furnace.	Fuel.		Horsepower of engine.
				Character.	Horsepower.		Kind.	Cost per short ton.	
38	Ohio	Light, heat, and power	Hot water	Water tube	2,800	Dutch oven	Run of mine	$2.20	3,000
39	do	do	do	do	1,400		Run of mine, slack, natural gas	1.30	550
40	do	do	do	Water and fire tube	1,100	Common	Pea and slack	1.50	750
41	do	do	do	Water tube	950	do	Bituminous run of mine	2.25	1,000
42	do	Heat	Steam	Fire and water tube	1,200	6 common; 2 Murphy	Run of mine and slack	1.75	0
43	Pennsylvania	do	do	Fire tube	1,600		Anthracite buckwheat	1.50	0
44	do	do	do		1,700	Common	Anthracite and bituminous	2.28	0
45	do	Power and heat	do	Fire and water tube	1,550	8 underfeed; 1 common	Bituminous	2.75	
46	do	Light, heat, and power	do	Fire tube	1,500	Roney stokers	Slack	1.00	1,200
47	do	do	do	Fire and water tube	1,400	Common	Bituminous	2.59	1,050
48	do	Heat	do	Fire tube	1,200		do	1.03	0
49	do	do	do	do	1,000	Common	Anthracite rice and buckwheat	1.14	0
50	do	Light, heat, and power	do	Water tube	950	Murphy stokers	Anthracite rice and bituminous run of mine.	2.63	1,050
51	do	Heat	do	Fire tube	900	Common	Anthracite	1.03	0
52	do	do	do	3 fire tubes; 1 water tube.	725	Wilkinson stokers	Bituminous	2.77	0
53	do	Light, heat, and power	do	Water tube	600	Common	Run of mine	1.38	300
54	do	Heat	do	Fire tubes	600	do	Bituminous run of mine	1.37	0
55	Rhode Island	Light, heat, and power	do	Water tube	3,315	do	Bituminous	3.75	4,250
56	Wisconsin	do	Hot water	Fire and water tube	600	do	Bituminous screenings	1.90	800
57	do	Light and heat	do	Water tube	600	do	Bituminous run of mine	2.50	800

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Live steam used (per cent).	Mains leading from plants.		Pressure (pounds).		Greatest distance heat is conveyed (feet).	Total length of heating mains (feet).	Insulation.	Radiation (square feet).	
			Number.	Size (inches).	On mains at plant.	Drop in main.				Direct.	Indirect.
1	Colorado	100			50	42	7,550	38,173	Lapped with asbestos inside 4-inch wood log		Very little.
2	Illinois		1 1	8 12	15	12	3,960	10,560	Tin, asbestos, and 4-inch wood log	200,000	None.
3	do		1	20	20	15	7,200	14,784	4-inch wood log		Very little.
4	do	33	1 1	10 6	10	6	2,000	4,000	1-inch magnesia pipe covering		
5	do	0	1 1	5 8	3–6	2	3,960	7,920	1-inch felt and wooden box		None.
6	do		1	8	6–15	1–3	2,640	2,640	6-inch wood logs	35,000	
7	do	0	1	8	2	¼	1,300	4,000	7-inch hemlock and hair	2,000	None.
8	do	50	a 1 b 1	16 12	a 8–b 50		5,280	a 15,840 b 31,680	Air chambers and sawdust	a 180,000 b 270,000	
9	do		a 1 b 1	12 8	6	6	a 3,000 b 6,600		Magnesia and oil shavings	75,000 x 2	Very little.
10	do	65	6	7	60	10	7,920	58,080	3-inch wood box	100,000	None.
11	do	0	1	10	88	9	2,640	17,500	2-inch sawdust and lime		Do.
12	Indiana	0	1	20	30				Boxing; mineral wool	400,000	Do.
13	do		2	12	48	20	3,960	10,560	3-inch wood covering	120,000	Do.
14	do		2	10	70	40	4,500	34,000	4-inch wood and hair felt	130,000	Do.
15	do		1 1	7 6	40	10	5,280	15,840	4-inch wood logs	60,000	Very little.
16	do	16	c 1	12	50	25	1,500	12,000	5-inch hemlock boards and air space	70,000	None.
17	do	15	c 1 c 1	6 7	60	15	5,000	18,480	5-inch air space; boards and shavings, and tarred felt	115,000	
18	Iowa	33⅓	1	8	45–60	10–15	3,520		Hemlock covering, with two air spaces	85,000	None.
19	do	75	c 1	7	51	8	3,000	d 8,800	3¾-inch wood	61,000	Do.
20	do	(e)	1	5	30		2,000	4,000	Wood	20,000	Do.
21	do		1	12	17	15	4,500	12,000	4-inch wood logs	138,000	
22	Michigan	66	2	10	3	¼	1,300	4,000	2-inch 85 per cent magnesia	50,000	None.
23	Minnesota	(f)	1	8	5	0	1,600	3,960	3-inch wood logs	30,000	
24	Missouri		1	16	3		1,072	1,460	1-inch paper; air cell	11,481	150,460
25	do	(g)	2	12	¾	0	400	700	1-inch 85 per cent magnesia	4,900	None.
26	do	100	1	10	5	1	4,600	7,920	4-inch kiln-dried pine; wood log	83,082	
27	do		7	6	1½	0	130	600	⅞-inch magnesia	33,000	None.
28	do	50	1	10	5½	1	400	700	1-inch asbestos	38,267	Do.
29	Montana		8	12	10	½	2,000	4,000	1-inch asbestos; sponge felt	70,000	Do.
30	New York	100	3	15	95	10	3,200	29,040	1-inch air space; 4-inch mineral wool inside conduit		

a Steam. b Hot water. c Pair. d Double pipe. e Very little. f 75,000 pounds per day. g 146,000 pounds per day.

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Live steam used (per cent).	Mains leading from plants.		Pressure (pounds).		Greatest distance heat is conveyed (feet).	Total length of heating mains (feet).	Insulation.	Radiation (square feet).	
			Number.	Size (inches).	On mains at plant.	Drop in main.				Direct.	Indirect.
31	New York	100	1 1	15 24	55	5–15	7,500	58,080	1-inch air space; 4-inch mineral wool inside conduit	1,100,000	
32	do	......	1 1	15 12	5	......	922	4,070	1½-inch 85 per cent magnesia	65,430	None.
33	do	70	4	14	4½	3½	3,960	31,680	4-inch kiln-dried sectional white pine, wood logs	124,000	
34	do	100	1	10	20	5	5,280	7,000	Tin, asbestos, 4-inch wood logs	......	Very little.
35	do	100±	1	8	5	0	1,200	......	4-inch wood log	......	
36	North Dakota	50	1	10	7½	......	1,500	3,000	Tin, asbestos, 4-inch wood logs	50,000	None.
37	do	......	1 1	12 8	......	......	1,000	2,000	Tin, asbestos, and wood logs	......	
38	Ohio	0	2	12	45	30	11,880	47,520	5-inch wooden box; air space; oil shavings	160,000	None.
39	do	0	2	8	70	......	6,600	21,120	Wood shavings and mineral wool	110,000	Do.
40	do	20	2	8	30	6	5,500	10,560	5-inch wood; air space; box	80,000	Do.
41	do	(*a*)	*b* 2	......	40	15	3,520	7,000	2-inch wood covering	30,000	Do.
42	do	100	1	14	½–6	¾	3,178	5,492	4-inch tin-lined wood casing	......	
43	Pennsylvania	(*c*)	12	3	50	47	5,280	46,200	Tin-lined 4-inch wood log	......	
44	do	100	10	3	5–20	......	5,280	11,880	3-inch wood log	42,000	
45	do	100	1 2	10 6	12–25	7	3,917	28,945	Asbestos and 4-inch wood logs	29,785	162,182
46	do	......	1	14	2–6	......	4,000	13,200	Tin, asbestos, 4-inch wood logs	50,400	5,600
47	do	100	1	12	15	11	......	9,500	4-inch asbestos and wood logs	......	
48	do	100	1	8	20	......	3,960	3,960	⅝-inch asbestos	......	
49	do	100	1	10	30	25	6,000	6,000	2-inch asbestos and wood log	......	Very little.
50	do	50	1	12	4	2¼	3,550	8,777	Tin, asbestos, 4-inch wood logs	88,611	None.
51	do	100	1	10	50–70	35–40	5,000	7,200	4-inch wood log	70,000	
52	do	100	1 1	8 12	10–20	5–15	4,620	17,911	3-inch concrete duct; 3-inch and 4-inch wood log; 3-inch air space.	57,324	60,909
53	do	......	1	8	6	(*a*)	3,960	7,920	1-inch wood	......	None.
54	do	100	1	8	15–40	10–35	2,640	10,560	Asbestos and 4-inch wood logs	45,000	
55	Rhode Island	100	1	8	14	5	2,042	5,285	Tin, asbestos, 4-inch wood logs	......	Very little.
56	Wisconsin	90	1	4	55	15	2,000	4,000	1½-inch wood log	10,000	None.
57	do	0	2	8	60	40	7,920	31,680	3-inch hemlock boxing and air space	70,658	Do.

a Very little. *b* Pair. *c* Nearly 100.

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Space in buildings (cubic feet).	Average price of heating.		Average cost per year for repairs on mains, tunnels, and insulation.	Years in operation.	Remarks.
			Per square foot.	Per 1,000 pounds of water.			
1	Colorado	700,000	$0.65		$1,500	26	Condensation loss, 12 per cent. Price to large dealers, $2 per 1,000 cubic feet of contents.
2	Illinois	1,200,000	.24			12	$4 per 1,000 cubic feet of contents.
3	do			$0.45	None.	3	Live steam one-tenth of season.
4	do				Very small.		Radiation direct and indirect.
5	do					7	Direct system.
6	do		.25		$100	5	Profitable when heat is furnished as a secondary product.
7	do		.28		None.	2	
8	do	a 9,000,000 b 9,450,000	a .25 b .15			a 17 b 5	Do.
9	do		a .22½ b .75½			6½	Would advise concentration of mains.
10	do		.15		10 per cent.	6	Would advise use of larger mains; also concentration of territory heated. Insulation could be improved.
11	do		.20			7	
12	Indiana		.20			5	
13	do		.18		$400	5	Profitable when heat is furnished as a secondary product.
14	do		.15½			5	Charge too low for successful operation.
15	do		.12½			7	Do.
16	do		.15			5	Condensation loss, 5 per cent.
17	do		.17		5 per cent.	10	Radiation mostly direct. Heat should be automatically regulated.
18	Iowa		.18		$300	7	Mains should not extend too far from plant.
19	do		.20		$100	6	
20	do		.15			5	Profitable when exhaust steam is used for heating.
21	do	10,000,000		.50	$359	15	Radiation mostly direct.
22	Michigan	2,389,900			$150	3	
23	Minnesota			.60	$6	8	Radiation direct and indirect. Condensation loss, 6 per cent.
24	Missouri	3,771,515				5	
25	do	3,634,365			$25	4	
26	do	5,391,295		.56	0	7	Radiation direct and indirect. Condensation loss 1 per cent.
27	do	1,650,000			0	15	
28	do	2,204,612	.25		0	10	Mains should not extend too far from plant.
29	Montana	7,777,000	.60		Very small.	7	88,000,000 pounds steam sold per year.
30	New York			.50		25	Over one-half of the steam is sold for power purposes.
31	do	100,000,000		.50			
32	do	15,500,000			Small.	10	Profitable when exhaust steam is used.
33	do	10,000,000		.42½	$175	28	Condensation loss, 3 to 6 per cent. Radiation both direct and indirect.

a Steam. b Hot water.

TABLE 57.—*Details of operation of central heating plants*—Continued.

No.	Location of plant.	Space in buildings (cubic feet).	Average price of heating.		Average cost per year for repairs on mains, tunnels, and insulation.	Years in operation.	Remarks.
			Per square foot.	Per 1,000 pounds of water.			
34	New York	7,000,000			3 per cent.	10	Condensation loss, 5 to 12 per cent. Radiation both direct and indirect. Business rate 4; residence rate $4.50 per 1,000 cubic feet of contents.
35	.....do			$0.48	Very small.	6	
36	North Dakota	5,000,000		.60	0	7	Condensation loss, 5 per cent on heavy load, to 50 per cent on light load.
37	.....do			.40		6	Profitable when exhaust steam is used.
38	Ohio		$0.15		0	3	
39	.....do		.15		Very small.	5	Natural gas 9 cents per 1,000 cubic feet.
40	.....do		.20		$300	7	
41	.....do	1,200,000	.17½		0	4	
42	.....do	10,000,000		.50	0	7	
43	Pennsylvania	26,000,000			$2,000	10	$4.50 per 1,000 cubic feet of contents; should have larger mains.
44	.....do	10,000,000			$0.41 per 1,000 cubic feet of space heated.	19	$4.43 per 1,000 cubic feet of contents; steam should be metered.
45	.....do	9,129,251			$300	14	Radiation should be direct and steam should be metered. Present price of heating based on cubic contents.
46	.....do	3,360,000	.25		$250	5	
47	.....do	9,000,000			$702	9	Radiation both direct and indirect. Profitable when exhaust steam is used for heating.
48	.....do				$500	20	$5.45 per 1,000 cubic feet of contents.
49	.....do					20	$4.50 per 1,000 cubic feet of contents. Insulation could be improved. Should run with higher steam pressure at plant.
50	.....do			.40	0	5	Condensation loss, 9 per cent. Profitable when steam is sold at 60 cents per 1,000 pounds.
51	.....do	5,000,000			$700	19	Radiation about 5 per cent. $5 per 1,000 cubic feet of contents.
52	.....do	5,093,161			$500	14	$6 per 1,000 cubic feet of contents. Radiation should be direct and service should be metered.
53	.....do		.34		$100	10	
54	.....do		.33⅓			24	Very little indirect radiation. Mains should not extend too far from plant.
55	Rhode Island			.66		6	Condensation loss, 4 to 15 per cent.
56	Wisconsin		.25			6	Profitable when exhaust steam is used.
57	.....do		.20			8	Insulation could be improved. Mains should not extend too far from plant. Profitable when exhaust steam is used.

Of the 57 plants included in Table 57 only 12 were operating for the express purpose of central heating. The remaining 45 were supplying either light and heat, power and heat, or power, light, and heat. Steam heat is furnished by 38 plants, hot water by 17, and a combination of steam and hot water by 2. The plants which have been installed in the last five or six years show about an equal proportion of steam and hot-water heating. The plants range in size from 300 to 16,000 horsepower; only 25 per cent are of 600 horsepower or less. Sixteen of the plants have mechanical stokers. The price of coal ranges from $4.60 per short ton in Montana to 90 cents in Illinois, the average cost from all the plants being $2.05 per short ton. Both direct and indirect radiation are used, but by far the greater proportion is direct. The greatest distance to which heat is sent from the station varies considerably, but a reasonable distance seems to be about 4,000 to 5,000 feet.

Payment for the use of steam is made in two ways—(1) at a flat rate, based on square feet of radiating surface installed or on 1,000 cubic feet of contents heated, or (2) at a meter rate, based on 1,000 pounds of condensed steam. The price paid per square foot of radiating surface averaged 33⅓ cents, and varied from 22½ to 65 cents. The plants selling on a basis of 1,000 cubic feet of contents charged an average of $4.46, the price varying from $2 to $6. On the basis of 1,000 pounds of condensed steam the payments averaged 50½ cents, ranging from 40 to 66 cents. One plant that sold heat on this basis for 40 cents intimated that such a rate was not profitable.

The hot-water plants sold heat only on the basis of square feet of radiating surface installed, the average rate being 17½ cents and the range from 12½ to 25 cents per square foot. Two plants, one selling at 12½ and the other at 15½ cents, claimed that their prices were too low for successful operation.

A comparison of the prices charged by central stations, as given in Table 57, with the cost of fuel only for a house-heating boiler, as published in Bulletin 366,[a] shows that in many cases the cost of producing heat on the premises equals the price charged by the central station. When heat is purchased the customer avoids the annoyance of having to supervise the operation of the heating plant, as well as the dust resulting from the delivery of fuel and the removal of ashes. Some allowance should also be made for the space that would be occupied by the heater and for the expense necessary to install and keep a boiler in repair.

The following suggestions have been made by the managers of the plants and are worthy of consideration:

Heat from a central plant should be, as largely as possible, a secondary product.

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[a] Randall, D. T., Tests of coal and briquets as fuel for house-heating boilers: Bull. U. S. Geol. Survey No. 366, 1908, p. 39.

Heating mains should be concentrated and should not extend too far from the station.

Direct radiation should be installed.

Mains should be of sufficient size to avoid the necessity of high pressure at the station.

Heat should be under automatic control.

The flat rate is not a successful basis for payment; the service should be metered.

GENERAL CONCLUSIONS ON SMOKE ABATEMENT.

Some general conclusions from the facts set forth in this volume are as follows:

The flame and the distilled gases should not be allowed to come into contact with the boiler surfaces until combustion is complete.

Fire-brick furnaces of sufficient length and a continuous or nearly continuous supply of coal and air to the fire make it possible to burn most coals efficiently and without smoke.

Coals containing a large percentage of tar and heavy hydrocarbons are difficult to burn without smoke and require special furnaces and more than ordinary care in firing.

Briquets are suitable for use under power-plant conditions when burned in a reasonably good furnace at the temperatures at which such furnaces are usually operated. In such furnaces briquets generally give better results than the same coal burned raw.

In ordinary boiler furnaces only coals high in fixed carbon can be burned without smoke, except by expert firemen using more than ordinary care in firing.

Combinations of boiler-room equipment suitable for nearly all power-plant conditions can be selected, and can be operated without objectionable smoke when reasonable care is exercised.

Of the existing plants some can be remodeled to advantage. Others can not, but must continue to burn coals high in fixed carbon or to burn other coals with inefficient results, accompanied by more or less annoyance from smoke. In these cases a new, well-designed plant is the only solution of the difficulty.

Large plants are for obvious reasons usually operated more economically than small ones, and the increasing growth of central plants offers a solution of the problem of procuring heat and power at a reasonable price and without annoyance from smoke.

The increasing use of coke from by-product coke plants in sections where soft coal was previously used, the use of gas for domestic purposes, and the purchase of heat from a central plant in business and residence sections all have their influence in making possible a clean and comfortable city.

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A classified list of Survey papers dealing with coal is given in Bulletin 316, and in an abstract from that bulletin, pp. 439 to 532, published separately.

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

BULLETIN 261. Preliminary report on the operations of the coal-testing plant of the United States Geological Survey at the Louisiana Purchase Exposition, in St. Louis, Mo., 1904; E. W. Parker, J. A. Holmes, M. R. Campbell, committee in charge. 1905. 172 pp. 10 cents.

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BULLETIN 334. The burning of coal without smoke in boiler plants; a preliminary report, by D. T. Randall. 1908. 26 pp. 5 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 339. The purchase of coal under government and commercial specifications on the basis of its heating value, with analyses of coal delivered under government contracts, by D. T. Randall. 1908. 27 pp. 5 cents.

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

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

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

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

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The following references supplement the list of books and papers given in Bulletin 334.

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KRAUSE, JOHN W., Smoke prevention: Proc. Eng. Soc. Western Pennsylvania, March, 1908, pp. 101–120. Reviews progress in smoke prevention in several cities, particularly Cleveland, Ohio; discusses causes of smoke and methods of abatement.

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Smoke Prevention in Newark, N. J.: Eng. Record, January 18, 1908, pp. 72–73. Gives new city ordinance against dense smoke and describes an automatic steam-jet device for preventing smoke.

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