RATING OF
DOMESTIC SAWDUST BURNERS

by

EARL C. WILLEY

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APPROVED:

[redacted]

Professor of Mechanical Engineering
In Charge of Major

[redacted]

Head of Department of Mechanical Engineering

[redacted]

Chairman of School Graduate Committee

[redacted]

Chairman of State College Graduate Council

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RATING OF DOMESTIC SAWDUST BURNERS

The burning of waste wood in the form of sawdust is relatively new to the heating industry. Although crudely constructed equipment, mostly homemade, has been used for ten or fifteen years, it has been during only the past five years that any attempt has been made to perfect small domestic equipment to the point where it is commercially acceptable to the general public.

The first attempts at constructing equipment for burning sawdust resulted in devices which gave trouble in the form of excessive smoking, backfiring, and creosoting. These were serious enough to discourage most anyone from using them even though the fuel was the cheapest on the market. It was because of investigation into the causes of these burner troubles that the writer discovered the importance of finding some standard method of rating them for output capacity.

The fact that so many of the installed burners were much larger than necessary for the job gave a clue toward solving some of the troubles encountered.

An investigation disclosed the fact that most manufacturers of sawdust burners knew little about the rating of their own product, were financially unable to make an investigation, or were not interested in so doing.

Source of Fuel Supply

Waste wood fuel is of two general types, "sawdust" which, as the name implies, is a by-product of the saw from the lumber mills, and "hogged fuel," also a by-product which is a much larger, coarser refuse. The hogged fuel is obtained by putting the slabs and larger waste pieces of wood into a machine having large rotating knives which cut it into small pieces averaging one-half to an inch in diameter. This machine is called a "hog" and hence the name "hogged fuel." The coarser fuel is used mostly in large industrial plants while the small domestic heating apparatus uses the finer sawdust. In sawmills having planers, the planer shavings are also included in the hogged fuel.

Naturally the source of supply is at the location of our largest wooded areas, which happen to be the northwest and extreme northeast portions of the United States. Oregon and Washington have the largest stand of timber of any of the states and are, therefore, the location of most interest in sawdust-burning equipment.

The nearest estimate to the availability of waste wood fuel sources in Oregon may be gotten by a study of

Table 1--Lumber Production in Oregon (1935)

By Species

Softwoods	M Board Feet (M=1000 Feet)
Douglas Fir	1,855,141
West Coast Hemlock	64,204
Cedar	52,451
Spruce	72,504
White Fir	13,076
Sugar Pine	31,599
Ponderosa Pine	1,028,258
White Pine	6,871
Larch	1,456
Lodgepole Pine	--°°
Hardwoods	
Ash	--°°
Cottonwood	5,752
Maple	3,190
Oak	--°°
Alder	--°°
All Other	10,735
Total	3,145,237

By Areas

Softwoods	Million Feet Board Measure
East Side	1,036
West Side	2,089
Hardwoods	
West Side	20
Total	3,145

°°Less than 50,000 feet.

a report compiled by the West Coast Lumbermen's Association from reports of the United States Forest Service which is shown in Table 1.

This report represents a typical average cutting extending over a number of years. According to authorities with practical experience in handling large sawmill waste, it is estimated that sixty per cent of the refuse is used to generate power in the mill. The other forty per cent has been disposed of by burning it in large retorts.

The average sawmill will produce as a by-product one unit of hogged fuel for every thousand board feet of lumber sawed. (A unit of hogged fuel or sawdust is two hundred cubic feet.) This being the case and using the preceding report as a basis for estimate, there would be available in Oregon enough refuse fuel to heat 414,000 homes of average size east of the Cascade Mountain Range and 840,000 homes on the coast side of the mountains.

Heat Value of Sawdust Fuels

The heating value of wood as sold varies greatly. This may be accounted for first by the physical structure and content of resins, gums, oils, etc. and then because of the moisture content. Because of the heat required to evaporate and superheat the moisture, there is a very marked decrease in the heat available when wet fuel is burned. Therefore, an increase in the amount of moisture in a pound of fuel causes a corresponding decrease in the heating value per pound of the fuel.

It is customary to refer to the amount of moisture in wood fuel as a percentage of either the oven dry weight or the green or original weight. The wood technicians or dry kiln operators use the first method, while the second method, basing calculations on the green weight, is often used by fuel technicians.

The latest available data on Pacific Northwest sawdust heat values is given in a report from the Forest Department of the Canada Department of Interior laboratory at Vancouver, B. C., as follows:

Douglas Fir	9200	Btu/lb of oven-dried fuel
Western Hemlock . . .	8500	" " " " " "
Sitka Spruce	8100	" " " " " "
°°Western Red Cedar . .	9700	" " " " " "
Western Yellow Pine .	9100	" " " " " "

The above report shows average heat values dry. These values were comparable to those obtained in tests to be discussed later, which were made in the Oregon State College Domestic Heating Research Laboratory. These tests made by the calorimeter bomb method on Douglas fir sawdust showed an average dry value of 9,070 Btu per pound.

°°Although the calorific value per pound of oven-dried wood is high for Western Red Cedar, the low weight of this wood materially reduces its available heat per unit.

Average moisture contents of fir sawdust run around 42%. An average unit of fuel at this moisture content will weigh 3700 pounds which makes available about 17 million Btu. However, the average installation using 50% excess air and 500 F stack temperature will leave about 13 million Btu available for useful heat.

From various field tests and laboratory data the following table has been prepared, based on an assumed

Table 2--Gross Heat Values of Sawdust by Units

Species	Moisture Content, %		Wt of Unit	Available Heat Btu	
	A	B	lb	Per lb	Per Unit
Douglas Fir	68	42	3750	4550	17,040,000
Hemlock	105	51	4300	3440	14,800,000
Yellow Pine	84	45.3	4050	3268	13,200,000
Red Cedar	77	44	2700	4930	13,320,000
Sitka Spruce	92	48	3320	3605	11,970,000

stack temperature of 500 F. In column "A" of the table the percentage is based on oven-dry weight, and in column "B" it is based on the original weight.

The gas analysis on field tests often shows from 16 to 18 per cent carbon dioxide in the flue gas compared to 21 per cent possible under perfect conditions.

The greatest efficiency is generally found in large commercial plants where trained attendants, using instruments, keep constant watch over the equipment twenty-four hours a day. As high as 65 per cent efficiency is sometimes attained under these conditions where the small domestic units will do well to get from 25 to 40 per cent.

Types of Burners

There is not a great difference among the various makes of sawdust burners on the market today. This is not only true of the domestic type but also the large commercial type burners.

In general, the burners consist of a combustion chamber, sometimes called a Dutch oven, in which are contained grates and refractory brick lining. On the top of the oven is an opening on which is placed a hopper into which the sawdust is fed. On the large commercial burners this opening is connected with a chute into which a sawdust conveyor discharges.

A typical domestic type burner is illustrated in section in Figure 1. Note that the grates are removable and adjustable. This feature is true of most burners. The top and sides of the oven are protected by refractory brick linings. In some cases there is provided space between the brick lining and the outer iron body through which auxiliary air is passed in order to keep an excessive amount of heat from escaping from the oven.

Most sawdust burners are built as individual units separate from the furnace and are intended to be placed in front of and connected with the furnace. In most cases

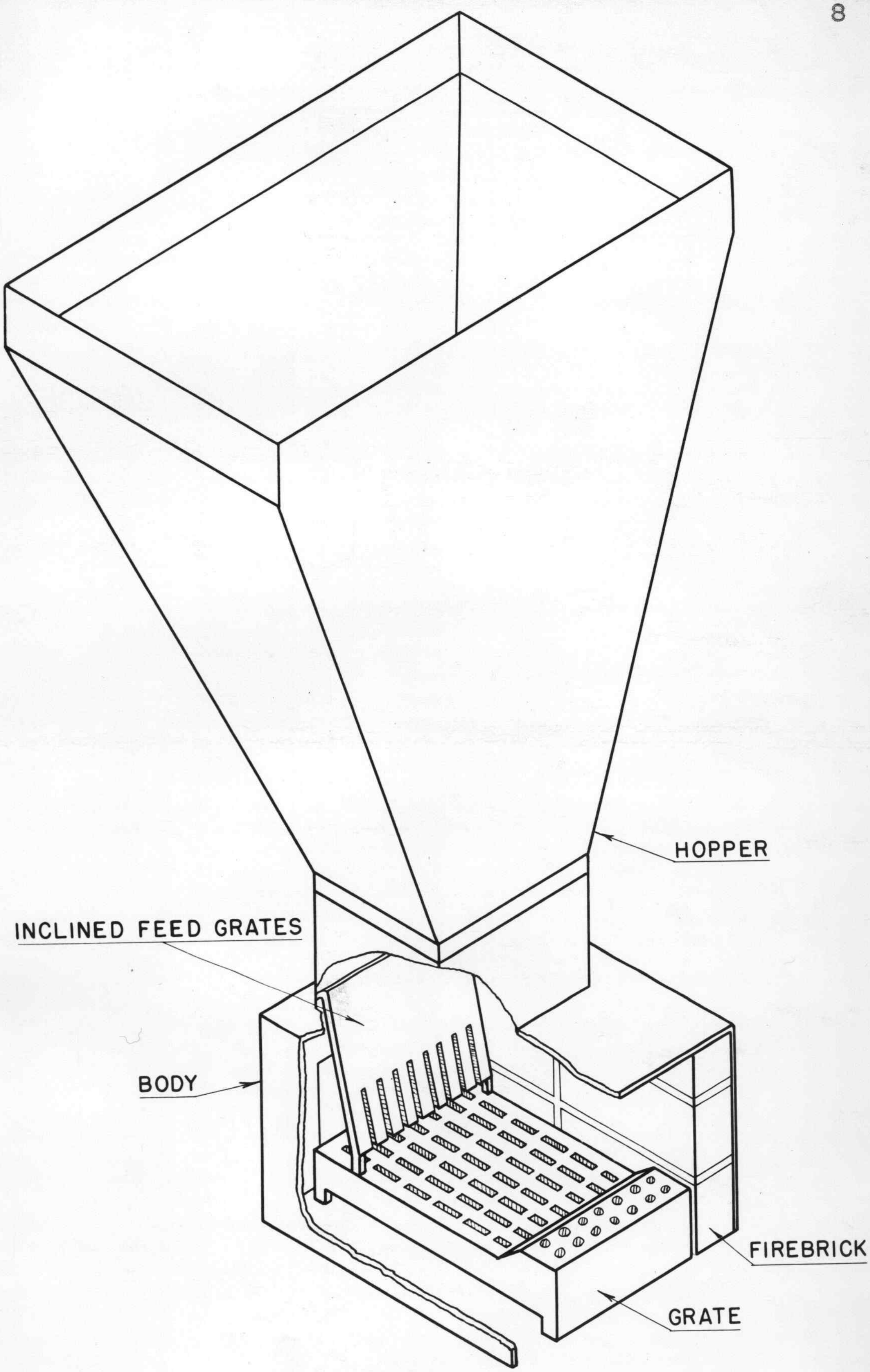

FIG. I

they are attached to the ash pit door after removing the coal or wood grates and relining the furnace with fire-brick. The firebrick of the furnace is connected with the firebrick of the sawdust burner so that there is a continuous sealed fire passage from the burner to the combustion chamber of the furnace.

Contrary to an apparent misconception of the majority of laymen, the sawdust burner is applicable to most any type of furnace using solid or oil fuels. The only problem is that of making suitable connection between the burner and the combustion chamber of the furnace. Figure 6 shows a burner connected to a gravity hot air system. A forced hot air system would look similar to this. In Figure 7 is shown a connection made to a boiler of the steam or water type.

In the case of the small domestic water heater it is customary to build the burner and heater in one unit. Figures 8 and 9 show two typical water heaters. These units are built ready to make chimney and water connections. The burner is essentially the same as the larger type burners. It is not unusual to see the larger sizes of these water heaters used to furnish hot water radiator heat for small homes.

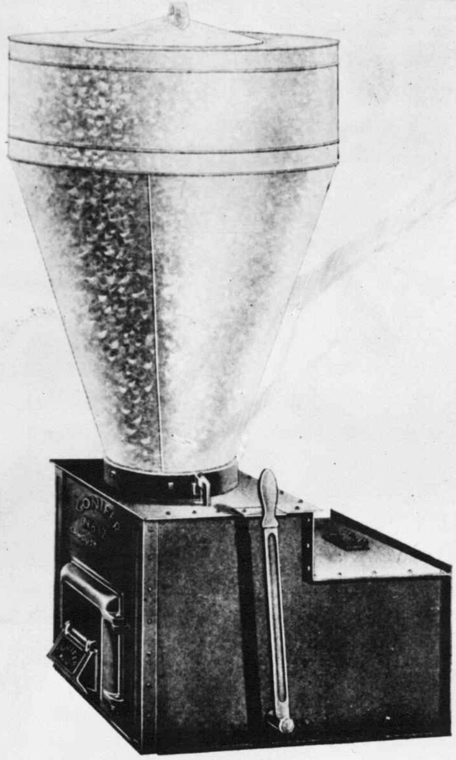

FIG. 2

FIG. 3

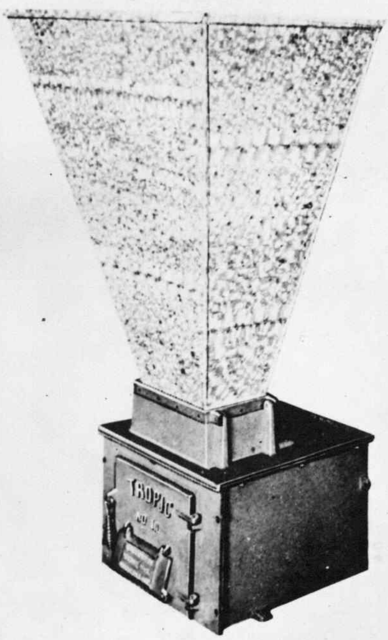

FIG. 4

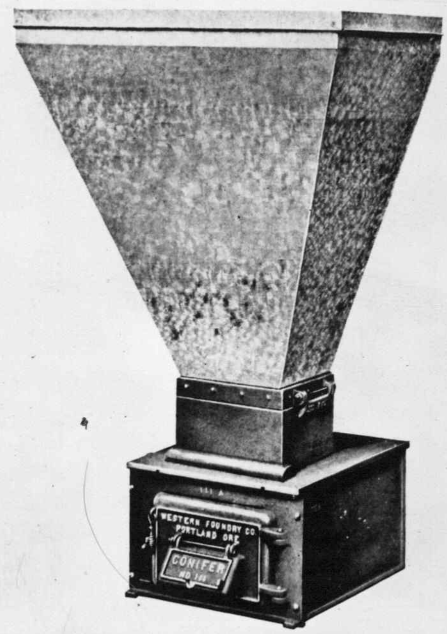

FIG. 5

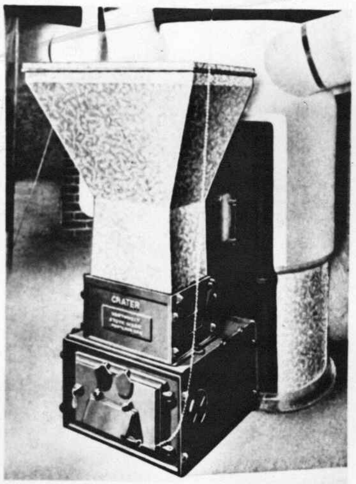

FIG. 6

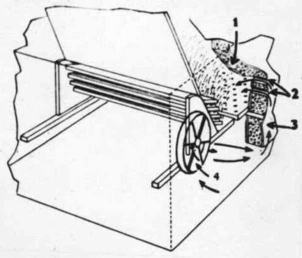

FIG. 6 A

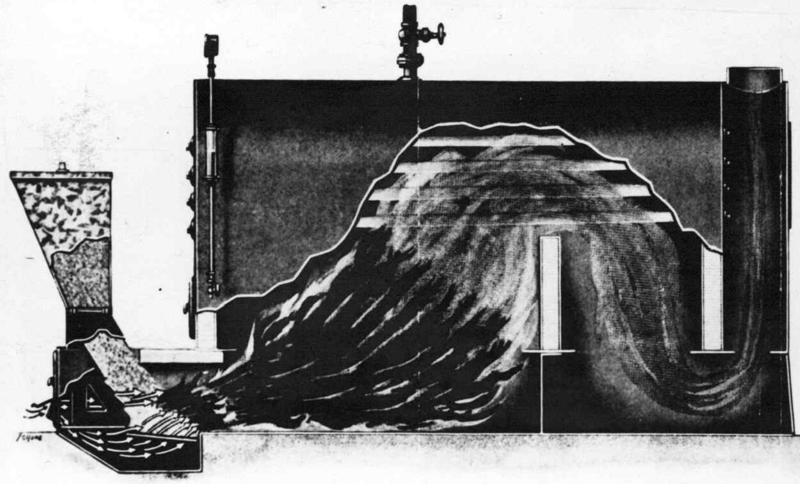

FIG. 7

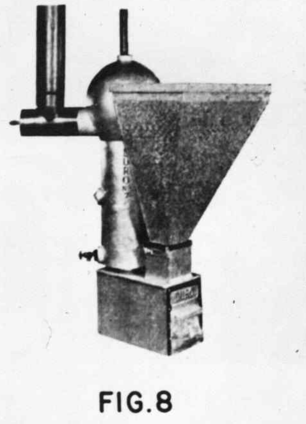

FIG. 8

FIG. 9

Differences in Design

Although there is a striking similarity in the general design of sawdust burners, the differences are mainly in shapes of grates, shapes of hoppers, and methods of introducing secondary air to the fuel bed.

Figures 4 and 5 show two popular makes of burners which one might mistake for any of a dozen other makes on the market. In Figure 2 is shown the outer view and Figure 3 shows the inner cutaway view of a burner having a round hopper and also a movable shaker grate.

There has been considerable experimenting, mostly by the cut and try method, to find the proper shape of hopper for best feeding of the sawdust. The steepness of the side angles has been pretty well agreed upon, but there is still experimental work being done with devices to place on the inside of the hopper to alleviate the packing of the fuel. The cutaway illustration in Figure 3 shows one method of attacking this problem.

Not only is the shape of the hopper important but the shape and size of the throat are of great importance to the proper feeding of fuel to the fire grates. The inclined feed grates in the throat of the burner are probably the most important contribution to efficient operation. One type of feed grate is pictured and marked in Figure 1. Also several different types of feed grates are shown in Figures 10, 11, and 12. In each case illustrated there is possibility of movement or adjustment of these grates. Although the feed grate shown in Figure 12 is one which is made stationary, there are similar grates which have the steps adjustable in order to accelerate or decelerate the fuel feed. As a further check or control of the fuel feed, one manufacturer has provided a cast iron apron (see Figure 11) which controls the forward movement of the fuel on the main grate. This apron can be adjusted to any conditions of fuel or stack draft.

The main grates are of two general types, the stationary or one-piece type and the movable or shaker type. Figures 10, 11, and 12 show the one-piece type, while in Figure 3 is pictured the movable shaker type similar to the old coal type grates. In Figure 10 the main grate shows a raised portion at the front end. It is the purpose of this to form a barrier to prevent the sawdust from covering the entire grate. An exposed air opening to admit air for combustion at low firing rates is thus obtained. It is the accidental covering of these air holes during the inrush of fresh fuel over a bed of hot coals which results in the cutting off of all air supply. This often results in an explosion when the accumulated gas is finally ignited.

The primary air supply is supplied to all burners alike, i.e., through the front draft door. The secondary

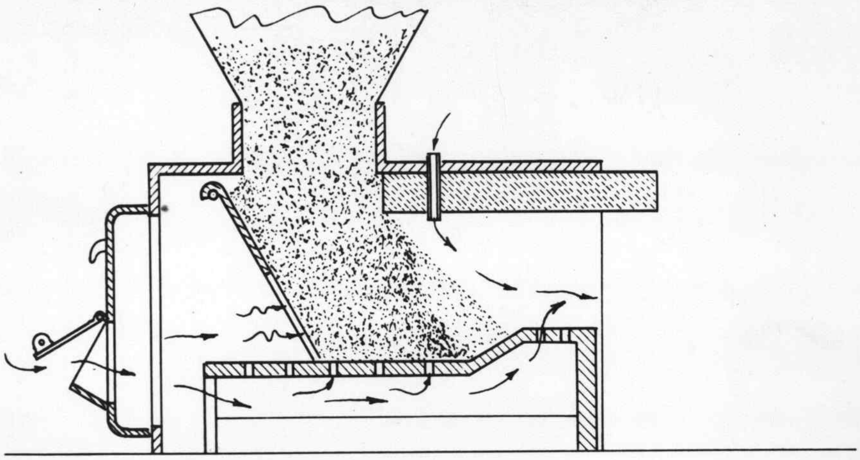

FIG.10

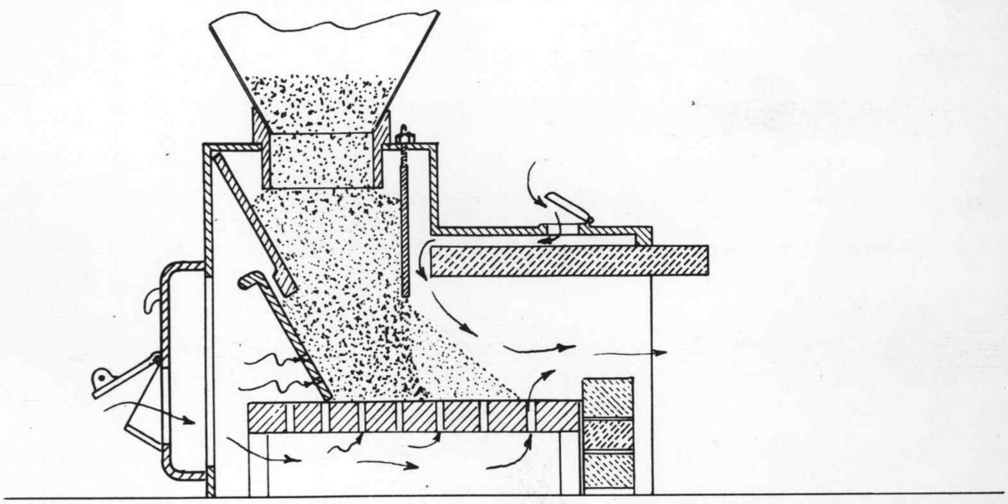

FIG.11

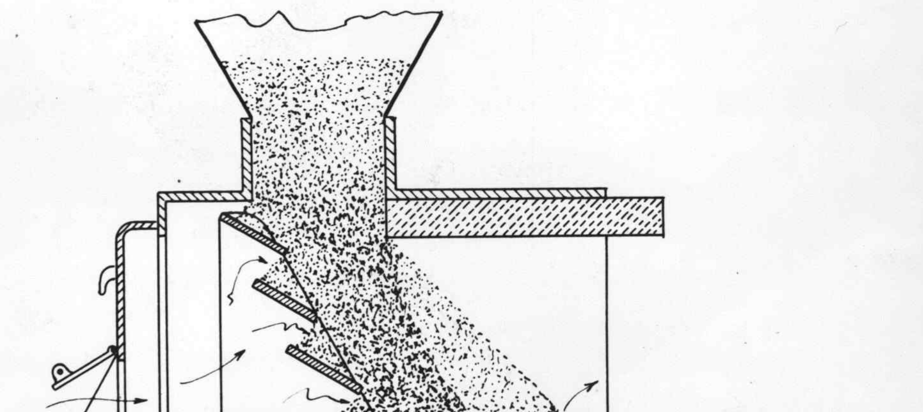

FIG.12

air is brought in by methods as numerous as there are makes of burners. Figure 10 shows one method used. In this burner a short pipe just over the fuel bed is always open for auxiliary air regardless of shutting off the main supply at the draft door. The method used in Figure 2 is similar although it does have an adjustment. Although the auxiliary air intake is not shown in Figure 12, the same burner has its auxiliary air intake pictured in Figure 6A. In this case the auxiliary air is taken in through the side wall and is controlled by an adjustable dial.

Common Burner Troubles

In the first part of this paper mention was made of troubles in the early makes of sawdust burners. It might be said that these same troubles appear now and then in the later models, and as there is a definite connection between them and the oversize burners, it is appropriate to discuss these in connection with the rating of burners.

According to the writer's judgment, these troubles in order of their seriousness should be classified as follows:

1. Backfiring and smoking
2. Burning back into the hopper
3. Creosoting in the smoke connection

4. Overheating

5. Underheating

Already mention has been made of the action which takes place and causes backfiring. It may be due to faulty adjustment of the grates or feed throat. At least when the new sawdust covers the burning incandescent fuel, there is not enough draft to pull air through the fuel bed to support combustion or there is not sufficient auxiliary air supply. A good many times this phenomenon occurs when the burner has been closed for long periods. In this case the chimney cools and the draft is reduced. The fuel bed having had insufficient draft effect there is not enough movement of the fuel to cause the new sawdust to feed from above properly. When the main body of sawdust finally feeds down, it does so with a rush and completely covers the incandescent fuel bed.

Condition of the fuel sometimes is a cause for this occurrence. Light dry shavings or old stored and dry sawdust are likely to do this because they are so light that they have a tendency to arch and pack. For this reason the new green sawdust will feed much better.

When a burner which is too large for the house is installed, it will be shut off and allowed to smoulder too much of the time. If the burner is smaller, it is possible for it to burn with a small movement on the off periods without overheating the house, thus giving the fuel bed a chance to move more regularly.

The same condition applies to the second-named trouble. If there could be more periodic movement of the fuel bed, there would be less tendency to burn back into the hopper. However, the condition of the fuel is sometimes a greater factor in causing this trouble. Another cause of poor feeding is insufficient fuel in the hopper. When there is not enough weight to force the fuel down on the grates, the burned ash will arch and cause burning into the upper portions of the hopper.

Creosoting is caused by the condensing of vapors from the smoke-laden gases. Types and conditions of sawdust fuel determine largely the degree of creosoting. Green woods having a large oil and resin content will of course give off more creosote in the condensation process. When air to the burner is shut off and very little combustion is taking place, there is not enough heat passing up the smoke connection to keep the chimney warm, and certain constituents of the smoke-laden gases will then condense on the cold sides of the pipe. There should be enough combustion taking place to keep the chimney warm without causing too much heat being supplied to the house.

Overheating, i.e., uncontrolled heat, is generally caused by leakage of air through draft openings. This can be governed by proper controls on the smoke connection and proper fitting of the front draft door. Again, if the burner is too large, it is very difficult to cut down the combustion rate sufficiently to prevent the excessive heating of the house.

Underheating is a rare thing with sawdust burners. If anything, it is generally caused by poor draft conditions of the chimney. The writer has yet to see a burner installed which was too small for the house.

Rating the Burners

In 1928 the writer started an investigation to determine, if possible, some basis for the rating of sawdust burners. At that time there was no record of any research or investigation made by any of the sawdust burner manufacturers themselves nor has any appeared up to the present.

As a beginning, a letter was sent to every known sawdust burner manufacturer in the Northwest, asking for a list of their burner sizes and output ratings for each size. In the returns from this questionnaire, only one manufacturer answered with any tangible material. This manufacturer submitted an estimate sheet showing sizes of burners and estimated outputs. This material was to be used by their field dealers who made the installations. Burners from 1.56 square feet to 26.05 square feet in area were listed. Following is the information from the data sheet in condensed form. As the burners with grate sizes larger than 8 square feet of area would logically be classed as commercial sizes, they have been left out of this table. Btu ratings for the following were calculated on the basis of 240 Btu per square foot of steam radiation. The data have also been rearranged in order that comparisons can be made later with information gathered in the research laboratory.

Table 3--Commercial Burner Output Rating

Grate Width inches	Grate Area square feet	Capacity square feet steam rad.	Total Output Btu/hour	Output per sq ft grate Btu/hour
10-3/4	1.56	675	162,000	104,000
11	1.8	810	194,000	107,000
12	2.08	1080	259,000	124,500
16	3.44	1620	389,000	113,000
18	4.2	2160	518,000	123,500
21	5.1	2700	648,000	127,000
28	8.17	4050	972,000	119,000

In a conference with the engineers who furnished the above manufacturer's data, the statement was made that it was not based on laboratory research but on information taken from field installations. They were all agreed that the estimates were low and allowed a high safety factor for the installing dealers.

Although there were no estimates on heating value of fuels or stack draft conditions, it is presumed that the high safety factor would allow for the poorest conditions of either.

The main conclusion that can be drawn from an analysis of these data is that the average output of the burners would be about 117,000 Btu per hour per square foot of grate area.

It was interesting to note from the same estimate sheet that the capacity per square foot increases quite perceptibly in the larger sized grates. Ratings for the four larger sizes of burners, taken from the same estimate sheet and not included in the above, showed,

13.36	sq	ft	grate,	estimated	136,000	Btu/hr/sq	ft	grate			
16.28	"	"	"	"	159,000	"	"	"	"	"	
20.47	"	"	"	"	158,000	"	"	"	"	"	
26.05	"	"	"	"	233,000	"	"	"	"	"	.

These higher ratings are to a great extent due to the fact that the larger commercial size burners are given constant personal attention.

<u>Rating Tests</u>

During the winter of 1938 a series of tests was made on sawdust burners with the object of arriving at some method of rating them. These tests were made in the Domestic Heating Research Laboratory of the Mechanical Engineering Department at Oregon State College. The writer supervised the test work and was assisted by A. P. Nicol and L. M. Klein, then both seniors in mechanical engineering.

Test Apparatus:

One 10-inch Monk sawdust burner and an assortment of grate sizes.

A vertical fire tube steam boiler. Boiler rated to deliver 143,500 Btu per hour at 100% rating with solid wood fuel. (See O. S. C. Engineering Experiment Station Reprint Series, No. 7, for further details.)

City water supply. Receiver barrel for water and platform scale for weighing. An electrically driven gear pump for water.

High velocity thermocouple connected to electrical pyrometer and an exhaust fan to furnish air movement.

One standard one-inch water draft gage.

One separating steam calorimeter and condenser.

Scales for weighing sawdust.

Apparatus for determining moisture content of sawdust and analyzing heating content.

Test Procedure:

Referring to flow diagram Figure 13, the burner was installed on the fire tube boiler and all boiler base cracks sealed against possible air leakage.

Water supply was taken from city water mains. It was first filled into the receiving barrel, weighed, and then pumped into the boiler by the electrically driven

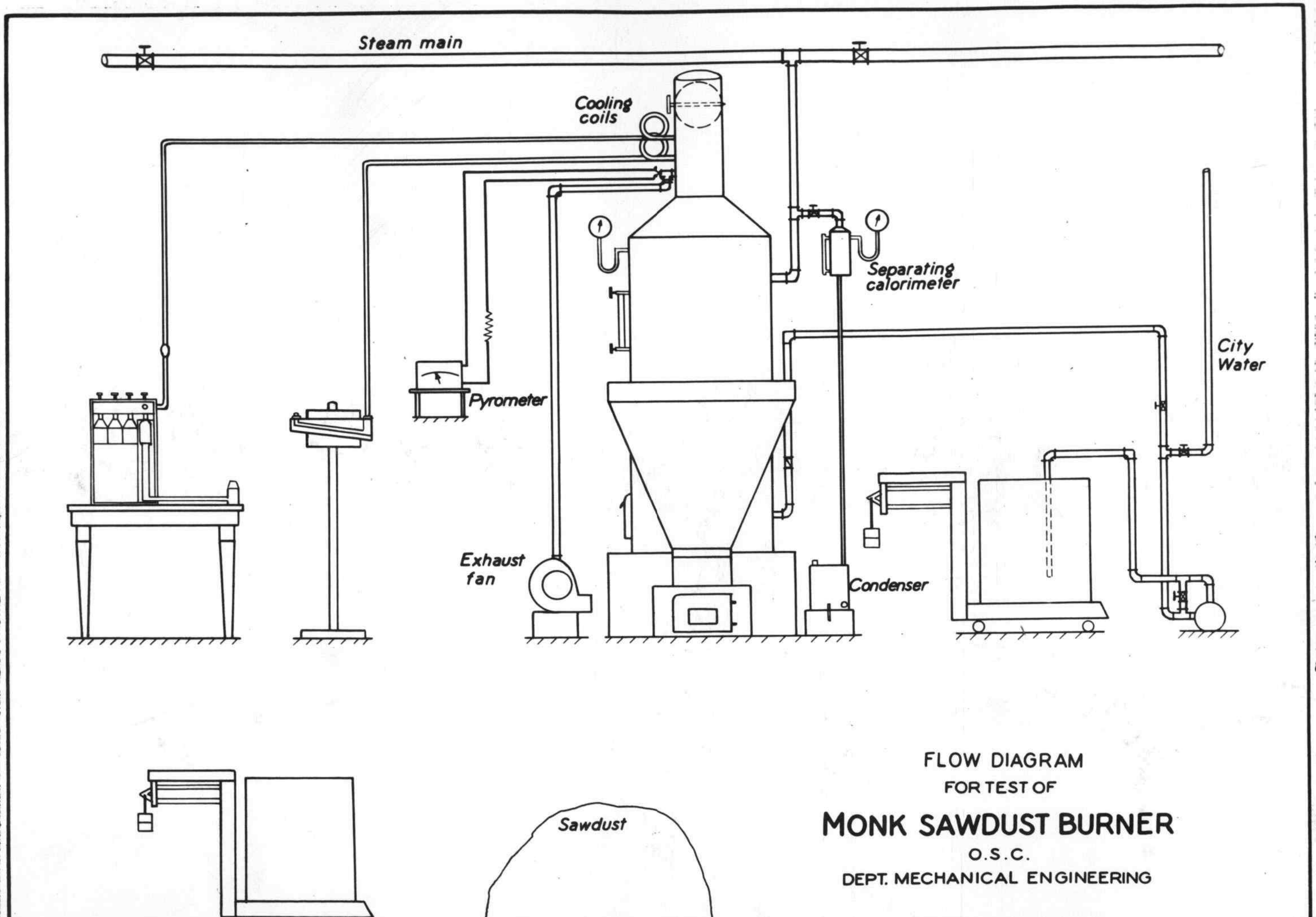
Steam main
Cooling coils
Separating calorimeter
Pyrometer
City Water
Exhaust fan
Condenser
Sawdust
FLOW DIAGRAM
FOR TEST OF
MONK SAWDUST BURNER
O.S.C.
DEPT. MECHANICAL ENGINEERING

Figure 13

gear pump.

Steam pressure was determined by a Bourdon gage which was checked for accuracy after each run.

Steam quality was determined by a steam separating calorimeter.

Stack temperature was determined by use of a high velocity thermocouple in conjunction with an electric pyrometer.

Stack pressures were measured with a standard one-inch water draft gage.

Flue gas was analyzed with an Ellison gas analyzer.

Fuel was weighed on a platform scale. In addition to the weighing of the fuel, a representative sample was taken at each run and analysis made of the moisture content. Also with each new batch of fuel a test of heat content was made with the calorimeter bomb.

During the tests, various kinds and conditions of sawdust were used. Douglas fir, red cedar, and hemlock mostly were used. Most of the sawdust was regular run (not resaw) and fresh from the mill. However, experiments were made using kiln dried sawdust as well as old sawdust that had become wet. One batch of sawdust (taken from under an old house) had been stored for six years. Heating value of all these fuels showed a very small degree of variation.

In preparation for each test, there was a warming-up period from one-half to two hours in duration.

Before the recorded tests were made, a large number of tests were conducted to study the characteristics of the burners. It was soon determined that the most important characteristics were, first, area of the grate; second, stack draft pressures; and, finally, the amount of opening available for the air supply.

Accordingly, the tests were based on these three functions. As the following data are taken from tests on the 10-inch burner, it will be noticed that the draft openings are recorded as 6.67 square inches, 12.37 square inches, and 80 square inches. The 80 square inch opening was obtained when the entire ash pit door was left open. This was, of course, the largest opening obtainable. The small draft door when wide open gave 12.37 square inches of draft area. When the small draft door opened 7/8 of an inch, it gave a draft area of 6.67 square inches. This last opening had no special significance only that it provided a point on a rating curve.

Included in the following pages are test data taken from twenty-four test runs as follows:

Tests No. 1-12 were made on burner having 117 sq in of grate surface.

Tests No. 13-18 were made using 43.5 sq in of grate.

Tests No. 19-24 were made using 70 sq in of grate.

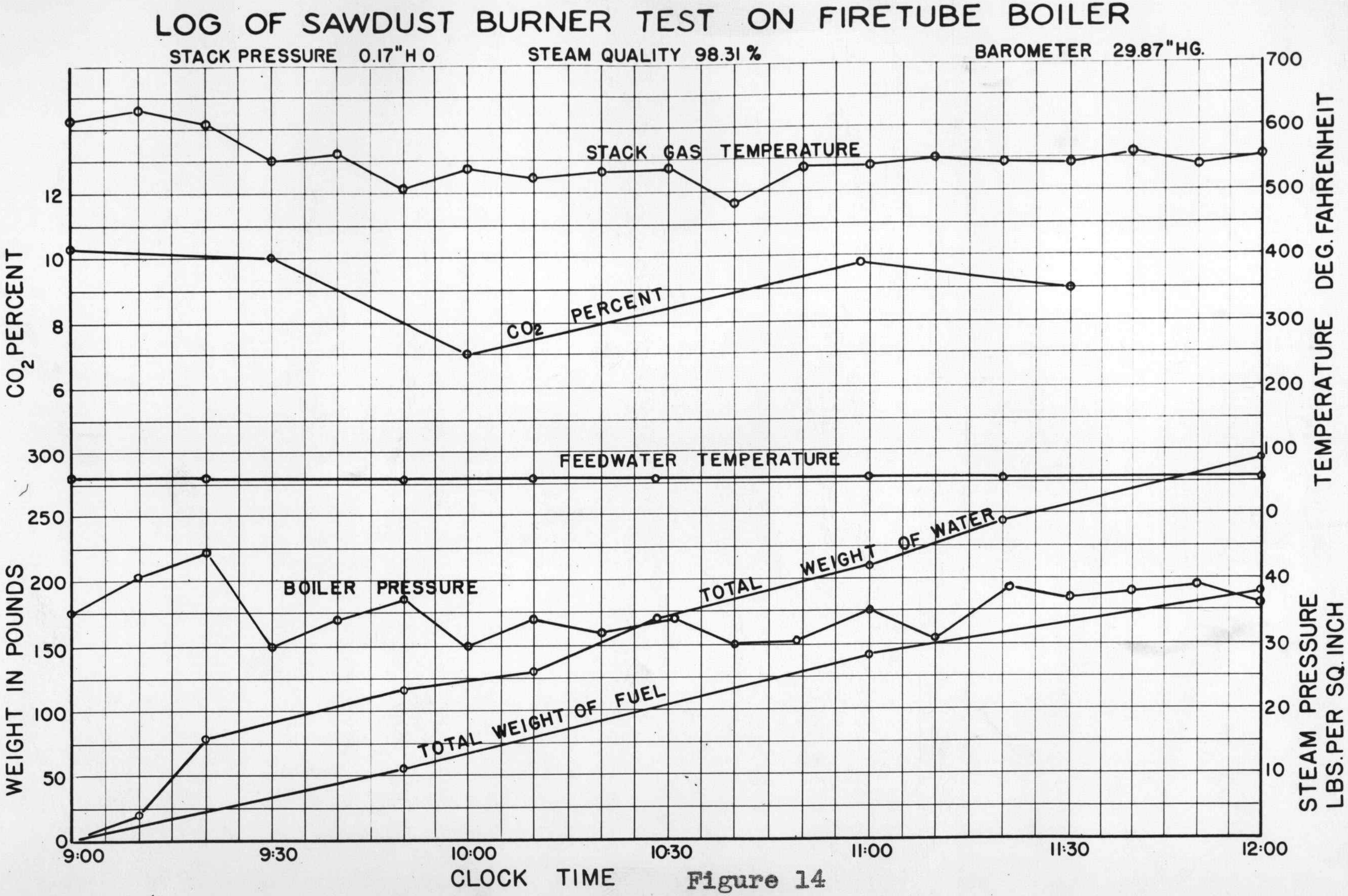
LOG OF SAWDUST BURNER TEST ON FIRETUBE BOILER
STACK PRESSURE 0.17" H O
STEAM QUALITY 98.31 %
BAROMETER 29.87" HG.
STACK GAS TEMPERATURE
CO2 PERCENT
FEEDWATER TEMPERATURE
BOILER PRESSURE
TOTAL WEIGHT OF WATER
TOTAL WEIGHT OF FUEL
CO2 PERCENT
WEIGHT IN POUNDS
TEMPERATURE DEG. FAHRENHEIT
STEAM PRESSURE LBS. PER SQ. INCH
CLOCK TIME
9:00
9:30
10:00
10:30
11:00
11:30
12:00

Figure 14

Tests made with low stack pressure (0.02" of water and under) were No. 6, 7, 8, 15, 21, and 22.

Tests with stack pressure averaging 0.05" of water were No. 4, 5, 9, 14, 18, 20, and 23.

Tests with stack pressure of 0.1" average were No. 10, 11, 12, 13, 16, 19, and 24.

Tests with stack pressure of greater than 0.1" were No. 1, 2, and 3.

Table 4, taken from laboratory test of No. 12 test run, is typical of information obtained from each of the twenty-four tests. Table 5 is a condensed tabulation of data taken from all tests made in the laboratory.

A Discussion of Test Results

Results of all the laboratory tests are shown in condensed form in Table 5. It is interesting to note that regardless of draft conditions, sizes of grates or draft openings, the efficiencies nearly all fell within a range of 30 and 50 per cent. The average efficiency was 40.6%. Also with the varied ages, moisture content, and kinds of sawdust fuel, there was an average heat content per pound as fired of 4790 Btu. The average output per square foot of grate area was 158,000 Btu per hour.

Analysis of test results also shows that the intensity of draft is a most important factor. This has been

Table 4--Typical Laboratory Test Data

Sawdust Burner Test — Test Run No. 12

Time	P_1 Steam	P_2 Stack	T_1	T_2	T_3	Steam Q %	Fuel Added	Water Added	CO_2 %	O_2 %	CO %
3:00	34	0.10	51	72	600				11.00	7.2	0
3:10	25	0.11	51	72	490			33			
3:20	30	0.09	52	72	445	98.58					
3:30	29	0.10	52	72	460			52	10.00	7.4	0
3:40	30	0.13	52	69	600			25			
3:50	32	0.11	52	68	600	99.14					
4:00	35	0.11	52	68	560			35			
4:10	30	0.13	52	68	575			27	10.4	7.0	0
4:20	31	0.11	53	68	530		59				
4:30	30	0.11	53	68	580	98.78		23	11.0	5.9	0
4:40	31	0.11	53	67	560			30			
4:50	29	0.10	53	68	570			20			
5:00	30	0.11		68	690		59				
Av. & Totals	30.3	0.109	52.2	69	574	98.83	118	245	10.7	6.8	0

P_1 = Steam Gage

P_2 = Stack Temp.

T_1 = Feedwater Temp.

T_2 = Room Temp.

T_3 = Stack Temp.

Bar. Pressure = 29.32" Hg

Sawdust used: Sample No. VI

Small draft door open 7/8"

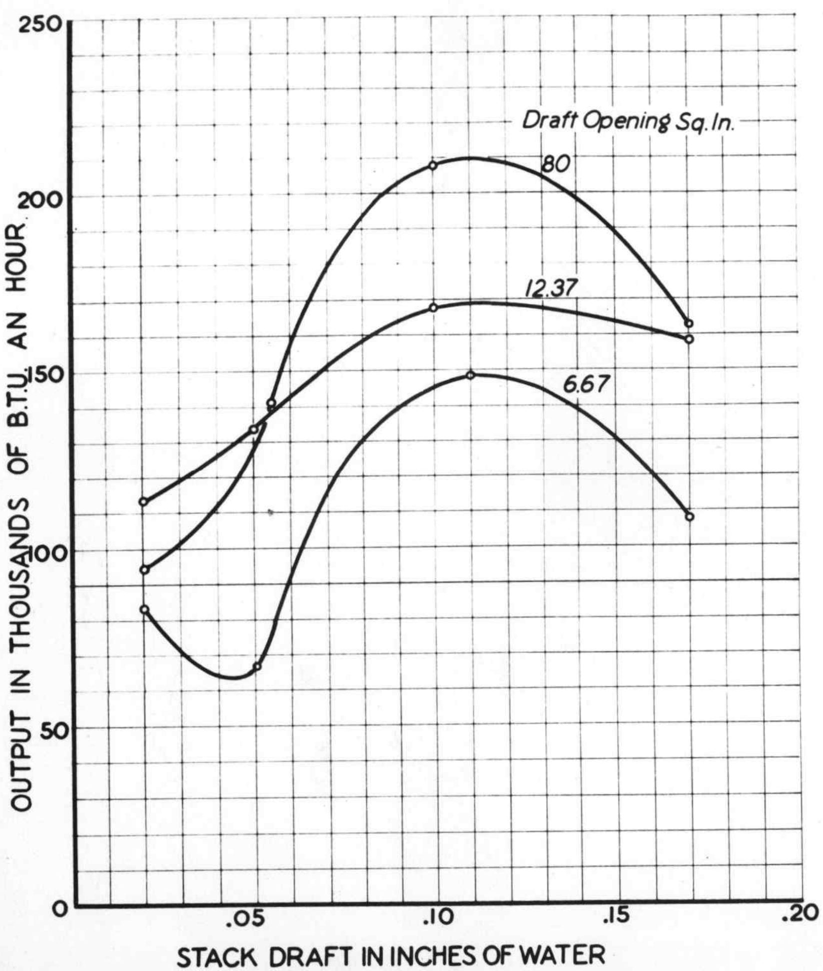

Figure 15

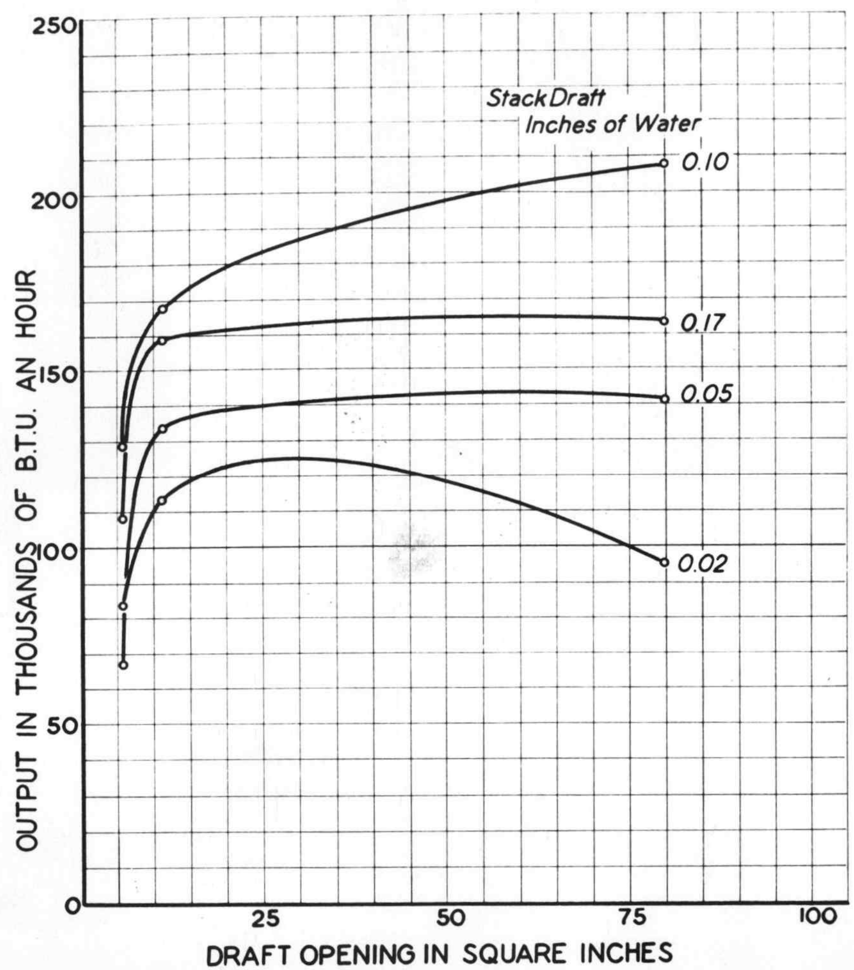

Figure 16

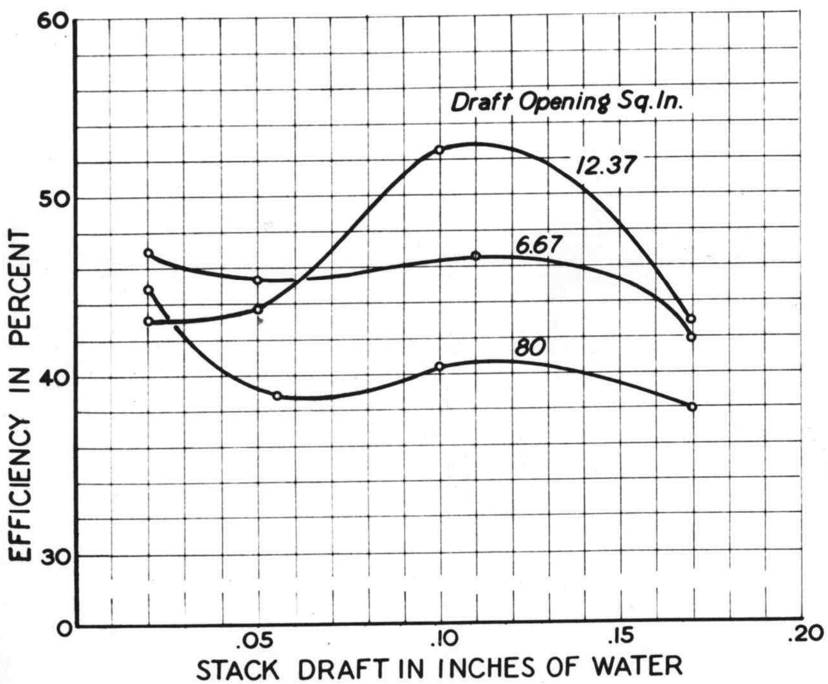

Figure 17

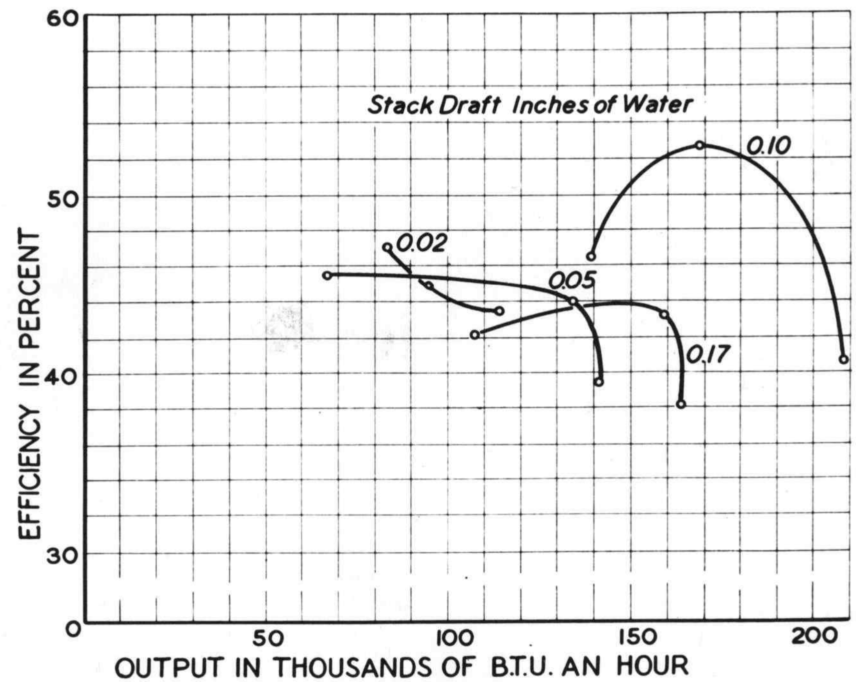

Figure 18

Table 5

SUMMARY OF TEST RESULTS

Run No	Stack press. in. of water	Fuel lbs. per hr. per sq. ft. grate	Heat per lb. fuel as fired	Moisture % by weight	Steam total lbs. per hour	Stack temp. °F	CO_2 %	O_2 %	Output Btu. per hr. per sq. ft. of grate	Total input Btu. per hour	Total output Btu. per hour	Overall eff. %
	GRATE AREA 117 SQ. INCHES								Draft opening 6.67 sq. in.			
7	0.02	44.3	4948	43.5	74.3	460	14.6	4.6	103 000	178 000	83 000	47.0
9	0.05	36.9	4915	41.8	60.0	500	6.8	10.7	82 500	147 000	67 000	45.5
12	0.11	72.6	5033	44.2	122.5	690	10.6	6.9	170 000	297 000	138 000	46.7
1	0.17	76.4	4166	53.3	96.7	549	9.0	11.4	133 000	258 000	108 000	42.1
									Draft opening 12.37 sq. in.			
6	0.02	65.3	4948	43.5	100.3	480	13.4	5.2	140 000	263 800	113 600	43.1
5	0.05	75.5	4980	44.4	117.8	522	14.9	4.1	164 000	305 500	133 700	43.8
10	0.10	80.0	4915	41.9	148.0	560	11.9	5.0	207 000	319 500	168 000	52.6
3	0.17	93.0	4890	47.7	140.0	628	11.2	8.6	196 000	369 000	159 000	43.1
									Draft opening 80 sq. in.			
8	0.02	52.9	4915	41.9	85.0	470	13.4	6.7	117 000	211 500	95 000	44.9
4	0.05	89.3	4980	44.4	124.3	508	14.5	4.7	174 000	362 200	141 000	39.0
11	0.10	128.6	4915	41.9	181.7	600	14.7	2.3	256 000	515 000	208 000	40.4
2	0.17	108.0	4890	48.7	143.7	644	13.3	5.8	200 000	429 000	163 100	38.1
	GRATE AREA 70.5 SQ. INCHES								Draft opening 12.37 sq. in.			
19	0.08	81.6	4560	47.4	65.0	350	7.9	12.2	150 000	182 000	73 300	40.3
20	0.05	71.0	4560	47.4	51.4	390	8.2	11.9	117 000	158 500	57 300	36.2
21	0.02	58.2	4560	47.4	33.0	250	7.0	13.4	75 000	130 000	36 800	28.3
									Draft opening 44 sq. in.			
24	0.09	100.0	4560	47.4	90.0	380	9.8	10.1	206 000	223 000	101 000	45.0
23	0.05	75.5	4560	47.4	45.0	350	8.2	11.8	103 000	168 500	50 300	29.8
22	0.02	53.0	4560	47.4	44.0	220	9.2	11.2	100 000	111 500	49 000	41.4
	GRATE AREA 43.5 SQ. INCHES								Draft opening 6.67 sq. in.			
16	0.08	89.3	4830	44.4	44.0	250	7.8	12.2	162 000	130 000	49 000	37.8
18	0.05	83.0	4830	44.4	38.0	200	6.8	13.4	141 000	120 500	42 700	35.4
									Draft opening 12.37 sq. in.			
13	0.09	184.0	4830	44.4	75.0	506	6.2	13.9	280 000	269 000	85 000	31.6
14	0.05	109.0	4830	44.4	56.0	217	8.2	11.7	208 000	159 000	62 000	39.5
15	0.02	76.0	4830	44.4	42.0	223	9.3	10.9	157 000	111 000	47 400	42.6

pictured in the curves shown in Figures 15, 16, 17, and 18. Referring to Figure 15, the highest output in Btu is shown as obtained not only with the draft opening at largest size but the draft intensity was around 0.10 inch. This is further emphasized in Figure 16 which shows that at the largest draft opening the 0.1 inch stack draft gave a higher Btu output than did a higher draft pressure.

Not only were the outputs higher but the efficiencies showed a tendency to follow the same trend. In Figure 17 the highest efficiency is shown for a draft of approximately 0.1 inch. Likewise the highest efficiency and largest output were obtained (see Figure 18) when draft was 0.1 inch.

Segregating the results of the tests into groups of stack pressure intensity it was found that all those tests having 0.1 inch stack pressure averaged 204,000 Btu per hour output per square foot of grate, while tests made with the 0.5 inch draft gave 141,000 Btu per hour and the 0.02 inch drafts gave an average of 132,000 Btu per hour per square foot of grate area.

There was no estimate made in the commercial rating sheets to show the amount of fuel consumption for the burners per square foot of grate surface. However, during the laboratory tests there were 83.5 pounds of fuel burned per square foot of grate surface on an average.

Of course this was during continuous and supervised firing. If a burner was being used intermittently and was subject to dirty grates, this rate would be somewhat reduced.

Using the results of the laboratory tests as a basis of comparison it is interesting to note the difference between these and the commercial rating mentioned in the first part of the paper. In these commercial ratings, the average output per square foot of grate per hour was 117,000 Btu. No mention was made in the estimate sheet about draft or the Btu content of fuel as fired. Assuming that these commercial burners had used fuel with average, as fired, heat value of 4025 Btu per pound (see Table 2, average fir and hemlock mix) and the average fuel burned was 80 pounds per hour per square foot of grate, then to attain 117,000 Btu per hour the burner would have only been giving 36.5% efficiency.

It is reasonable to expect at least 80 pounds of fuel consumption per square foot of grate on any of the small domestic burners. The average of 83.5 pounds obtained in laboratory tests was an average for all the test runs including those with a very low stack draft. The average of tests where the stack draft was 0.1 inch of water showed 105 pounds burned per square foot per hour. Also, investigations of burners in home installations during the past five years disclosed the fact that there are few small domestic burners with less than 0.1 inch water stack draft available. The average home with a well constructed smoke stack of 25 to 35 feet high will give 0.15 to 0.19 inches of water draft.

This burning rate may seem abnormally high when comparison is made with the results of tests made by Henry Kreisinger (Combustion Engineering Company, New York) in the Bureau of Mines Laboratory in Pittsburgh, Pennsylvania. These tests, as reported in the magazine Mechanical Engineering of February, 1939, were made on large 500 to 1000hp steam boilers in which hogged fuel (waste wood of much larger size than sawdust) is used. In these large burners the fuel is fed to the Dutch ovens by means of chutes over the grates. The fuel piles up in cone shape on the grates and the air is admitted for combustion, 10% through the fuel bed and 90% over the top of the fuel bed. The fact that a top rate of combustion was shown to be only 60 pounds per square foot per hour may be accounted for from a quotation in the article entitled "Effect of Size of Fuel Particles" as follows:

"The surface of a freshly fired fuel receives heat by radiation and convection from the already burning volatile matter. From the surface the heat travels by conduction to the inner parts of the piece. Large pieces of fuel have a comparatively small surface and a large interior mass to which heat must be transferred by conduction. Inasmuch as the heat conductivity of wood is low, it takes a longer time to drive off the moisture and the volatile matter from a single large piece of fuel than several smaller pieces of equal total weight. A bunch of excelsior or wood shavings burns in a few seconds because they have a very large surface to receive heat and practically no interior to which heat must be supplied by conduction. A stick of wood takes several minutes and a log in a fireplace takes several hours to burn, because they have a small surface to receive the heat and a large interior mass to which heat must be transferred by conduction to drive off the moisture and the volatile matter. The surface at first receives heat by radiation and by convection. After the volatile matter has been distilled from the surface layer, the temperature of the layer is raised and the surface begins to glow. If oxygen has access to the surface the fixed carbon burns and heat is generated at the surface and transferred to the inner parts. As the fixed carbon burns off, a layer of fluffy ash is left at the surface of the piece of wood or log. This fluffy layer of ash is a hindrance to heat transfer and also to the heat generation because it prevents the oxygen making contact with the fixed carbon underneath the layer of ash. If there is an intensive turbulence of the gases and air above the fuel bed, the layer of ash may be torn off and carried away by the gases, and expose the fixed carbon to contact with oxygen, or, absorption of heat by radiation and convection. In an open grate fire, where no turbulence is provided to remove the layer of ash, the latter accumulates on the surface and unless it is scraped or shaken off with a poker the fire goes out.

Therefore, the size of the pieces of fuel has a marked effect on the rapidity of combustion. Wood-waste fuel should be chopped up into reasonably small pieces to increase the surface and to reduce the amount of combustible inside of the pieces to which heat must be transmitted by conduction for driving off moisture and volatile matter, and to which oxygen must be supplied through a layer of ash to burn the fixed carbon."

This article also states that the average moisture content is about 50%. This does not agree with our findings which averaged 42% moisture found in testing the sawdust fuel. This may be accounted for from the fact that the sawdust is largely taken from the inside wood while the bark and sapwood which goes into the hogged fuel refuse would probably give a much higher moisture content.

In further justification for the higher burning rate of the small domestic burner it should be pointed out that the method of introducing the air to the fuel bed is of much importance.

In the large size industrial burners the fuel is piled on grates in a large conical pile. Ninety per cent of the air for combustion is taken in through draft doors over the top of the fuel bed. On the other hand the air is taken in through the fuel bed almost entirely in the small domestic burners.

Consequently the smaller burner not only has better control of the excess air but by taking the air through the fuel bed there is better and quicker absorption of the moisture in the fuel, the air currents help to keep the fuel bed moving, and there is better control of the grate temperatures.

For the purpose of more clearly comparing the results of this investigation Figure 19 has been prepared to show the laboratory rating results with the results obtained from the commercial burner company.

A study of many home installations during the past five years shows that other burner companies are underrating their burners as much or more than the one from which these data were obtained. Referring to the curve of Figure 19, the commercial field rating shows an average heat output of 119,000 Btu per hour per square foot of grate area.

The curve (Figure 19) indicating the output of

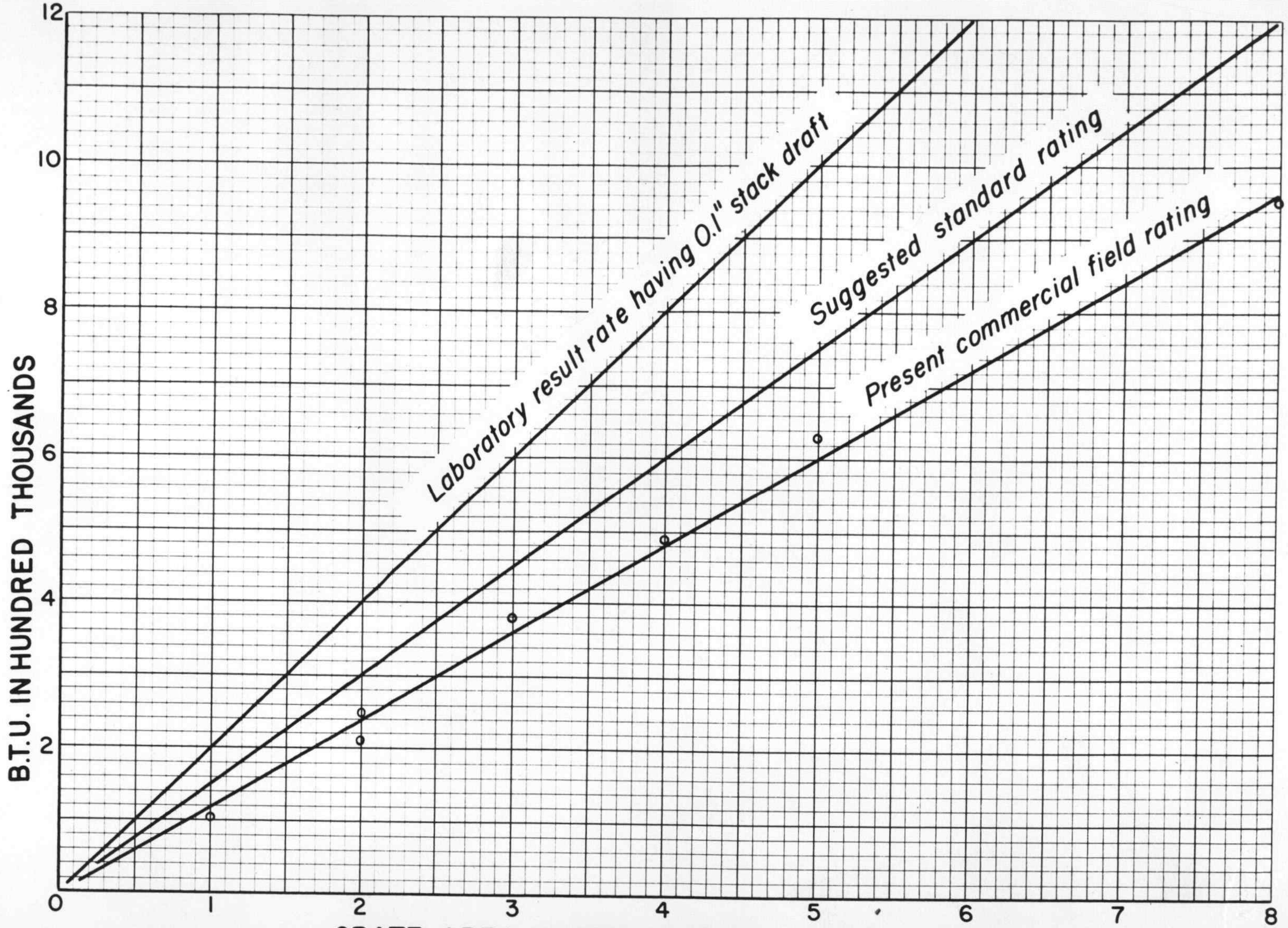
B.T.U. IN HUNDRED THOUSANDS
GRATE AREA IN SQUARE FEET
Laboratory result rate having 0.1" stack draft
Suggested standard rating
Present commercial field rating
0
1
2
3
4
5
6
7
8
2
4
6
8
10
12

Figure 19

burners plotted during the stack pressure of 0.1" show an average output of 200,000 Btu per hour per square foot of grate. This was obtained while using all types of fuel and for various draft openings.

Two ratings not shown but which should be mentioned at this time are, the average rating for all the tests made in the laboratory which included the very high and very low stack pressures, and the tests with the very lowest stack pressures. The average for all conditions showed an output of 158,000 Btu per square foot of grate per hour while the very lowest stack pressure (0.02") averaged 132,000 Btu per hour per square foot of grate.

It does not seem unreasonable to say that any good well-constructed burner should, even under poor conditions, be able to consistently produce 150,000 Btu per hour per square foot of grate area. This rating which is shown on the curve of Figure 19 would make ample allowance for poor draft, poor fuel, and to some extent dirty grates, and still it would be much higher than the rating which is now given by one commercial manufacturer and which is followed by the majority of the present manufacturers.

Conclusion

This investigation has been made with a view to formulating a definite standard rating for the output of domestic sawdust burners. Investigational work was carried out in home installations as well as in a series of tests which were made in the research laboratory.

From these tests and investigations the following conclusions are indicated:

1. Domestic sawdust burners should be rated for capacity according to the size (projected square feet area) of their grates. For all general purposes it is found that a rate of 150,000 Btu per hour per square foot of grate surface output will meet all general conditions.

2. The intensity of stack draft pressure is a very important factor in the rate of burning and the stability and smoothness of operation of combustion.

A minimum of 0.1" of water stack draft should be available at the smoke connection of the furnace. In cases of higher draft conditions there should be a draft regulator provided in the smoke connection.

3. Oversized burners, that is, burners which have a capacity for more than is needed to supply the normal heating demand of a residence, are the source of much trouble and inconvenience. For example, when a burner has been shut off it is necessary to carry on some combustion in order to keep the fire from extinguishing. An auxiliary air intake is provided for this, and if the burner is of excessive size this auxiliary burning will

cause an overheating of the living quarters. On the other hand, if the auxiliary air is reduced it will cause the fire to smoulder and unburned gas to fill the combustion chamber of the burner and furnace. This unburned gas is a potential source of the much dreaded backfiring. Also when the smoke connection is cooled there is tendency for the cool pipe to condense the vapors of the unburned gas, and this results in creosoting.

4. Domestic size sawdust burners are very well adapted to automatic control. By having thermostatic controls on the draft doors of the burners as much as twenty-five per cent of the fuel may be saved over the hand regulated method. Also a much more even temperature may be obtained by the automatic control method.

5. A general rule for calculating sawdust burner capacity may be taken from the following equation:

$$A = \frac{Q}{R \times H \times Eff.}$$

When, A = The area of the burner grates in square feet.

Q = The total Btu output of the burner.

R = The rate of burning in pounds of fuel per hour per square foot of grate.

H = Heating value of fuel per pound as fired.

Eff. = Overall efficiency of the burner

From evidence gained in this investigation it is pointed out that for all general purposes this equation can be written,

$$A = \frac{Q}{150,000}$$

However when the specific heating value is known or the output rating or efficiency are known to be different than those found in this investigation, then application to this equation will give the desired area of grate or output of burner. For example, by using a heating value of 5000 Btu per pound which is not uncommon for pine wood sawdust and by using a firing rate of 80 pounds of fuel per square foot of grate along with a 40 per cent overall efficiency and applying this to the formula, the result would be:

$$A = \frac{Q}{5000 \times 80 \times 0.40}$$

$$\text{or} \quad A = \frac{Q}{160,000}$$

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