THE EFFICIENCY OF GAS BURNERS FOR HOUSE HEATING BOILERS

by

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INTRODUCTION

The last few years have witnessed a definite change in the attitude of the gas companies toward domestic consumption. In the past a conservative attitude was taken believing that domestic consumption of gas was undesirable because of the seasonable nature of the heating load. The present attitude is a progressive one encouraging domestic heating by introducing special rates which would tend to bring the cost of gas within the reach of the average house holder.

The adoption of special rates points to the desirability of house-heating by gas and the many inquiries which have been received by the gas companies seem to indicate that the general public is of the same mind.

Gas space heating not only is no longer considered an expensive luxury, but whether desired by the gas companies or not, most of the customers utilize gas for space heating to some extent.

Since gas is being considered more than ever as a fuel, it does not seem consistent to hesitate in developing its largest field of expansion, particularly when it is an application that suits the purpose so well that the public use it in spite of makeshift appliances and other inconveniences. Central house-heating systems render such excellent service when properly installed that the use of makeshift appliances ought to be thoroughly discouraged if the good will of the consumer is to be preserved and developed. It is well to reiterate both here and later, the need for careful consideration and study to be sure that an installation is adequate, safe, and reliable; and that the gas company should stand ready at all times to assist the consumer if occasion arises.

Gas today, wherever it can be obtained is the ideal fuel for domestic heating exactly as it is for cooking. The problems concerned may not be identical since heating requires fuel in larger amounts than cooking and the question of price might therefore become important. Yet every advantage presented by gas for cooking purposes is likewise doubly valuable for heating purposes. From the standpoint of comfort, convenience, cleanliness, safety, and health, gas is the lowest priced fuel obtainable today. And as for costs when gas is properly burned, and the value of the labor saved by its use is credited to it, the balance of economy is all in its favor.

Many different kinds of fuel have been tried in domestic furnaces and boilers. But wherever gas has been available there was awakened a rapidly growing appreciation of its large number of advantages over all other fuels.

Object

The purpose of this research was to test several different types of natural gas burners, such as have been installed in the homes of Manhattan and that in all probability will be installed in large numbers in the near future. The object was to test each burner under several different operating conditions and to determine which set of conditions gave the best efficiency.

ACKNOWLEDGMENT

The author wishes to express his thanks to Professor J. P. Calderwood, his Major Instructor for his assistance given in the development of this thesis, also to Professor A. J. Mack for his effort in obtaining the use of the four burners tested from the different companies handling them in Manhattan. His thanks are also due them for their suggestions and constructive criticism in the writeup of the thesis.

TYPES OF BURNERS TESTED

Experiments were conducted on four different natural gas burners. Two of these burners were of the premix type

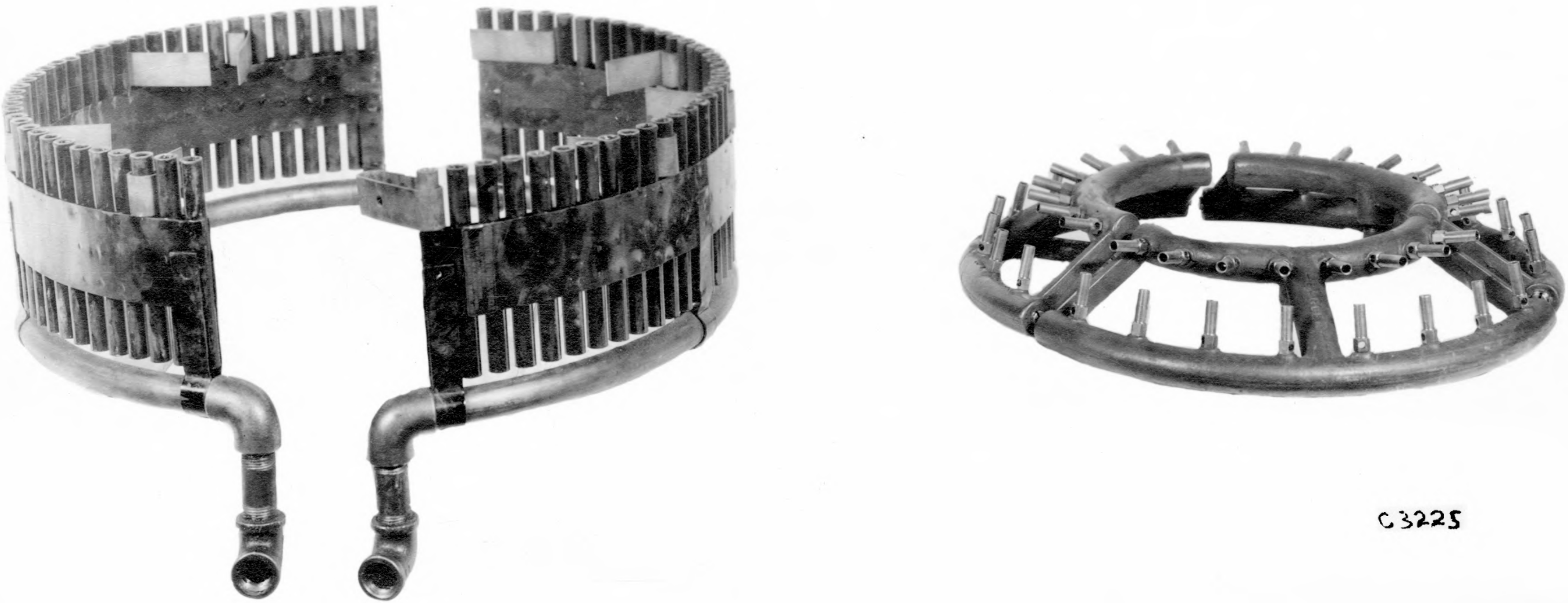


Fig. 1

Fig. 2

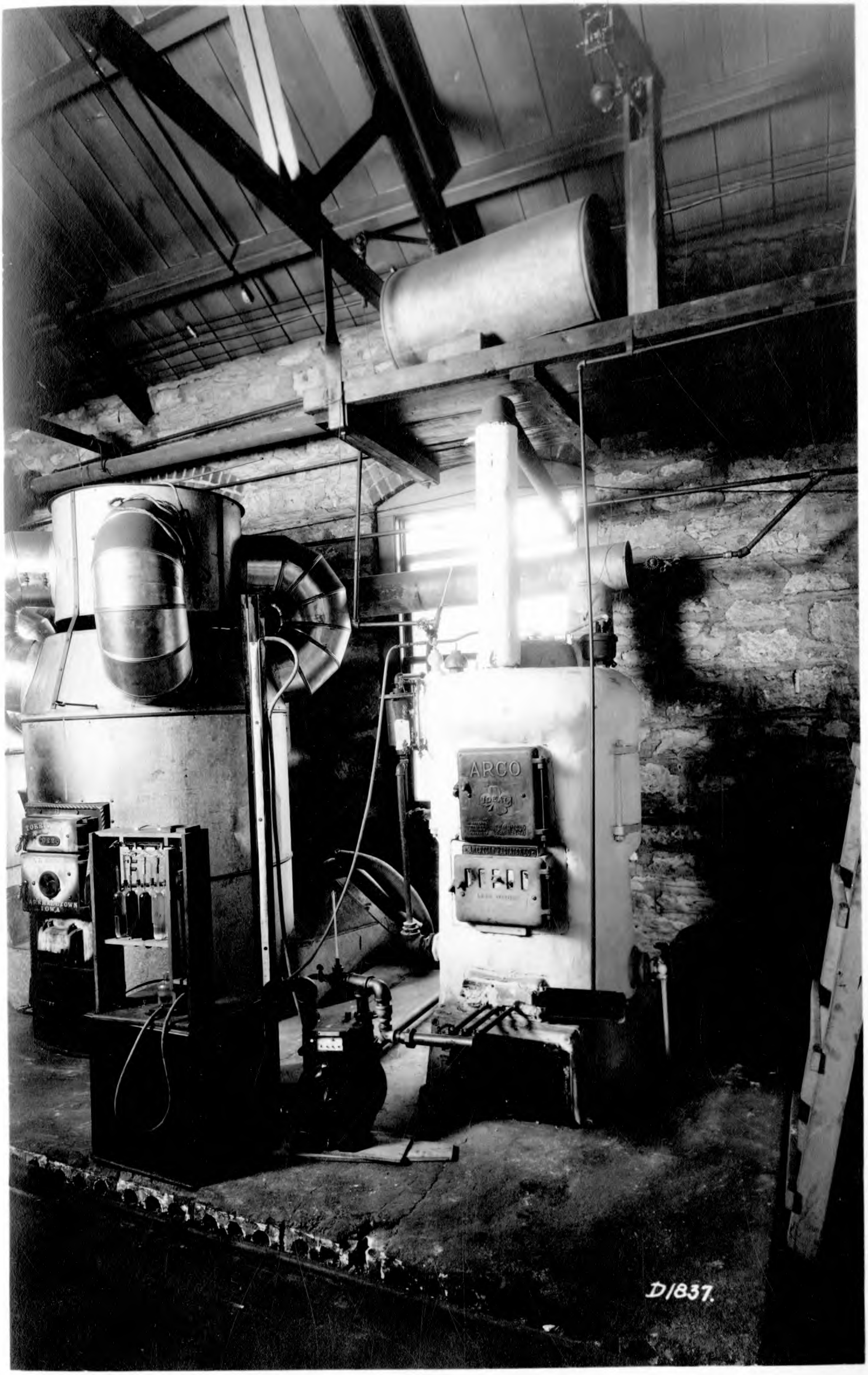
and the other two were of the bunsen or jet type. The premix type of burner is one in which the air and gas are mixed in the correct proportion in a combining tube leading up to the burner. The bunsen type of burner operates similar to an ordinary bunsen burner as can be seen from Fig. 1. The burners tested are as follows: The Ironton Circular Furnace Burner, manufactured by The Ironton Stove and Manufacturing Company, located in Ironton, Ohio; The Eclipse Leaning Radiant Burner made by the Eclipse Fuel Engineering Company, located at Rockford, Illinois; The Maxon Premix Burner made by The Maxon Manufacturing Company, Muncie, Indiana; and The Barber Jet Gas Burner made by the Cleveland Gas Burner and Appliance Company of Cleveland, Ohio. Hereafter in this thesis these burners will be denoted as follows: Burner "B", Burner "C", Burner "D", and Burner "A", respectively.

All tests were conducted with these burners installed in an Arco Steam boiler similar to those used for house heating purposes. This boiler is manufactured by The American Steam Radiator Company and is designed to meet the specifications of a standard boiler for experimental work as set forth by the American Society of Mechanical Engineers. The diameter of the firebox of this boiler is twenty-two inches.

METHODS USED

The actual set up used in performing the experiments can be noted by referring to Fig. 3. All tests were made over a period of four hours and readings of the data were taken at intervals of fifteen minutes. The data taken was as follows: temperature of the water as it was fed to the boiler from a tank overhead, temperature of the stack gases, temperature of the surrounding air, temperature of the gas at the meter, pressure of the gas at the meter, atmospheric pressure, weight of water used, volume of gas burned and determinations of the stack gas analysis. All temperatures were recorded in degrees fahrenheit, the pressure of the gas in inches of water and the flue gas analysis in percent by volume.

Each burner was operated under nine different sets of conditions. The variable factors were load, that is varying the volume of gas burned per hour, and the opening of the damper. Three tests were made on each of three different loads, the variable in this case being the position of the damper. The first test was made with the damper practically closed which for convenience will hereafter be denoted as one-third open. On the second test the damper was two-thirds open and on the third test the damper was


ARCO
D/1837.

wide open. Using these three positions of the damper, tests were then run burning enough fuel to approximate two-thirds load of the burner and the final set of runs only having the gas burner approximately one-third open, thus giving nine sets of conditions under which the burners were tested.

Theoretical Treatment

Before considering what may or should happen in the operation of a gas burner or dealing with any of the calculations involved, it will be well to discuss, first, the theory involved in the combustion or burning of natural gas and thus lay a back ground for the development of the formulas that will be used later in the calculations.

Natural gas consists mainly of methane (CH_4) with smaller quantities of other hydrocarbons, particularly ethane, although carbon dioxide, carbon monoxide, oxygen, and nitrogen are usually present in small amounts. The analysis of the natural gas available in Manhattan as furnished by the gas company is methane 84 percent, ethane 12 percent, and inert gas 4 percent. The inert gas will be considered as nitrogen.

Combustion is a chemical process where the oxygen of the air unites with the combustible elements of the fuel at such a rate to produce heat and light. In other words it is rapid oxidation in the presence of heat and light.

All combustion calculations are based on a relatively few simple laws and on a number of concepts concerning the application of these laws to combustion work. The considerations will now be discussed.

The four laws on which all combustion calculations depend are:

1. Conservation of energy.
2. Conservation of matter.
3. The Gas Law.
4. The Law of Combining Weights.

The law of conservation of matter simply states that over a sufficient period of time, whatever material enters a process must also leave it. There can be no destruction or production of matter during the process, although the form of the combinations usually change. Thus the materials entering a boiler furnace are air and natural gas. Here they combine and go up the stack as flue gas. The air all leaves as flue gas. The total material in the flue gas must equal the total material in the fuel and air used.

The law of the conservation of energy is the same principle applied to energy instead of to matter. In the boiler example above, the heat in the fuel is distributed so that some goes into the water to form steam, some is lost up the stack as sensible heat in the gases and possibly as undeveloped heat in carbon monoxide, and some is lost by radiation from the furnace and flues. The total heat energy, utilized and lost, must however, over a suitable period of test, equal the heat energy in the fuel used.

The fundamental gas law is expressed by the equation

$$PV = NRT$$

where

R is the gas constant.

P is the absolute pressure.

V is the volume.

N is the number of mols.

T is the absolute temperature of the gas.

To use this equation to its fullest extent it is necessary to thoroughly understand the mol. A mol of a substance is the number of pounds of the substance equivalent to the molecular weight. For example, the molecular weight of carbon is twelve and, therefore, the mol of carbon equals twelve pounds.

The law of combining weights states that the elements combine in simple and constant proportions to form definite compounds. The use of this law requires a knowledge of the relative proportion in which substances combine. These amounts are shown by chemical equations, in which the chemical symbols of the substances involved represent one mol unless otherwise designated by a number placed before the symbol.

The combustion reactions used in this work are as follows:

(1) $CH_4 + 2O_2 = CO_2 + 2H_2O$

(2) $2C_2H_6 + 7O_2 = 6H_2O + 4CO_2$

Other more simple reactions, such as are found in the burning of coal follow:

(3) $C + O_2 = CO_2$

(4) $2C + O_2 = 2CO$

(5) $2H_2 + O_2 = 2H_2O$

The third reaction shows that one mol of carbon (twelve pounds) unites with one mol of oxygen (thirty-two pounds or 359 cubic feet under standard conditions) to form one mol of CO_2 (forty-four pounds or 359 cubic feet).

If, in accordance with the first reaction we wish to calculate the air required to burn completely one mol of methane, we find that one mol of oxygen is required for the carbon plus one mol of oxygen for the two mols of hydrogen. Thus the air required is 2(100)/21, or 9.52 mols air per mol of methane, since there is only twenty-one percent of oxygen in the air by volume. Since molal relationships are volume relationships, 9.52 cubic feet of air would be required also to burn one cubic foot of methane.

All combustion calculations necessitate the use of analyses for the determination of the quantities of various elements. Analyses are fully as important as absolute weight measurements in most cases, and frequently relative weights, as calculated from analyses, are sufficient for the purpose intended. For example, the percent stack loss from a boiler may be quite accurately determined from analyses and temperatures alone, while actual weight or volume measurements usually cannot be made.

Analyses of gases obtained with the Orsat apparatus (the method used in this work to determine the analysis of the flue gas) are on a volume percentage basis. Thus an Orsat analysis of air would show twenty-one percent oxygen and seventy-nine percent nitrogen. Since the mol is a volume unit corresponding to 359 cubic feet at standard conditions, gas analyses give molal compositions directly.

Due to the analytical method employed, gas analyses as obtained from the Orsat determination are always on the dry basis, exclusive of the moisture present. Gas analyses are usually made over water, but all the measurements are made at the same temperature and therefore with the same partial pressure of water vapor in the gas. Therefore, if ten percent of the total gas is absorbed by some reagent, ten percent of the water vapor originally present will condense out, so that the partial pressure of water vapor remains unchanged. Thus the final result is the same as if dry gas were used.

Much use is made of gas analyses in combustion calculations in determining relative volumes. Thus if the analysis of a fuel gas and of the flue gas formed from it are known, the relative amounts of fuel gas, air, and flue gas may be determined.

A set of sample calculations will now be shown using the data as taken from the use of the "B" burner, operating under full load and with the damper practically closed.

The data as taken is as follows: feed water temperature 77.5° F., stack temperature 656° F., room temperature 92.5° F., gas temperature 98° F., steam pressure 28.82" Hg., pressure of gas 5" H_2O, CO_2 - 6.8%, O_2 - 8.6%, CO - 0.0%, N_2 - 84.6%, water evaporated per hour 163#, total gas cubic feet per hour = 270. The analysis of the fuel gas is CH_4 = 84%, C_2H_6 = 12%, nitrogen = 4%.

The relative volumes of fuel gas and flue gas may be determined from a carbon balance, that is the carbon in the fuel equals the carbon in the flue gas. Taking as a basis 100 mols of dry flue gas, there are 6.8 mols of carbon as CO_2, 15.4 mols total oxygen (6.8 mols as CO_2 and 8.6 mols as free oxygen) and 84.6 mols of N_2.

The burning of the methane in the fuel gas can be represented by the following chemical equation:

$$CH_4 + 2O_2 = CO_2 + 2H_2O$$

From this equation it can be seen that one mol of CH_4 unites with two mols of oxygen to give one mol of CO_2 and two mols of water vapor. In other words the volume of the resulting CO_2 is the same as the volume of the original methane.

The combustion of the ethane in the fuel gas may be shown in the same manner:

$$C_2H_2 + \frac{7}{2} O_2 = 2CO_2 + 3H_2O$$

In this case it can be seen that the resulting volume of CO_2 is twice that of the original ethane.

Now if we assume that the initial volume of the fuel gas is 100 mols, then we will have 84 mols of methane gas, 12 mols of ethane gas, and 4 mols of inert nitrogen. Now if the 84 mols of methane gas is burned completely it will give 84 mols of carbon dioxide and the 12 mols of ethane gas will give 24 mols of carbon dioxide, as can be seen from the above equations. Therefore, our 100 mols of fuel gas if burned completely will give in this case 108 mols of CO_2, or if one mol of fuel gas is burned 1.08 mols of CO_2 will be produced.

Now, in this example 6.8 mols of CO_2 resulted, therefore, the mols of gas burned to cause this is:

$$\frac{6.8}{1.08} = 6.296$$

That is 6.296 mols of fuel gas were burned to obtain 6.8 mols of CO_2.

The number of mols of methane gas then is equal to 6.296 x .84 = 5.28864.

The number of mols of ethane gas is equal to 6.296 x .12 = 0.75552.

The number of mols of inert nitrogen = 6.296 x .04 = 0.25184.

Thus the ratio of dry flue gas to fuel gas is 100/6.296 = 15.883 mols dry flue gas per mol fuel gas. Since molal relationships are also volume relationships, there were also 15.883 cubic feet of dry flue gas for every cubic foot of dry fuel gas measured under the same conditions.

By the use of a nitrogen balance, that is the nitrogen in the air plus the nitrogen in the fuel is equal to the nitrogen in the flue gas, the ratio of dry flue gas to dry air may be calculated. In this example there are 84.6 mols of nitrogen per 100 mols of dry flue gas. Part of this nitrogen is the inert nitrogen from the fuel gas. The amount in this case is 6.296 x .04 mols = 0.25184 mols. The difference between 84.6 mols and 0.25184 is supplied by the air. Thus 84.34816 mols of nitrogen comes from the air which contains 79 percent nitrogen (79 mols of nitrogen per 100 of air) so that to obtain 84.34186 mols of nitrogen 84.34816 x 100/79 mols of air was necessary. The ratio dry flue gas / dry air is thus

$$\frac{100}{84.34816 \times 100/79} = 0.9375$$ mols of dry flue gas per mol of air or 0.9375 cubic feet of dry flue gas per cubic foot of air used for the combustion of the flue gas.

The ratio of air to fuel gas may now be determined from the above relationships. Since there were 15.883 cubic feet of flue gas per cubic foot of fuel gas and .9375 cubic feet of dry flue gas per cubic foot of air, the ratio of air to fuel gas is 15.883/0.9374 or 16.95 cubic feet of air used per cubic foot of fuel gas.

Excess Air

The term percent of excess air is used to denote the percent of air in excess of that theoretically required for complete combustion. Thus for this fuel gas taking 100 mols as the basis we can see from the above equations that one mol of CH_4 requires two mols of oxygen to completely burn it and one mol of C_2H_6 requires $3\frac{1}{2}$ mols of oxygen to completely burn it. Therefore, 84 mols of CH_4 requires 168 mols of oxygen and 12 mols of C_2H_6 requires 42 mols of oxygen. Therefore 100 mols of fuel gas requires 210 mols of oxygen, since 4 mols of the fuel gas is inert. The corresponding quantity of air is $210/.21 = 1000$ mols. In other words, one mol of fuel gas requires 10 mols of air or one cubic foot of fuel gas requires 10 cubic feet of air for complete combustion. In the example as shown by the fuel gas - air ratio, the amount actually used was 16.95 cubic feet of air per cubic foot of gas so that the percent excess air is $(16.95 - 10.0)/10.0 \times 100 = 69.5$ percent. Therefore, combining all the steps just discussed the percent of excess air may be found from the following equation:

Excess air in percent

$$= \frac{100}{\frac{CO_2}{108}} \div \left(\left(N - \frac{CO_2}{1.08} \times .04\right) \frac{100}{79} - 10 \right) 100$$

$$= \frac{1.366}{CO_2} \; \frac{(N - 0.0371\ CO_2) - 10)}{10} \; 100$$

$$= \frac{13.66}{CO_2} \; (N - 0.0371\ CO_2) - 100$$

$$= 13.66 \; \left(\frac{N}{CO_2} - 0.0371\right) - 100$$

Now by dropping the constant 0.0371 which for all practical purposes is too small to materially effect the result, the following equation may be used:

$$\text{Excess air in percent} = 13.66 \; \frac{N}{CO_2} - 100$$

It should be noticed that this equation only holds for a gas having this particular analysis.

Efficiency

The efficiency of the burner was determined by dividing the output by the input, the unit used being the British thermal unit. The output is determined from the weight of water evaporated per hour, the heat in the water as it is fed to the boiler and the heat in the steam as it is evaporated. Therefore the output can be determined from the following equation:

$$\text{Output} = W\,(H_2 - h_1)$$

where

W = weight of water evaporated per hour.

H_2 = total heat in one pound of steam above 32° F.

h_1 = total heat in the feed water as fed to the boiler above 32° F.

The input to the boiler is found knowing the heating value of the gas under the conditions of operation and the volume of fuel gas burned. The input then is equal to

$$Vg \times H.\ V.\ g.$$

where

Vg = volume of gas in cubic feet per hour as measured by the meter.

$H.\ V.\ g.$ = heating value of the gas in British thermal units per cubic foot.

Then the efficiency is

$$\frac{\text{Output}}{\text{Input}} = \frac{W(H_2 - h_1)}{Vg \times H.\ V.\ g.}$$

For the above example the efficiency will be:

$$\text{Efficiency} = \frac{(163\ (1149.3 - 45.4)}{(270 \times 963\ )} = 0.69$$

EXPERIMENTAL DATA AND RESULTS

The data as taken from the various tests may be found from tables I, II, III, and IV. This data as recorded are average values taken during the runs. The resulting calculations made from this data may be found in tables VI and VII, a sample of which has been given under the previous heading. Table V shows a sample data sheet as taken for one test.

The results will now be discussed under the following headings:

(a) efficiency of the burners operating under different conditions.

(b) flue gas temperatures.

(c) percent of excess air.

(d) percent of CO_2.

Referring to figures 4, 5, and 6, which show the efficiency of the various burners operating under different loads it can be seen that the highest efficiency obtained was 74 percent. This efficiency was obtained when the burner was operated burning its full capacity of fuel gas and with the damper practically closed. As can be seen by referring to these figures the highest efficiency of all the burners was obtained when the damper

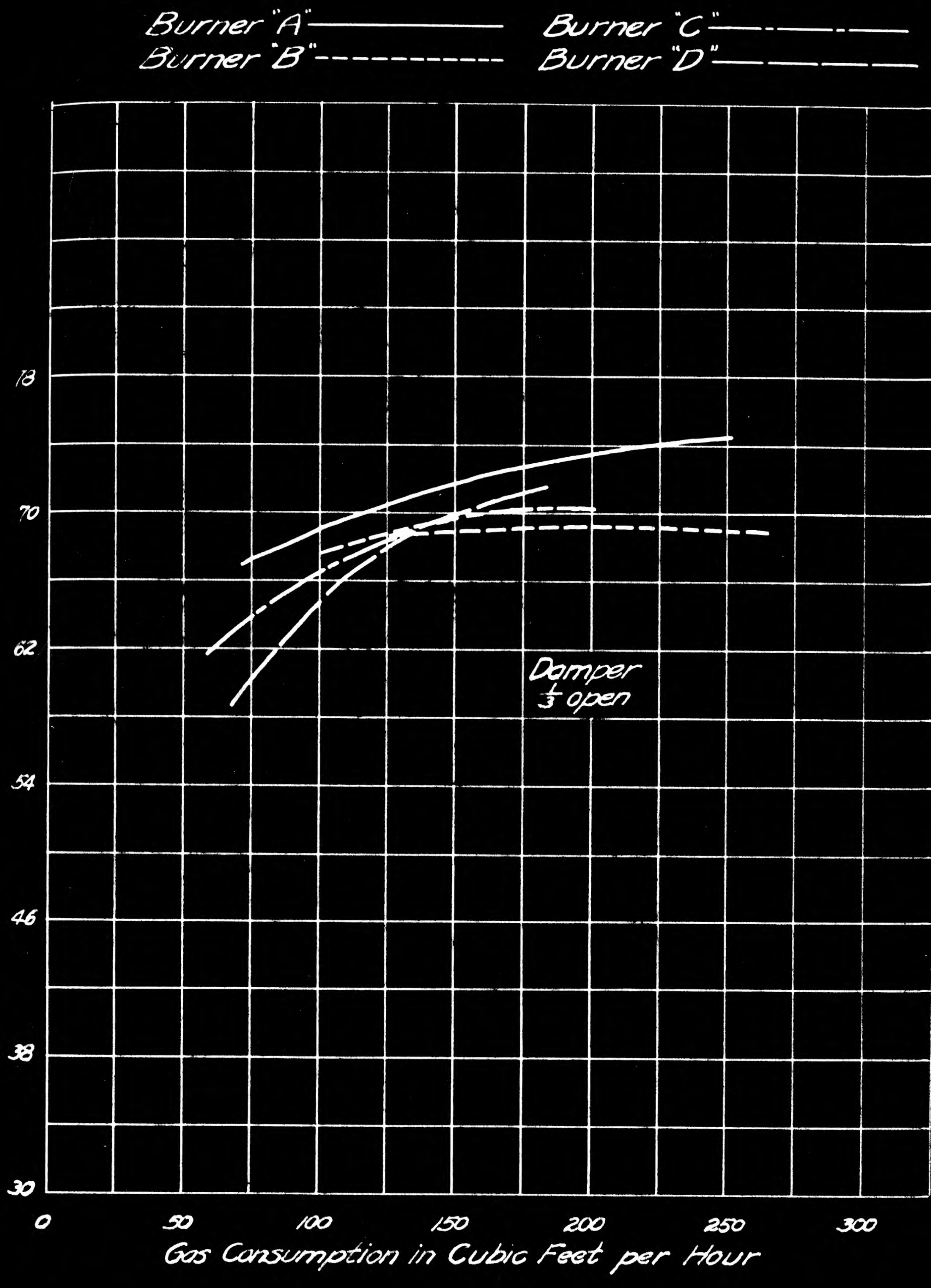

Burner "A"
Burner "B"
Burner "C"
Burner "D"
78
70
62
54
46
38
30
Damper
1/3 open
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 4

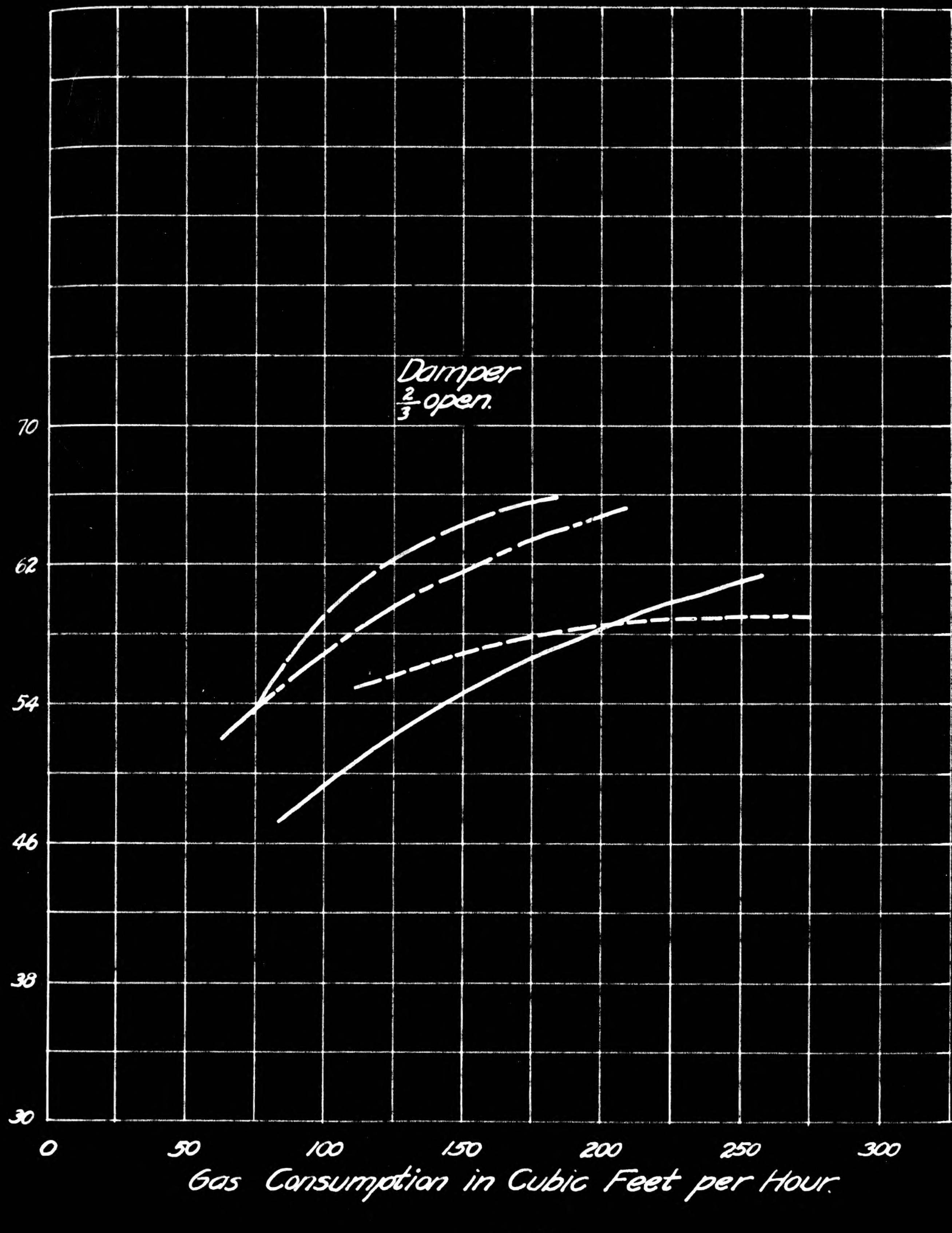

Damper
$\frac{2}{3}$ open.
70
62
54
46
38
30
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 5

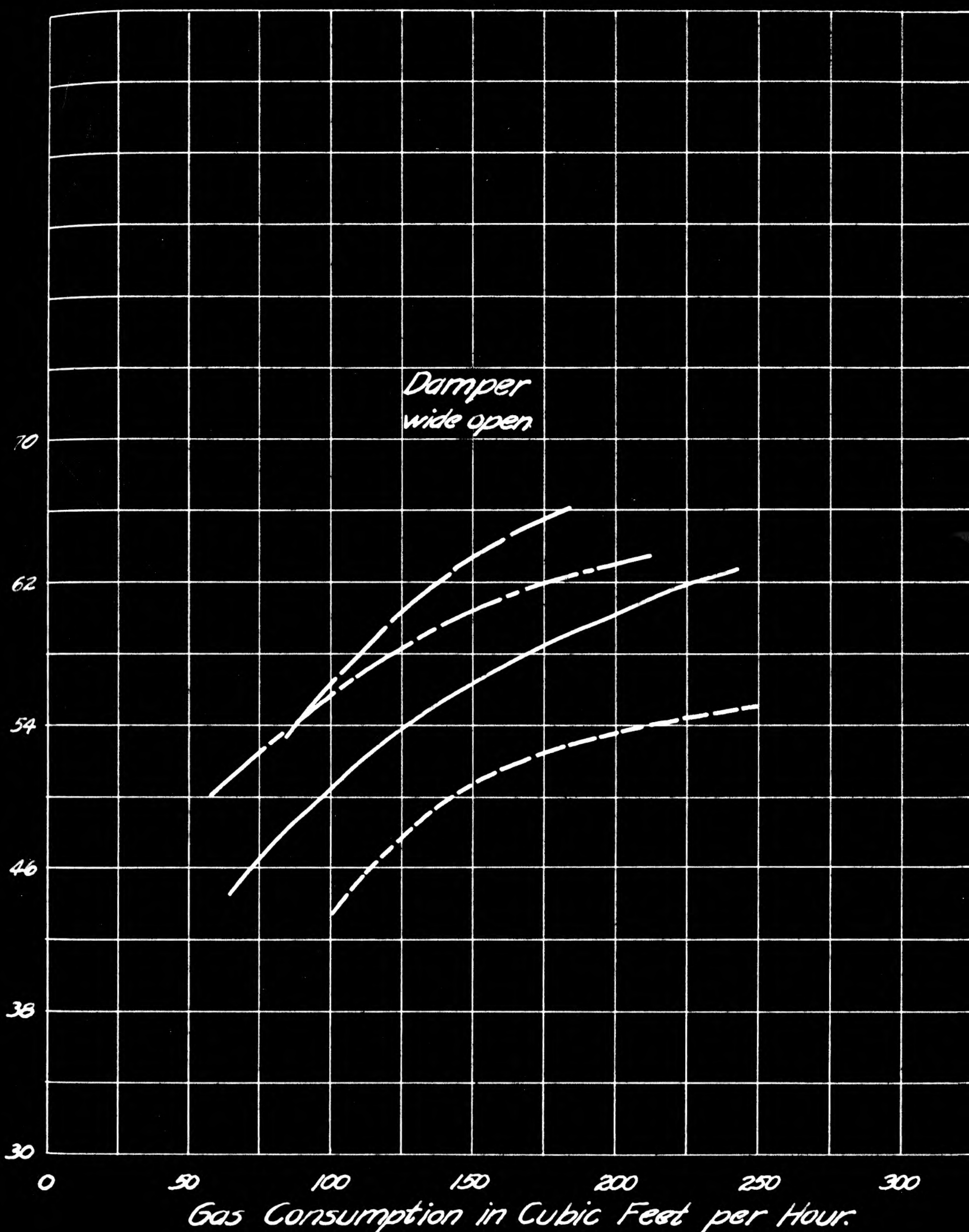
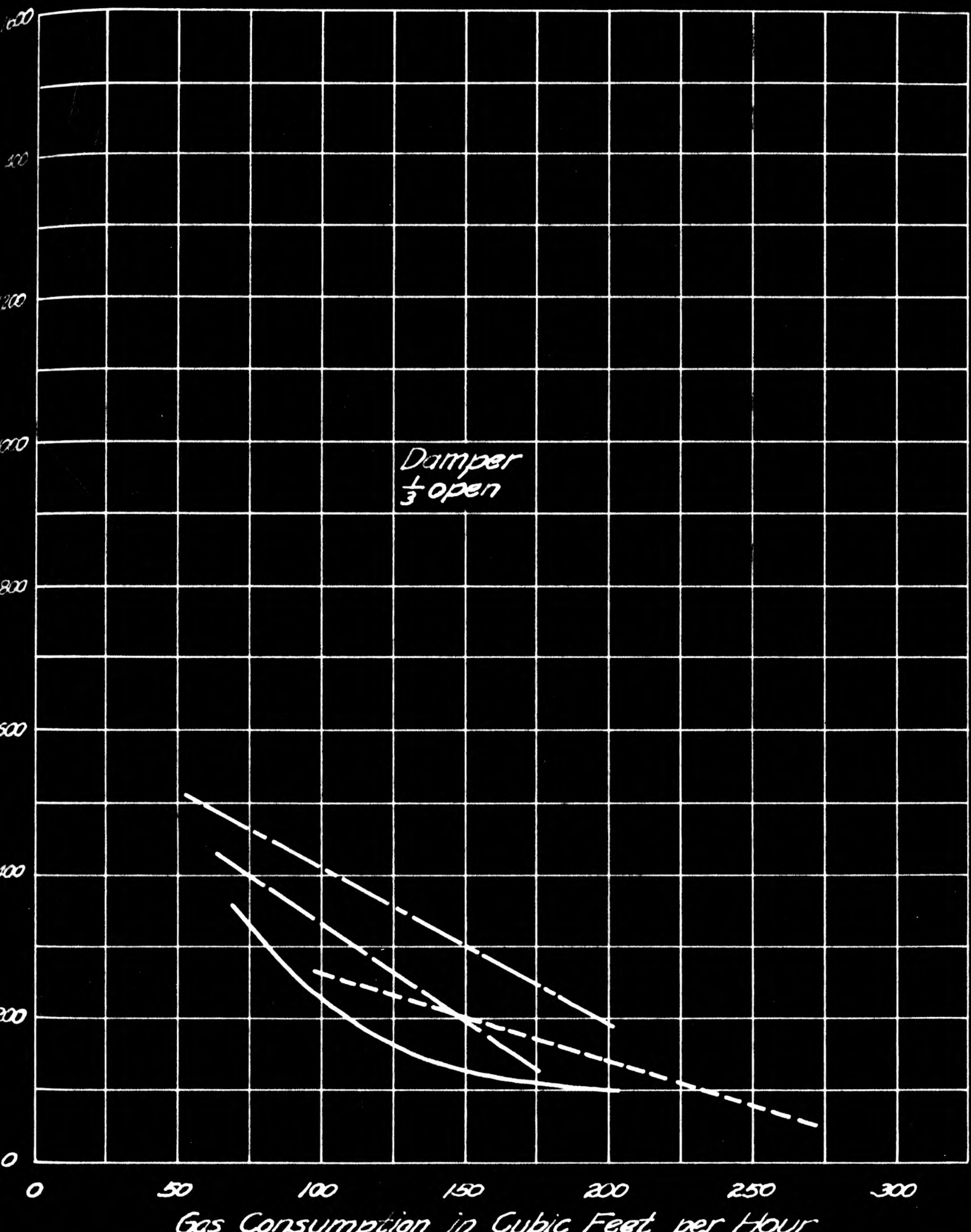

Damper
wide open
70
62
54
46
38
30
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 6



Damper
1/3 open
0
800
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 7

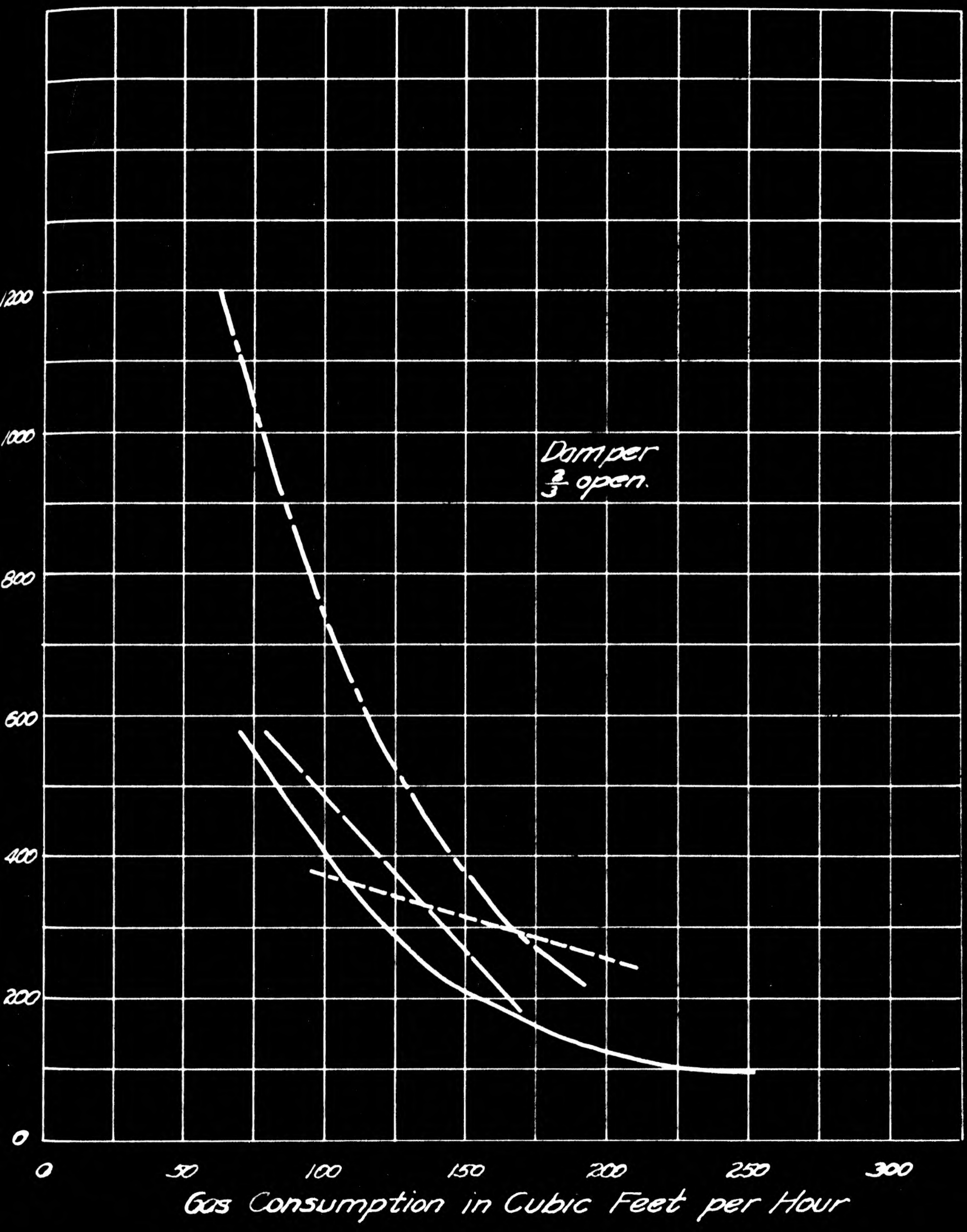
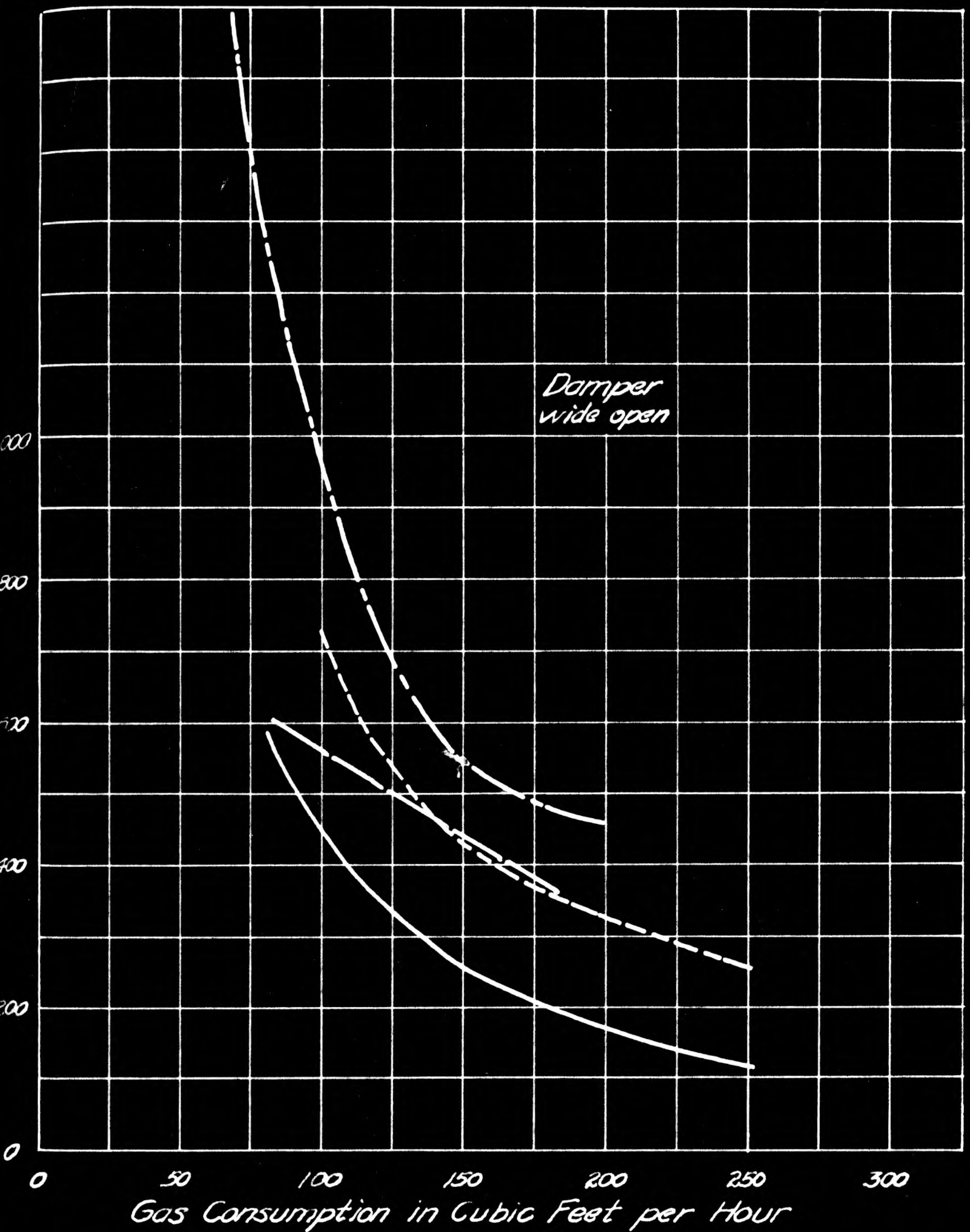
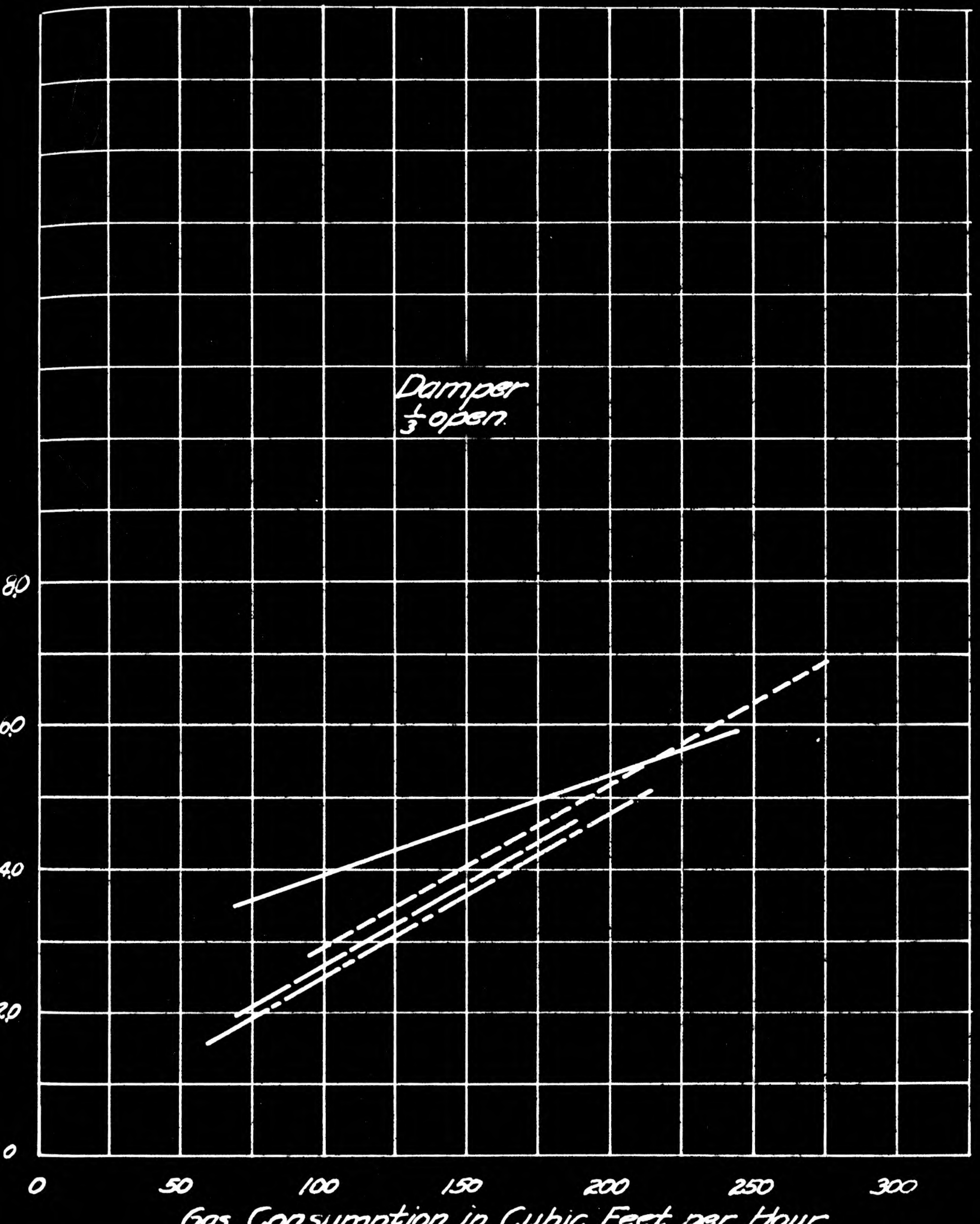

1200
1000
800
600
400
200
0
Damper
⅔ open.
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 8



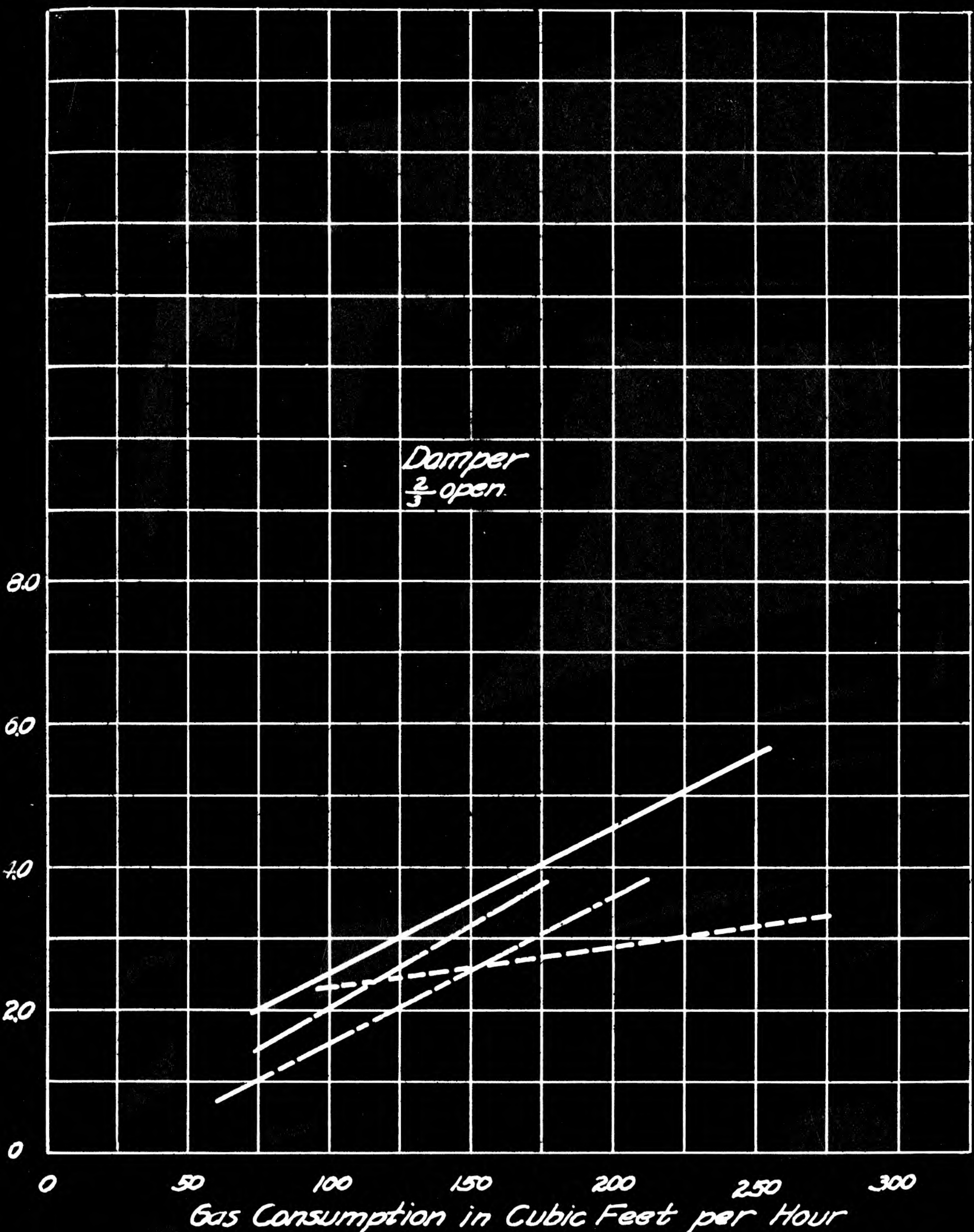
Damper wide open
000
800
600
400
200
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 9



Damper
1/3 open.
8.0
6.0
4.0
2.0
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 10



Damper
2/3 open
8.0
6.0
4.0
2.0
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 11

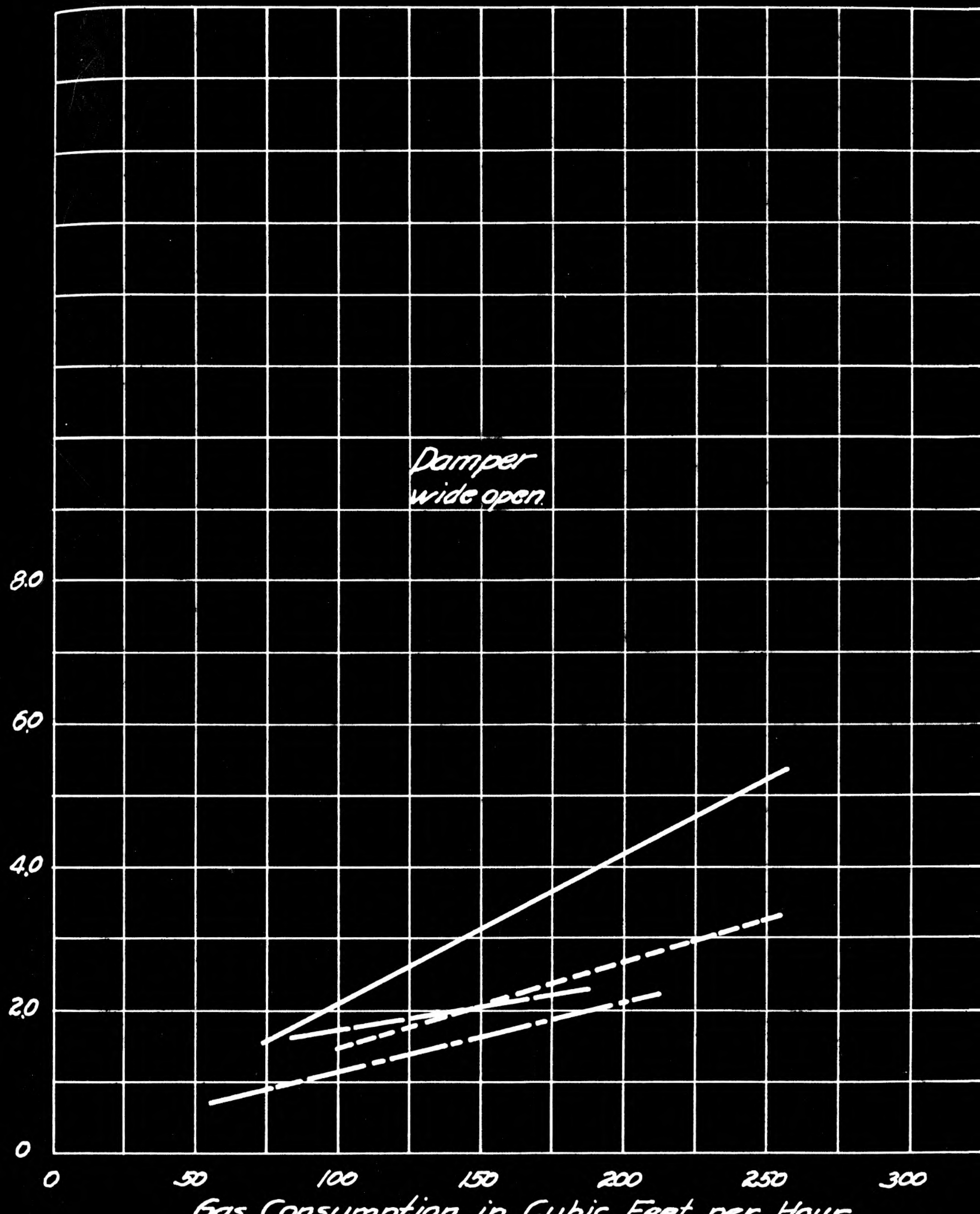
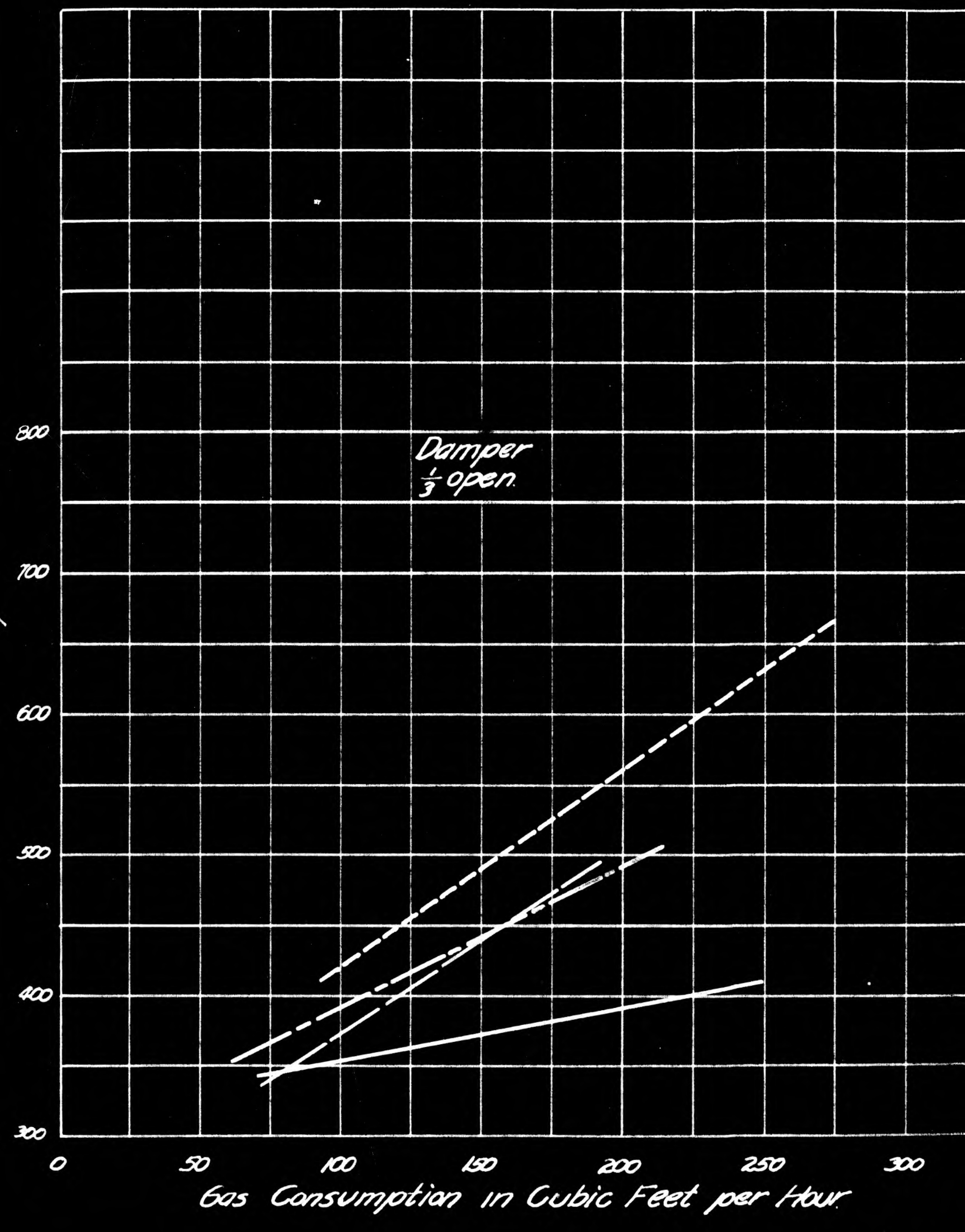

Damper
wide open
8.0
6.0
4.0
2.0
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 12



800
700
600
500
400
300
Damper
1/3 open.
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 13

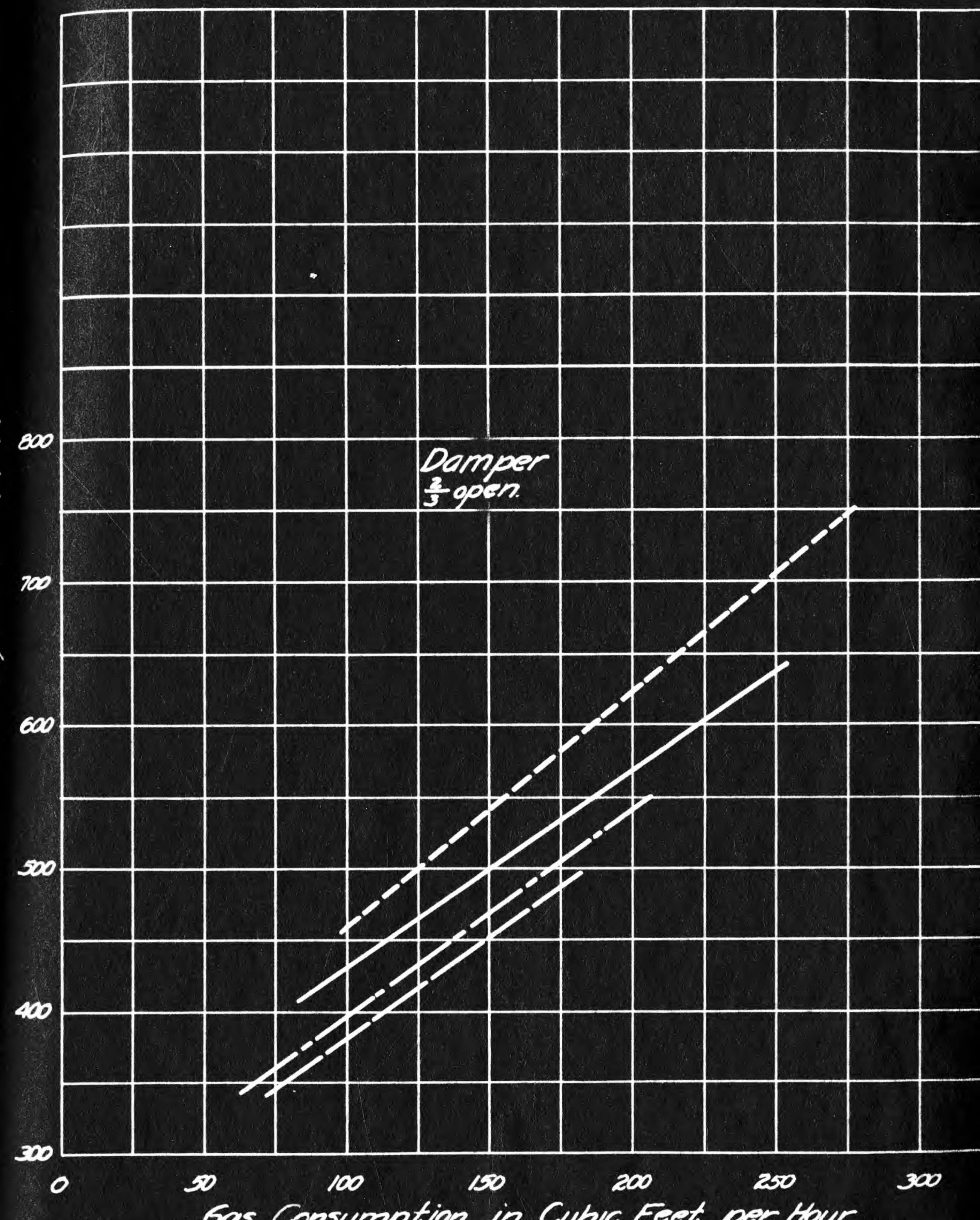

Damper
2/3 open.
800
700
600
500
400
300
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 14

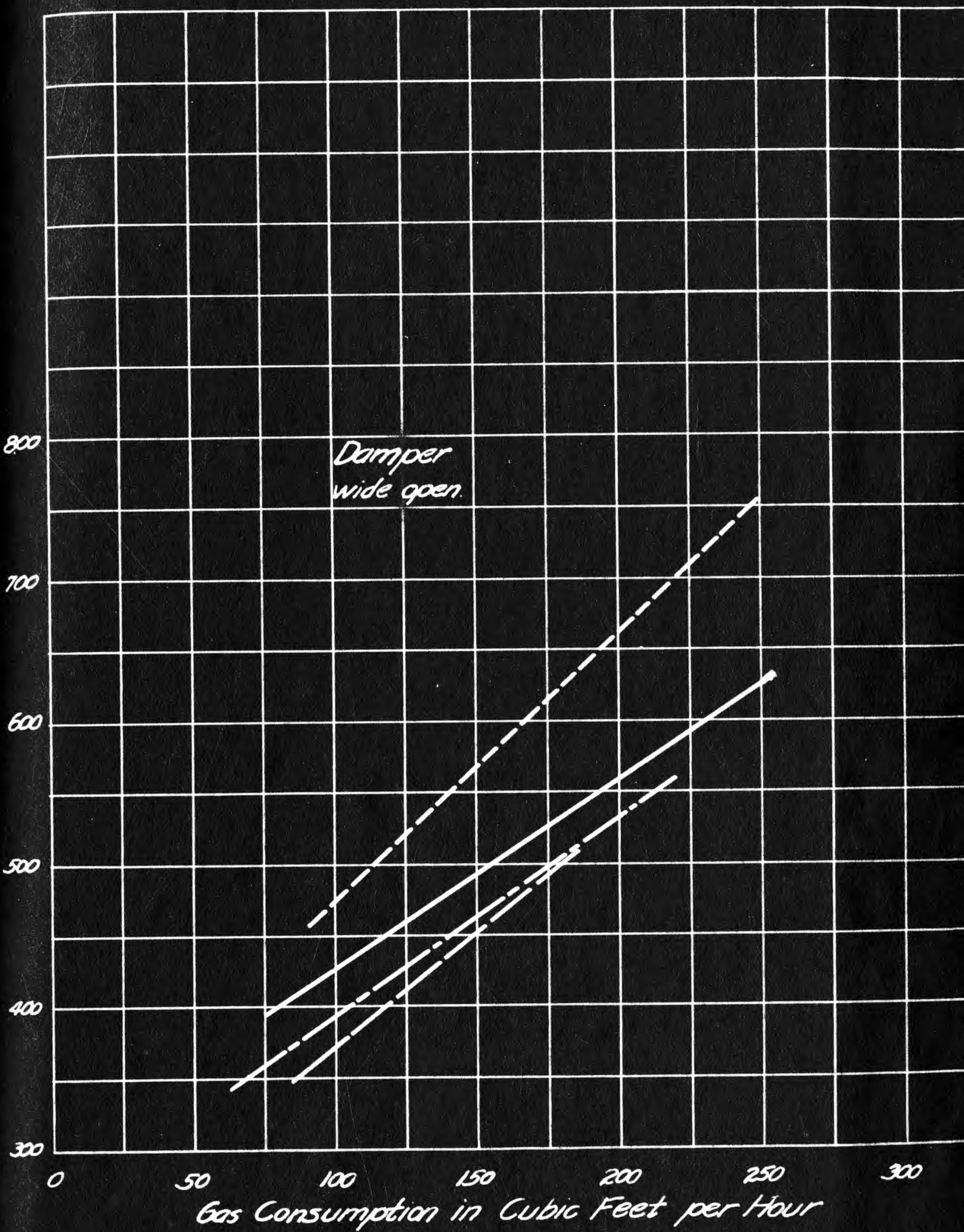

Damper
wide open.
800
700
600
500
400
300
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 15

Table I

AVERAGE DATA FOR "B" BURNER

Condition:	Temperature °F.				Pressure		Orsat				H_2O	Heat:	Vol:	H.V.
Operation:	F.W.	Stack	Room	Gas	Steam	Gas	CO_2	O_2	CO	N_2	Evap.	F.W.	Gas	Gas
One	77.5	646	92.5	98	28.83	5.0	6.8	8.6	0	84.6	651	45.5	1081	963
Two	77.2	569	87.5	85	28.68	9.0	4.53	11.9	0	83.5	409	45.2	715	990
Three	78.5	409	84.0	89	28.31	11.5	2.94	16.3	0	80.7	250	46.5	409	979
Four	73	731	84	89	28.47	5.0	2.0	16.7	0	81.3	565	41.0	1100	960
Five	74.8	614	90	85	28.61	9.0	3.0	14.8	0	82.2	346	42.8	721	977
Six	80.3	453	85.5	92	28.31	11.5	2.3	16.2	0	81.5	208	48.3	417	971
Seven	80.0	725	83.5	88	28.69	5.0	3.0	14.7	0	82.3	479	48.0	984	973
Eight	77.0	591	85	90	28.66	9.0	1.9	16.9	0	81.2	224	45.0	516	980
Nine	80.0	440	87	92	28.31	12.0	1.4	17.5	0	81.1	165	48.0	425	973

Explanation of operation:
One - Full load with damper one-third open
Two - Two-thirds load - damper one-third open
Three - One-third load with damper one-third open
Four - Full load with damper two-thirds open
Five - Two-thirds load with damper two-thirds open
Six - One-third load, damper two-thirds open
Seven - Full load, damper wide open
Eight - Two-thirds load, damper wide open
Nine - One-third load, damper wide open

Table II

AVERAGE DATA FOR "A" BURNER

Condition:	Temperature °F.				Pressure		Orsat			H_2O	Heat	Vol.	
Operation	F.W.	Stack	Room	Gas	Steam	Gas	CO_2	O_2	N_2	Evap.	F.W.	Gas	Gas
One	69	408	91	96	29.09	5.0	5.8	8.0	85.7	546	37	842	974
Two	72	460	87	92	28.83	11.0	4.4	12.5	83.1	283	40	482	990
Three	80	344	88	93	29.16	12.0	2.6	15.6	81.8	181	48	296	997
Four	77	629	86	92	28.79	5.5	5.6	10.3	84.1	477	44	884	973
Five	77	492	89	93	28.73	10.5	3.3	14.6	82.1	210	44	451	980
Six	84	408	92	96	29.16	12.0	1.7	17.8	80.5	150	52	347	994
Seven	76	617	89	95	29.17	5.5	5.2	10.6	84.2	562	44	1009	980
Eight	78	475	88	93	28.75	11.0	2.6	15.7	81.7	228	45	481	982
Nine	85	391	92	96	29.16	12.0	1.65	17.5	80.8	115	53	284	996

Table III

AVERAGE DATA FOR "C" BURNER

Condition Operation	Temperature °F. F.W.	Stack	Room	Gas	Pressure Steam	Gas	Orsat CO_2	O_2	N_2	H_2O Evap.	Heat F.W.	Vol. Gas	H.V. Gas
One	71	480	90	95	28.92	9.0	5.0	11.4	83.6	484	39	775	986
Two	77	437	85	92	28.50	11.0	2.6	15.4	82.0	339	45	551	977
Three	79	342	89	94	28.90	12.0	1.9	16.1	82.0	143	47	255	990
Four	77	522	86	90	28.89	9.0	3.4	13.7	82.9	440	45	762	987
Five	80	463	85	90	28.63	11.0	2.2	17.8	80.0	312	48	580	985
Six	76	345	86	91	29.44	12.0	0.85	18.8	80.3	126	44	263	1011
Seven	71	525	86	91	28.81	9.0	1.93	16.5	81.5	438	39	787	984
Eight	78	456	83	88	28.73	11.0	1.74	17.3	80.9	328	46	606	988
Nine	84	343	83	88	29.19	12.0	0.63	19.3	80.0	123	52	264	1010

Table IV

AVERAGE DATA FOR "D" BURNER

Condition Operation	Temperature °F. F.W.	Stack	Room	Gas	Pressure Steam	Gas	Orsat CO_2	O_2	N_2	H_2O Evap.	Heat F.W.	Vol. Gas	H.V. Gas
One	77	471	88	93	28.77	9.0	4.6	12.1	83.3	442	45	699	980
Two	75	394	85	89	29.11	11.0	3.0	15.6	81.4	290	43	476	1000
Three	79	340	89	93	29.06	12.0	2.2	16.7	81.1	161	47	300	996
Four	74	481	87	92	28.77	9.0	3.6	14.5	81.9	393	42	678	982
Five	77	397	90	92	29.11	11.0	2.0	16.3	81.7	261	45	467	996
Six	85	354	90	94	28.89	12.0	1.8	17.2	81.0	149	53	305	988
Seven	72	487	82	90	28.85	9.0	2.3	15.8	81.9	407	40	694	988
Eight	75	393	86	94	29.18	11.0	2.0	17.1	80.9	259	43	479	996
Nine	83	354	90	95	28.84	12.0	1.7	17.5	80.8	160	51	325	988

Table V

Sample Data Sheet

Time	Temperature °F F.W.	Stack	Room	Gas	Gas Press	CO_2	O_2	N_2	CO	Gas Meter	Remarks
11:01	77	570	88	90	9.0					16855	
11:16	74	569	88	86	9.0						
11:31	77	565	87	82	9.0						
11:46	88	563	87	81	8.5	4.6	12.2	83.2	0		
12:01	74	574	87	81	8.5						
12:16	78	574	87	81	8.5	4.2	12.2	83.6	0		
12:31	78	569	89	81	8.5						
12:46	77	571	89	82	9.0						
1:01	84	571	88	82	9.0	4.8	11.4	83.8	0		
1:16	85	572	87	85	9.0						Barometer 28.68
1:31	77	570	90	85	9.0						Total water evaporated 409 lbs. for four hours
1:46	77	568	90	85	9.0						Test conducted on "B" Burner
2:01	79	569	88	85	9.0	4.0	13.0	83.0	0		Approximately two thirds load. Damper one third open.
2:16	82	566	84	85	9.0						
2:31	70	566	88	85	9.0						
2:46	70	570	86	85	9.0						
3:01	66	570	86	85	9.0					17570	
Ave.	77	569	87	85	9.0	4.5	11.9	83.5	0	715	

Table VI

Calculated Results

Condition: Operation	Ht. Per Lb. Steam	Eff. %	Excess Air Percent	H_2O Evap Per Hour	Gas / Hour	Ht./ lb. Steam	Eff. %	Excess Air Percent	H_2O Evap Per Hr.	Gas / Hour
One	1149.5	74.1	98	156	240	1149.3	68.9	70	163	270
Two	1149.3	65.7	155	71	121	1149.2	63.8	150	102	179
Three	1149.5	67.5	333	45	74	1149.0	68.7	274	63	102
Four	1149.2	61.3	105	136	252	1149.1	59.0	450	141	275
Five	1149.3	52.5	241	60	129	1149.2	54.3	274	87	180
Six	1149.5	47.7	540	37	87	1149.0	56.4	383	52	104
Seven	1149.5	62.8	120	141	252	1149.1	55.2	274	119	246
Eight	1149.2	53.3	330	57	120	1149.2	48.8	480	56	129
Nine	1149.5	44.5	560	33	81	1149.0	44.0	690	41	106

Table VII

Calculated Results

Condition: Operation	Ht. Per Lb. Steam	Eff. %	Excess Air: Percent	H_2O Evap: Per Hour	Gas / Hour	Ht./ lb. Steam	Eff. %	Excess Air: Percent	H_2O Evap: Per Hr.	Gas / Hour
One	1149.4	70.1	210	121	194	1149.2	71.0	147	110	175
Two	1149.0	69.2	330	85	138	1149.5	67.3	270	73	119
Three	1149.4	62.4	488	36	64	1149.5	59.4	407	40	75
Four	1149.3	64.5	229	110	190	1149.2	65.1	210	98	169
Five	1149.1	60.0	404	78	145	1149.5	61.9	457	65	117
Six	1149.7	52.3	1180	32	66	1149.3	54.2	525	40	81
Seven	1149.2	62.8	477	109	197	1149.3	65.7	384	102	173
Eight	1149.1	60.3	533	82	151	1149.5	60.0	452	86	160
Nine	1149.5	50.5	1630	31	66	1149.3	54.0	576	42	86

was closed as tight as possible. This fact is as it might be expected since the burning of natural gas requires the minimum of excess air of any fuel burned. Therefore, operating with the damper practically closed would lower the percent of excess air and thus raise the efficiency. Of course, it can be readily seen how the efficiency can be raised by lowering the percent of excess air. Each cubic foot of air supplied in excess of that required represents a direct loss, in that it has to be heated up to stack temperature just the same as the air used for combustion. However, it must be borne in mind that the percent of excess air must be kept high enough so that no carbon monoxide appears in the flue gas. Otherwise there would be a loss due to incomplete combustion. There appears then that a balance must be obtained such that we have enough excess air to produce complete combustion and no more so that the heat lost up the stack is kept at a minimum.

The burners tested in this experiment may be classified as to premix and the bunsen type. In the premix type the air and gas are mixed in a combining tube before the gas reaches the burner. In this work it can be noticed that the premix type of burner did not give as high efficiency as the bunsen type nor were the efficiency curves as flat as for the other type. A flat efficiency curve is very desirable inasmuch as it shows that the burner operates at practically the same efficiency under all loads. This factor would be of very great importance in determining the desirability of any particular burner particularly if the burner is to be mechanically operated, since the burner would be operating under light loads a large percentage of the time.

In discussing the flue gas temperatures, it might be well to state that the lowest theoretical temperature that would be possible would be a temperature slightly higher than the steam itself, otherwise there would be no flow of heat from the flue gases to the water. Ordinarily a flue gas temperature of forty to seventy-five degrees above that of the steam is the minimum obtainable. Several factors enter in to the question of flue gas temperature control. From figures 13, 14, and 15, it can be seen that the lowest temperatures were obtained under the condition of operation where the damper was practically closed. This fact can be very readily explained. With the damper closed as tightly as possible there is a blanketing effect placed upon the flow of the flue gases and the discharge of the flue gases from the boiler are hindered to such an extent that more time is given them to cool somewhat before they leave the boiler. With the damper wide open this blanketing effect is removed and the draft draws the flue gases out of the boiler with a much shorter flame travel and consequently much more heat is lost up the stack.

It can also be noticed that with an increase in load, that is increasing the rate of consumption of fuel gas, that the flue gas temperature also increased with the same setting of the damper. This was due to the fact, that, with an increased gas consumption with the damper setting constant the percent of excess air was proportionally decreased and therefore the temperature of the flue gas had to increase. Of course with an increased consumption the efficiency would increase slightly, but this would not over balance the decreased percent of excess air, therefore an increased flue gas temperature would result.

In discussing the results as outlined above, it is very difficult to discuss one phase without bringing into the discussion several other different parts. The percent of excess air found has been discussed somewhat. It might be added, however, that the percent of excess air decreased with an increase in load as might be expected. Also that the lowest percent of excess air was obtained with the damper practically closed. Of course with the damper wide open the amount of air drawn through was somewhat unlimited and the percent of excess air then would increase as the amount of fuel gas burned was decreased. This is one explanation of the very low efficiency obtained with the damper wide open.

Before discussing the results from the carbon dioxide standpoint it will be well to determine the maximum percent of CO_2 possible to obtain with perfect combustion and no excess air. Referring back to the discussion on combustion it can be seen that one mol of CH_4 burned completely will give one mol of CO_2 and that one mol of C_2H_6 burned completely will give two mols of CO_2. Therefore, 100 mols of the natural gas used will give when burned completely 108 mols of CO_2 and 790 mols of nitrogen making a total of 898 of dry flue gas for each hundred mols of fuel gas burned. Therefore the percent of carbon dioxide would be 108/898 or twelve percent. Therefore, knowing the analysis of the fuel used, the maximum percent of carbon dioxide obtainable can be calculated. This fact is used to great advantage, in the modern central station of today and could be used as well in the installation of natural gas burners in house-heating boilers. That is the volume of the flue gas will remain practically constant, therefore with a decrease in the percent of carbon dioxide from the percent theoretical possible would indicate an increase in the percent of excess air and vice versa.

The maximum percent of carbon dioxide obtained in this test was 6.8 percent which represented seventy percent of excess air. The amount of carbon dioxide ranged from this high value down to 0.65 percent with a corresponding percent of excess air equal to 1600 percent. Of course, this latter condition resulted from a very light load and with the damper wide open. The percent of carbon dioxide in every case showed an increase with an increase in load under the same damper setting. This was due to the fact that with an increased load, the percent of excess air decreased, thus giving an increase in the percent of carbon dioxide as explained above. There was only one exception to this condition. This exception might have been due to error in data or adverse conditions of operation.

CONCLUSIONS AND RECOMMENDATIONS

The conclusions reached are that the installation of a so called conversion type that is the installation of a gas burner in a boiler designed to burn coal, calls for a careful study of the existing conditions. The best results in this test were obtained in an installation where the flue gases were blocked off somewhat, thus giving a longer flame travel which decreases the amount of heat lost in the flue gases. Also that using the same method of installation, the efficiency under full load conditions will be about the same for every well designed gas burner. In using a gas burner the damper should be closed as tight as possible without causing a leakage of gas from the furnace into the room. Keeping the damper closed will decrease the percent of excess air and thus decrease the loss of heat up the stack. If it is possible in the installation it is desirable to block the travel of the gases in some manner and thus increase the length of time that the gas is in contact with the heating surface. This operation will lower the flue gas temperature.

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