DETERMINATION OF FACTORS VITAL TO ECONOMICAL OPERATION OF A GAS BURNER INSTALLED IN A FURNACE DESIGNED FOR COAL BURNING IN HOME HEATING

by

HARRY LLEWELLYN KENT, JR.

B. S., New Mexico College of Agriculture and Mechanic Arts, 1929

A THESIS

submitted in partial fulfillment of the

requirements for the degree of

MASTER OF SCIENCE

KANSAS STATE AGRICULTURAL COLLEGE

1930

TABLE OF CONTENTS

INTRODUCTION

At the present time there is a very distinct trend toward the use of natural gas as a fuel for home heating.

At one time coal was the chief source of heat for home heating. Gas was considered undesirable because of the seasonal fluctuation of demand for it. In order to reduce somewhat the change in demand, gas companies put on special reduced rates which would make its more general use possible. As a result of this and other factors there is a very decided increase in the number of homes using gas as a means of heating. Gas is no longer considered a luxury since it has become as cheap or even cheaper than coal.

In choosing a fuel to be used for home heating, it is easily seen that gas has a very distinct advantage over any other type of fuel available. From the viewpoint of comfort, convenience, health, and economy it is by far the lowest priced fuel obtainable. From the standpoint of cleanliness no fuel on the market today can compare with it.

When a fuel is being chosen there are two chief factors to be considered, that of economy and that of the amount of heat to be produced. Economy is the most important of these. However, it may be noted that each of these depends somewhat on the other. The problem of providing sufficient heat is determined largely by the size of the unit installed. The economy is a matter of regulation, provided modern equipment is used. With many of the rather hurriedly built and cheaply constructed types of furnaces economy is almost impossible of attainment. There are now on the market many very good burners, most of which sell for a very reasonable figure and there is no necessity for using one of the less desirable types.

The problem of economical operation of gas burners installed in furnaces, originally designed for coal burning, is becoming a very important item in the field of home heating systems. It has become a very common thing to change from coal to gas as a fuel. Since the heating system has been installed in the homes it seems undesirable to completely revise the system, in fact it is not necessary. If a suitable burner is installed, then the question of operating on an economical basis becomes the most important problem.

The number of inquiries has become sufficient to warrant research work being done on the subject . Some work has been done on the subject in general. It has been discovered that gas fired furnaces are more efficient than coal fired furnaces. When it comes to the actual operation of a gas furnace for best results, very little information is available. Further work now seems necessary in order to obtain this more detailed information.

PURPOSE

The object of this research was to test a burner of a common type which is being used in this locality. The tests were run to determine the effect of the damper, primary air and secondary air settings upon the efficiency of a gas burner installed in a furnace designed for coal burning in home heating. Then to determine the best setting for economical operation.

ACKNOWLEDGMENT

The author wishes to express his thanks to Professor J. P. Calderwood, his major instructor, and to Professor A. J. Mack for their suggestions from time to time during the course of the research work and preparation of the material.

EQUIPMENT USED

The arrangement of the test apparatus is shown in Figure 1. (page 6). The tank, located on a platform above the boiler, was used to measure the weight of the water evaporated. The weight of the tank and water before and after the test gave a direct measure of the water admitted to

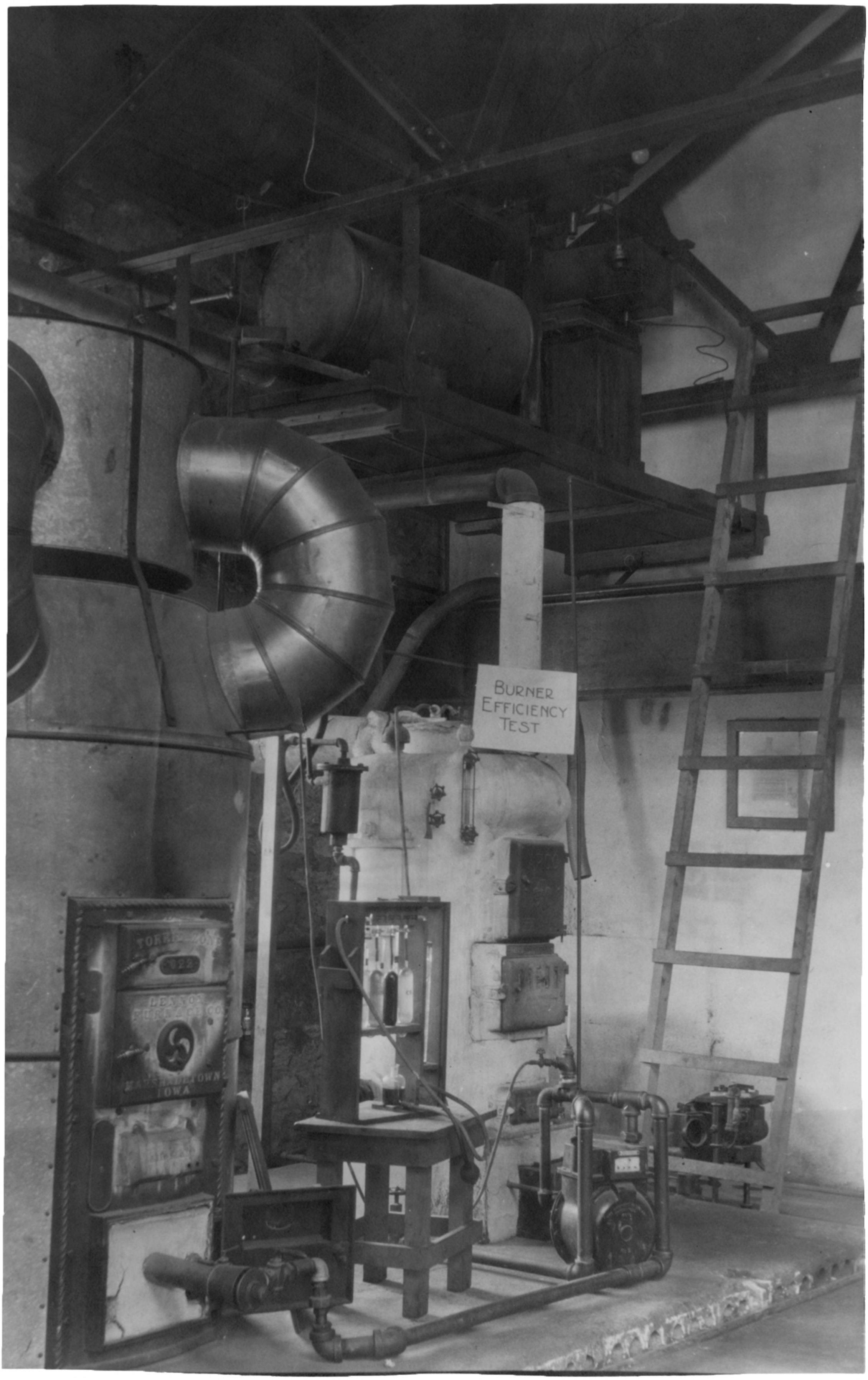


Figure 1.

the boiler. The tank was placed permanently on the scales so no extra calculations for weight of the tank were necessary.

The pressure of the gas was read in inches by means of a manometer. The gas volume was measured by means of a standard gas meter. All temperatures were read with Fahrenheit thermometers.

The burner used was manufactured by the Superheat Gas Burner Company of Salina, Kansas. It is of the premix type. In this type of burner the gas and air are combined in the desired proportions in a combining tube before entering the combustion chamber. The volume of gas passing may be varied by the openings at the point of combination with the primary air. The volume of primary air may be controlled by two circular cast-iron plates at the entrance to the combining tubes. These may be opened or closed to any desired position. The combining tube conducts the mixture to the burner nozzles. These nozzles are in cast-iron tubes, each being a half circle, thus making a circular burner. Nine fire clay radiants were used to radiate the heat to the furnace walls.

The furnace used was manufactured by the American Radiator Company of Kansas City, Missouri. It is of the Arco type designed to meet the specifications of the American Society of Mechanical Engineers. This furnace was built for coal burning and to be used in a steam house heating plant. The burner was installed in it and made a very satisfactory set-up. The diameter of the firebox of this furnace is twenty-two inches.

The flue gas analysis was obtained in per cent by volume with a standard Orsat apparatus.

PROCEDURE

By referring to Figure 1 (page 6) the actual set-up during a run may be seen. Each test was run for a period of four hours. Readings were taken every fifteen minutes. A setting was held constant throughout the entire four hours. Since it was possible to regulate the gas pressure, it was decided to run all tests at eight inches of water.

The readings taken were stack or flue gas temperature, temperature of water fed to the furnace from an overhead tank, temperature of the gas at the meter, and temperature of the surrounding air, all in degrees Fahrenheit. The gas was measured in cubic feet by means of a standard gas meter. The gas pressure was taken in inches of water. The flue gas analysis was made in per cent by volume. Readings of CO_2, O_2, and CO were recorded. The weight of water supplied to the furnace was taken in pounds. The heating value of the gas was found with the Sargent's Standard Gas Calorimeter.

The investigations were carried on in three groups of five tests each. There are three factors which determine the economy of a burner. They are damper, primary air, and secondary air setting. In order to get any comparable results it was necessary to set two factors constant and vary the third. In this case that was done, with each factor being varied in a separate set of tests of five runs each.

In the first set of tests the damper was held shut and the primary air held constant at the three-fourths open position. The secondary air being varied through five positions, one for each test. The settings used were shut, one-fourth open, one-half open, three-fourths open, and wide open.

The next set of tests was run with the secondary air one-fourth open and the primary air three-fourths open, both held in the same position through the entire range of tests. In this case the damper was varied through the five positions of shut, one-fourth open, one-half open, three-fourths open, and wide open.

The third series of tests was run with the secondary air held constant at one-fourth open and the damper held shut. In this case the primary air was varied through the five positions of shut, one-fourth open, one-half open, three-fourths open, and wide open.

THEORETICAL TREATMENT

In order to prepare the way for a more complete understanding of the formulas used in the calculations to follow it will be necessary to discuss the theory involved in the combustion or the burning of natural gas. This is necessary before the discussion of what happens in a gas burner, during operation, can be taken up. There are certain fundamental equations and formulas which must be clear before discussing the results.

Natural gas is made up mainly of methane (CH_4) with small quantities of other hydrocarbons, chiefly ethane; however, carbon dioxide, carbon monoxide, oxygen, and nitrogen are usually present in smaller quantities. The natural gas available in Manhattan, and which was used in this research work, is analyzed by the Gas Company as follows: methane 84 per cent, ethane 12 per cent, and inert gas 4 per cent. The inert gas will be considered as nitrogen in this thesis.

Combustion is a chemical process in which the oxygen of the air combines with the combustible elements of the gas at such a rate as to produce light and heat. It is in reality a rapid oxidation in the presence of light and heat

Calculations concerning combustion all depend on a few simple laws and on a number of applications of these laws to combustion.

The four laws on which all combustion calculations depend are:

1. Conservation of matter
2. Conservation of energy
3. The gas law
4. The law of combining weights

The law of conservation of matter is very simple and merely states that over a period of time, matter can neither be gained nor lost. In any process then, all materials which enter must also leave it. The form of the combinations may change entirely but there is no destruction or production of matter. Now it can be seen that all materials entering a furnace must in some form leave it. These materials entering a furnace are air and natural gas. In the furnace they combine to form flue gas and pass on up the stack. It can be stated that the total material which passes off as flue gas must be equal to the total material entering in the form of fuel and air.

The law of conservation of energy is the same principle as that of matter. It can be neither gained nor lost. The heat from the fuel entering the furnace is distributed so that some goes to heat the water in the boiler, some is lost up the stack as heat above water temperature in the gases, in some cases it may be undeveloped heat in the form of carbon monoxide, and some is lost by radiation through the walls of the furnace and flues. Then it must be that the total heat, utilized and lost, must be equal to the heat energy of the fuel gas, providing a suitable period of time elapses.

The fundamental gas law is expressed by the equation:

$$PV = NRT$$

where

P is the absolute pressure

V is the volume

N is the number of mols

R is the gas constant

T is the absolute temperature of the gas.

In order to use this equation to the best advantage with accurate results it is necessary thoroughly to understand what is meant by a mol. By definition a mol of a substance is the number of pounds of the substance equivalent to the molecular weight. For example the molecular weight of oxygen is thirty-two and therefore, the mol of oxygen must be thirty-two pounds.

When the theory of combustion is studied a knowledge of the law of combining weights is necessary. The law of combining weights states that the elements combine in simple and constant proportions to form definite compounds. In using this law the fundamentals of the relative proportion in which substances combine must be kept in mind. These may be easily shown by simple chemical reactions. In these reactions the chemical symbols represent one mol of the substance unless a number be placed before it designating the number of mols required to complete the reaction.

The primary equations used in the combustion of natural gas and, therefore, the ones used in this research are as follows:

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

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

In the discussion to follow it will be much simpler to show the theory by less involved equations, such as those used in the burning of coal. In the case of coal burning the following reactions take place:

(3) $C + O_2 = CO_2$

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

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

Here it may easily be seen in equation (3) that one mol of carbon (twelve pounds) will combine with one mol of oxygen (thirty-two pounds) to form one mol of CO_2 (fortyfour pounds).

The products of combustion of natural gas, commonly known as flue gases, consist chiefly of carbon dioxide, oxygen and nitrogen. In cases of poor combustion some carbon monoxide may be present. In all cases small amounts of water vapor are present. An analysis of the flue gas will afford an excellent basis for judging the efficiency of combustion. The first step in the analysis is to obtain a representative sample of the flue gas. Since the gases in the stack may be far from homogeneous, great care must be taken in obtaining this sample.

The analysis is ordinarily made volumetically, as was done in these investigations. The apparatus used was a standard Orsat apparatus for measuring the content of flue gases volumetically. An analysis of air would show twenty-one per cent oxygen and seventy-nine per cent nitrogen. These would be, of course, percentages by volume. Now since the mol may be made into a volume unit of 385 cubic feet, molal relationships may be obtained directly from the flue gas analysis.

The analyses of flue gas are always made on the dry basis. These analyses are usually made over water, with the same partial pressure and temperature throughout. Then if a certain per cent of a gas is absorbed out by one of the liquids in the apparatus the same percentage of the water vapor content must also be absorbed. This will give a final result on a dry basis the same as if dry gas were actually used.

Much use is made of the flue gas analysis in studying combustion. In case the analysis of the flue gas and of the fuel gas are available, as they are in almost every case, the results of combustion may readily be calculated. The chief use of it would be made in determining the relative volumes of fuel gas and air required.

It might be well to show a set of sample calculations as used in the actual calculating of the data.

The data used here are from an actual test run in the course of the investigations. The setting of the furnace was, damper shut, secondary air one-fourth open, and primary air one-fourth open.

The data recorded were as follows: feed-water temperature 69.4° F., stack temperature 281° F., room temperature 84° F., gas temperature 89.4° F., barometric pressure 29.00 inches of mercury, CO_2 - 8.6%, O_2 - 5.2%, CO - 0.0%, N_2 - 86.2%, by difference, total pounds of water evaporated 364, total gas burned 540 cubic feet. Fuel gas analyses CH_4 - 84%, C_2H_6 - 12%, and N_2 - 4%. Duration of test four hours.

One method of finding the relative volumes of fuel gas and flue gas is by means of a carbon balance. That is the carbon in the fuel gas must equal the carbon in the flue gas. If we take 100 mols of dry flue gas as a basis we find there are 8.6 mols of carbon, 13.8 mols total oxygen and 86.2 mols of N_2. The total oxygen consists of 8.6 mols as CO_2 and 5.2 mols of free oxygen.

When the methane is burned the reaction as follows occurs:

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

It can now be seen that it takes two mols of oxygen to combine with one mol of CH_4, giving one mol of CO_2 and two mols of water vapor.

The combustion of the ethane in the fuel gas results in the following reaction:

$$2C_2H_2 + 7O_2 = 2CO_2 + 3H_2O$$

This results in twice the volume of CO_2 as was originally in the ethane.

Taking up the fuel gas it will be assumed as before that there are 100 mols, 84 mols of methane gas, 12 mols of ethane gas and 4 mols of inert nitrogen. From the above equations it may be seen that the result of this combustion will result in 84 mols of carbon dioxide formed from the 84 mols of methane and 24 mols of carbon dioxide from the 12 mols of ethane. Now in order to determine the total amount of CO_2 obtained from 100 mols of fuel gas we must add the amount from methane and ethane. That gives a total result of 108 mols of CO_2 from 100 mols of fuel gas.

In the example there were 8.6 mols of CO_2 formed. In order to produce this amount of CO_2 there must be 8.6/1.08 or 8.04 mols of fuel gas burned. For from the above example it may be seen that 1.08 mols of gas must be burned to produce 1 mol of CO_2.

Since the fuel gas is 84 per cent methane there must be 8.04 X .84 or 6.75 mols of methane gas burned to give the amount of CO_2 formed from it.

Now there was a content of 12 per cent ethane in the fuel gas. Then there must have been .12 X 8.04 or .9745 mols of ethane gas burned to produce the amount of CO_2 formed by the ethane gas in combustion.

The number of mols of inert nitrogen in this combustion will be 8.04 X .04 or .3215 mols.

It is now relatively easy to determine the ratio of dry flue gas to the fuel gas. The ratio will be 100/8.04 or 12.45 mols of dry flue gas per mol of fuel gas. This value may be converted directly to volumes since the molal relationship is also a volume relationship. There were then 12.45 cubic feet of dry flue gas produced for every cubic foot of fuel gas entering the furnace under the same conditions.

The dry flue gas to dry air may be found through the nitrogen balance. That is, the nitrogen supplied in the air plus the nitrogen in the fuel gas must equal the nitrogen in the flue gas. In the example previously used there were 86.2 mols of nitrogen present in 100 mols of dry flue gas. As a part of this nitrogen is inert nitrogen from the fuel gas an allowance must be made for it. There were, as determined above, .3215 mols of inert nitrogen in 100 mols of flue gas. Then the amount of nitrogen supplied by the air in this case must be 86.2 - .3215 or 85.9785 mols. Since the air contains 79 mols of nitrogen per 100 mols of dry air there must be 85.9785 X 100/.79 or 108.75 mols of nitrogen supplied from the air. The ratio of dry flue gas to the dry flue gas would then be $\frac{100}{85.9785 \times 100/.79} = .9195$ mols of dry flue gas per mol of air; converting to cubic feet, there must be .9195 cubic feet of flue gas per cubic foot of air used for the combustion of the fuel gas.

From this relationship is to be determined the ratio of air to dry fuel gas. From above there were 12.45 cubic feet of dry flue gas per cubic foot of fuel gas and .9195 cubic feet of flue gas per cubic foot of air. Then it will be seen that there must be supplied 12.45/.9195 or 13.56 cubic feet of air per cubic foot of fuel gas.

Excess Air

In furnace and boiler computations the term excess air is defined as the per cent of air in excess of that theoretically required for complete combustion of the given fuel. Taking 100 mols of the fuel used it is seen that one mol of CH_4 requires two mols of oxygen to burn it completely, then the 84 mols contained in the 100 used would require 168 mols of oxygen. There are 12 mols of C_2H_6 contained in 100 mols of the gas; as each mol of C_2H_6 requires 3.5 mols of air to burn it completely, it takes 42 mols to burn the 12 mols of C_2H_6. Now it can be seen that there will be required 210 mols of oxygen to completely burn 100 mols of gas, since 4 mols of it are inert

The quantity of air required would then be 210/.21 or 1000 mols. From this it can be seen that one cubic foot of gas requires ten cubic feet of air to completely burn it.

In the previous example it was found that the amount of air actually supplied was 12.45 cubic feet. Now the per cent of excess air in that particular case would be $(12.45 - 10)/10 \times 100 = 24.5$ per cent.

Efficiency

The efficiency of each run was found by dividing the output by the input both values being in British Thermal Units. The values used in forming an equation for the efficiency were heat in the water as fed to the boiler, the heat in the evaporated water, and the number of pounds of water evaporated for the output. The input is the amount of heat contained in the gas per cubic foot in British Thermal Units.

The heat put out by the boiler may be found by the following formula:

Output = $W(H_1 - h_2)$ in which

W = the number of pounds of water evaporated

h_2 = heat of the water above 32° F.

H_1 = the total heat in one pound of steam above 32° F.

The input may be found by knowing the volume of gas as measured by the meter in cubic feet, and the heating value of the gas in British Thermal Units.

The following formula will give the result:

Input = $V \times H$ in which

V = volume of gas in cubic feet

H = heating value of the gas in British Thermal Units.

The efficiency is then:

$$\frac{\text{output}}{\text{input}}$$

Substituting the above values for output and input the following equation for efficiency is determined:

$$\text{Efficiency} = \frac{W(H_1 - h_2)}{V \times H}$$

Using the same set of data as in the previous examples the efficiency is found to be:

$$\frac{364(1148 - 37.4)}{540 \times 1000} = 75.0\%$$

EXPERIMENTAL DATA AND RESULTS

In taking up the data as recorded from the various tests it will be well to refer to Tables I, II and III. Table IV is a sample of the manner in which the data from each test were taken. Tables V, VI and VII show the calculated results. Samples and methods of these calculations were shown previously.

The results of these series of investigations will be discussed under the following headings:

(a) Efficiency of the burner and the different causes of its change

(b) The flue gas temperatures

(c) The per cent of CO_2

(d) The per cent of excess air

Each of these topics will be taken up in detail and their effects shown as well as the factors affecting them.

In most of the discussion it will be necessary to overlap slightly because of the numerous ways in which one of the factors may affect the others. That is to say, for example, the effect of the CO_2 cannot be shown without bringing the stack temperature and draft setting into the discussion.

Referring to Figures 5, 6 and 7 it may be seen that in order to show the effects and relationships of the efficiency, CO_2, and stack temperature the three curves must be shown on the same sheet. It then gives a very clear basis for determining the actual effects of each upon the other. It may be noted in these curves that the efficiency depends to a great extent on the regulation of the damper. The highest efficiencies occur when the damper is shut and the lowest efficiencies when the damper is open. When the damper is opened it allows more gas to escape up the stack, thus increasing the draft at the entrance. Now every cubic foot of gas going up the stack must be heated to the flue gas temperature. When a large amount of draft is allowed it means a direct loss of heat up the stack. There is no benefit received from it whatsoever. Some excess air is usually considered necessary in order to insure complete combustion. The damper is the best means of regulating this and of course indirectly of maintaining a good efficiency. In this series of tests the best efficien-

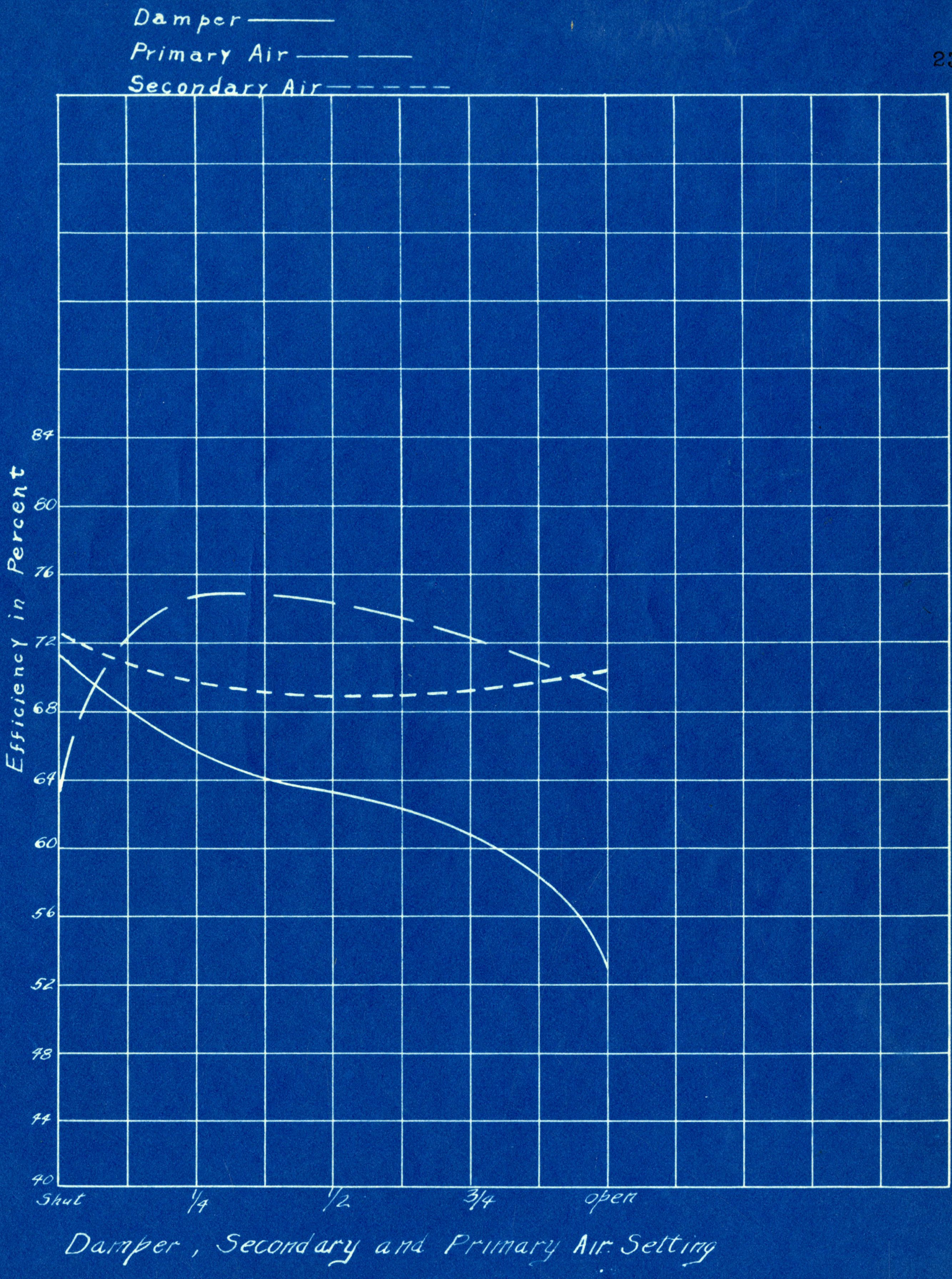

Damper ———
Primary Air —— ——
Secondary Air - - - - -
Efficiency in Percent
84
80
76
72
68
64
60
56
52
48
44
40
Shut
1/4
1/2
3/4
open
Damper, Secondary and Primary Air Setting

Fig 2

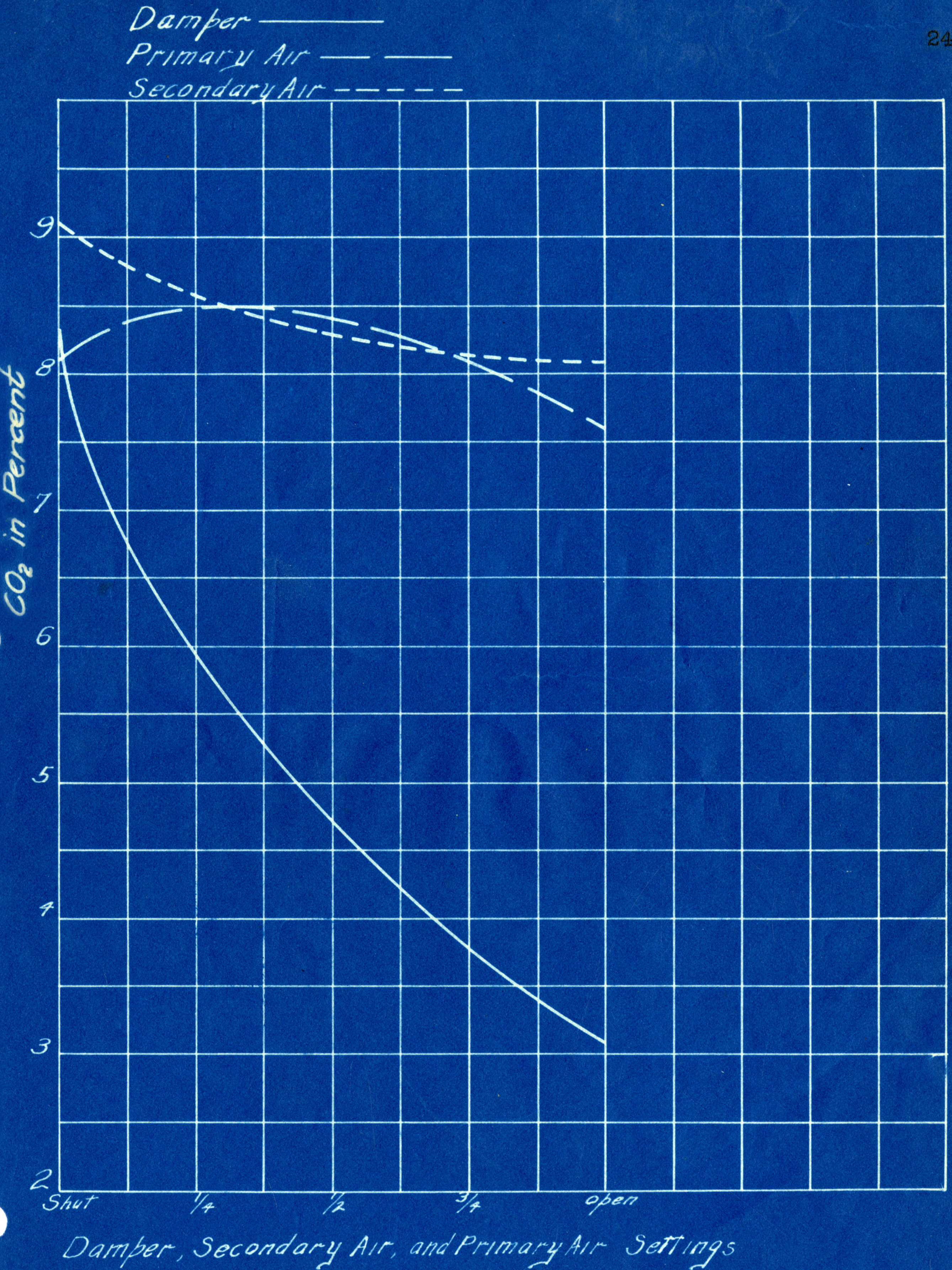

Damper
Primary Air
Secondary Air
CO2 in Percent
9
8
7
6
5
4
3
2
Shut
1/4
1/2
3/4
open
Damper, Secondary Air, and Primary Air Settings

Fig. 3.

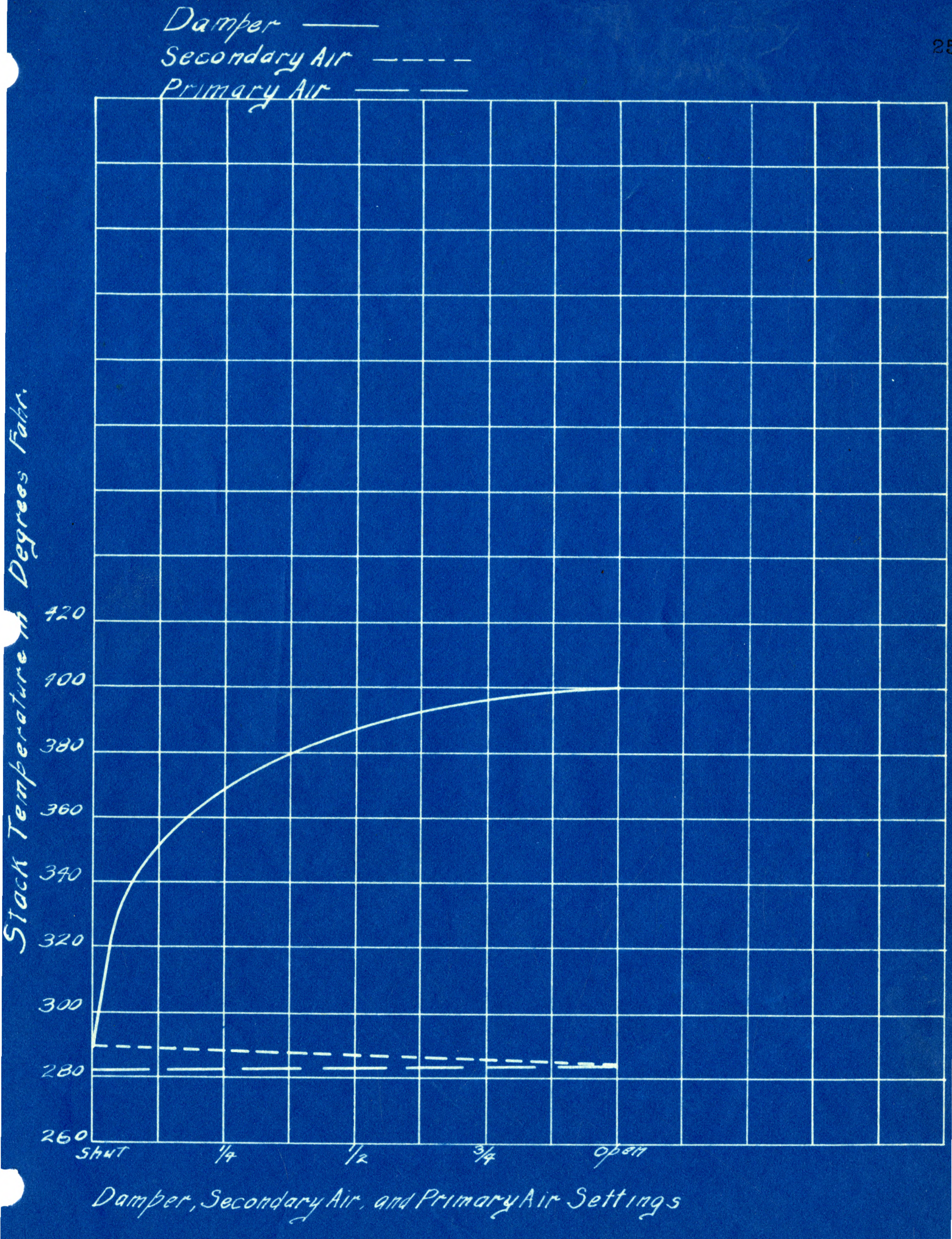

Damper
Secondary Air
Primary Air
Stack Temperature in Degrees Fahr.
420
400
380
360
340
320
300
280
260
Shut
1/4
1/2
3/4
open
Damper, Secondary Air, and Primary Air Settings

Fig 4

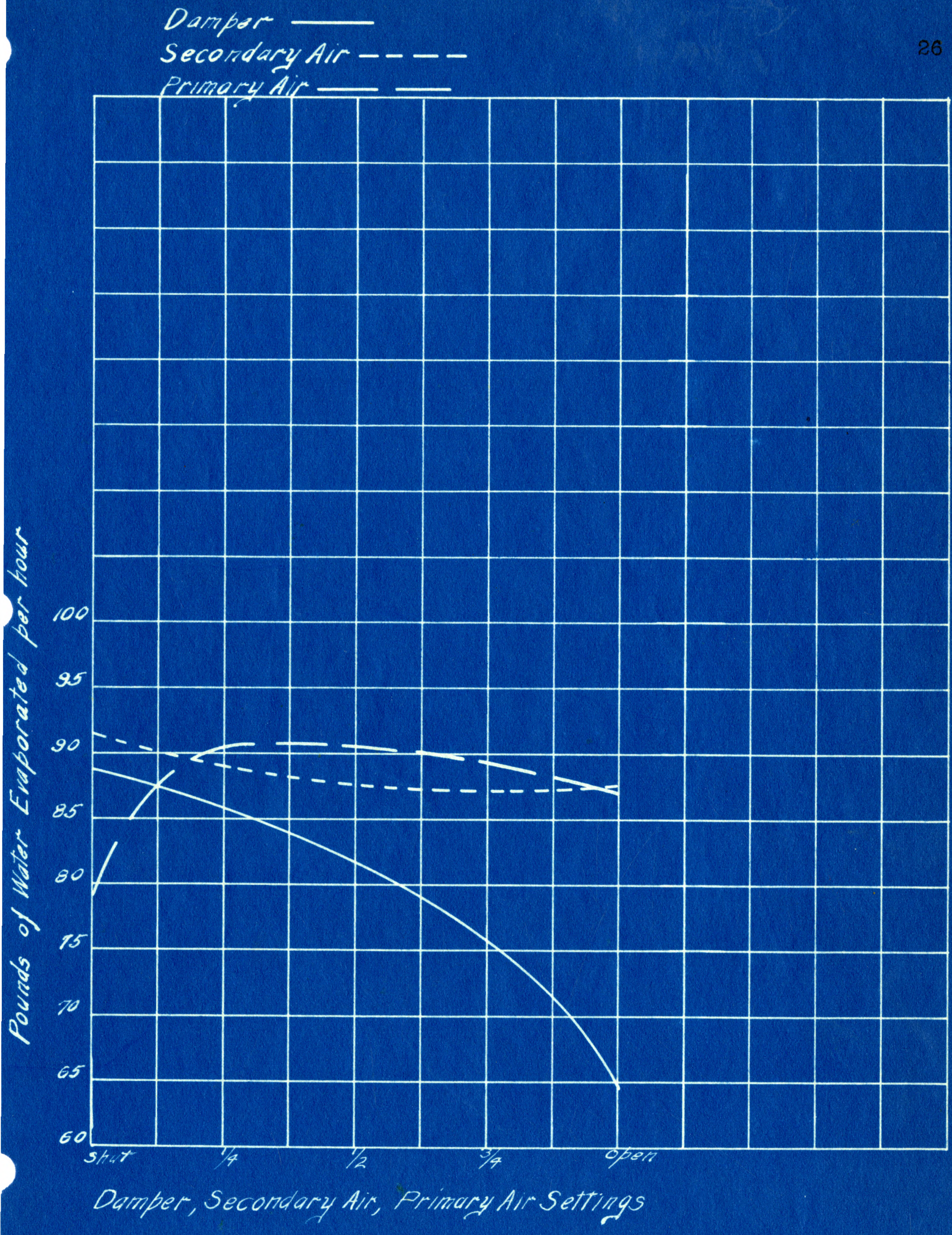
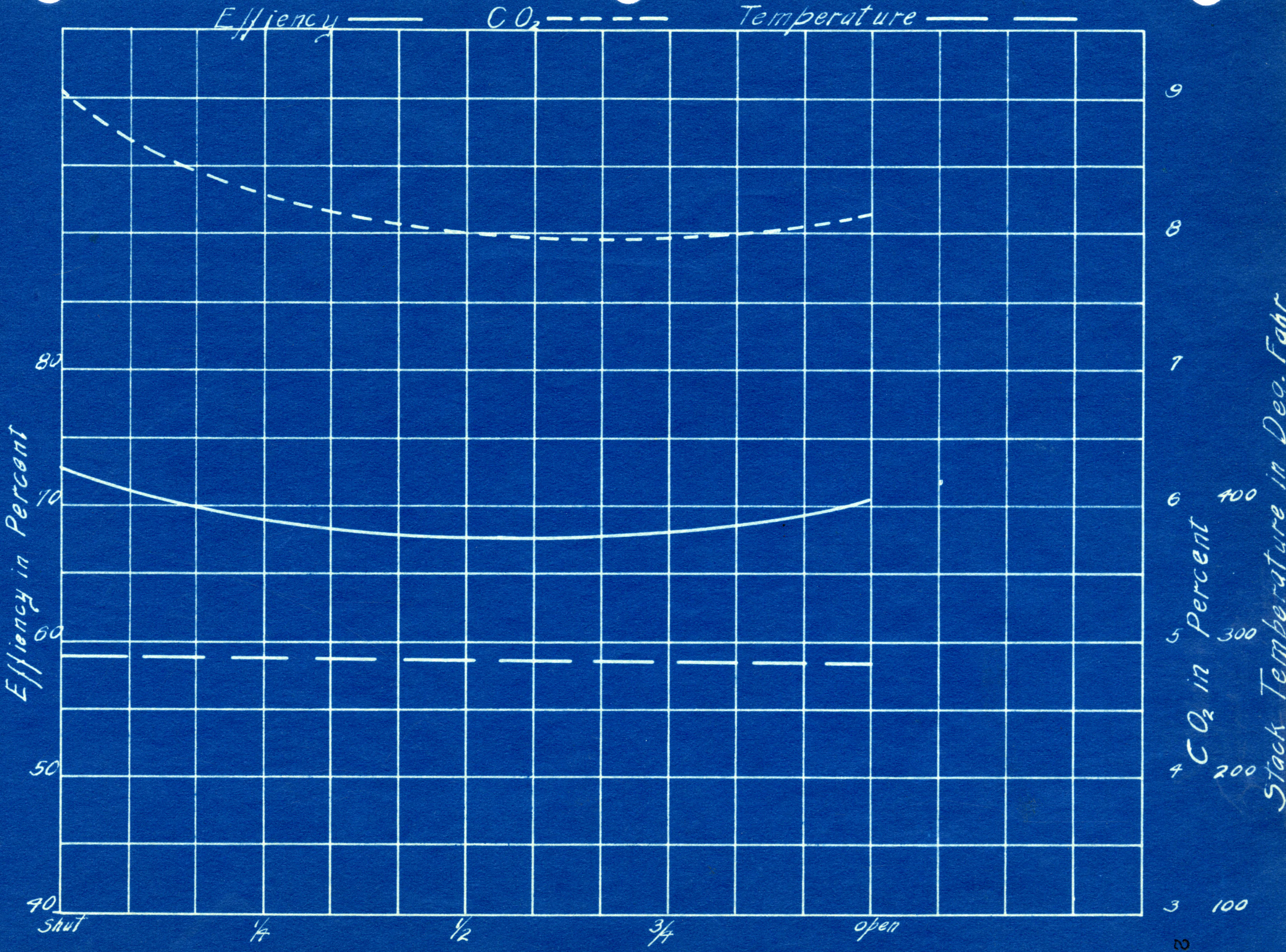
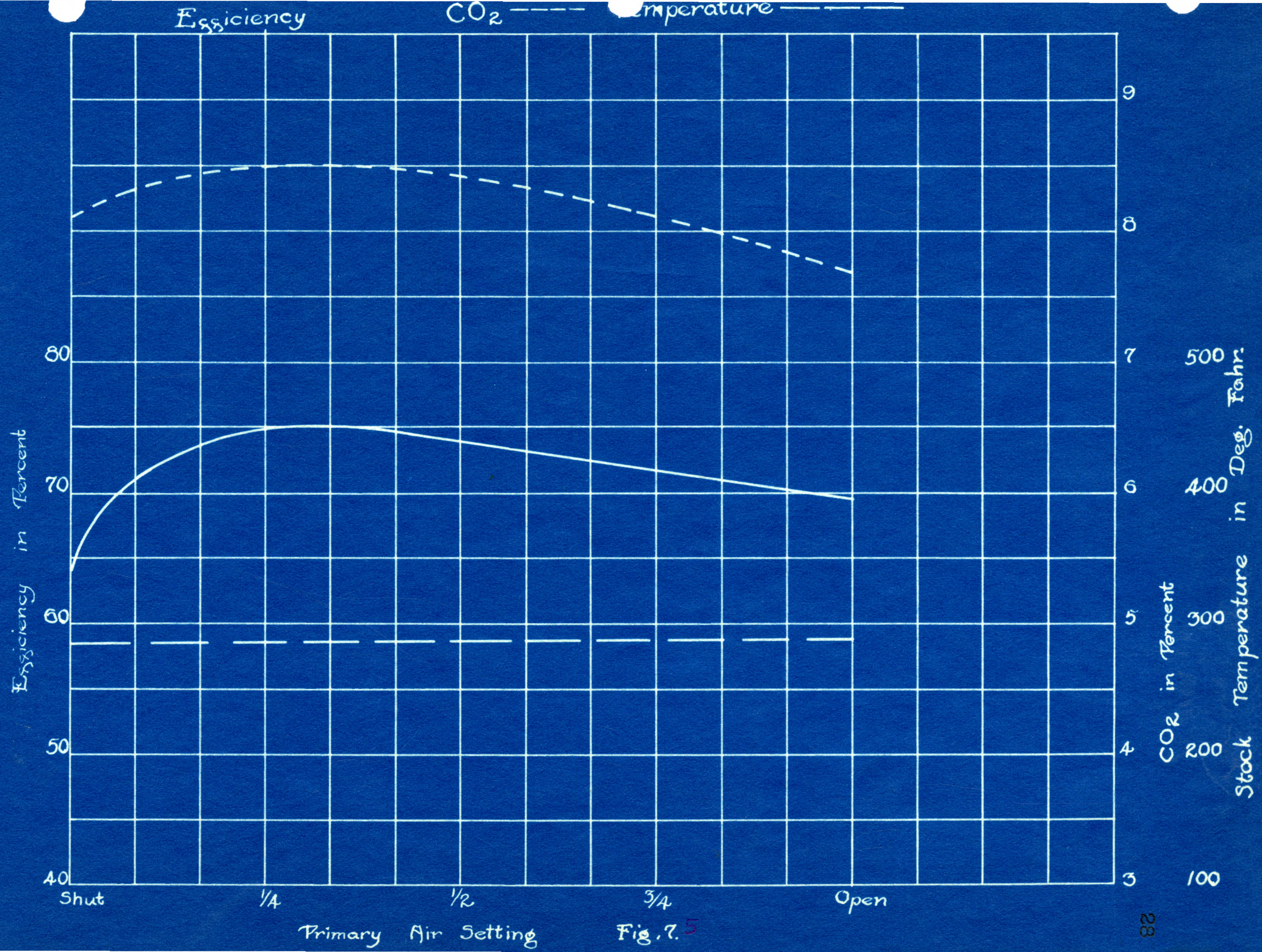

Damper
Secondary Air
Primary Air
Pounds of Water Evaporated per hour
100
95
90
85
80
75
70
65
60
Shut
1/4
1/2
3/4
Open
Damper, Secondary Air, Primary Air Settings

Fig 5

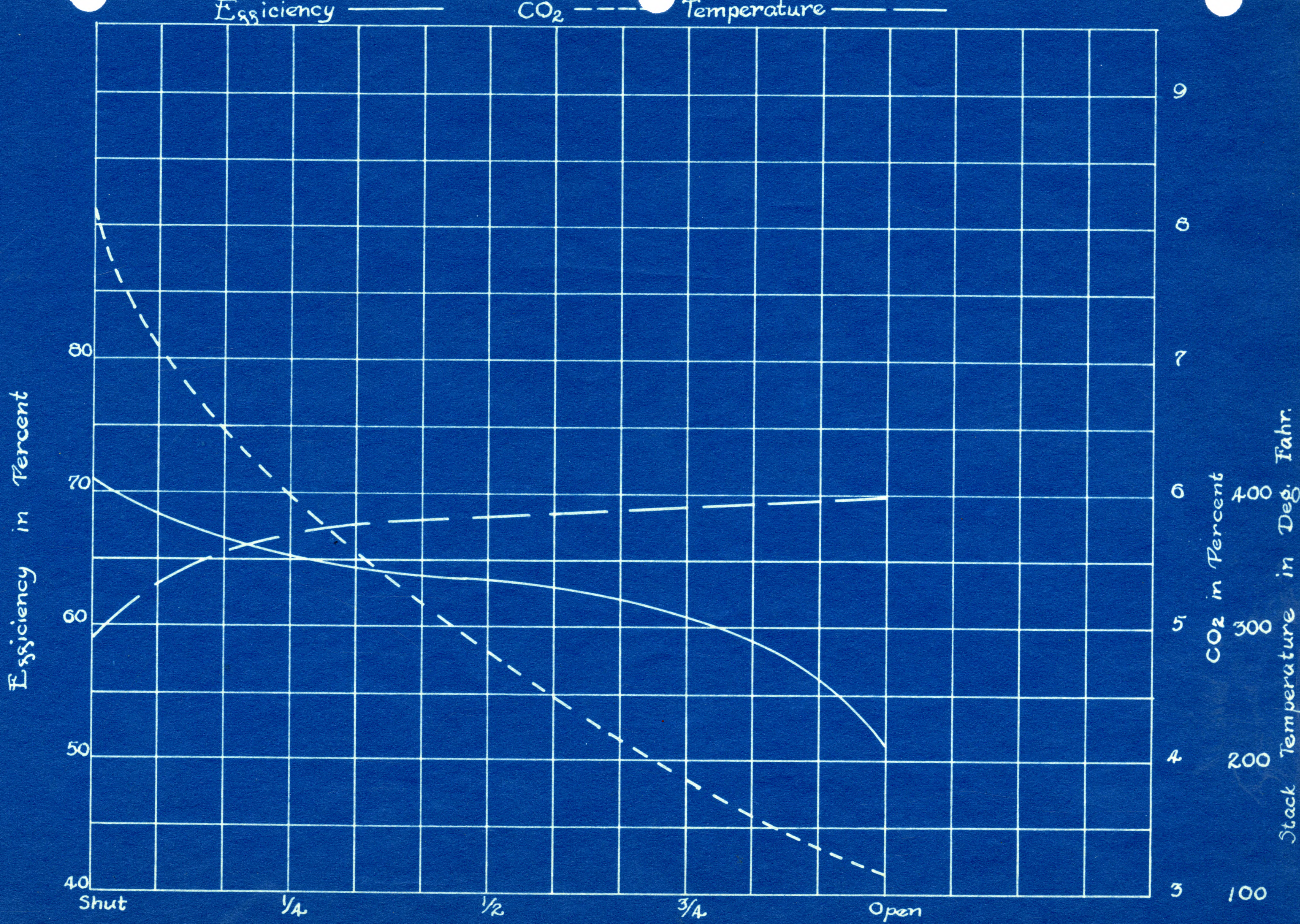


Secondary Air Setting Fig. 6.6



Efficiency
CO_2 ----
emperature — — —
80
70
60
50
40
9
8
7
6
5
4
3
500
400
300
200
100
Shut
1/4
1/2
3/4
Open
Efficiency in Percent
CO_2 in Percent
Stock Temperature in Deg. Fahr.
Primary Air Setting

Fig. 7. 5



Damper Setting Fig. 8.

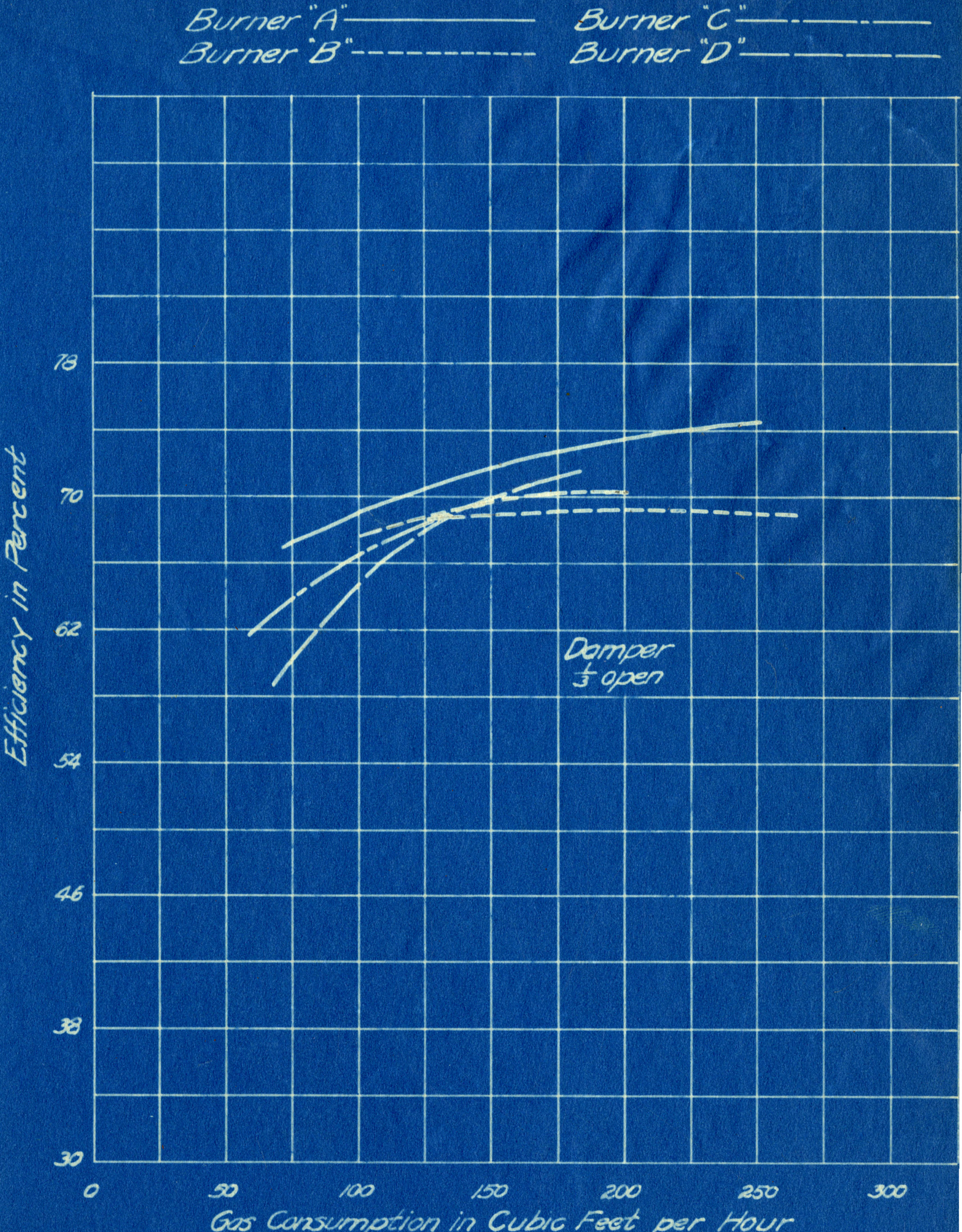

Burner "A"
Burner "B"
Burner "C"
Burner "D"
78
70
62
54
46
38
30
Efficiency in Percent
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour
Damper
1/3 open

Fig. 4

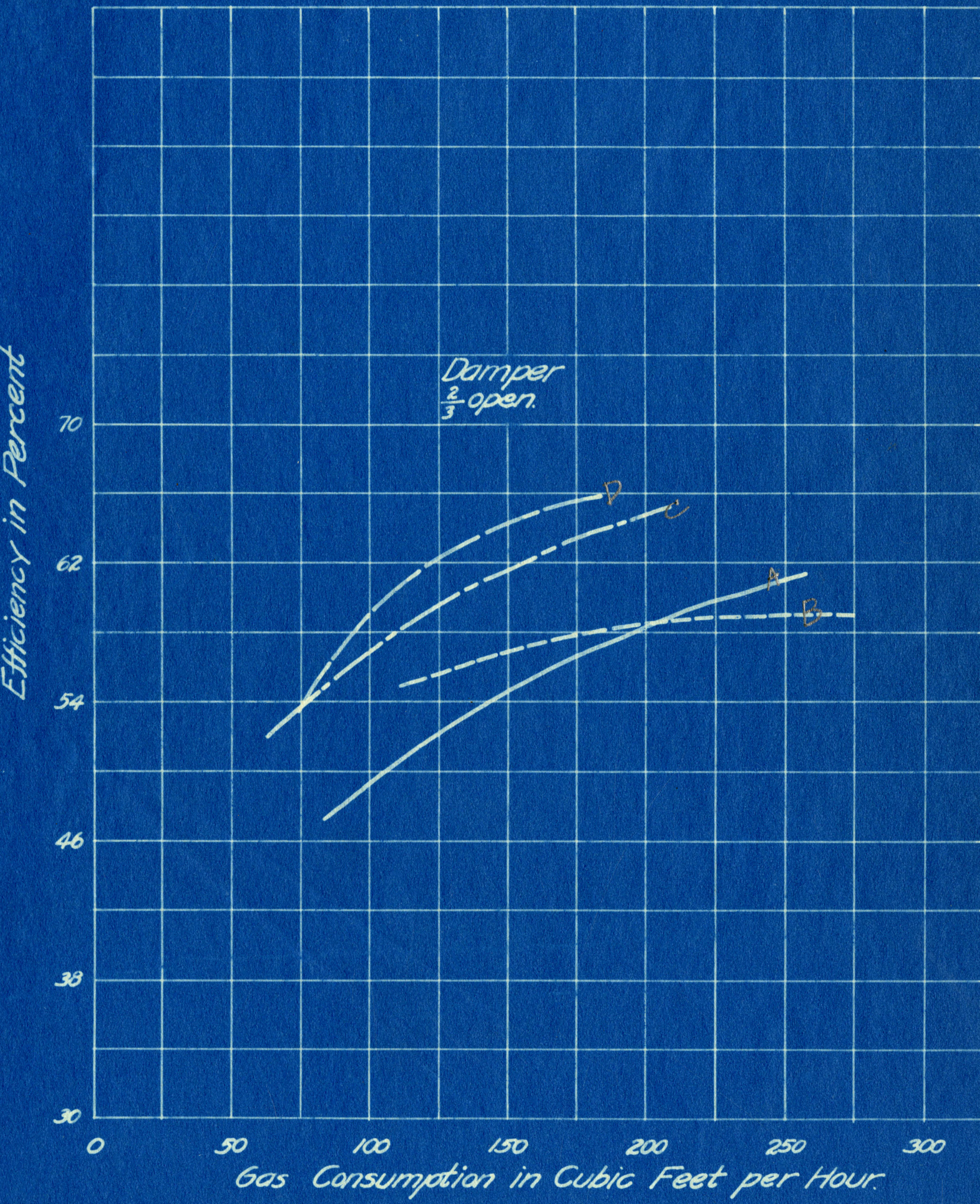

Efficiency in Percent
30
38
46
54
62
70
Damper
$\frac{2}{3}$ open.
D
C
A
B
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 5

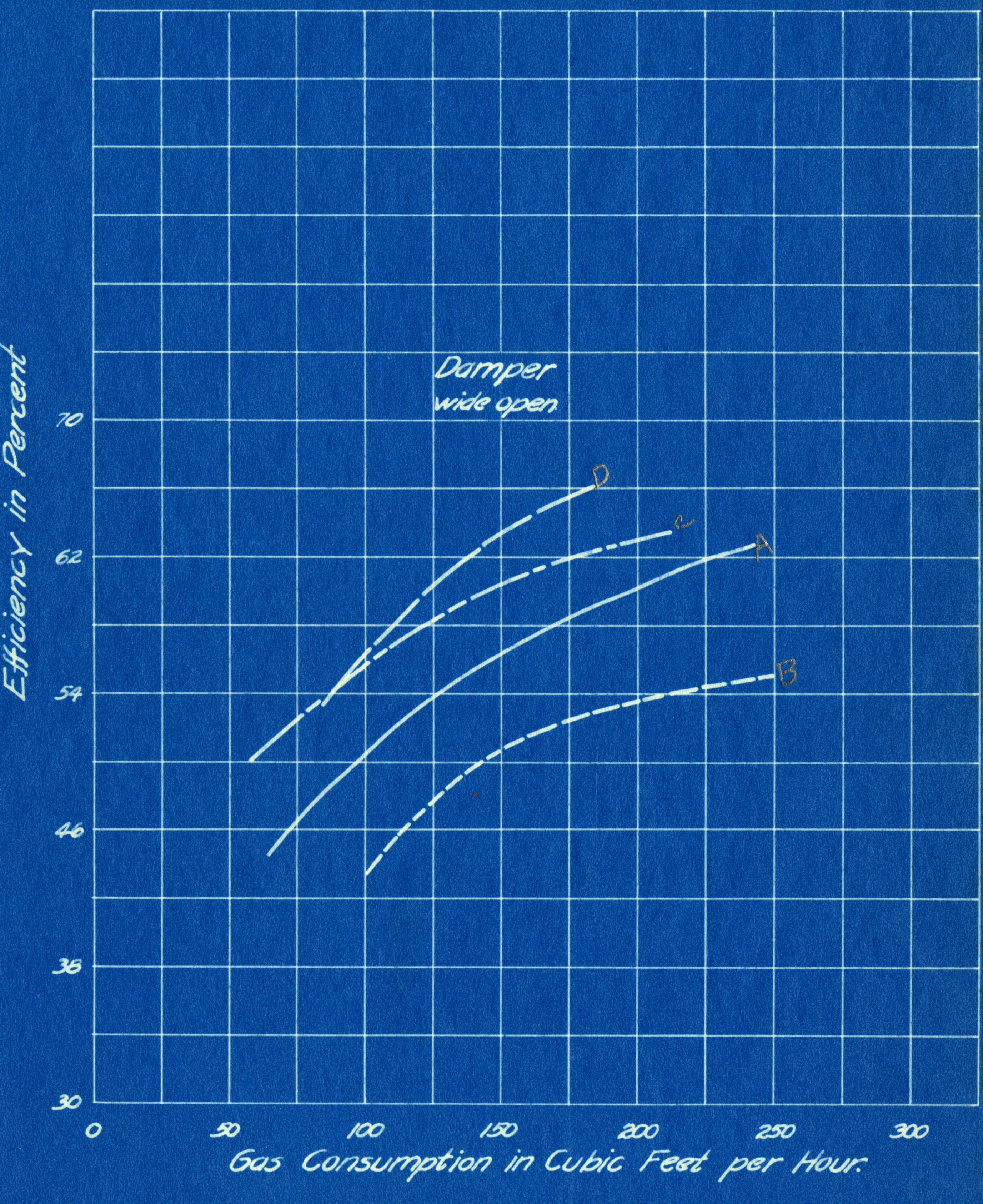
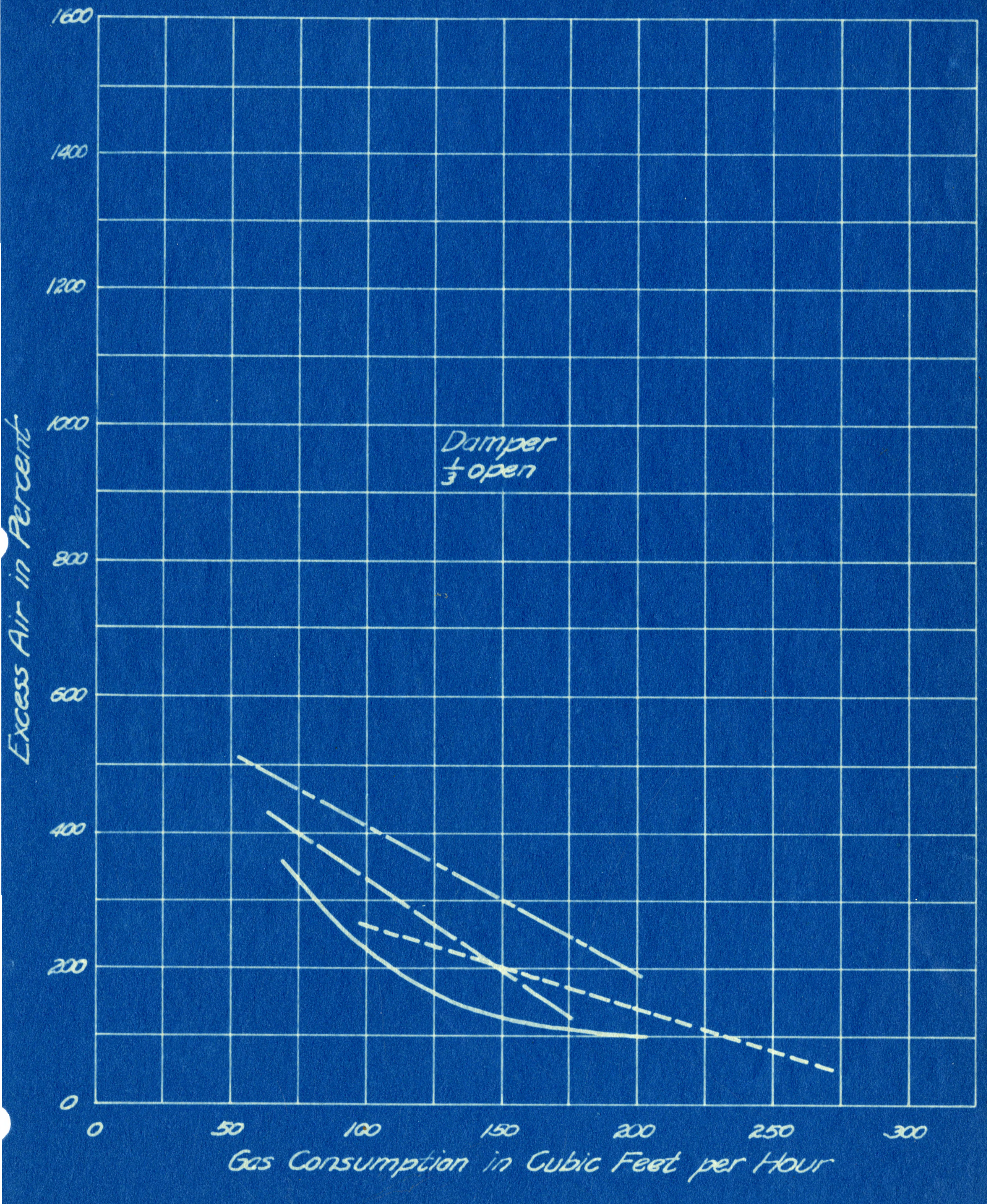

Damper
wide open
D
c
A
B
Efficiency in Percent
70
62
54
46
38
30
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 6



1600
1400
1200
1000
800
600
400
200
0
Excess Air in Percent
Damper
1/3 open
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 7

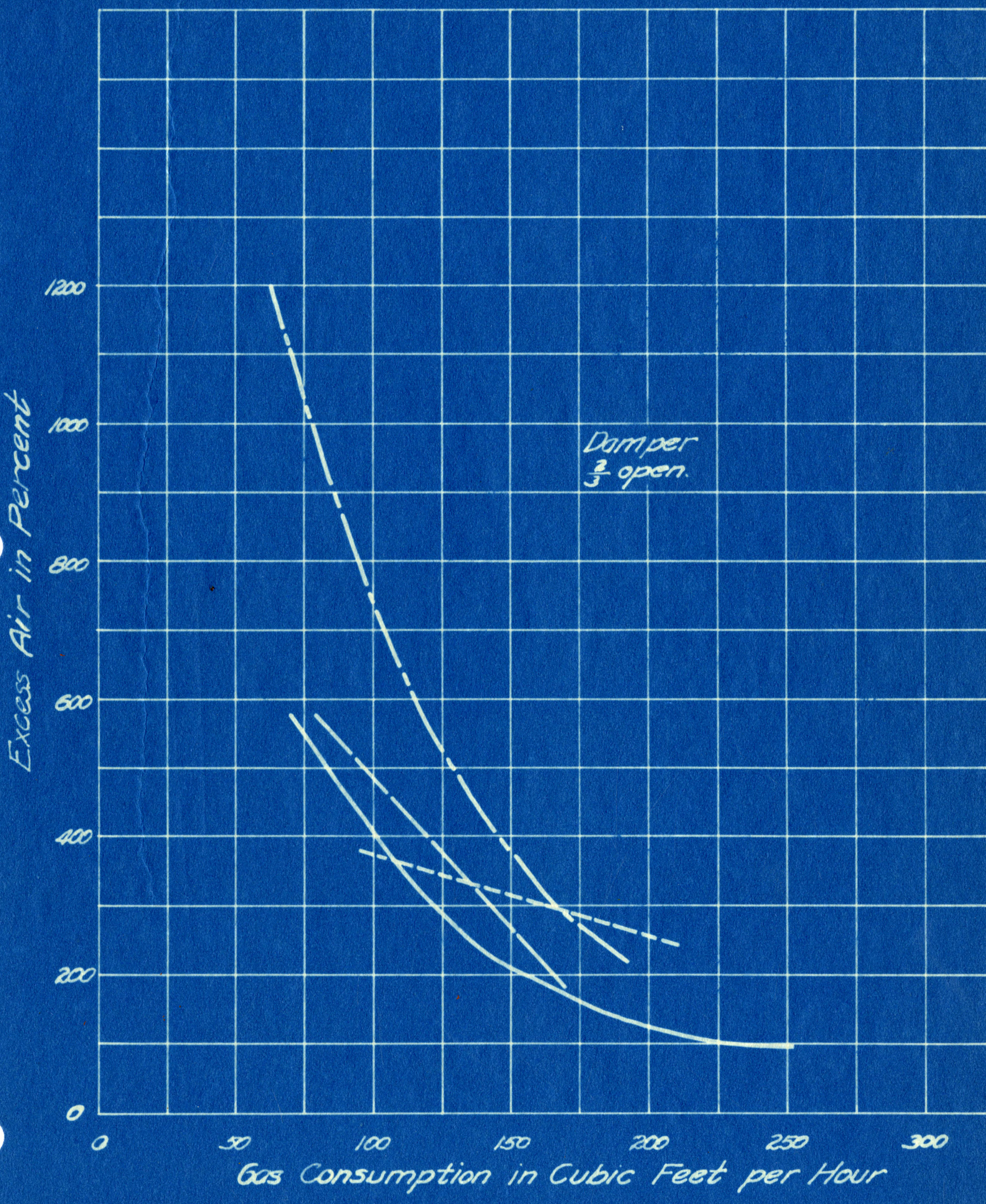

Excess Air in Percent
1200
1000
800
600
400
200
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour
Damper
2/3 open.

Fig. 8

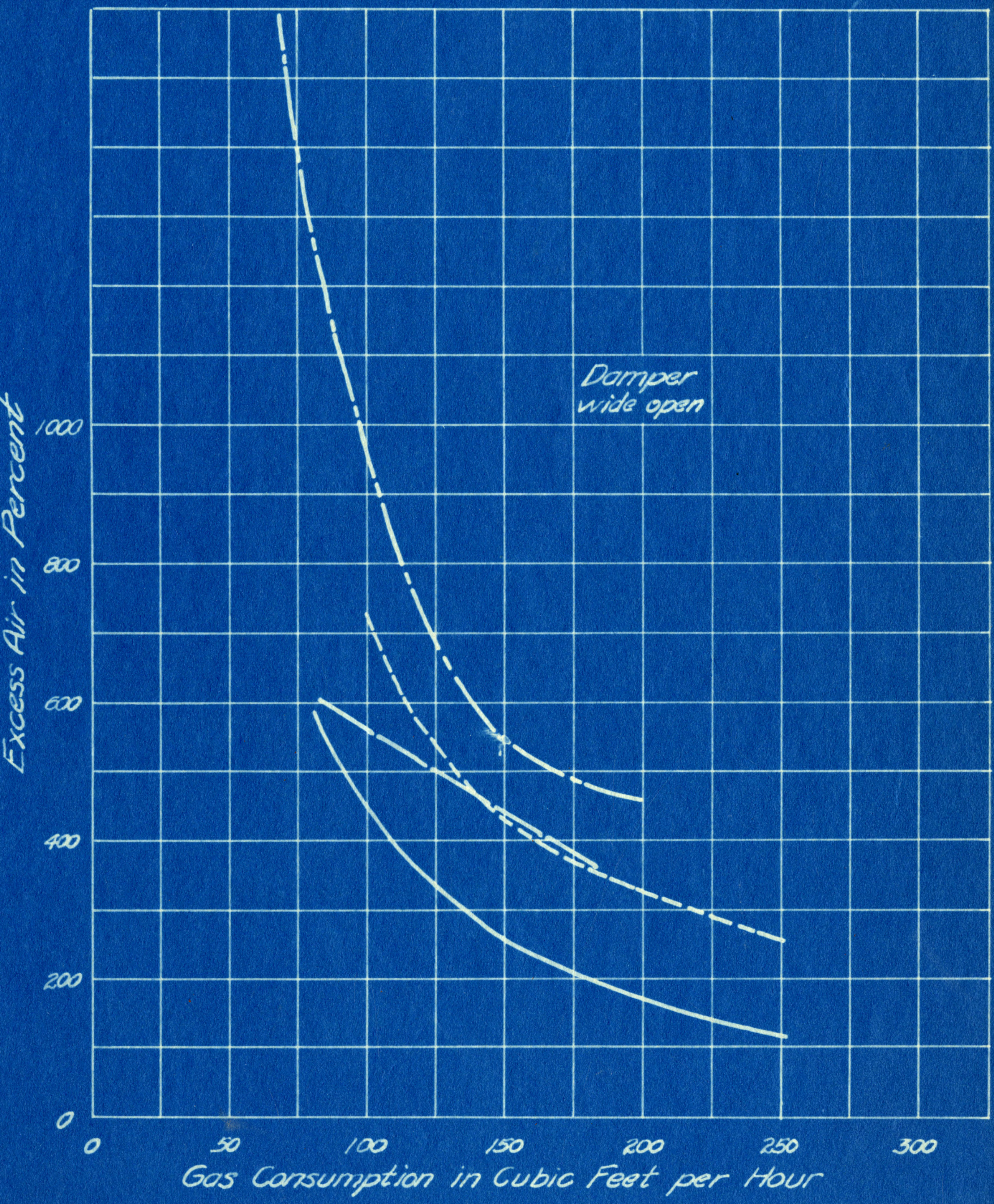

Damper
wide open
Excess Air in Percent
1000
800
600
400
200
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 9

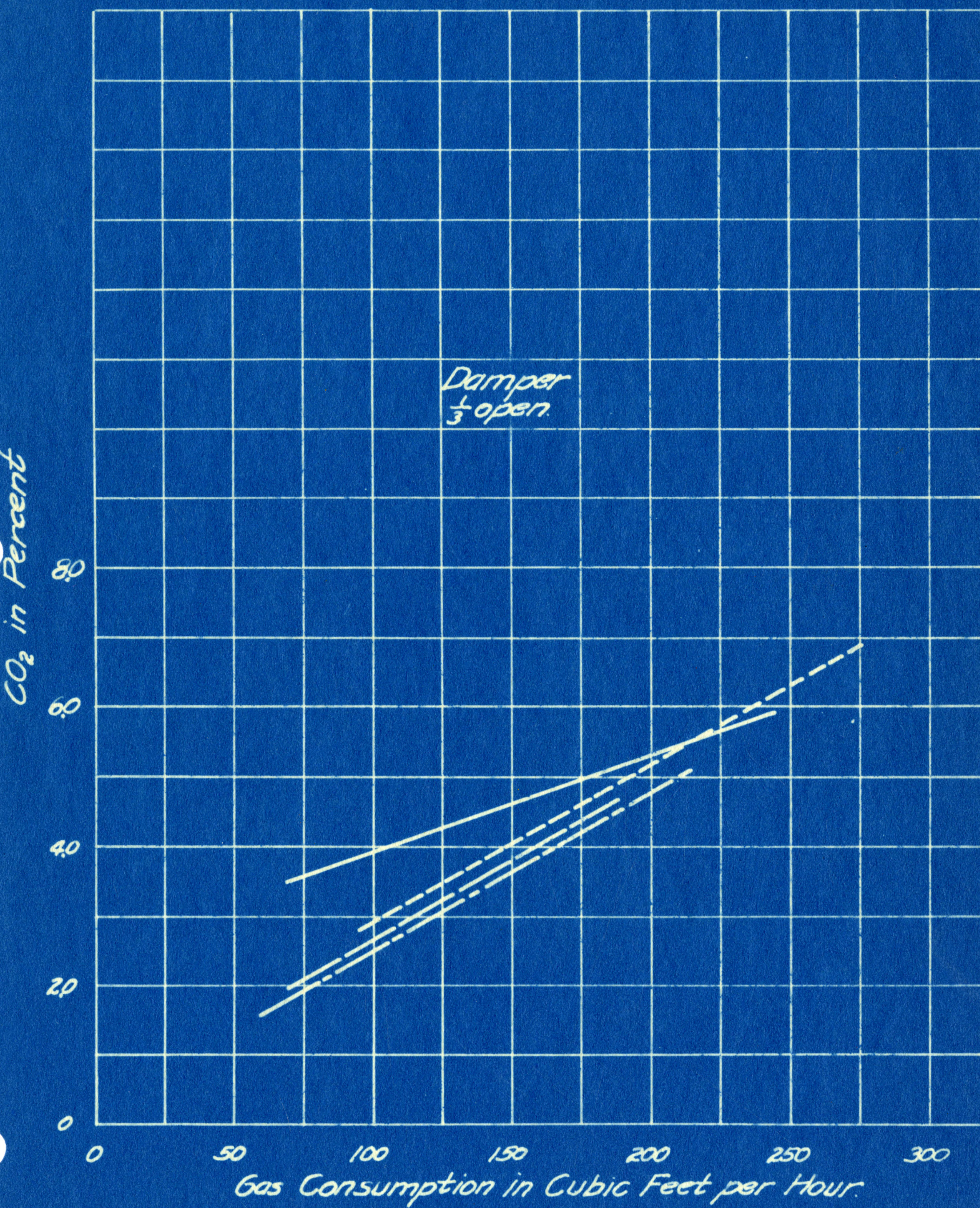

Damper
1/3 open
CO_2 in Percent
8.0
6.0
4.0
2.0
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 10

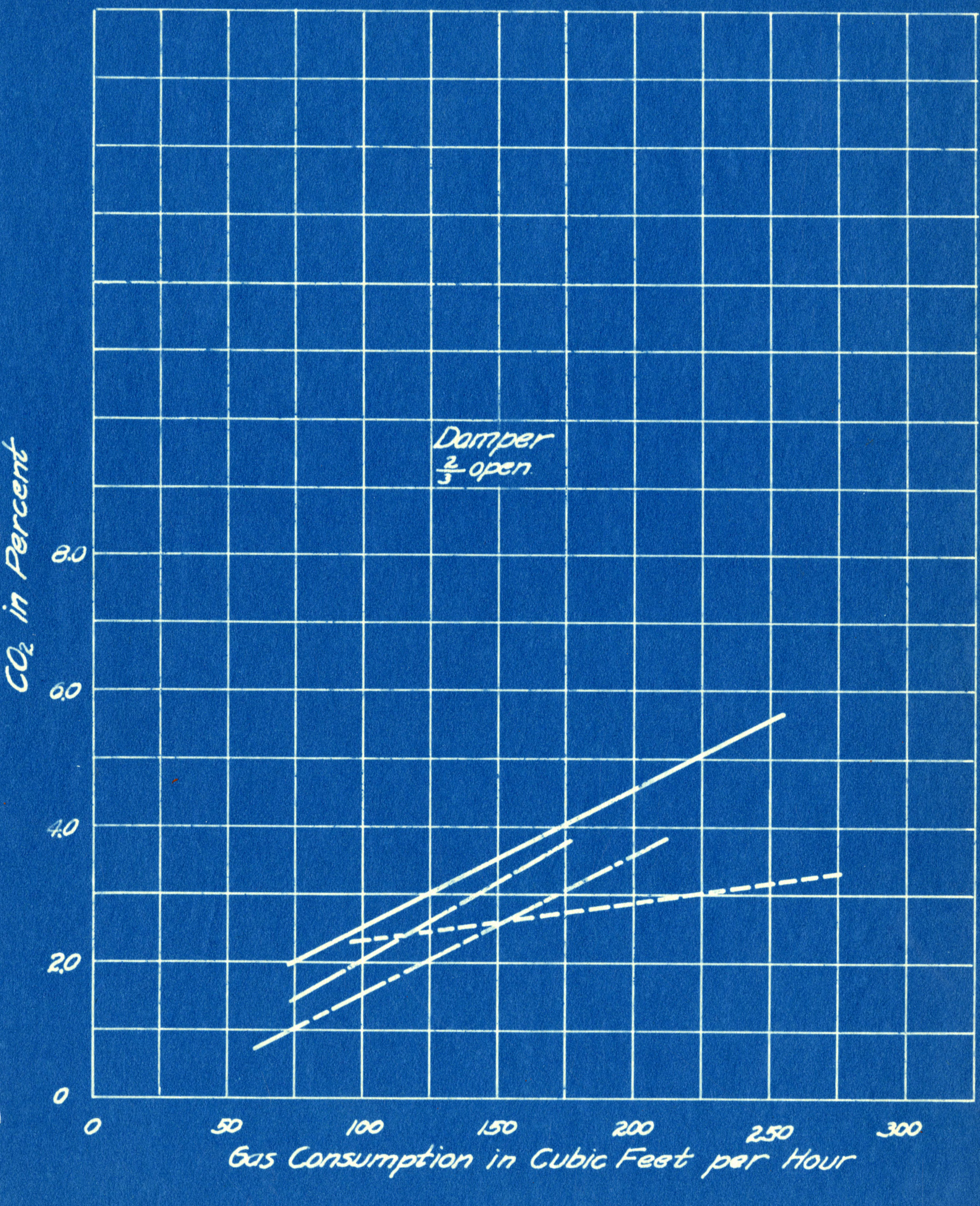

Damper
2/3 open
CO2 in Percent
8.0
6.0
4.0
2.0
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 11

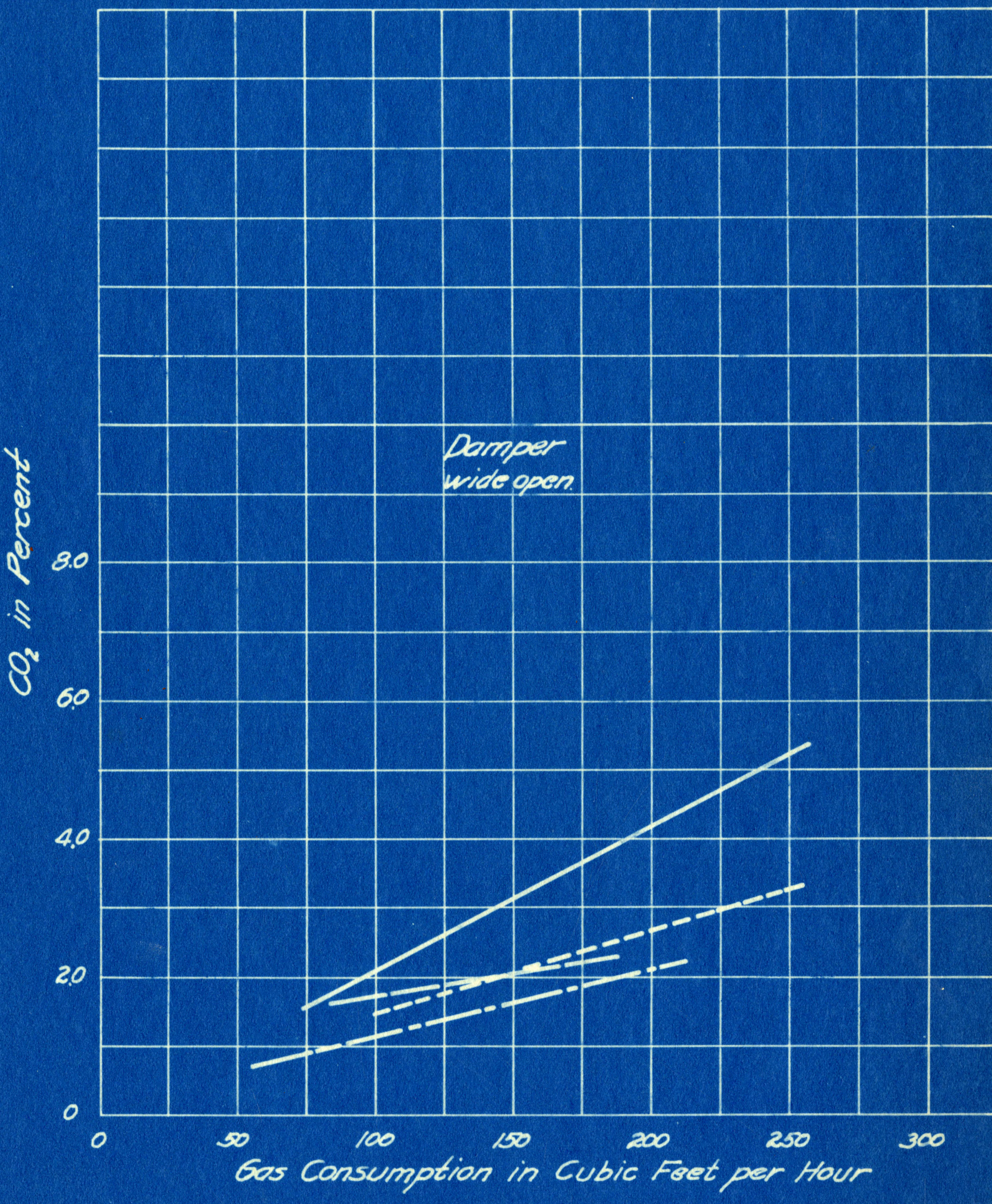

Damper
wide open
CO_2 in Percent
8.0
6.0
4.0
2.0
0
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 12

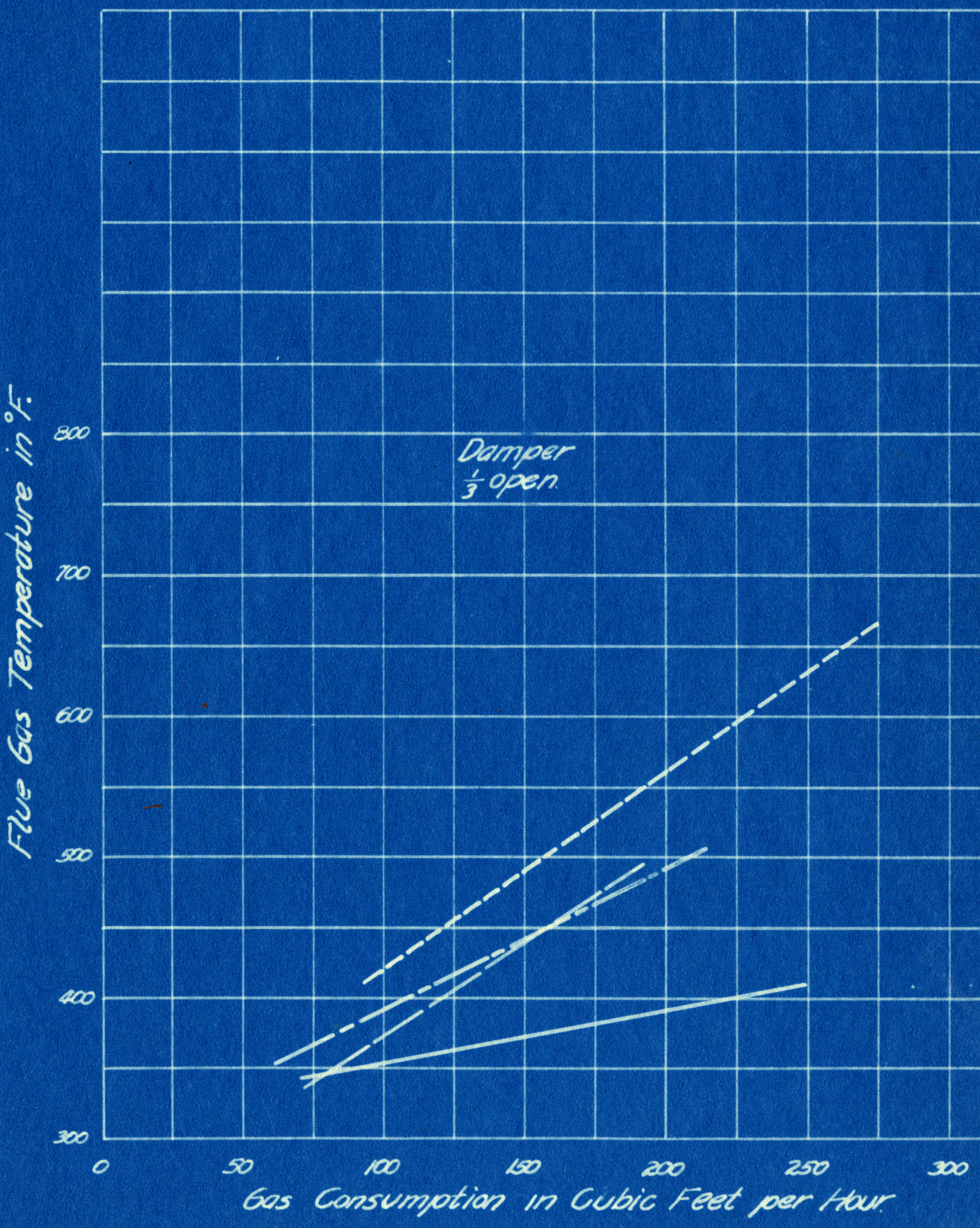

Flue Gas Temperature in °F.
800
700
600
500
400
300
Damper
$\frac{1}{3}$ open.
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour.

Fig. 13

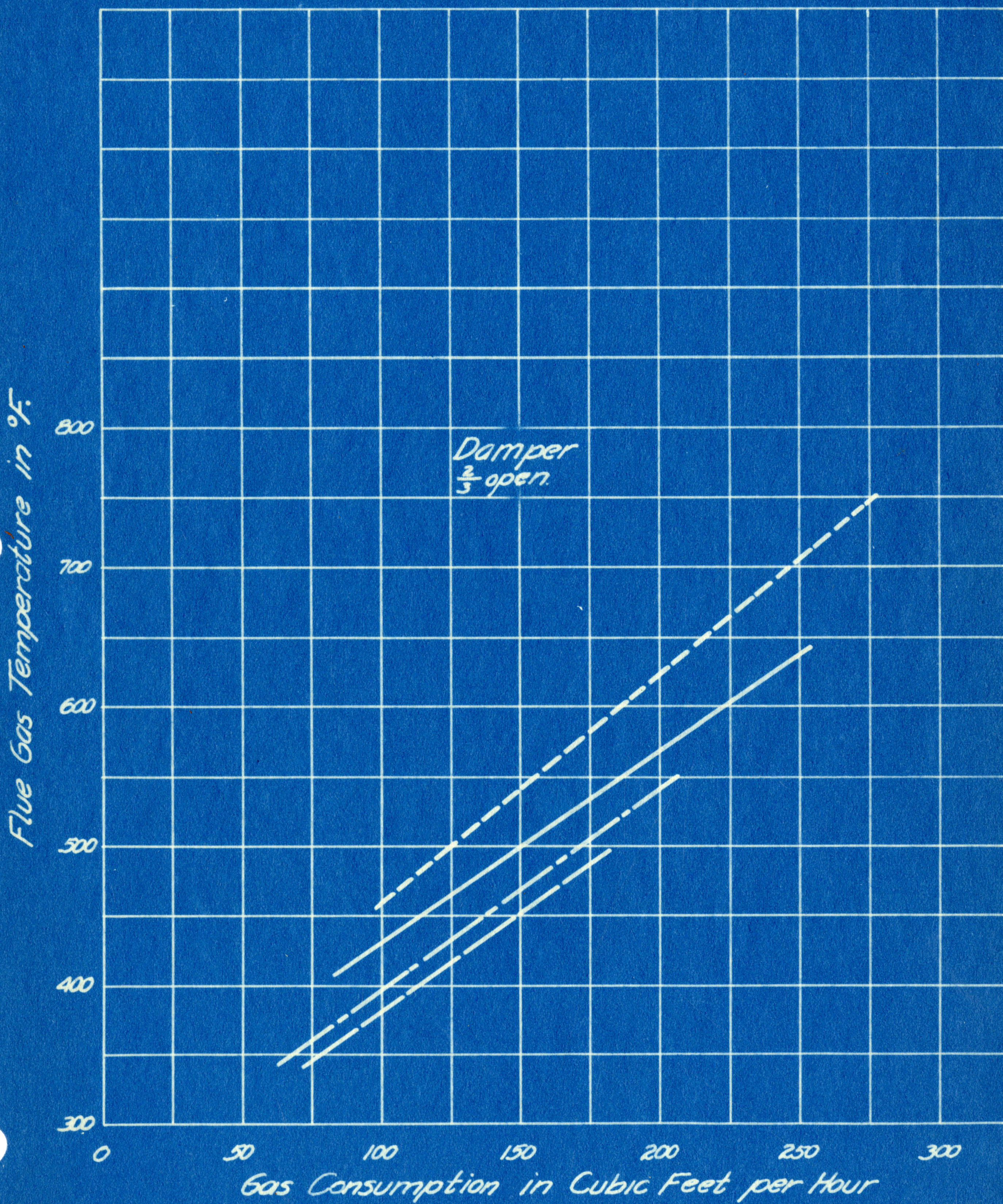

Damper
2/3 open.
Flue Gas Temperature in °F.
800
700
600
500
400
300
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 14

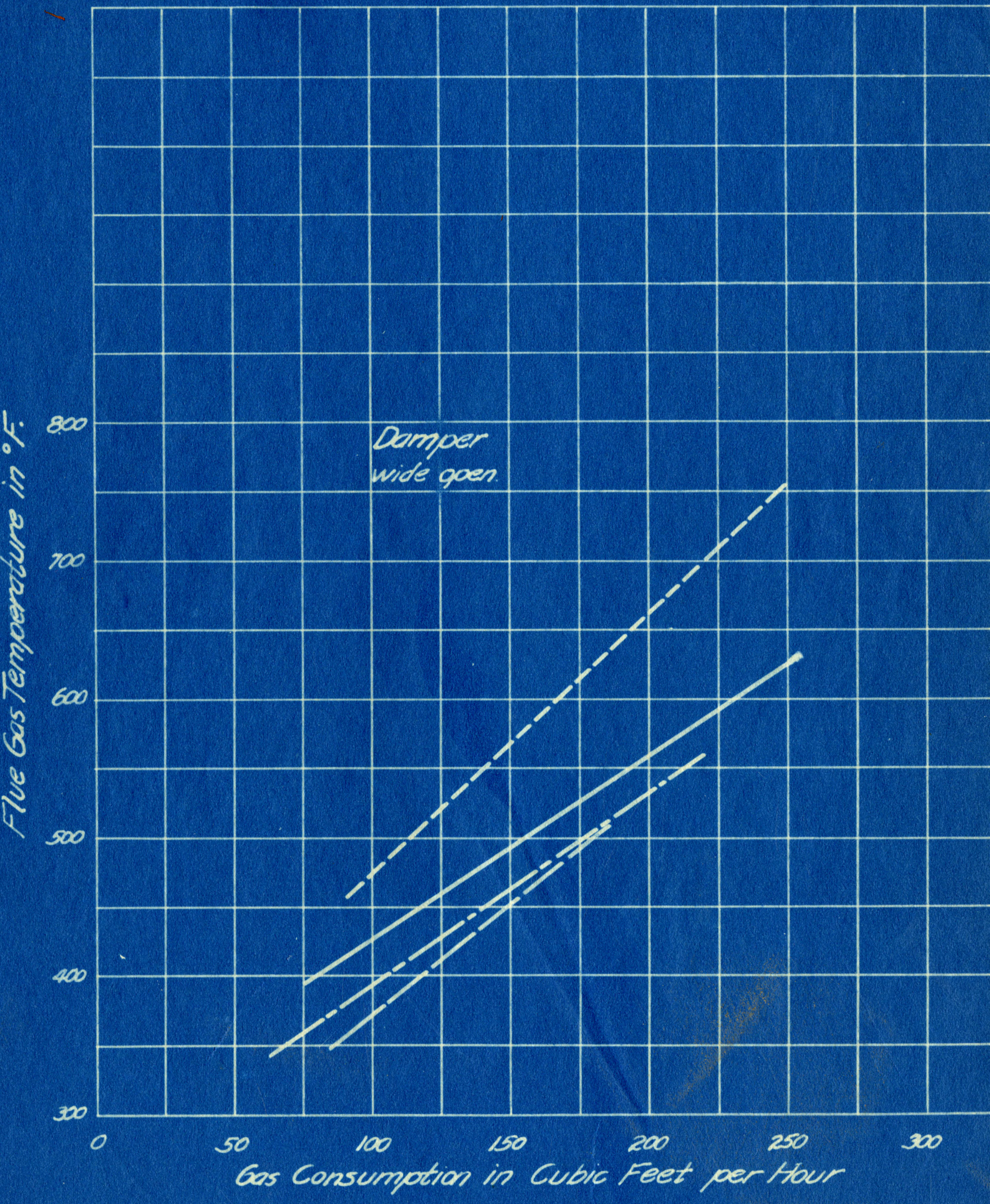

Damper
wide open.
Flue Gas Temperature in °F.
300
400
500
600
700
800
0
50
100
150
200
250
300
Gas Consumption in Cubic Feet per Hour

Fig. 15

TABLE I. AVERAGE DATA FOR FIRST SERIES

Condition of Operation	Temperature ° F.				Pressure		Orsat				H_2O Evaporation	Heat in F.W.	Volume Gas	H.V. of Gas
	F.W.	Stack	Room	Gas	Steam	Gas	CO_2	O_2	CO	N_2				
One	66.2	289	85.3	95.2	29.03	8	9.1	3.4	0	87.5	370	34.0	570	1000
Two	65.3	283	71.4	89.8	28.81	8	8.3	6.0	0	85.7	350	33.3	550	1000
Three	63.5	289	74.8	92.1	29.06	8	7.9	6.4	0	85.7	347	31.5	565	1000
Four	68.8	286	80.7	96.7	29.00	8	8.1	6.4	0	85.5	342	36.8	545	1000
Five	65.7	283	73.4	88.4	28.96	8	8.1	6.1	0	85.8	340	33.7	540	1000

Explanation of operation:

All tests with damper shut, primary air 3/4 open

Variations of secondary air:

One - Secondary air shut
Two - Secondary air one-fourth open
Three-Secondary air one-half open
Four- Secondary air three-fourths open
Five- Secondary air wide open

TABLE II. AVERAGE DATA FOR SECOND SERIES

Condition of Operation	Temperature °F.				Pressure		Orsat				H_2O Evaporation	Heat in F.W.	Volume Gas	H.V. of Gas
	F.W.	Stack	Room	Gas	Steam	Gas	CO_2	O_2	CO	N_2				
One	65.3	284	74.1	89.8	28.81	8	8.3	6	0	85.7	350	33.3	550	1000
Two	68.2	370	79.2	89.4	28.96	8	5.8	10	0	84.2	334	36.2	570	1000
Three	68.4	379	82.8	89.4	29.0	8	4.8	11.2	0	84.0	312	36.4	550	1000
Four	65.8	393	81.0	89.8	28.73	8	3.8	12.4	0	83.8	307	33.8	560	1000
Five	71.3	398	84.4	89.6	29.04	8	3.1	13.0	0	84.9	257	39.3	560	1000

Explanation of operation:

All tests with primary air three-fourths open and secondary air one-fourth open

Variations of damper setting:

One - Damper shut
Two - Damper one-fourth open
Three - Damper one-half open
Four - Damper three-fourths open
Five - Damper wide open

TABLE III. AVERAGE DATA FOR THIRD SERIES

Condition of Operation	Temperature ° F.				Pressure		Orsat				H_2O Evaporation	Heat in F.W.	Volume Gas	H.V. of Gas
	F.W.	Stack	Room	Gas	Steam	Gas	CO_2	O_2	CO	N_2				
One	72.0	284.0	84.2	90.5	29.04	8	8.1	6.1	0	85.8	314	40.0	550	1000
Two	69.4	281.0	84.0	89.4	29.0	8	8.6	5.2	0	86.2	364	37.4	540	1000
Three	71.2	284.0	85.5	88.5	29.0	8	8.1	5.9	0	86.0	351	39.2	540	1000
Four	65.3	283.8	74.1	89.8	28.81	8	8.3	6.0	0	85.7	350	33.3	550	1000
Five	67.5	285.0	77.0	93.4	28.9	8	7.6	6.5	0	85.9	351	35.5	560	1000

Explanation of operation:

All tests with damper shut and secondary air one-fourth open

Variations of primary air:

One - Primary air shut

Two - Primary air one-fourth open

Three - Primary air one-half open

Four - Primary air three-fourths open

Five - Primary air wide open

TABLE IV. SAMPLE DATA SHEET

Time	T.F.W.	Room T.	Stack T.	Gas T.	#H_2O	Gas P.	Cu. Ft. Gas
10:00	65.0	80.5	280	88.5	454	8	64220
10:15	65.0	81.0	280	92.0		8	
10:30	65.0	81.0	280	93.5		8	
10:45	66.0	82.0	280	95.0		8	
11:00	66.0	83.0	280	96.0		8	
11:15	66.0	83.5	280	97.5		8	
11:30	67.0	84.0	280	98.0		8	
11:45	68.0	84.5	285	99.5		8	
12:00	69.0	85.0	285	100.0		8	
12:15	69.0	85.0	283	101.0		8	
12:30	70.0	85.5	285	101.0		8	
12:45	71.0	84.5	280	99.0		8	
1:00	72.0	85.0	280	97.0		8	
1:15	73.0	85.0	280	91.5		8	
1:30	73.0	85.5	280	89.0		8	
1:45	74.0	85.5	280	90.0		8	
2:00	75.0	88.0	280	90.0	90	8	64760
Average	69.4	84.0	281	89.4	364	8	540

Barometer reading 29.00 in. Hg.

Damper shut

Secondary air one-fourth open

Primary air one-fourth open

Orsat readings (Average)

CO_2	8.6%
O_2	5.2%
CO	0.0%
N_2	86.2%

TABLE V. CALCULATED RESULTS FIRST SERIES

Condition of Operation	Heat Per Pound Steam	Efficiency Per Cent	Excess Air Per Cent	H_2O Evaporation Per Hour	Gas Per Hour
One	1149.8	72.5	31.5	92.5	143.0
Two	1148.5	71.0	42.7	87.6	137.5
Three	1148.8	68.7	50.0	86.9	141.0
Four	1149.1	69.5	44.2	85.5	136.2
Five	1148.9	70.0	45.0	85.0	135.0

TABLE VI. CALCULATED RESULTS SECOND SERIES

Condition of Operation	Heat Per Pound Steam	Efficiency Per Cent	Excess Air Per Cent	H_2O Evaporation Per Hour	Gas Per Hour
One	1148.5	71.0	41.3	87.6	143
Two	1148.9	65.2	197.5	83.5	143
Three	1149.1	63.2	239.1	77.9	137
Four	1148.4	61.0	302.0	76.6	140
Five	1149.6	51.0	374.5	64.3	140

TABLE VII. CALCULATED RESULTS THIRD SERIES

Condition of Operation	Heat Per Pound Steam	Efficiency Per Cent	Excess Air Per Cent	H_2O Evaporation Per Hour	Gas Per Hour
One	1149.6	63.4	44.5	78.5	137
Two	1149.1	75.0	24.5	91.0	135
Three	1149.1	72.6	45.0	87.7	135
Four	1148.5	71.0	41.0	87.6	143
Five	1149.0	69.5	54.5	87.6	140

cy occurred with the damper shut. It is not desirable to have a high stack temperature because of the loss of heat; the damper is also the best means of regulating the stack temperature.

The secondary air is also a very effective means of regulating the efficiency of a furnace. The secondary air is the air introduced into the firebox to make up the necessary oxygen for complete combustion of the gas. That is, over and above the primary air, which enters the burner with the gas. The secondary air may be one of the causes of a high stack temperature and also cause a lowering of the efficiency. In case the secondary air is opened an excess amount of air is present in the furnace. That of course allows a large amount of heat to be carried up the stack, regardless of the position of the damper. The draft is increased by opening the secondary air thus increasing the velocity of flow of the flue gas up the stack. This increased amount of heat lost will be very slight and may be overlooked in most cases. By referring to the CO_2 curve in Figure 5 it may be seen that it follows the same general shape that the efficiency curve takes. They both drop somewhat with the opening of the secondary air duct.

The primary air setting as shown in Figure 6 causes a very distinct change in the shape of the efficiency curve.

As the primary air is the air used to make up the necessary oxygen for the combustion of the fuel gas it would naturally make a difference in efficiency as it is varied. The shape of the curve takes an upward trend and then slopes off to a low efficiency as the primary air is increased. That would seem to indicate there were two extremes to the problem. That of too much and too little air to create good combustion. On the one hand would be a large excess air per cent and on the other a quantity of unburned gas passing up the stack. It may be seen from the curve that about a medium should be reached where best results would occur. The stack temperature is very slightly affected by any change of primary air introduced. The CO_2 curve again follows the efficiency curve in shape. This would show that CO_2 content of flue gases is a good indication of the efficiency as well as the type of combustion undergone in the boiler.

The desirable form for an efficiency curve should be a flat curve, showing a more or less constant efficiency regardless of the setting used. This of course is not practical because of the loss due to heat going up the stack when the damper is opened. A burner should be capable of being operated at all loads with about the same efficiency in order to have economy when the furnace is not under a heavy load.

In taking up the discussion of the flue gas or stack temperatures it might be well to state some of the aims in furnace and burner regulation. Since the stack temperature is very indicative of the efficiency it is desirable to have the stack temperature as low as possible. A temperature from fifty to seventy-five degrees above the steam temperature is about as good as can be obtained. If the stack temperature were lower than the steam temperature there would be no flow of heat to the steam.

In order to keep the stack temperature low the amount of heat flow up the stack must be controlled. This may be done by keeping the damper shut and preventing any very great flow of flue gas up the stack or by closing the secondary air inlet and never allowing this excess air to be heated.

In Figures 5, 6 and 7, it may be seen that in all cases where the damper was shut the lowest flue gas temperatures were recorded. The curves for variation of secondary and primary air show a very flat flue temperature curve, which is very desirable. When the damper is shut the flow of flue gas is somewhat retarded and the gases are allowed to cool before passing out of the furnace. When the damper is opened flue gases are not held in the furnace and large quantities of heat escape in this manner.

The matter of CO_2 content of the flue gas has been touched on somewhat in the previous discussion but its full import has not been stressed. The CO_2 content of the flue gas is a direct indication of the combustion in the furnace. It indicates at once whether excess air in large or small quantities is present. It also shows what the efficiency might be expected to be, high or low. A large content of CO_2 is very desirable as it shows complete combustion, however it is very easy to have too much excess air above that needed for complete combustion. The CO_2 content of flue gases should be so that the O_2 content is low and no CO is apparent. The volume of flue gas will remain practically constant and any decrease in the CO_2 content will show an increase in the oxygen content and likewise the reverse.

The carbon dioxide content of the flue gases in the tests show a great variance from a value of about 9 per cent down to about 3 per cent. These represent the extremes. It may be seen from the above discussion that the low CO_2 content occurred when the damper was open, allowing a large excess in air. Whereas the high carbon dioxide content occurred with the damper closed and a relatively low per cent of excess air. The primary and secondary air have very little effect upon the carbon dioxide content.

The excess air is air which goes up the stack without being used in the process of combustion. A certain small per cent of excess air is desirable in order to insure complete combustion. However, as before stated a large amount of excess air means a direct loss of heat up the stack. The excess air has been discussed in conjunction with other factors leaving very little to be said concerning it. In this research the excess air varied from 24.5 per cent to 374 per cent. The low values represented the best condition of efficiency and with the draft shut. The high value was recorded at the lowest efficiency and with the draft open. It may be seen then that excess air is a very vital factor in burner efficiency.

CONCLUSIONS

The conclusions reached were that a gas burner installed in a furnace designed for coal burning required careful consideration of the damper setting, and some adjustment of primary and secondary air. All three of these factors are vital to the economical operation of gas burners installed in furnaces designed for coal burning. The damper was found to be the most important of the three. It controls the excess air, stack temperature and efficiency to such an extent that it is very important that it be properly regulated.

The stack temperature was found to be a factor affecting efficiency very materially. A high stack temperature was found to be very undesirable from a standpoint of efficiency.

The stack temperature may be regulated to within sixty degrees of the steam temperature by proper regulation of the damper. Figure 3 shows a graphic representation of the action of the damper, primary air and secondary air, upon the stack temperature.

Figures 1, 2, 3 and 4 show the results obtained after calculating the experimental data. These curves serve to show the operation that might be expected under practically any setting of the burner. From these curves the recommendations have been made.

In operating a gas burner installed in a furnace designed for coal burning the primary factor to be considered is the damper setting. The damper will control the economy of the entire set-up to a very great extent. In making a recommendation of the regulation to be used for best results, all factors have been considered before forming a decision.

The damper should be as nearly closed as possible without creating a pressure in the combustion chamber, for the following reasons:

A low stack temperature results, a high CO_2 content in the flue gas is available, a low per cent of excess air is found, and a high efficiency results from the combined actions of all factors mentioned above.

In considering the setting of the primary air it has been decided best results are obtained when the openings are about one-fourth open. When the primary air is in this position very good results were obtained.

The secondary air gave best results when it was one-fourth open, with the above settings as recommended.

Now for a setting of all three factors to give their combined aid in good economy it has been decided to recommend as an economical setting as follows: damper shut, primary air one-fourth open, and secondary air one-fourth open. When this setting is used the best economy should result.

BIBLIOGRAPHY

American Gas Association

1926. Industrial Gas Series. Combustion. Second Edition. New York: American Gas Association. 84 pages.

1929. Industrial Gas Series. House Heating. Second Edition. New York: American Gas Association. 102 pages.

Gebhardt, G. F.

1928. Steam Power Plant Engineering. Sixth Edition. New York: John Wiley and Sons. 1036 pages.

Kent, R. T.

1923. Mechanical Engineer's Handbook. Tenth Edition. New York: John Wiley and Sons. 2247 pages.

Leonard, C. M.

1929. Efficiency of Gas Burners for House Heating. Master's Thesis, Kansas State Agricultural College. 50 pages.

Marks, L. S.

1924. Mechanical Engineer's handbook. Second Edition. New York: McGraw-Hill Book Company. 1986 pages.

Parr, S. W.

1922. Fuel, Gas, Water and Lubricants. New York: McGraw-Hill Book Company. 250 pages.

The Surface Combustion Company.

1928. Gas Fired Equipment. Series 990-S. Toledo: The Surface Combustion Company. 90 pages.