A method for testing a domestic gas-fired warm furnace
by Gordon Conrad

A Thesis Submitted to the Graduate Committee in partial fulfillment of the requirements for the Degree of Master of Science in Mechanical Engineering
Montana State University

Abstract:
Within the last six years, gas fired furnaces, either of the gas designed or conversion type, have been installed in a large number of homes in Montana. These are of all types, steam, hot water, and warm air. Each of these three types of systems would require a different method of testing. It was decided to confine this investigation to a single type for the present, and the warm air system was the one selected.

Due to the relatively short time that gas has been used, to any great extent, for domestic heating purposes in other than the immediate vicinity of a natural gas supply, there has been very little work done on the determination of the efficiency of domestic gas fired furnaces. A test code for gas designed furnaces, established by the American Gas Association specifies minimum requirements which must be fulfilled in order that the appliance may be approved by the Association. A code has also been established for the installation of conversion burners, but no testing code for the conversion burners has been established.

The conversion burner has been developed to a point where it has made a definite place for itself in the field o domestic heating and, consequently, a method of testing must include the conversion burner as well as the gas designed type of furnace.

Since natural gas has gained such wide distribution and is continually gaining in popularity as a house heating fuel, it was felt that an investigation into the efficiencies obtained with this fuel would be a service to users, and to those contemplating the use of gas as a fuel for house heating purposes.

It was with this service in Mind that the project of devising a method for testing was started.

It is hoped that the testing may be carried on over a period of years so that some reliable data can be accumulated on a number of different types of warm air furnaces, and that the testing may be extended to steam and hot water heating systems.

PURPOSE OF INVESTIGATION The purpose of the investigation is to develop a method for testing domestic gas fired warm air furnaces. The method has been devised so that it would be equally well suited to the testing of either gas designed or conversion types of furnaces and, consequently, establish a means of comparison between them on the basis of their efficiencies.

BASIC PREMISES It is generally conceded that the more nearly test conditions approach actual operating conditions the more acceptable are the results of the test. This is the first premise on which the method is based. The method has been held to this requirement as rigorously as possible. The laboratory has been in a residence and the apparatus a conversion installation put in by the distributors of the gas, without their knowledge of the fact that it would be used for testing purposes. A few slight modifications of the installation have been made to facilitate the use of testing instruments, hut the installation remains essentially as it was placed by the installation men in the employ of the distributors.

The second premise of the method is that all heat is utilised except that which goes up the stack. Radiation in the basement of a home cannot be considered as a loss unless it is excessive. The radiation from the furnace and leaders is generally not greater than is required to maintain a proper temperature in the basement to prevent cold floors. A dry warm basement is essential to proper heating of the house. A properly installed warm air heating system will not give radiation from the furnace and leaders in excess of what is required for maintenance of proper temperature in the basement.

A METHOD FOR TESTING A DOMESTIC GAS-FIRED WARM AIR FURNACE

by

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in Mechanical Engineering at
Montana State College

Approved:

In Charge of Major Work

Chairman Examining Committee

Chairman Graduate Committee

Bozeman, Montana
June 1935

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INTRODUCTION

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DISCUSSION OF TEST METHODS

The principle material available on testing methods for domestic furnaces is as follows:

1. Investigation of Warm Air Furnaces and Heating Systems at the University of Illinois.[6,7,8,9,10,11]
2. Tests of Gas Home-Heating Equipment at Purdue University.[17]
3. American Gas Association Approval Requirements for Central Heating Appliances.[1]

The most extensive tests on warm air furnaces have been carried on at the University of Illinois. These tests have been devised for, and made with coal fired furnaces.

In collaboration with the National Warm Air Heating Association, the University of Illinois has carried on a research program over a period of about twelve years on the investigation of all phases of warm air heating. There have been six bulletins, each of considerable length, issued on the work which has been done.

The methods of testing are very complete, and a great deal of data on the performance and operation of warm air furnaces has been obtained. Briefly the method used is to measure the heat input by weighing the fuel, and to determine the stack losses by means of Orsat apparatus. The furnace output is measured at each register face by means of anemometer traverses and temperature measurements with thermocouples and thermometers. The efficiency is based on the measurement of input to the furnace and the output as measured at the register faces. It would be entirely unnecessary to duplicate work which has already been so well done. If it should become desirable to extend the scope of these tests at some later date, many of the methods and devices used at Illinois could be adopted to a good advantage.

In May 1931 a bulletin entitled "Test of Gas Home-Heating Equipment"[17] was issued by Purdue University. This bulletin covers the method of testing and results of tests made on domestic steam boilers fired with gas. Research was carried on over a period of two years, tests being made on a number of different types of conversion burners in several makes of boilers. Tests were also made on a gas designed boiler.

The method of testing as devised at Purdue, used the principle of testing intermittent operation of the boiler. Previous to these tests, no testing with intermittent operation had been done. Since these tests were made, a code, drawn up by an A.S.H.V.E. committee, for testing oil burning devices included a provision for intermittent tests.[20]

The A.G.A. Approval Requirements for Central Heating Appliances are specified as requirements which "represent minimum standards for safe operation, satisfactory performance, substantial and durable construction." A method of testing gas designed warm air furnaces is specified in the code. The method, however, is only applicable where the furnace can be set up in a laboratory where certain apparatus is available for the test. While the method with certain modifications could be used in testing conversion furnaces, the method was devised for determining the minimum performance requirements in order to obtain the approval of the A.G.A. Laboratories, which is primarily for the testing of gas burning devices submitted by the manufacturers.

The principle on which this method is devised is the second basic premise. The method is, briefly stated, to measure the gas input and the air supplied for combustion; to measure the loss to the stack, and by taking the difference of these two quantities the heat output utilized in heating the house can be found. By knowing the input, the output and the losses, the efficiency of the furnace can be determined.

The principle of testing on intermittent operation is used in this method. The furnace is allowed to operate normally with thermostatic control and no specific period of operation is required. Testing is done during the "off" periods, as well as during the "on" periods so that the entire loss through the furnace is measured. Entirely normal operation of the furnace is thus obtained and adherence to the first basic premise is strictly maintained.

TESTING PLANT AND APPARATUS

Figure 1 gives a diagramatic layout of the testing plant and Figures 2 and 3 are photographs of the setup made.

The furnace, part 11, is a warm air furnace of steel construction, installed for burning coal. For burning gas, the grates have been removed, and the burner placed at about the position occupied by the grates. The ash pit door was removed for installing the burner and the entire opening, with the exception of a small secondary air opening near the floor, was bricked up and sealed with high temperature cement.

The burner is of the bunsen type. The burner head, is a ring which fits the fire pot, over which is placed radiants to throw the heat against the walls of the fire pot.

The gas input to the furnace is measured by a standard volumetric, dry type of meter, part 1, Figure 2, which has a maximum capacity of 150 cubic feet per hour. The meter was new when it was installed. A ten foot prover is available at the gas warehouse of the Montana Power Company, where the calibration of the meter can be checked as frequently as desired.

A tee is placed in the gas line just ahead of the meter, arranged as shown in the diagram, in which is placed a thermometer, part 10, Figure 2, to obtain the temperature of the gas as it is metered. It is necessary that the thermometer be inserted a sufficient distance so that the bulb is in the gas stream. Another connection to the same tee is provided to which is attached a water manometer, part 7, Figure 2, for obtaining the gas pressure as metered.

A specially constructed box of galvanized iron, part 4, Figure 2, and Figure 4, is used to cover the mixer and the secondary air inlet. In the box between the mixer and secondary air inlet is placed a damper for the re-

DIAGRAM OF APPARATUS USED FOR TESTS

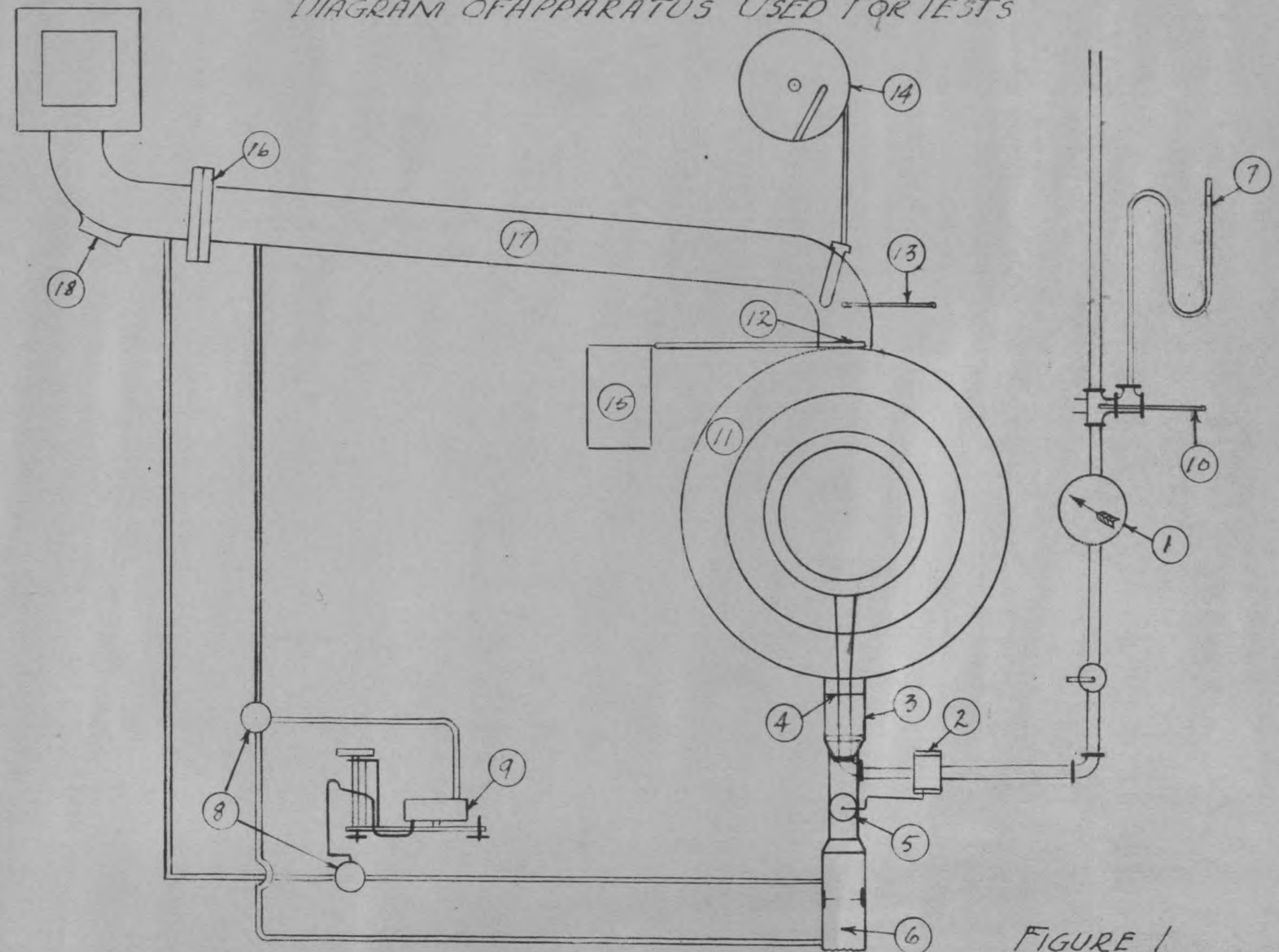


FIGURE 1

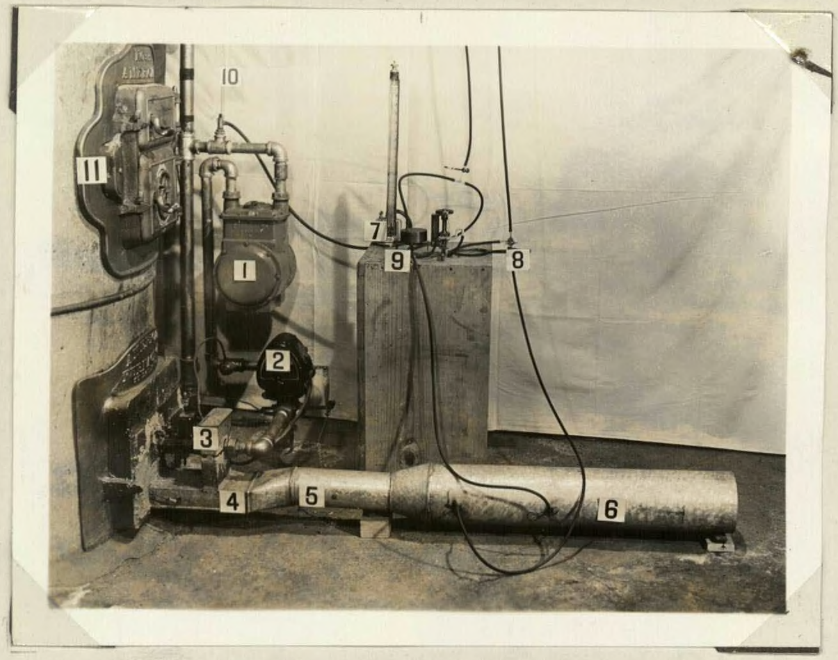


Fig. 2

Arrangement of Apparatus at Front of Furnace

1. Gas Meter
2. Thermostatically Controlled Electric Valve
3. Primary Air and Gas Mixer
4. Air Control Box
5. Total Air Damper
6. Inlet Air Metering Pipe
7. Gas Pressure Manometer
8. Three Way Cock
9. Micromanometer
10. Fuel Gas Thermometer
11. Furnace.

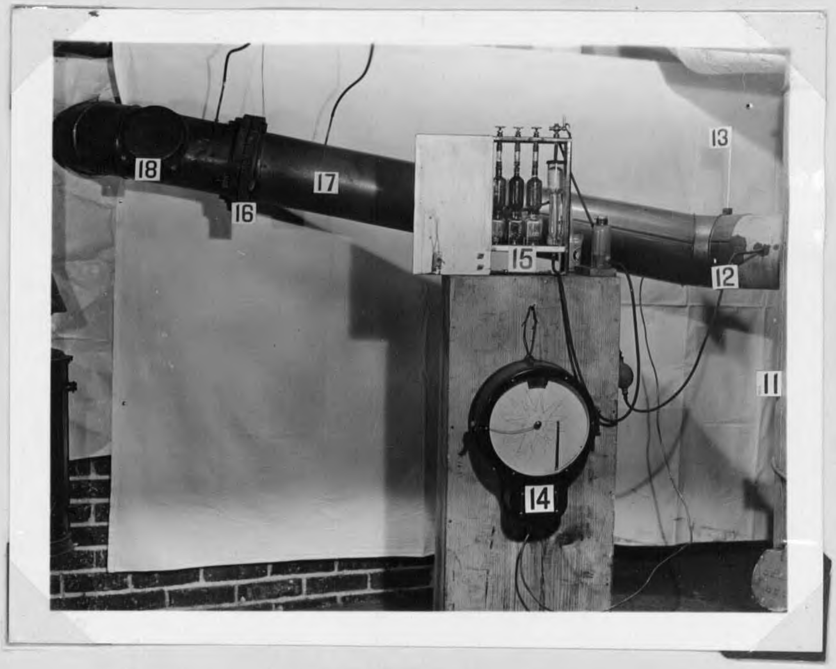


Fig. 3

Arrangement of Apparatus at Rear of Furnace.

11. Furnace

12. Flue Gas Sampling Tube

13. Flue Gas Thermometer

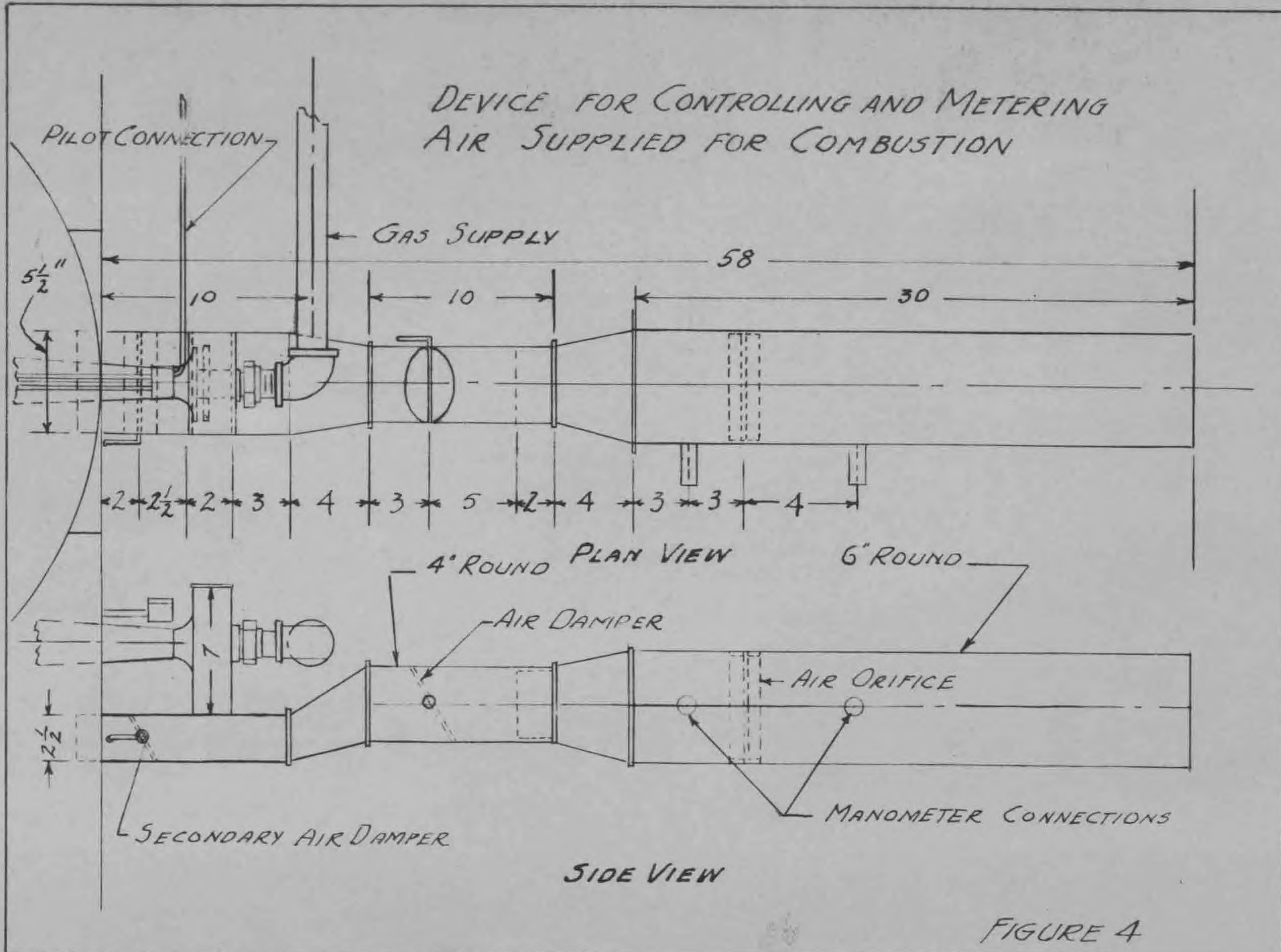
14. Flue Gas Recording Thermometer

15. Orsat Apparatus

16. Chimney Flue Orifice Flanges

17. Chimney Flue Pipe

18. Check Damper Opening (Capped)


DEVICE FOR CONTROLLING AND METERING
AIR SUPPLIED FOR COMBUSTION
PILOT CONNECTION
GAS SUPPLY
5½"
58
10
10
30
2
2½
2
3
4
3
5
2
4
3
3
4
PLAN VIEW
4" ROUND
6" ROUND
AIR DAMPER
7
AIR ORIFICE
2½
MANOMETER CONNECTIONS
SECONDARY AIR DAMPER
SIDE VIEW
FIGURE 4

gulation of the secondary air. The box is terminated by a length of four inch air pipe, part 5, in which is installed a damper to shut off all air when the furnace is not operating. The damper is connected by a suitable linkage to the thermostatically controlled electric valve, part 2, so that the damper opens simultaneously with the valve. At the end of the four inch pipe is placed a length of six inch pipe, part 6, with a suitable reducer. This is the metering pipe and contains the orifice for metering the air supplied for combustion. The metering pipe is removable so that it can be placed in a calibrating apparatus and the orifice calibrated in place. The method of calibration is explained in detail in another section of this paper.

An Orsat apparatus, part 15, Figure 3, is used for analyzing the flue gases. The Orsat sampling tube, part 12, is placed in the chimney flue, part 17, as close to the furnace as possible.

The bulb of a recording flue gas thermometer, part 14, is placed in the chimney flue a short distance behind the Orsat sampling tube. The principal use of the recording thermometer is to show the period of operation. A high range mercury thermometer, part 13, is placed as near the recording thermometer bulb as possible. When testing is in progress readings are to be taken from the mercury thermometer and not from the recorder.

In the chimney flue, part 17, Figure 3, one pipe diameter ahead of the elbow by which the flue is connected to the stack, is placed a pair of flanges, part 16, instead of the ordinary slip joint used for flue pipes. The flanges are used for an orifice which is placed in the flue. This chimney flue orifice serves a twofold purpose (1) as a substitute for a draft hood to reduce the chimney draft, and (2) for metering the products of combustion.

The check damper opening, part 18, Figure 3, is at the elbow between the flanges and the stack. For reasons which will be explained later, this opening is kept capped.

In order to use the orifices, in the inlet air metering pipe and the chimney flue, for measuring the flow of gases, it is necessary to have differential pressure taps in the pipes in which the orifices are placed. The taps are taken one pipe diameter from the plane of the orifice, on the inlet side and one-half pipe diameter from the plane of the orifice on the outlet side.

A differential manometer of low range and high accuracy is required for the measurement of the differentials and drafts encountered in this work. A manometer, part 9, Figure 2, accurate to .001 inch of water, was constructed especially for this project. The manometer and its manipulation will be described in detail in another section of this paper.

Rubber tubing connections were run from the pressure taps at each of the orifices to the place where the manometer is located. Three way cocks, part 8, Figure 2, were placed to form a header, so that the differential, either at the chimney flue orifice or the orifice in the inlet air metering pipe, could be obtained without removing the hose connections. By this means readings can be taken successively at each orifice by simply changing the position of the cocks.

A small isinglass window in the furnace door was provided for observing the condition of the flame at the burner while adjustments for proper combustion are being made. This eliminates the necessity for opening the furnace door, or admitting air to the combustion chamber through any but the proper sources.

A specially constructed dewpoint apparatus*, for determining the humidity of gases at high temperatures, is used to obtain the moisture content of the flue gases.

OPERATION OF BURNER

The device for the proper mixing of the gas and air for combustion is illustrated in Figure 5. The gas expanding from the pressure in the gas supply line to atmospheric, through the small orifice in the spud, attains a high velocity causing a slight vacuum at the mixer throat. This suction draws in the air at the mixer face, and the mixture of air and gas passes to the burner head. The mixture is ignited as it issues from the burner ports. The amount of air being drawn into the mixer throat is controlled by means of the primary air adjustment plate which can be placed as close to the mixer face as desired, to give the proper air and gas mixture for good combustion conditions. Secondary air, controlled by a damper in a small opening in the front of the furnace, is drawn in underneath the burner head, and supplies a sufficient amount of oxygen to complete the combustion of the gas.

PRELIMINARY ADJUSTMENTS

A rule, determined from practice, for the size of flue is given by N. T. Branche[3]. This rule states that "one square inch of flue area for

* An undergraduate thesis project by George Van Winkle, M. S. C., '34

SKETCH OF BURNER MIXER

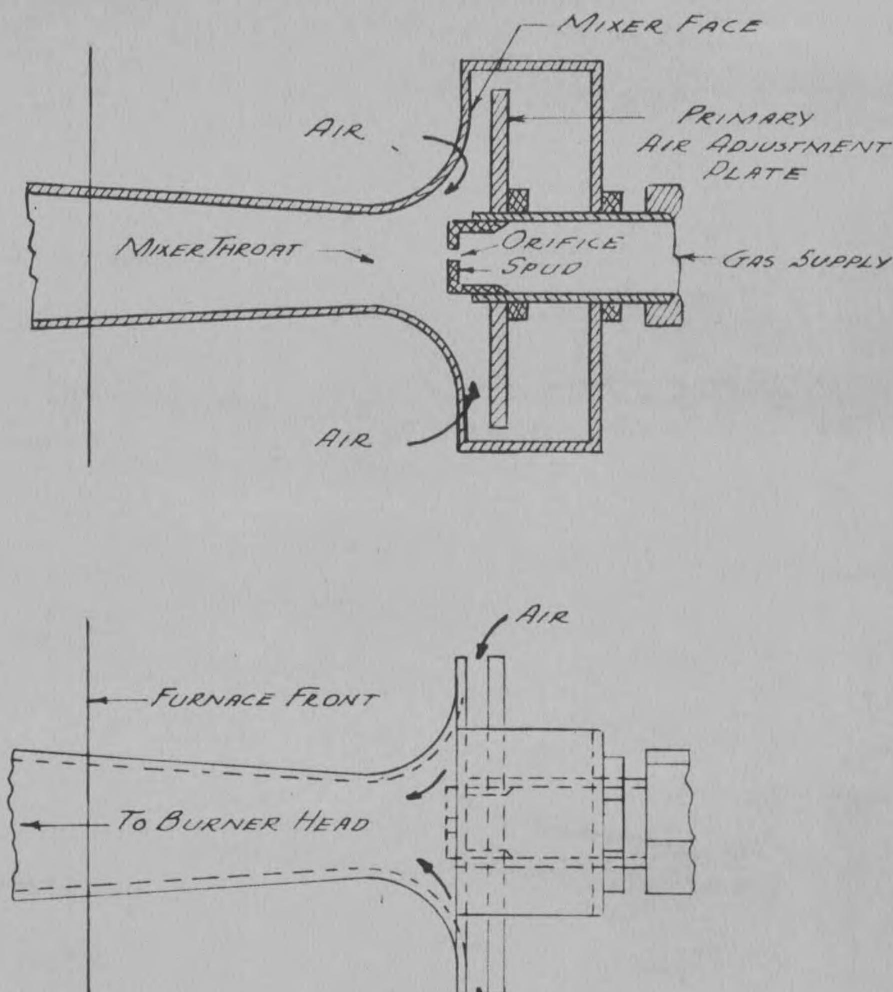


FIG 5

every 10,000 B.t.u. is somewhere near the required area". This rule was used to approximate the size of the chimney orifice, the final size being determined by trial. It was decided that a gas rate in the neighborhood of 120 cubic feet per hour was desirable for the tests in prospect, since the burner was designed for rates between 100 and 150 cubic feet per hour. The heating value of the gas is known so the size of the chimney orifice could be computed from the rule given above. Computation showed that an opening about four inches in diameter would be required. An orifice of this size was made and placed in the flue. By varying the size of the gas orifice in the spud, the gas rate was adjusted to about 120 cubic feet per hour.

An orifice of an arbitrarily assumed size was placed in the inlet air metering pipe. Adjustments of the primary and secondary air were made until the best possible flame was obtained. Tests were then made with the Orsat apparatus to determine the amount of excess air being used. If too much excess air was found, the size of the air orifice was reduced, primary and secondary air readjusted, and another trial made with the Orsat. This process was continued until CO was detected in the flue gases. The size of the air orifice was then increased until the CO disappeared. The burner was judged to be adjusted with as small an amount of excess air as could be used to obtain complete combustion, when this condition was reached.

When these trials were completed, tests for neutrality of draft were made. This was done by opening the fire door slightly and holding a lighted match at a number of points along the edge of the door. If the flame was drawn in slightly when the match was held below the middle of the door, and was not drawn in or was extinguished when held above the middle of the door, the draft was judged to be as nearly neutral as could be obtained. This method of draft adjustment was used in making the tests on all equipment tested at Purdue, and is also recommended by N. T. Branche[3].

If a neutral draft is not obtained, it is necessary to change the size of the chimney orifice and repeat the process outlined above until proper adjustment of both air and draft is obtained.

When these conditions were established, the air metering pipe containing the air orifice was removed and placed in the critical flow apparatus for calibration.

PROCEDURE OF TESTING

After the orifice is calibrated, the apparatus set us as previously described, and the burner properly adjusted, the testing may be started. Since the testing is to be done while the furnace is operating intermittently, tests must be made over a complete cycle or a series of complete cycles of operation. For example, if the testing is started at the time the furnace comes on, the testing must be done during the "on" period and the subsequent "off" period up to the time the furnace comes on again. This insures the temperature in the house being the same at the end of the test as it was at the start. It is immaterial at what point of the cycle the test is started, or for how many periods the test is made, but it is important that the test be ended at the same point of a cycle as that from which it was started.

ANALYSIS OF FLUE GASES

The usual practice in combustion testing is to take a continuous sample of the flue gas which is analyzed after the completion of the test. In this work, however, a grab sample is taken and analyzed as each set of readings is taken. The necessity for this method of flue gas sampling is shown when the operation of the intermittent burner is examined. The "off" period is usually of sufficient duration so that the entire system is cold when the furnace starts up. The flame impinging on these cold surfaces causes the formation of CO for a short period. As the furnace warms up the combustion becomes complete. The stack is cold at the start of the cycle and as it heats up, a greater draft is created which draws more air through the furnace and reduces the CO_2 content of the gases.

Another factor in which the grab sample plays an important part is the air leakage inside the furnace. No ordinary furnace installation is absolutely air tight, and consequently, there will be some leakage into the combustion chamber. This leakage will very due to the increase in draft with increase in stack temperature, and increase of the viscosity of gases with increase in temperature.

ANALYSIS OF FUEL GAS

The carbon and hydrogen content of the gas used for the tests was determined by means of a slow combustion process[24]. This part of the work was undertaken by the Chemical Engineering Department and the data for this test work were obtained from them. The hydrogen content was also obtained from the Junkers type calorimeter when the heating value was determined.

HEATING VALUE OF FUEL GAS

The heating value of the fuel was determined by means of an American Meter Company Junkers type calorimeter. The procedure of obtaining the heating value by means of this instrument is completely described in Bureau of Standards Circular No. 48[21] and does not require repetition in this paper, as the results of the heating value tests are the only data pertinent to this method.

COMPILATION AND COMPUTATION OF DATA

Before any test data are obtained, it is desirable that certain tables and curves be prepared to facilitate the calculation of the results of the tests. Standard conditions of reference have been established and all results have been corrected to these conditions to assure uniformity. The conditions established are as follows;

Atmospheric Pressure	25 inches of Mercury
Atmospheric Temperature	70 degrees F.

All tables and curves are based on a quantity of 100 cubic feet of fuel gas supplied to the furnace for combustion.

The gas analysis obtained consisted of the following;

C	66.1%	Molecular Weight	19.2
H_2	23.7%	Specific Gravity	0.664
N_2	10.2%		

From these data the Orsat analysis for varying percentages of CO_2 was computed. A tabulation of the results is given in Table I.

Using the volume of wet gases and the percentage of CO_2 from Table I, the curve in Figure 6 was plotted. This curve was used to obtain the volume of wet flue gases from the Orsat analysis made during the test.

From the data in Table I the heat losses as tabulated in Table II were calculated by the following formulas:

Loss due to sensible heat in the dry flue gases

$$0.24\, W(t_g - t_r)$$

where

W = weight of flue gases/100 cubic feet of fuel

0.24 = specific heat of flue gases at constant press

t_g = temperature of flue gases, degrees F.

t_r = temperature of room, degrees F.

Loss due to moisture formed by burning hydrogen

$$\frac{9w(H_2)(1089 + 0.46t_g - t_r)}{100}$$

where

w = weight of fuel gas/100 cubic feet fuel gas

H_2 = % by weight of hydrogen in fuel gas analysis

Since there is no CO present the total heat loss is the sum of the sensible heat loss due to dry gases and the loss due to the moisture formed in burning the hydrogen.

From the data of Table II, the curves in Figure 7 were drawn. These curves were used to determine the heat loss when no CO was detected in the flue gases. If CO was present in the gases, as was usually the case

TABLE I

ORSAT ANALYSES AND GAS VOLUMES

Computed for various assumed percentages of CO_2 in the Orsat Analysis.

Gas volumes based on 100 cubic feet of fuel burned.

	CO_2	O_2	N_2	Total Volume Dry	Excess Air %	Total Volume Wet
Orsat Analysis %	11.3-	0.0	88.7			
Vol. Dry Cu.Ft.	105.4	0.0	832.0	937.4	0.0	1162
Orsat Analysis %	11.0	0.5	88.5			
Vol. Dry Cu.Ft.	105.4	4.8	849.[illegible]	960.0	2.2	1182
Orsat Analysis %	10.5	1.4	88.1			
Vol. Dry Cu.Ft.	105.4	14.0	884.6	1005.0	6.7	1229
Orsat Analysis %	10.0	2.3	87.7			
Vol. Dry Cu.Ft.	105.4	24.4	932.2	1054.0	11.6	1278
Orsat Analysis %	9.5	3.2	87.3			
Vol. Dry Cu.Ft.	105.4	36.0	968.6	1111.0	17.2	1335
Orsat Analysis %	9.0	4.3	86.7			
Vol. Dry Cu.Ft.	105.4	51.0	1014.6	1171.0	23.2	1395
Orsat Analysis %	8.5	5.2	86.3			
Vol. Dry Cu.Ft.	105.4	64.0	1070.6	1240.0	30.0	1464
Orsat Analysis %	8.0	6.0	86.0			
Vol. Dry Cu.Ft.	105.4	78.6	1134.0	1318.0	37.9	1542

Volume of water vapor from 100 cu.ft. of fuel = 224 cu.ft.

All volumes for conditions of 25 in. Hg. - 70 deg. F.

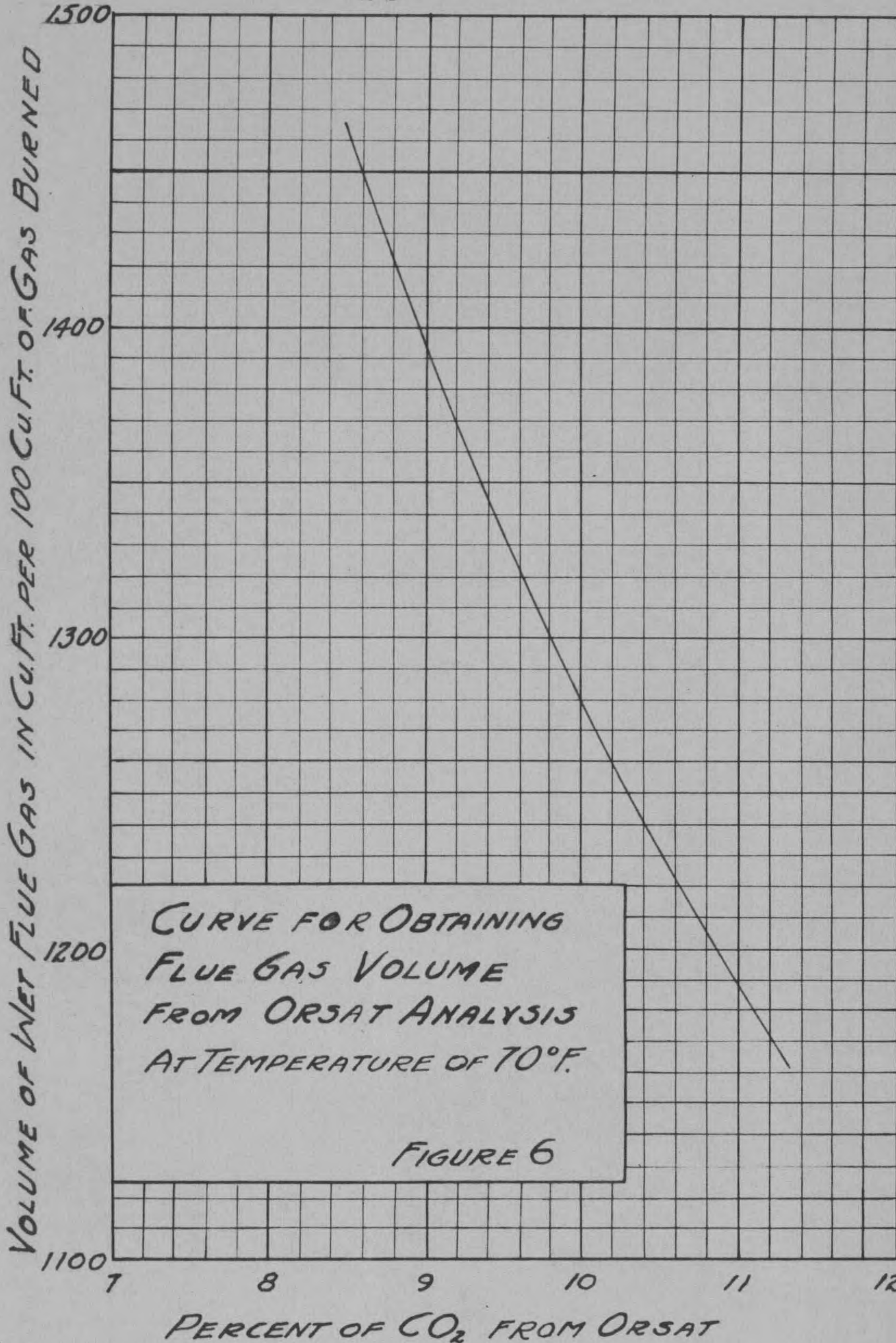

1500
1400
1300
1200
1100
VOLUME OF WET FLUE GAS IN CU.FT. PER 100 CU.FT. OF GAS BURNED
7
8
9
10
11
12
PERCENT OF CO_2 FROM ORSAT
CURVE FOR OBTAINING FLUE GAS VOLUME FROM ORSAT ANALYSIS AT TEMPERATURE OF 70°F.

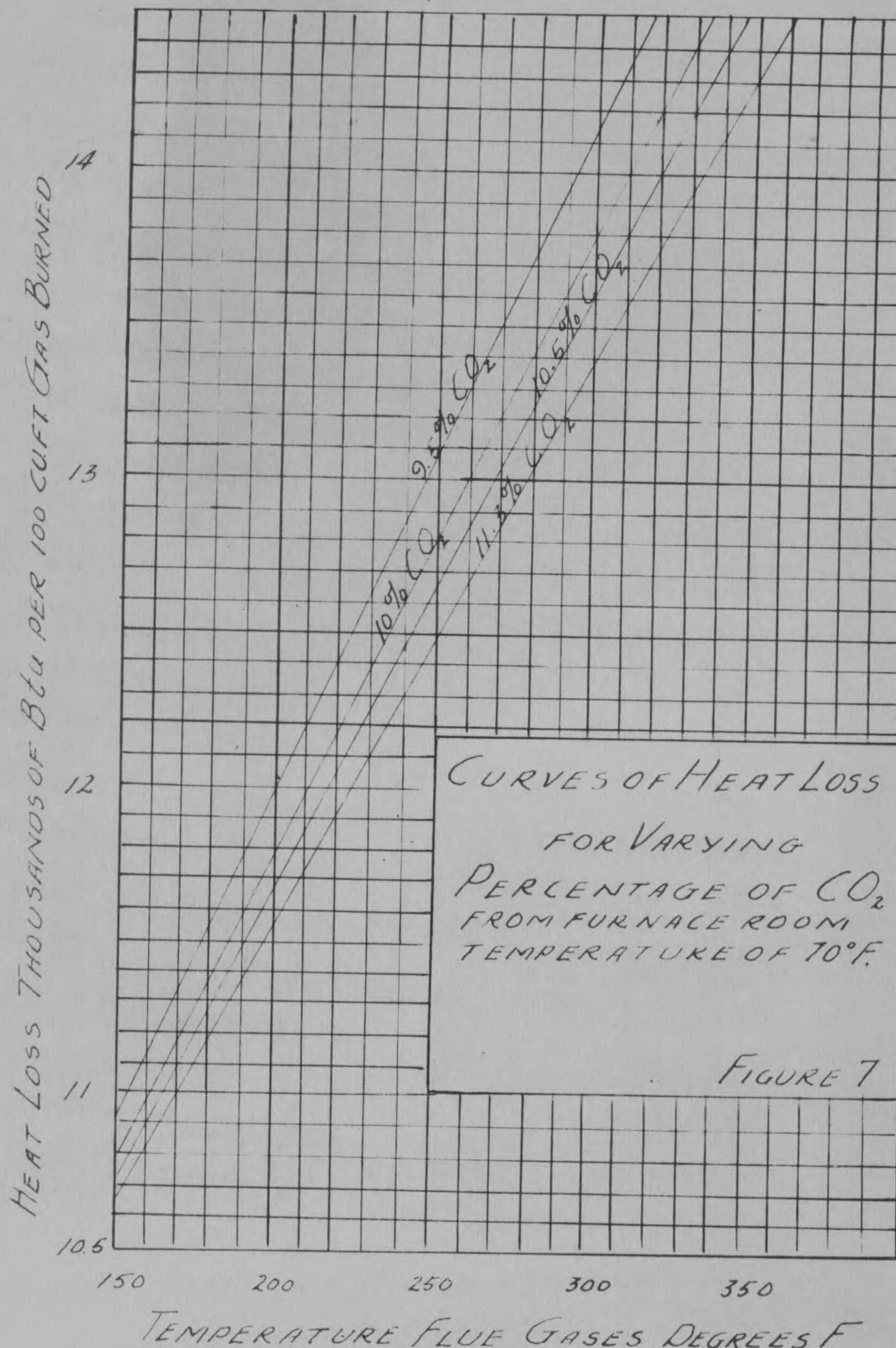
FIGURE 6

TABLE II

HEAT LOSSES DUE TO FLUE GASES

Weight of products based on 100 cubic feet of fuel burned

% CO_2	Weight Dry Products	Temp. Flue Gases	Dry Flue Gas Loss Btu	Moisture Loss From H_2 Btu	Total Loss Btu
11.3	59.50	150	1150	9520	10670
		200	1860	9720	11580
		250	2540	9930	12470
		300	3300	10100	13400
		350	4015	10310	14325
10.5	63.11	150	1210	9520	10730
		200	1970	9720	11690
		250	2730	9930	12660
		300	3480	10100	13580
		350	4240	10310	14550
10.0	67.09	150	1285	9520	10805
		200	2090	9720	11810
		250	2900	9930	12830
		300	3700	10100	13800
		350	4510	10310	14820
9.5	70.62	150	1415	9520	10935
		200	2300	9720	12020
		250	3180	9930	13110
		300	4070	10100	14170
		350	4950	10310	15260



CURVES OF HEAT LOSS FOR VARYING PERCENTAGE OF CO_2 FROM FURNACE ROOM TEMPERATURE OF 70°F.

FIGURE 7

for the beginning of the "on" period, the heat loss was computed directly.

Table III is an example of the data sheet used for testing, and lists the readings which should be taken in the course of the test. About ten minutes is required for one observer to take a set of readings. If two observers are available for the test, observations at five minute intervals would be desirable.

Table IV illustrates the derived and computed data. The method of obtaining each item is given in the "Sample Calculations", Appendix A.

The input is a constant quantity during the operation of the furnace and is obtained by multiplying the metered gas rate, corrected to atmospheric pressure and temperature, by the heating value per cubic foot of gas. The input was plotted, as a horizontal line, for the period of the cycle during which the furnace was operating, Figure 8.

The heat losses for the entire cycle were plotted on the same sheet with the heat input, Figure 8. With these curves, the B.t.u. input and the B.t.u. loss for the cycle were computed. The efficiency was obtained as follows;

Rate of heat input = 113,000 B.t.u./hour. (Figure 8)

Time furnace was "on" = 50 minutes

Heat input to furnace for cycle $113{,}000 \times \frac{50}{60} = 94{,}200$ B.t.u.

Rate of heat loss during "on" period = 17,000 B.t.u. per hour, Figure 8.

Rate of heat loss during "off" period = 2200 B.t.u. per hour.

Time of "off" period = 97 minutes.

TABLE III OBSERVED DATA

Test No. 1 Furnace - Conversion Gas Rate = 119 cu.ft./hr Barometer - 24.93" Hg
Weather - Rain Wind - None Outside Temp. - + 39 deg.F. Date - May 3, 1933

1	2	3	4	5	6	7	8	9	10
Time	Manometer Readings			Flue Gas	Fuel Gas	Orsat Analysis			
	Zero	Air Orifice	Chimney Orifice	Temp.	Temp.	CO_2	$CO_2 + O_2$	$CO_2 + O_2 + CO$	Entering Air Temp.
7:40P	Furnace On								
7:40P	26.2	54.8	40.5	164	70	9.8	12.0	13.0	68
7:50P	26.2	60.0	45.0	240	71	10.2	12.8	13.0	68
8:03P	26.3	63.3	51.0	300	73	10.2	13.3	13.3	68
8:14P	26.4	65.0	48.0	340	76	10.3	13.3	13.3	68
8:22P	26.3	65.0	48.0	352	78	10.2	13.4	13.4	68
8:28P	26.3	70.0	52.0	376	78	9.9	13.6	13.6	70
8:30P	Furnace Off								
8:40P	26.1	27.0	34.8	308					
8:50P	26.1	26.8	33.6	275					
9:00P	26.1	26.8	33.5	253					
9:10P	26.1	26.7	33.4	231					
9:20P	26.1	26.8	33.0	212					
9:30P	26.1	26.7	32.8	195					
9:40P	26.1	26.7	32.5	185					
9:50P	26.1	26.8	32.2	176					
10:00P	26.2	26.7	31.9	167					
10:07P	Furnace On								

TABLE IV DERIVED AND CALCULATED DATA

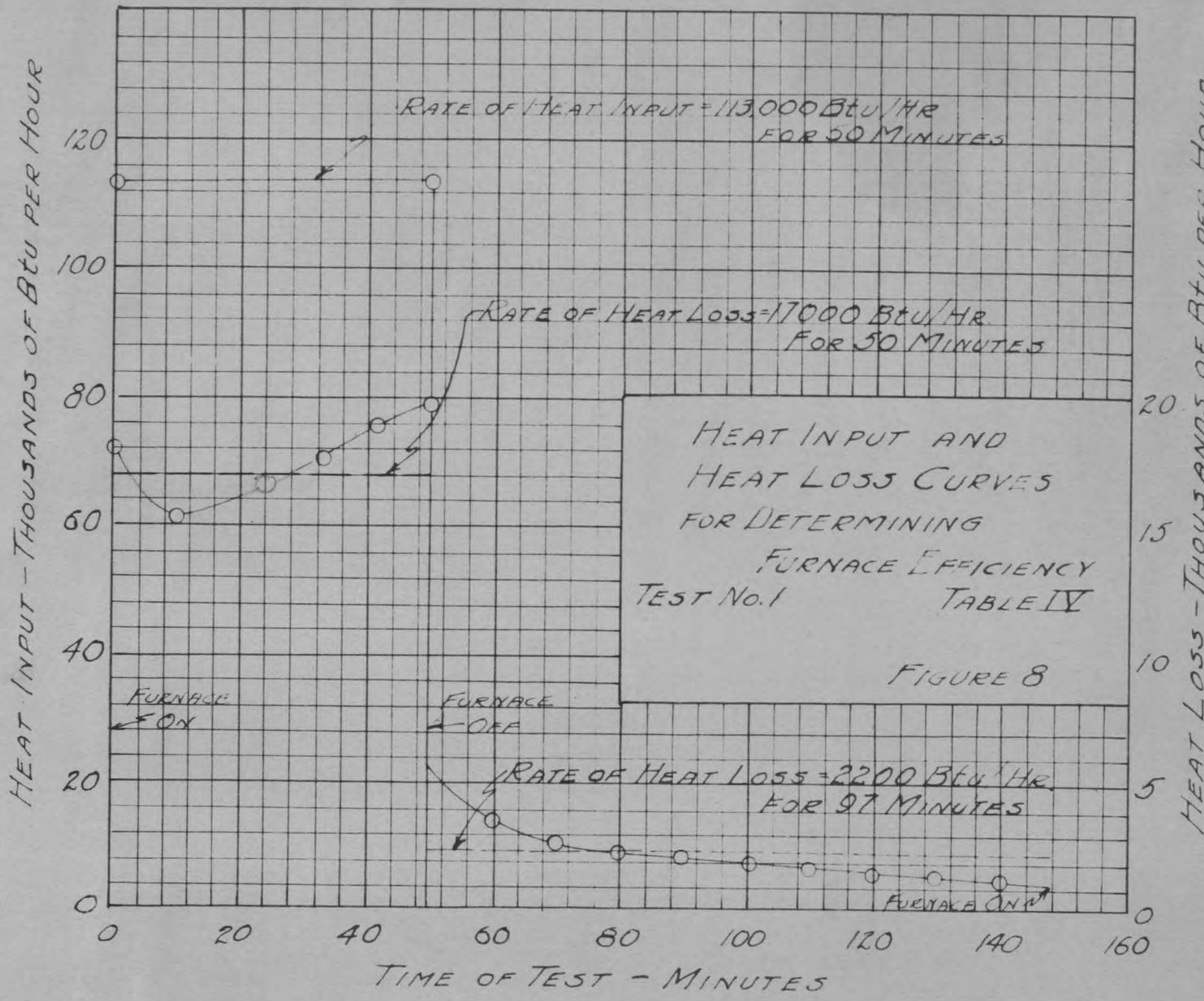
Test No. 1 Analysis of Gas C = 66.1% H_2 = 23.7% N_2 = 10.2% Mol. Wt. = 19.2

Specific Gravity of Flue Gases 0.96 Average Heating Value of Gas = 936 Btu at 25"Hg-70 deg.F.

Pressure on Fuel Gas Line = 6.6" H_2O Gas Rate Corrected = 120 cu.ft./Hr.

11	12	13	14	15	16	17	18	19	20	21
Differentials At Orifices		Gas Flow From Orifice Diff.		Flue Gas Density	Orsat Analysis				Vol.FlueGas From Orsat Cu.Ft./Hr.	Btu Loss/Hr From Flue Gases
Air	Chimney	Air	Flue Gas		CO_2	O_2	CO	N_2		
0.0286	0.0143	925	1700	0.0503	9.8	2.2	1.0	87.0	1720	18000
0.0338	0.0188	1008	2075	0.0450	10.2	2.6	0.2	87.0	2010	15200
0.0370	0.0247	1022	2460	0.0417	10.2	3.1	0.0	86.7	2180	16600
0.0386	0.0216	1087	2365	0.0396	10.3	3.0	0.0	86.7	2290	17500
0.0387	0.0217	1090	2400	0.0388	10.2	5.2	0.0	86.6	2360	17950
0.0437	0.0257	1145	2630	0.0380	9.9	3.7	0.0	86.4	2400	18800
	Furnace Off									
	0.0087		1460	0.0423						3540
	0.0075		1325	0.0442						2890
	0.0074		1295	0.0455						2580
	0.0073		1265	0.0469						2305
	0.0069		1215	0.0483						2020
	0.0067		1182	0.0495						1765
	0.0064		1145	0.0503						1600
	0.0061		1110	0.0510						1440
	0.0057		1065	0.0518						1288

See P. 37 for Calculation



HEAT INPUT AND HEAT LOSS CURVES FOR DETERMINING FURNACE EFFICIENCY

TEST No. 1 TABLE IV

FIGURE 8

Heat loss for "on" period $= 17{,}000 \times \frac{50}{60} = 14{,}150$ B.t.u.

Heat loss for "off" period $= 2{,}200 \times \frac{97}{60} = \underline{\ 3{,}550}$ B.t.u.

Total heat loss for cycle $=$ 17,700 B.t.u.

$$\text{Efficiency} = \frac{(94{,}200 - 17{,}700) \times 100}{94{,}200} = 81.3\%$$

DISCUSSION OF TEST DATA

The test data given are the results of a test made over a single cycle and are not necessarily representative of results which might be obtained. It is merely used for the purpose of illustrating the operation of the method.

Several discrepancies occur in these data which require explanation. The first is the variation in the actual Orsat analysis from the computed values as given in Table I. This was probably due to the change in the gas which had been made shortly before the data were taken. The gas was being supplied from different wells than those which were ordinarily used. This necessitated making an analysis of the gas after the test. There was not sufficient time available to make enough analyses for a good average value.

The agreement between the volumes of gas as measured at the orifice and the volume from the Orsat analysis is fair in most cases but would probably be much closer if a reliable gas analysis were available.

In Table III the air flow differential reading at 8:05 P. M. is high compared to the other differentials recorded. This was probably caused by a surge in the draft occurring at the time the manometer was read.

The shape of the heat loss curve, Figure 8, is characteristic of the performance of a burner in intermittent operation and bears out the prediction of performance as given in the section on Analysis of Flue Gases. The large losses shown during the first few minutes of operation is caused by the formation of CO. When the temperature of the furnace and radiants has become sufficiently high so that the combustion is complete, the loss drops to the minimum point and then rises steadily for the remainder of the "on" period in a direct ratio to the temperature increase and increase in draft.

Figure 9 is a reproduction of a chart obtained from the flue gas temperature recorder during the winter. The period of operation was 48 hours and the chart shows clearly the necessity for testing over a complete cycle of operation.

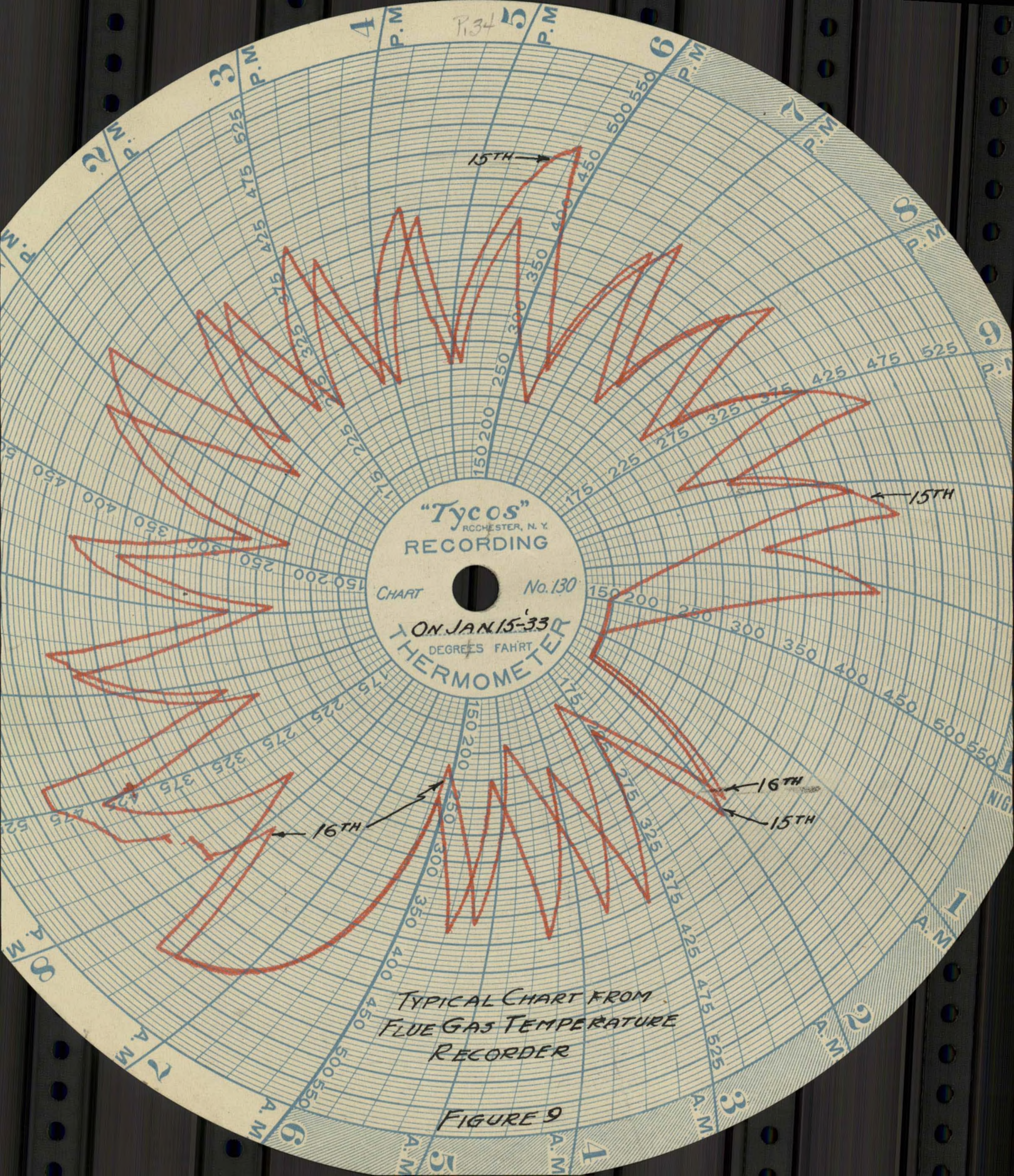
DISCUSSION

The test method as given in this paper is by no means complete. There are a number of points which require investigation.

The next step would be to calibrate the chimney orifice. It may be possible to develop a method of calibration similar to that used for calibrating the inlet air orifice. For this purpose it will be necessary to heat the air passing through the orifice to temperatures corresponding to the temperatures of the flue gases. The necessity for the calibration may be seen from the following facts:-

1. The orifice has not been used to measure differentials caused by velocities as low as those encountered in a furnace flue.

P.34



TYPICAL CHART FROM
FLUE GAS TEMPERATURE
RECORDER

FIGURE 9

2. The change in the viscosity of the gases with the change in temperature may have an appreciable effect on the coefficient of discharge of the orifice when there is a temperature variation over a wide range.

After the chimney orifice has been calibrated it will be possible to determine the sensible heat loss due to dry chimney gases directly from the orifice measurement when combustion is complete and use the Orsat apparatus only as a check on combustion conditions. Since there was not sufficient time to devise a method of calibration for the chimney orifice, an orifice coefficient of .60 was assumed for the calculation of the test data. This coefficient was given in several papers read,[2,5] as correct for differentials in the neighborhood of one inch of water when the ratio of the diameter of the orifice hole to the diameter of the pipe was 0.50.

A departure from the ordinary installation was the substitution of the chimney orifice for the draft hood. When a gas installation is made, whether gas designed or conversion, it is necessary to make a provision for a draft hood between the furnace and the stack. The purpose of the draft hood is threefold and is given in the A.G.A. "Requirements" as follows:-

" (1). To insure the ready escape of the products of combustion in the event of no draft, back draft, or stoppage beyond the draft hood.

" (2). To prevent a back draft from entering the appliance.

" (3). To neutralize the effect of stack action of the chimney upon the operation of the appliance."

The draft hood in practice takes one of two forms. The first form is the standard draft hood used when a gas appliance is installed. This consists of a bell shaped device of considerably larger diameter than the flue pipe on one end and tapered to the same diameter as the flue pipe on the other. The small end goes to the stack. The large opening is telescoped for a short distance over the chimney flue from the furnace. In the hood just above the opening of the flue pipe is placed a V-shaped baffle. From this arrangement it may be seen that there is an area of at least the equivalent of the flue area, which is open to the basement and thus kills the draft. The baffle prevents a down draft from affecting the burner in the furnace. The second type of draft hood is that used for the conversion burner and consists simply of removing the check damper from the flue pipe. As a check damper opening generally has an area as large or nearly as large as the cross sectional area of the chimney flue, this serves the same purpose as the large end area in the first type of hood described.

From the basic theory of the hood, it may be seen that it would be impossible to provide a means for covering these openings at any time during the heating season. With a draft on the stack varying from .05 inches of water to about 0.3 inches depending on the wind, outside temperature, and temperature of the gases in the stack, a large volume of air is removed from the house through the draft hood opening. The draft increases with the temperature differential between the inside and outside of the house; there is generally a greater draft when a strong wind is blowing; therefore the loss through the draft hood opening is greatest when the weather is most severe. The amount of air removed from the house by means of the draft hood is sufficiently large to raise the rate of air change in the house to an appreciable degree. The air is removed from the basement but since a foundation is as a rule quite tight and basements have few windows, infiltration must take place in the upper portion of the house to replace the air removed from the basement. From the foregoing discussion, it may be seen that the draft hood loss is due to the installation of a gas appliance and should be taken into account as a loss in computing the efficiency of the appliance.

The orifice placed in the flanges in the chimney flue serves a double purpose, (1) for metering the products of combustion going to the stack and (2) as a substitute for a draft hood. The check damper opening was capped and the resistance and baffling effect of the orifice relied upon to serve the purpose of the draft hood in killing the draft and preventing back draft. From observations made over a period of about six months this has been very successful and may be a development which could be adopted to good advantage on all gas appliances. A longer period of testing and more complete investigation would be necessary before it could be definitely shown as an advantage. It is evident, however, that it has a very definite advantage in eliminating the heat loss due to the draft hood.

As to the other purposes, when the draft hood is used:- If stoppage should occur beyond the hood, the products of combustion would fill the house in a short time making it disagreeable: if the orifice is used and the opening capped, the products of combustion will back up into the furnace extinguishing the burner and pilot. When the pilot is extinguished it automatically shuts off the gas so this would be more desirable than filling the house with the combustion products, and at the same time is just as safe as the draft hood.

APPENDIX A

SAMPLE CALCULATIONS OF TEST DATA

Column No.

1-10 Observed during test

11 (Col. 3) - (Col. 2)

12 (Col. 4) -(Col. 2)

13 (From curve in Figure 15 using value in Col. 1) x $\frac{\text{gas rate}}{100}$ x 60

14 Flow Formula $V = CM \sqrt{2 g h_o \frac{d_o}{d}} \times 3600$

Where V = flow cu. ft. per hour.

C = orifice coefficient = .60

4" orifice in 8" pipe

M = meter constant = .0903 for orifice used. = $0.3488 \sqrt{\frac{4^4}{8^4-4^4}}$ (area of pipe in sq ft.)

g = acceleration of gravity = 32.2 ft. per sec.^{2}

$0.3488 \sqrt{\frac{3^4}{8^4-3^4}}$
$= 0.3488 \sqrt{\frac{81}{4096-81}}$
$= 0.0495$ for 3" orifice

h_o= differential head in ft. of liquid used in manometer = $\frac{\text{col. 12}}{12}$

d_o= density of liquid in manometer in lbs. per cu. ft.

d = density of fluid measured in lbs. per cu. ft. (see item 15 for calculation)

$V = .60 \times .0903 \left(\sqrt{.2 \times 32.2 \times \frac{.0143}{12} \times \frac{50.5}{.0503}}\right) \times 3600 = 1700$ cu. ft. per hour.

15 The density of air at 25" Hg - 70° F. = .0612 lbs. per cu. ft.

The specific gravity of the flue gases (from table IV) is .96

Then the density of flue gas at 164° F = (624° abs.) = .0612 x .96 x $\frac{530}{624}$ = .0503 lbs. per cu. ft.

16 Same as Col. 7

17 (Col. 8) - (Col. 7)

18 (Col. 9) - (Col. 8)

19 (100) - (Col. 9)

20 From curve Figure 6 using value in Col. 16)

$$\text{(Volume from curve)} \times \frac{\text{gas rate}}{100} \times \frac{\text{(Col. 5 + 460)}}{530}$$

21 $$\text{(From curve Figure 7 using Col. 5)} \times \frac{\text{gas rate in cu. ft. per hr.}}{100}$$

During the "on" period the specific gravity of the flue gases may be taken as .96 and the heat loss obtained as illustrated. During the "off" period air is passing up the chimney flue and the flow is calculated in the same way but to obtain the heat loss the volume is changed to weight and the loss calculated from the formula = $W \times .24\ (tg - t_r)$ as illustrated on page 23.

APPENDIX B

MEASUREMENT OF INLET AIR AND FLUE GASES

The principal problem in connection with the testing method adopted was the measurement of the air supplied for combustion and the measurement of the products of combustion. The volume of the flue gases could be computed from the flue gas analysis, but since the flue gases are considered as the only losses from the furnace, it was decided that the Orsat in itself was not sufficiently reliable so that its results could be accepted without verification by other means.

It was equally important that the air supplied for combustion be measured so that the entire input to the furnace would be known. The air leakage into the furnace, can be determined by difference if the Orsat analysis of the gases leaving is known, and the amount of air supplied is also known. The method of doing this has been shown in a previous section of this paper.

In considering the measurement of the flow of gases at the very low velocities encountered in a domestic furnace, three methods were considered. These are (1) the anemometer, (2) the pitot tube, and (3) the orifice. Each of these methods has certain advantages and disadvantages, and the selection of the one to be used was based on the consideration of the following factors; (1) Apparatus available, (2) facility of construction, (3) data available and previous usage (4) accuracy, (5) ease of manipulation.

The anemometer [16] is the most commonly used instrument for determining the air flow at low velocities in heating tests. It has the advantage of being a self contained unit that is direct reading. It has the disadvantage of being a rather delicate instrument of many mechanical parts and requires constant recalibration in order that its readings may be relied upon. Furthermore, a careful traverse of the opening, through which the flow is being measured, is required unless the anemometer is calibrated in place. If this is done, it is necessary to have some type of calibrating apparatus at hand so that checks on the accuracy of the instrument can be made at frequent intervals. Since it was desired to measure the flue gases with the instrument selected, it was questionable whether an instrument of this kind could be constructed which would give reliable readings when placed in a gas stream where the range of temperature is as large as that encountered in a furnace flue. There was one anemometer available which could have been used for metering the air supplied for combustion, but a considerable amount of research and experimentation would have been required to construct an anemometer which would be suitable for use in the chimney flue.

The pitot tube is an instrument which has also been widely used for the measurement of fluid flow at low velocities. Its principal advantage is that it has been used in a sufficient number of investigations so that its characteristics and performance are quite well known[13,16,19]. If it is constructed according to specifications and used with care, the results obtained may be relied upon. Disadvantages of the instrument are the following;

1. A traverse for each detemmination is required which makes

the manipulation slow and the method of computation rather involved.

2. It is not an integral unit and requires the use of a differential gage of very high accuracy.

3. When the pipe in which the measurements are to be made has a diameter of six inches or less a special pitot tube is required and this tube must be calibrated with a standard tube before it can be used for measurement purposes.[16]

Standard pitot tubes were available but it would have been necessary to construct a small tube for use in the pipe through which the air was supplied for combustion.

The sharp-edged orifice has been accepted as an accurate method of determining fluid flow. A search showed that the orifice has been used quite extensively for the measurement of gases where the velocities were sufficiently high so that a differential across the orifice of one inch or more of water could be obtained. However, no material could be found where gas with velocities as low as those encountered in this work had been measured by means of the orifice. No reason can be found for not using the orifice for measurement of gas flow at much lower velocities than those for which it has been used up to the present time.

The use of an orifice for the flow measurement has these advantages;

1. a single calibration is sufficient and recalibration at frequent intervals is not necessary.

2. it is easy to construct and install.

3. a traverse is not necessary and a single reading is sufficient for the calculation of the rate of flow, unless the flow varies quite rapidly.

The disadvantages of using an orifice are as follows;

1. it is not an integral unit and requires the use of a very sensitive manometer.
2. it has not been used previously for the measurement of velocities as low as those encountered in this work and consequently no data are available on the coefficients over the range required.

It was decided that the orifice was the most logical means of controlling both the air supplied for combustion and the draft and since it would be used for this purpose it would be advantageous to use it for metering also. It was decided that the orifice had a sufficient number of advantages over the other methods of measurement so that its selection was justified without the additional advantage of being an excellent means of controlling the air and draft. In order to eliminate the most serious disadvantage, which is the last listed above, it was decided to calibrate the orifices with conditions as nearly similar to the operating conditions as could be obtained.

CALIBRATION OF AIR ORIFICE

Due to the fact that there were no data on the use of orifices for measurement of fluids flowing at velocities as low as those encountered in domestic furnaces, an effort has been made to take every precaution possible to insure the proper calibration of the orifice so that measurements made with it would be reliable.

In order to calibrate the orifices with conditions of flow as near to the condition of operation as possible it was necessary to find some way to draw small quantities of air through the pipe in which the orifice was placed. The solution to this problem was found in the critical flow of air into a vacuum through a small nozzle. In the A.S.M.E. Transactions for 1920 is a paper by W. L. DeBaufre entitled, "Calibration of Nozzles for the Measurement of Air Flowing Into a Vacuum".[4] In this article Mr. DeBaufre calibrated a series of nozzles having diameters varying from .085 inches up to 1 inch for measuring the flow of air into a vacuum. In these calibrations the vacuum was maintained at a sufficient magnitude so that critical flow through the nozzle took place. Critical flow occurs when the absolute pressure on the outlet side of the nozzle is 53 per cent or less of the pressure on the inlet side. When this condition has been reached the maximum amount of air which will pass through the nozzle will flow continuously through it and the pressure on the outlet side will not affect the flow.

The nozzles had been carefully calibrated and all the data on their calibration were given as well as the design and exact sizes of the nozzles. A set of the nozzles was made up which would measure volumes over the range for which it was necessary to calibrate the orifices. Figure 10 shows the design of the nozzles used, the sketch being taken from the paper by Mr. DeBaufre.

In order to use the nozzles it was necessary to design some type

CONSTRUCTION OF DE BAUFRE NOZZLE

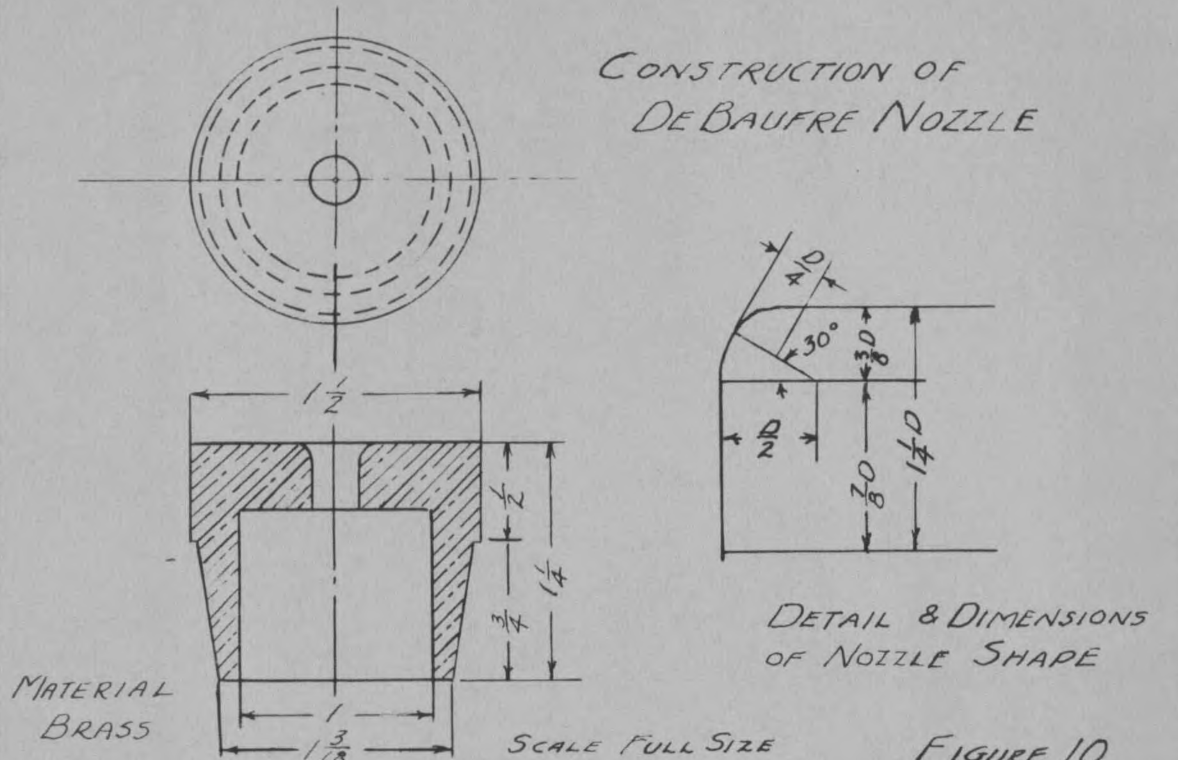


FIGURE 10

CONSTRUCTION OF AIR ORIFICE

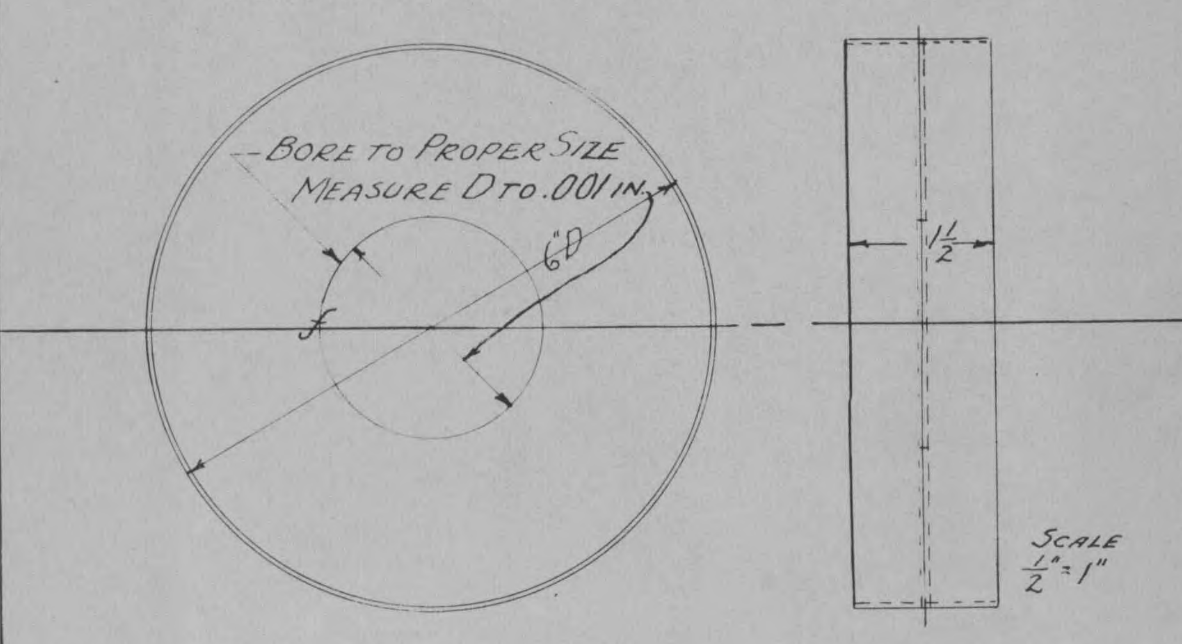


FIGURE 11

of apparatus by means of which they could be used for the air flow measurement. Figure 12 shows the complete set-up of the apparatus devised for this purpose. It consists of the inlet air metering pipe, removed from the furnace with the orifice in place and set up in this apparatus, two lengths of four-inch stove pipe, the differential manometer, the vacuum chamber, a mercury vacuum gage, and the pipe connections to the vacuum pumps.

It was mentioned in an earlier part of this paper that the inlet air metering pipe was made in such a manner that it could be removed for the calibration of the orifice. The purpose of this was to permit the removal of the entire unit so that the position of the orifice with relation to the pressure taps could be easily preserved, calibration was made under these conditions, and the pipe then replaced at the furnace for use in measuring the air input to the furnace. Since the reducer is an integral part of the inlet air pipe it was necessary to use four inch pipe for the section immediately following it. The purpose of this four-inch pipe was to form a chamber between the metering pipe and the nozzle to prevent the possibility of any turbulence caused by the nozzle from affecting the micromanometer used for measuring the differential at the orifice.

The vacuum chamber and the nozzles are illustrated in Figure 13. The vacuum chamber was constructed of a three-inch standard pipe nipple and 2 three-inch pipe caps. The outside of one of the pipe caps was turned on the lathe to the size of the four-inch pipe so that a good tight fit was obtained. A brass bushing was made which had an inside taper the same as the taper on the nozzles and the inside polished smooth so that a good fit with the nozzle was obtained. The face of the cap which had been turned to

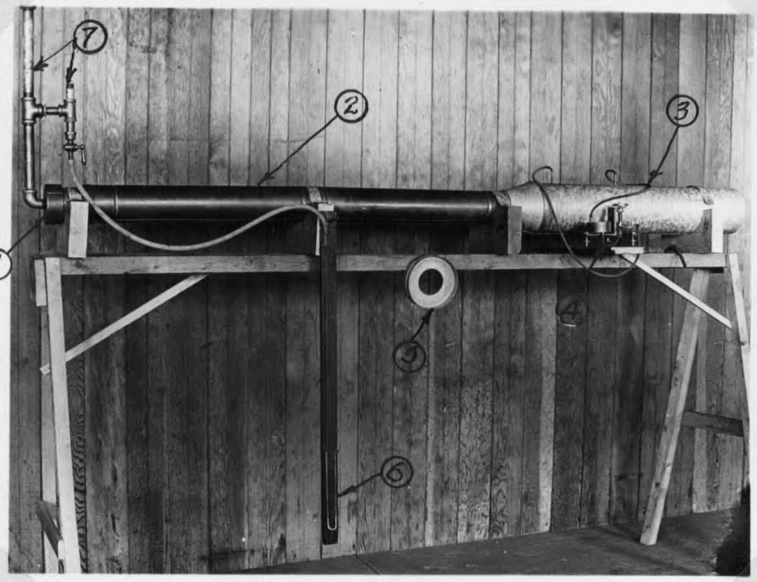


Fig. 12

Apparatus for Calibrating Air Orifices

1. Vacuum Chamber
2. 4 inch Stove Pipe
3. Inlet Air Metering Pipe
4. Micromanometer
5. Extra Air Orifice
6. Mercury Manometer for Vacuum
7. Connections to Vacuum Pumps

Fig. 13

DeBaufre Nozzles and Vacuum Chamber

fit the four-inch pipe was then bored to the size of the outside diameter of the brass bushing and a drive fit was obtained. The bushing was then driven from the inside of the cap so that it came flush with the face. The face of the other cap was drilled and tapped for 3/4 inch pipe and a street ell was placed in it. The chamber was then assembled and when placed on the stand with the other apparatus and connected to the vacuum pumps, was ready for use.

The mercury manometer was used to determine the magnitude of vacuum which was maintained in the chamber.

A steam driven vacuum pump was used to maintain the vacuum in the chamber. However, for the largest nozzle used, (11/32 inch diam.) the pump did not have sufficient capacity to maintain the required vacuum and it was necessary to connect a small motor driven vacuum pump in parallel with the steam pump to obtain sufficient vacuum.

The nozzles were made of brass according to the design shown in Figure 10, page 46. A template was made for the shape of the inlet and the nozzle fitted to this template so that the proper shape was assured. The faces and throats of the nozzles were highly polished with emery cloth and crocus cloth. The throat diameters were then measured with a micrometer. The final sizes of the nozzles, compared with those of DeBaufre, are given in Table V. A curve, Figure 14, was made for interpolating the capacities for the sizes made so as near exact capacity was obtained as possible. The capacities given in the Table and on the curve are values taken from DeBaufre's data[4] which was for a barometric pressure of 29.92 inches Hg. and 70 degrees F. The volumes must be corrected to the conditions of temperature

TABLE V

NOZZLES CALIBRATED BY DEBAUFRE

Values taken from Table I of De Baufre's paper.

Drill Size	Diameter By Measurement	Capacity Cu.Ft./Min
1/4	0.249	12.90
9/32	0.277	15.90
5/16	0.315	20.60
11/32	0.344	24.50
3/8	0.375	29.10

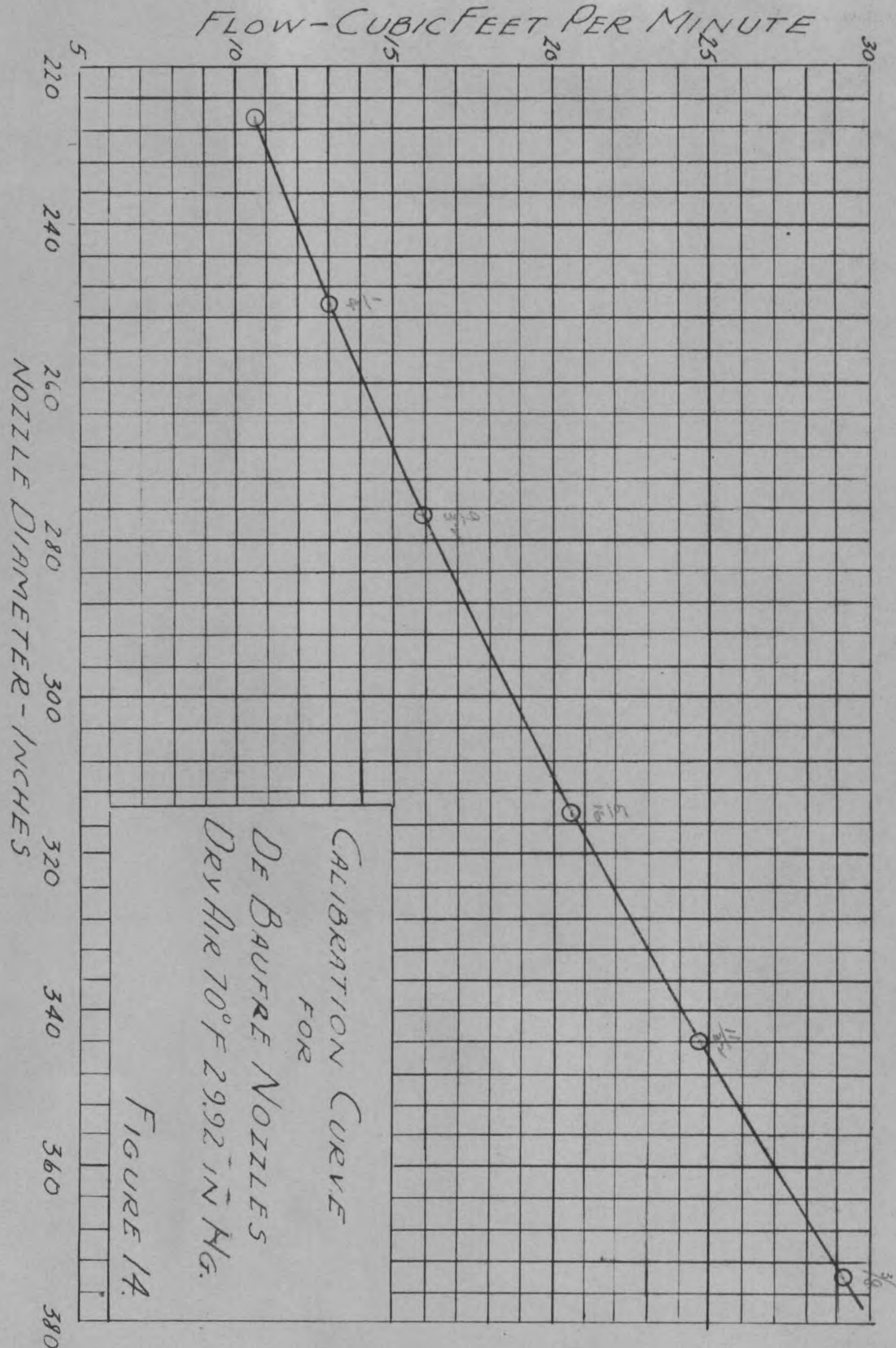
Volumes for dry air at 70 degrees F. 29.92" Hg.

NOZZLES CONSTRUCTED AT M.S.C.

Capacity obtained from curve, Fig. 14

Drill Size	Diameter By Measurement	Capacity Cu.Ft./Min.
1/4	0.255	13.30
9/32	0.280	16.20
5/16	0.315	20.60
11/32	0.345	24.50
3/8	0.380	30.00

Volumes for dry air at 70 degrees F. 29.92" Hg.



FLOW - CUBIC FEET PER MINUTE
5
10
15
20
25
30
220
240
260
280
300
320
340
360
380
NOZZLE DIAMETER - INCHES
CALIBRATION CURVE
FOR
DE BAUFRE NOZZLES
DRY AIR 70°F 29.92 IN HG.
FIGURE 14.

and pressure existing at the time the nozzles are used for calibration of the orifice.

With the apparatus set up as shown in Figure 12 the calibration of the orifice may be made. Machine oil is placed on the tapered part of the first nozzle to be used, to insure a seal, and the nozzle placed in in position in the vacuum chamber. The pipe connecting the chamber with the metering pipe is slipped into place and carefully examined to see that it is tight. If there is any possibility of the joint leaking it is well to seal it with tallow or wax. The pumps are started and adjusted to such speed that in the vacuum obtained the absolute pressure is somewhat less than 50 per cent of atmospheric pressure. When this condition is established critical flow through the nozzle is taking place and all the air passing through the nozzle is being drawn in through the orifice. A series of readings on the manometer are then taken to determine the differential caused by the flow. A test is shown in Table VI and the readings required for the calibration are tabulated there. When a number of readings have been taken a nozzle of the next larger size is placed in the apparatus and the process outlined above is repeated. When the range over which the calibration is desired has been covered the data may be plotted as shown in Figure 15. In this way the volume of air can be taken directly from the curve when differential readings taken in the furnace tests are made, and it is not necessary to go through a series of calculations involving coefficients and density ratios. However, if the liquid used in the manometer is not the same for the calibration as that used in the furnace tests then it is necessary to know the specific gravity of the liquid used

TABLE VI

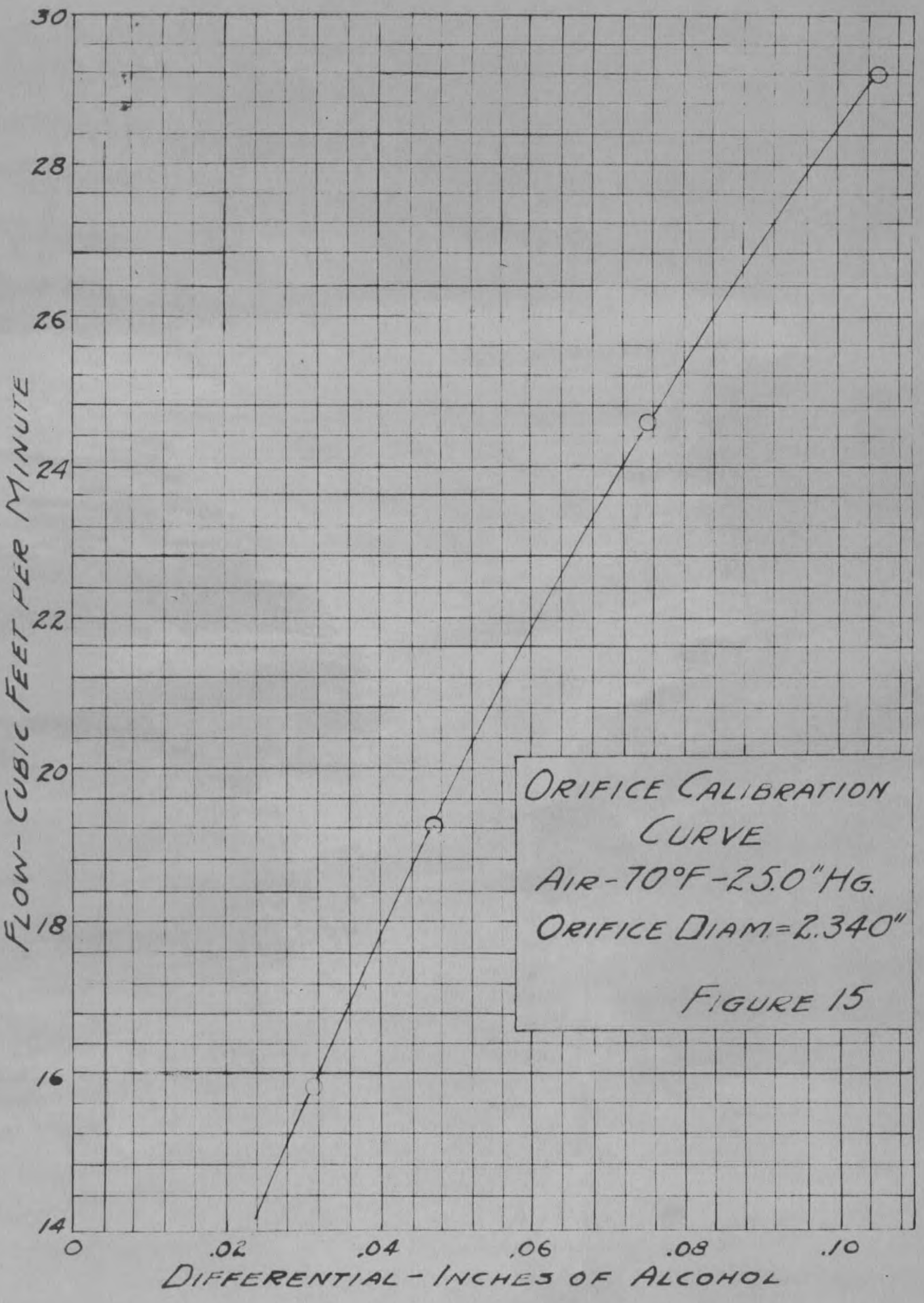
TEST DATA ON ORIFICE CALIBRATION

Date 4 - 4 - 33 Orifice Diameter = 2.340"

Manometer Fluid - Methyl Alcohol Specific Gravity = 0.808

Barometer = 25.1" Hg.

Nozzle Size Inches	Vacuum Inches Hg.	Manometer Differential In. Alcohol	Flow (From Fig 14) Cu.ft/min @29.92"	@25"	Entering Air Temperature
1/4	15.0	0.0310	13.30		76
	14.9	0.0310			76
	14.8	0.0308		15.91	77
	15.0	0.0310			76
	15.0	0.0312			76
9/32	14.0	0.0472	16.20		75
	14.0	0.0465			75
	14.0	0.0465		19.39	75
	14.0	0.0468			75
	14.0	0.0467			76
5/16	13.2	0.0760	20.60		75
	13.2	0.0756			77
	13.2	0.0748			76
	13.6	0.0748		24.65	76
	13.6	0.0750			76
11/32	12.8	0.1040	24.60		76
	12.8	0.1040			78
	12.8	0.1045		29.35	77
	12.8	0.1050			77
	12.7	0.1050			76



30
28
26
24
22
20
18
16
14
0
.02
.04
.06
.08
.10
FLOW - CUBIC FEET PER MINUTE
DIFFERENTIAL - INCHES OF ALCOHOL
ORIFICE CALIBRATION CURVE
AIR - 70°F - 25.0" HG.
ORIFICE DIAM = 2.340"

FIGURE 15

each time and the equivalent head in terms of the liquid used when calibration was made must be computed before the air flow is read from the curve.

The effect of humidity in the calibration, unless excessive, is negligible. This may be seen by examining the table given in DeBaufre's paper[4] in which the largest correction factor given is 0.994. This is also brought out in S. A. Moss's[14] paper and in Mr. Moss's discussion of DeBaufre's paper.

CONSTRUCTION AND USE OF MICROMANOMETER.

Some preliminary trials showed that differentials ranging from less than 0.01 inch of water up to 0.05 inches of water would be experienced at the orifices where it was desired to make measurements of flow. An inclined manometer graduated to 0.01 of an inch of water was used for these trials. With differentials as low as these the apparatus available was not sufficiently sensitive so that measurements of the order of accuracy desired could be made. If either an orifice or a pitot tube were to be used for measurement it was necessary to have an instrument of much greater sensitivity than those available. Some study of manometers of high sensitivity was therefore necessary.

Since a differential gage was only one of quite a number of instruments required for this test work, a great deal of time could not be devoted to this study. However, a sensitive, reliable gage was sufficiently important so that the progress of the present project had to be interrupted until a suitable gage could be constructed.

In selecting a gage for this work the following characteristics were deemed desirable;

1. Simplicity of Construction.
2. Accuracy to 0.001 inch of water.
3. Ease and speed in manipulation.
4. A standard gage which did not require calibration.
5. Ruggedness of construction.

In connection with the furnace tests at Illinois it was found desirable to have a sensitive manometer of the type mentioned above. A gage known as the "Wahlen Gage"[8], a micromanometer sensitive to 0.0001 inch of water was designed and constructed for use with pitot tubes and orifices when calibrations of the amemometers were made. This gage involved the use of two liquids. It was studied but its construction was rather difficult and the gage somewhat cumbersome.

In "Measurement of Air Flow"[16] by E. Ower a chapter is devoted to micromanometers. A number of manometers having various ranges and accuracies are discussed and described. Two types of tilting micromanometers are described. These manometers complied with three of the five points specified above, (numbers 2,3, and 4), but departed sufficiently from the other two to cause their rejection. The reason for this was that a good deal of expensive and complicated glass work was involved and this made them objectionable according to points 1 and 5.

One manometer described by Mr. Ower seemed to be of the type which would comply with all the requirements listed. It is a large range manometer of the U tube type with a movable limb. The principle of the manometer was adopted and using this principle a design has been made which suits the needs of this test. The complete design is given in Figure 16 and the completed instrument is illustrated by Figure 17. Mr. Ower describes the principle of the instrument as a "manometer employing virtually a flexible U tube consisting of two limbs whose lower ends are connected by a length of rubber tubing. One of the limbs remains stationary while the other is raised or lowered by an amount corresponding to the applied pressure difference, by means of a micrometer screw to which it is attached." The "stationary limb" consists of a reservoir of large area so that the movement of the other limb will not have an appreciable effect on the level of the liquid in the reservoir. The movable limb consists of a piece of glass tubing inclined at a very slight angle fixed to a nut on the micrometer screw. The glass tubing is fastened to the nut in such a way that its inclination can be varied to change the sensitivity of the manometer. Rotation of the nut to which the tubing is fastened is prevented by milling a groove in the nut which slides over the center support of the micrometer screw bracket and moves along the side of the scale. The top edge of the nut is used as the indicating pointer for the position of the limb.

The selection of a suitable liquid for use in the manometer was the next consideration. In an article, "How to Make Differential Manometers" by A. J. Nicholas[15] he states "For low differentials water is an unsatisfactory fluid for use since the water meniscus is liable to be sluggish---- "oil or alcohol are more satisfactory since for very small tubing the capillary action is small or negligible and the meniscus is distinct and

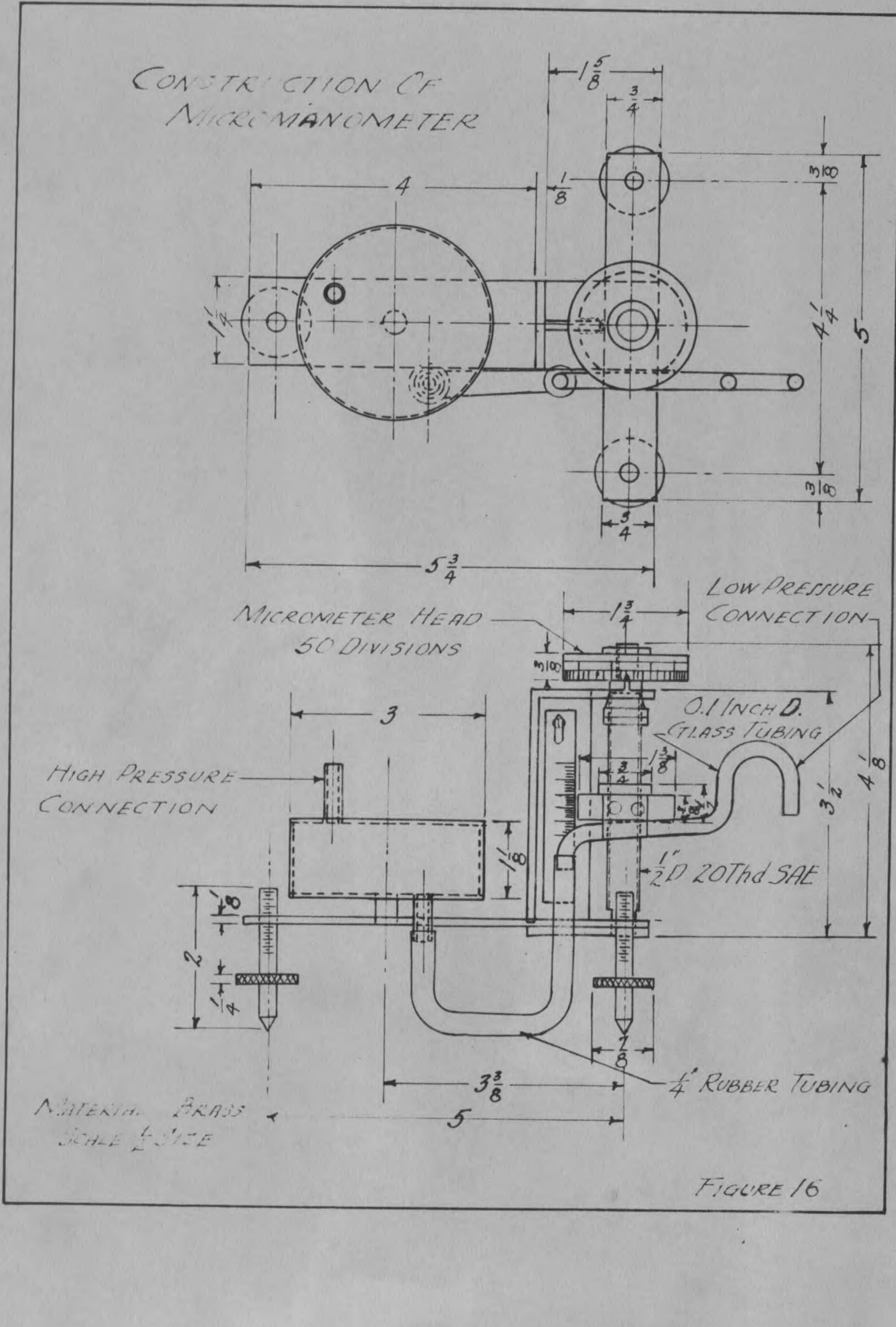

CONSTRUCTION OF MICROMANOMETER
MICROMETER HEAD 50 DIVISIONS
LOW PRESSURE CONNECTION
0.1 INCH D. GLASS TUBING
HIGH PRESSURE CONNECTION
1/2" D 20Thd SAE
1/4" RUBBER TUBING
MATERIAL BRASS
SCALE 1/2 SIZE

FIGURE 16

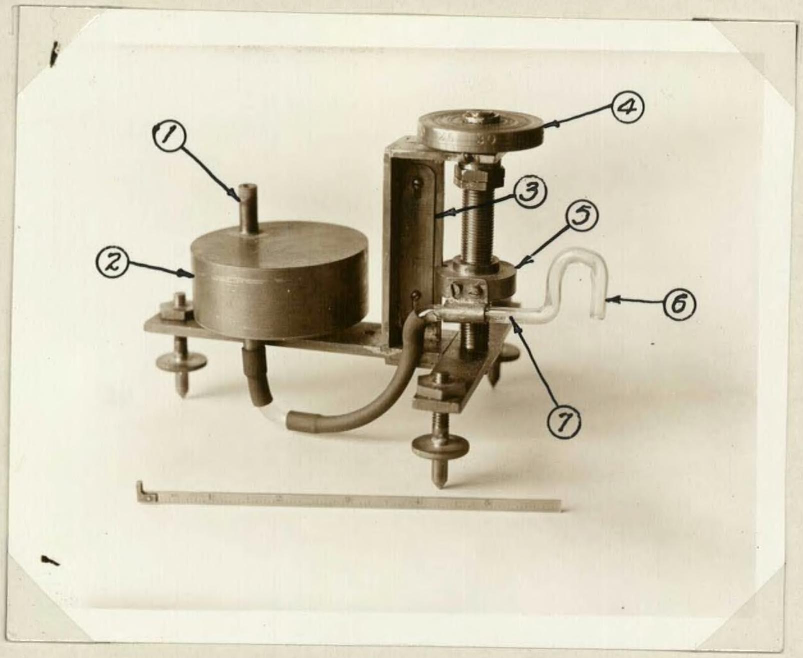


Fig. 17

Micro-manometer for Measuring Extremely Low Differentials

1. High Pressure Connection
2. Liquid Reservoir
3. Scale
4. Micrometer Head
5. Movable Limb Nut
6. Low Pressure Connection
7. Hair Line for Meniscus on Inclined Glass Tube