DEVELOPMENT OF A STANDARD TEST FOR FORCED WARM AIR HEATING PLANTS

THESIS FOR THE DEGREE OF M. S.

J. E. Arnold

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THESIS

Furnaces
Heating

DEVELOPMENT OF A STANDARD TEST

FOR

FORCED WARM AIR HEATING PLANTS

Thesis

Submitted as Part of the Requirements

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THESIS

The author wishes to express his appreciation to Professor L. G. Miller, as director of this problem, and to the various members of the Department of Mechanical Engineering for their assistance. Also to those students who assisted in making the preliminary tests.

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INTRODUCTION.

With an ever increasing number of different kinds of forced warm air furnaces being placed on the market, it is becoming more and more necessary that some method of testing these furnaces be developed, so that one furnace may be fairly compared with another. Many manufacturers, either knowingly or unknowingly overrate their furnaces. The result is that these furnaces can be sold at a lower price than those which are properly rated. The home owner in turn finds that the overrated furnace must be overheated, even in moderately cold weather. This overheating is highly undesirable from the standpoint of fire hazard, comfort and economy.

Economy brings in another item, that of efficiency. It is a comparatively easy matter to figure the amount of fuel which is being consumed by the furnace, but when this heat is to be accounted for it is an altogether different matter. The temperature of the air entering and leaving the furnace can be measured quite accurately if extreme care is observed, even in actual installations. It is much more difficult to measure the volume or weight of air being circulated by the furnace. This has been accomplished by a few, by very painstaking work and at great expense. For examples see some of the Bulletins published by the University of Illinois[1]. Thus it will be seen that the heat delivered by the furnace cannot be very easily obtained and hence any efficiency should be calculated from a heat balance in which all losses have been accounted for to within a very close margin.

1. Univ. of Ill. Bul. #189 - Investigation of Warm-Air Furnaces and Heating Systems
   Bul. #120 - Investigation of Warm-Air Furnaces & Heating Systems.

This test is therefore designed with the purpose of prescribing an accurate and uniform method of testing forced warm air furnaces at a minimum of expense and under conditions similar to those encountered in actual operation. Also to bring out the characteristics of the furnace, its capacity and the efficiency that may be expected under certain operating conditions.

STANDARD TEST FOR FORCED WARM AIR HEATING PLANTS

P A R T I

CONTINUOUS TEST

SCOPE OF THE TEXT

This Standard Test is based on experiments run on a forced warm air steel furnace using an oil burner of the wall flame type. The fans are located in the top of the furnace and the furnace inlets unrestricted by boots or return pipes. Additional help was obtained from references which are referred to throughout the test and the discussion.

Variations and additions will possibly have to be made to make this test applicable to all types of forced warm air furnaces and oil burners. Since only fuel oil was used in these experiments, no attempt will be made to include solid or gaseous fuels in this test.

This Test is divided into two parts. Part I covers continuous or steady state conditions and Part II intermittent tests.

A. DEFINITIONS.

1. "Standard air is air weighing 0.07488 lbs. per cubic foot. This weight corresponds to dry air at 70°F or air with 50% relative humidity at a dry bulb temperature of 68°F" and a pressure of 29.92 inches of mercury.

2. "Static pressure (S.P.) is the pressure measured at right angles to the direction of air flow"[1], expressed in inches of water, and is the pressure required to overcome the frictional resistance of the system.[2]

3. "Velocity pressure (V.P.) is the pressure required to produce the velocity of flow", is measured by means of a pitot tube, and expressed as inches of water.[2]

4. The Entering Air Temperature is the average temperature of the air entering the furnace, measured at the furnace inlet and expressed in degrees F.

5. The Bonnet Temperature is the average temperature of the air discharged at the furnace, obtained by adding the equivalent temperature drop between the furnace and the nozzle, to the average temperature of the air in the nozzle.

6. The oil rate is the weight of oil burned during the test divided by the length of the test period in hours, expressed as pounds per hour.

1. A.S.H.V.E. Test Code for Unit Heaters
2. Heating & Ventilation, Allen & Walker, pp. 309

7. Furnace Efficiency shall be defined as the quotient obtained by dividing the heat required to raise the circulated air from the inlet temperature to the bonnet temperature by the heat represented in the fuel input, times 100. The bonnet temperature is obtained by correcting the nozzle temperature for losses in the duct work.

8. Heat losses include the following:

   Losses to the flue gas composed of sensible heat of the gas above the room temperature, latent heat of vaporization of the water vapor, and heat of the unburned CO.

   Loss from the jacket due to radiation and convection. There are points for including all or at least part of this heat as useful since it would be used to advantage in an actual installation. However, for this test it will all be considered as a loss.

9. For simplicity the duct work connecting the furnace and the mixing chamber will be referred to as "pipe".

B. OUTLINE OF TEST.

This test prescribes a method of determining the B.t.u. output of a forced warm air furnace by measuring the weight and the temperature rise of the air passing through the furnace.

For check purposes it is required that all losses be accounted for except those from the mixing chamber and through the base of the furnace to the floor. These losses are considered negligible for the purposes of this test, as is the heat added by the fans.

Tolerance - The unaccounted for loss shall not be more than $2\frac{1}{2}$ per cent of the heat in the fuel for the test period considered. This tolerance shall be increased to 4 per cent for intermittent tests.

Six or eight tests distributed over the range of the furnace are sufficient to establish the curves where the fans are in the bonnet of the furnace. For greater accuracy in locating these curves, three or four tests may be run for each oil rate covering the range of the furnace fan. Where the fans are in the supply side of the furnace it may be necessary to run the four tests of each oil rate. The same four conditions of fan static pressure and r.p.m. should be maintained for each oil rate so that a performance chart may be made for each set of fan static and r.p.m.'s.

The performance chart is constructed such that the efficiencies obtained for the furnace tested can be plotted against the temperature rise. Then for any temperature rise and the corresponding heat supply rate, the heat input to the air may be determined and hence the volume of air, measured as standard air, that

will be raised to the above temperature (70 + the temperature rise) may be obtained.

Oil rate lines in pounds per hour are substituted for the fuel consumption lines by dividing the fuel consumption by the heating value of the oil in B.t.u. per pound. Thus for a fuel having a heating value of 20,000 B.t.u. per pound, the 10 pound per hour line coincides with the 200,000 B.t.u. per hour line.

The average flue gas temperature for each oil rate shall be indicated on the corresponding oil rate lines.

A chart shall be constructed showing the capacity of the furnace fans in c.f.m. at 70^{o}F and 29.92 inches height against r.p.m. The data shall be obtained by running the fans, with the furnace cold, at given r.p.m.'s. and varying the static pressure as desired by means of the exhaust fan controls. Four speeds at the same static are sufficient to plot the curves. These curves shall be plotted covering the range of the fans.

C. EQUIPMENT FOR TESTING.

Chamber and Exhaust Fan.

A chamber for receiving and mixing the air discharged from the furnace shall be constructed of any suitable material. It shall be air tight, and insulated with two inches of cork or the equivalent.[1]

This chamber shall be connected by a duct to an independent exhaust fan of such capacity that it will overcome the resistance of the nozzle and duct work and produce, together with the furnace fan, such static as may be desired at the furnace for any c.f.m., fan r.p.m., and static pressure.

The chamber shall be of such size that the furnace to be tested will produce from 20 to 90 air changes per minute.[1]

The outlet or outlets of the furnace shall be joined to the chamber with as little communicating duct as possible. The outside of this duct should be unpainted, rather a bright polished metal surface.[2] This duct should not be insulated unless two inches of cork or its equivalent be used. If insulated, the calculations pertaining to it shall be omitted.

Two or more static orifices shall be located in the receiving chamber, not in the direct air blast from the furnace or where eddy currents will effect them. These openings shall be connected to a draft gauge as shown in Fig. 1. Standard static tubes may

1. A.S.H.V.E. - Test Code for Unit Heater
2. Univ. of Ill. Bulletin No. 117 - Coefficients of Emissivity for Various Surfaces.

be used in place of the orifices. Means shall be provided with which to vary the capacity of the exhaust fan so as to maintain the static desired on the furnace.

Draft Gauges.

Three draft gauges shall be provided, each accurately calibrated and capable of being read to 0.005 inch H_2O. They should be checked for 0 each hour. They shall be arranged to determine the draft in the smoke pipe at the furnace, the static pressure on the furnace and the velocity pressure of the air passing through the nozzle. Two of these may be used for determining the resistance to the flue gases for each test.

Temperature Measurements.

Accurately calibrated instruments should be provided for all temperature measurements. Iron-Constantan thermocouples should be used for temperatures above 600°F. If thermocouples are used for measuring air temperatures, Copper-Constantan couples shall be used and the cold junctions immersed in a medium kept at the temperature of melting ice. All instruments used for measuring air temperatures shall be capable of being accurately read to .5°F, Flue gas temperatures to 5.0°F. Any instrument exposed to direct radiation shall be shielded therefrom. Any suitable method and instruments may be used for measuring the surface temperatures of the jacket and the connecting duct.

Nozzle.

A calibrated nozzle shall be fitted into one wall of the chamber, discharging into a duct leading to the exhaust fan. The outlet opening of this nozzle shall be of such area that the air velocity is not less than 3000 ft. per minute. If the nozzle, described on Plate 2 is used, a coefficient (k) = .99[1] may be assumed without calibration.

Instruments shall be located at the point of 3000 feet per minute minimum velocity for measuring the final temperature and the velocity pressure. The temperature shall be the average of the temperatures taken simultaneously at least two points in the plane of the nozzle outlet for each square foot of outlet area, but in no case less than four points.

A standard pitot tube shall be used for measuring the velocity pressure.

Flue Gas Analysis.

The flue gas shall be analyz ed with an orsat or equivalent gas analyzer for CO_2, CO and O_2. The sample shall be taken from the smoke pipe at a point not more than one-pipe diameter beyond the smoke pipe collar. (See Plate 1, Fig. 1). The temperature and draft shall also be measured at this same point. The smoke pipe shall be insulated from a point at least two-pipe diameters beyond the collar back to the furnace with two inches of 85 per cent magnesia.

A 1/8 inch open-end iron pipe can be used to obtain the sample[2]

1. A.S.H.V.E. - Test Code for Unit Heaters
2. A.S.H.V.E. - Standard Short Heat Balance Codes for Testing Low Pressure Steam Heating Solid Fuel Boilers.

in such a manner as to obtain a fair average sample of the gas stream. Except where temperatures above 750°F are encountered when a clay or silica pipe shall be used.[1] The open end tube reaching about one-fourth the way across the pipe or into the most probable gas stream is usually sufficient, however, a more complicated sampling tube may be used.

Since an average sample is desired, the gas may be collected at a constant rate in a bottle and the analyses made from the bottle. Each sample should be collected for the same length of time and their analyses averaged. The water in the bottles shall be thoroughly saturated with the gas before any samples are taken. The gas in the bottle shall be mixed thoroughly before taking out the sample. Plate 1, Fig. 3 shows this method of collecting the gas. As shown, bottle B and the tube E are filled with water, clamps E and F are closed - G open. To start sampling, open clamp E enough so that the bottle will fill with gas in about fifteen minutes. The rate can be judged by the bubbles in bottle C. The positions of the bottles are indicated at levels so that the water will not run over. When the desired sample has been obtained, close all clamps and place bottle A at position D. Take the sample by opening clamps E and F. The bottles should be of about one gallon capacity.

A thermocouple should be used for measuring the flue gas temperature, although a mercury thermometer may be used. The

1. A.S.H.V.E. - Standard and Short Heat Balance Codes for Testing Low Pressure Steam Heating Solid Fuel Boilers.

thermo-junction or thermometer bulb shall be placed in the center of the smoke pipe at the point indicated above.

Scales and Oil Supply.

The fuel oil used shall be weighed by means of scales of the beam type. These scales shall be capable of being accurately read to the ounce. They shall be equipped similar to the diagram in Plate 1, Fig. 2 for accurate timing of the oil consumption.

The oil shall be supplied to the burner through a rubber hose or long copper tube in such a manner that it does not effect the accuracy of the scales.

Constant level valve or such equipment shall be used in the oil line as is ordinarily used by the manufacturer of the burner.

Air Disposal.

The air from the furnace shall be disposed of in such a manner as to prevent fluctuation in the temperature of the air entering the furnace.

Chimney.

The furnace shall be connected directly to a chimney of suitable size, height and construction to give the desired draft.

A stop watch shall be provided for accurate timing of the readings.

A barometer shall be provided to determine the atmospheric pressure during the tests.

A revolution counter shall be provided to determine the r.p.m. of the fans.

D. TEST PROCEDURE.

The burner shall be installed and adjusted according to the manufacturers specifications. Only standard equipment to the burner may be use, i.e., automatic draft regulators, igniters, etc.

The furnace shall be thoroughly sealed up to the point where the flue gas samples are taken. This seal shall be maintained during all tests. Thus any check damper or draft regulating devise shall be located beyond the point where the flue gas samples are taken.

The burner shall be adjusted so that it will start from cold satisfactorily and continue to operate so when the furnace is hot. This adjustment shall be maintained such that the percentage of CO_2 in the flue gas is, as nearly as possible, the same for all tests. The excess air to the burner shall be sufficient to produce a clean flame at all times.

All air connections shall be tight, at least up to the point where the air is measured. Start the oil burner, the furnace fan or fans and the exhaust fan. Calculate the oil rate over a period required to burn one or two pounds of oil and adjust if necessary until the desired rate is obtained. Adjust the exhaust fan controls so that the desired conditions are obtained, i.e., the desired c.f.m. at a given fan r.p.m. or static pressure.

Continue warming up until the air-outlet conditions have stabilized to such an extent that the average temperature change

is less than $1^{o}F$ for 10 minutes.[1] The inlet-outlet temperature change shall not have varied more than $3^{o}F$ for the test period

Disconnect draft gauge tubes and check for zero. Reconnect and readjust exhaust fan controls if necessary.

When a steady condition has been reached, weigh the oil, then set the scales about ½ pound short and close the switch. When the bell rings start the watch and take the first set of readings.

The following readings shall be recorded at regular intervals of about 10 minutes:

A. Velocity pressure at the nozzle

B. Static pressure at the furnace

C. Temperatures at the nozzle

D. Inlet temperatures

E. Furnace Jacket temperatures

F. Chimney temperature

G. Chimney draft

H. Room temperature.

The following readings shall be recorded at the beginning and end of each test; the two being averaged for the final reading:

W. R.p.m. of fan

V. Power input to fan (watt hrs.)

U. Power " " burner & controls (watt hrs.)

T. Barometer reading.

1. A.S.H.V.E. - Std. Code for Testing and Rating Steam Unit Heaters.

"If the data recorded for successive periods are inconsistent or vary beyond a reasonable margin, the test shall be continued until one hour of consistent data are recorded." Care must be used in accurately weighing the oil.[1]

Weighing the Oil.

After the first set of readings have been recorded, the weight on the scale beam shall be moved back $\frac{1}{2}$ pound, 1 pound, or 2 pounds, depending on the oil rate, and the switch closed. The contact point will then be out of the mercury so that when the pound of oil has been consumed the point will again make contact with the mercury and ring the bell. Then the time shall be accurately taken and recorded and the process repeated. This procedure makes it possible to use any portion of the data for the test computations.

1. A.S.H.V.E. - Std. Code for Testing and Rating Steam Unit Heaters.

E. SYMBOLS USED.

The various symbols and constants used in the calculations for this test are listed and defined as follows:

Symbol		Units
A_J	Area of the furnace jacket from which heat loss takes place	sq.ft.
A_N	Outlet area of the nozzle	sq.ft.
A_p	Area of the ductwork connecting the furnace and the mixing chamber from which heat is lost	sq.ft.
b	Barometer reading in inches of mercury	"Hg.
E	The efficiency of the furnace	%
E_A	The heat which cannot be accounted for	%
E_J	The heat lost from the furnace jacket	%
E_S	" " " to the flue gas	%
h_c	The coefficient of heat transfer from the surface of large horizontal pipes due to convection. This value is assumed to be .8.	Btu/hr./sq.ft./°F
h_p	The coefficient of heat transfer from the vertical jacket surface due to convection. (Either square or round). Values are given for h_p on Graph 1.	"
h_r	The coefficient of heat transfer, due to radiation from any surface. This assumes p = 1.	"
Q_J	Heat lost from the furnace jacket of area A_J	Btu./min.
H	The heat supplied to the furnace from the fuel.	"
K	The discharge coefficient of the nozzle = .99	
p	The emissivity coefficient of the radiating surface. Values given in Table I.	Btu./hr./sq.ft./°F
Q_p	The heat loss from the connecting duct	Btu./min.
S.P.	Static pressure	"H_2O

Symbol		Units
t_i	The air temperature entering the furnace	^oF
t_j	The average temperature of the furnace jacket	^oF
t_p	" " " " " connecting duct	^oF
t_n	" " " " " air in the nozzle	
t_r	The room temperature	
T	Temperature change	
V	Volume of the air passing through the nozzle under nozzle conditions, i.e., t_n and b	c.f.m.
V_s	Volume of air passing through the nozzle corrected to standard conditions, i.e., dry air at 70°F and pressure of 29.92"Hg.	c.f.m.
V.P.	Velocity pressure of the air passing through the nozzle	"H_2O
w	Weight of the air in lbs./cu.ft.	#/cu.ft.
W	Weight of the air passing through the nozzle	#/min.

Constants

.172	Stefan-Boltzman constant for radiation equation Btu./sq.ft./(deg. F. abs.)^4	
.2415	The average specific heat of air under conditions encountered during tests	Btu./lb./°F
.24	The average specific heat of the dry flue gas.	"
.47	The average specific heat of the water vapor in the flue gas.	"

TABLE I

EMISSIVITIES FROM VARIOUS SURFACES[1]

Black shiny lacquer sprayed on iron	.875
Black lacquer, flat	.98
White lacquer	.95
Oil paints - all colors	.95
Aluminum lacquer	.30
Aluminum paint, after heating to 620°F	.35
Sheet iron not rusted	.50
Sheet iron rusted	.88

1. McAdams - Heat Transmission, pp. 45-9.

F. CALCULATIONS OF RESULTS.

J. The weight of air passing through the nozzle in pounds per minute shall be calculated by one of the following formulae:

a. $W = A_N \, 1096.2 \sqrt{VPw} \; k$ (1)

Where an accurate set of tables for w are not accessible, the following formula may be used. This formula is obtained by eliminating w from a above.

b. $W = A_N \, 1264 \sqrt{\dfrac{VPb}{t_N + 460}} \; x \; k$ (2)

K. The volume of air passing through the nozzle, in cubic feet per minute at the temperature and pressure in the nozzle, shall be calculated by one of the following formulae:

a. $V = A_N \, 1096.2 \sqrt{\dfrac{VP}{w}} \; x \; k$ (2)

Eliminating w as in J_b above, the following is obtained

b. $V = A_N \, 953 \sqrt{\dfrac{VP \, (t_N + 460)}{b}} \; x \; k$ (2)

L. The volume of standard air passing through the nozzle shall be calculated by one of the following formulae:

a. $V_s = \dfrac{W}{w}$

Where w is the weight of the air under the desired conditions. For standard air it is 0.07488#/cu.ft.

b. $V_s = \dfrac{V \; b \; 17.7}{460 + t_N}$

1. A.S.H.V.E. - Test Code for Unit Heaters
2. Ower - Measurements of Air Flow", p. 57

M. The heat in the air at the nozzle shall be calculated by the following formula:

$$Q_N = .2415\ W(t_N - t_i)$$

N. The heat lost from the duct work connecting the furnace and mixing chamber shall be calculated by the following formula:

$$Q_p = A_p/60\ (t_p - t_r)(p^{(a)}h_r^{(b)} + h_c)$$

O. $$\Delta t = \frac{Q_p}{.2415w} + (t_N - t_r)$$

Where $Q_p/.2415w$ is the temperature drop due to the heat loss from the connecting duct.

P. The heat supplied to the furnace, in the case of oil, shall be calculated by the following formula:

$$H = \frac{\text{B.t.u. per lb. of oil x No. of lbs. used}}{\text{length of test period in hours x 60}}$$

R. The heat lost from the furnace jacket in B.t.u. per minute shall be calculated by the following formula

$$Q_J = \frac{A_J}{60}(t_J - t_r)(p^{(a)}h_r^{(b)} + h_p)$$

X. The heat lost to the flue gas, in per cent of the heat supplied to the furnace or of the heating value of the fuel, may be taken from an accurate chart prepared for the particular fuel used. If no such chart is available, this value may be calculated as in the following example or by any other suitable method.

a. Values of p obtained from Table I for the kind of surface being considered.
b. Values of h_r for vertical surfaces obtained from Plate 3.

Assume:

The oil as being 86% C, 14% H_2, and heating value of 18,000 B.t.u./lb. Flue gas temperature = 360°F, room temperature = 60°F. The dry gas analysis by volume (from orsat):

CO_2	12%
CO	1
O_2	4
N (By difference)	83.

Convert to per cent by weight

	% by Vol.	Times Mol. Wt.					% by Weight
CO_2	12	44	=	5.29	$\frac{5.29}{30.07}$	=	17.59
CO	1	28	=	.28	$\frac{.28}{30.07}$	=	.93
O_2	4	32	=	1.28	$\frac{1.28}{30.07}$	=	4.28
N_2	83	28	=	23.22	$\frac{23.22}{30.07}$	=	77.20
				30.07			100.00

1 lb. of carbon will form $\frac{\text{mol. wt. of } CO_2}{\text{mol. wt. of C}} = \frac{44}{12} = 3.12$ lbs. CO_2

∴ 1 lb. of the oil will form .86 x 3.12 = 2.685 lbs. of CO_2

Then if the dry flue gas contains .1759 lbs. CO_2 per lb. of gas

1 lb. of oil will form $\frac{2.685}{.1759}$ or 15.3 lbs. of dry gas.

The heat lost in the dry gas is .24 x 15.3 (360 - 60) = 1100 B.t.u. per lb. of oil

The weight of water vapor formed is 9 x .14 = 1.26 lbs. per lb. of oil. The 9 being $\frac{\text{mol. wt. of } H_2O}{\text{mol. wt. of } H_2} = \frac{18}{2}$. The heat in the vapor, at 65°F or the room temperature, is 1089[1] B.t.u. per lb. The heat loss due to the water vapor is therefore

1089 + the heat of the vapor above the room temperature

or 1089 + .47 x 300 = 1230 B.t.u. per lb. of water

or 1230 x 1.26 = 1550 B.t.u. per lb.

The heat lost by the unburned CO is the heating value of the CO per lb. x the number of lbs., or is

4370 x .0093 x 15.3 = 621 B.t.u. per lb. of oil[2]

The total heat lost to the flue gas is then

1100 + 1550 + 621 = 3271, which is 18.2% of the heating value of the oil.

1. Goodenough - Steam Tables, p. 38
2. Haslam and Russell - Fuels and Their Combustion, p. 137.

FORCED WARM AIR FURNACE TEST SPECIFICATION SHEET

Make of furnace____ No.________

Manufactured at__________________________ By__________________________

Rating________________B.t.u./hr.______________________ type burner

________________B.t.u./hr.______________________ type burner

at bonnet temperature of ______°F and _______________________ c.f.m.

Type of furnace____

Volume of combustion chamber_____________ cu.ft. Surface of combustion chamber exposed to flames (excluding refractory lining)________ sq.ft. Inside diameter of combustion chamber at largest part ______ inches. Diameter at burner level _____ inches. Height of combustion chamber above burner_____ inches. Outside area of combustion chamber exposed to air flow _____ sq. ft. Area of radiators or flues exposed to air flow ______ sq. ft. Total radiating surface _______ sq. ft. Area of jacket (outside) sq. ft._____. Finish - paint or lacquer and color____

Insulating material between jacket and radiator or flues____________

____. __________ inches thick.

Shortest distance between jacket and radiating surface ______ inches.

Smallest free area between jacket and furnace _____________ sq. ft.

Type of fan used________________________________ No. used__________

Rated capacity_________________ c.f.m. at ____________ r.p.m. static pres. of _____ ins. H_2O, and dir. at _____°F. Power reqd._____ H.P.

Fan draws or blows air through furnace_____________________________

Burner Used____

Rated capacity in furnace under test ________ pounds of oil per hour.

Ignition______. No. of igniters_____. Length of ignition period___min.

SHEET NO____

STANDARD TEST

FOR FORCED WARM AIR FURNACES

SUMMARY DATA AND RESULTS CONTINUOUS TEST

OBSERVERS________________________

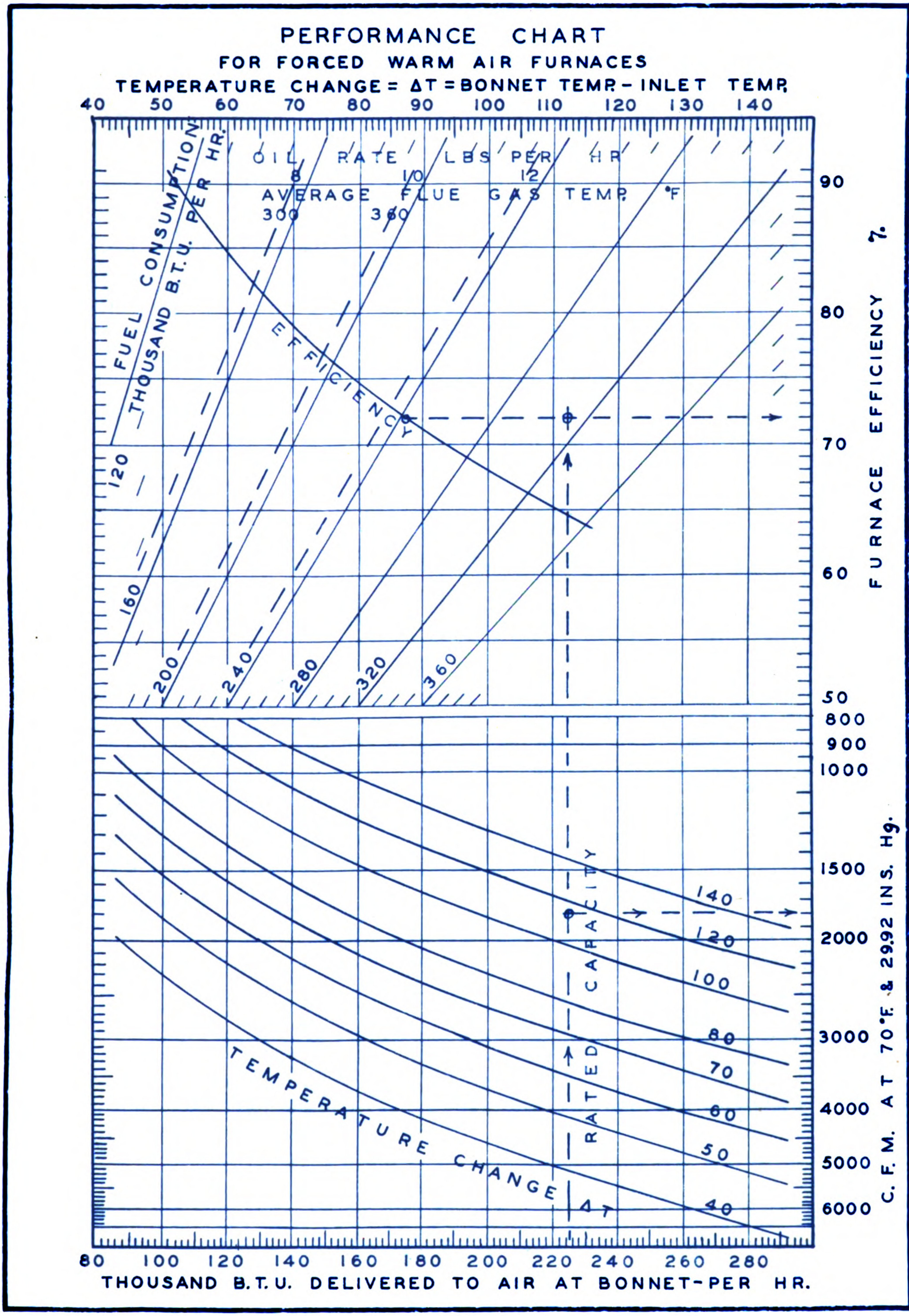
TEST RUN AT________________________

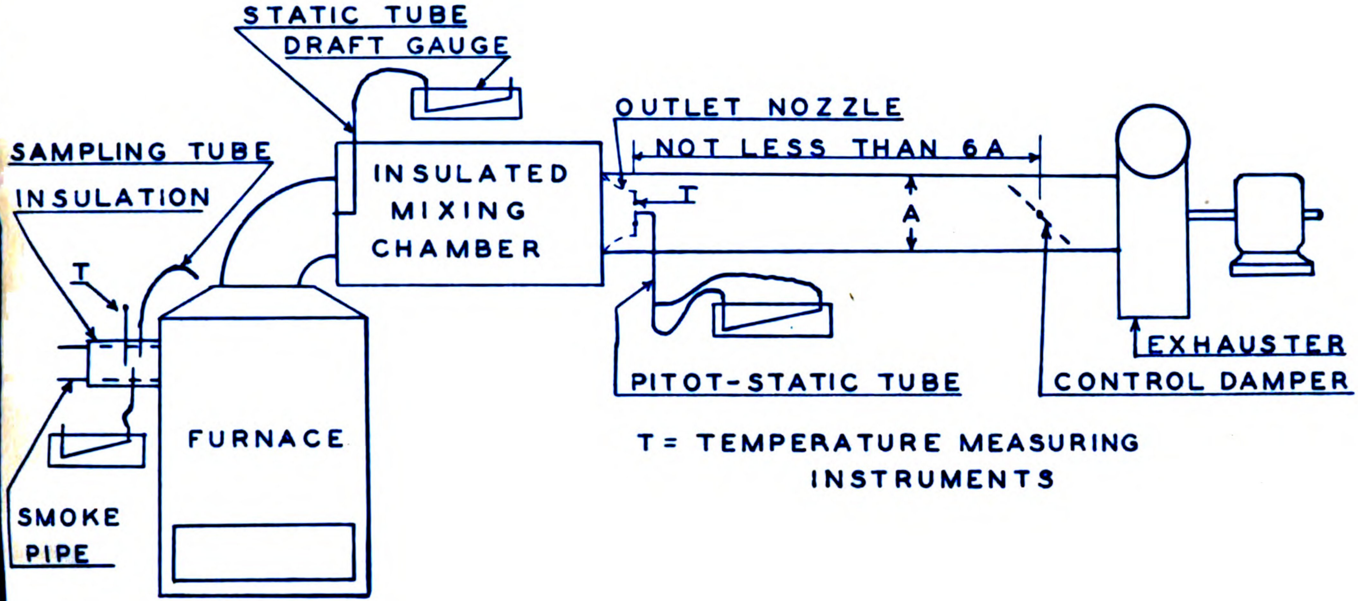
OIL USED________________________ DEG. A.P.I. AT___F

ANALYSIS________________________

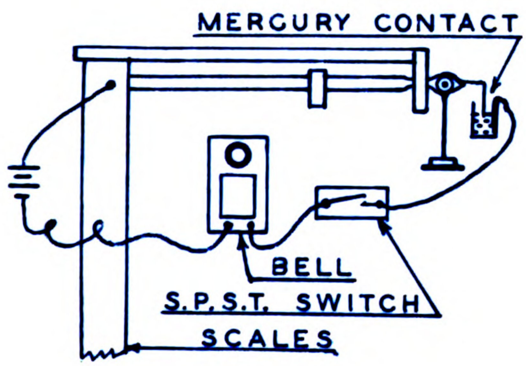
HEATING VALUE __________ B.T.U. PER POUND

ITEM		SYMBOL					
1	DATE OF TEST						
2	DURATION OF TEST		hrs				
3	OIL USED DURING TEST		lbs.				
4	BAROMETER READING	b	Hg				
5	ROOM TEMPERATURE	t_r	°F				
6	JACKET TEMPERATURE	t_J	"				
7	PIPE "	t_p	"				
8	STACK "	t_s	"				
9	NOZZLE "	t_N	"				
10	NOZZLE VELOCITY PRES	VP	" H_2O				
11	FURNACE STATIC PRES	SP	"				
12	FURNACE RESISTANCE		"				
13	STACK DRAFT		"				
14							
15							
16	FLUE GAS ANALYSIS — CO_2		%				
17	FLUE GAS ANALYSIS — CO		%				
18	FLUE GAS ANALYSIS — O_2		%				
19	AIR FLOW THRU NOZZLE — WEIGHT	W	lbs/min	J			
20	AIR FLOW THRU NOZZLE — STANDARD AIR	V_s	c.fm	K			
21	AIR FLOW THRU NOZZLE — AT TEST CONDS.	V	c.fm.	L			
22	TEMPERATURE RISE	ΔT		O			
23	HEAT IN AIR AT NOZZLE	Q_N	Btu/min	M			
24	HEAT LOST FROM PIPE	Q_P	"	N			
25	HEAT DELIVERED BY FURNACE	Q	"	23+24			
26	OIL RATE		lbs/hr	3/2			
27	HEAT SUPPLIED TO FURNACE	H	Btu/min	P			
28	FURNACE EEFICIENCY	E	%	25/27			
29	HEAT LOST FROM JACKET	Q_J	Btu/min	R			
30	JACKET LOSS % OF H	E_J	%	29/27			
31	HEAT LOSS TO FLUE GAS	E_S	%	X			
32	% OF H ACCOUNTED FOR		%	28+30+31			
33	HEAT NOT ACCOUNTED FOR	E_A	%	100-32			

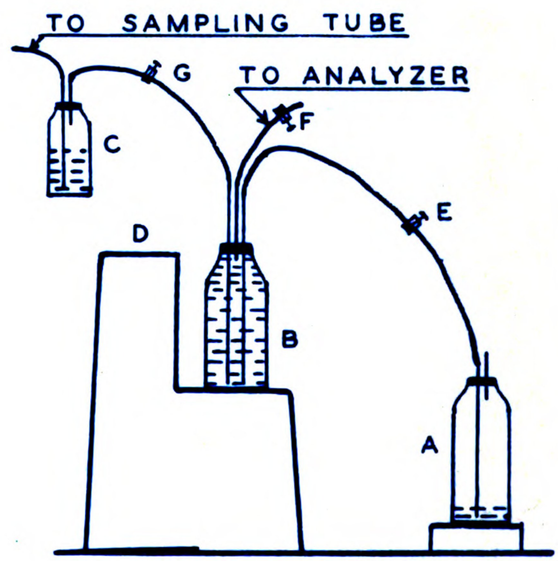

PERFORMANCE CHART
FOR FORCED WARM AIR FURNACES
TEMPERATURE CHANGE = ΔT = BONNET TEMP. - INLET TEMP.
40 50 60 70 80 90 100 110 120 130 140
FUEL CONSUMPTION
THOUSAND B.T.U. PER HR.
OIL RATE LBS PER HR
8 10 12
AVERAGE FLUE GAS TEMP. °F
300 360
EFFICIENCY
120 160 200 240 280 320 360
90 80 70 60 50
FURNACE EFFICIENCY %
800 900 1000 1500 2000 3000 4000 5000 6000
C. F. M. AT 70°F. & 29.92 INS. Hg.
RATED CAPACITY
140 120 100 80 70 60 50 40
TEMPERATURE CHANGE ΔT
80 100 120 140 160 180 200 220 240 260 280
THOUSAND B.T.U. DELIVERED TO AIR AT BONNET-PER HR.



ARRANGEMENT OF EQUIPMENT FIG. 1.

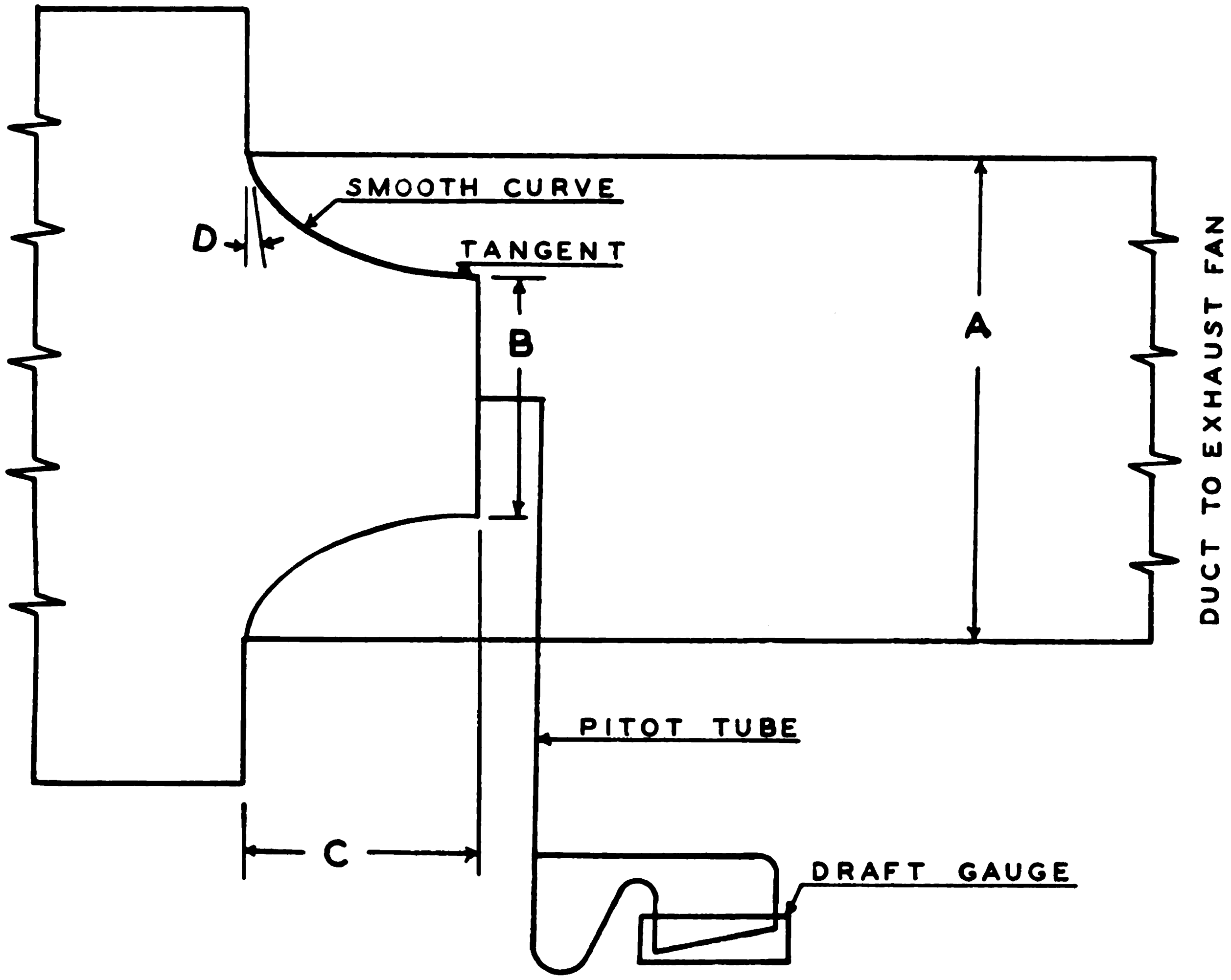


METHOD OF TIMING OIL RATE
FIG. 2



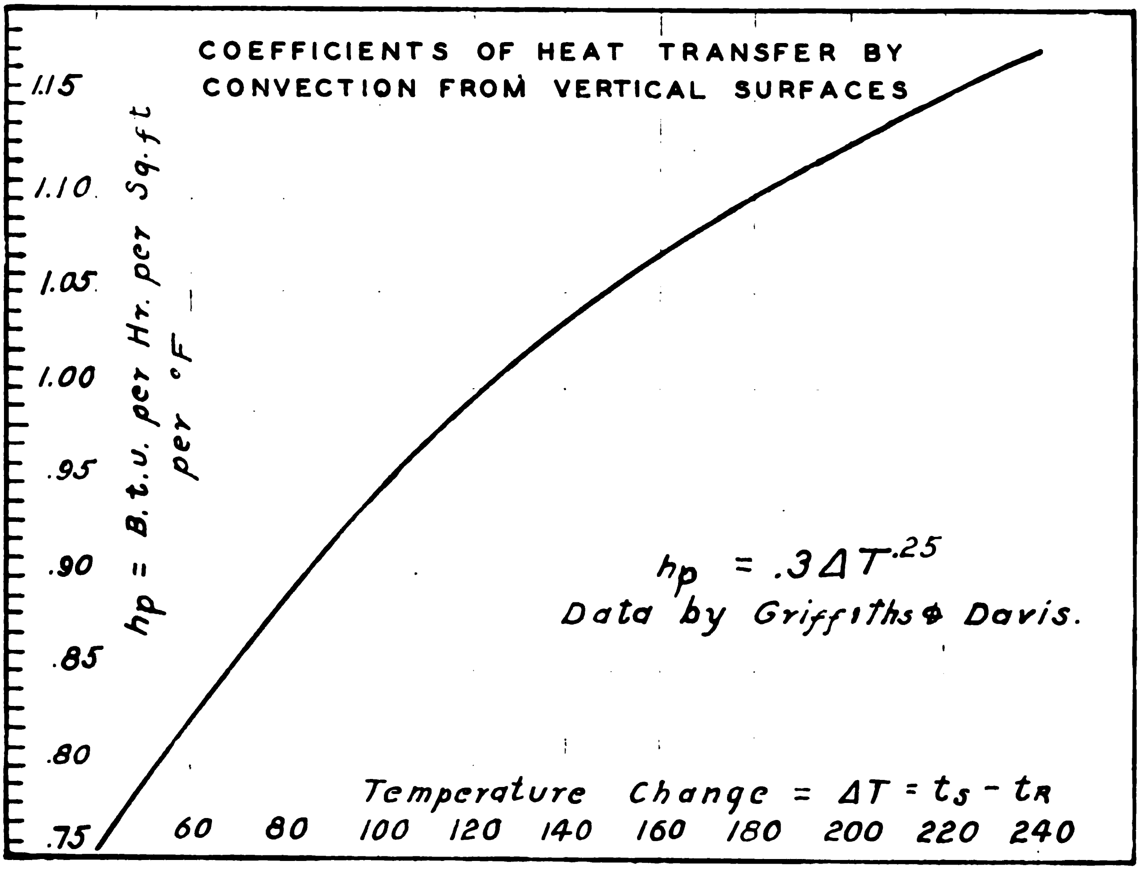
METHOD OF COLLECTING AVERAGE
FLUE GAS SAMPLES
FIG. 3

PLATE 1

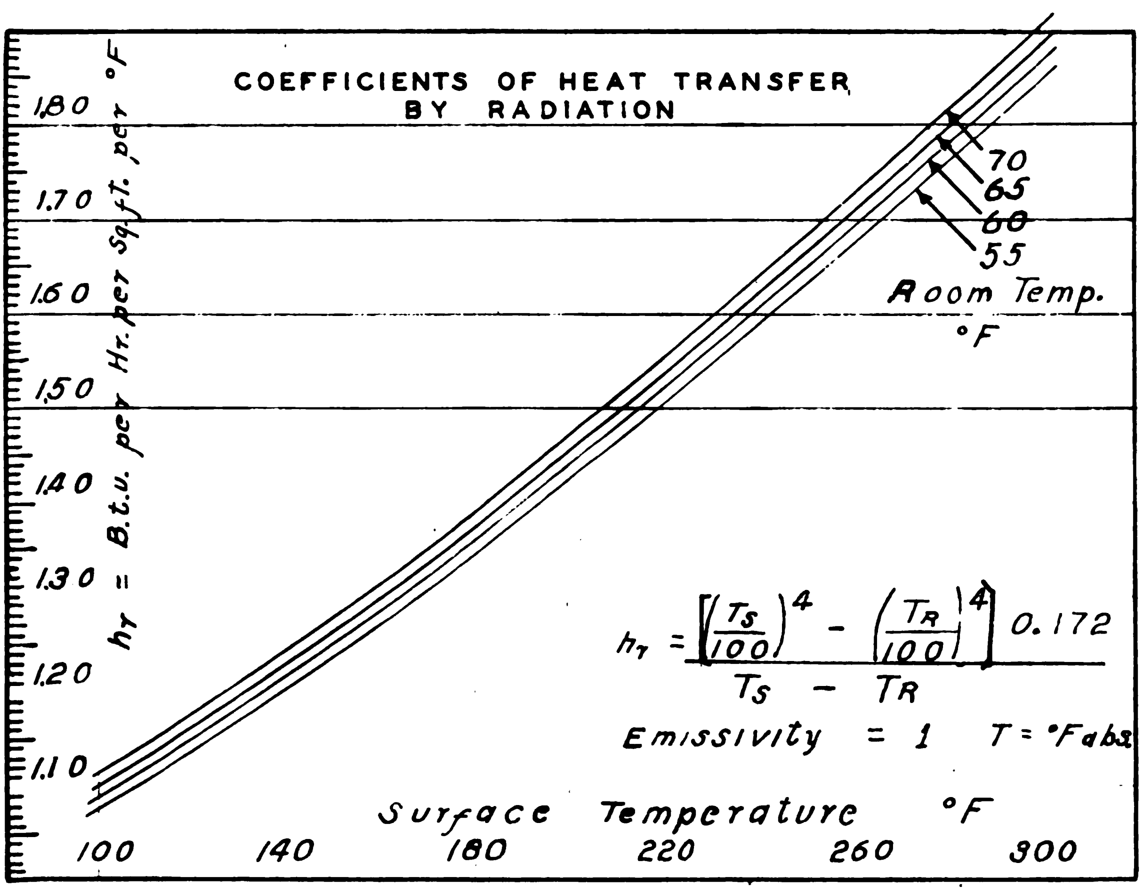


B DIAMETER TO BE ACCURATELY MACHINED
C NOT LESS THAN B
D NOT MORE THAN 15°
B NOT MORE THAN $\frac{A}{2}$

SPECIFICATIONS OF NOZZLE FOR AIR MEASUREMENT
PLATE 2

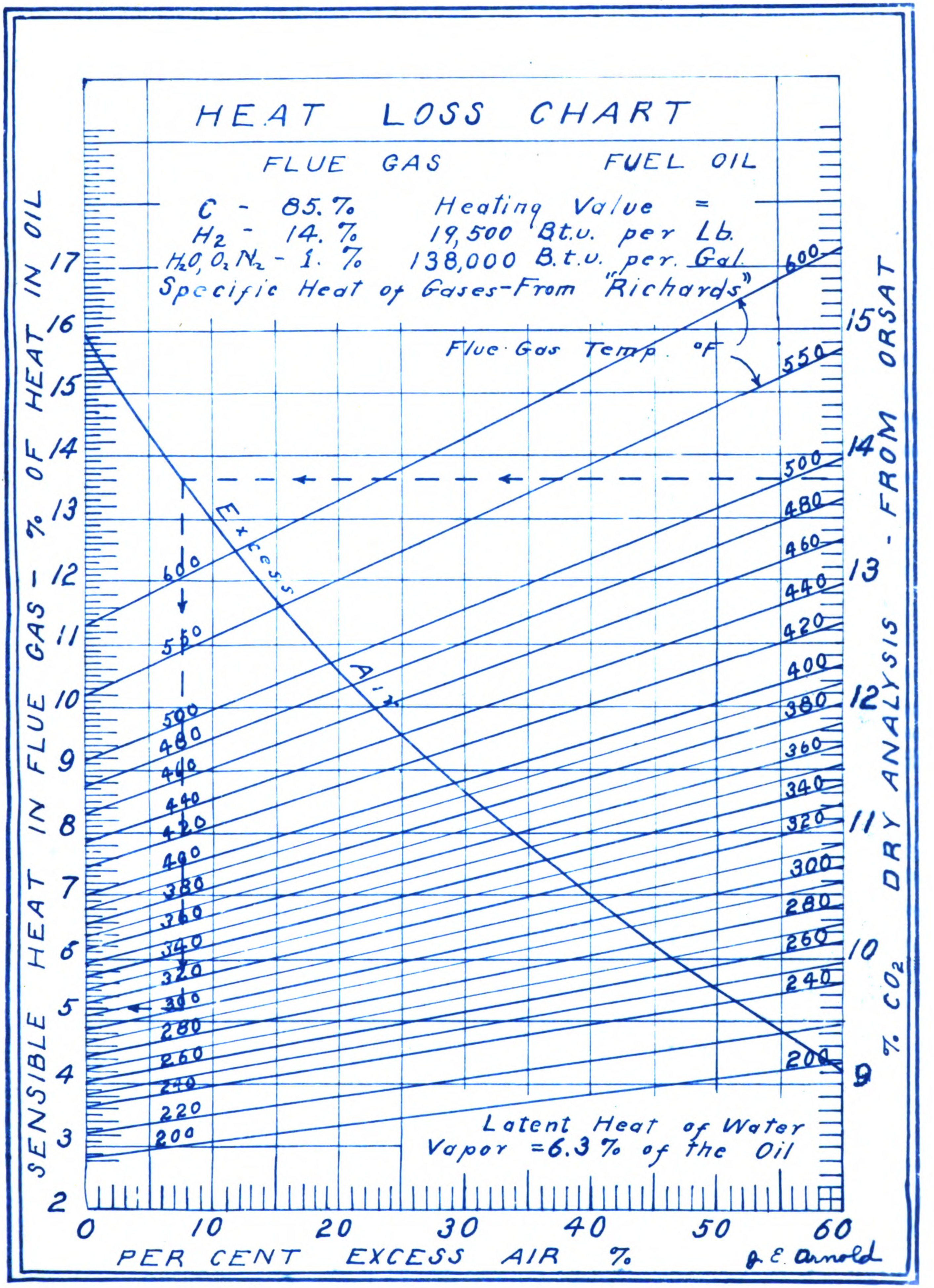


COEFFICIENTS OF HEAT TRANSFER BY CONVECTION FROM VERTICAL SURFACES
hp = B.t.u. per Hr. per Sq. ft per °F
hp = .3ΔT^.25
Data by Griffiths & Davis.
Temperature Change = ΔT = tS - tR
1.15
1.10
1.05
1.00
.95
.90
.85
.80
.75
60 80 100 120 140 160 180 200 220 240



COEFFICIENTS OF HEAT TRANSFER BY RADIATION
hr = B.t.u. per Hr. per Sq. ft. per °F
70
65
60
55
Room Temp. °F
hr = [(TS/100)^4 - (TR/100)^4] 0.172 / (TS - TR)
Emissivity = 1 T = °F abs
Surface Temperature °F
1.80
1.70
1.60
1.50
1.40
1.30
1.20
1.10
100 140 180 220 260 300

PLATE 3


HEAT LOSS CHART
FLUE GAS
FUEL OIL
C - 85.%
H2 - 14.%
H2O, O2 N2 - 1.%
Heating Value =
19,500 Bt.u. per Lb.
138,000 B.t.u. per Gal.
Specific Heat of Gases-From "Richards"
Flue Gas Temp. °F
Excess Air
Latent Heat of Water Vapor =6.3% of the Oil
SENSIBLE HEAT IN FLUE GAS - % OF HEAT IN OIL
% CO2 DRY ANALYSIS - FROM ORSAT
PER CENT EXCESS AIR %
J. E. Arnold

SAMPLE COMPUTATIONS.

The following actual data will be used in the computations.

Time in Minutes	Gross Oil Wt.	Nozzle Temp. °F	Nozzle V.P. "H_2O	Fce. S.P. "H_2O	Stack Temp. °F	Room Temp. °F
0	72	132	.760	.16	290	69
14.40	70	133	.760	.16	290	69
29.75	68	133	.750	.15	294	69
40.00	—	133	.760	.15	290	69
60.40	64	134	.750	.16	294	69
Avg. 1.006 hr.	8	133	.755		292	69

Average flue gas analysis from Orsat - 12% CO_2, 4% O_2, 0.0% CO.

Furnace Jacket

	Average Temp. °F	Area sq.ft.
N.	120	15
E.	145	17
S.	125	15
W.	145	17

Connecting duct work.

Average temperature = 120

Area = 56 sq. ft.

	Fan r.p.m.	Barometer Reading	Furnace Draft "H_2O	Furnace Reactance "H2
Beginning of test	820	28.92	.07	.04
End	830	28.92	.07	.04
Average	825	28.92	.07	.04

The volume of air circulated at nozzle conditions is, from the air flow chart, 2055 c.f.m.

The weight of air circulated per minute is, by formula, J_b

$$W = A_N \, 1264 \sqrt{\frac{VPb}{t_N + 460}} \times k$$

$$W = \frac{78.54}{144} \times 1264 \sqrt{\frac{.755 \times 28.92}{133 + 460}}$$

$$= 133\#/\text{minute}$$

This weight converted to cu.ft. per minute for standard air, by formula, L_a is

$$V_s = \frac{W}{w} = \frac{133}{0.07488} = 1780 \text{ c.f.m.}$$

or by formula L_b, from the volume of air obtained from the chart,

$$V_s = \frac{Vb\,17.7}{460 + t_N} = \frac{2055 \times 28.92 \times 17.7}{460 + 133} = 1775$$

The heat in the air at the nozzle, above room temperature, by formula M

$$Q_N = .2415\, W(t_N - t_i)$$

$$Q_N = .2415 \times 133 \times (133 - 69)$$

$$= 2060 \text{ B.t.u./Min.}$$

The heat lost from the connecting duct or pipe, by equation N

$$Q_p = \frac{AQ}{60} (t_p - t_r)(ph_r + h_c)$$

$$Q_p = \frac{56}{60} (120 - 69)(.6 \times 1.18 + .8)$$

$$= 71.8 \text{ B.t.u./Min.}$$

The total equivalent temperature drop, by formula O is

$$T = \frac{Q_p}{.2415w} + (t_N - t_r)$$

$$= \frac{71.8}{.2415 \times 133} + (133 - 69) = 66.5 \text{ deg. F.}$$

The heat supplied to the furnace in the oil, by formula P is

$$H = \frac{\text{B.t.u. per lb. of oil} \times \text{No. of lbs. used}}{\text{length of test period in hours}}$$

$$H = \frac{19{,}500 \times 8}{1.006} = 2{,}590 \text{ B.t.u./Min.}$$

In this case where the furnace jacket was square, formula R was applied to each side of the jacket and the sum taken as the total heat loss. The loss for one side will be calculated here, and the total loss shown. For side W, the loss, by formula R, is

$$Q_J = \frac{A_J}{60} (t_J - t_r) (p\, h_r + h_p)$$

$$= \frac{17}{60} (145 - 69) (.95 \times 1.26 + .8) = 43 \text{ B.t.u./Min.}$$

The total heat loss from the jacket, calculated in this manner is 141.5 B.t.u. per Min.

The heat lost to the flue gas is obtained from the chart prepared for this particular fuel. For the gas at 292°F, 12% CO_2 the loss due to the dry gas and vapor above the room temperature is 5.5% and the latent heat of vaporization, 6.3, a total of 11.8% of the heating value of the oil.

P A R T I I

INTERMITTENT TESTS

In order to prevent repetition, only that part of the intermittent test which differs from Part I will be given here.

The intermittent test shall be made following a preliminary test made to determine the oil rate. This rate shall check with that obtained in the intermittent test.

The fans shall be run continuously during the intermittent test.

The operation of the burner shall be controlled manually from a position where the operator can accurately read the nozzle temperature.

Temperature limits at the nozzle shall be selected according to the oil rate used, the higher temperatures accompanying the high oil rates. These limits shall not be lower than 100°F or higher than 165°F.

Method.

Warm up the furnace and set the fan controls so that the desired volume of air and static pressure are obtained. Shut off the burner when the upper temperature of the test is reached. When the nozzle temperature falls to the lower limit, turn on the burner until the upper temperature is again reached. Repeat this process until the on periods are equal and the off periods equal.

A variance of 30 seconds in these periods will not be considered excessive.

A total cycle time of 15 minutes to $\frac{1}{2}$ hour should be used.

When uniform cycles are obtained, the oil shall be accurately weighed during an off period. Start the watch and oil burner simultaneously and take the first set of readings when the lower temperature is reached. Continue taking readings for 2 or 3 cycles. The following readings shall be taken and recorded at regular intervals of 1 or 2 minutes:

Nozzle temperature

Nozzle velocity

Flue gas temperature

Jacket temperature

Pipe temperature.

The flue gas analyses shall be made from a sample taken continuously over the on-period of the burner.

The data for the best cycle shall be plotted on cross-section paper and a smooth curve drawn through the points. See Sheet 1. Values shall be taken from these curves in accounting for the heat supplied to the burner. These values shall be plotted on cross-section paper against the time in minutes. See Sheet 2.

The area under these curves shall be used to obtain the various losses and efficiency. The heat added to the air is represented by the area under the curve A, B, C, also the area under D, E, and FG. The losses to the flue gas and from the jacket are represented by the area under the curve LLL, which is also the area above FG marked losses. The remaining area is the unaccounted for loss.

The efficiency shall be obtained by dividing area under line FG by the area under line HI x 100.

The per cent losses shall be obtained by dividing the area indicated as losses by the area under line HI x 100.

The per cent unaccounted for loss shall be the area left divided by the area under line HI x 100.

DISCUSSION OF METHODS

The methods as outlined in this test are not as exacting as some experimental work requires. It is necessary, however, that the work shall be accurate enough so that the variations allowed are not exceeded. In the test conducted in the laboratory all the heat supplied to the burner could be accounted for except in a few cases where the CO_2 was run very high. These tests showed an unaccounted for loss of some 7%. This was explained by the fact that soot was deposited on the walls of the combustion chamber, indicating unburned carbon.

The nozzle was calibrated by disconnecting the furnace and forcing air through the mixing chamber from a separate fan. A long straight pipe was used between the fan and the mixing chamber. A traverse was made at the middle of this pipe, using a Wahlen gauge[1] to check the volume of air at the nozzle. When the conditions as prescribed in the test were observed, the variations in the two volumes were less than $1\frac{1}{2}$%.

For more detailed methods of measuring air flow refer to S. A. Moss[2], J. H. Parkin[3], or R. O. King[4].

The flue gas chart included is for one fuel only. Additional charts may be constructed similar to this one or others which are equally as good. This chart was constructed similar to one by Haslam and Russell[5], except the values for specific heats of the

1. Univ. of Ill. Bulletin No. 112
2. A.S.M.E. Trans., Vols. 49-50, A.P.M. 3.
3. Heating, Piping and Air Conditioning, Jl. '29, pp. 149-56.
4. Engineering, Vol. 17, pp. 136-7.
5. Haslam & Russell - Fuels and Their Combustion, p. 249.

gases which were taken from Richards[1]. A simpler and not quite so accurate chart is given in Power[2].

The chart for determining the radiation coefficient is constructed similar to one by McAdams.[3]

The chart for determining the volume of air flowing through the nozzle is a graphical solution of the formula for the volume of air flowing through a nozzle or pipe.

The performance chart was constructed, having in view a graphical representation of the capacity of the furnace.

The surface temperatures were measured by means of a "Pyro point" which is in reality a thermocouple. It consists of a galvanometer and two pointers, one of iron and the other constantan. When these points are pressed against the metal surface, they make electrical contact and assume the temperature of the metal, thus acting as a thermocouple. This instrument was calibrated against a thermocouple embedded in the surface of a piece of sheet metal. The temperatures obtained checked very closely to those obtained from the thermocouple.

1. Richards - Metallurgical Calculations, pp. 93, 94, 91, and 62.
2. Power - Vol. 66, Aug. 30, '27, p. 328.
3. McAdams - Heat Transmission, p. 223.

Intermittent Test.

Method of Showing Data

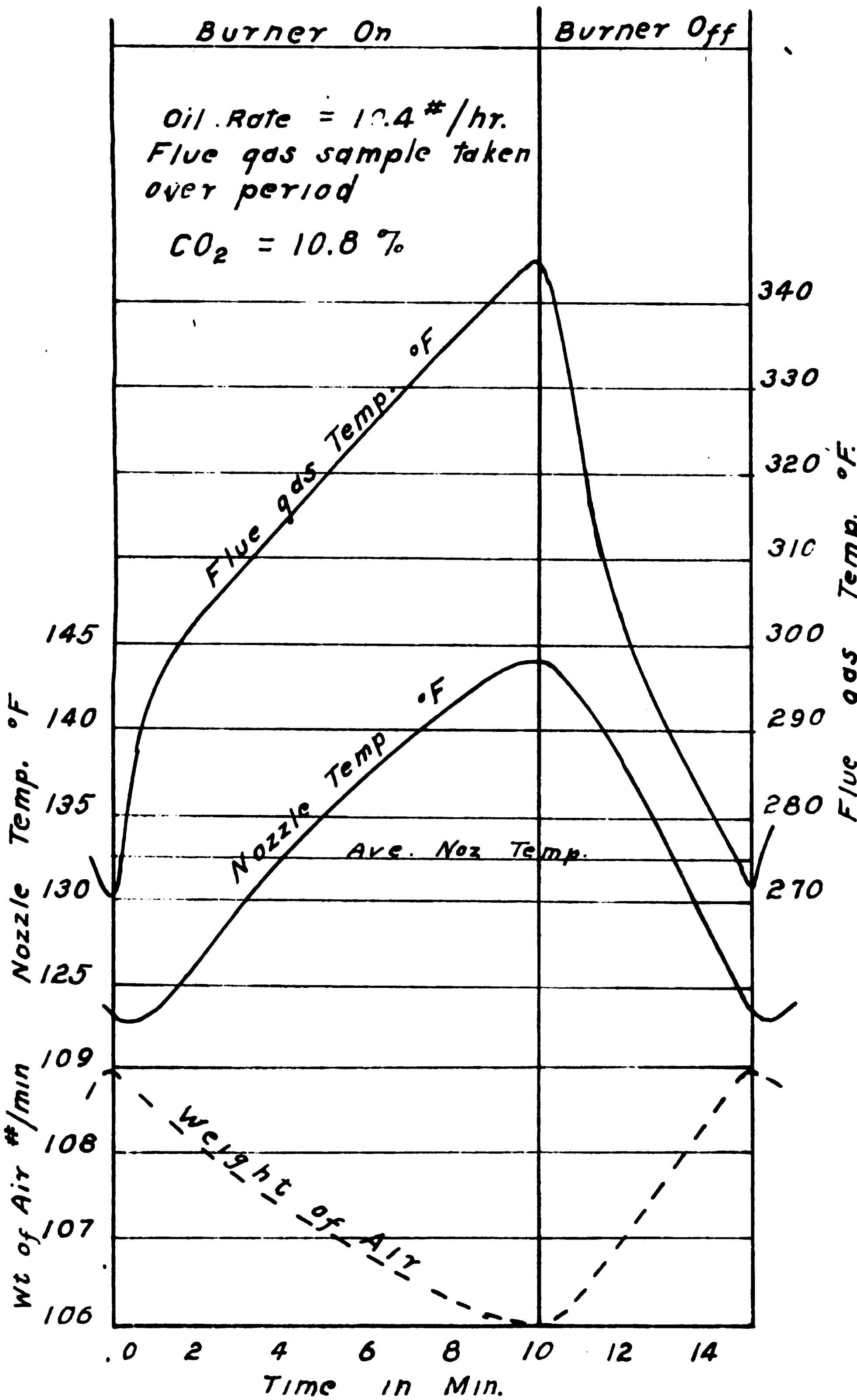
Test run 5/1/34

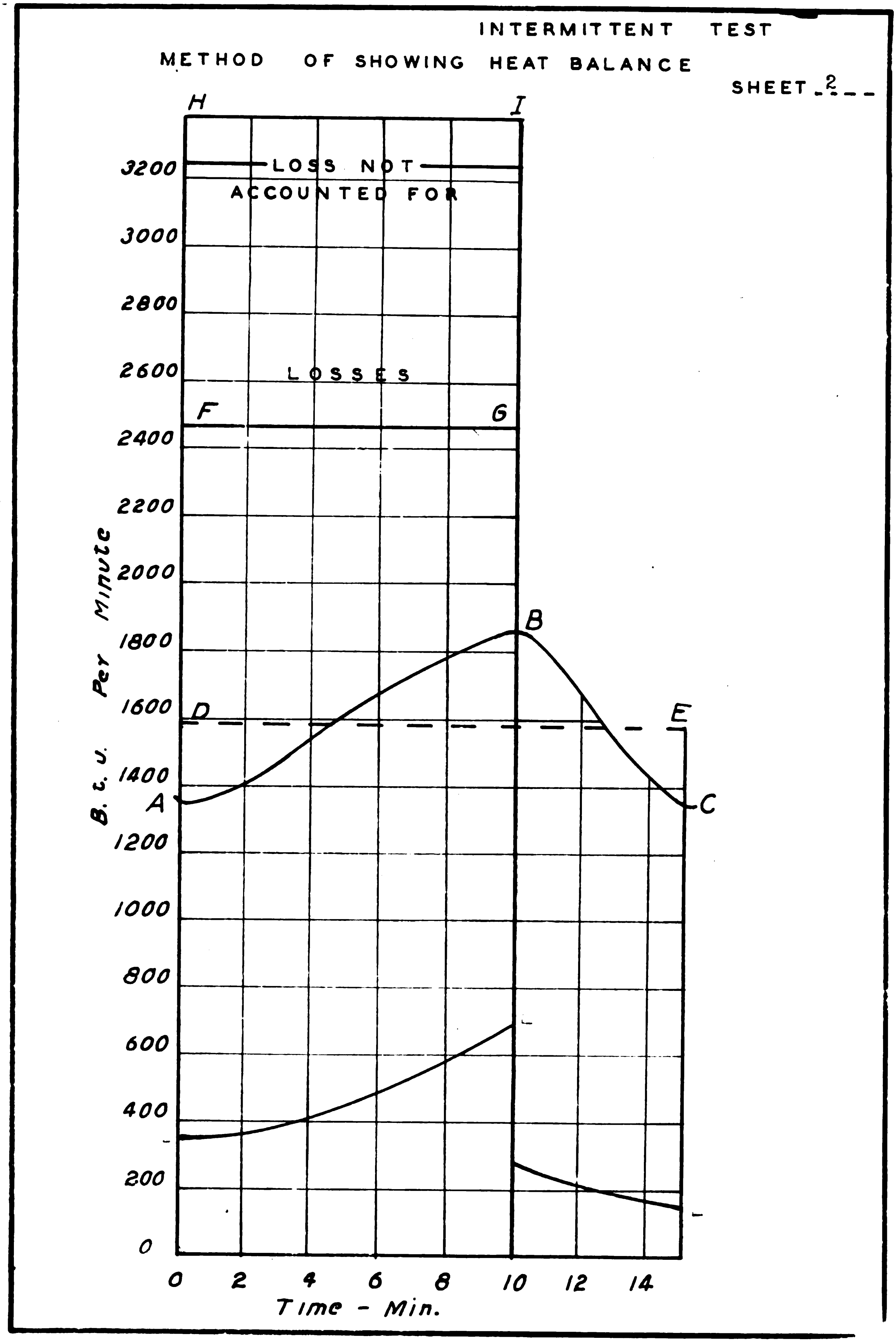
Sheet 1

At Mich. State College.

Bar. = 29.6 "Hg

Room T = 70.0 °F




INTERMITTENT TEST
METHOD OF SHOWING HEAT BALANCE
SHEET 2
H
I
LOSS NOT ACCOUNTED FOR
LOSSES
F
G
B
D
E
A
C
B.t.u. Per Minute
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
0
2
4
6
8
10
12
14
Time - Min.

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1. A.S.H.V.E. - Test Code for Unit Heater

2. Allen & Walker - Heating & Ventilation, p. 309

3. Univ. of Ill. Bulletin No. 117

Coefficients of Emissivity for Various Surfaces.

4. A.S.H.V.E. - Standard and Short Heat Balance Codes for Testing

Low Pressure Steam Heating Solid Fuel Boilers.

5. McAdams - Heat Transmission, pp. 45-9.

6. Ower,- Measurements of Air Flow, p. 57.

7. McAdams - Heat Transmission, p. 250

8. Univ. of Ill. Bulletin No. 189

Investigation of Warm Air Furnaces and Heating Systems.

9. Univ. of Ill. Bulletin No. 120

Investigation of Warm-Air Furnaces and Heating Systems.

10. Goodenough - Steam Tables, p. 38

11. Moss, S. A. - A.S.M.E. Trans., Vols. 49-50, A.P.M. 3.

12. Univ. of Ill. Bulletin No. 112

13. Heating, Piping, and Air Conditioning, June '29, pp. 149-52

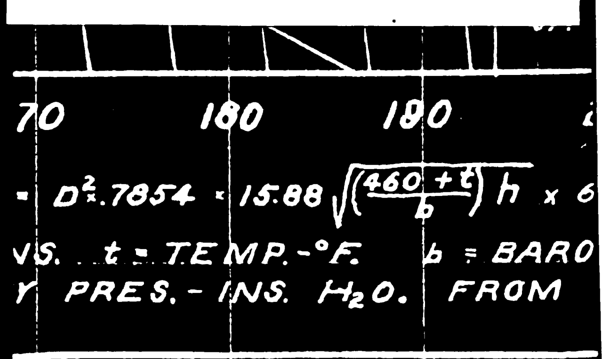
14. Engineering, Vol. 17, pp. 136-7

15. Haslam & Russell - Fuels and Their Combustion, p. 249

16. Richards - Metallurgical Calculations, pp. 93, 94, 91, & 62.

17. Power, Vol. 66, Aug. 30, '27, p. 328.

18. McAdams - Heat Transmission, p. 223.


70 180 190
= D²×.7854 × 15.88 √((460 + t)/b) h × 6
VS. t = TEMP.-°F. b = BARO
Y PRES.- INS. H₂O. FROM