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Convection heat transfer in boiler furnace watertube rear walls.

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CONVECTION HEAT TRANSFER IN BOILER FURNACE WATERTUBE REAR WALLS

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CONVECTION HEAT TRANSFER
IN
BOILER FURNACE
WATERTUBE REAR WALLS

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NOTATION

A	-	Coefficient
A_p	-	Projected area of boiler rear wall, sq. ft.
A_o	-	Area of burners = $\frac{n \pi d^2}{4}$, sq. ft.
a	-	Exponent of Reynolds Number
B	-	Constant of integration
b	-	Thickness of boundary layer
C_1	-	Constant
C_p	-	Specific heat, BTU/lb. - degrees F.
D	-	Furnace depth - ft.
d	-	Burner or orifice diameter - ft.
G	-	Mass flow in units of lb/sq.ft. - hr.
h	-	Heat transfer coefficient, BTU/hr. - degrees F. - sq. ft.
k	-	Thermal conductivity, BTU/ft.- degrees F. - hr.
m	-	Subscript denoting mean value
n	-	Number of burners
Q	-	Two dimensional quantity of flow
q	-	Heat transfer per unit time, BTU/hr.
R	-	Air to fuel ratio by weight
r	-	Distance from side wall to burner
S_c	-	Effective cold heat absorption surface
S_w	-	Projected heat transfer surface in rear wall, sq. ft.
T	-	Absolute temperature, degrees R.
T_c	-	Absolute tempeature of cold surface
T_E	-	Furnace exit temperature from radiation calculation
T_F	-	Effective flame temperature
T_f	-	Film temperature

T_s - Steam or boiling water temperature

T_1 - Actual exit temperature from furnace

U_c - Coefficient of convection heat transfer, BTU/hr. - degrees F. - sq. ft.

V_x - Velocity in x direction

V_y - Velocity in y direction

V_o - Free stream velocity along rear wall

W_a - Weight of air, lbs/hr.

W_F - Weight of fuel, lbs/hr.

W_g - Weight of gas, lbs/hr.

w - Complex potential function

z - Complex plane, $x + iy$

N_{Nu} - Nusselt Number $= \frac{hD}{k}$

N_{Re} - Reynolds Number $= \frac{GD}{\mu} = \frac{\rho N D}{\mu}$

N_{Pr} - Prandtl Number $= \frac{C_p \mu}{k}$

ΔT_o - Temperature difference between free stream and wall

ΔT_m - Log mean temperature difference

α - Constant for heat transfer equations

μ - Dynamic viscosity

ν - Absolute viscosity

INTRODUCTION

Since the end of the nineteenth century, the marine boiler, both merchant and naval, has gone through an extensive period of evolution. The firetube boilers,such as the Scotch boiler,have given way to watertube boilers of either the header or drum type. In more recent years, the integral furnace two-drum boiler with integral uncontrolled superheater has gained considerable favor due to its simplicity, relatively light weight and low cost. In order for these boilers to meet the specified superheated steam temperatures without control, it is necessary to pay considerable attention to the proper design of all heat transfer surfaces in the boiler.

All boilers possess some sort of combustion chamber or furnace for burning the fuel. The gaseous products of combustion pass over the generating and superheating surfaces prior to entering any other heat recovery equipment and exhausting to the atmosphere. It is obvious that in order to effectively evaluate the heat transferred in the generating and superheating sections and thus the superheat temperature, the temperature of the gasses leaving the furnace must be accurately determined.

The method of calculating the furnace exit temperature is one of equating the heat given up by the gasses to the heat absorbed by the furnace surfaces and solving for the exit temperature[1]. Numerous descriptions covering the several methods of attack on this problem may be found in the current literature[1,2,3,4,5,6]. In general, the heat transferred to the

furnace surfaces by convection has been neglected and the problem has become one of radiation only. Until recently good results have been obtained using these methods, whether empirical, theoretical, or a combination of both.

In recent years the severe space and weight limitations imposed on naval boilers in particular, combined with increased demands on the boiler, have forced the designer to use heat release rates in excess of 500,000 BTU/cu. ft. In order to cool the surfaces of the furnace, water-cooled walls, floors, and overheads have been adopted. These inovations were adequately handled as cold surface when using the conventional method of solution of the furnace problem. However, as increased space limitations have dictated decreasing the depth of the boiler, a discrepancy arose between the calculated and measured superheater outlet temperature. The error can be traced to too high an estimate of furnace exit temperature. It appeared that heat was being absorbed in the furnace by some means other than radiation. Examination of the designs involved showed that they were fitted with shallow furnaces and watertube rear walls. The additional means of transfer was by convection through impingement of the gaseous flame on this rear wall.

Since no data on this means of heat transfer was available in the literature, early evaluations were by "rule of thumb" empirical means. Bethge and Townsend[7] carried out an investigation on one particular boiler. Holmboe and Hove[8] investigated impingement on a flat plate with the use of

models, but the results are not directly applicable to furnace walls due to limitations on the geometry of the models, i.e., flat plates as the surface instead of tubes. It is because of this lack of adequate basic data that the present investigation was undertaken.

GENERAL CONSIDERATIONS

The problem of heat transfer by fluid impingement on a boiler rear wall resolves into a problem of forced convection. Since the heat is conducted through a turbulent boundary layer or film, the thermal conductivity of the fluid k will be a factor. The film thickness depends on the mass velocity through the burners G, the distance between the rear wall and the burners or furnace depth D, and the viscosity of the fluid μ. For a given quantity of heat transferred, the temperature of the fluid stream depends on the specific heat C_p. Letting ϕ represent a function, the following equation for the coefficient of heat transfer h may be written:

$$h = \phi(G, D, \mu, C_p, k) \qquad \text{. . . . . (1)}$$

This may be written in an infinite series, all terms of which will have the same form. Therefore, taking the first term only:

$$h = \alpha\, G^a D^b \mu^c C_p^e k^f \qquad \text{. . . . .(2)}$$

where the factor α is an arbitrary constant dependent on the geometry of the furnace and the boundary conditions. Substituting the dimensions and solving simultaneously for the exponents in terms of a and e gives the following equation:

$$\frac{hD}{k} = \alpha \left(\frac{GD}{\mu}\right)^a \left(\frac{C_p \mu}{k}\right)^e \qquad \text{. . . . . (3)}$$

In more familiar terms:

$$N_{Nu} = \alpha\, N_{Re}^{a}\, N_{Pr}^{e} \qquad \text{. . . . . (4)}$$

The problem now remains to find the values of the exponents a and e and the constant α. Examination of the geometry of the fluid flow in the furnace reveals that the fluid leaves

the burners in a cone shaped stream directed at the rear wall. However, in order for continuity to be satisfied, the fluid must eventually flow parallel to the rear wall and out through the tube bank. Therefore, the convection heat transfer to the rear wall is conducted through a boundary layer of fluid streaming parallel to the surface. For this reason, the constant α must contain those parameters that have a significant effect on the thickness of this layer as well as its velocity.

For a given weight of gas flowing, G will be dependent on the size and number of burner orifices. Instead of using the number of burner orifices, the ratio of projected rear wall area to burner area Ap/Ao will be more flexible while still defining the significant factors in the geometry. Also evident is the fact that increasing D will increase N_{Re} proportionately; however, the heat transfer will obviously not increase due to the decrease in fluid velocity as depth increases. Therefore, the ratio of furnace depth to burner orifice diameter $\frac{D}{d}$ was chosen as a significant parameter. This ratio, together with Ap/Ao, fix the significant features of the geometry. Therefore, the constant α will be a function of these parameters $\frac{D}{d}$ and $\frac{Ap}{Ao}$.

Holmboe and Hove[8] conclusively demonstrated the validity of this approach. Using two similar models having a linear size ratio of 2:1, they were able to measure the same value of N_{Nu} for equal values of the dimensionless ratios $\frac{GD}{\mu}$, $\frac{A_p}{A_o}$, AND $\frac{D}{d}$. Therefore, they justly concluded that extrapolation of model results to full size by using the dimensionless Equation 4 was a valid approach.

METHOD OF APPROACH

Since the geometry of the problem is so complex and the variables so numerous, the easiest and by far the most dependable method of finding a, e, and α was by experimentation.

The method used consisted basically of testing a model boiler on which the parameters $\frac{Ap}{Ao}$ and $\frac{D}{d}$ could be varied. The actual phenomenum of heat transfer was the reverse of that found in an actual boiler in that the rear wall heated the gasses flowing through the furnace instead of cooling them. Air was blown through the burner orifices of the model, impinged on the rear wall, and then passed out the stack. By measuring the weight of air flowing Wa, the inlet and outlet temperatures T_1 and T_2, the heat transferred could be computed. From this, Nusselt Number and Reynolds Number were calculated and plotted for each change in geometry. The apparatus was tested over a range of 5 values of $\frac{D}{d}$ from 3 to 10.5 and over a range of 4 values of $\frac{Ap}{Ao}$ from 11.47 to 45.8. The weight of air flowing W_a varied from about 260 to 1200 lbs/hour. In all, data at 567 points was taken. For a more detailed description of the apparatus and testing procedures, see Appendices A and B.

In the early stages of testing, it was necessary to run many of the tests twice or even three times to be sure that the data was reliable. However, as the testing procedure became more refined, this was no longer necessary. By insuring that steady state conditions existed in the model, reliable and repeatable results were obtained in almost all cases.

Figures 1 through 5 are plots of N_{Nu} vs. N_{Re} for the five values of $\frac{D}{d}$ and air flowing through plain orifices. Figures 6 through 10 are plots of N_{Nu} vs. N_{Re} for the same five values of $\frac{D}{d}$ but with the air flowing through model burners.

In addition to the experimental approach an attempt was made to develop a theoretical analysis of the problem. This analysis consisted of considering the two dimentional problem only. Using conformal mapping techniques, the fluid flow in the furnace was mapped giving the free stream velocity distribution across the rear wall. Then considering the problem as one of heat transfer through a turbulent boundary layer on a flat plate, a relationship for Nusselt Number in terms of the Reynolds Number using the velocities previously calculated was derived and the results of this derivation compared with the test results. The differences in results are covered in the discussion.

ANALYSIS OF TEST RESULTS

Figures 1 through 10 are plots of N_{Nu} vs. N_{Re} plotted on log-log paper. It is evident that for each value of $\frac{D}{d}$ and $\frac{Ap}{Ao}$, the test spots plot in straight lines. Therefore, N_{Nu} is definitely a function of N_{Re} to some power a; and a will be equal to the slope of the lines.

With the equipment available for these tests, it was impossible to vary the Prandtl Number of the gas. Therefore, the value of the exponent a is assumed to be 1/3. This is in agreement with the equations for forced convection heat transfer over various shaped surfaces as given by McAdams[3], and Jakob[9,10,11]. The differences in most of these equations lies in the exponent of N_{Re} and in the constant.

From Figures 1 through 5 for the case of air discharging through plain circular orifices, the value of a is 0.87 for all curves. There are some slight variations in slope, but they are small enough to be considered negligible. Therefore, for fluid discharging through circular orifices and impinging on the boiler rear wall, the equation of convection heat transfer is:

$$\frac{hD}{k} = \alpha_o \left(\frac{GD}{\mu}\right)^{.87} \left(\frac{Cp\mu}{k}\right)^{\frac{1}{3}} \qquad \ldots\ldots(5)$$

where the values of α_o are given in Table 1, and Cp, μ, and k are evaluated at the film temperature.

For the case of air discharging through burners, analysis of Figures 6 through 10 yields the value of a as 0.90 for $\frac{D}{d}$ = 3,

5, 7, and 9. However, at $\frac{D}{d} = 10.5$, the value of a increases to 1.0. Therefore, the following are the equations for convection heat transfer with fluid discharging through burners and impinging on the boiler rear wall:

$$\text{for} \quad \frac{D}{d} \leq 9 \qquad \frac{hD}{k} = \alpha_b \left(\frac{GD}{\mu}\right)^{.9} \left(\frac{C_p \mu}{k}\right)^{\frac{1}{3}} \quad \ldots\ldots (6)$$

$$\text{for} \quad \frac{D}{d} > 9 \qquad \frac{hD}{k} = \alpha_b \left(\frac{GD}{\mu}\right) \left(\frac{C_p \mu}{k}\right)^{\frac{1}{3}} \quad \ldots\ldots (7)$$

where the values of α_b are given in Table 2 and Cp, μ, and k are again evaluated at the film temperature.

Table 1--- Values of α_o for Equation 5

Air Discharging Through Plain Circular Orifices.

A_p/A_o \ D/d	3	5	7	9	10.5
11.47	.0195	.0160	.0127	.0110	.0095
15.29	.0210	.0172	.0139	.0116	.0120
22.9	.0174	.0172	.0146	.0123	.0123
45.8	.0153	.0141	.0127	.0116	.0107

Table 2--- Values of α_b for Equations 6 and 7

Air Discharging Through Typical Marine Burners.

A_p/A_o \ D/d	3	5	7	9	10.5
11.47	.0103	.0086	.0069	.0057	.00117
15.29	.0103	.0086	.0069	.0057	.00117
22.9	.0090	.0073	.0058	.0049	.00093
45.8	.0075	.0066	.0053	.0044	.00064

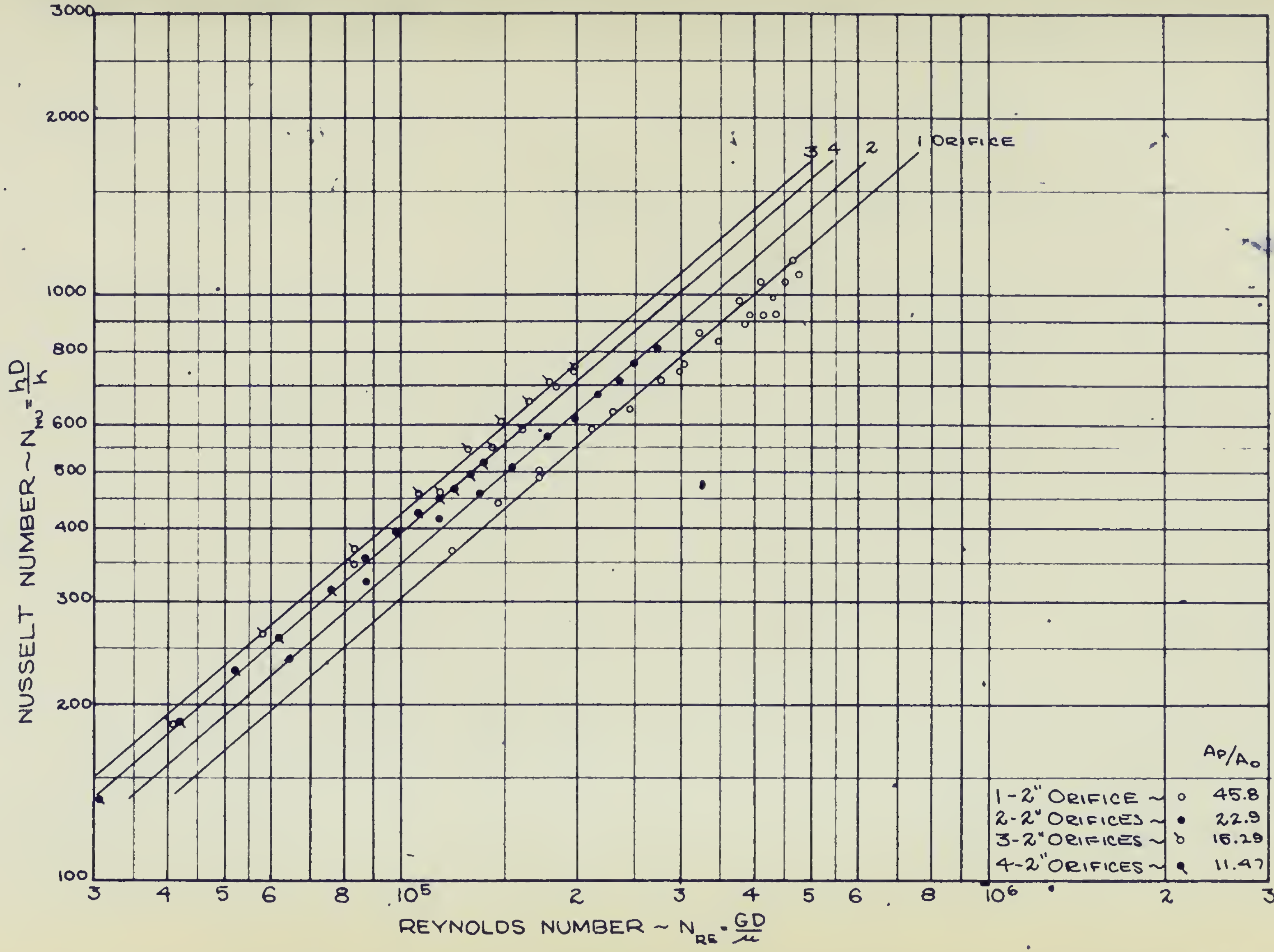


FIGURE 1 - NUSSELT NUMBER VS. REYNOLDS NUMBER; 1, 2, 3, AND 4 - 2" ORIFICES; 6" DEPTH, $D/d = 3$

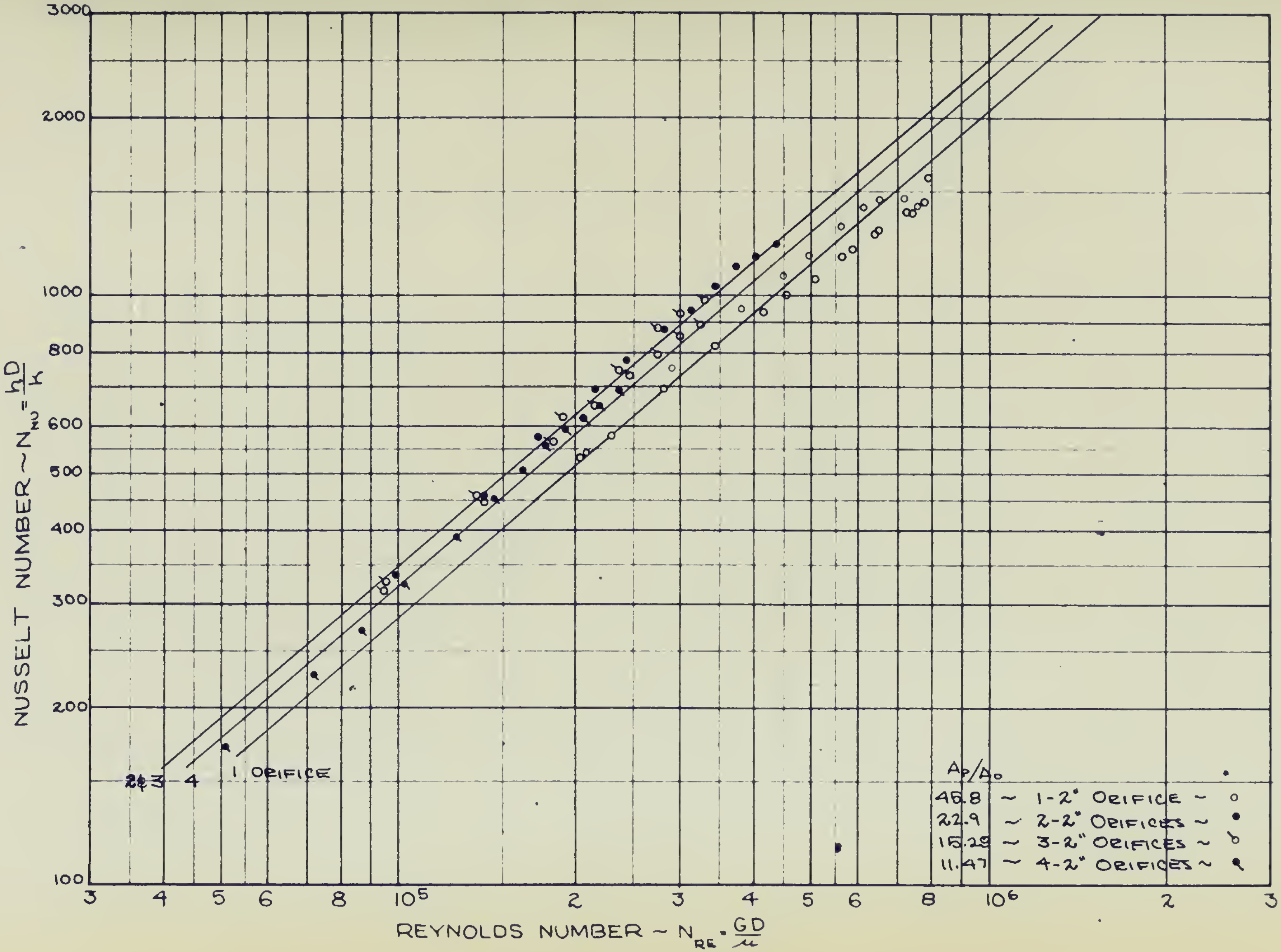


FIGURE 2 - NUSSELT NUMBER VS. REYNOLDS NUMBER ; 1, 2, 3 AND 4 - 2" ORIFICES ; 10" DEPTH, D/d = 5

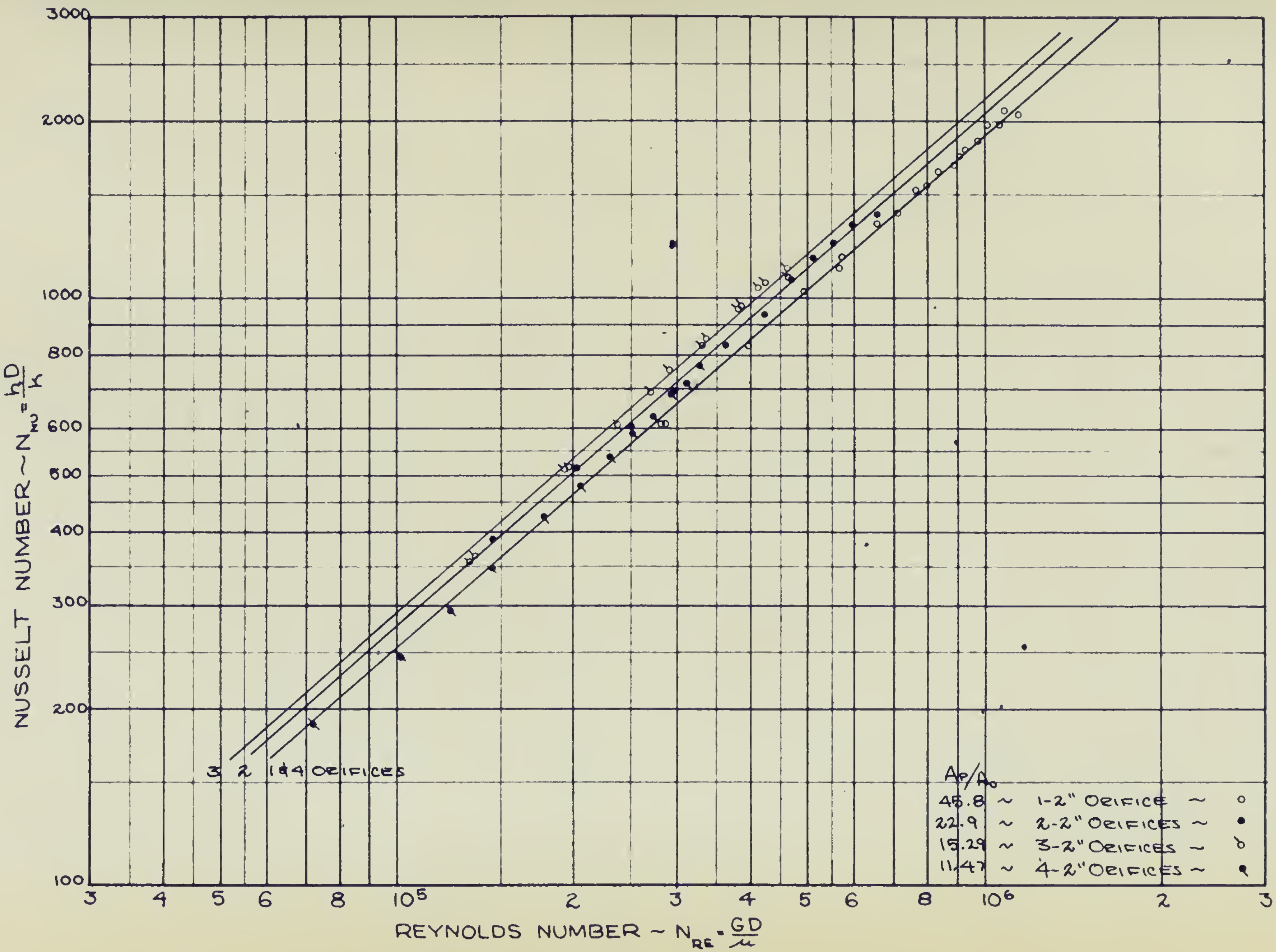


FIGURE 3 – NUSSELT NUMBER VS. REYNOLDS NUMBER; 1, 2, 3, AND 4 - 2" ORIFICES; 14" DEPTH, D/d = 7

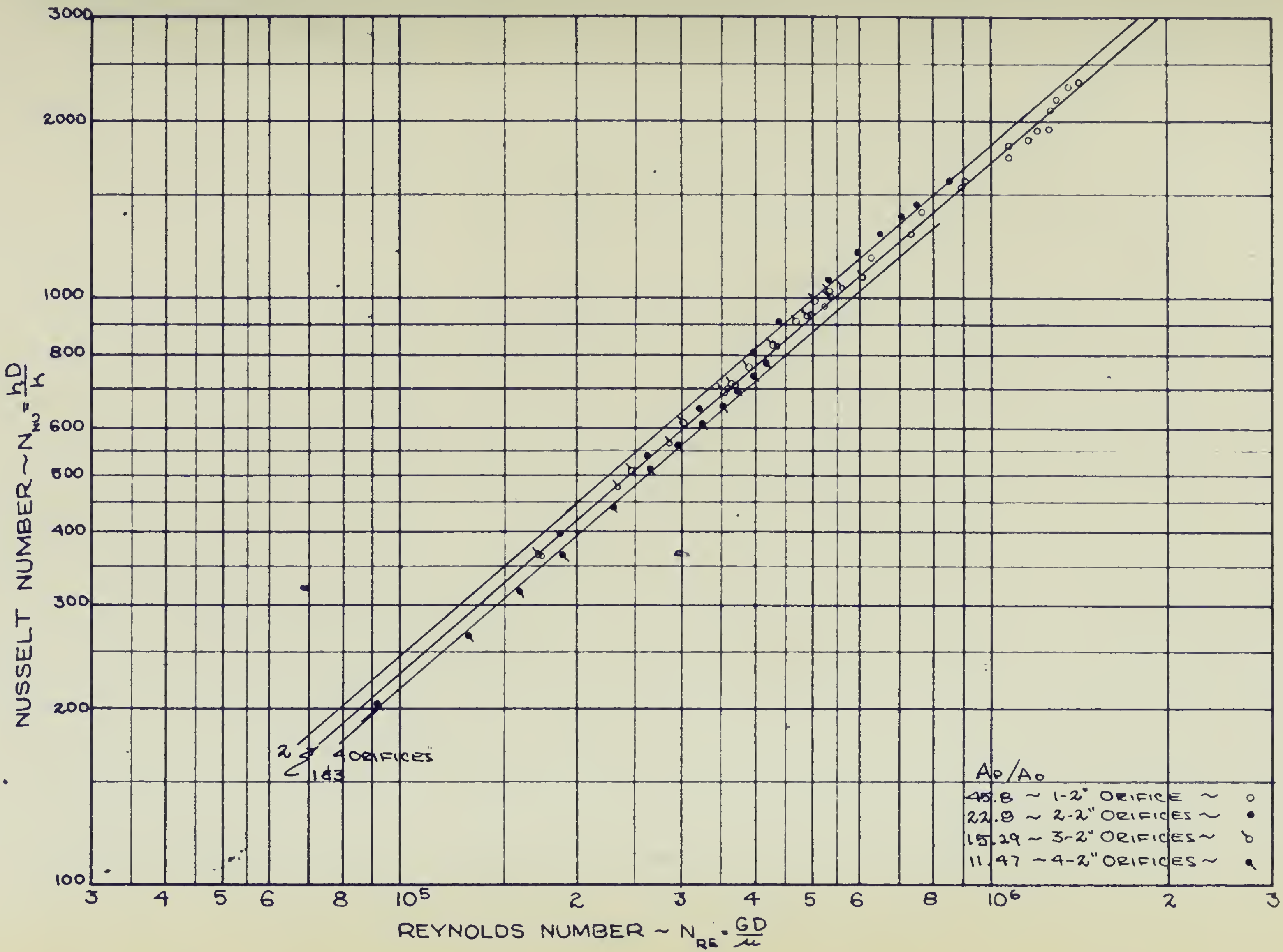


FIGURE 4 -NUSSELT NUMBER VS. REYNOLDS NUMBER; 1, 2, 3 AND 4 - 2" ORIFICES; 18" DEPTH, D/d = 9

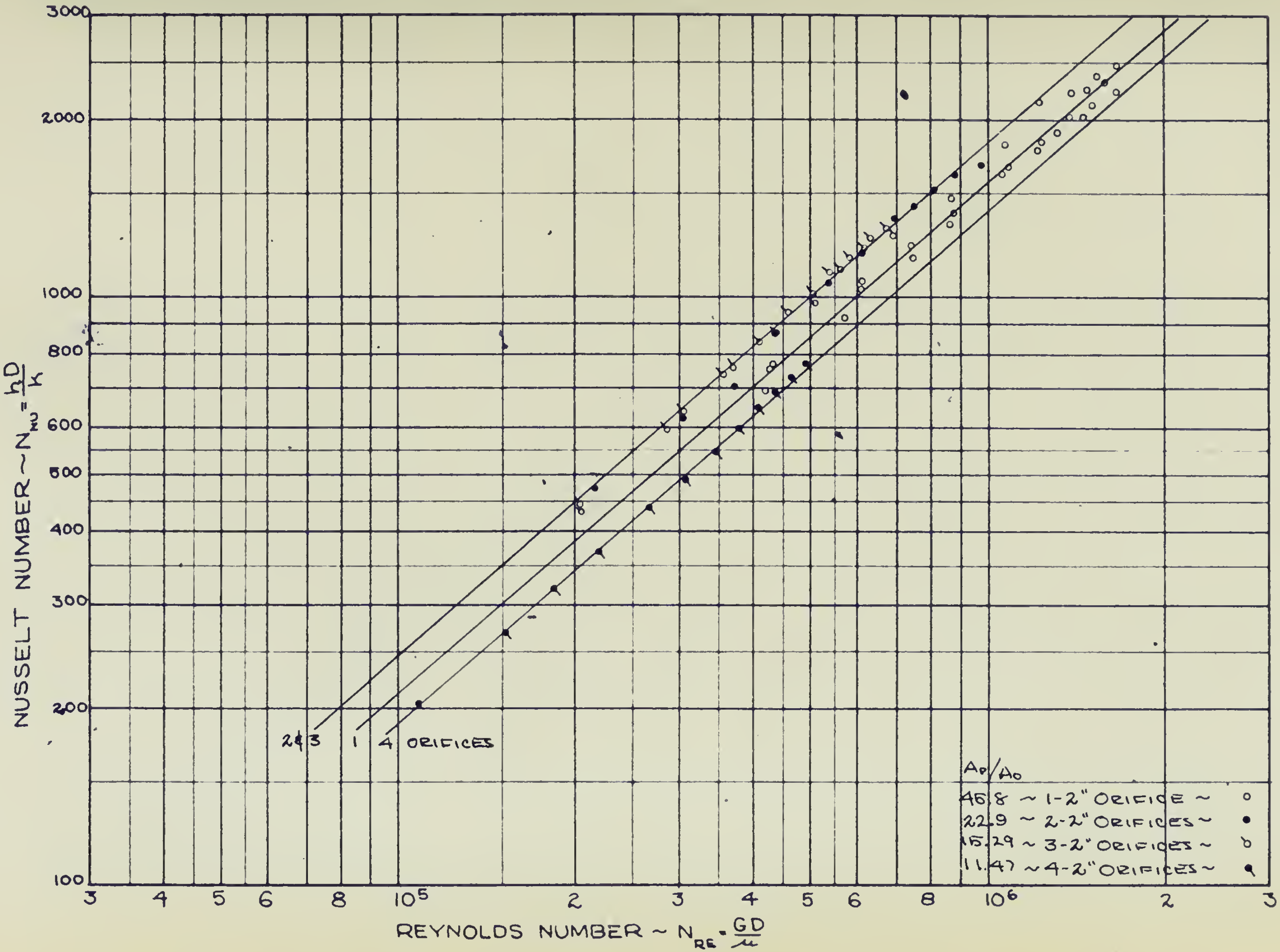


FIGURE 5 - NUSSELT NUMBER VS. REYNOLDS NUMBER; 1, 2, 3, AND 4-2" ORIFICES; 21" DEPTH, D/d = 10.5

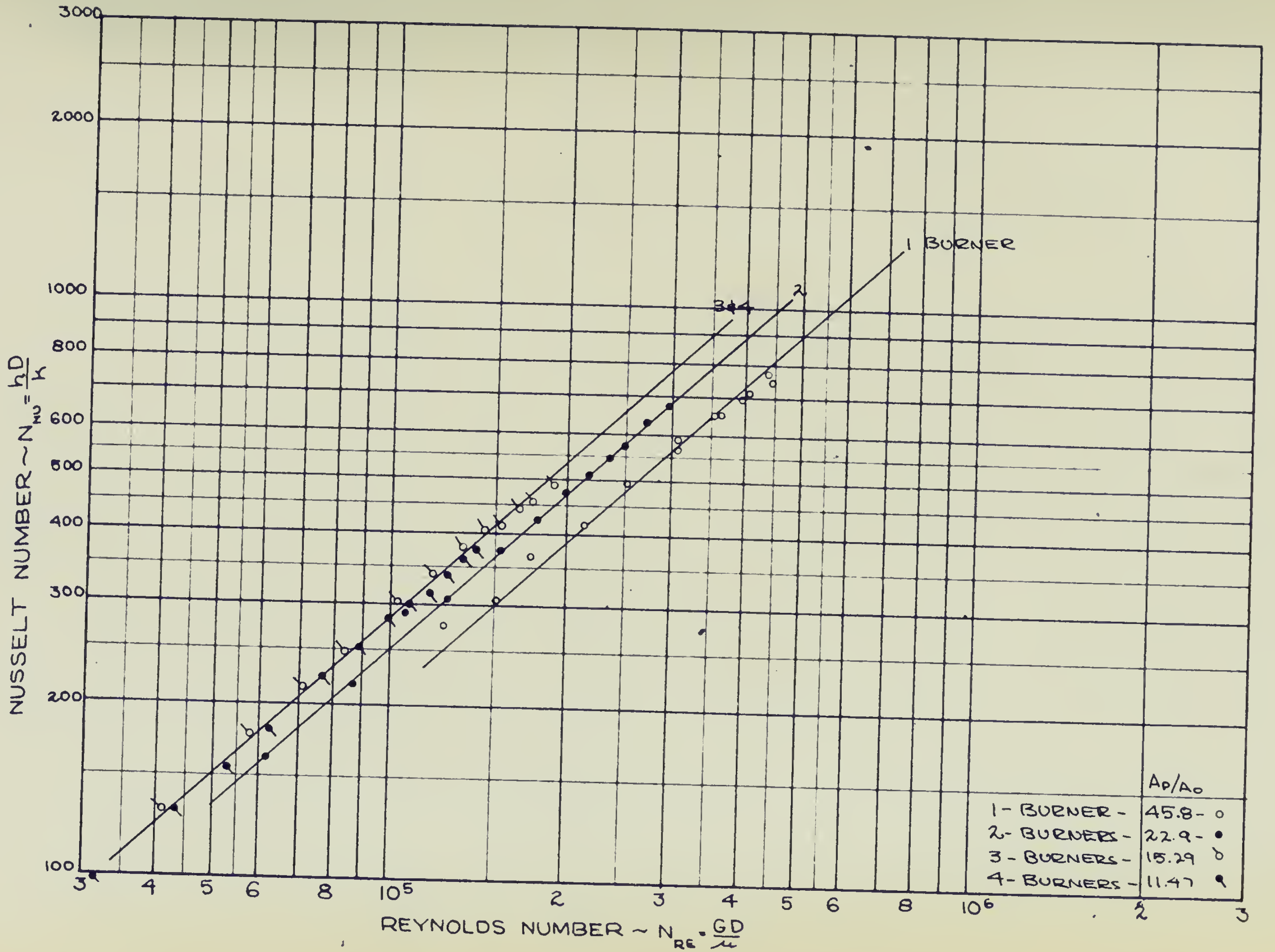


FIGURE 6 ~ NUSSELT NUMBER VS. REYNOLDS NUMBER, WITH BURNERS, 6" DEPTH, $D/d = 3$

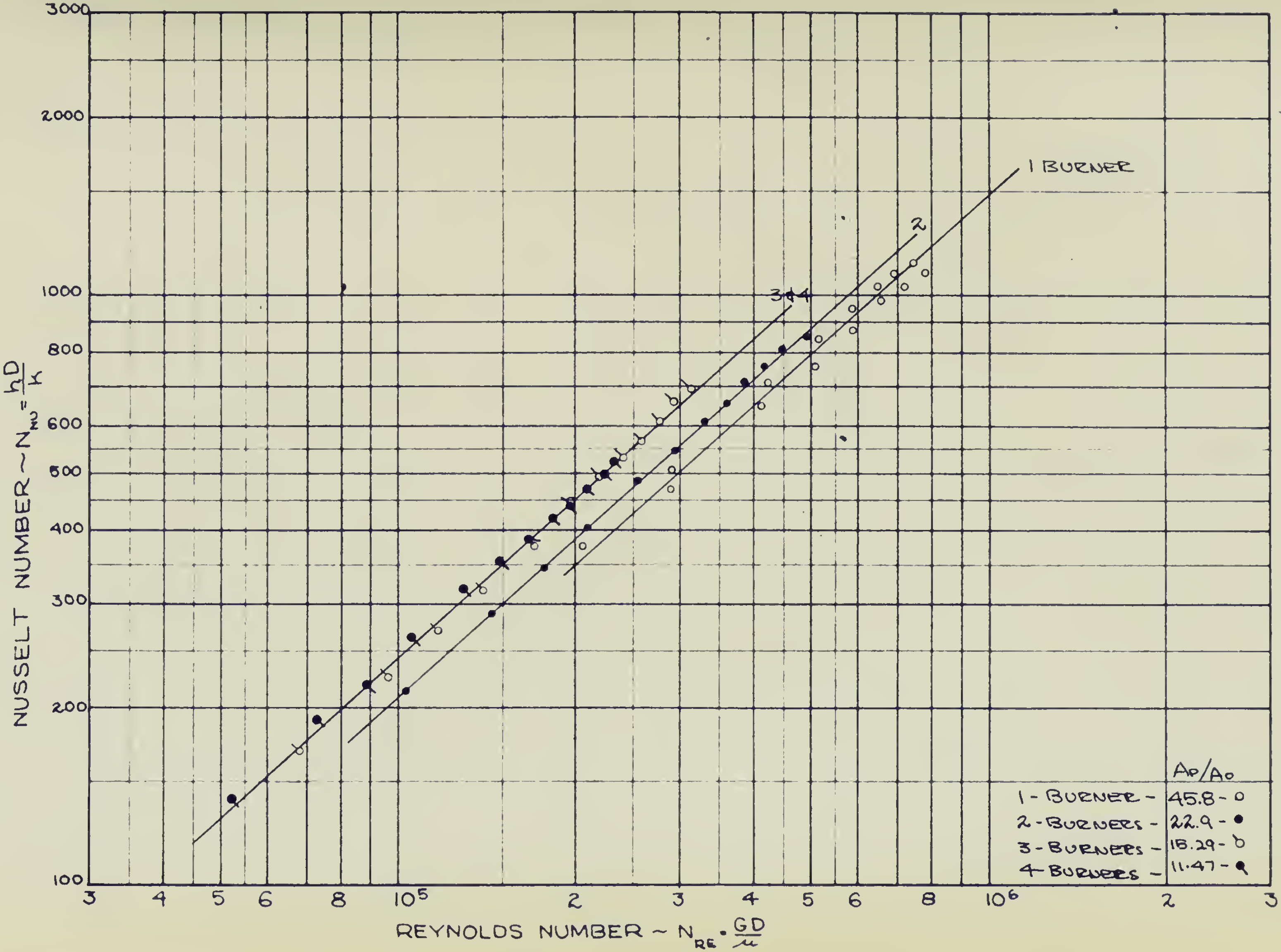


FIGURE 7- NUSSELT NUMBER VS. REYNOLDS NUMBER, WITH BURNERS, 10" DEPTH, D/d = 5

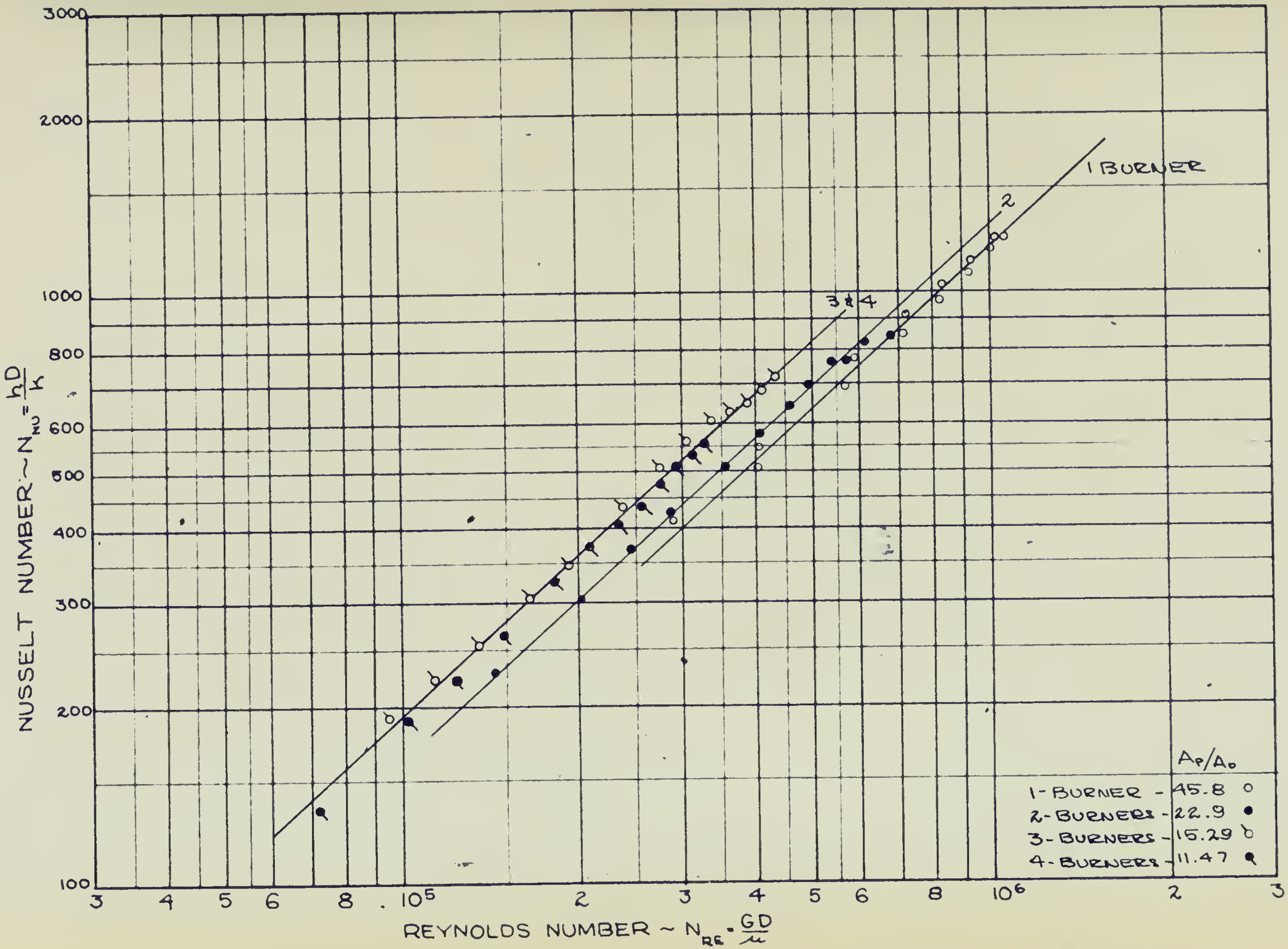


FIGURE 8 - NUSSELT NUMBER VS. REYNOLDS NUMBER, WITH BURNERS, 14" DEPTH, D/d = 7

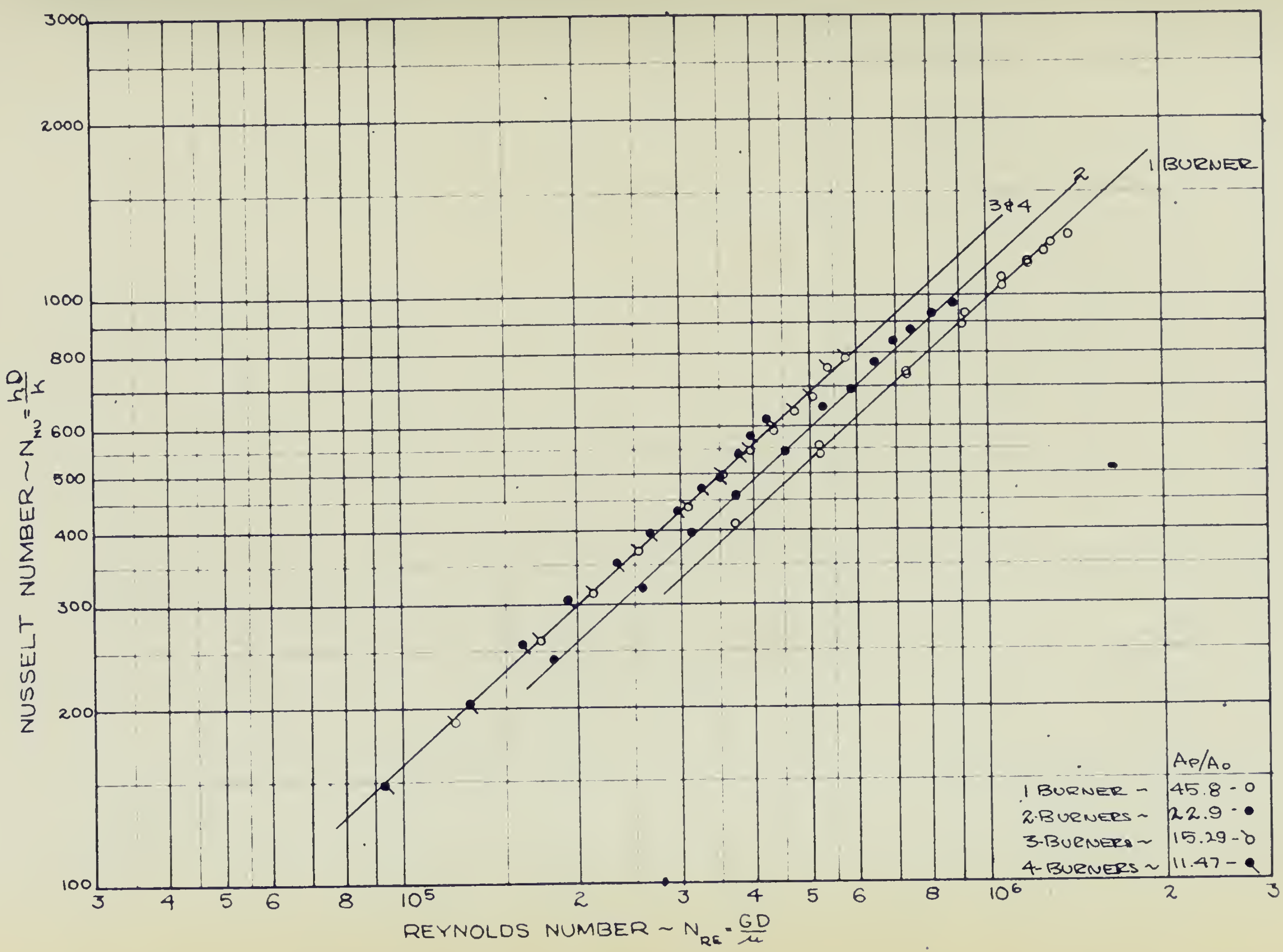


FIGURE 9 - NUSSELT NUMBER VS. REYNOLDS NUMBER, WITH BURNERS, 18" DEPTH, D/d = 9

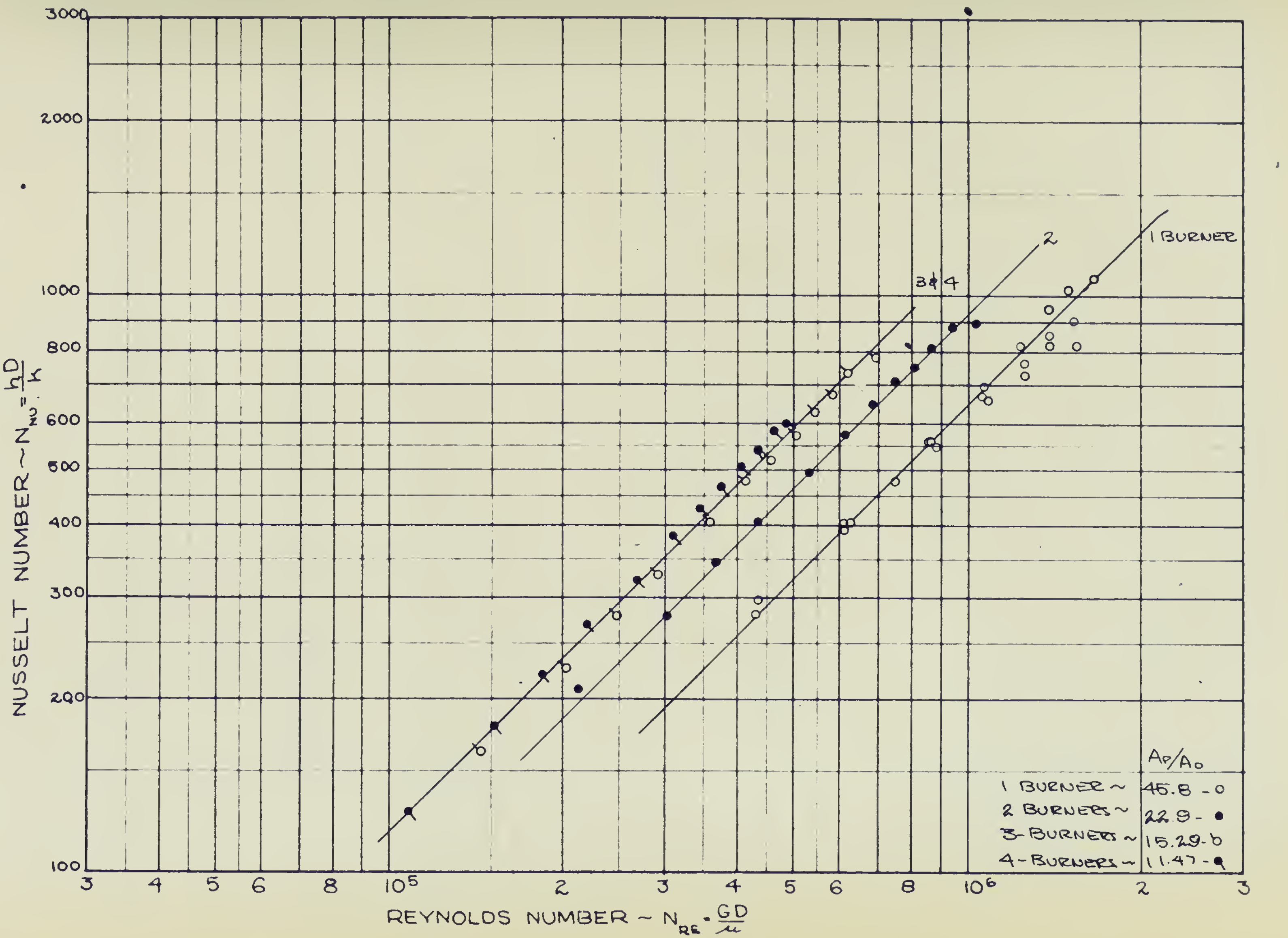
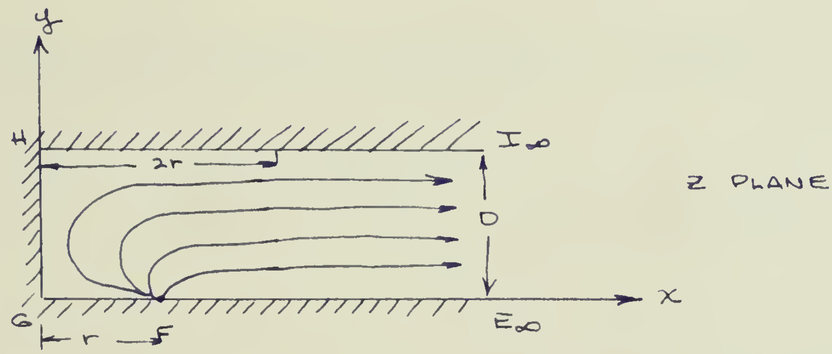


FIGURE 10 - NUSSELT NUMBER VS. REYNOLDS NUMBER, WITH BURNERS, 21" DEPTH, D/d = 10.5

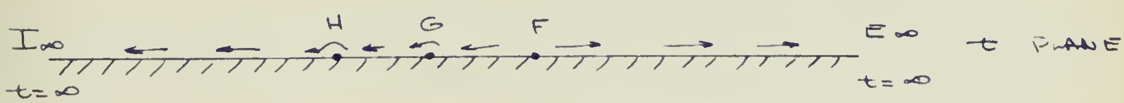
THEORETICAL ANALYSIS

Considering the two dimensional case only, the plan view of the boiler furnace may be considered as a semi-infinite strip in the z plane[12]. The burner is assumed to be a source in the front wall a distance r from the side wall. The effective width of rear wall is assumed to be 2r. Thus, the boiler furnace with one central burner orifice can be represented by the following figure:



Using the Schwarz-Christoffel theorem[13], the solution for the free stream velocity along the rear wall may be obtained in the following manner:

The flow in the t plane may be represented thus:



where H is at t = -1, G at t = 1, and F at t = k and $k > 1$.

The deflection angles at H and G are $\pi/2$ and at F it is zero. Therefore, the Schwarz-Christoffel theorem may be written as follows:

$$\frac{dz}{dt} = A(1-t)^{-1/2}(-1-t)^{-1/2} = \frac{A}{\sqrt{t^2-1}}$$

$$\therefore \quad z = \int \frac{A\,dt}{\sqrt{t^2-1}} = A \cosh^{-1} t + B$$

Applying the boundary conditions as follows:

AT G, $z = 0$, $t = +1$

$$0 = A\cosh^{-1}(1) + B \qquad \text{BUT} \quad \cosh^{-1}(1) = 0$$

$$\therefore \quad B = 0$$

AT H, $z = iD$, $t = -1$

$$\frac{iD}{A} = \cosh^{-1}(-1) \qquad \text{OR} \qquad \cosh \frac{iD}{A} = -1$$

BUT, $\cosh \frac{iD}{A} = \cos \frac{D}{A} = 1$

$$\therefore \quad \frac{D}{A} = \pi$$

AND. $z = \frac{D}{\pi} \cosh^{-1}(t)$

For a source at F:

$$w = m \ln (t-k) \qquad \text{WHERE} \quad k > 1$$

Since the total strength of the source is -Q, in the upper half of the t plane only (½ circle) $m = -\frac{Q}{\pi}$.

$$w = -\frac{Q}{\pi} \ln (t-k)$$

AT. F, $z = r$ AND $t = +k$

$$a = \frac{D}{\pi} \cosh^{-1} k$$

$$\text{OR} \quad k = \cosh \frac{r\pi}{D}$$

$$\text{SINCE} \quad z = \frac{D}{\pi} \cosh^{-1} t \quad \text{THEN} \quad t = \cosh \frac{\pi z}{D}$$

Substituting into the equation for w gives:

$$w = -\frac{Q}{\pi} \ln\left[\cosh \frac{\pi z}{D} - \cosh \frac{\pi r}{D}\right]$$

Stagnation points will occur where $\frac{\partial w}{\partial z} = 0$

$$\frac{\partial w}{\partial z} = \frac{\partial w}{\partial t} \frac{\partial t}{\partial z} = 0$$

Therefore, this is true of $\frac{\partial t}{\partial z} = 0$

$$\text{SINCE} \quad t = \cosh \frac{\pi z}{D}$$

$$\frac{\partial t}{\partial z} = \frac{\pi}{D} \sinh \frac{\pi z}{D} = 0$$

$$\text{OR} \quad \sinh \frac{\pi z}{D} = 0 \quad \text{FOR STAGNATION}$$

AT G, $z = 0$ $\quad \therefore \sinh \frac{\pi(0)}{D} = 0 \quad \therefore z = 0$ IS A STAGNATION POINT

AT H, $z = iD$ $\quad \sinh \frac{\pi i D}{D} = \sinh i\pi$

BUT. $\sinh i\pi = i \sin \pi = 0$

Therefore, $z = iD$ is a stagnation point also.

To get free stream velocity along rear wall,

$$\frac{dw}{dz} = -v_x + i v_y$$

where v_x and v_y are velocity components in the x and y directions respectively.

$$\frac{dw}{dz} = -\frac{Q}{D} \frac{\sinh \frac{\pi z}{D}}{\cosh \frac{\pi z}{D} - \cosh \frac{\pi r}{D}}$$

Along the rear wall, $z = x + iD$.

$$\text{THEN} \quad \sinh \frac{\pi z}{D} = \sinh\left(\frac{\pi x}{D} + i\pi\right) = \sinh \frac{\pi x}{D} \cos \pi + i \cosh \frac{\pi x}{D} \sin \pi$$

$$\text{BUT} \quad \sin \pi = 0, \quad \cos \pi = -1$$

$$\therefore \sinh \frac{\pi z}{D} = -\sinh \frac{\pi x}{D} \quad \text{ALONG } z = x + iD.$$

In a like manner:

$$\cosh \frac{\pi z}{D} = - \cosh \frac{\pi x}{D} \qquad \text{AT } z = x + iD$$

$$\therefore \quad \frac{dw}{dz} = - \frac{Q}{D} \, \frac{\sinh \frac{\pi x}{D}}{\cosh \frac{\pi x}{D} + \cosh \frac{\pi r}{D}} = - v_x + i v_y$$

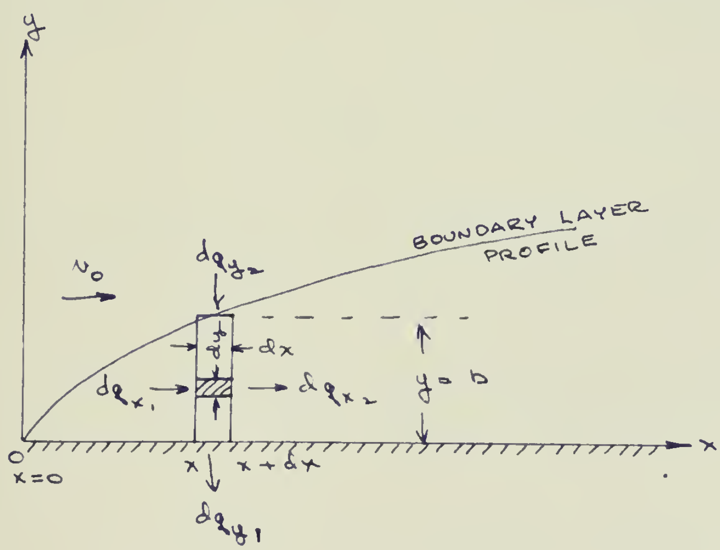
Therefore, equating real and imaginary parts, along the rear wall:

$$v_y = 0$$

$$\text{AND} \quad v_x = \frac{Q}{D} \, \frac{\sinh \frac{\pi x}{D}}{\cosh \frac{\pi x}{D} + \cosh \frac{\pi r}{D}} = v_o \cdot \quad . \; . \; . \; . \; . \; (8)$$

It will now be necessary to arrive at a suitable equation for N_{Nu} using this velocity. Due to the complexities of the geometry, attempts to analyze the problem in three dimensions, or even allow for the fact that the surface is composed of tubes, proved fruitless. Therefore, it became necessary to simplify the problem.

As an approximation one can consider the boiler rear wall as a flat plate with a turbulent boundary layer.



The origin of the axis system chosen will be at the stagnation point in the corner between the side AND rear wall. To simplify the problem greatly, only the two dimensional case will be considered. It can be seen that for unit width in the z direction:

$dq_{y_1} = dq_0 \, dx$ where dq_0 is heat transferred to the wall over a unit length in the x direction.

$$q_{x_1} = \int_0^b dq_{x_1} dy = \int_0^b v \rho c_p \Delta T \, dy$$

where v is the velocity of the fluid at y

ΔT is the temperature of the fluid above the wall temperature.

Likewise: $$q_{x_2} = \int_0^b v \rho c_p \Delta T \, dy + \frac{\partial}{\partial x}\left[\int_0^b v \rho c_p \Delta T dy\right] dx$$

Over the distance dx the increased volume of fluid in the boundary layer may be represented by $\frac{\partial}{\partial x}\left[\int_0^b v \, dy\right] dx$. This increased volume of fluid brings in a quantity of heat equal to dq_{y_2} DUE TO ITS TEMPERATURE DIFFERENCE ΔT_0.

$$dq_{y_2} = \left[\frac{\partial}{\partial x}\int_0^b v \, dy\right] \rho c_p \Delta T_0 \, dx.$$

Due to continuity for steady state operation:

$$q_{x_1} + dq_{y_2} - q_{x_2} - dq_{y_1} = 0$$

$$\int_0^b v \rho c_p \Delta T \, dy + \frac{\partial}{\partial x}\int_0^b v \, dy \, \rho c_p \Delta T_0 \, dx - \int_0^b v \rho c_p \Delta T dy$$

$$- \frac{\partial}{\partial x}\int_0^b v \rho c_p \Delta T \, dy \, dx - dq_0 \, dx = 0$$

Combining terms and dividing by dx gives:

$$dq_0 = \frac{\partial}{\partial x}\int_0^b v\,dy\,\rho C_p \Delta T_0 - \frac{\partial}{\partial x}\int_0^b v\rho C_p \Delta T\,dy$$

However, von Kármán(9) gives the velocity distribution as:

$$v = v_0\left(\frac{y}{b}\right)^{\frac{1}{7}}$$

and Rubesin(10), simplifying the equation for b by omiting the buffer layer and assuming a somewhat thicker boundary layer, gives the following relationship for b:

$$b = 0.371\,x\left(\frac{\nu}{v_0 x}\right)^{\frac{1}{5}}$$

By assuming that ΔT VARIES AS v (9)

$$\Delta T = \Delta T_0\left(\frac{y}{b}\right)^{\frac{1}{7}}$$

Substituting for v AND ΔT,

$$dq_0 = \frac{\partial}{\partial x}\left[\int_0^b v_0\left(\frac{y}{b}\right)^{\frac{1}{7}}\rho C_p \Delta T_0\,dy - \int_0^b v_0\left(\frac{y}{b}\right)^{\frac{1}{7}}\rho C_p \Delta T_0\left(\frac{y}{b}\right)^{\frac{1}{7}}dy\right]$$

$$dq_0 = \frac{\partial}{\partial x}\rho C_p \Delta T_0 v_0 \int_0^b\left[\left(\frac{y}{b}\right)^{\frac{1}{7}} - \left(\frac{y}{b}\right)^{2/7}\right]dy$$

OR $$dq_0 = \frac{\partial}{\partial x}\left[.097\rho C_p v_0 \Delta T_0 b\right]$$

Since both v_0 and b will vary with x:

$$dq_0 = .097\rho C_p \Delta T_0 \frac{\partial}{\partial x}\left[v_0 b\right]$$

or integrating with respect to x between the limits of 0 to x gives:

$$q_0 = .097\rho C_p \Delta T_0 v_{0_x} b_x$$

where the SUBSCRIPT x denotes the quantity evaluated at x.

Substituting $b = .371\,x\left(\frac{\nu}{v_{0_x} x}\right)^{\frac{1}{5}}$ YIELDS:

$$q_0 = .036\rho C_p \Delta T_0 v_{0_x} x\left[\frac{\nu}{v_{0_x} x}\right]^{\frac{1}{5}}$$

$$\frac{h x}{k} = \frac{q_0}{k\Delta T_0} = .036\left[\frac{\rho v_{0_x} x}{\mu}\right]^{.8}\left[\frac{C_p \mu}{k}\right] \quad \text{. . . . . . (9)}$$

Selecting values of depth between r and 4r, and substituting values of x from 0 to 2r into Equation 8 gives values of $[\nu_{o_x} x]$. Raising each value of $[\nu_{o_x} x]$ to the .8 power and taking a Simpson's mean gives $[\nu_{o_x} x]^{.8}_{m} = C_1 \left[\frac{Q}{r} r\right]^{.8}$ where C_1 is given below:

DEPTH	r	2r	3r	4r
C_1	.540	.289	.184	.128

Noting that $\left[\frac{hx}{k}\right]_{m} = \frac{hr}{k}$ and substituting the above values of $[\nu_{o_x} x]^{.8}_{m}$ into Equation 9 gives:

$$\frac{hr}{k} = .036\, C_1 \left[\frac{\rho \frac{Q}{r} r}{\mu}\right]^{.8} \left[\frac{c_p \mu}{k}\right]$$

Since r = D, D/2, D/3, D/4 respectively, the following equation may be written:

$$\frac{hD}{k} = \alpha_t \left[\frac{\rho \frac{Q}{r} D}{\mu}\right]^{.8} \frac{c_p \mu}{k} \qquad \text{. . . . . . (10)}$$

where α_t is given by Table 3.

Table 3 - Values of α_t for Equation 10.

D/r	1	2	3	4
α_t	.0194	.012	.00825	.00609

DISCUSSION OF RESULTS

In comparing the results obtained with circular orifices, burners for $\frac{D}{d} \leq 9$, and burners with $\frac{D}{d} > 9$, care must be taken to note that each case has a different power of N_{Re} as well as different values of α. For example, using air with $N_{Re} = 300,000$ and $N_{Pr} = .7$ gives:

Circular orifice	~	$N_{Nu} = \alpha_o (51,800)$
Burners $\frac{D}{d} \leq 9$	~	$N_{Nu} = \alpha_b (75,500)$
Burners $\frac{D}{d} > 9$	~	$N_{Nu} = \alpha_b (266,000)$

Although the values of N_{Nu} will diverge somewhat due to changes in N_{Re}, the values for the above case are plotted in Figure 11 and several general trends are evident.

N_{Nu} with circular orifices is roughly 50% greater than with burners. Since the use of burners imparts a whirling motion to the fluid, the sideward velocity is considerably increased while the forward velocity is decreased. Therefore, the convection of heat by efflux into the boundary layer will be proportionately reduced and the burners will give a lower value of heat transfer.

Another interesting aspect is that beyond $\frac{D}{d}$ of 9 the curves of N_{Nu} for burners falls off sharply. It is apparent that beyond this point the free area through the screen tubes is large and the forward velocity small so that the fluid fails to reach the rear wall in sufficient quantity to prevent

some stagnation from occuring. The net affect is a resultant decrease in heat transfer. With circular orifices, however, the major component of velocity is forward; and the fluid reached the rear wall in all cases within the ranges tested. From this dropping off, it may be assumed that in actual boiler furnaces the convection heat transfer to the rear wall is negligible beyond $\frac{D}{d} = 9$. This is substantiated with observations on marine boilers where $\frac{D}{d}$ of 9 would mean a depth of about 12 feet.

Although the curves for $\frac{Ap}{Ao}$ of 22.9 AND 45.8 cross the other curves for the orifice case, the general trend of both the orifice curves and burner curves is the same. Also, with reference to Figure 12 & 13, it is evident that as $\frac{Ap}{Ao}$ decreases, α first increases to a maximum value and then decreases again. For the circular orifices the value of $\frac{Ap}{Ao}$ for maximum α_o becomes larger as depth increases. This may be interpreted to mean that at greater depths maximum heat transfer will occur with smaller orifices. For the burners, all the curves are similar and maximum α_b is at $\frac{Ap}{Ao}$ of about 13. Beyond that point there is no advantage in adding more burner area.

A search of the current literature revealed that McAdams[3] gives the following equation attributed to Colburn for heat transfer through a turbulent boundary layer with flow parallel to a plane surface:

$$\frac{h_m}{C_p V_1 \rho_1}\left[\frac{C_p \mu}{k}\right]_f^{\frac{2}{3}} = \frac{0.036}{(L V_1 \rho_1/\mu)^{.2}}$$

With suitable transformation, this becomes:

$$\frac{hL}{k} = 0.036\left[\frac{\rho V L}{\mu}\right]^{.8}\left[\frac{C_p \mu}{k}\right]^{\frac{1}{3}} \qquad \text{. . . . . . . (11)}$$

This equation is of the same form as Equation 9 except that the Prandtl Number, $[C_p \mu / k]$ is to the 1/3 power. In addition, McAdams gives the following relationship attributed to Jurges for flow of air at room temperature parallel to a vertical copper plate:

$$h_{m_1} = a_1 + b_1 (V^1)^m \qquad \ldots\ldots (12)$$

where h_{m_1} is expressed in BTU/HR-FT^2-DEG.F. INITIAL ΔT. and V^1 is in ft/sec. The factors for Equation 12 are given in Table 4.

Table 4 - Factors for Equation 12

TYPE SURFACE	$V^1 < 16$ FT/SEC			16 FT/SEC $< V^1 <$ 100 FT/SEC		
	a_1	b_1	m	a_1	b_1	m
SMOOTH	.99	0.21	1.0	0	0.50	0.78
ROUGH	1.09	0.23	1.0	0	0.53	0.78

It is clear that the value of h_{m_1} is dependent on $(V^1)^{.78}$ when $V^1 > 16$ ft/sec. but is dependent on V^1 with $V^1 < 16$ ft/sec. With the burners at $\frac{D}{d} = 10.5$, Equation 7 shows the same dependence on the velocity, rather than the velocity to the .9 power. As previously stated, some stagnation must occur on the rear wall beyond $\frac{D}{d} = 9$, and thus the mean velocity would be very low - even below 16 ft/sec.

Since very few tests have been run on heat transfer by fluid impingement, there is very little data available for

comparison purposes. Friedman and Mueller[4] ran some tests on air impinging on a horizontal heated plate and obtained the following equation:

$$h_{m_1} = C_1 G^{.78} \quad \text{. . . . .} \quad (13)$$

where C_1 was dependent on the plate and the spacing of the discharge orifice from the plate. C_1 varied from .011 to .321 depending on the geometry. The geometry of these tests was considerably different from that of a boiler furnace so no comparison can be made.

Holmboe and Hove[8] give the following equation for impingement on a flat copper plate in the same boiler model used in these tests:

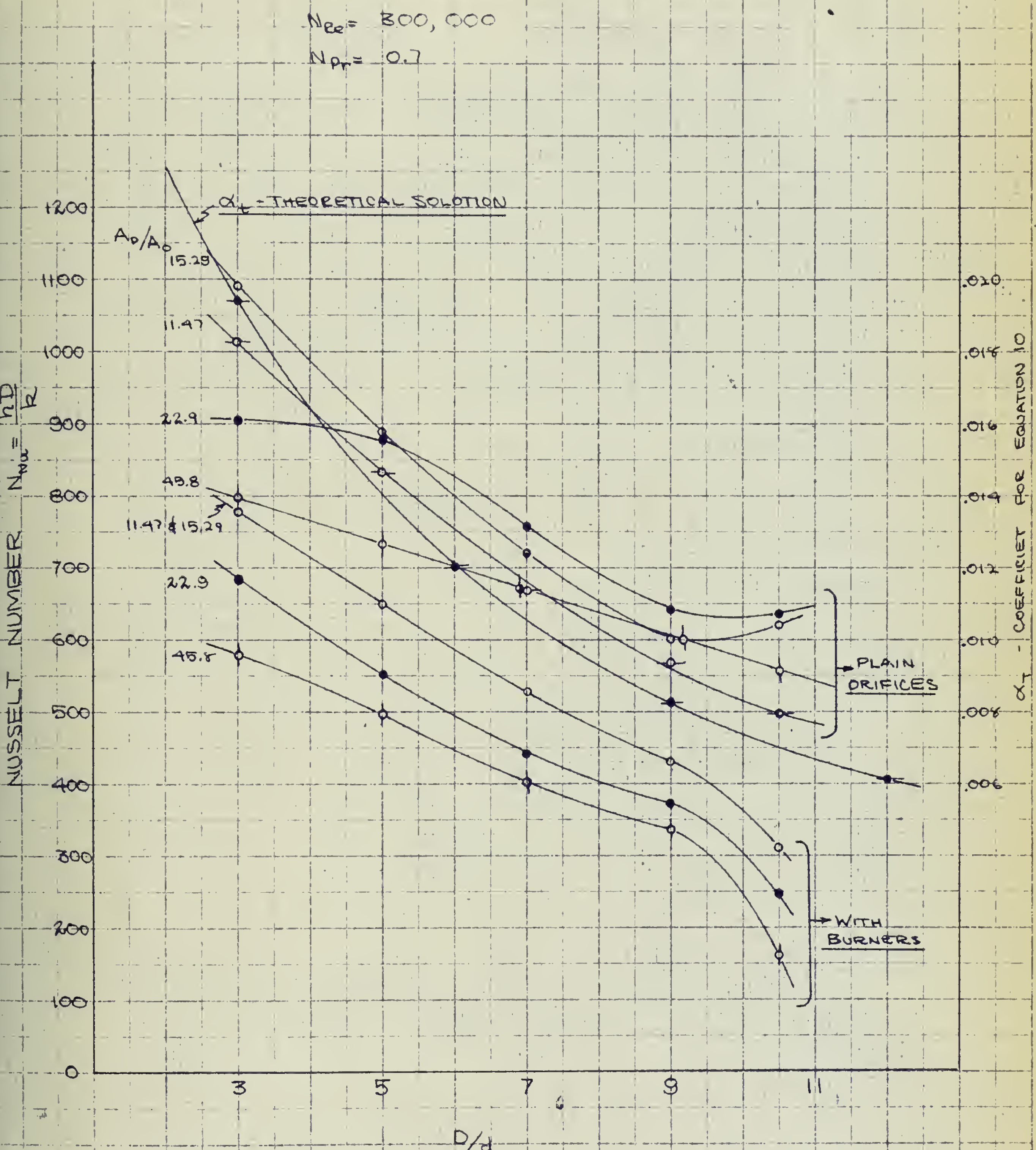
$$\frac{hD}{k} = .0258 \left[\frac{GD}{\mu}\right]^{.823} \left[\frac{C_p \mu}{k}\right]^{\frac{1}{3}} \quad \text{. . . . .} \quad (14)$$

The value of of .0258 is slightly higher than the values of .0095 to .021 found in the present tests for air discharging through orifices. This discrepancy is due to the lower exponent of N_{Re} found by Holmboe and Hove. The lower value of the exponent is believed due to inability of the equipment to maintain steady state at high rates. This caused their plots to curve over, and thus the resulting line had a lower slope. This equation gives a value of N_{Nu} of 738 for the case of N_{Pr} = .7 and N_{Re} = 300,000. This is approximately the mean value of the curves of N_{Nu} for the orifice case as plotted in Figure 11. It is of interest that the use of tubes instead of a flat plate made very little change on the heat transferred. This would support the use of the projected rear wall heat transfer surface in the calculation of h in Appendix E.

In analyzing the theoretical solution, no direct comparison can be made since N_{Re} is actually based on the velocity along the rear wall rather than the mass flow through the burners. Since $G = \frac{Wg}{Ao}$ and A_o is zero for a source, G has no meaning in this solution as it would be infinite. However, since the Reynolds Number is represented by $\frac{\rho \frac{Q}{r} D}{\mu}$ it is of interest to note that $\rho \frac{Q}{r}$ is the mass flow along the rear wall. If $\frac{\rho \frac{Q}{r} D}{\mu}$ equaled $\frac{GD}{\mu}$ where G is mass flow through the burners, a direct comparison could be made. Since for a constant value of Reynolds Number, N_{Nu} is proportional to α_t, α_t is plotted in Figure 11 for the sake of examining the trend of the curve. In the model, r was 6" and d was 2"; therefore, for comparison purposes $\frac{D}{d}$ may be assumed to equal $3\frac{D}{r}$. It may be seen that the shape of the curve is similar to the burner curves with the exception that the drop off beyond $\frac{D}{d} = 9$ is not included in the theory. It is interesting to note that the curve is steep at shallow depths and levels off as depth increases.

FIGURE 11

VARIAIONS IN NUSSELT NUMBER VS CHANGES IN D/d & Ap/Ao



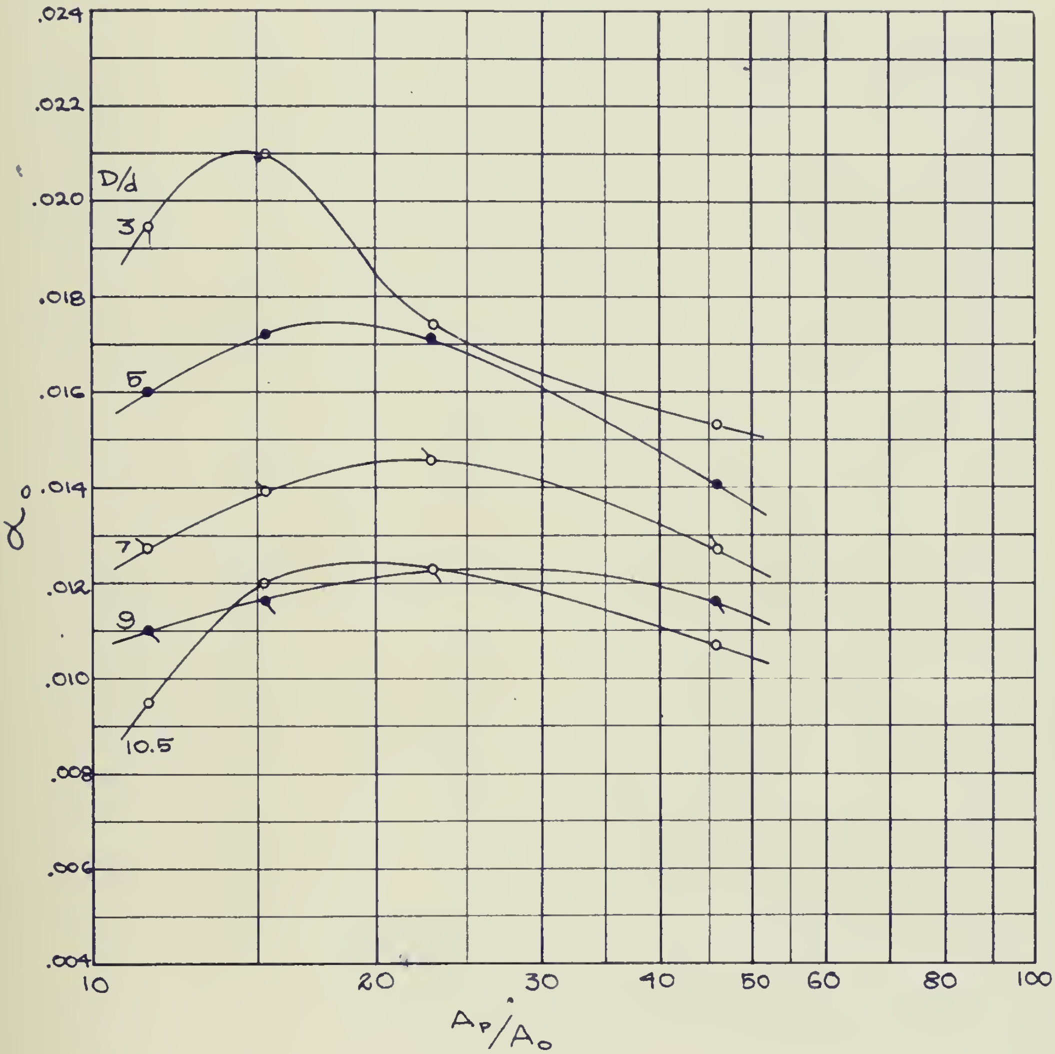


FIGURE-12 ~ VALUES OF α_o FOR EQUATION 5
AIR DISCHARGING THROUGH PLAIN CIRCULAR ORIFICES

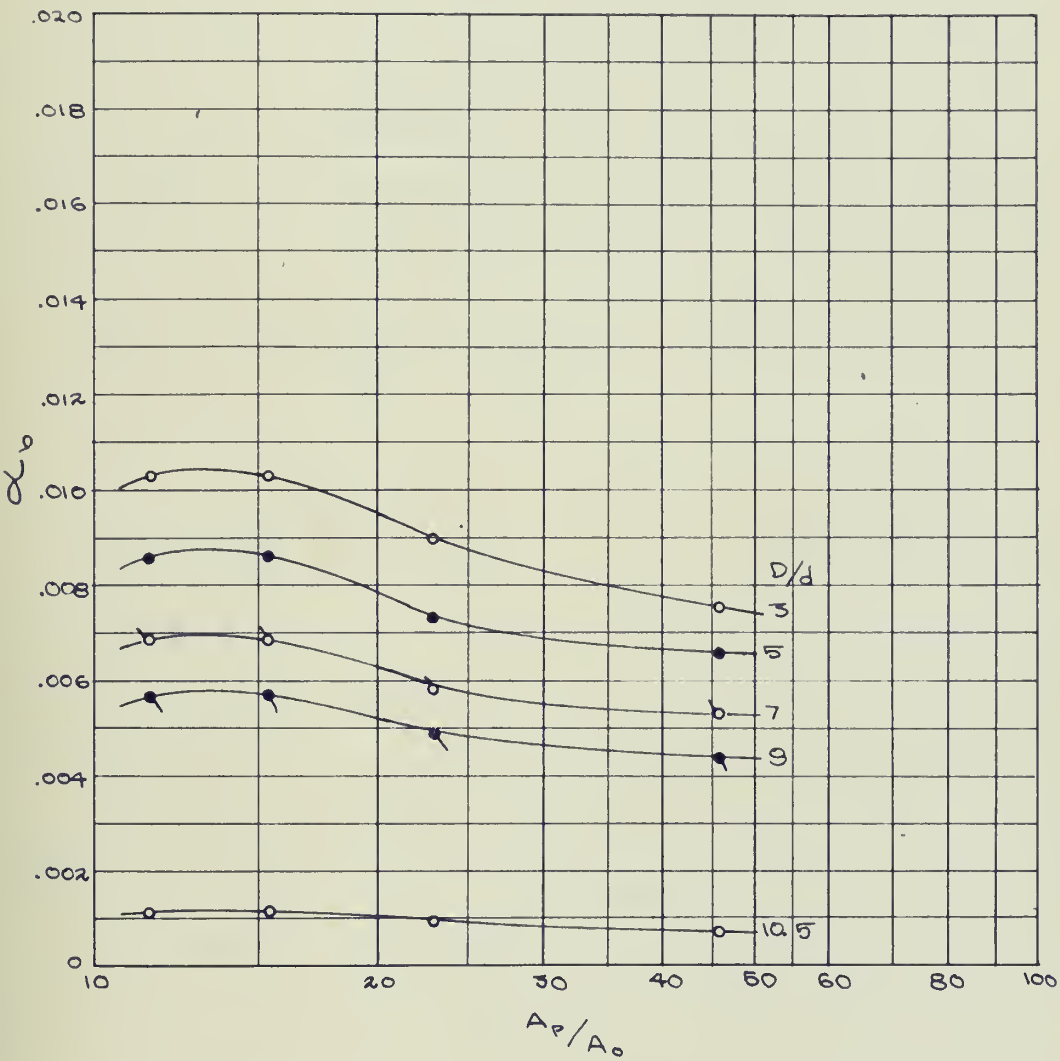


FIGURE - 13 ~ VALUES OF α_b FOR EQUATION 6 & 7

AIR DISCHARGING THROUGH TYPICAL MARINE BURNERS

APPLICATION TO DESIGN

As previously stated, the method of calculating furnace exit temperature is one of equating the heat given up by the gasses to the heat absorbed by the furnace surfaces and solving for the exit gas temperature. The rigorous solution of the problem would involve equating radiation plus convection to the heat given up by the gas using the following equation[1]:

$$1730\, S_c (F_E F_A)\left[\left(\frac{T_F}{1000}\right)^4 - \left(\frac{T_c}{1000}\right)^4\right] + U_c \,\Delta T_m\, S_w$$

$$= W_F(R+1)\left[\left(\frac{\overline{LHV} + q_f + (t_a - t_o)\overline{C_p}\,R}{R+1}\right) - q_{T_E}\right] \quad . \; . \; .(15)$$

where S_c is cold surface, $F_E F_A$ is the combined shape emissivity factor, T_F is effective flame temperature, T_c gas side temperature of the cold surface, U_c is the coefficient of convection heat transfer, T_m is the mean temperature difference, S_W is the projected heat transfer surface of the rear wall, W_F is weight of fuel, R is air to fuel ratio by weight, $\overline{LHV}$ is the low heating value of the fuel, q_f is the enthalpy of the fuel above t_o, $(t_a - t_o)$ is the temperature of the air above t_o, $\overline{C}_p$ is the specific heat of the incoming air, and q_{T_E} is the sensible heat of the flue gas at the furnace exit temperature T_E.

However, the question remains as to what value of ΔT_m should be used in the convection problem. The flame temperature T_F is too high a gas temperature since the gasses in the vicinity of the boiler rear wall have been found to be considerably cooler[15, 16]. In obtaining the data presented herein, the

gas was assumed to enter the boiler front at some constant initial temperature. In the actual furnace, combustion takes place after the fuel and air enter the furnace; while in the test apparatus, combustion was assumed to have taken place prior to blowing the gasses into the furnace. Therefore, in order to use the data as presented, the assumption must be made that combustion has taken place and the gasses have assumed some initial temperature prior to impinging on the rear wall.

The easiest way to handle this is to first calculate the furnace exit temperature T_E using only the radiation portion of Equation 15. The gasses are then assumed to impinge on the rear wall at this temperature T_E. Using the following equation, a corrected temperature of the gas leaving the furnace T_1 may be computed:

$$\varepsilon^{\frac{U_c S_w}{W_g C_p}} = \frac{T_E - T_c}{T_1 - T_c}$$

$$\text{or} \quad T_1 = \frac{T_E - T_c}{\varepsilon^{\frac{U_c S_w}{W_g C_p}}} + T_c \qquad \dots\dots\dots (16)$$

where T_E was previously calculated, and T_c is the outside temperature of the rear wall tubes, and may be considered equal to the temperature of the boiling water within the tubes T_s, since the coefficients of heat transfer through the metal and to a boiling liquid are very high. S_w is the projected area of the rear wall heat transfer surface, $W_g = W_a + W_f$; C_p is the specific heat of the gas evaluated at the average

gas temperature $\frac{T_E + T_1}{2}$, and U_c is given by the following:

$$\frac{1}{U_c} = \frac{1}{h} + \frac{1}{k_m} + \frac{1}{h_w}$$

For change of state, the coefficient of heat transfer through the water film inside the tubes h_w is very large; so $\frac{1}{h_w}$ may be neglected. Likewise, k_m the thermal conductivity of the tube wall, may also be neglected unless the wall thickness is large. Therefore, $U_c \approx h$, and h may be found from Equation 6 repeated below:

$$\frac{hD}{k} = \alpha_b \left[\frac{GD}{\mu}\right]^{.9} \left[\frac{C_p\mu}{k}\right]^{\frac{1}{3}} \quad \ldots\ldots\ldots (6)$$

$$\text{or} \quad h = \alpha_b \frac{G^{.9}}{D^{.1}\mu^{.9}} k \left[\frac{C_p\mu}{k}\right]^{\frac{1}{3}} \quad \ldots\ldots\ldots (17)$$

where C_p, μ, and k are evaluated at the film temperature T_f and $T_f = T_s + \frac{\Delta T_m}{2}$ where ΔT_m is given by the following equation:

$$\Delta T_m = \frac{T_E - T_1}{\ln \frac{T_E - T_s}{T_1 - T_s}} \quad \ldots\ldots\ldots (18)$$

Values of α_b are plotted in Figure 13 vs. D/d and A_p/A_o. In computing G, the vanes in the registers are not allowed for; therefore:

$$G = \frac{W_g}{A_o} \quad \ldots\ldots\ldots (19)$$

where W_g is the total weight of gas and A_o is the total burner area.

By estimating T_1, the film temperature and average gas temperature are computed. Using these, U_c and C_p are determined and T_1 solved for using Equation 16. With this new T_1, the process is repeated solving for another value of T_1. Usually

two estimates will converge on the solution with enough accuracy for engineering calculations.

This correction for rear wall convection may be considered negligible with D/d greater than 9.

CONCLUSIONS

One of the basic assumptions made in analyzing this problem is that the gas enters the boiler front at some initial condition. In actual practice, oil and air enter through the atomizers and air register respectively; the oil ignites, and the burning gasses expand outward. The total weight of gas is equal to the weight of air and oil together. This doesn't change in the combustion process; but the velocities do.

In spite of this, the data presented for the fluid discharging through burners should give a good approximation of the heat transfer by convection in the boiler rear walls. The method of applying this data is given in the preceeding section.

In general, the following conclusions may be drawn in regards to the convection heat transfer in boiler rear walls:

1. At depths beyond D/d = 9 the heat transfer is negligible.

2. The heat transfer is a function of D/d and Ap/Ao, and the use of these parameters in testing was correct.

3. There is no increase in heat transfer by reducing Ap/Ao beyond a value of about 13.

4. In computing the heat transfer, the projected area of the heat transfer surface may be used.

RECOMMENDATIONS

The following recommendations may be made as a result of this study:

1. Tests should be run on models with the tubes at various spacing and backed by both tangent and "T" tile to determine if the use of the projected area would be justified in these cases.

2. Further small scale testing such as this should be done using liquids as the fluid. This would allow more accurate measurement of velocity, weight of fluid, and temperature since radiation would be virtually eliminated. The use of liquids would also allow the Prandtl Number of the fluid to be easily varied.

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APPENDIX A

DESCRIPTION OF APPARATUS

In order to effectively evaluate the convection heat transfer on the boiler rear wall, it was necessary to simulate with models the fluid flow and heat transfer phenomena that occur in a boiler furnace. To accomplish this, a model boiler was used. Air supplied by a turboblower through a flow meter was blown through the model. The heat transfer was accomplished by reversing the normal boiler process and allowing the heated rear wall to heat the air. By measuring the weight of air flowing and inlet and outlet temperatures, the actual heat transferred to the fluid could be computed.

Therefore, with reference to Figure A-1, the testing apparatus consisted of a model boiler, steam generator, turboblower, flow meter, and associated valving and instruments.

The model boiler (see Figure A-2) was a modification of the 12 inch model used by Holmboe and Hove[8]. It consisted of a plywood box similar to a boiler furnace with an adjustable front, tubular rear wall, and a row of dowels representing the screen tubes in a marine boiler. The furnace front was a movable copper plate containing the burner orifices. The scale chosen was 1/8 inch = 1 inch; so that the two inch orifices represented 16 inch diameter burners. By moving this plate, the furnace depth could be varied from 6 to 21 inches. Four different orifice plates were constructed with 1, 2, 3, and 4 orifices respectively. The orifices were arranged so that the

center of area of the orifices coincided with the center of the plate. In addition they were cut $3\frac{1}{4}$" between centers to correspond with normal boiler practice of 26 inches.

The tubular rear wall (see Figure A-3) was a series of thirty-two 3/8" O.D. copper tubes brazed into an upper and lower header. The lower ends of the tubes were curved through slightly less than a right angle to give flexability for thermal expansion. Sufficient length was allowed so that a 12 inch by 12 inch flat surface of tangent-tubes was exposed to the impinging fluid. The upper header was fitted with a steam inlet and a combination vent and pressure tap. The steam was distributed in the header through a length of 3/8" O.D. copper tubing, plugged at the end, and drilled with 1/16" holes whose combined area was equal to the cross sectional area of the inlet line. The lower header was fitted with a condensate drain. As installed in the model, the tubes were backed by 1 inch of asbestos cement, and the headers insulated with rock wool padding.

Steam for heating the model rear wall and to run the turboblower was supplied by a Clayton Steam generator. Steam to the rear wall passed through a needle valve into a moisture separator. A small tangential hole admitted the steam with a swirling motion, separating the entrained water which drained out the bottom. The dry steam passed out the tap to the upper header and into the tubular rear wall. The condensed steam drained into the lower header and out the condensate drain.

The turboblower was an Allis-Chalmers aircraft turbo-supercharger with the nozzle blocks modified to take steam. Saturated steam at 110 psig, as provided by the steam generator, passed through a regulating valve and a throttle valve providing a nozzle chest pressure of 50 psig. A bypass was used to direct any excess air back through the turbine and out the exhaust.

The flow meter was a concentric, square-edge orifice meter fitted with flange taps. The meter was installed in sufficient straight length of 3 inch standard pipe to insure accurate readings. A 2.114 inch diameter orifice was used, and the pressure drop across this orifice was read directly in inches of water on a differential manometer.

In addition to the above, manometers were installed to measure positive steam pressure in the model rear wall and air pressure in the inlet chamber of the model boiler.

Two mercury thermometers were installed, one in the air inlet chamber and one in the stack, to measure the Δ T of the air through the boiler. They had a range of 51° C. and were graduated in 0.1°C. allowing the temperature to be read quite accurately to the nearest $.02^{\circ}$ C.

A small balance and a timer were originally used for measuring and timing the steam condensed in the rear wall. However, this was eliminated when good agreement could not be obtained between the heat of condensation and the heat absorbed by the air.

Model burners similar in geometry to those used on marine boilers were constructed. They could be attached to the orifice plate in the furnace front and imparted a swirling motion to the air as it entered the furnace. Details of the burners are shown in Figure A-4.

A description of the test procedure and method of operation of the equipment is given in Appendix B.

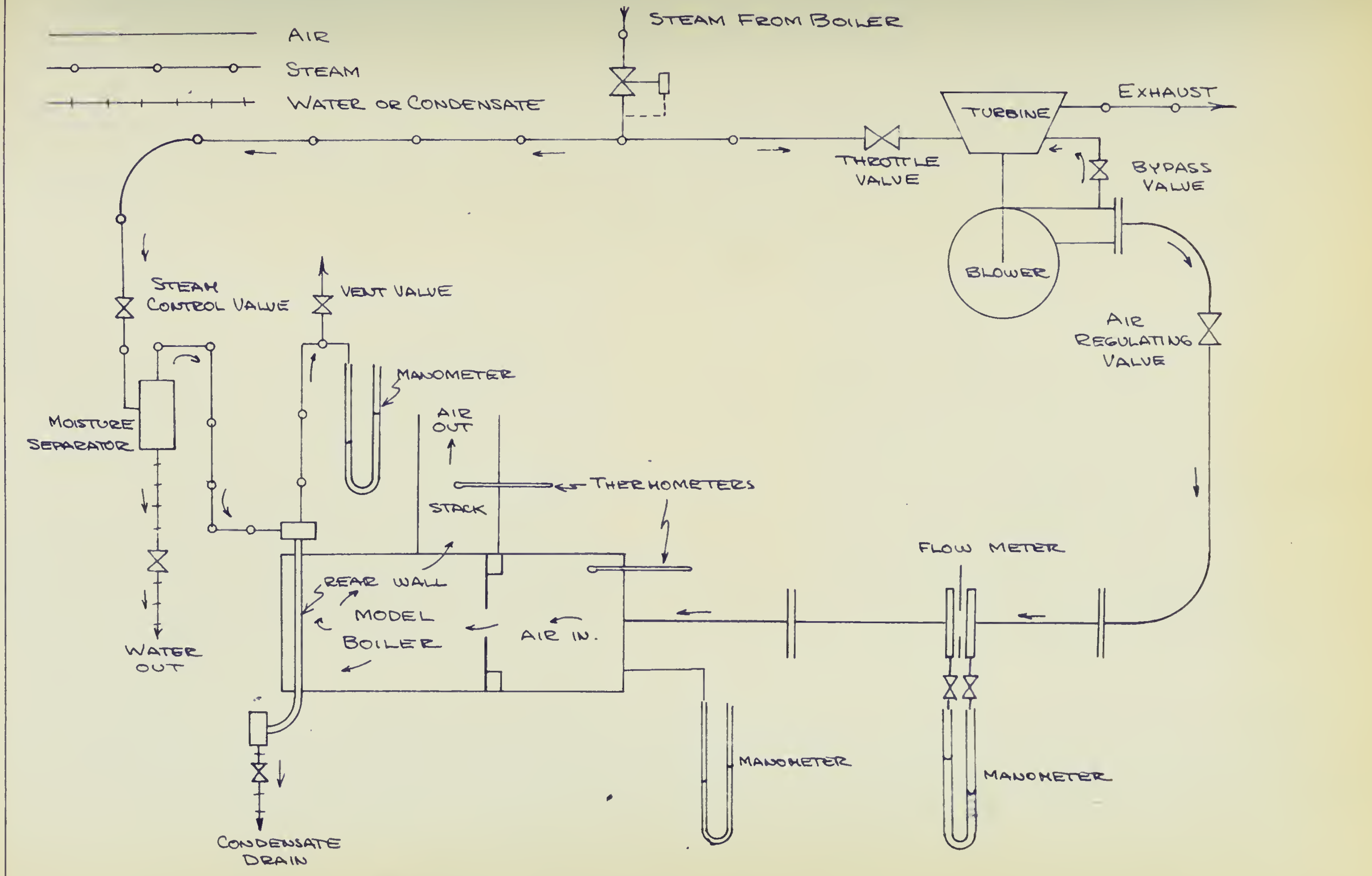
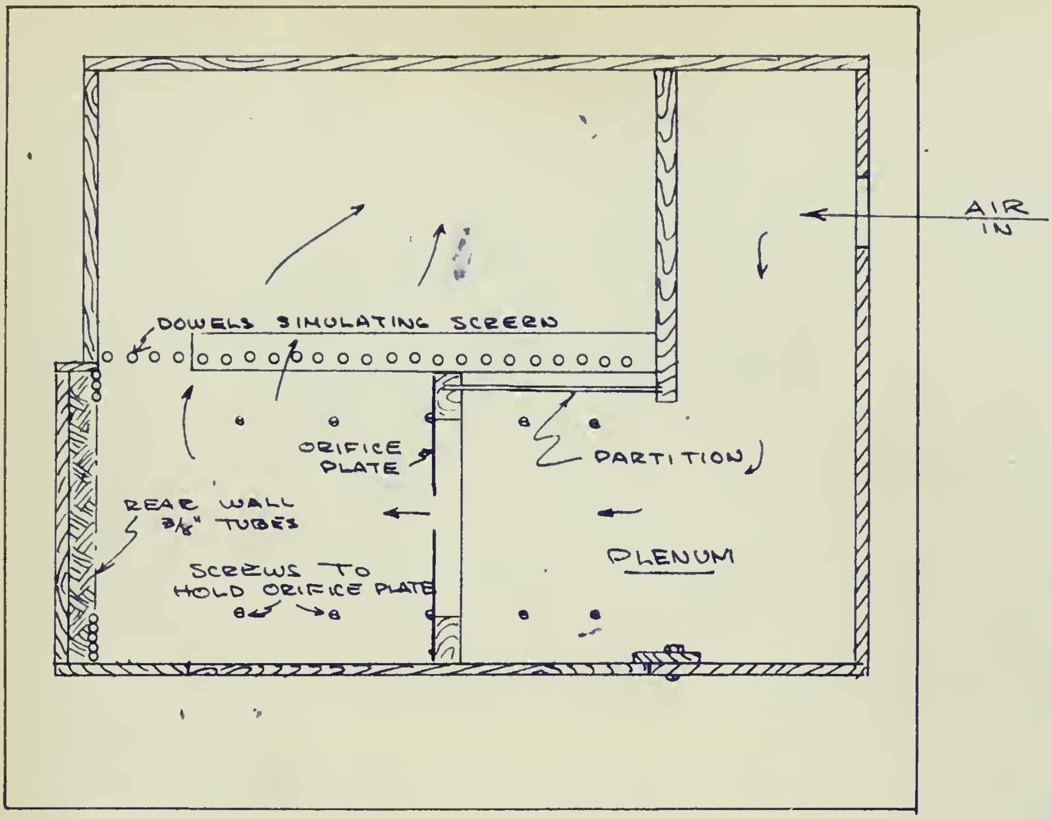


FIGURE A-1 ~ SCHEMATIC FLOW DIAGRAM



SECTION B-B

NOTE: ALL JOINTS MADE AIR TIGHT BY SCREWS, BOLTNG, GLUE, AND RUBBER GASKETS.

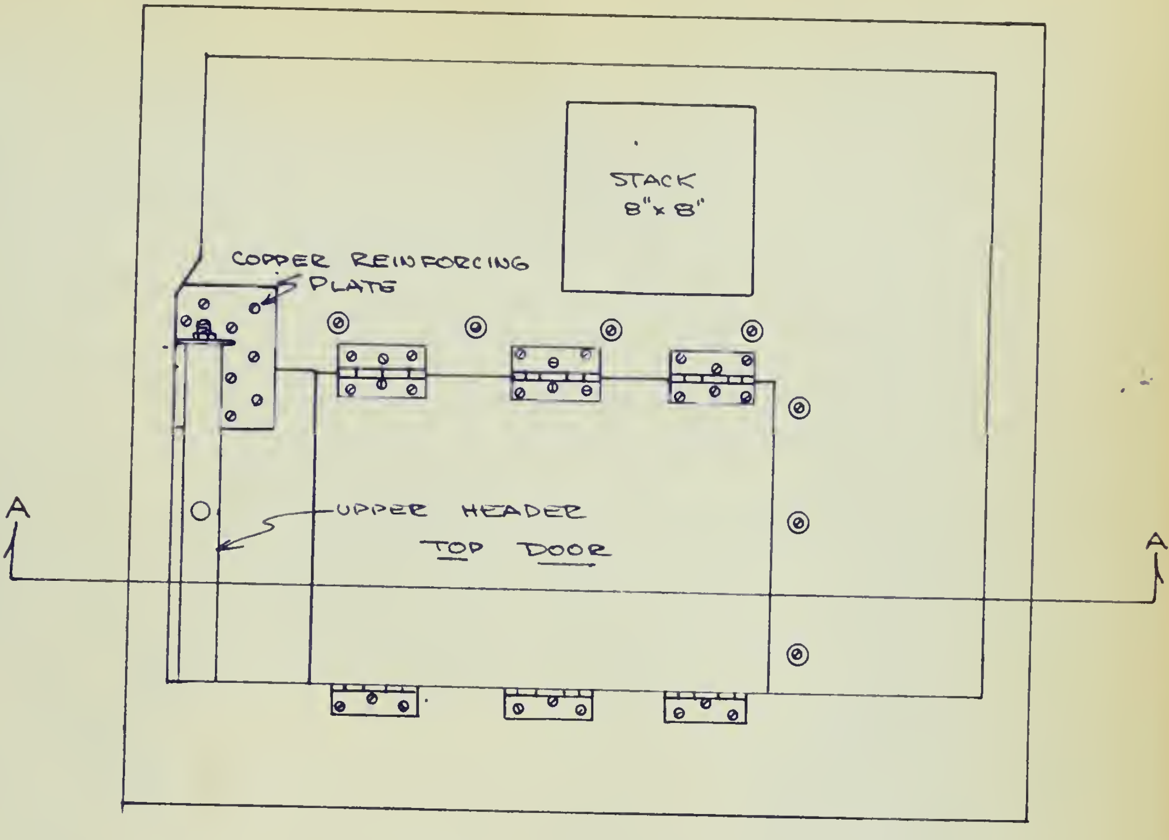
RUBBER TUBING USED TO MAKE THE AIR TIGHT JOINT BETWEEN THE DOORS AND THE ORIFICE PLATE HOLDER & THE DOORS.

SPLIT RUBBER TUBING WAS USED AT TOP AND BOTTOM OF PARTITIONS.

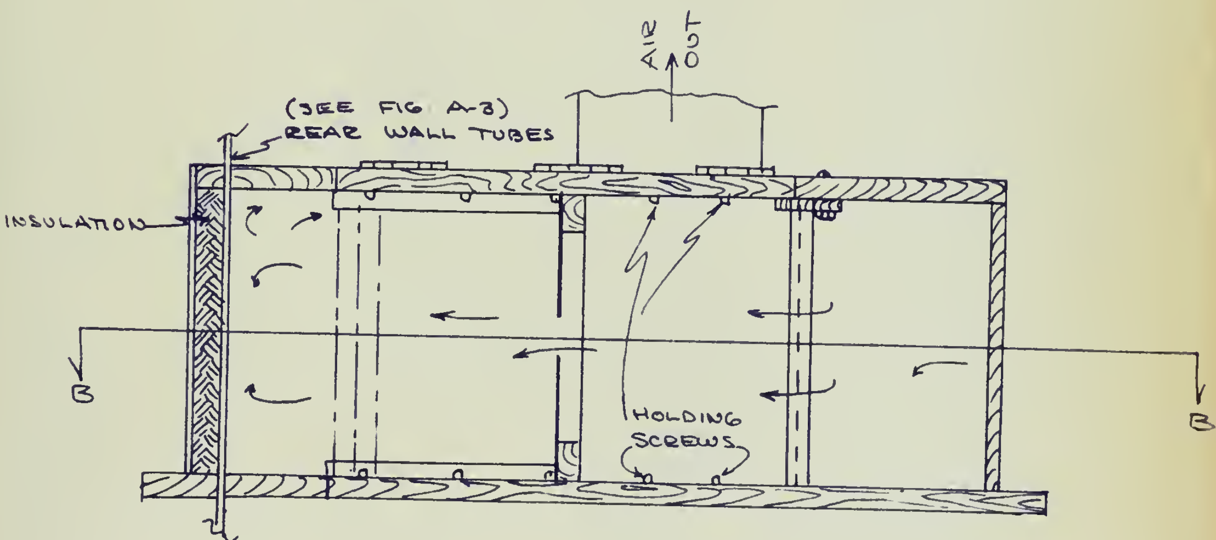
ALL CONSTRUCTION PLYWOOD EXCEPT PARTITIONS WERE MASONITE & ORIFICE PLATE WAS COPPER

SCALE $\frac{1}{8}$" = 1"

FIGURE A-2 ~ MODEL BOILER



PLAN VIEW



SECTION A-A

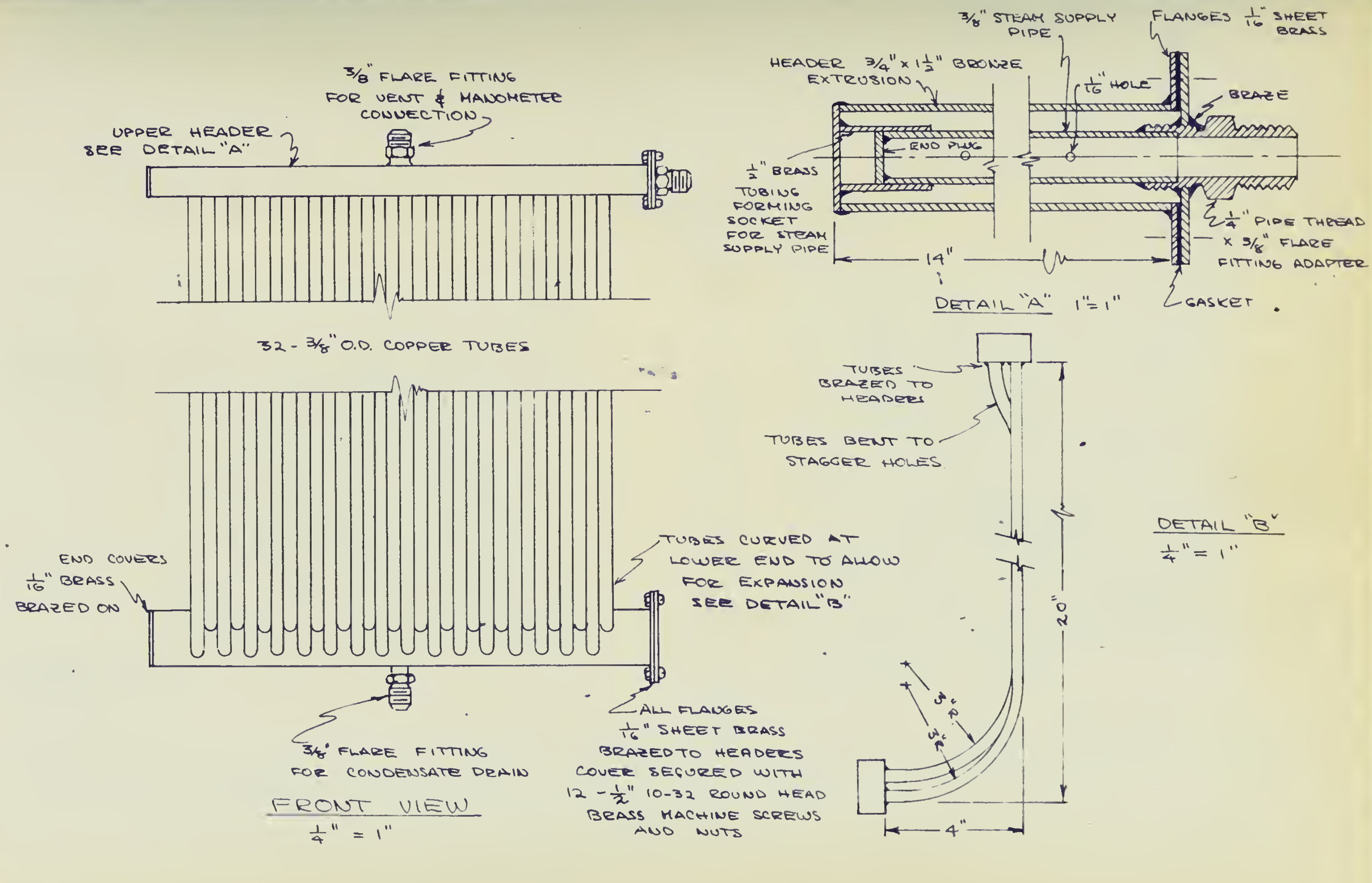
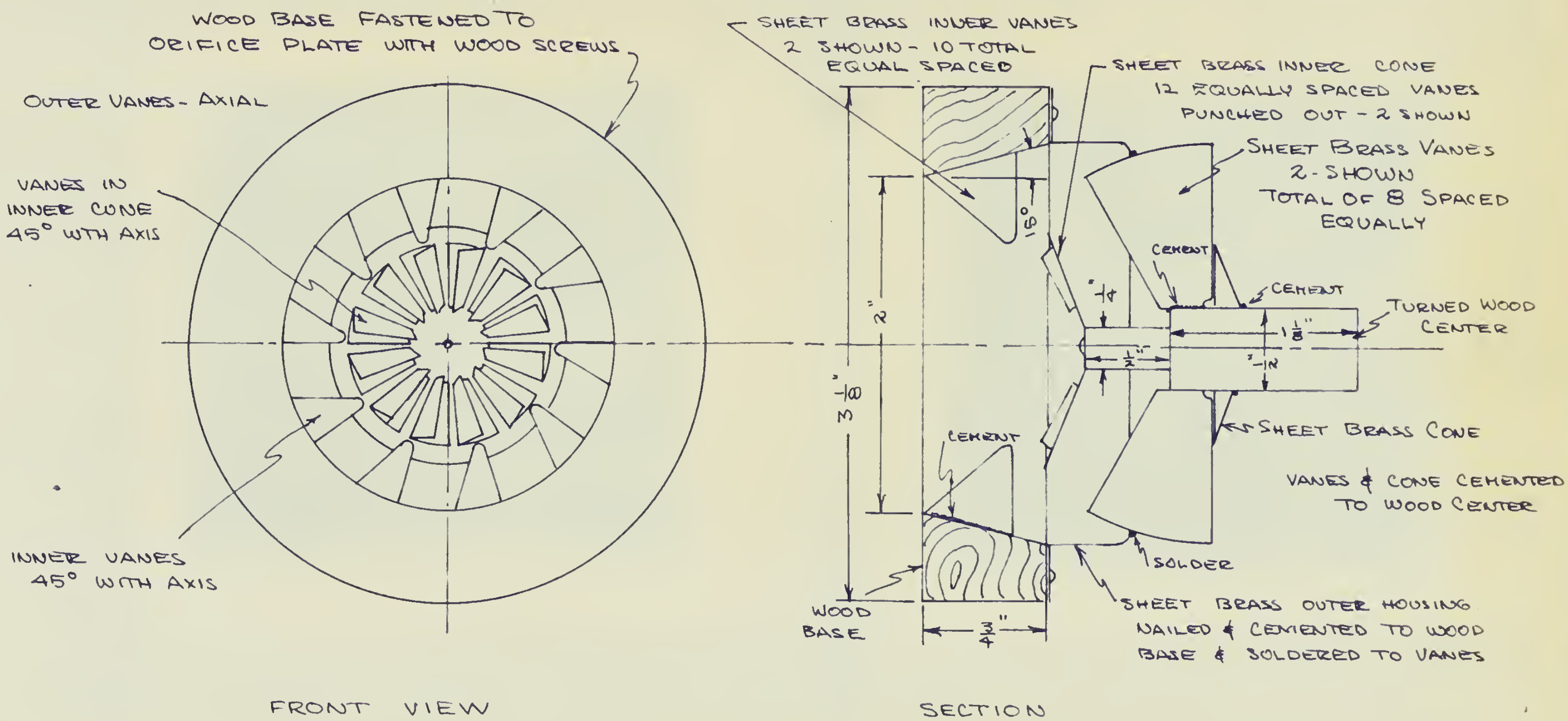


FIGURE A-3 DETAIL OF MODEL REAR WALL



~ FULL SCALE ~

FIGURE A-4 ~ DETAILS OF MODEL BURNER

Figure A-5 View of Model Boiler Taken from Rear Wall End

Figure A-6 View of Model Boiler Taken from Inlet End

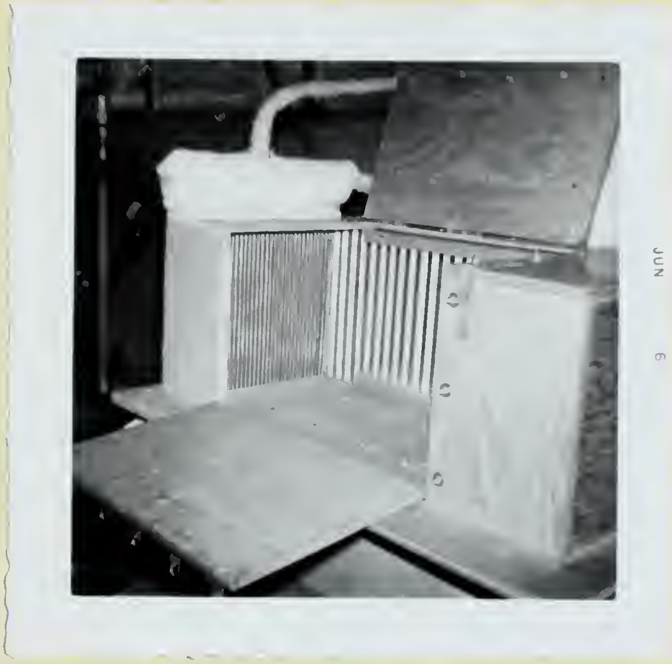


Figure A-7 View of Model Boiler With Doors Open

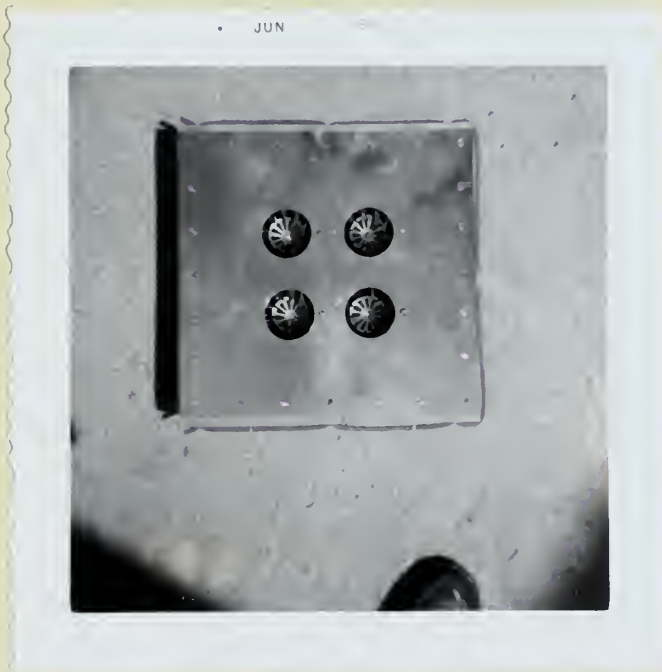


Figure A-8 Burner Orifice Plate with Four Burners

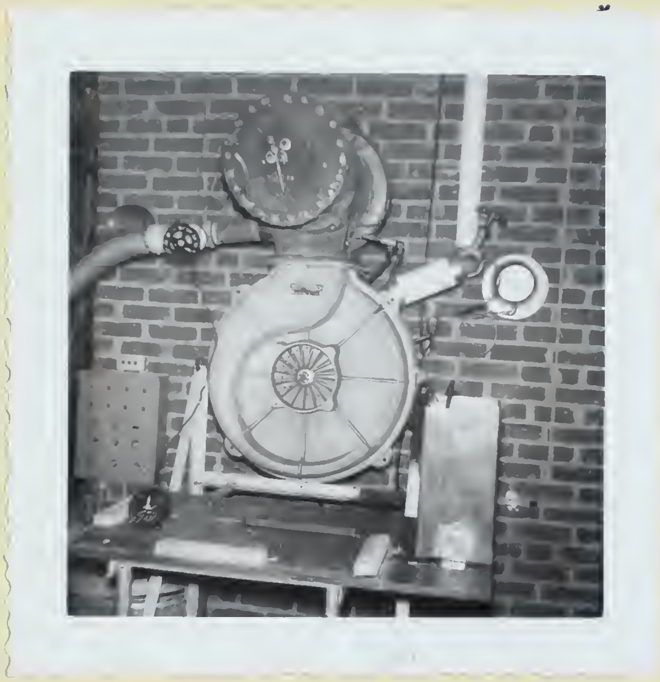


Figure A-9 Steam Driven Turbosupercharger as Used in the Tests

APPENDIX B

TEST PROCEDURE

The procedure for preparing the model and running a test is as follows:

1. While the steam generator was coming up to pressure, the model was made ready for the test. The desired orifice plate and partition necessary for a given depth were selected and assembled in the model with the orifice plate against the screws in the floor. After insuring that the split rubber tubing on the partition and the rubber tubing seals around the doors and orifice plate assembly were properly located, the doors were closed and tapped with a hammer to set the points on the orifice plate assembly into the wood. The trunk snaps were then closed, squeezing the rubber tubing and making an air tight seal.

2. At this point all the manometers were adjusted to zero and the two thermometers checked for identical readings.

3. When the steam generator was up to pressure, the turboblower was warmed up and the speed slowly increased to maximum speed. The bypass control, in the combustion chamber on the turbine, was closed and the air regulating valve opened wide (see Figure A-1). Steam was next cut into the rear wall; and the vent valve, water trap drain valve, and condensate drain valve adjusted to allow a wisp of steam to flow out. This insured that the rear wall was completely filled with steam and no condensate or air were trapped in it. The steam pressure

in the rear wall was adjusted with the needle valve to a positive pressure of one inch of mercury. This pressure was maintained throughout the testing. The apparatus was allowed to run at this maximum rate for about 20 to 30 minutes until it was completely warmed up.

4. During the above warm-up time, the barometric pressure was recorded as was the wet and dry bulb temperature which was taken with a sling psychrometer. These readings were also taken and recorded at the end of the test. The average were used to determine the specific humidity using the psychrometric charts in Ellenwood and Mackey(17).

5. After the apparatus was warmed up, the bypass was opened to the turbine and the weight flow of air adjusted by closing the air regulating valve. Originally the weight flow was adjusted by throttling the steam to the turbine, but this proved unsatisfactory as the blower tended to hunt. Therefore, in order to maintain a steady state, the turbine was run at top speed at all times and the weight flow of air regulated by bypassing the excess. This method of control proved quite satisfactory.

The steam pressure in the rear wall was then adjusted and the transfer of heat allowed to reach a steady state. This could be determined by observing when the inlet and outlet temperatures remained fairly constant.

6. When steady state was reached, the burner orifice and flow meter heads were recorded in inches of water. The first

temperature reading was then recorded, followed by the second and third at two minute intervals. The flow meter head was again checked, and if unchanged, the next weight flow would be tested. If a change in flow was noted, the run would be repeated.

7. After adjusting to the next weight flow, and while awaiting steady state, the average inlet and outlet temperature was calculated. Using this T_1 and T_2, ΔT through the model was recorded. The value of $\Delta T \sqrt{\Delta H_F}$ was then plotted against $\sqrt{\Delta H_F}$. This gave a good check on the consistency of the data from point to point since:

$$W_a \sim \sqrt{\Delta H_F}$$

But $Q = W_a C_p \Delta T$ and $h = \frac{Q}{A_p \Delta T_M}$

Therefore, $h = W_a \Delta T \frac{C_p}{A_p \Delta T_m}$

or since $\frac{C_p}{A_p \Delta T_m}$ is nearly constant, $h \sim \Delta T \sqrt{\Delta H_F}$

and since $N_{Nu} = \frac{hD}{k}$, $N_{Nu} \sim \Delta T \sqrt{\Delta H_F}$

Also $N_{Re} = \frac{GD}{\mu}$ and $G = \frac{W_a}{A_o}$

Therefore, $N_{Re} \sim \sqrt{\Delta H_F}$

Since N_{Nu} was assumed to be proportional to N_{Re} to some power, then on a log-log plot $\Delta T \sqrt{\Delta H_F}$ vs. $\sqrt{\Delta H_F}$ should plot as a straight line. This proved to be an excellent way of checking for points in error while still testing. A sample plot is shown in Figure B-1.

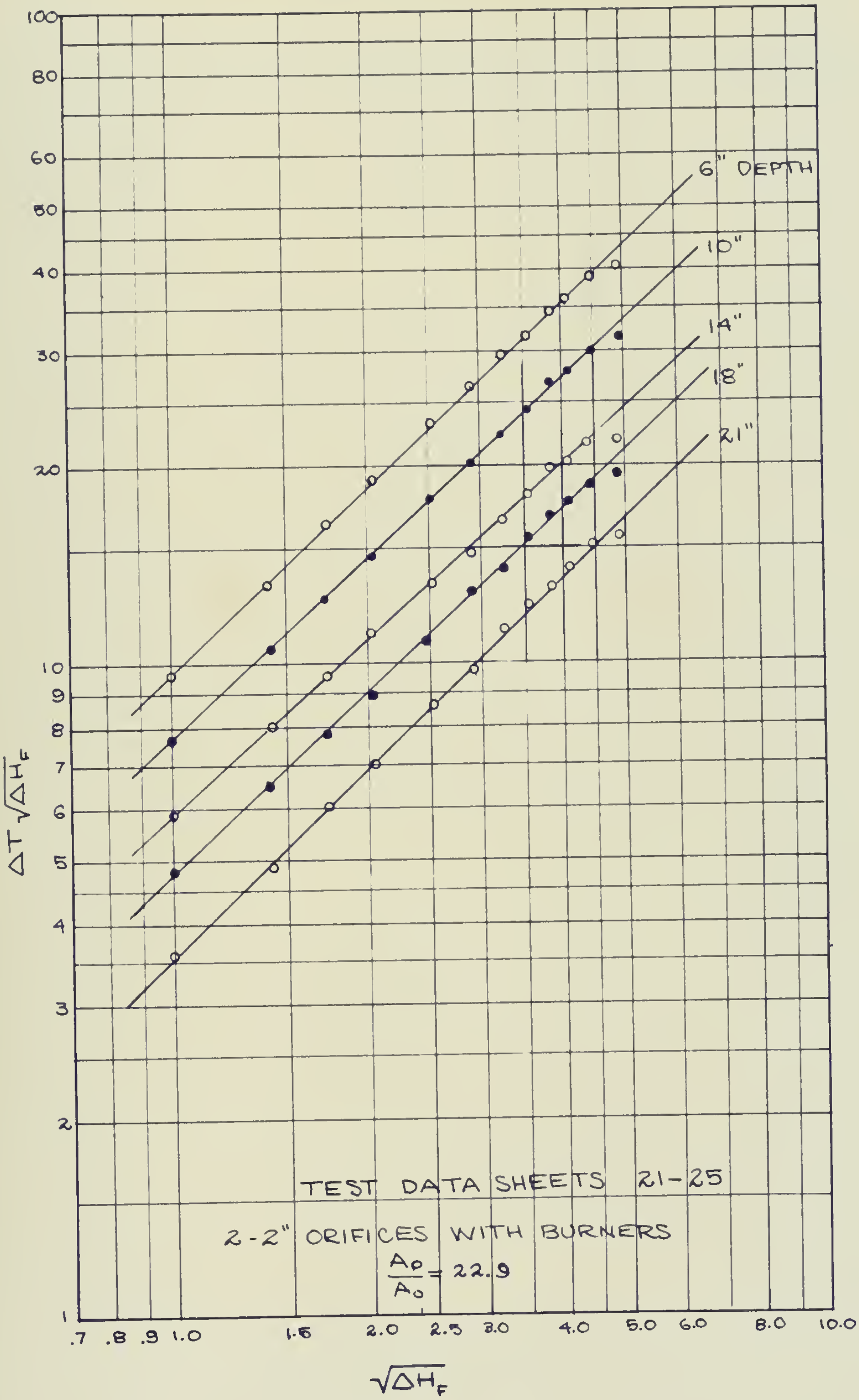


FIGURE B-1 ~ EXPERIMENTAL PLOTS OF $\Delta T\text{-}\sqrt{\Delta H_F}$ VS. $\sqrt{\Delta H_F}$

APPENDIX C

TEST DATA

The following pages contain the data as recorded in the actual tests:

APPENDIX C.

TEST DATA SHEET NUMBER 1

DATE 10-9-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	72.0 °F	75.6 °F	73.8 °F
DRY BULB TEMPERATURE	74.5 °F	79.0 °F	76.75 °F
BAROMETER	29.93 "Hg	29.91 "Hg	29.92 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. .121 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	12.90	20.8	3.59	T_1	36.90	36.60	36.80	36.77	8.23	14.80	53.1
				T_2	45.20	44.80	45.00	45.00			
2	10.10	17.6	3.18	T_1	36.75	36.55	36.80	36.70	8.91	16.05	51.0
				T_2	45.53	45.60	45.70	45.61			
3	6.30	11.6	2.51	T_1	37.05	37.12	37.20	37.12	9.58	17.25	43.3
				T_2	46.60	46.70	46.80	46.70			
4	3.05	6.8	1.75	T_1	37.20	37.25	37.35	37.32	10.47	18.82	32.9
				T_2	47.73	47.80	47.85	47.79			
5	1.45	4.0	1.20	T_1	37.20	37.10	37.15	37.15	11.20	20.16	24.3
				T_2	48.30	48.35	48.40	48.35			
6	14.00	22.0	3.74	T_1	39.10	39.12	39.20	39.14	8.68	15.61	58.4
				T_2	47.80	47.80	47.85	47.82			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 1-A

DATE 10-13-59

TANGENT TUBE MODEL W/ITHOUT BURNERS

1-2" ORIFICE(S), 6 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	58.5 °F	59.5 °F	59.0 °F
DRY BULB TEMPERATURE	69.1 °F	69.0 °F	69.05 °F
BAROMETER	29.98 "Hg	29.97 "Hg	29.975 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 59 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	14.70	23.0	3.83	T_1	35.05	35.15	35.20	35.13	9.75	17.57	67.1
				T_2	44.85	44.90	44.90	44.88			
2	11.50	18.50	3.39	T_1	34.70	34.52	34.50	34.57	9.02	16.23	55.0
				T_2	43.60	43.60	43.56	43.59			
3	7.00	12.6	2.65	T_1	34.80	34.90	35.00	34.90	10.51	18.92	50.1
				T_2	45.37	45.40	45.45	45.41			
4	5.20	9.7	2.28	T_1	34.30	34.35	34.40	34.35	10.27	18.50	42.2
				T_2	44.50	44.65	44.70	44.62			
5	2.00	4.4	1.414	T_1	34.10	34.05	34.00	34.05	11.48	20.65	29.2
				T_2	45.60	45.50	45.50	45.53			
6	11.45	18.5	3.39	T_1	34.80	34.80	34.70	34.77	10.15	18.28	61.8
				T_2	44.90	44.95	44.90	44.92			
7	9.50	16.0	3.08	T_1	34.55	34.68	34.70	34.64	10.29	18.52	57.1
				T_2	44.90	44.92	44.96	44.93			
8	3.50	7.3	1.87	T_1	35.00	35.00	34.95	34.98	10.87	19.58	36.6
				T_2	45.85	45.90	45.80	45.85			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 1-B

DATE 10-16-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.10 °F	57.60 °F	57.35 °F
DRY BULB TEMPERATURE	69.80 °F	70.00 °F	69.90 °F
BAROMETER	30.21 "Hg	30.21 "Hg	30.21 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 50 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	15.50	24.0	3.94	T_1	37.80	37.75	37.90	37.77	8.83	15.90	62.6
				T_2	46.60	46.50	46.70	46.60			
2	12.60	20.2	3.55	T_1	37.00	36.95	36.95	36.97	8.90	16.02	56.9
				T_2	45.90	45.85	45.85	45.87			
3	10.50	17.6	3.24	T_1	36.95	36.80	36.70	36.82	9.16	16.50	53.4
				T_2	46.05	46.00	45.90	45.98			
4	8.30	14.5	2.88	T_1	36.80	36.80	36.85	36.82	9.43	17.00	49.0
				T_2	46.20	46.25	46.30	46.25			
5	6.20	11.0	2.49	T_1	36.96	37.00	37.00	36.99	9.65	17.37	43.3
				T_2	46.62	46.65	46.65	46.64			
6	4.10	8.4	2.03	T_1	36.85	36.90	36.90	36.88	10.00	18.00	36.5
				T_2	46.85	46.90	46.90	46.88			
7	2.00	4.4	1.414	T_1	36.70	36.75	36.60	36.68	10.89	19.60	27.7
				T_2	47.60	47.60	47.50	47.57			
8	1.00	3.2	1.00	T_1	36.20	36.20	36.20	36.20	11.48	20.65	20.65
				T_2	47.65	47.70	47.70	47.68			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 2

DATE 9-29-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	75.9 °F	75.9 °F	75.9 °F
DRY BULB TEMPERATURE	83.5 °F	83.8 °F	83.65 °F
BAROMETER	30.20 "Hg.	30.19 "Hg.	30.195 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 122 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	41.60	41.96	42.15	41.90			
1	14.5	21.20	3.81	T_2	48.15	48.70	48.95	48.60	6.70	12.07	46.0
				T_1	42.25	42.30	42.30	42.28			
2	13.0	18.50	3.605	T_2	49.31	49.50	49.55	49.45	7.17	12.90	46.55
				T_1	41.30	41.30	41.26	41.29			
3	10.7	16.0	3.27	T_2	49.20	49.30	49.30	49.27	7.98	14.38	47.00
				T_1	41.50	41.60	41.62	41.57			
4	9.4	13.65	3.065	T_2	49.68	49.78	49.80	49.75	8.18	14.72	45.25
				T_1	41.80	41.90	42.00	41.90			
5	7.90	11.55	2.81	T_2	50.20	50.20	50.21	50.20	8.30	14.93	41.95
				T_1	42.00	42.00	42.08	42.03			
6	6.10	8.70	2.47	T_2	50.40	50.40	50.43	50.41	8.38	15.10	37.25
				T_1	42.03	42.25	42.40	42.23			
7	5.00	7.57	2.236	T_2	50.60	50.71	50.87	50.73	8.50	15.30	34.2
				T_1	42.30	42.39	42.40	42.36			
8	3.65	4.84	1.91	T_2	51.00	51.09	51.10	51.06	8.70	15.68	29.95
				T_1	42.33	42.28	42.25	42.29			
9	2.10	2.25	1.45	T_2	51.25	51.35	51.40	51.33	9.04	16.28	23.60
				T_1	41.90	41.83	41.75	41.83			
10	1.0	1.0	1.0	T_2	51.30	51.15	51.10	51.18	9.35	16.83	16.83
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 2 - A

DATE 10-9-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 10 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	74.7 °F	74.9 °F	74.8 °F
DRY BULB TEMPERATURE	79.2 °F	79.6 °F	79.4 °F
BAROMETER	29.90 "Hg.	29.90 "Hg.	29.9 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 122 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	40.40	40.55	40.60	40.52			
1	14.00	22.1	3.745	T_2	47.20	47.35	47.40	47.32	6.80	12.24	45.9
				T_1	40.30	40.35	40.40	40.35			
2	10.30	17.7	3.21	T_2	47.60	47.65	47.65	47.64	7.29	13.11	42.1
				T_1	40.60	40.60	40.60	40.60			
3	8.05	14.5	2.84	T_2	48.05	48.10	48.13	48.09	7.49	13.48	38.25
				T_1	46.75	40.80	40.95	40.83			
4	5.10	9.6	2.26	T_2	48.70	48.80	48.90	48.80	7.97	14.35	32.40
				T_1	40.85	40.90	40.95	40.90			
5	3.00	6.78	1.732	T_2	49.35	49.43	49.45	49.41	8.51	15.32	26.6
				T_1	40.70	40.65	40.66	40.67			
6	1.30	1.44	1.14	T_2	49.65	49.70	49.68	49.68	9.01	16.22	18.5
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 2-B

DATE 10-21-59

TANGENT TUBE MODEL Without BURNERS

1-2" ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	52.3 °F ,	56.5 °F ,	54.4 °F
DRY BULB TEMPERATURE	63.5 °F ,	67.1 °F ,	65.3 °F
BAROMETER	30.45 "Hg. ,	30.45 "Hg. ,	30.45 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE , SPEC. HUM. 46 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T \sqrt{\Delta H_F}$
				T_1	33.50	33.57	33.50	33.52			
1	14.80	23.0	3.85	T_2	41.15	41.20	41.20	41.18	7.66	13.80	53.10
				T_1	33.00	33.20	33.10	33.10			
2	13.00	19.4	3.605	T_2	40.92	41.10	41.05	41.02	7.92	14.26	51.40
				T_1	32.90	32.82	32.90	32.87			
3	10.50	16.8	3.345	T_2	41.10	41.00	41.02	41.04	8.17	14.71	49.20
				T_1	32.80	32.77	32.80	32.79			
4	8.40	13.7	2.90	T_2	41.30	41.30	41.30	41.30	8.51	15.32	44.45
				T_1	33.05	33.10	33.10	33.08			
5	6.25	10.9	2.50	T_2	41.80	41.90	41.92	41.87	8.79	15.81	39.55
				T_1	33.09	33.10	33.05	33.08			
6	4.20	8.4	2.05	T_2	42.22	42.40	42.50	42.37	9.29	16.72	34.25
				T_1	32.90	32.90	32.80	32.87			
7	1.90	4.0	1.379	T_2	42.95	43.00	43.00	42.98	10.11	18.21	25.10
				T_1	32.38	32.30	32.30	32.33			
8	1.00	3.25	1.00	T_2	43.12	43.10	43.05	43.09	10.76	19.38	19.38
				T_1	33.80	33.80	33.86	33.82			
9	15.20	23.50	3.90	T_2	42.05	42.05	42.10	42.07	8.25	14.85	57.5
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 3

DATE 9-30-59

TANGENT TUBE MODEL *without* BURNERS

1-2" ORIFICE(S), 14 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	72.9 °F	79.5 °F	76.2 °F
DRY BULB TEMPERATURE	80.2 °F	84.3 °F	82.2 °F
BAROMETER	30.12 "Hg	30.12 "Hg	30.12 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 127 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	14.50	19.80	3.81	T_1	41.50	41.70	41.65	41.62	5.91	10.65	40.6
				T_2	47.20	47.70	47.70	47.53			
2	13.15	18.0	3.625	T_1	41.30	41.40	41.60	41.43	6.49	11.86	43.0
				T_2	47.80	47.90	48.06	47.92			
3	11.10	16.0	3.33	T_1	41.30	41.40	41.30	41.33	6.92	12.46	41.5
				T_2	48.10	48.20	48.15	48.15			
4	10.25	14.4	3.20	T_1	41.30	41.20	41.30	41.27	6.96	12.52	40.01
				T_2	48.20	48.20	48.30	48.23			
5	9.0	12.25	3.00	T_1	41.38	41.50	41.48	41.45	7.03	12.66	37.95
				T_2	48.41	48.50	48.52	48.48			
6	7.50	10.25	2.74	T_1	41.50	41.70	41.90	41.70	7.15	12.88	35.30
				T_2	48.70	48.85	49.00	48.85			
7	5.55	7.85	2.355	T_1	41.90	42.03	42.10	42.01	7.22	13.00	30.60
				T_2	49.20	49.20	49.30	49.23			
8	4.20	5.30	2.05	T_1	42.30	42.30	42.32	42.31	7.21	12.99	26.60
				T_2	49.50	49.50	49.55	49.52			
9	3.10	4.00	1.76	T_1	42.30	42.40	42.41	42.37	7.32	13.18	23.2
				T_2	49.65	49.70	49.73	49.69			
10	1.0	1.0	1.00	T_1	42.00	41.90	41.80	41.90	7.66	13.80	13.8
				T_2	49.65	49.55	49.48	49.56			
11	15.50	20.7	3.94	T_1	43.58	43.58	43.70	43.62	6.64	11.94	47.1
				T_2	50.20	50.22	50.35	50.26			
12	13.25	18.10	3.64	T_1	43.80	43.60	43.55	43.65	6.77	12.20	44.4
				T_2	50.50	50.40	50.35	50.42			

APPENDIX C.

TEST DATA SHEET NUMBER 3-A

DATE 10-21-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 14 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.5 °F	55.4 °F	56.0 °F
DRY BULB TEMPERATURE	67.1 °F	68.2 °F	67.6 °F
BAROMETER	30.45 "Hg.	30.45 "Hg.	30.45 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 48 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	16.25	23.0	4.03	T_1	35.00	34.95	35.00	34.98	7.20	12.97	52.2
				T_2	42.20	42.15	42.20	42.18			
2	13.90	20.3	3.73	T_1	34.55	34.50	34.28	34.44	7.51	13.52	50.5
				T_2	42.03	42.00	41.82	41.95			
3	11.90	17.7	3.45	T_1	34.62	34.58	34.56	34.58	7.60	13.69	47.2
				T_2	42.20	42.18	42.18	42.18			
4	9.70	14.5	3.11	T_1	34.60	34.56	34.48	34.55	7.62	13.71	42.6
				T_2	42.22	42.17	42.12	42.17			
5	7.95	12.2	2.82	T_1	34.40	34.40	34.45	34.42	7.78	14.02	39.5
				T_2	42.20	42.20	42.20	42.20			
6	6.25	9.6	2.50	T_1	34.43	34.60	34.65	34.56	7.82	14.08	35.2
				T_2	42.30	42.40	42.45	42.38			
7	4.00	6.3	2.00	T_1	34.60	34.75	34.65	34.67	7.86	14.18	28.4
				T_2	42.45	42.60	42.55	42.53			
8	1.90	4.0	1.378	T_1	34.31	34.40	34.40	34.37	8.41	15.15	20.88
				T_2	42.75	42.80	42.80	42.78			
9	1.00	3.0	1.00	T_1	34.10	33.95	34.00	34.02	8.58	15.44	15.45
				T_2	42.65	42.60	42.55	42.60			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 4

DATE 10-6-59

TANGENT TUBE MODEL Without BURNERS

1-2" ORIFICE(S), 18 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	78.4 °F	75.2 °F	76.8 °F
DRY BULB TEMPERATURE	87.0 °F	84.9 °F	86.0 °F
BAROMETER	29.94 "Hg	29.94 "Hg	29.94 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 124 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F "H_2O	ΔH_B "H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	45.10	44.90	44.65	44.88			
1	13.1	19.1	3.62	T_2	49.80	49.80	49.80	49.80	4.92	8.85	32.0
				T_1	44.20	44.70	44.80	44.57			
2	11.50	16.8	3.39	T_2	49.80	50.10	50.25	50.05	5.48	9.86	33.4
				T_1	45.28	45.55	45.20	45.34			
3	9.25	14.5	3.04	T_2	50.80	51.10	51.00	50.97	5.63	10.13	30.8
				T_1	44.90	44.63	44.60	44.71			
4	6.45	9.0	2.54	T_2	50.85	50.70	50.70	50.75	6.04	10.87	27.6
				T_1	44.20	44.00	44.15	44.12			
5	4.60	7.3	2.144	T_2	50.50	50.35	50.40	50.42	6.30	11.35	24.35
				T_1	44.30	44.40	44.40	44.37			
6	3.10	4.0	1.76	T_2	50.70	50.65	50.68	50.68	6.31	11.37	20.00
				T_1	44.30	44.25	44.20	44.25			
7	1.90	2.25	1.377	T_2	50.75	50.75	50.70	50.74	6.49	11.69	16.1
				T_1	43.90	43.80	43.80	43.83			
8	1.0	1.0	1.0	T_2	50.60	50.55	50.50	50.55	6.72	12.10	12.1
				T_1	45.20	45.10	45.10	45.13			
9	14.70	21.1	3.83	T_2	50.90	50.85	50.85	50.87	5.74	10.32	39.6
				T_1	45.25	45.30	45.40	45.32			
10	11.85	18.0	3.44	T_2	51.10	51.15	50.20	51.15	5.83	10.50	36.10
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 4-A

DATE 10-16-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 18 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	55.2 °F	56.5 °F	55.85 °F
DRY BULB TEMPERATURE	65.5 °F	67.1 °F	66.30 °F
BAROMETER	30.20 "Hg	30.21 "Hg	30.205 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE , SPEC. HUM. 50 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T \sqrt{\Delta H_F}$
1	15.25	24.5	3.91	T_1	36.30	36.45	36.60	36.45	6.47	11.65	45.5
				T_2	42.80	42.90	43.05	42.92			
2	11.90	18.9	3.45	T_1	34.00	34.00	34.10	34.03	6.43	11.59	40.0
				T_2	40.45	40.43	40.50	40.46			
3	10.05	16.0	3.17	T_1	34.05	34.10	34.15	34.10	6.60	11.89	37.7
				T_2	40.65	40.70	40.75	40.70			
4	8.25	12.25	2.87	T_1	34.30	34.40	34.60	34.43	6.74	12.13	34.8
				T_2	41.00	41.20	41.30	41.17			
5	6.00	10.25	2.445	T_1	34.45	34.50	34.60	34.52	7.00	12.60	30.8
				T_2	41.45	41.50	41.60	41.52			
6	3.95	7.85	1.986	T_1	34.45	34.50	34.60	34.52	7.24	13.02	25.85
				T_2	41.70	41.72	41.85	41.76			
7	2.05	4.85	1.43	T_1	34.60	34.70	34.75	34.68	7.42	13.36	19.10
				T_2	42.05	42.10	42.15	42.10			
8	1.00	3.25	1.00	T_1	34.55	34.51	34.53	34.53	7.78	14.00	14.00
				T_2	42.30	42.30	42.32	42.31			
9	12.80	20.3	3.58	T_1	35.78	35.80	35.85	35.81	6.77	12.18	43.6
				T_2	42.60	42.56	42.60	42.58			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 5

DATE 10-6-59

TANGENT TUBE MODEL Without BURNERS

1-2" ORIFICE(S), 21" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	74.0 °F	78.4 °F	76.2 °F
DRY BULB TEMPERATURE	83.5 °F	87.0 °F	85.25 °F
BAROMETER	29.95 "Hg.	29.94 "Hg.	29.945 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 122 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	13.80	19.40	3.715	T_1	40.60	40.70	41.00	40.77	4.61	8.30	30.8
				T_2	45.15	45.30	45.70	45.38			
2	12.25	16.80	3.50	T_1	41.40	41.55	41.80	41.58	5.03	9.05	31.7
				T_2	46.30	46.60	46.83	46.61			
3	9.95	14.50	3.155	T_1	42.00	42.25	42.50	42.25	5.20	9.36	29.55
				T_2	47.20	47.45	47.70	47.45			
4	8.50	12.25	2.92	T_1	42.70	42.95	43.00	42.88	5.22	9.40	28.0
				T_2	47.95	48.15	48.20	48.10			
5	6.60	9.0	2.57	T_1	43.10	43.40	43.50	43.33	5.32	9.57	24.6
				T_2	48.46	48.70	48.80	48.65			
6	4.25	5.75	2.06	T_1	43.50	43.60	43.60	43.57	5.40	9.72	20
				T_2	48.90	49.05	49.00	48.97			
7	3.20	4.40	1.79	T_1	43.60	43.66	43.70	43.65	5.44	9.79	17.5
				T_2	49.05	49.10	49.11	49.09			
8	1.85	2.25	1.36	T_1	43.50	43.40	43.40	43.47	5.60	10.09	13.7
				T_2	49.10	49.05	49.05	49.07			
9	1.0	1.0	1.0	T_1	43.20	43.20	43.25	43.22	5.77	10.40	10.4
				T_2	49.00	48.97	49.00	48.99			
10	15.5	22.5	3.94	T_1	46.40	46.30	46.30	46.33	4.77	8.59	33.8
				T_2	51.00	51.10	51.20	51.10			
11	12.80	18.50	3.58	T_1	46.10	46.50	46.45	46.35	5.09	9.16	32.8
				T_2	51.30	51.50	51.50	51.44			
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 5-B

DATE 10-16-59

TANGENT TUBE MODEL WITHOUT BURNERS

1-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.5 °F	57.10 °F	56.80 °F
DRY BULB TEMPERATURE	67.1 °F	69.8 °F	68.45 °F
BAROMETER	30.21 "Hg.	30.21 "Hg.	30.21 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 50 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	15.35	24.5	3.915	T_1	36.00	36.15	36.25	36.13	6.00	10.80	42.3
				T_2	42.00	42.15	42.23	42.13			
2	13.25	20.3	3.64	T_1	36.15	36.00	35.90	36.02	6.24	11.23	40.9
				T_2	42.33	42.25	42.20	42.26			
3	10.70	17.7	3.27	T_1	35.90	35.90	35.90	35.90	6.41	11.56	37.8
				T_2	42.30	42.30	42.37	42.31			
4	8.35	15.1	2.89	T_1	35.95	35.95	36.00	35.97	6.62	11.91	34.4
				T_2	42.60	42.56	42.60	42.59			
5	6.30	10.6	2.51	T_1	36.00	36.08	36.15	36.08	6.61	11.90	29.9
				T_2	42.62	42.75	42.70	42.69			
6	4.15	8.0	2.05	T_1	36.30	36.30	36.33	36.31	6.72	12.10	24.7
				T_2	43.05	43.00	43.05	43.03			
7	2.05	4.5	1.43	T_1	36.30	36.28	36.20	36.26	6.86	12.35	19.1
				T_2	43.15	43.10	43.10	43.12			
8	1.00	3.25	1.00	T_1	36.00	35.90	35.85	35.92	7.02	12.63	12.63
				T_2	43.00	42.92	42.90	42.94			

APPENDIX C

TEST DATA SHEET NUMBER 5-B

DATE 3-10-60

TANGENT TUBE MODEL Without BURNERS

1-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	52.0 °F	52.0 °F	52.0 °F
DRY BULB TEMPERATURE	62.0 °F	62.0 °F	62.0 °F
BAROMETER	30.06 "Hg	30.02 "Hg	30.04 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE , SPEC. HUM. 42 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	32.40	32.50	32.65	32.52			
1	15.20	22	3.90	T_2	38.10	38.20	38.30	38.20	5.68	10.22	39.9
				T_1	32.60	32.57	32.50	32.56			
2	12.35	18.5	3.52	T_2	38.55	38.55	38.50	38.53	5.97	10.75	37.8
				T_1	32.35	32.30	32.30	32.32			
3	10.50	16.0	3.24	T_2	38.55	38.50	38.50	38.52	6.20	11.18	36.2
				T_1	32.37	32.40	32.35	32.37			
4	8.40	13.0	2.90	T_2	38.67	38.70	38.65	38.67	6.30	11.34	32.9
				T_1	32.28	32.25	32.30	32.28			
5	6.35	9.7	2.52	T_2	38.80	38.80	38.83	38.81	6.53	11.76	29.6
				T_1	32.20	32.23	32.20	32.21			
6	4.20	6.7	2.05	T_2	38.90	38.97	38.95	38.94	6.73	12.12	24.8
				T_1	32.00	31.90	31.80	31.90			
7	3.00	4.4	1.732	T_2	38.90	38.90	38.87	38.89	6.99	12.58	21.8
				T_1	31.50	31.40	31.35	31.42			
8	2.00	3.6	1.414	T_2	38.75	38.70	38.65	38.70	7.28	13.10	18.52
				T_1	30.85	30.75	30.70	30.77			
9	1.00	2.0	1.00	T_2	38.40	38.40	38.40	38.40	7.63	13.74	13.74
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 6

DATE 10-27-59

TANGENT TUBE MODEL WITH BURNERS

1-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	59.8 °F	61.6 °F	60.7 °F
DRY BULB TEMPERATURE	66.9 °F	68.7 °F	67.8 °F
BAROMETER	29.64 "Hg	29.65 "Hg	29.645 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 68 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	36.10	36.30	36.25	36.22			
1	13.00	28.00	3.605	T_2	43.10	43.30	43.30	43.23	7.01	12.62	45.5
				T_1	33.75	33.50	33.40	33.55			
2	10.50	23.00	3.24	T_2	41.00	40.90	40.80	40.90	7.35	13.24	42.9
				T_1	33.30	33.35	33.35	33.33			
3	8.40	18.9	2.90	T_2	40.95	41.00	41.00	40.98	7.65	13.78	39.9
				T_1	33.42	33.40	33.51	33.44			
4	6.35	15.2	2.52	T_2	41.30	41.35	41.40	41.35	7.91	14.25	35.9
				T_1	33.50	33.65	33.95	33.80			
5	4.20	10.3	2.05	T_2	41.75	41.85	42.08	41.89	8.09	14.56	29.8
				T_1	33.80	33.90	34.00	33.90			
6	2.00	5.75	1.414	T_2	42.40	42.50	42.60	42.50	8.60	15.50	21.9
				T_1	33.90	33.85	33.80	33.85			
7	1.00	4.00	1.00	T_2	42.85	42.90	42.85	42.88	9.03	16.28	16.28
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER *6-A*

DATE *11-20-59*

TANGENT TUBE MODEL *with* BURNERS

1-2" ORIFICE(S), *6 "* FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	*54.0* °F	*54.0* °F	*54.00* °F
DRY BULB TEMPERATURE	*64.5* °F	*65.0* °F	*64.75* °F
BAROMETER	*30.24* "Hg	*30.24* "Hg	*30.24* "Hg

REAR WALL STEAM PRESSURE *1* "Hg GAGE, SPEC. HUM. *45* GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	$\dot{\Delta H}_B$ " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	32.00	32.05	32.10	32.05			
1	13.20	27.5	3.64	T_2	39.10	39.20	39.20	39.17	7.12	12.82	46.6
				T_1	32.05	32.30	32.40	32.25			
2	11.0	23.5	3.32	T_2	39.50	39.70	39.85	39.68	7.43	13.38	44.4
				T_1	32.70	32.90	33.15	32.92			
3	8.90	18.5	2.985	T_2	40.20	40.40	40.60	40.40	7.48	13.49	40.25
				T_1	33.20	33.40	33.45	33.35			
4	6.30	15.2	2.51	T_2	40.90	41.00	40.10	41.00	7.65	13.78	34.6
				T_1	33.00	33.00	33.10	33.03			
5	3.00	7.9	1.732	T_2	41.10	41.15	31.30	31.18	8.15	14.68	25.45
				T_1	33.00	33.00	33.05	33.02			
6	1.50	4.0	1.225	T_2	41.40	41.40	41.45	41.42	8.40	15.13	18.51
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 2

DATE 10-27-59

TANGENT TUBE MODEL WITH BURNERS

1-2 ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	61.6 °F	62.5 °F	62.05 °F
DRY BULB TEMPERATURE	68.7 °F	69.3 °F	69.0 °F
BAROMETER	29.65 "Hg	29.65 "Hg	29.65 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 72 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	13.40	28.6	3.66	T_1	35.80	35.88	35.90	35.86	6.14	11.06	40.5
				T_2	42.00	42.00	42.00	42.00			
2	11.60	25.0	3.406	T_1	35.20	35.12	35.04	35.12	6.40	11.52	39.3
				T_2	41.60	41.50	41.45	41.52			
3	10.20	21.6	3.195	T_1	34.87	34.80	35.00	34.89	6.46	11.62	37.1
				T_2	41.35	41.30	41.40	41.35			
4	8.35	18.9	2.89	T_1	35.05	35.00	35.00	35.02	6.56	11.81	34.15
				T_2	41.60	41.55	41.58	41.58			
5	6.35	15.2	252	T_1	34.90	34.95	35.00	34.95	6.67	12.00	30.2
				T_2	41.62	41.60	41.65	41.62			
6	4.30	10.2	2.07	T_1	34.90	35.10	35.20	35.07	6.78	12.20	25.25
				T_2	41.80	41.85	41.90	41.85			
7	2.00	5.8	1.414	T_1	34.90	34.95	34.93	34.93	7.05	12.70	17.95
				T_2	42.00	42.00	41.95	41.98			
8	1.00	4.0	1.00	T_1	34.60	34.50	34.30	34.47	7.41	13.36	13.36
				T_2	41.95	41.90	41.80	41.88			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 7-A

DATE 11-20-59

TANGENT TUBE MODEL With BURNERS

1-2" ORIFICE(S), 10 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.0 °F	54.5 °F	54.25 °F
DRY BULB TEMPERATURE	65.0 °F	64.8 °F	64.9 °F
BAROMETER	30.24 "Hg	30.24 "Hg	30.24 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE , SPEC. HUM. 46 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T \sqrt{\Delta H_F}$
				T_1	34.95	35.00	34.90	34.95			
1	15.10	30.0	3.89	T_2	40.60	40.65	40.60	40.62	5.67	10.21	39.7
				T_1	34.60	34.57	34.45	34.54			
2	12.60	26.0	3.55	T_2	40.50	40.50	40.40	40.47	5.93	10.69	37.9
				T_1	34.20	34.15	34.18	34.18			
3	10.45	21.5	3.23	T_2	40.35	40.30	40.30	40.32	6.14	11.05	35.7
				T_1	33.20	33.40	33.45	33.35			
4	8.30	17.7	2.78	T_2	39.50	39.60	39.65	39.58	6.23	11.22	31.2
				T_1	34.00	34.10	34.00	34.03			
5	6.20	14.40	2.49	T_2	40.25	40.30	40.20	40.25	6.22	11.20	27.9
				T_1	33.30	33.30	33.40	33.37			
6	4.00	9.1	2.0	T_2	39.80	39.85	39.90	39.85	64.8	11.68	23.36
				T_1	33.80	33.80	33.90	33.83			
7	2.00	5.3	1.414	T_2	40.40	40.35	40.45	40.40	6.57	11.83	16.73
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 8

DATE 10-30-59

TANGENT TUBE MODEL WITH BURNERS

1-2" ORIFICE(S), 14 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.1 °F	57.5 °F	57.3 °F
DRY BULB TEMPERATURE	67.5 °F	68.5 °F	68.0 °F
BAROMETER	30.48 "Hg.	30.50 "Hg.	30.40 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 53 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	35.68	35.60	35.70	35.66			
1	13.10	28.50	3.62	T_2	40.55	40.50	40.55	40.53	4.87	8.77	31.75
				T_1	34.40	34.40	34.40	34.40			
2	10.75	24.00	3.28	T_2	39.40	39.40	39.40	39.40	5.00	9.00	29.55
				T_1	34.60	34.60	34.60	34.60			
3	8.55	19.80	2.925	T_2	39.70	39.70	39.70	39.70	5.10	9.18	26.87
				T_1	34.60	34.60	34.70	34.63			
4	6.40	16.00	2.53	T_2	39.80	39.85	39.90	39.85	5.22	9.40	23.80
				T_1	34.60	34.78	34.80	34.73			
5	4.30	10.90	2.075	T_2	40.00	40.10	40.10	40.07	5.34	9.60	19.90
				T_1	34.55	34.60	34.65	34.60			
6	2.00	6.00	1.414	T_2	40.20	40.20	40.20	40.20	5.60	10.09	14.28
				T_1	34.15	34.10	34.10	34.12			
7	1.00	4.00	1.00	T_2	40.08	40.05	40.00	40.04	5.92	10.66	10.66
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 8-A

DATE 11-20-59

TANGENT TUBE MODEL with BURNERS

1-2" ORIFICE(S), 14" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.5 °F	55.2 °F	54.85 °F
DRY BULB TEMPERATURE	64.9 °F	64.8 °F	64.85 °F
BAROMETER	30.24 "HG	30.24 "HG	30.24 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 48 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.65	34.51	34.55	34.57			
1	14.50	30.5	3.81	T_2	39.30	39.22	39.25	39.26	4.69	8.44	32.2
				T_1	34.35	34.30	34.20	34.28			
2	12.50	27.0	3.54	T_2	39.20	39.20	39.10	39.13	4.85	8.73	30.9
				T_1	34.10	34.08	34.00	34.06			
3	10.40	23.0	3.23	T_2	39.00	38.95	38.90	38.95	4.89	8.80	28.4
				T_1	34.10	34.30	34.40	34.27			
4	8.30	18.4	2.88	T_2	39.00	39.20	39.25	39.15	4.88	8.78	25.3
				T_1	34.40	34.45	34.55	34.47			
5	6.20	14.4	2.49	T_2	39.35	39.38	39.40	39.38	4.91	8.85	22.0
				T_1	34.50	34.50	34.50	34.50			
6	4.00	10.3	2.00	T_2	39.50	39.50	39.50	39.50	5.00	9.00	18.00
				T_1	34.45	34.45	34.58	34.49			
7	2.00	6.0	1.414	T_2	39.60	39.60	39.65	39.62	5.13	9.23	13.06
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 9

DATE 10-20-59

TANGENT TUBE MODEL WITH BURNERS

1-2" ORIFICE(S), 18" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	55.2 °F	54.0 °F	54.6 °F
DRY BULB TEMPERATURE	64.8 °F	64.0 °F	64.4 °F
BAROMETER	30.24 "Hg	30.24 "Hg	30.24 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 48 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	35.48	35.65	35.75	35.63			
1	14.35	30.5	3.79	T_2	39.30	39.40	39.50	39.40	3.77	6.79	25.7
				T_1	35.12	34.95	35.00	35.02			
2	12.50	27.5	3.54	T_2	39.10	38.98	38.95	39.01	3.99	7.18	25.4
				T_1	35.20	35.30	35.35	35.28			
3	10.40	23.0	3.23	T_2	39.20	39.30	39.30	39.27	3.99	7.18	23.2
				T_1	35.28	35.28	35.22	35.26			
4	8.50	18.5	2.92	T_2	39.30	39.70	39.25	39.28	4.02	7.24	21.1
				T_1	35.20	35.15	35.12	35.16			
5	6.20	14.5	2.49	T_2	39.30	39.25	39.20	39.25	4.09	7.36	18.33
				T_1	35.30	35.40	35.46	35.39			
6	4.00	10.0	2.00	T_2	39.40	39.50	39.55	39.48	4.09	7.36	14.72
				T_1	35.35	35.33	35.33	35.33			
7	2.00	6.0	1.414	T_2	39.55	39.57	39.60	39.57	4.24	7.63	10.8
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 9-A

DATE 12-17-59

TANGENT TUBE MODEL With BURNERS

1-2" ORIFICE(S), 18" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.3 °F	57.3 °F	56.8 °F
DRY BULB TEMPERATURE	66.5 °F	67.5 °F	67.0 °F
BAROMETER	30.13 "HG	30.13 "HG	30.13 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 52 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C					ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				TRIAL	1	2	3	AVG.			
				T_1	32.80	32.75	32.80	32.78			
1	11.7	25.0	3.42	T_2	36.90	36.82	36.86	36.86	4.08	7.34	25.1
				T_1	32.47	32.40	32.35	32.41			
2	10.3	23.0	3.21	T_2	36.65	36.60	36.55	36.60	4.19	7.54	24.2
				T_1	32.80	32.88	33.00	33.89			
3	8.45	18.5	2.91	T_2	37.00	37.10	37.20	37.10	4.21	7.59	22.1
				T_1	32.70	32.65	32.70	32.68			
4	6.20	15.2	2.49	T_2	37.10	37.05	37.10	37.08	4.40	7.92	19.7
				T_1	33.20	33.30	33.40	33.30			
5	4.00	9.8	2.00	T_2	37.55	37.60	37.70	37.62	4.32	7.78	15.5
				T_1	32.90	32.92	32.92	32.91			
6	2.00	5.8	1.414	T_2	37.45	37.45	37.45	37.45	4.54	8.16	11.55
				T_1	32.80	32.80	32.78	32.79			
7	1.00	4.00	1.00	T_2	37.45	37.45	37.45	37.45	4.66	8.40	8.40
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 10

DATE 11-20-59

TANGENT TUBE MODEL WITH BURNERS

1-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.0 °F	52.0 °F	53.0 °F
DRY BULB TEMPERATURE	64.0 °F	64.0 °F	64.0 °F
BAROMETER	30.24 "HG	30.24 "HG	30.24 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 42 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	35.90	35.95	36.05	35.97			
1	15.00	31.0	3.875	T_2	38.65	38.65	38.72	38.67	2.70	4.86	18.83
				T_1	35.80	35.35	35.18	35.34			
2	12.30	25.5	3.51	T_2	38.30	38.22	38.10	38.21	2.87	5.16	18.10
				T_1	35.10	35.10	35.10	35.10			
3	10.50	22.0	3.24	T_2	38.00	38.00	38.00	38.00	2.90	5.22	16.90
				T_1	35.10	35.15	35.25	35.17			
4	8.30	18.0	2.88	T_2	37.95	37.95	38.00	37.97	2.80	5.04	14.5
				T_1	35.20	35.25	35.27	35.24			
5	6.20	14.4	2.49	T_2	38.00	38.00	38.00	38.00	2.76	4.97	12.4
				T_1	35.15	35.20	35.20	35.18			
6	4.10	9.6	2.025	T_2	37.92	37.90	37.90	37.91	2.73	4.91	9.95
				T_1	34.90	34.85	34.80	34.85			
7	2.00	6.0	1.414	T_2	37.70	37.65	37.60	37.65	2.80	5.04	7.13
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 10-A

DATE 12-17-59

TANGENT TUBE MODEL With BURNERS

1-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.3 °F	57.7 °F	57.5 °F
DRY BULB TEMPERATURE	67.5 °F	67.7 °F	67.6 °F
BAROMETER	30.13 "Hg	30.13 "Hg	30.13 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 52 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F "H_2O	ΔH_B "H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.50	34.60	34.67	34.59			
1	12.65	26.0	3.56	T_2	37.00	37.10	37.20	37.10	2.51	4.51	16.1
				T_1	34.60	34.60	34.70	34.63			
2	10.45	23.0	3.23	T_2	37.25	37.20	37.25	37.23	2.60	4.68	15.1
				T_1	34.95	35.00	35.00	34.98			
3	8.55	18.9	2.92	T_2	37.50	37.55	37.60	37.55	2.58	4.65	13.6
				T_1	34.95	34.90	34.80	34.88			
4	6.05	15.0	2.46	T_2	37.58	37.50	37.50	37.53	2.65	4.76	11.7
				T_1	34.80	34.80	34.80	34.80			
5	4.00	9.6	2.00	T_2	37.40	37.40	37.40	37.40	2.60	4.68	9.36
				T_1	34.13	34.22	34.35	34.23			
6	2.00	6.5	1.414	T_2	36.90	36.98	37.00	36.96	2.73	4.91	6.95
				T_1	34.25	34.25	34.20	34.23			
7	1.00	4.00	1.00	T_2	37.00	37.00	36.90	36.97	2.74	4.93	4.93
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 10-13
DATE 3/10/60

TANGENT TUBE MODEL WITH BURNERS

1-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	52.0 °F	52.6 °F	52.3 °F
DRY BULB TEMPERATURE	62.0 °F	65.2 °F	63.6 °F
BAROMETER	30.02 "Hg	30.02 "Hg	30.02 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 41 GRAINS/lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TRIAL	TEMPERATURE °C 1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	12.8	25.0	3.58	T_1	30.85	31.05	31.20	31.03	2.39	4.30	15.4
				T_2	33.25	33.40	33.60	33.42			
2	10.3	19.1	3.21	T_1	31.03	31.08	31.10	31.07	2.66	4.79	15.35
				T_2	33.70	33.70	33.75	33.73			
3	8.4	17.6	2.90	T_1	31.65	31.75	31.85	31.75	2.57	4.63	13.40
				T_2	34.25	34.30	34.40	34.32			
4	6.3	13.0	2.51	T_1	31.80	31.90	31.95	31.88	2.67	4.81	12.07
				T_2	34.50	34.55	34.60	34.55			
5	4.2	9.0	2.05	T_1	32.10	32.15	32.20	32.15	2.73	4.91	10.1
				T_2	34.85	34.90	34.90	34.88			
6	3.0	6.2	1.732	T_1	32.15	32.10	32.15	32.13	2.78	5.00	8.67
				T_2	34.90	34.90	34.93	34.91			
7	2.0	4.4	1.414	T_1	32.10	32.10	32.15	32.12	2.90	5.22	7.35
				T_2	35.00	35.00	35.05	35.02			
8	1.0	2.0	1.00	T_1	32.05	32.08	32.05	32.06	3.01	5.42	5.42
				T_2	35.05	35.10	35.05	35.07			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 11

DATE 11-6-59

TANGENT TUBE MODEL Without BURNERS

3-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	68.6 °F	70.2 °F	69.40 °F
DRY BULB TEMPERATURE	73.7 °F	75.0 °F	74.35 °F
BAROMETER	30.06 "HG	30.06 "HG	30.06 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 100 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	38.83	38.92	39.00	38.92			
1	24.45	6.30	4.945	T_2	43.65	43.74	43.80	43.73	4.81	8.66	42.8
				T_1	38.75	38.75	38.65	38.72			
2	20.65	5.30	4.55	T_2	43.70	43.60	43.60	43.65	4.93	8.88	40.4
				T_1	38.50	38.57	38.50	38.52			
3	16.10	4.80	4.01	T_2	43.30	43.40	43.40	43.37	4.85	8.83	35.00
				T_1	38.35	38.45	38.40	38.40			
4	12.50	4.20	3.54	T_2	43.35	43.40	43.40	43.38	4.98	8.96	31.70
				T_1	38.35	38.30	38.30	38.32			
5	8.35	4.00	2.89	T_2	43.45	43.40	43.43	43.43	5.11	9.20	26.60
				T_1	38.03	38.06	38.10	38.06			
6	4.25	3.70	2.06	T_2	43.43	43.47	43.50	43.47	5.41	9.75	20.1
				T_1	37.55	37.43	37.38	37.45			
7	1.00	2.25	1.00	T_2	43.40	43.35	43.28	43.34	5.89	10.60	10.6
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 11-A

DATE 11-8-59

TANGENT TUBE MODEL WITHOUT BURNERS

3-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.9 °F	56.5 °F	57.2 °F
DRY BULB TEMPERATURE	64.5 °F	63.5 °F	64.0 °F
BAROMETER	30.30 "Hg	30.30 "Hg	30.30 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 59 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	32.70	32.65	32.75	32.70			
1	23.55	5.8	4.86	T_2	38.10	38.05	38.15	38.10	5.40	9.72	47.25
				T_1	32.20	32.22	32.18	32.20			
2	19.65	4.85	4.43	T_2	37.80	37.80	37.80	37.80	5.60	10.10	44.8
				T_1	32.20	32.25	32.20	32.22			
3	16.4	4.40	4.05	T_2	37.90	37.90	37.90	37.90	5.68	10.22	41.8
				T_1	32.30	32.25	32.27	32.27			
4	13.2	4.00	3.635	T_2	38.05	38.05	38.05	38.05	5.78	10.41	37.85
				T_1	32.30	32.20	32.20	32.23			
5	10.0	3.70	3.16	T_2	38.20	38.15	38.15	38.18	5.95	10.72	33.9
				T_1	32.20	32.20	32.20	32.20			
6	6.85	2.90	2.62	T_2	38.30	38.30	38.30	38.30	6.10	10.99	28.8
				T_1	32.15	32.15	32.20	32.18			
7	4.15	2.40	2.04	T_2	38.40	38.40	38.45	38.43	6.25	11.27	23.0
				T_1	32.00	32.07	32.10	32.06			
8	2.00	2.00	1.414	T_2	38.45	38.50	38.50	38.48	6.42	11.58	16.4
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER *12*

DATE *11-6-59*

TANGENT TUBE MODEL *without* BURNERS

3-2" ORIFICE(S), *10* " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	*70.2* °F	*69.6* °F	*69.9* °F
DRY BULB TEMPERATURE	*75.0* °F	*74.5* °F	*74.75* °F
BAROMETER	*30.06* "Hg	*30.06* "Hg	*30.06* "Hg

REAR WALL STEAM PRESSURE *1* "Hg GAGE, SPEC. HUM. *101* GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	39.65	39.40	39.15	39.40			
1	24.60	6.3	4.96	T_2	43.35	43.20	43.00	43.18	3.78	6.80	33.80
				T_1	38.75	38.60	38.50	38.62			
2	20.35	5.6	4.51	T_2	42.70	42.60	42.50	42.60	3.98	7.16	32.30
				T_1	38.40	38.40	38.35	38.38			
3	16.55	5.0	4.06	T_2	42.50	42.50	42.45	42.48	4.10	7.38	30.0
				T_1	38.65	38.62	38.60	38.62			
4	12.50	4.0	3.54	T_2	42.70	42.70	42.70	42.70	4.08	7.35	26.0
				T_1	38.15	38.18	38.25	38.19			
5	8.35	3.7	2.89	T_2	42.40	42.40	42.43	42.41	4.22	7.60	22.0
				T_1	37.80	37.75	37.70	37.75			
6	4.10	2.6	2.025	T_2	42.20	42.15	42.10	42.15	4.40	7.92	16.04
				T_1	37.40	37.40	37.40	37.40			
7	2.00	2.3	1.414	T_2	41.90	41.90	41.87	41.89	4.49	8.08	11.43
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 12-A

DATE 11-12-59

TANGENT TUBE MODEL WITHOUT BURNERS

3-2" ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.2 °F	60.0 °F	58.1 °F
DRY BULB TEMPERATURE	63.0 °F	65.0 °F	64.0 °F
BAROMETER	30.15 "Hg	30.15 "Hg	30.15 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 63 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	31.85	31.90	32.00	31.92			
1	22.60	5.3	4.76	T_2	35.80	35.87	36.00	35.89	3.97	7.15	34.0
				T_1	31.80	31.80	31.80	31.80			
2	19.40	4.9	4.41	T_2	35.93	35.93	35.93	35.93	4.13	7.44	32.8
				T_1	32.00	31.95	31.93	31.96			
3	16.10	4.4	4.01	T_2	36.15	36.15	36.18	36.16	4.20	7.56	30.3
				T_1	32.02	32.01	32.02	32.02			
4	12.90	4.0	3.595	T_2	36.30	36.30	36.30	36.30	4.28	7.70	27.65
				T_1	32.15	32.20	32.20	32.18			
5	9.80	3.8	3.138	T_2	36.50	36.55	36.58	36.54	4.36	7.85	24.6
				T_1	32.45	32.50	32.55	32.50			
6	7.25	3.3	2.69	T_2	36.85	36.90	36.95	36.90	4.40	7.92	21.3
				T_1	32.50	32.55	32.60	32.55			
7	4.20	3.0	2.05	T_2	37.03	37.08	37.10	37.07	4.52	8.14	16.7
				T_1	32.40	32.35	32.35	32.37			
8	1.90	2.0	1.35	T_2	37.15	37.10	37.15	37.13	4.76	8.57	11.8
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 13

DATE 10-6-59

TANGENT TUBE MODEL Without BURNERS

3-2" ORIFICE(S), 14" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	69.6 °F	69.4 °F	69.5 °F
DRY BULB TEMPERATURE	74.5 °F	74.5 °F	74.5 °F
BAROMETER	30.06 "Hg	30.05 "Hg	30.045 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 100 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C					ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				TRIAL	1	2	3	AVG.			
				T_1	38.75	38.80	39.00	38.85			
1	24.55	5.8	4.955	T_2	41.80	41.85	42.00	41.88	3.03	5.45	27.1
				T_1	38.45	38.50	38.50	38.48			
2	20.75	5.3	4.56	T_2	41.70	41.70	41.70	41.70	3.22	5.80	26.4
				T_1	38.30	38.40	38.35	38.35			
3	16.65	4.4	4.08	T_2	41.55	41.65	41.60	41.60	3.25	5.85	23.9
				T_1	38.40	38.35	38.35	38.37			
4	12.50	4.0	3.54	T_2	41.66	41.65	41.65	41.65	3.28	5.90	20.9
				T_1	38.50	38.40	38.40	38.43			
5	8.35	3.6	2.89	T_2	41.75	41.70	41.75	41.73	3.30	5.94	17.18
				T_1	38.15	38.10	38.10	38.12			
6	4.25	2.9	2.06	T_2	41.60	41.52	41.55	41.56	3.44	6.19	12.75
				T_1	37.98	37.90	37.85	37.91			
7	2.00	2.3	1.414	T_2	41.48	41.40	41.38	41.42	3.51	6.32	8.94
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 13-A

DATE 11-12-59

TANGENT TUBE MODEL WITHOUT BURNERS

3-2" ORIFICE(S), 14" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	60.0 °F	59.4 °F	59.7 °F
DRY BULB TEMPERATURE	65.0 °F	67.0 °F	66.0 °F
BAROMETER	30.16 "HG	30.16 "HG	30.16 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM 66 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	32.80	32.85	32.90	32.85			
1	23.6	5.8	4.86	T_2	36.28	36.29	36.30	36.29	3.44	6.19	30.1
				T_1	32.50	32.35	32.37	32.41			
2	19.6	4.9	4.43	T_2	36.05	35.92	35.92	35.96	3.55	6.39	28.3
				T_1	32.88	32.95	33.00	32.94			
3	16.0	4.4	4.00	T_2	36.45	36.47	36.55	36.49	3.55	6.39	25.6
				T_1	32.75	32.80	32.80	32.78			
4	12.45	4.0	3.53	T_2	36.40	36.40	36.40	36.40	3.62	6.51	23.0
				T_1	33.00	32.90	32.80	32.90			
5	9.30	3.7	3.05	T_2	36.70	36.60	36.50	36.60	3.70	6.66	20.3
				T_1	33.50	33.50	33.50	33.50			
6	6.2	3.4	2.49	T_2	37.10	37.10	37.10	37.10	3.60	6.48	16.15
				T_1	33.10	33.20	33.30	33.20			
7	4.20	2.6	2.05	T_2	36.85	36.90	36.98	36.91	3.71	6.68	13.7
				T_1	33.35	33.30	33.20	33.28			
8	2.00	2.0	1.414	T_2	37.10	37.10	37.05	37.08	3.80	6.84	9.68
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 14

DATE 11-7-59

TANGENT TUBE MODEL WITHOUT BURNERS

3 - 2" ORIFICE(S), 18 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.0 °F	61.0 °F	59.0 °F
DRY BULB TEMPERATURE	64.0 °F	67.2 °F	65.6 °F
BAROMETER	30.27 "Hg	30.28 "Hg	30.275 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 64 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	24.8	5.7	4.98	T_1	34.80	35.00	35.10	34.97	2.50	4.50	22.4
				T_2	37.30	37.50	37.60	37.47			
2	19.4	4.8	4.40	T_1	33.65	33.55	33.60	33.60	2.65	4.77	21.0
				T_2	36.30	36.20	36.25	36.25			
3	16.0	4.4	4.00	T_1	33.45	33.40	33.45	33.43	2.69	4.85	19.4
				T_2	36.15	36.10	36.10	36.12			
4	12.8	4.0	3.58	T_1	33.85	33.85	33.65	33.78	2.69	4.85	17.35
				T_2	36.50	36.50	36.40	36.47			
5	8.95	3.7	2.99	T_1	34.80	34.70	34.65	34.72	2.70	4.86	14.55
				T_2	37.50	37.40	37.38	37.42			
6	5.45	2.9	2.335	T_1	33.90	33.90	33.85	33.88	2.79	5.02	11.72
				T_2	36.70	36.70	36.60	36.67			
7	3.65	2.3	1.91	T_1	33.75	33.70	33.70	33.72	2.88	5.19	9.90
				T_2	36.60	36.60	36.60	36.60			
8	2.00	2.0	1.414	T_1	33.50	33.50	33.50	33.50	2.97	5.35	7.56
				T_2	36.50	36.47	36.43	36.47			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

TEST DATA SHEET NUMBER 14-A

DATE 11-13-59

TANGENT TUBE MODEL WITHOUT BURNERS

3-2" ORIFICE(S), 18" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET. BULB TEMPERATURE	53.6 °F	59.2 °F	56.4 °F
DRY BULB TEMPERATURE	62.6 °F	66.0 °F	64.3 °F
BAROMETER	30.37 "HG.	30.37 "HG.	30.37 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 55 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	31.20	31.10	31.10	31.13			
1	21.0	5.3	4.59	T_2	33.90	33.85	33.85	33.87	2.74	4.93	22.6
				T_1	30.85	30.95	30.90	30.90			
2	18.8	4.9	4.34	T_2	33.70	33.80	33.75	33.75	2.85	5.13	22.2
				T_1	31.00	31.05	31.15	31.07			
3	16.7	4.4	4.09	T_2	33.90	33.91	34.05	33.97	2.90	5.22	21.3
				T_1	31.50	31.63	31.70	31.61			
4	14.7	4.0	3.84	T_2	34.35	34.45	34.50	34.43	2.82	5.08	19.5
				T_1	31.75	31.80	31.85	31.80			
5	12.2	3.8	3.50	T_2	34.60	34.65	34.70	34.65	2.85	5.13	17.95
				T_1	32.20	32.25	32.25	32.23			
6	10.05	3.6	3.20	T_2	35.05	35.10	35.10	35.08	2.85	5.13	16.40
				T_1	32.40	32.40	32.75	32.38			
7	8.25	3.3	2.87	T_2	35.25	35.25	35.20	35.23	2.85	5.13	14.75
				T_1	32.25	32.20	32.20	32.22			
8	6.00	3.0	2.45	T_2	35.20	35.20	35.15	35.18	2.96	5.33	13.05
				T_1	32.30	32.35	32.40	32.35			
9	4.00	2.6	2.00	T_2	35.30	35.35	35.40	35.35	3.00	5.40	10.80
				T_1	32.40	32.40	32.35	32.38			
10	2.00	2.0	1.414	T_2	35.45	35.40	35.40	35.42	3.05	5.49	7.76
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 15

DATE 11-8-59

TANGENT TUBE MODEL WITHOUT BURNERS

3-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	58.1 °F	57.9 °F	58.0 °F
DRY BULB TEMPERATURE	64.5 °F	64.5 °F	64.5 °F
BAROMETER	30.31 "Hg	30.30 "Hg	30.305 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE , SPEC. HUM. 61 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	23.4	5.2	4.84	T_1	32.30	32.40	32.50	32.40	2.67	4.80	23.2
				T_2	35.05	35.20	35.25	35.17			
2	19.6	4.6	4.43	T_1	32.05	32.05	31.95	32.02	2.90	5.22	23.1
				T_2	34.95	34.95	34.85	34.92			
3	15.85	4.1	3.98	T_1	31.70	31.70	31.65	31.68	2.88	5.18	20.6
				T_2	34.60	34.57	34.50	34.56			
4	12.55	4.0	3.54	T_1	31.77	31.78	31.72	31.76	2.86	5.15	18.25
				T_2	34.65	34.65	34.55	34.62			
5	9.40	3.6	3.07	T_1	31.65	31.70	31.75	31.70	2.90	5.22	16.0
				T_2	34.55	34.60	34.65	34.60			
6	6.70	3.4	2.59	T_1	31.75	31.70	31.75	31.73	3.00	5.40	14.0
				T_2	34.75	34.70	34.75	34.73			
7	4.10	3.2	2.025	T_1	31.75	31.80	31.87	31.81	3.07	5.53	11.2
				T_2	34.80	34.90	34.93	34.88			
8	2.00	2.0	1.414	T_1	31.55	31.60	36.60	31.58	3.21	5.78	8.16
				T_2	34.77	34.80	34.80	34.79			
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 15-B

DATE 11-13-59

TANGENT TUBE MODEL WITHOUT BURNERS

3-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	59.2 °F	59.6 °F	59.4 °F
DRY BULB TEMPERATURE	66.0 °F	68.0 °F	67.0 °F
BAROMETER	30.37 "HG	30.37 "HG	30.37 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 63 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	22.5	5.3	4.75	T_1	33.17	33.17	33.14	33.16	2.77	4.99	23.7
				T_2	35.95	35.95	35.90	35.93			
2	18.8	4.8	4.34	T_1	32.97	32.92	32.85	32.92	2.80	5.04	21.8
				T_2	35.80	35.80	35.55	35.72			
3	16.75	4.4	4.09	T_1	33.12	33.20	33.20	33.17	2.85	5.13	20.95
				T_2	36.00	36.00	36.06	36.02			
4	14.35	4.0	3.79	T_1	33.15	33.15	33.20	33.18	2.91	5.24	19.85
				T_2	36.10	36.07	36.10	36.09			
5	12.45	4.0	3.53	T_1	33.45	33.42	33.40	33.43	2.85	5.13	15.10
				T_2	36.25	36.25	36.30	36.28			
6	10.35	3.6	3.22	T_1	33.40	33.35	33.38	33.38	2.92	5.26	16.9
				T_2	36.30	36.30	36.30	36.30			
7	8.30	3.2	2.88	T_1	33.35	33.45	33.58	33.46	2.91	5.24	15.1
				T_2	36.30	36.30	36.50	36.37			
8	6.25	2.6	2.50	T_1	33.65	33.60	33.55	33.60	2.93	5.27	13.18
				T_2	36.60	36.52	36.48	36.53			
9	4.00	2.3	2.00	T_1	33.70	33.70	33.72	33.72	2.94	5.29	10.58
				T_2	36.60	36.67	36.70	36.66			
10	2.00	2.00	1.414	T_1	33.70	33.70	33.75	33.72	3.00	5.40	7.64
				T_2	36.70	36.70	36.75	36.72			
				T_1							
				T_2							
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 16

DATE 1-6-60

TANGENT TUBE MODEL WITHOUT BURNERS

2-2" ORIFICE(S), 6 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	50.7 °F	51.0 °F	50.85 °F
DRY BULB TEMPERATURE	63.5 °F	62.5 °F	63.0 °F
BAROMETER	30.06 "Hg	29.96 "Hg	30.01 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 36 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	29.90	29.75	29.70	29.78			
1	19.7	9.0	4.44	T_2	36.40	36.30	36.25	36.32	6.5	11.78	52.2
				T_1	29.08	29.10	29.20	29.13			
2	16.8	8.4	4.045	T_2	36.00	35.96	36.00	35.99	6.86	12.36	50.0
				T_1	29.45	29.45	29.30	29.40			
3	14.6	7.1	3.82	T_2	36.20	36.10	36.05	36.12	6.72	12.10	46.1
				T_1	28.80	28.90	28.85	28.85			
4	12.3	6.0	3.51	T_2	35.75	35.80	35.75	35.77	6.92	12.47	43.75
				T_1	29.50	29.65	29.80	29.65			
5	10.3	5.0	3.21	T_2	36.40	36.56	36.70	36.53	6.88	12.40	39.80
				T_1	29.95	30.00	30.05	30.00			
6	8.3	4.0	2.88	T_2	37.00	37.10	37.15	37.08	7.08	12.75	36.70
				T_1	30.45	30.60	30.70	30.58			
7	6.3	4.0	2.51	T_2	37.60	37.75	37.85	37.73	7.15	12.88	32.30
				T_1	31.00	31.00	31.05	31.02			
8	4.85	3.6	2.20	T_2	38.25	38.30	38.40	38.32	7.30	13.15	28.90
				T_1	30.95	30.90	30.90	30.92			
9	3.50	3.25	1.87	T_2	38.60	38.60	38.60	38.60	7.68	13.82	25.90
				T_1	30.80	30.75	30.80	30.78			
10	2.00	2.5	1.414	T_2	38.75	38.70	38.70	38.72	7.94	14.30	20.20
				T_1	30.70	30.60	30.30	30.53			
11	1.00	1.5	1.00	T_2	38.85	38.80	38.70	38.78	8.25	14.86	14.86
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 17

DATE 1-6-59

TANGENT TUBE MODEL *Without* BURNERS

2-2" ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	51.0 °F	50.00 °F	50.5 °F
DRY BULB TEMPERATURE	62.5 °F	60.07 °F	61.6 °F
BAROMETER	29.96 "Hg.	29.93 "Hg.	29.945 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 37 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	31.40	31.40	31.40	31.40			
1	19.9	9.0	4.46	T_2	37.20	37.25	37.23	37.23	5.83	10.50	46.9
				T_1	31.55	31.50	31.40	31.48			
2	17.0	8.4	4.13	T_2	37.50	37.50	37.45	37.48	6.00	10.80	44.5
				T_1	30.85	30.78	30.70	30.78			
3	14.5	7.5	3.81	T_2	37.00	37.00	36.95	36.98	6.20	11.18	42.5
				T_1	30.55	30.60	30.70	30.62			
4	12.4	6.5	3.52	T_2	36.90	36.90	36.90	36.90	6.28	11.31	39.8
				T_1	31.05	30.90	30.80	30.92			
5	10.3	4.9	3.21	T_2	37.25	37.15	37.10	37.17	6.25	11.26	36.1
				T_1	30.30	30.20	30.20	30.23			
6	8.3	4.3	2.88	T_2	36.80	36.70	36.70	36.73	6.50	11.70	33.7
				T_1	30.05	30.00	30.05	30.03			
7	6.2	4.0	2.49	T_2	36.70	36.65	36.70	36.68	6.65	11.98	29.8
				T_1	30.00	30.00	29.80	29.93			
8	4.85	4.00	2.20	T_2	36.70	36.70	36.55	36.65	6.72	12.10	26.6
				T_1	29.70	29.65	29.55	29.63			
9	3.10	3.00	1.76	T_2	36.65	36.65	36.55	36.62	6.99	12.58	22.1
				T_1	29.75	29.90	30.05	29.90			
10	2.00	2.5	1.414	T_2	36.70	36.80	36.90	36.80	6.90	12.42	17.57
				T_1	30.00	30.00	30.00	30.00			
11	1.00	2.0	1.00	T_2	37.10	37.10	37.10	37.10	7.10	12.78	12.78
				T_1							
				T_2							

APPENDIX C

TEST DATA SHEET NUMBER 18

DATE 3-8-60

TANGENT TUBE MODEL WITHOUT BURNERS

2-2" ORIFICE(S), 14" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	48.0 °F	53.0 °F	50.5 °F
DRY BULB TEMPERATURE	60.0 °F	63.0 °F	61.5 °F
BAROMETER	30.17 "Hg	30.17 "Hg	30.17 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 37 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	29.85	29.70	29.65	29.73			
1	21.0	8.0	4.59	T_2	34.50	34.40	34.32	34.41	4.68	8.42	38.6
				T_1	28.97	28.81	28.72	28.85			
2	17.2	7.0	4.15	T_2	33.95	33.80	33.80	33.85	5.00	9.00	37.3
				T_1	28.50	28.60	28.65	28.58			
3	14.7	6.5	3.84	T_2	33.60	33.70	33.70	33.67	5.09	9.15	35.15
				T_1	28.70	28.65	28.60	28.65			
4	12.6	5.3	3.55	T_2	33.80	33.80	33.75	33.78	5.13	9.24	32.8
				T_1	29.60	29.80	30.00	29.80			
5	10.6	4.8	3.26	T_2	34.50	34.70	34.90	34.70	4.90	8.82	28.8
				T_1	30.05	30.10	30.30	30.15			
6	8.6	4.0	2.935	T_2	35.00	35.10	35.20	35.10	4.95	8.91	26.1
				T_1	30.80	30.95	31.15	30.95			
7	6.4	3.5	2.53	T_2	35.80	35.95	36.10	35.95	5.00	9.00	22.8
				T_1	31.25	31.30	31.30	31.28			
8	4.25	3.0	2.06	T_2	36.35	36.45	36.40	36.40	5.12	9.22	19.0
				T_1	31.30	31.32	31.30	31.31			
9	3.00	2.0	1.732	T_2	36.55	36.58	36.55	36.56	5.25	9.45	16.3
				T_1	31.00	30.95	30.90	30.95			
10	2.00	1.5	1.414	T_2	36.50	36.45	36.50	36.48	5.53	9.95	14.05
				T_1	30.55	30.45	30.35	30.45			
11	1.00	1.0	1.00	T_2	36.35	36.30	36.25	36.30	5.85	10.54	10.54
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 19

DATE 3-8-40

TANGENT TUBE MODEL Without BURNERS

2-2" ORIFICE(S), 18. " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	53.00 °F	54.3 °F	53.65 °F
DRY BULB TEMPERATURE	63.0 °F	62.8 °F	65.4 °F
BAROMETER	30.18 "Hg	30.18 "Hg	30.18 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 42 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	32.30	32.40	32.40	32.37			
1	21.8	8.0	4.67	T_2	36.30	36.40	36.40	36.37	4.0	7.2	33.6
				T_1	31.80	31.80	31.75	31.78			
2	16.8	7.0	4.10	T_2	36.00	36.00	35.95	35.98	4.20	7.56	31.0
				T_1	31.70	31.65	31.70	31.68			
3	14.75	6.5	3.84	T_2	35.95	35.90	35.95	35.93	4.25	7.65	29.4
				T_1	31.70	31.70	31.65	31.68			
4	12.6	6.0	3.55	T_2	36.00	36.00	36.00	36.00	4.32	7.78	27.6
				T_1	31.60	31.60	31.60	31.60			
5	10.5	5.0	3.24	T_2	36.00	36.00	36.00	36.00	4.40	7.92	25.7
				T_1	31.70	31.65	31.60	31.65			
6	8.35	4.0	2.89	T_2	36.10	36.05	36.00	36.05	4.40	7.92	22.9
				T_1	31.60	31.45	31.30	31.45			
7	5.70	3.0	2.39	T_2	36.10	35.95	35.90	35.98	4.53	8.15	19.5
				T_1	31.65	31.90	32.15	31.90			
8	4.20	2.0	2.05	T_2	36.15	36.30	36.50	36.32	4.42	7.95	16.3
				T_1	32.40	32.45	32.55	32.47			
9	3.00	1.5	1.732	T_2	36.80	36.85	36.90	36.85	4.38	7.88	13.68
				T_1	32.60	32.60	32.65	32.62			
10	2.00	1.00	1.414	T_2	37.00	37.05	37.10	37.05	4.43	7.98	11.22
				T_1	32.50	32.47	32.50	32.49			
11	1.00	1.00	1.00	T_2	37.10	37.10	37.10	37.10	4.61	8.30	8.30
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 20

DATE 3-8-60

TANGENT TUBE MODEL WITHOUT BURNERS

2-2" ORIFICE(S), 21" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.3 °F	54.0 °F	54.15 °F
DRY BULB TEMPERATURE	67.8 °F	63.5 °F	65.65 °F
BAROMETER	30.18 "Hg	30.18 "Hg	30.18 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 44 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	35.70	35.20	35.10	35.20			
1	21.0	9.0	4.59	T_2	38.80	38.80	38.70	38.77	3.57	6.43	29.5
				T_1	34.70	34.70	34.40	34.33			
2	17.1	8.0	4.14	T_2	38.15	38.15	38.20	38.17	3.84	6.92	28.6
				T_1	34.25	34.10	34.00	34.12			
3	14.6	7.0	3.82	T_2	38.10	38.05	37.95	38.03	3.91	7.04	26.9
				T_1	33.65	33.65	33.50	33.60			
4	12.5	6.0	3.54	T_2	37.65	37.70	37.55	37.63	4.03	7.25	25.7
				T_1	33.15	33.10	33.10	33.12			
5	10.5	5.0	3.24	T_2	37.30	37.20	37.20	37.27	4.15	7.47	24.2
				T_1	33.20	33.15	33.10	33.15			
6	8.3	4.0	2.88	T_2	37.30	37.30	37.25	37.28	4.13	7.44	21.4
				T_1	33.05	33.10	33.12	33.09			
7	6.3	3.0	2.51	T_2	37.25	37.30	37.30	37.28	4.19	7.54	18.9
				T_1	33.05	33.00	33.00	33.02			
8	4.2	2.0	2.05	T_2	37.70	37.25	37.25	37.27	4.25	7.65	15.7
				T_1	32.90	32.85	32.80	32.85			
9	3.0	2.5	1.732	T_2	36.80	36.86	37.00	36.89	4.04	7.20	12.6
				T_1	32.75	32.70	32.70	32.72			
10	2.0	1.0	1.414	T_2	37.10	37.10	37.15	37.12	4.40	7.92	11.2
				T_1	32.30	32.10	32.00	32.13			
11	1.0	1.0	1.0	T_2	36.90	36.80	36.75	36.32	4.69	8.44	8.44
				T_1							
				T_2							

APPENDIX C.

TEST DATA SHEET NUMBER 21

DATE 3-14-60

TANGENT TUBE MODEL WITH BURNERS

2-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.0 °F	54.5 °F	55.25 °F
DRY BULB TEMPERATURE	65.0 °F	63.2 °F	64.1 °F
BAROMETER	30.16 "Hg	30.16 "Hg	30.16 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 51 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.40	34.40	34.40	34.40			
1	23.7	13.7	4.87	T_2	39.10	39.15	39.13	39.13	4.73	8.52	40.6
				T_1	34.50	34.50	34.50	34.50			
2	19.8	12.3	4.45	T_2	39.35	39.36	39.35	39.35	4.85	8.73	38.8
				T_1	32.85	32.90	32.85	32.87			
3	16.6	10.0	4.08	T_2	37.80	37.80	37.70	37.77	4.90	8.82	36.0
				T_1	32.80	32.80	32.80	32.80			
4	14.7	9.0	3.84	T_2	37.75	37.75	37.75	37.75	4.95	8.91	34.2
				T_1	32.70	32.68	32.60	32.65			
5	12.6	8.0	3.55	T_2	37.70	37.65	37.60	37.65	5.00	9.00	31.9
				T_1	32.55	32.50	32.75	32.60			
6	10.6	7.3	3.26	T_2	37.60	37.60	37.80	37.67	5.07	9.12	29.7
				T_1	32.75	32.73	32.65	32.71			
7	8.4	5.3	2.90	T_2	37.85	37.83	37.75	37.81	5.10	9.18	26.6
				T_1	32.75	32.80	32.85	32.80			
8	6.3	4.0	2.51	T_2	37.90	38.00	38.00	37.97	5.17	9.30	23.4
				T_1	32.90	32.90	33.00	32.97			
9	4.2	3.0	2.05	T_2	38.10	38.13	38.20	38.14	5.17	9.30	19.1
				T_1	33.10	33.10	33.30	33.17			
10	3.0	2.0	1.732	T_2	38.45	38.37	38.50	38.42	5.25	9.45	16.4
				T_1	33.60	33.65	33.70	33.65			
11	2.0	1.0	1.414	T_2	38.80	38.90	38.85	38.85	5.20	9.36	13.25
				T_1	33.35	33.30	33.30	33.32			
12	1.0	—	1.0	T_2	38.75	38.72	38.75	38.74	5.42	9.75	9.75

APPENDIX C

TEST DATA SHEET NUMBER 22

DATE 3-14-60

TANGENT TUBE MODEL With BURNERS

2-2" ORIFICE(S), 10 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.5 °F	52.5 °F	53.5 °F
DRY BULB TEMPERATURE	63.2 °F	63.0 °F	63.1 °F
BAROMETER	30.16 "Hg.	30.16 "Hg.	30.16 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE , SPEC. HUM. 46 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	35.03	35.00	35.00	35.01			
1	23.7	14.0	4.87	T_2	38.60	38.55	38.55	38.58	3.57	6.42	31.3
				T_1	34.50	34.50	34.60	34.53			
2	19.9	12.2	4.46	T_2	38.25	38.25	38.30	38.28	3.75	6.75	30.1
				T_1	34.40	34.40	34.50	34.43			
3	16.8	9.6	4.10	T_2	38.20	38.20	38.30	38.23	3.80	6.84	28.0
				T_1	34.40	34.45	34.50	34.45			
4	14.6	9.0	3.82	T_2	38.25	38.30	38.30	38.28	3.83	6.90	27.0
				T_1	34.75	34.90	34.90	34.85			
5	12.6	7.9	3.55	T_2	38.50	38.70	38.70	38.63	3.78	6.80	24.2
				T_1	34.97	35.00	35.00	34.99			
6	10.5	6.75	3.24	T_2	38.80	38.80	38.80	38.80	3.81	6.86	22.2
				T_1	34.90	34.90	34.95	34.92			
7	8.4	4.9	2.90	T_2	38.75	38.80	38.80	38.78	3.86	6.95	20.15
				T_1	34.90	34.90	34.90	34.90			
8	6.3	4.0	2.51	T_2	38.85	38.85	38.85	38.85	3.95	7.11	17.85
				T_1	34.90	34.93	34.95	34.93			
9	4.2	3.0	2.05	T_2	38.90	38.90	38.90	38.90	3.97	7.15	14.65
				T_1	34.90	34.90	34.90	34.90			
10	3.0	2.0	1.732	T_2	38.93	38.93	38.95	38.94	4.04	7.27	12.60
				T_1	34.70	34.70	34.70	34.70			
11	2.0	1.0	1.414	T_2	38.90	38.87	38.85	38.87	4.17	7.51	10.6
				T_1	34.45	34.45	34.45	34.45			
12	1.0	—	1.0	T_2	38.75	38.75	38.75	38.75	4.30	7.74	7.74

APPENDIX C

TEST DATA SHEET NUMBER 23

DATE 3-17-60

TANGENT TUBE MODEL WITH BURNERS

2-2" ORIFICE(S), 14" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	58.0 °F	56.5 °F	57.25 °F
DRY BULB TEMPERATURE	64.5 °F	64.5 °F	64.5 °F
BAROMETER	29.83 "Hg	29.83 "Hg	29.83 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 58 GRAINS/lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	23.6	14.4	4.86	T_1	36.40	36.50	36.60	36.50	2.50	4.50	21.9
				T_2	38.90	39.00	39.10	39.00			
2	19.0	12.2	4.36	T_1	36.55	36.40	36.30	36.42	2.71	4.88	21.75
				T_2	39.20	39.13	39.05	39.13			
3	16.8	10.2	4.10	T_1	36.50	36.55	36.57	36.54	2.68	4.82	20.25
				T_2	39.20	32.20	32.25	39.22			
4	14.7	9.0	3.84	T_1	35.35	35.37	35.35	35.36	2.90	5.22	20.0
				T_2	38.25	38.27	38.25	38.26			
5	12.4	7.9	3.52	T_1	35.47	35.50	35.55	35.81	2.90	5.22	18.4
				T_2	38.37	38.40	38.45	38.41			
6	10.5	6.4	3.24	T_1	35.70	35.70	35.75	35.72	2.85	5.13	16.6
				T_2	38.50	38.60	38.60	38.57			
7	8.4	5.3	2.90	T_1	35.80	35.80	35.80	35.80	2.86	5.15	14.9
				T_2	38.65	38.68	38.66	38.66			
8	6.3	4.4	2.51	T_1	35.65	35.67	35.67	35.66	2.97	5.35	13.3
				T_2	38.65	38.60	38.63	38.63			
9	4.1	3.6	2.025	T_1	35.30	35.30	35.30	35.30	3.05	5.49	11.1
				T_2	38.35	38.35	38.35	38.35			
10	3.0	3.0	1.732	T_1	35.25	35.25	35.25	35.25	3.08	5.54	9.60
				T_2	38.33	38.35	38.30	38.33			
11	2.0	2.0	1.414	T_1	34.90	34.90	34.87	34.89	3.15	5.67	8.00
				T_2	38.05	38.05	38.02	38.04			
12	1.0	1.0	1.00	T_1	34.40	34.40	34.35	34.38	3.30	5.94	5.94
				T_2	37.70	37.70	37.65	37.68			

APPENDIX C

TEST DATA SHEET NUMBER 24

DATE 3-17-60

TANGENT TUBE MODEL With BURNERS

2-2 ORIFICE(S), 18 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.5 °F	56.5 °F	56.5 °F
DRY BULB TEMPERATURE	64.5 °F	65.0 °F	64.75 °F
BAROMETER	29.83 "Hg	29.83 "Hg	29.83 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 55 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	37.38	37.45	37.50	37.44			
1	23.7	14.4	4.87	T_2	39.60	39.70	39.70	39.67	2.23	4.01	19.55
				T_1	37.20	37.15	37.15	37.17			
2	19.7	12.2	4.45	T_2	39.55	39.50	39.50	39.52	2.35	4.23	18.80
				T_1	37.10	37.10	37.10	37.10			
3	16.8	9.6	4.10	T_2	39.50	39.50	39.50	39.50	2.40	4.32	17.70
				T_1	37.00	37.00	37.00	37.00			
4	14.7	9.0	3.84	T_2	39.45	39.45	39.45	39.45	2.45	4.41	16.9
				T_1	37.05	37.10	37.10	37.08			
5	12.6	8.4	3.55	T_2	39.50	39.50	39.50	39.50	2.42	4.36	15.5
				T_1	37.05	37.05	37.00	37.03			
6	10.5	6.8	3.24	T_2	39.45	39.45	39.40	39.43	2.40	4.32	14.0
				T_1	36.60	36.70	36.75	36.68			
7	8.4	4.9	2.90	T_2	39.15	39.20	39.20	39.18	2.50	4.50	13.05
				T_1	36.80	36.85	36.90	36.85			
8	6.2	4.0	2.49	T_2	39.25	39.30	39.30	39.28	2.43	4.38	10.9
				T_1	36.60	36.60	36.60	36.60			
9	4.2	3.6	2.05	T_2	39.10	39.10	39.10	39.10	2.50	4.50	7.8
				T_1	36.70	36.65	36.60	36.65			
10	3.0	3.0	1.732	T_2	39.20	39.15	39.10	39.15	2.50	4.50	7.8
				T_1	36.30	36.30	36.25	36.28			
11	2.0	2.0	1.414	T_2	38.85	38.80	38.80	38.82	2.54	4.57	6.46
				T_1	35.70	35.65	35.60	35.65			
12	1.0	1.0	1.00	T_2	38.40	38.35	38.30	38.35	2.70	4.86	4.86

APPENDIX C.

TEST DATA SHEET NUMBER 25

DATE 3-17-60

TANGENT TUBE MODEL WITH BURNERS

2-2" ORIFICE(S), 21" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	56.5 °F	56.5 °F	56.5 °F
DRY BULB TEMPERATURE	65.0 °F	65.0 °F	65.0 °F
BAROMETER	29.83 "Hg	29.83 "Hg	29.83 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 54 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	37.35	37.40	37.40	37.38			
1	24.0	13.7	4.90	T_2	39.10	39.15	39.20	39.15	1.77	3.19	15.6
				T_1	39.15	37.10	37.10	37.12			
2	19.8	12.2	4.45	T_2	39.05	39.05	39.00	39.03	1.91	3.44	15.3
				T_1	37.05	37.05	37.00	37.03			
3	16.8	9.6	4.10	T_2	38.95	38.95	38.90	38.93	1.90	3.42	14.0
				T_1	37.15	37.15	37.15	37.15			
4	14.65	9.0	3.83	T_2	39.05	39.05	39.05	39.05	1.90	3.42	13.1
				T_1	37.15	37.20	37.20	37.18			
5	12.6	7.8	3.55	T_2	39.10	39.10	39.10	39.10	1.92	3.46	12.3
				T_1	37.20	37.20	37.20	37.20			
6	10.5	6.8	3.24	T_2	39.10	39.10	39.15	39.12	1.92	3.46	11.2
				T_1	37.30	37.30	37.35	37.32			
7	8.4	5.3	2.90	T_2	39.20	39.20	39.25	39.22	1.90	3.42	9.9
				T_1	37.30	37.30	37.25	37.28			
8	6.3	4.0	2.51	T_2	39.20	39.20	39.15	39.18	1.90	3.42	8.6
				T_1	37.15	37.10	37.05	37.10			
9	4.2	3.0	2.05	T_2	39.00	39.00	39.00	39.00	1.90	3.42	7.0
				T_1	36.70	36.70	36.65	36.68			
10	3.0	2.6	1.732	T_2	38.62	38.60	38.60	38.61	1.93	3.47	6.02
				T_1	36.40	36.40	36.40	36.40			
11	2.0	2.0	1.414	T_2	38.30	38.30	38.30	38.30	1.90	3.42	4.84
				T_1	36.15	36.05	36.00	36.07			
12	1.0	1.0	1.00	T_2	38.15	38.05	38.00	38.07	2.00	3.60	3.6

APPENDIX C.

TEST DATA SHEET NUMBER 26

DATE 3-19-60

TANGENT TUBE MODEL WITH BURNERS

3-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	58.5 °F	60.0 °F	59.25 °F
DRY BULB TEMPERATURE	66.5 °F	68.9 °F	67.7 °F
BAROMETER	29.72 "Hg	29.72 "Hg	29.72 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 62 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	37.10	37.10	37.10	37.10			
1	21.8	6.5	4.67	T_2	40.60	40.60	40.60	40.60	3.50	6.30	29.4
				T_1	35.80	35.80	35.80	35.80			
2	18.5	5.3	4.30	T_2	39.40	39.40	39.40	39.40	3.60	6.48	27.9
				T_1	35.80	35.80	35.80	35.80			
3	16.8	4.8	4.10	T_2	39.45	39.45	39.45	39.45	3.65	6.57	26.9
				T_1	35.90	36.00	35.95	35.95			
4	14.6	4.4	3.82	T_2	39.60	39.63	39.60	39.61	3.66	6.59	25.2
				T_1	35.35	35.30	35.30	35.32			
5	12.4	4.0	3.52	T_2	39.25	39.25	39.20	39.22	3.90	7.02	24.7
				T_1	35.08	35.08	35.05	35.07			
6	10.55	3.6	3.25	T_2	39.08	39.03	39.04	39.05	3.98	7.16	23.3
				T_1	35.10	35.15	35.20	35.15			
7	8.50	3.2	2.92	T_2	39.10	39.13	39.16	39.13	3.98	7.16	20.9
				T_1	35.10	35.10	35.10	35.10			
8	6.40	2.9	2.53	T_2	39.15	39.15	39.15	39.15	4.05	7.29	18.45
				T_1	35.05	35.05	35.05	35.05			
9	4.25	2.0	2.06	T_2	39.15	39.15	39.15	39.15	4.10	7.38	15.2
				T_1	34.95	34.95	34.95	34.95			
10	3.00	1.5	1.732	T_2	39.15	39.15	39.15	39.15	4.20	7.56	13.1
				T_1	34.70	34.70	34.70	34.70			
11	2.00	1.0	1.414	T_2	39.05	39.05	39.05	39.05	4.35	7.65	10.82
				T_1	34.50	34.50	34.50	34.50			
12	1.00	—	1.00	T_2	38.90	38.90	38.90	38.90	4.40	7.92	7.92

APPENDIX C

TEST DATA SHEET NUMBER 27

DATE 3-19-60

TANGENT TUBE MODEL WITH BURNERS

3-2" ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	60.0 °F	57.0 °F	58.5 °F
DRY BULB TEMPERATURE	68.9 °F	65.5 °F	67.2 °F
BAROMETER	29.77 "Hg	29.79 "Hg.	29.78 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 59 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	21.5	6.0	4.65	T_1	36.30	36.20	36.10	36.20	3.05	5.49	25.5
				T_2	39.30	39.25	39.20	39.25			
2	18.8	5.3	4.34	T_1	36.00	36.00	36.00	36.00	3.10	5.58	24.2
				T_2	39.10	39.10	39.10	39.10			
3	16.8	4.4	4.10	T_1	36.05	36.08	36.08	36.07	3.03	5.45	22.4
				T_2	39.10	39.10	39.10	39.10			
4	14.7	4.0	3.84	T_1	36.10	36.10	36.10	36.10	3.00	5.40	20.7
				T_2	39.10	39.10	39.10	39.10			
5	12.7	3.8	3.57	T_1	36.15	36.15	36.20	36.17	3.03	5.45	19.5
				T_2	39.20	39.20	39.20	39.20			
6	10.5	3.0	3.24	T_1	36.25	36.20	36.25	36.23	3.07	5.53	17.9
				T_2	39.30	39.30	39.30	39.30			
7	8.5	2.6	2.92	T_1	36.25	36.25	36.20	36.23	3.05	5.49	16.0
				T_2	39.30	39.30	39.25	39.28			
8	6.35	2.0	2.52	T_1	36.20	36.20	36.20	36.20	3.00	5.40	13.6
				T_2	39.20	39.20	39.20	39.20			
9	4.25	1.7	2.065	T_1	36.10	36.10	36.10	36.10	3.10	5.58	11.55
				T_2	39.20	39.20	39.20	39.20			
10	3.00	1.4	1.732	T_1	35.95	35.90	35.90	35.93	3.15	5.67	9.84
				T_2	39.10	39.08	39.05	39.08			
11	2.00	1.0	1.414	T_1	35.70	35.70	35.70	35.70	3.25	5.85	8.28
				T_2	38.95	38.95	38.95	38.95			
12	1.00	—	1.0	T_1	35.40	35.35	35.30	35.35	3.40	6.12	6.12
				T_2	38.80	38.75	38.70	38.75			

APPENDIX C.

TEST DATA SHEET NUMBER 28

DATE 3-19-60

TANGENT TUBE MODEL With BURNERS

3-2" ORIFICE(S), 14 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.0 °F	57.0 °F	57.0 °F
DRY BULB TEMPERATURE	65.5 °F	66.0 °F	65.75 °F
BAROMETER	29.79 "HG	29.79 "HG	29.79 "HG

REAR WALL STEAM PRESSURE 1 "HG GAGE, SPEC. HUM. 55 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	37.65	37.60	37.60	37.63			
1	21.4	5.3	4.63	T_2	39.88	39.85	39.85	39.86	2.23	4.01	18.6
				T_1	37.65	37.65	37.65	37.65			
2	18.7	4.8	4.33	T_2	39.90	39.90	39.90	39.90	2.25	4.05	17.5
				T_1	37.80	37.80	37.80	37.80			
3	16.7	4.0	4.09	T_2	40.05	40.05	40.05	40.05	2.25	4.05	16.6
				T_1	37.65	37.50	37.45	37.53			
4	14.7	4.0	3.84	T_2	39.95	39.85	39.80	39.87	2.34	4.21	16.2
				T_1	37.05	37.00	37.00	37.02			
5	12.6	3.7	3.56	T_2	39.50	39.45	39.45	39.47	2.45	4.41	15.7
				T_1	36.75	36.70	36.70	36.72			
6	10.5	3.5	3.24	T_2	39.25	39.20	39.20	39.22	2.50	4.50	14.6
				T_1	36.65	36.63	36.60	36.63			
7	8.4	3.0	2.90	T_2	39.15	39.15	39.12	39.14	2.51	4.52	13.1
				T_1	36.55	36.50	36.50	36.52			
8	6.3	2.3	2.51	T_2	39.05	39.00	39.00	39.02	2.50	4.50	11.3
				T_1	36.40	36.40	36.40	36.40			
9	4.2	2.0	2.05	T_2	38.90	38.90	38.90	38.90	2.50	4.50	9.2
				T_1	36.20	36.20	36.20	36.20			
10	3.00	1.5	1.732	T_2	38.75	38.75	38.75	38.75	2.55	4.59	7.95
				T_1	36.00	36.00	36.00	36.00			
11	2.00	1.0	1.414	T_2	38.60	38.60	38.60	38.60	2.60	4.68	6.62
				T_1	35.60	35.55	35.50	35.55			
12	1.00	—	1.00	T_2	38.35	38.30	38.25	38.30	2.75	4.95	4.95

APPENDIX C.

TEST DATA SHEET NUMBER 29

DATE 3-24-60

TANGENT TUBE MODEL WITH BURNERS

3-2" ORIFICE(S), 18" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.5 °F	54.0 °F	54.25 °F
DRY BULB TEMPERATURE	63.5 °F	64.0 °F	63.75 °F
BAROMETER	29.70 "Hg	29.70 "Hg	29.70 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 48 GRAINS / lb DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	31.75	31.78	3.85	31.79			
1	21.9	6.5	4.68	T_2	33.75	33.80	33.85	33.80	2.01	3.62	16.93
				T_1	31.85	31.75	31.70	31.77			
2	19.1	5.3	4.37	T_2	33.90	33.83	33.80	33.84	2.07	3.73	16.30
				T_1	32.55	32.60	32.65	32.60			
3	16.85	4.4	4.11	T_2	34.50	34.55	34.60	34.55	1.95	3.51	14.43
				T_1	33.00	33.20	33.20	33.13			
4	14.70	4.0	3.84	T_2	35.00	35.10	35.10	35.07	1.94	3.49	13.41
				T_1	33.30	33.27	33.30	33.29			
5	12.60	3.6	3.55	T_2	35.27	35.20	35.25	35.24	1.95	3.51	12.47
				T_1	33.33	33.28	33.20	33.27			
6	10.50	3.2	3.24	T_2	35.30	35.25	35.20	35.25	1.98	3.56	11.55
				T_1	33.20	33.20	33.30	33.23			
7	8.40	2.8	2.90	T_2	35.20	35.28	35.30	35.26	2.03	3.65	10.60
				T_1	33.30	33.25	33.25	33.27			
8	6.35	2.3	2.52	T_2	35.30	35.30	35.30	35.30	2.03	3.65	9.20
				T_1	33.10	33.10	33.10	33.10			
9	4.25	2.0	2.06	T_2	35.20	35.20	35.20	35.20	2.10	3.78	7.79
				T_1	33.05	33.05	33.00	33.03			
10	3.00	1.4	1.732	T_2	35.15	35.18	35.10	35.14	2.11	3.80	6.59
				T_1	32.90	32.90	32.90	32.90			
11	2.00	1.0	1.414	T_2	35.05	35.05	35.05	35.05	2.15	3.87	5.47
				T_1	32.70	32.70	32.70	32.70			
12	1.00	—	1.0	T_2	34.90	34.90	34.90	34.90	2.20	3.96	3.96

APPENDIX C

TEST DATA SHEET NUMBER 30

DATE 3-24-60

TANGENT TUBE MODEL WITH BURNERS

3-2" ORIFICE(S), 21" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	54.0 °F	53.2 °F	53.6 °F
DRY BULB TEMPERATURE	64.0 °F	62.8 °F	63.4 °F
BAROMETER	29.70 "Hg	29.70 "Hg	29.70 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 46 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TRIAL	TEMPERATURE °C 1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.20	34.20	34.20	34.20			
1	23.8	6.3	4.88	T_2	35.80	35.80	35.80	35.80	1.60	2.88	14.07
				T_1	33.90	33.90	33.93	33.91			
2	19.0	5.5	4.36	T_2	35.60	35.60	35.60	35.60	1.69	3.04	13.26
				T_1	34.05	34.05	34.05	34.05			
3	16.8	4.4	4.10	T_2	35.70	35.70	35.70	35.70	1.65	2.97	12.18
				T_1	34.10	34.15	34.17	34.14			
4	14.7	4.0	3.84	T_2	35.75	35.80	35.78	35.78	1.64	2.95	11.33
				T_1	34.50	34.50	34.50	34.50			
5	12.7	3.6	3.56	T_2	36.10	36.10	36.10	36.10	1.60	2.88	10.25
				T_1	34.50	34.50	34.50	34.50			
6	10.5	3.0	3.24	T_2	36.10	36.10	36.10	36.10	1.60	2.88	9.33
				T_1	34.35	34.30	34.30	34.32			
7	8.5	2.6	2.92	T_2	36.00	35.95	35.90	35.95	1.63	2.94	8.57
				T_1	34.30	34.30	34.30	34.30			
8	6.35	2.3	2.52	T_2	35.90	35.90	35.90	35.90	1.60	2.88	7.26
				T_1	34.20	34.18	34.10	34.16			
9	4.20	2.0	2.05	T_2	35.80	35.78	35.70	35.76	1.60	2.88	5.90
				T_1	34.05	34.00	33.95	34.00			
10	3.00	1.4	1.732	T_2	35.65	35.60	35.55	35.60	1.60	2.88	4.99
				T_1	33.90	33.90	33.90	33.90			
11	2.00	1.0	1.414	T_2	35.50	35.50	35.50	35.50	1.60	2.88	4.07
				T_1	33.70	33.60	33.60	33.63			
12	1.00	—	1.0	T_2	35.30	35.20	35.20	35.23	1.60	2.88	2.88

APPENDIX C.

TEST DATA SHEET NUMBER 31
DATE 4-1-60

TANGENT TUBE MODEL WITHOUT BURNERS

4-2" ORIFICE(S), 6 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	61.2 °F	62.5 °F	61.85 °F
DRY BULB TEMPERATURE	68.5 °F	71.2 °F	69.85 °F
BAROMETER	29.93 "Hg	29.93 "Hg	29.93 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM 70 GRAINS / lb DRY AIR

RUN NO.	ΔH_F "H_2O	ΔH_B "H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	36.60	36.60	36.65	36.62			
1	21.0	3.2	4.59	T_2	40.35	40.40	40.40	40.38	3.76	6.76	31.1
				T_1	36.75	36.70	36.70	36.72			
2	18.9	3.0	4.35	T_2	40.55	40.50	40.50	40.52	3.80	6.84	29.8
				T_1	36.60	36.60	36.60	36.60			
3	16.55	2.50	4.07	T_2	40.45	40.45	40.45	40.45	3.85	6.93	28.2
				T_1	36.85	36.90	36.90	36.88			
4	14.70	2.0	3.84	T_2	40.75	40.80	40.80	40.78	3.90	7.02	26.95
				T_1	36.95	36.97	37.00	36.97			
5	12.60	1.0	3.55	T_2	40.90	40.90	40.95	40.92	3.95	7.11	25.2
				T_1	37.10	37.05	37.05	37.07			
6	10.50	.5	3.24	T_2	41.10	41.05	41.05	41.07	4.00	7.20	23.3
				T_1	37.10	37.15	37.30	37.18			
7	8.40	—	2.90	T_2	41.15	41.20	41.30	41.22	4.04	7.27	21.1
				T_1	37.30	37.30	37.30	37.30			
8	6.30	—	2.51	T_2	41.40	41.40	41.40	41.40	4.10	7.38	15.5
				T_1	37.35	37.40	37.40	37.38			
9	4.20	—	2.05	T_2	41.50	41.50	41.55	41.52	4.14	7.45	15.3
				T_1	37.40	37.40	37.40	37.40			
10	3.00	—	1.732	T_2	41.60	41.60	41.60	41.60	4.20	7.55	13.1
				T_1	37.35	37.35	37.35	37.35			
11	2.00	—	1.414	T_2	41.65	41.65	41.65	41.65	4.30	7.74	10.95
				T_1	37.20	37.15	37.10	37.15			
12	1.00	—	1.00	T_2	41.65	41.60	41.55	41.60	4.45	8.01	8.01

APPENDIX C

TEST DATA SHEET NUMBER 32

DATE 4-1-60

TANGENT TUBE MODEL WITHOUT BURNERS

4-2 ORIFICE(S), 10" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	62.5 °F	61.2 °F	61.85 °F
DRY BULB TEMPERATURE	71.2 °F	70.3 °F	70.75 °F
BAROMETER	29.93 "Hg	29.93 "Hg	29.93 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 68 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	22.0	4.0	4.70	T_1	37.90	37.90	37.90	37.90	2.92	5.25	24.7
				T_2	40.85	40.80	40.80	40.82			
2	19.0	3.5	4.36	T_1	38.10	38.20	38.20	38.18	2.95	5.31	23.1
				T_2	41.05	41.15	41.20	41.13			
3	16.8	3.0	4.10	T_1	38.40	38.45	38.50	38.45	2.95	5.31	21.7
				T_2	41.35	41.40	41.45	41.40			
4	14.7	2.0	3.84	T_1	38.60	38.60	38.60	38.60	3.00	5.40	20.7
				T_2	41.60	41.60	41.60	41.60			
5	12.6	1.0	3.55	T_1	38.55	38.55	38.45	38.52	3.04	5.47	19.4
				T_2	41.60	41.58	41.50	51.56			
6	10.5	—	3.24	T_1	38.40	38.40	38.40	38.40	3.05	5.49	17.8
				T_2	41.45	41.45	41.45	41.45			
7	8.4	—	2.90	T_1	38.40	38.45	38.50	38.45	3.03	5.45	15.8
				T_2	41.45	41.50	41.50	41.48			
8	6.3	—	2.51	T_1	38.60	38.60	38.60	38.60	3.00	5.40	13.6
				T_2	41.60	41.60	41.60	41.60			
9	4.2	—	2.05	T_1	38.65	38.65	38.65	38.65	3.05	5.49	11.2
				T_2	41.70	41.70	41.70	41.70			
10	3.0	—	1.732	T_1	38.70	38.70	38.70	38.70	3.00	5.40	9.36
				T_2	41.70	41.70	41.70	41.70			
11	2.0	—	1.414	T_1	38.50	38.45	38.40	38.45	3.10	5.58	7.91
				T_2	41.60	41.55	41.50	41.55			
12	1.0	—	1.00	T_1	38.00	37.95	37.90	37.95	3.32	5.98	6.0
				T_2	41.30	41.25	41.25	41.27			

APPENDIX C

TEST DATA SHEET NUMBER 33

DATE 4-2-60

TANGENT TUBE MODEL Without BURNERS

4-2" ORIFICE(S), 4 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	61.0 °F	57.8 °F	59.4 °F
DRY BULB TEMPERATURE	69.0 °F	66.5 °F	67.75 °F
BAROMETER	30.33 "Hg	30.33 "Hg	30.33 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 62 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C, TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	21.2	3.7	4.61	T_1	34.00	34.00	33.95	33.98	2.47	4.45	20.5
				T_2	36.50	36.45	36.40	36.45			
2	19.0	3.0	4.36	T_1	34.07	34.07	34.07	34.07	2.43	4.38	19.1
				T_2	36.50	36.50	36.50	36.50			
3	17.0	2.5	4.125	T_1	34.10	34.10	34.10	34.10	2.47	4.45	18.35
				T_2	36.60	36.57	36.55	36.57			
4	14.7	2.0	3.84	T_1	34.25	34.30	34.35	34.30	2.42	4.36	17.1
				T_2	36.70	36.70	36.75	36.72			
5	12.6	1.5	3.55	T_1	34.40	34.40	34.40	34.40	2.45	4.41	15.6
				T_2	36.85	36.85	36.85	36.85			
6	10.5	1.0	3.24	T_1	34.45	34.50	34.50	34.48	2.42	4.36	14.1
				T_2	36.90	36.90	36.90	36.90			
7	8.4	—	2.90	T_1	34.50	34.55	34.60	34.55	2.43	4.38	12.7
				T_2	36.95	36.95	37.00	36.98			
8	6.3	—	2.51	T_1	34.55	34.55	34.55	34.55	2.44	4.46	11.2
				T_2	37.00	37.05	37.05	37.03			
9	4.2	—	2.05	T_1	34.50	34.50	34.50	34.50	2.50	4.50	9.2
				T_2	37.00	37.00	37.00	37.00			
10	3.00	—	1.732	T_1	34.50	34.55	34.55	34.53	2.50	4.50	7.8
				T_2	37.00	37.05	37.05	37.03			
11	2.00	—	1.414	T_1	34.40	34.37	34.35	34.37	2.55	4.59	6.5
				T_2	36.95	36.92	36.90	36.92			
12	1.00	—	1.00	T_1	33.75	33.76	33.75	33.75	2.75	4.95	4.95
				T_2	36.50	36.50	36.50	36.50			

APPENDIX C.

TEST DATA SHEET NUMBER 34

DATE 4-2-60

TANGENT TUBE MODEL WITHOUT BURNERS

4-2" ORIFICE(S), 18" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.8 °F	58.0 °F	57.9 °F
DRY BULB TEMPERATURE	66.5 °F	66.8 °F	66.65 °F
BAROMETER	30.33 "Hg.	30.33 "Hg.	30.33 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 58 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.65	34.65	34.65	34.65			
1	21.0	3.5	4.59	T_2	36.60	36.60	36.60	36.60	1.95	3.51	16.1
				T_1	39.80	34.80	34.80	34.80			
2	19.0	2.7	4.36	T_2	36.75	36.75	36.75	36.75	1.95	3.51	15.3
				T_1	35.00	35.00	35.00	35.00			
3	16.8	2.0	4.10	T_2	36.95	36.95	36.95	36.95	1.95	3.51	14.4
				T_1	35.25	35.25	35.25	35.25			
4	14.7	1.0	3.84	T_2	37.20	37.20	37.20	37.20	1.95	3.51	13.5
				T_1	35.30	35.70	35.30	35.30			
5	12.6	—	3.55	T_2	37.25	37.25	37.25	37.25	1.95	3.51	12.5
				T_1	35.30	35.35	35.35	35.33			
6	10.5	—	3.24	T_2	37.30	37.35	37.35	37.33	2.00	3.60	11.65
				T_1	35.35	35.40	35.37	35.37			
7	8.4	—	2.90	T_2	35.35	37.40	37.38	37.37	2.00	3.60	10.4
				T_1	35.45	35.45	35.50	35.47			
8	6.3	—	2.51	T_2	37.45	37.045	37.50	37.47	2.00	3.60	9.0
				T_1	35.50	35.45	35.45	35.47			
9	4.2	—	2.05	T_2	37.50	37.48	37.45	37.48	2.01	3.62	7.4
				T_1	35.25	35.25	35.25	35.25			
10	3.0	—	1.732	T_2	37.35	37.35	37.35	37.35	2.10	3.78	6.55
				T_1	35.10	35.10	35.10	35.10			
11	2.0	—	1.414	T_2	37.25	37.25	37.25	37.25	2.15	3.87	5.5
				T_1	34.80	34.75	34.70	34.75			
12	1.0	—	1.00	T_2	37.10	37.05	37.00	37.05	2.30	4.14	4.14

APPENDIX C

TEST DATA SHEET NUMBER 35

DATE 4-2-60

TANGENT TUBE MODEL Without BURNERS

4-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	58.00 °F	58.2 °F	58.1 °F
DRY BULB TEMPERATURE	66.8 °F	67.0 °F	66.9 °F
BAROMETER	30.33 "Hg.	30.33 "Hg.	30.33 "Hg

REAR WALL STEAM PRESSURE / "Hg GAGE, SPEC. HUM. 59 GRAINS/lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C					ΔT °C	ΔT °F	$\Delta T \sqrt{\Delta H_F}$
				TRIAL	1	2	3	AVG.			
				T_1	35.5	35.5	35.5	85.5			
1	21.0	3.7	4.59	T_2	37.15	37.15	37.15	37.15	1.65	2.97	13.6
				T_1	35.55	35.60	35.60	35.58			
2	19.0	3.0	4.36	T_2	37.20	37.25	37.25	37.23	1.65	2.97	13.0
				T_1	35.70	35.70	35.70	35.70			
3	16.8	2.5	4.10	T_2	37.35	37.35	37.35	37.35	1.65	2.97	12.2
				T_1	35.75	35.75	35.75	35.75			
4	14.7	2.0	3.84	T_2	37.40	37.40	37.40	37.40	1.65	2.97	11.4
				T_1	35.80	35.80	35.80	35.80			
5	12.6	1.0	3.55	T_2	37.45	37.45	37.45	37.45	1.65	2.97	10.5
				T_1	35.80	35.80	35.80	35.80			
6	10.5	—	3.24	T_2	37.45	37.45	37.45	37.45	1.65	2.97	9.6
				T_1	35.85	35.90	35.85	35.87			
7	8.4	—	2.90	T_2	37.50	37.55	37.50	37.52	1.65	2.97	8.6
				T_1	35.80	35.80	35.80	35.80			
8	6.3	—	2.51	T_2	37.50	37.50	37.50	37.50	1.70	3.06	7.7
				T_1	35.75	35.75	35.75	35.75			
9	4.2	—	2.05	T_2	37.50	37.50	37.50	37.50	1.75	3.15	6.45
				T_1	35.60	35.60	35.60	35.60			
10	3.0	—	1.732	T_2	37.40	37.40	37.40	37.40	1.80	3.24	5.6
				T_1	35.40	35.40	35.40	35.40			
11	2.0	—	1.414	T_2	37.25	37.25	37.25	37.25	1.85	3.33	4.7
				T_1	35.20	35.15	35.10	35.15			
12	1.0	—	1.00	T_2	37.15	37.10	37.10	37.12	1.97	3.55	3.55

APPENDIX C.

TEST DATA SHEET NUMBER 36

DATE 4-7-60

TANGENT TUBE MODEL WITH BURNERS

4-2" ORIFICE(S), 6" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	55.3 °F	55.9 °F	55.6 °F
DRY BULB TEMPERATURE	65.5 °F	66.1 °F	65.8 °F
BAROMETER	29.76 "Hg.	29.76 "Hg.	29.76 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 48 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T \sqrt{\Delta H_F}$
				T_1	34.70	34.70	34.70	34.70			
1	21.3	4.0	4.62	T_2	37.50	37.50	37.50	37.50	2.80	5.04	23.3
				T_1	34.65	34.65	34.65	34.65			
2	19.0	3.7	4.36	T_2	37.50	37.50	37.50	37.50	2.85	5.13	22.4
				T_1	34.70	34.65	34.55	34.63			
3	16.9	3.2	4.11	T_2	37.50	37.50	37.40	37.47	2.84	5.11	21.0
				T_1	34.65	34.67	34.65	34.66			
4	14.8	3.0	3.85	T_2	37.50	37.55	37.50	37.52	2.86	5.19	19.9
				T_1	34.70	34.75	34.70	34.72			
5	12.7	2.7	3.57	T_2	37.60	37.65	37.60	37.62	2.90	5.22	18.6
				T_1	34.85	34.90	34.90	34.88			
6	10.7	2.4	3.28	T_2	37.80	37.85	37.85	37.83	2.95	5.31	17.4
				T_1	35.05	35.05	35.05	35.05			
7	8.5	2.0	2.92	T_2	38.00	38.00	38.00	38.00	2.95	5.31	15.5
				T_1	35.05	35.05	35.05	35.05			
8	6.4	1.0	2.53	T_2	38.05	38.05	38.05	38.05	3.00	5.40	13.7
				T_1	35.10	35.10	35.10	35.10			
9	4.2	—	2.05	T_2	38.10	38.10	38.10	38.10	3.00	5.40	11.1
				T_1	35.10	35.10	35.10	35.10			
10	3.0	—	1.732	T_2	38.15	38.15	38.15	38.15	3.05	5.49	9.5
				T_1	35.00	34.95	34.90	34.95			
11	2.0	—	1.414	T_2	38.10	38.05	38.05	38.08	3.13	5.64	8.0
				T_1	34.60	34.55	34.50	34.55			
12	1.0	—	1.0	T_2	37.90	37.85	37.80	37.85	3.30	5.94	5.94

APPENDIX C.

TEST DATA SHEET NUMBER 37

DATE 4-23-60

TANGENT TUBE MODEL without BURNERS

4-2" ORIFICE(S), 10 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.0 °F	58.0 °F	57.5 °F
DRY BULB TEMPERATURE	65.8 °F	66.0 °F	65.9 °F
BAROMETER	30.00 "Hg.	30.00 "Hg.	30.00 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 57 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F " H_2O	ΔH_B " H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.45	34.45	34.50	34.47			
1	21.1	4.0	4.6	T_2	36.80	36.80	36.85	36.82	2.35	4.23	19.55
				T_1	34.65	34.70	34.75	34.70			
2	19.0	3.5	4.36	T_2	37.00	37.05	37.10	37.05	2.35	4.23	18.45
				T_1	34.85	34.90	34.95	34.90			
3	16.85	3.2	4.11	T_2	37.20	37.30	37.30	37.27	2.37	4.26	17.5
				T_1	35.45	35.37	35.35	35.39			
4	14.8	3.0	3.85	T_2	37.80	37.75	37.70	37.75	2.36	4.25	16.37
				T_1	34.87	34.87	34.87	34.87			
5	12.6	2.7	3.55	T_2	37.30	37.30	37.30	37.30	2.43	4.37	15.35
				T_1	34.90	35.00	35.00	34.97			
6	10.5	2.5	3.24	T_2	37.40	37.42	37.40	37.41	2.44	4.39	14.2
				T_1	35.00	35.00	35.00	35.00			
7	8.5	2.0	2.92	T_2	37.50	37.50	37.50	37.50	2.50	4.50	13.1
				T_1	34.80	34.80	34.80	34.80			
8	6.4	1.5	2.53	T_2	37.30	37.35	37.35	37.33	2.53	4.55	11.5
				T_1	34.70	34.70	34.70	34.70			
9	4.3	1.0	2.08	T_2	37.30	37.30	37.30	37.30	2.60	4.67	9.75
				T_1	34.30	34.30	34.35	34.32			
10	3.0	—	1.732	T_2	36.95	36.90	36.95	36.93	2.61	4.70	8.15
				T_1	32.87	32.85	32.90	32.87			
11	2.0	—	1.414	T_2	35.70	35.70	35.73	35.71	2.84	5.11	7.23
				T_1	32.90	32.80	32.75	32.82			
12	1.0	—	1.000	T_2	35.77	35.70	35.70	35.72	2.90	5.22	5.22

APPENDIX C

TEST DATA SHEET NUMBER 38

DATE 4-23-60

TANGENT TUBE MODEL WITH BURNERS

4-2" ORIFICE(S), 14" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	58.0 °F	57.0 °F	57.5 °F
DRY BULB TEMPERATURE	66.0 °F	65.4 °F	65.7 °F
BAROMETER	30.00 "Hg.	30.00 "Hg.	30.00 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 58 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F "H_2O	$\dot{\Delta} H_B$ "H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	33.90	33.90	34.00	33.93			
1	21.1	4.0	4.6	T_2	35.70	35.75	35.80	35.75	1.82	3.28	15.1
				T_1	34.12	34.10	34.10	34.11			
2	19.0	3.5	4.36	T_2	35.95	35.90	35.92	35.93	1.82	3.28	14.3
				T_1	34.25	34.25	34.25	34.25			
3	16.85	3.2	4.11	T_2	36.10	36.10	36.10	36.10	1.85	3.33	13.7
				T_1	34.25	34.25	34.25	34.25			
4	14.80	3.0	3.85	T_2	36.10	36.10	36.10	36.10	1.85	3.33	12.8
				T_1	34.30	34.40	34.40	34.37			
5	12.70	2.5	3.57	T_2	36.15	36.20	36.20	36.18	1.81	3.26	11.65
				T_1	34.10	34.10	34.10	34.10			
6	10.70	2.2	3.28	T_2	35.95	36.00	36.00	35.98	1.88	3.38	11.1
				T_1	34.00	33.90	33.90	33.93			
7	8.50	2.0	2.92	T_2	35.90	35.85	35.80	35.85	1.92	3.46	10.1
				T_1	33.90	33.90	33.90	33.90			
8	6.40	1.5	2.53	T_2	35.85	35.85	35.85	35.86	1.95	3.51	8.9
				T_1	34.20	34.20	34.20	34.20			
9	4.30	1.0	2.08	T_2	36.10	36.10	36.10	36.10	1.90	3.42	7.1
				T_1	34.10	34.10	34.10	34.10			
10	3.00	—	1.732	T_2	36.00	36.00	36.00	36.00	1.90	3.42	5.9
				T_1	33.80	33.80	33.80	33.80			
11	2.00	—	1.414	T_2	35.80	35.80	35.80	35.80	2.00	3.60	5.1
				T_1	33.40	33.35	33.30	33.35			
12	1.00	—	1.00	T_2	35.40	35.35	35.30	35.35	2.00	3.60	3.6

APPENDIX C.

TEST DATA SHEET NUMBER 39

DATE 4-23-60

TANGENT TUBE MODEL WITH BURNERS.

4-2" ORIFICE(S), 18" FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.0 °F	57.4 °F	57.2 °F
DRY BULB TEMPERATURE	65.4 °F	65.4 °F	65.4 °F
BAROMETER	30.00 "Hg.	30.00 "Hg.	30.00 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 57 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F "H_2O	ΔH_B "H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
1	21.0	4.0	4.59	T_1	34.30	34.30	34.33	34.31	1.57	2.83	13.0
				T_2	35.88	35.85	35.90	35.88			
2	18.8	3.5	4.34	T_1	34.30	34.35	34.35	34.33	1.55	2.79	12.1
				T_2	35.85	35.90	35.90	35.88			
3	16.9	3.0	4.11	T_1	34.90	34.85	34.85	34.87	1.50	2.70	11.1
				T_2	36.40	36.35	36.35	36.37			
4	14.8	2.7	3.85	T_1	34.90	34.90	34.90	34.90	1.50	2.70	10.4
				T_2	36.40	36.40	36.40	36.40			
5	12.6	2.2	3.55	T_1	34.90	34.95	34.95	34.93	1.54	2.77	9.85
				T_2	36.45	36.50	36.45	36.47			
6	10.6	2.0	3.26	T_1	34.95	35.00	35.00	34.98	1.54	2.77	9.04
				T_2	36.55	36.50	36.50	36.52			
7	8.4	1.5	2.90	T_1	34.90	34.95	35.00	34.95	1.58	2.84	8.25
				T_2	36.50	36.55	36.55	36.53			
8	6.4	1.0	2.53	T_1	35.00	35.05	35.10	35.05	1.60	2.88	7.27
				T_2	36.60	36.65	36.70	36.65			
9	4.3	—	2.08	T_1	34.80	34.80	34.80	34.80	1.70	3.06	6.36
				T_2	36.50	36.50	36.50	36.50			
10	3.00	—	1.732	T_1	34.80	34.80	34.80	34.80	1.70	3.06	5.30
				T_2	36.50	36.50	36.50	36.50			
11	2.00	—	1.414	T_1	34.65	34.65	34.65	34.65	1.65	2.97	4.20
				T_2	36.30	36.30	36.30	36.30			
12	1.01	—	1.00	T_1	34.30	34.30	34.30	34.30	1.70	3.06	3.06
				T_2	36.00	36.00	36.00	36.00			

APPENDIX C.

TEST DATA SHEET NUMBER 40

DATE 3-23-60

TANGENT TUBE MODEL With BURNERS.

4-2" ORIFICE(S), 21 " FURNACE DEPTH, 2.114" FLOW METER

AMBIENT CONDITIONS

	START	FINISH	AVERAGE
WET BULB TEMPERATURE	57.4 °F	57.4 °F	57.4 °F
DRY BULB TEMPERATURE	65.4 °F	65.6 °F	65.5 °F
BAROMETER	30.00 "Hg.	30.00 "Hg.	30.00 "Hg

REAR WALL STEAM PRESSURE 1 "Hg GAGE, SPEC. HUM. 58 GRAINS / lb. DRY AIR

RUN NO.	ΔH_F "H_2O	ΔH_B "H_2O	$\sqrt{\Delta H_F}$	TEMPERATURE °C TRIAL	1	2	3	AVG.	ΔT °C	ΔT °F	$\Delta T\sqrt{\Delta H_F}$
				T_1	34.90	34.90	34.90	34.90			
1	21.0	4.00	4.59	T_2	36.20	36.20	36.20	36.20	1.30	2.34	10.72
				T_1	34.85	34.90	34.90	34.88			
2	19.0	3.50	4.36	T_2	36.20	36.20	36.20	36.20	1.32	2.38	10.39
				T_1	34.90	34.90	34.90	34.90			
3	16.9	3.20	4.11	T_2	36.20	36.20	36.20	36.20	1.30	2.34	9.62
				T_1	35.00	35.00	35.00	35.00			
4	14.7	3.00	3.84	T_2	36.30	36.30	36.30	36.30	1.30	2.34	8.98
				T_1	35.00	35.05	35.05	35.05			
5	12.6	2.50	3.56	T_2	36.30	36.35	36.35	36.35	1.30	2.34	8.33
				T_1	35.05	35.00	35.05	35.03			
6	10.6	2.00	3.26	T_2	36.35	36.30	36.35	36.33	1.30	2.34	7.62
				T_1	35.00	35.00	35.00	35.00			
7	8.5	1.60	2.92	T_2	36.30	36.30	36.30	36.30	1.30	2.34	6.83
				T_1	35.10	35.10	35.10	35.10			
8	6.40	1.20	2.53	T_2	36.35	36.35	36.35	36.35	1.25	2.25	5.70
				T_1	35.05	35.05	35.05	35.05			
9	4.30	1.0	2.08	T_2	36.30	36.30	36.30	36.30	1.25	2.25	4.68
				T_1	34.95	34.95	34.95	34.95			
10	3.00	—	1.732	T_2	36.20	36.20	36.20	36.20	1.25	2.25	3.90
				T_1	34.75	34.75	34.75	34.75			
11	2.00	—	1.414	T_2	36.00	36.00	36.00	36.00	1.25	2.25	3.18
				T_1	34.20	34.20	34.20	34.20			
12	1.00	—	1.00	T_2	35.45	35.45	35.45	35.45	1.25	2.25	2.25

APPENDIX D

CALCULATION OF WEIGHT FLOW, SPECIFIC HEAT, VISCOSITY, AND THERMAL CONDUCTIVITY.

The weight of air flowing is dependent on the following:

1. Geometry of the fluid meter.
2. Head loss across the fluid meter.
3. Specific humidity of the air.
4. Air temperature.
5. Air pressure.

Factors 1 and 2 are considered when using the method of calculating fluid velocity, as recommended by The American Society of Mechanical Engineers(18). Mass flow, however, is also dependent on the specific volume of the fluid.

Using the gas equation, i.e., pv = RT, it is evident that v is dependent on R, T, and p. The specific humidity of the air has the effect of changing the molecular weight of the fluid and thus the gas constant, R. Since the value of R is not very sensitive to small changes in specific humidity, an average value of 50 grains per pound of dry air was assumed only for the purpose of calculating the weight of fluid flowing.

Since the air temperature varies considerably from day to day over the year, the temperature of the air had to be accounted for. An assumed temperature of 100° F. was used in calculating the weight flow curve, and corrected to the actual temperature by the following relationship:

Since $\Delta H_F \sim v$ and $c \sim \sqrt{\Delta H_F}$, then $c \sim \sqrt{v}$ but $G = \frac{c}{v}$ and $v \sim T$

Therefore $W_a \sim G \sim \frac{1}{\sqrt{T}}$

From some early testing it became evident that the upstream pressure varied from run to run. The maximum pressure was less than 30 inches of water or about 7% of atmospheric pressure. Since the velocity of flow c was proportional to p, the maximum error introduced by assuming atmospheric pressure is about 3½%. However, when metering an expansible fluid, an adiabatic expansion factor Y must be introduced[18]. This factor, less than unity, will reduce the flow. Considering the maximum pressure of 30 inches of water, the pressure ratio, $r = \frac{P2}{P1} = .93.$

From Figure 97 of Reference 18, using $\beta = .689$, the adiabatic expansion factor $Y_1 = .975$.

Therefore, by considering the pressure at atmospheric, i.e., $r = 1.0$, $Y_1 = 1$, the maximum error is:

$1.035 (.975) - 1 = .009$ or 9/10 of 1%.

In addition, since both Nusselt Number and Reynolds Number are directly proportional to W_a, both values have the same maximum error or .9%. Since N_{Nu} is proportional to $N_{Re}^{.87}$, the maximum error introduced in the actual plots of N_{Nu} vs. N_{Re} is of the order of $(1.009)^{.87} - (1.009)$, or .12%. Since this is the maximum possible error and decreases with decreased weight of fluid flowing, it is negligible. Therefore, the pressure was assumed at 14.7 psia and no correction made for changes in pressure.

Values of W_a corresponding to ΔH_F values of 0 to 30 inches of water were calculated and are plotted in Figure D-2. The following is a sample calculation showing the method used:

$$C = C_d \sqrt{2gH}$$

where C is velocity of fluid flowing in ft/sec, H is head loss through the flow meter in feet of fluid flowing, and C_d is the coefficient of discharge. Since ΔH_F was measured in inches of water, then:

$$H = \Delta H_F \times \frac{1}{12} \times 144 \times .433 \times V$$

where V is the specific volume of fluid flowing in cubic feet per pound.

Therefore;

$$C = C_d \sqrt{2 \times 32.2 \times .433 \times 144 \times \frac{1}{12} \times V \times \Delta H_F}$$

$$\text{or} \quad C = 18.3\, C_d \sqrt{V} \sqrt{H_F}$$

Assuming an average specific humidity of 50 gr/lb. dry air, a temperature of 100° F, and a standard pressure of 14.7 psia, and using:

M_a = molecular weight of air = 28.970[19].

M_{H_2O} = molecular weight of water vapor = 18.016[19].

$$M_{WET\ AIR} = \frac{50(18.016) + 7000(28.970)}{7000 + 50} = 28.892$$

$$R = \frac{1545.32}{M} = \frac{1545.32}{28.892} = 53.486$$

$$V = \frac{RT}{P} = \frac{53.486(560)}{14.7(144)} = 14.15 \ \text{ft}^3/\text{lb.}$$

$$G = \frac{C}{V} = \frac{18.3\, C_d \sqrt{\Delta H_F}}{\sqrt{V}} = \frac{18.3}{\sqrt{14.15}} C_d \sqrt{\Delta H_F} = 4.87\, C_d \sqrt{\Delta H_F}$$

$$A = \frac{\pi d^2}{4 \times 144} = \frac{\pi (2.114)^2}{4 \times 144} = .02441 \text{ FT}^2$$

$$W_a = 3600 \times G \times A = 3600 \times .02441 \times G = 87.8766 \text{ lbs/HR}$$

Again at the conditions assumed:

$$\mu_a = .04605 \quad \text{lbs/HR-FT}^{(19)}$$

$$\mu_{H_2O} = .0231 \quad \text{lbs/HR-FT}^{(19)}$$

Therefore: $\mu_{\text{WET AIR}} = \dfrac{50(.0231) + 7000(.04605)}{7000 + 50} = .0459$ lbs/HR-FT

$$N_{Re} = \frac{Gd}{\mu} = \frac{3600 \times 2.114}{12 \times .0459} G = 1.382 \times 10^4 G$$

$$C_d = K\sqrt{1-(\beta)^4}$$

Where β is D_2/D_1, D_1 is inside pipe diameter, and D_2 is orific diameter, and K is the coefficient from Table 12, ASME[18].

$$\beta = \frac{D_2}{D_1} = \frac{2.114}{3.068} = .689$$

$$C_d = K\sqrt{1-(.689)^4} = .881 K$$

Values of K interpolated from Reference 18 are plotted in Figure D-1.

Assuming ΔH_F = 16 inches, then $\sqrt{\Delta H_F}$ = 4.0. Estimating C_d as .609 gives the following:

$$G = 4.87 C_d \sqrt{\Delta H_F} = 4.87(.609)4.0 = 11.8633$$

$$N_{Re} = 1.381 \times 10^4 G = 1.381 \times 10^4 (11.8633) = 163,951$$

FROM FIG. D-1, $K = .6911$ AND $C_d = .881 K = .6089$.

$$\therefore G = 4.87(.6089)4 = 11.8614$$

Therefore:

$$W_a = 87.876 \times 11.8614 = 1044 \text{ lbs WET AIR/HOUR}$$

The values of specific heat were computed for a pound of wet air by the following equation and are plotted in Figure D-3:

$$C_P = \frac{x(C_{P_{H_2O}}) + 7000(C_{P_a})}{7000 + x} = \text{BTU/lb. WET AIR,}$$

where $C_{p_{H_2O}}$ is specific heat of water vapor[19],

C_{p_a} is specific heat of air[19], and

x is specific humidity in gr/lb. of dry air.

Viscosity and thermal conductivity are taken directly from the table for dry air[19] and are plotted in Figure D-4.

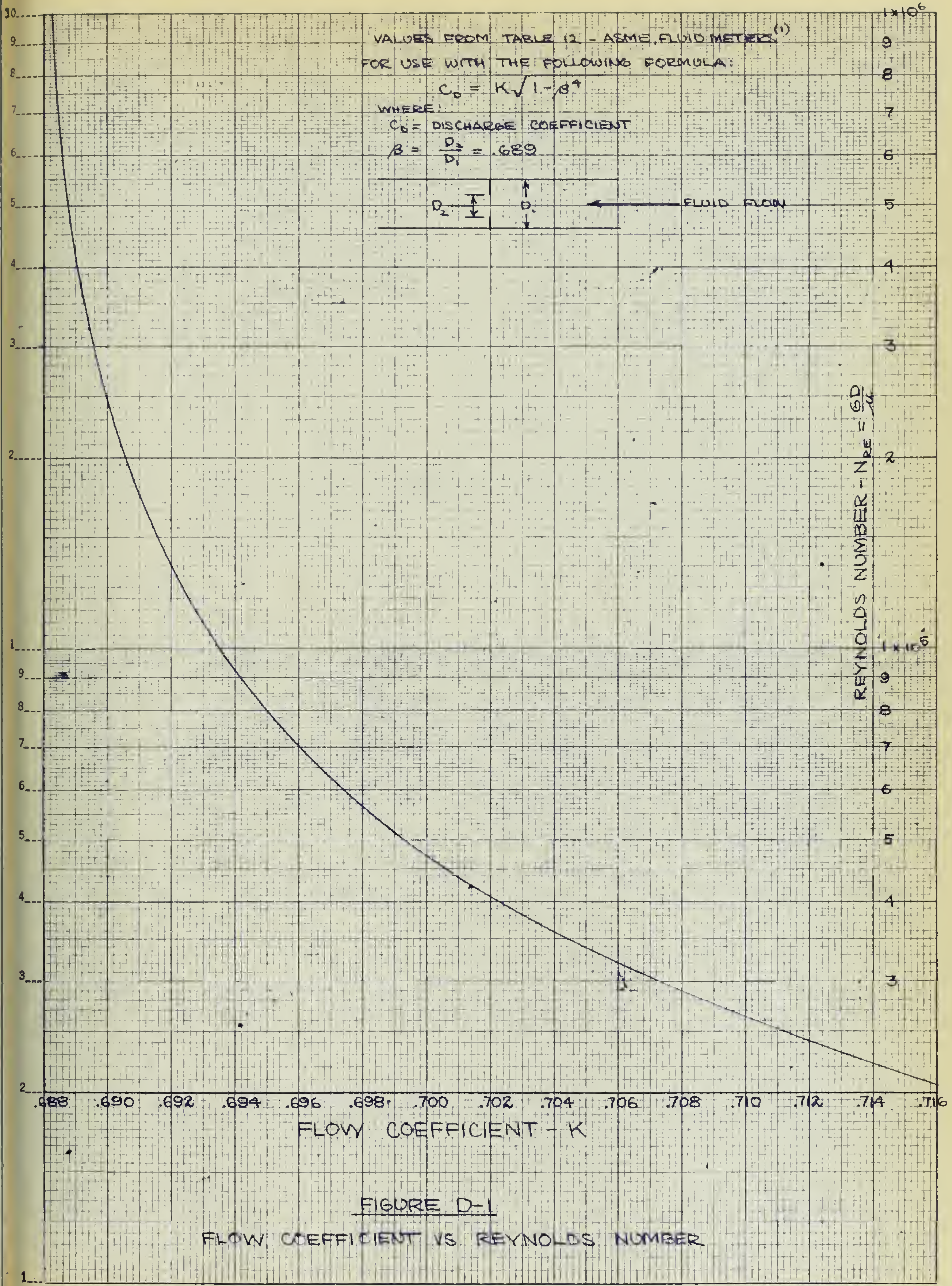


FIGURE D-1

FLOW COEFFICIENT VS REYNOLDS NUMBER

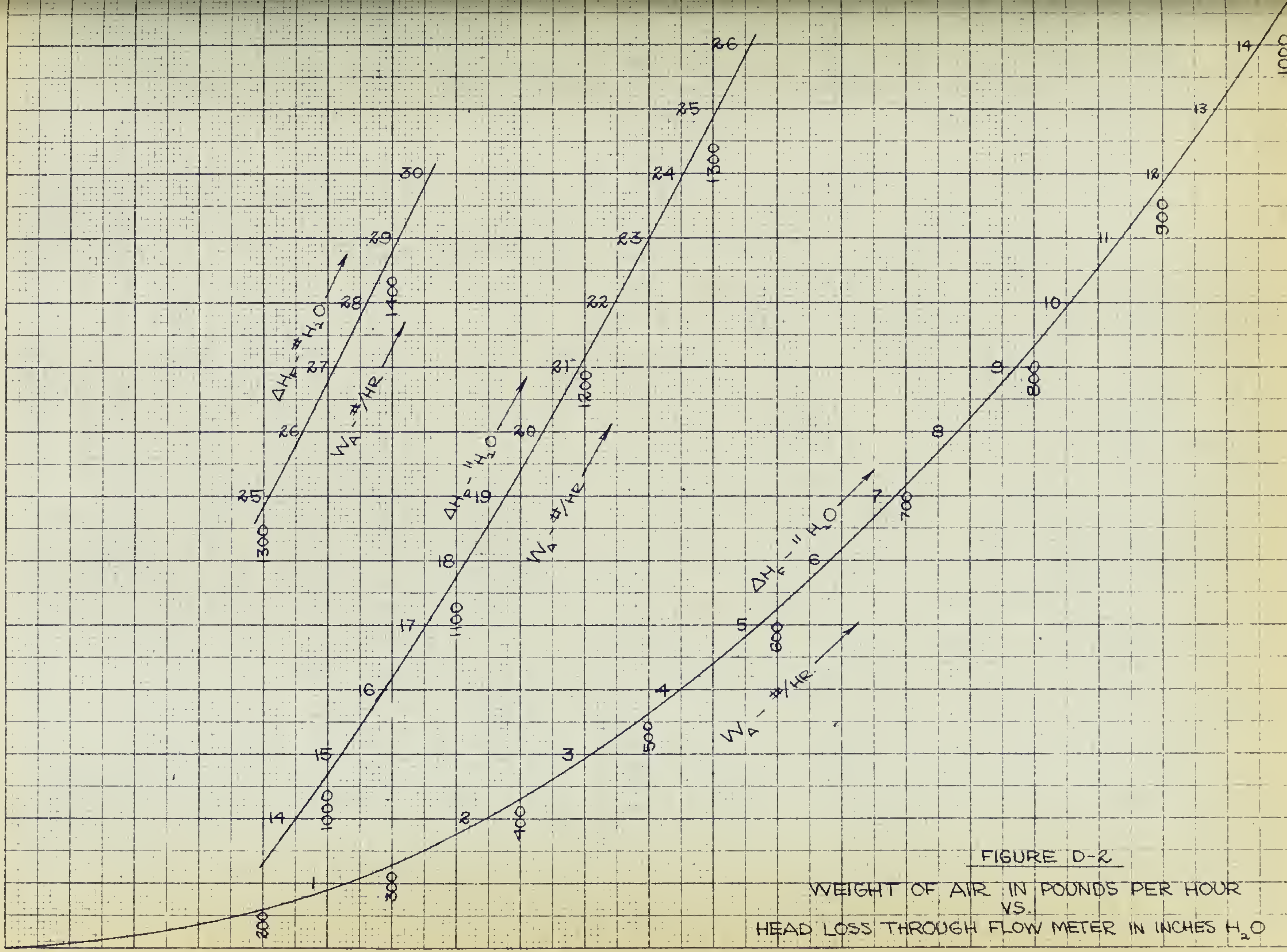


FIGURE D-2

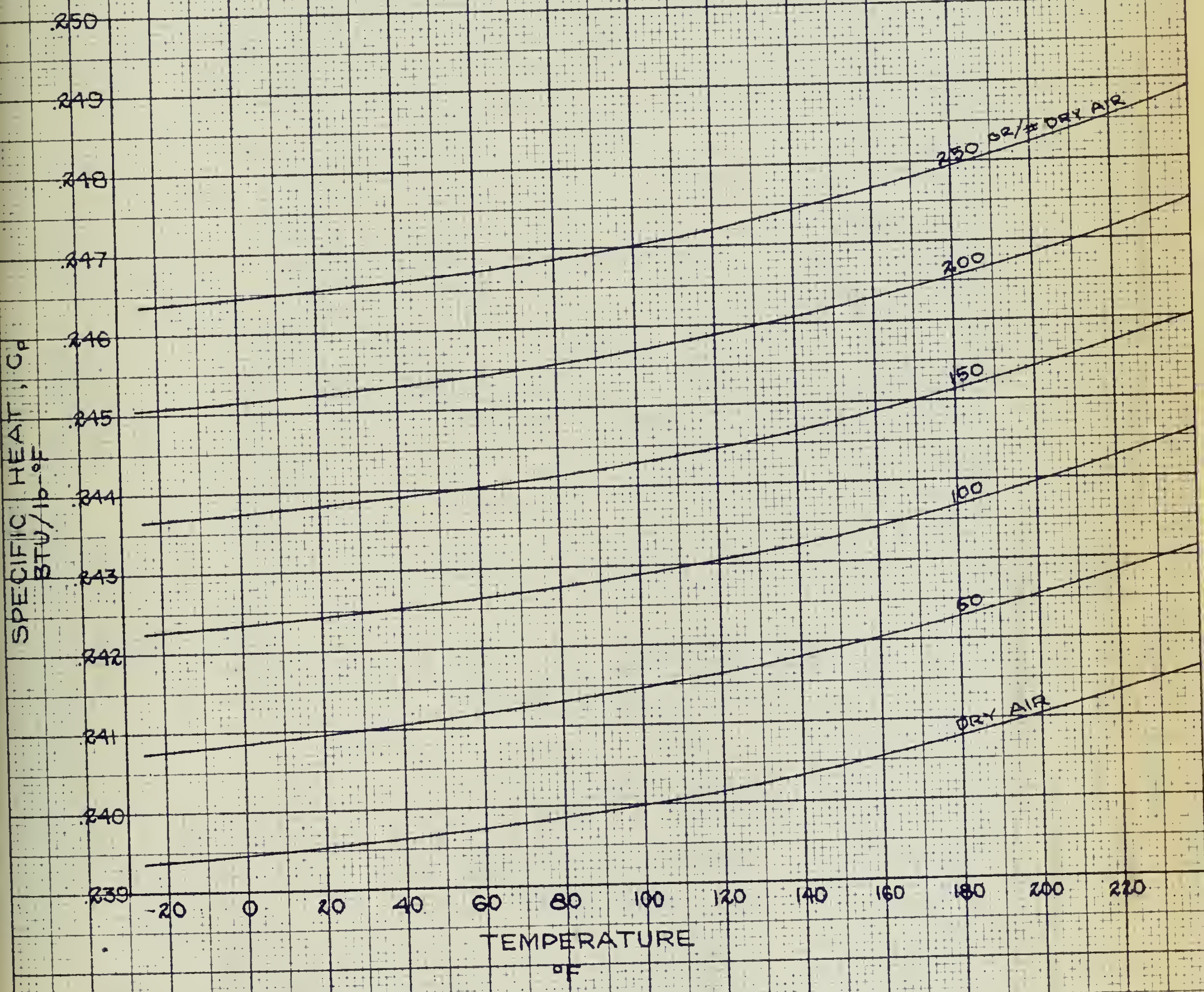
WEIGHT OF AIR IN POUNDS PER HOUR
VS.
HEAD LOSS THROUGH FLOW METER IN INCHES H_2O

FIGURE D-3

SPECIFIC HEAT OF AIR WITH MOISTURE

VALUES ARE PER lb. WET AIR

COMPUTED FROM VALUES OF SPECIFIC HEAT
FOR DRY AIR AND WATER VAPOR
FROM
"GAS TABLES", KEENAN & KAYE (9)



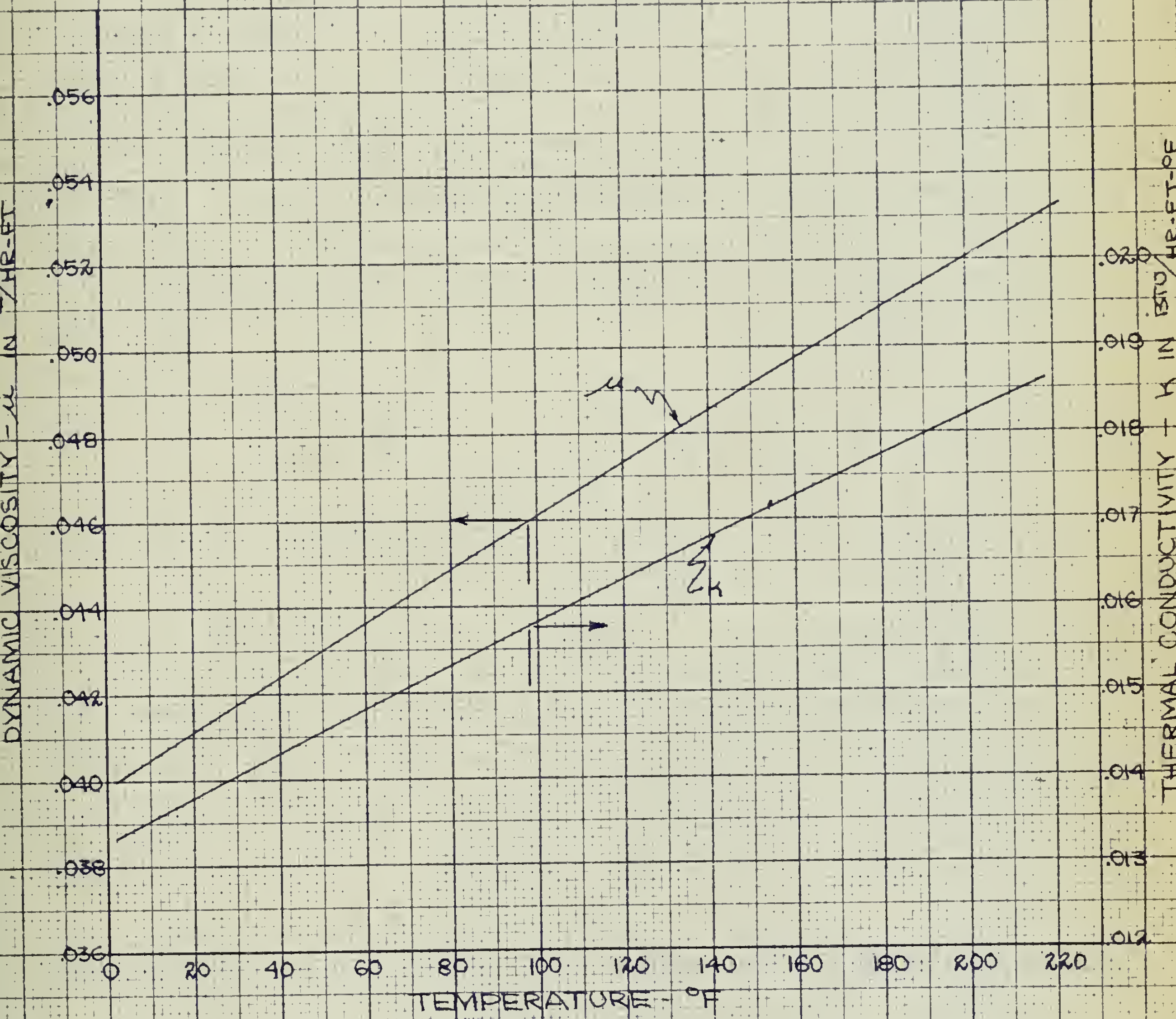


FIGURE D-4
PROPERTIES OF DRY AIR

FROM: KEENAN AND KAYE, GAS TABLES (19)

APPENDIX E

CALCULATION OF NUSSELT NUMBER and REYNOLDS NUMBER

For each test spot the Nusselt Number and Reynolds Number was calculated and plotted in Figures 1 through 10. The heat transferred was equal to the weight of gas times the specific heat times the change in temperature. Using ΔH_F and $T_{1_{avg}}$ from the test data, W_a was determined from Figure D-2. Also using ΔT, the values of film temperature T_f and the mean temperature difference ΔT_m were calculated using the following relations:

$$T_g = T_1 + \frac{\Delta T}{2} \qquad \text{AND} \qquad \Delta T_m = t_s - T_g$$

$$\therefore T_f = T_g + \frac{\Delta T_m}{2}$$

The heat transfer coefficient h equals the total heat transferred divided by the area and the mean temperature difference. The projected rear wall area A_p was used as the heat transfer surface giving the following equation for h:

$$h = \frac{W_a \times C_p \times \Delta T}{A_p \times \Delta T_m}$$

where the specific heat C_p was evaluated at the bulk temperature of the gas T_g and corrected for moisture content. Values of C_p were taken from Figure D-3.

From Figure D-4, values of k and μ at the film temperature were taken. Using $N_{Nu} = \frac{hD}{k}$ the value of Nusselt Number was

readily calculated.

Reynolds Number was calculated using the following equation:

$$N_{Re} = \frac{GD}{\mu}$$

where $G = \frac{W_a}{A_o}$ and A_o was the total burner area and W_a the total weight of air flowing.

The actual calculation of Nusselt Number vs. Reynolds Number was done in tabular form. For the purpose of illustration, a sample calculation sheet is shown in Table E-1.

APPENDIX E TABLE E-1

CALCULATION OF NUSSELT NUMBER vs. REYNOLDS NUMBER

SHEET NO. 26

3-2 "d. ORIFICE(S), D= 6 " FURNACE DEPTH, 2.114" FLOW METER, SPECIFIC HUMIDITY = 62 GRAINS/# DRY AIR

$\frac{D}{d} = 3$; $\frac{A_P}{A_o} = 15.29$; $T_g = T_1 + \frac{\Delta T_1}{2}$, $\Delta T_M = t_s - T_g = 212 - T_g$; $T_f = T_g + \frac{\Delta T_M}{2}$; $h = \frac{W_A \times C_P \times \Delta T}{A_P \times \Delta T_M} = \frac{W_A \times C_P \times \Delta T}{1 \times \Delta T_M}$

$N_{NU} = \frac{hD}{K} = .5 \times \frac{h}{K}$; $G = \frac{W_A}{A_o} = 15.29 \times W_A$; $N_{RE} = \frac{GD}{\mu} = .5 \times \frac{G}{\mu}$

NOTE - C_P AT T_g AND SPEC. HUM. OF THE AIR ; μ AND K AT T_f.

RUN NO.	ΔH_F "H_2O	W_A #/HR.	AVG. T_1 °F	ΔT °F	T_g °F	ΔT_M °F	T_f °F	C_P BTU/#-°F	h BTU/HR-FT²-°F	K BTU/HR-FT-°F	N_{NU}	G #/FT²-HR	μ #/HR-FT	N_{RE}
1	21.8	1218	98.7	6.30	101.85	110.15	156.93	.2418	16.81	.0172	489	18,623	.0494	188,500
2	18.5	1125	96.4	6.48	99.64	112.36	155.82	.2418	15.68	.0172	456	17,201	.0494	174,100
3	16.8	1071	96.4	6.57	99.70	112.30	155.85	.2418	15.15	.0172	440	16,376	.0494	165,700
4	14.6	1000	96.6	6.59	99.94	112.06	155.97	.2418	14.20	.0172	413	15,290	.0494	154,800
5	12.4	931	95.5	7.02	99.01	112.99	155.51	.2418	13.98	.0172	406	14,235	.0494	144,100
6	10.55	854	95.1	7.16	98.68	113.32	155.34	.2418	13.02	.0172	378	13,058	.0494	132,200
7	8.5	766	95.2	7.16	98.78	113.22	155.39	.2418	11.70	.0172	340	11,712	.0494	118,500
8	6.4	665	95.1	7.29	98.74	113.26	155.37	.2418	10.34	.0172	301	10,168	.0494	102,900
9	4.25	542	95.1	7.38	98.79	113.21	155.39	.2418	8.53	.0172	248	8,287	.0494	83,900
10	3.0	457	94.9	7.56	98.68	113.32	155.34	.2418	7.36	.0172	214	6,988	.0494	70,700
11	2.0	374	94.5	7.65	98.32	113.68	155.16	.2418	6.09	.0172	177	5,718	.0494	57,900
12	1.0	266	94.0	7.92	97.96	114.04	154.98	.2418	4.47	.0172	130	4,067	.0494	41,200