INVESTIGATION OF THE HEAT TRANSFER CHARACTERISTICS OF A WIRE AND TUBE HEAT EXCHANGER

BY

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A
THESIS SUBMITTED IN PARTIAL
FULFILMENT OF REQUIREMENTS
FOR
MASTER OF ENGINEERING
IN
APPLIED THERMODYNAMICS
(Refrigeration and Air Conditioning)

DEPARTMENT OF MECHANICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE INDIA

[redacted] 1964

CERTIFICATE

Certified that the thesis entitled "INVESTIGATION OF THE HEAT TRANSFER CHARACTERISTICS OF A WIRE AND TUBE HEAT EXCHANGER", which is being submitted by Shri NARESH CHANDRA SRIVASTAVA in partial fulfilment for the award of degree of MASTER OF ENGINEERING in Applied Thermodynamics - Refrigeration and Air-Conditioning, of University of Roorkee, is a record of student's own work carried out by him under my supervision and guidance. The results embodied in this thesis have not been submitted for the award of any other degree or diploma.

This is further to certify that he has worked for a period of about one year and four months from 1st July, 1963 to 23th October, 1964 for preparing thesis for Master of Engineering Degree at this University.

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ACKNOWLEDGEMENTS

The author expresses his deep and sincere gratitude to Shri Rajendra Prakash, Reader in Mechanical Engineering, University of Roorkee, for his valuable advice and expert guidance in initiation and completion of this project.

The author is indebted to Prof. M.V. Kamlani, Head of the Mechanical Engineering Department, Dr. T.J. Price, U.S.A.I.D. Guest Professor in Mechanical Engineering and Dr. Shankar Lal, Professor in Mechanical Engineering for their perpetual encouragement and advice.

In the end the author would like to express his thanks to the Mechanical Engineering Workshop, Electrical Engineering Department, staff of Refrigeration and Air-Conditioning Laboratory and Measurement Laboratory for extending their help and co-operation in the fabrication of the test setup.

U.C. Srivastava

ABSTRACT

The present work was taken up to investigate mainly the effect of wire and tube geometry of heat exchanger on transfer of heat when it is placed at different angular positions. The problem has been analysed theoretically and experimentally. The effect of chimney action has also been studied side by side, by confining the exchanger between two vertical plates. Within limits the theoretical and experimental results obtained agree to a good extent.

CONTENTS

CHAPTER 1

INTRODUCTION

" With a brief introduction the present work has been explained fully and the work done by the previous investigators has been summarized ".

INTRODUCTION

Engineers are continuing to carry-out extensive researches for making refinements and explorations. Wire and tube heat exchanger is one of the results of such researches being carried out for producing an economic and effective heat exchanger for domestic refrigeration units. Besides simplicity, the wire and tube geometry renders compactness, low production cost, ease of manufacture and lightness. These are the main attractions which divert the attention of engineers towards the investigation of the heat transfer characteristics of such a geometry.

The theory involved in conduction and convection of heat from the wires is based upon the Langmuir Theory of heat conduction. A fully satisfactory expression for the process of heat transfer from a wire and tube heat exchanger can not be given due to its constructional complexity. Even then the heat transfer equations based on the necessary assumptions have been worked out by many workers of this field. In order to simplify the analysis the whole exchanger is usually considered to contain a number of units each comprising of a single tube and two wires attached to it cross-wise on two diametrically opposite points.

The present work has been carried out in order to find out the characteristics of the exchanger for its off horizontal positions (i.e. different yaw angles). Besides this the effects of wire spacing and wire diameter has also been studied. Necessary assumptions have been made in order to simplify the problem to the near satisfaction. While determining the effect of varied positions, the heat exchanger has been tilted from horizontal to vertical positions. In one case wires are kept horizontal while in the other case tubes are kept horizontal.

Though the work on the natural convection from tubes and wires has been conducted for last fifty years or so, but it were late 1950s when few of the research engineers of U.S.A. started work particularly for this configuration of heat exchanger. From the literature available it seems that Mr. O.W. Witzell, and W.E. Fontain[1] formulated for the first time in March 1957, the heat transfer equations for wire and tube geometry. Later, after conducting the tests, in Sept. 1957 they suggested the following emperical equation for the design of heat exchanger.

$$Nu = 0.4724 \quad Gr^{0.2216}$$

However, they did not bother about the effect of off horizontal positions of the heat exchanger, which obviously seem to bear some relation with the effectiveness of the heat exchanger because the transfer of heat takes place by free convection only.

Apparently anybody would guess that heat transfer will be most effective in the horizontal position of the exchanger since the convection currents will be least interacted with each other for each pair of wire & tube. But horitontal placing of the heat exchanger is found to be more space consuming in most of the applications, and it is also possible that depending upon the design, such a large free horizontal space may not be available. More-over it is always desirable to place the exchanger outside the refrigeration unit where the free convection may be more effective; obviously the horizontal position of the exchanger will increase the floor space required by the unit.

All these draw backs emphasize the need of investigating the effect of off horizontal position in which the heat exchanger can be easily placed in the available free space. With this view point, Cyphers, Cess & Somers[3] conducted the work for off horizontal positions and in 1959 they published their results. Later on in June 1959, Witzel, Fontain & Papanek introduced the concept of Average Nusselt & Grashof number for the entire heat exchanger with the help of characteristic diameter defined by the average heat transfer coefficient.

Problem of evaluating the average heat transfer coefficient has been solved by evaluating coefficients for tubes and wires separately, and then determining the convective coefficient for the whole heat exchanger defined by equation 11.

In addition the radiative heat transfer coefficient has been evaluated by the help of equation 6, since the previous investigators found that the heat transferred by radiation forms a significant part of total heat transfer. From the literature available it has been found that much of the work has been carried out for horizontal and vertical cylinders [9, 10, 11] but the field of yawed position of cylinders or plate was almost untouched before 1950s. During 1950s we find only the work of B.R. Rich and that too for the inclined flat plate. Later Tritton in July 1963 gives some concept for the solution of boundary layer equations for inclined flat plate. But still problem of inclined cylinder remains unexploited. In the present work, the solution of boundary layer equations for inclined flat plate has been explained and the same has been extended for application to inclined cylinders.

It was also considered advisable to study the chimney effect by confining the exchanger in a duct made of two plates in vertical position. It might affect the heat transfer coefficient since the convection current will be aided due to the density difference between outside and inside air column.

Only experimental studies of the above mentioned phenomena have been made in this work. Theoretical treatment is complicated due to the situation posed by the presence of combined free and forced convection at very low reynold numbers.

Recently Collicott H.E., Fontain & Witzell have presented the effect on radiation and free convection heat transfer from wire and tube heat exchangers. Their work emphasized the radiation characteristics along with the convection characteristics.

CHAPTER 2

HEAT FLOW IN WIRE & TUBE HEAT EXCHANGER

" Mechanism of heat flow through the heat exchanger explained, and convective co-efficients for different positions of the cylinder analysed for determination of h_a".

2.01 GENERAL

As the name indicates the wire and tube heat exchanger consists of number of tubes where ends are joined in such a way that they form one long tube in serpentine shape, with wires welded crosswise to tube length on both sides of tubes Though the above conception indicates the simplicity of the shape and its manufacture on large scale, but it is very difficult to develop an expression which could satisfy all the physical conditions and give the effectiveness of the unit by the use of the concept of average heat transfer coefficient applicable to unit as a whole. By physical conditions we mean that in actual practice the wires are spot-welded on the diametrically opposite points of the cross section of the tube. So actually the wire comes tangentially outward from the tube section as shown in the diagram below

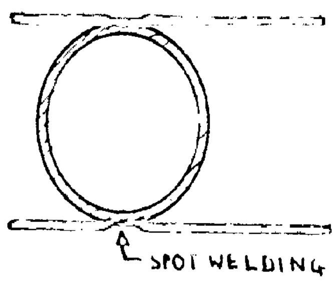


FIG 1

For this situation of wire and tube it is rather difficult to obtain an exact expression for the dissipation of heat and the effectiveness of the geometry. Though a case of the wire projecting radially outwards is simpler and the effectiveness of the geometry can also be predicted in comparatively easier way.

The problem may be dealt in two ways. In the first way we can consider the wire projected from the tube to half way between two adjacent tubes, just like the pin fins with tip temperature somewhat other than atmospheric temperature. The second way is to consider the wire extending from one tube to other adjacent tube which may be assumed to be at the same temperature and dissipating heat to the surrounding air. In both cases the problem will be altered when either the tubes are made vertical or the wires made vertical or changed to a position other than horizontal.

It is quite apparent that the effectiveness should be maximum when the exchanger is in horizontal position, since no interference of heat currents will take place, while in case of off-horizontal positions, the hot air rising from a lower tube or wire will interfere more and more with the upper tubes & wires, as the angle increases, in-turn the effectiveness will go down.

2.02 MECHANISM OF HEAT FLOW

The best approach of tackling the problem is to differentiate the whole heat exchanger into a number of geometrically similar components consisting of one tube and one cross wire spot welded on it and then considering each component separately. For such a mechanism, heat flows from inside liquid to outside air in the following ways-

1. Heat is transferred by convection from the inside

hot fluid to the inside wall of the tube.

ii. Heat then flows from inside to outside surface of the tubes by conduction.

iii. Heat dissipation from inside to the outside air takes place by two mechanisms.

(a) Natural convection of heat from the outside surface of the tube wall.

(b) Natural convection from wire surfaces which are conducting heat away from the tube wall.

iv. Heat is transferred by radiation from tube and wire surfaces.

Total Resistance to Heat Flow Defined:- If the flow condition inside the tube is considered to remain constant, then the resistance to heat flow by different ways will be constant. Total heat resistance may be devided into three different resistances:

i. Inside tube resistance $= R_i$

ii. Tube wall resistance $= R_t$

iii. Outside tube resistance $= R_o$

Outside surface resistance can be further subdivided into two parts operating in parallel:

i. Convective heat resistance from the outer surfaces $= R_c$

ii. Radiative heat resistance from all outside surfaces $= R_r$

$$\therefore \quad R_o = \frac{1}{\frac{1}{R_c} + \frac{1}{R_r}}$$

Combining all the resistances we get total resistance R_{tot}:

$$R_{tot} = R_i + R_t + \frac{1}{\frac{1}{R_c} + \frac{1}{R_r}} \qquad \text{......} \quad (1)$$

If U = Overall heat transfer coefficient for the heat exchanger.

Then the total heat dissipation

$$q_{tot} = Q = U A \theta$$

where $UA = \frac{1}{R_{tot}}$

$$\therefore \quad R_{tot} = \frac{1}{UA} = \frac{\theta}{q_{tot}} \qquad \text{......} \quad (2)$$

Thus $R_{tot} = \frac{1}{A_i h_i} + \frac{\log r_o/r_i}{2\pi L k_t} + \frac{1}{(A_c h_c + A_r h_r)}$

Last term of this equation defines overall outside heat transfer coefficient h_a

$$h_a A = A_c h_c + A_r h_r \qquad \text{......} \quad (3)$$

Inside Heat Transfer Coefficient:- (h_i) This can be determined by the well established equation:

$$Nu = \frac{hd}{k} = 0{\cdot}023 (R_e)^{0{\cdot}8} (P_r)^{0{\cdot}3} \qquad \text{......} \quad (4)$$

where $R_e = \frac{VD\rho}{\mu}$ & $P_r = \frac{C_p \mu}{k}$

Radiative Heat Transfer Coefficient:- (h_r) The radiative coefficient can also be determined by defining it by the following equations

$$q_r = h_r A_o \theta \qquad \ldots\ldots \quad (5)$$

whereas in actual

$$q_r = \sigma A \epsilon (T_{surface}^4 - T_{ambient}^4)$$

$$\therefore h_r = \sigma \epsilon (T_S^2 + T_e^2)(T_S + T_e) \qquad \ldots\ldots \quad (6)$$

Total Heat Transfer Rate:- (a) The total heat transfer from the exchanger can be determined by measuring the flow rate of liquid and inlet and outlet temperature of the liquid. Thus

$$Q = M C_p (T_i - T_o) \qquad \ldots\ldots \quad (7)$$

2.03 OUTSIDE CONVECTIVE COEFFICIENTS ANALYSED

Now in finding h_c the convective outside coefficient we shall consider that the total heat is dissipated by wires and tubes separately. Thus

$$q_{total} = q_{wire} + q_{tube}$$

$$= h_{tot} A_{tot} \theta_t \qquad \ldots\ldots \quad (8)$$

Since $A_{tot} = A_t + A_w$ ...... (9)

$$\therefore h_{tot}(A_w + A_t)\theta_t = h_w A_w \theta_t + h_t A_t \theta_t \qquad \ldots\ldots \quad (10)$$

$$\text{Thus } h_c = \frac{A_w h_w \eta + A_t h_t}{(A_t + A_w)} \qquad \ldots (11)$$

In the equation No. 10, h_{tot} is nothing but h_c for the heat exchanger and A_{tot} is A_c for the exchanger.

$$\text{Thus } h_c A_c = (h_w A_w \eta + h_t A_t) \qquad \ldots (10a)$$

where η is defined by

$$\eta = \frac{\tanh mL}{mL} \qquad \ldots (12)$$

where $m = \sqrt{\frac{4 h_t}{k_w D_w}}$

Fin efficiency of wire can be readily estimated from the above formulae, with sufficient accuracy. For most of the wire configurations it lies between .80 and .95.

Heat transfer coefficient h_t for tubes will now be evaluated for vertical, horizontal and yawed positions of the cylinder, from various formulations for free convection. Each case will be considered separately in details.

1. <u>Free Convection from Horizontal Cylinders</u>.- Following the treatment of Eckert and Drake[4] an equation for the evaluation of h_t for horizontal cylinder will be developed. The boundary layer equation for this problem were solved by R. Hermann[6], the solution of which agreed with experimental results of Jodlbauer[7]. Summary of the results renders that the average heat transfer coefficient on circular tube with diameter d has the same value of h as with the wall with 2.5 d height. Hermann's calculations

are based on the assumption that the boundary layer thickness is negligible as compared to the diameter of the cylinder which is not true for the case of very thin wires. In order to account for this also we shall take the help of the theory of heat conduction in Gases developed by Irving Langmuir[5] and later taken up by Rice.[8] The summary of which is given in the following paragraphs.

Irving's Theory:- The fluid in the immediate vi-cinity of the horizontal wire maintained at a constant temperature, gets heated and rises up while it is replaced by the cooler fluid of greater density. The difference in density causes the convection current to set up. A film of the fluid remains stationary at the surface of the wire due to viscous effect. The velocity of the convection currents increases as we move away from the film until the critical velocity is reached and the flow at this point suddenly changes to turbulent flow. Where the discontinuity between the streamline and turbulent motion takes place, the outer boundary of the film is developed. The temperature at the inner boundary is equal to the surface temperature of the wire while that at the outer it is equal to ambient temperature.

Langmuir simplified this complex problem of convection into a simple conduction problem by assuming that outer boundary of relatively stagnant film was a cylinder concentric with the wire and it has a definite diameter.

With this concept of the Langmuir Theory and taking r_w as the radius of wire, t_w as wire temperature and $d (= 2r_w)$ diameter of wire then by definition, we get

$$Q = h\, 2\pi r_w L (t_w - t_a) \qquad \text{.... (13)}$$

Also from the equation of heat conduction for hollow cylinders:

$$Q = \frac{2\pi k L (t_w - t_a)}{\log \frac{r_o}{r_w}} \qquad \text{.....(14)}$$

.....(15)

& since $$Nu_d = \frac{hd}{k} \qquad \text{....(16)}$$

Substituting from equation(15)

$$Nu_d = 2 / \log \frac{r_o}{r_w} \qquad \text{..... (17)}$$

If $r_o - r_w = b$ = Thickness of the film

Then $$\frac{r_o}{r_w} = \frac{b + r_w}{r_w}$$

$$= \left(1 + \frac{b}{r_w}\right) = \left(1 + \frac{2b}{d}\right)$$

$$\therefore Nu_d = 2 / \log (1 + 2b/d) \qquad \text{.......... (18)}$$

For vertical heated plates Eckert and Drake[10] has suggested the use of following equation for air with $Pr = .714$ and for small temperature differences

$$Nu_x = 0.378\, (Gr_x)^{1/4} \qquad \text{.... (19)}$$

So by changing to average heat transfer coefficient and substituting x = 2.5d for horizontal cylinder.

$$Nu_d \simeq 0{\cdot}400\,(Gr_d)^{1/4} \qquad \ldots\ldots \quad (20)$$

For small values of b/d, the expression log(1 + 2b/d) is approximately equal to 2b/d and therefore

$$Nu_d = d/b \qquad \ldots\ldots \quad (21)$$

$$\therefore \quad \frac{d}{b} = 0{\cdot}400\,(Gr_d)^{1/4} \qquad \ldots\ldots \quad (22)$$

Introducing it into equation(18) we gets

$$Nu_d = \frac{2}{\log\left[1 + \left\{2/0{\cdot}400\,(Gr_d)^{1/4}\right\}\right]} \qquad \ldots\ldots \quad (23)$$

$$\text{or} \quad Nu_d = \frac{2}{\log\left\{1 + \dfrac{5}{(Gr_d)^{1/4}}\right\}} \qquad \ldots\ldots \quad (23a)$$

This equation will be useful in evaluating h_t, the heat transfer coefficient for horizontal cylinders.

ii. <u>Free Convection from the Vertical Cylinders</u>- The analysis of this problem was made by Sparrow and Gregg[9]. They obtained the result by solution of the differential equations of the laminar boundary layer. In addition an analysis based on pure conduction through an equivalent stagnant layer of fluid was also made.

The physical situation of the problem is shown in the fig. 2. There will be established an upward gravity force

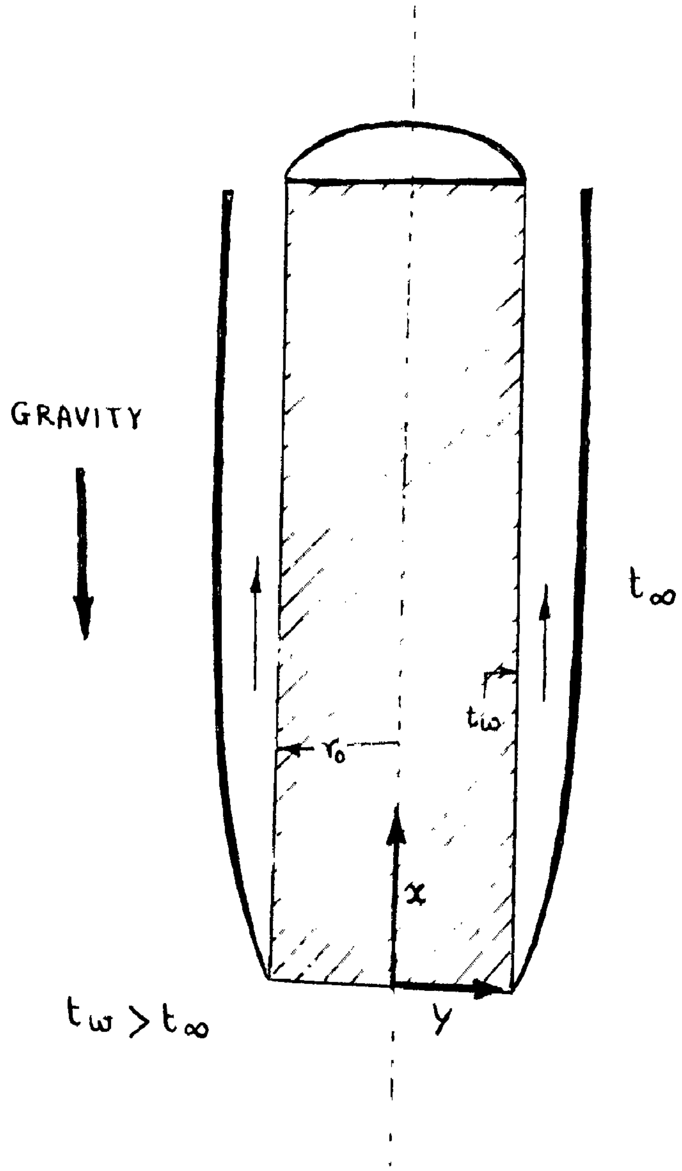


FIG - 2

FREE CONVECTION FROM VERTICAL CYLINDER

due to the density difference between the fluids just near the vicinity of the cylindrical wall which is at higher temperature and lower density, and the fluid far away from the wall which is at low temperature and higher density. The region where the upward flow primarily occurs is called velocity boundary layer, and similarly thermal boundary layer is the region of space where the temperature deviates markedly from the temperature at infinity, t_∞. In general velocity boundary layer and thermal boundary layer have different thicknesses, relative magnitude depending upon fluid properties. The thickness of both the boundary layers may be assumed to be zero at the leading edge ($x = 0$).

The equation expressing conservation of mass, momentum and energy for laminar free convection in boundary layer on the vertical cylinder will be respectively as follows:

$$\frac{\partial (r u)}{\partial x} + \frac{\partial (r v)}{\partial r} = 0 \qquad \ldots\ldots (24)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial r} = g\beta(t - t_\infty) + \frac{\nu}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right) \qquad \ldots\ldots (25)$$

$$u\frac{\partial t}{\partial x} + v\frac{\partial t}{\partial r} = \frac{\alpha}{r}\frac{\partial}{\partial r}\left(r\frac{\partial t}{\partial r}\right) \qquad \ldots\ldots (26)$$

The following assumptions for free convection are made while solving the above equations:

1. The density has been taken as a variable only

in formulating the buoyancy term $g\beta(t - t_\infty)$. All other fluid properties are taken to be constant.

ii. Viscous dissipation and the work against gravity has been neglected.

Sparrow and Gregg[9] have obtained the results in infinite series form and developed the expression for Nusselt number in the following way.

Analysis is based on Langmuir Theory of conducting layer, in which the free convection heat transfer problem is replaced by a pure conduction problem in cylindrical annulus of stagnant fluid over a length of the cylinder from x = 0 to x = x. The temperature difference across the conducting layer is $(t_w - t_\infty)$. Overall heat flow through such a conducting annulus will be

$$Q = \frac{2\pi x k}{\log\left(\frac{r_w + b}{r_w}\right)} (t_w - t_\infty) \qquad \ldots\ldots (27)$$

$$\therefore Nu_{x,cyl.} = \frac{hx}{k} = \frac{x}{r_w \log\left(\frac{r_w + b}{r_w}\right)} \qquad \ldots\ldots (28)$$

when $b/r_w \ll 1$, then $\log\left(\frac{r_w + b}{r_w}\right)$ will approach b/r_w

$$\therefore \frac{x}{r_w} \frac{1}{\log\left(1 + \frac{b}{r_w}\right)} \simeq \frac{x}{b r_w} \times r_w = \frac{x}{b} = Nu_{x,fp}$$

$$Nu_{x,cyl} = \frac{x/r_w}{\log\left(1 + \frac{x/r_w}{Nu_{x,fp}}\right)} \qquad \ldots\ldots (29)$$

Here Nu_x is Nusselt number based on x. It can be reduced to expression based on diameter d of the cylinder considering $x = L$ = Length of the cylinder. Thus

$$Nu_d = \frac{hd}{k} = \frac{hL}{k}\,\frac{d}{L} \qquad \text{.... (30)}$$

$$\therefore\ Nu_{d,cyl} = \frac{2L/d}{\log\left(1 + \frac{2L/d}{N}\right)}$$

For $P_r = 0.72$ Sparrow and Gregg gave the value of $Nu_{x,fp}$, as

$$\begin{aligned} Nu_{x,fp} &= .4757\ Gr_x^{1/4} \\ &\simeq .5\ Gr_x^{1/4} \\ &= .5\left\{\frac{g\beta(t_w - t_\infty)L^3}{\nu^2}\right\}^{1/4} \\ &= .5\left\{\frac{g\beta(t_w - t_\infty)d^3}{\nu^2}\right\}^{1/4}\left(\frac{L}{d}\right)^{3/4} \\ &= .5\ Gr_d^{1/4}\left(\frac{L}{d}\right)^{3/4} \qquad \text{---(31)} \end{aligned}$$

Substituting in equation (30) we get

$$Nu_d = \frac{2}{\log\left\{1 + 4\left(Gr_d \frac{d}{L}\right)^{-\frac{1}{4}}\right\}} \qquad \text{.... (32)}$$

This equation will be applicable for vertical position of tubes and wires.

iii. Free Convection from Yawed Cylinders.- For Laminar free convection from yawed cylinder, average Nusselt number may be predicted by extending the solutions for horizontal and vertical cylinders, and the heat transfer rate from the surface may be determined by solution of the equations of conservation of mass, momentum & energy.

If these equations are compared with the corresponding equation for the horizontal plate, they seem to be identical except that the equation of conservation of momentum is having a term representing buoyant force, which is multiplied by cosine of the yaw angle. Thus the solution of horizontal cylinder can be extended so as to obtain the solution for yawed cylinder within certain limits. Once again concept of the stagnant layer analysis of Langmuir modified by Eckert can be used for finding out the solution.

<u>Free Convection from Inclined Flat Plates</u>[7,14,3] The equations of conservation of mass momentum and energy for inclined plate will be:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad \cdots (33)$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \nu\frac{\partial^2 u}{\partial y^2} + g\cos\phi\,\beta\,(t - t_\infty) \qquad \cdots (34)$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = \nu\frac{\partial^2 v}{\partial y^2} + g\sin\phi\,\beta\,(t - t_\infty) \qquad \cdots (34a)$$

$$u\frac{\partial \theta}{\partial x} + v\frac{\partial \theta}{\partial y} = \alpha\frac{\partial^2 \theta}{\partial y^2} \qquad \cdots (35)$$

Since $v \lll u$, equation (34a) may be ommitted.

Boundary conditions are -

$y = 0$: $u = v = 0$, $t = t_w$ or $\frac{\partial t}{\partial y} = 0$

$y = \infty$: $u = U_\infty = 0$, $t = t_\infty$

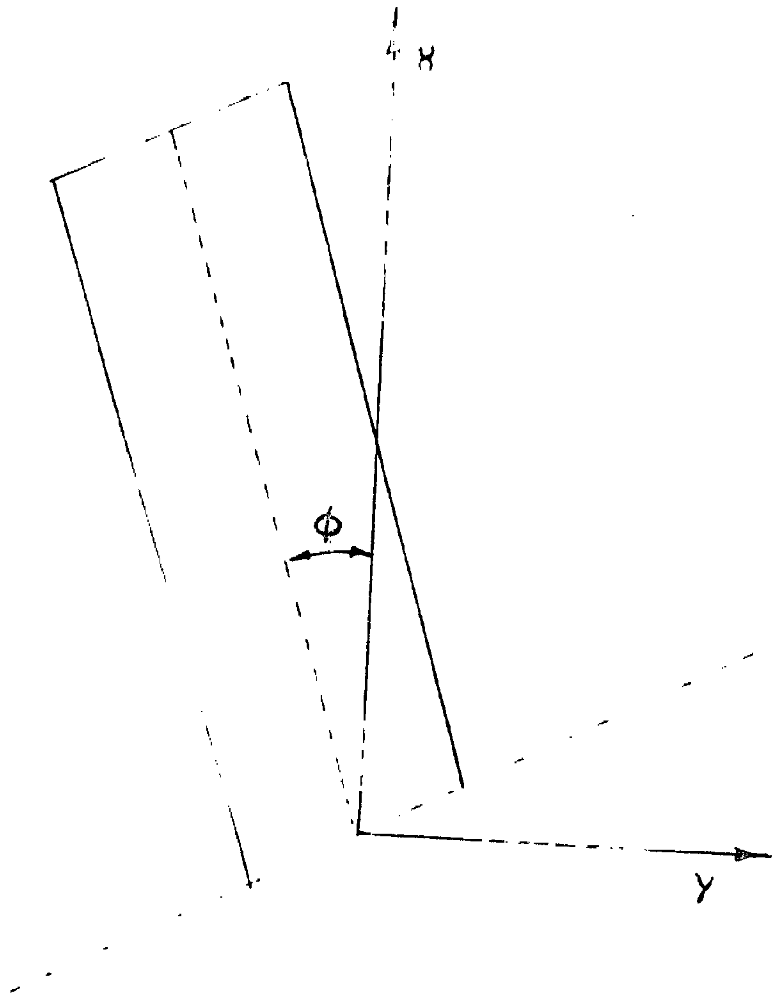


FIG -3

FREE CONVECTION FROM INCLINED FLAT PLATE

E. Pohlhausen has suggested the introduction of a new stream function ψ for solution of flow equation, so that $u = \frac{\partial \psi}{\partial y}$ and $v = -\frac{\partial \psi}{\partial x}$, then the resulting partial differential equation for ψ are reduced to an ordinary differential equation by similarity transformation.

$$\eta = \left[\frac{g \cos\phi \, (t - t_\infty)}{4 \nu^2 \, x \, t_\infty} \right]^{\frac{1}{4}} y \qquad \cdots (36)$$

$$\psi = 4\nu \left[\frac{g \cos\phi (t - t_\infty)}{4 \nu^2 t_\infty} \right]^{\frac{1}{4}} x^{3/4} \xi(\eta) \qquad \cdots (37)$$

let, $$\left[\frac{g \cos\phi (t - t_\infty)}{4 \nu^2 t_\infty} \right]^{\frac{1}{4}} = c \qquad \cdots (38)$$

$\therefore$ $\eta = c \frac{y}{x^{1/4}}$, $\psi = 4 \nu c x^{3/4} \xi$

$\therefore$ velocity components will be

$$u = \frac{\partial \psi}{\partial y} = \frac{\partial}{\partial y} \left[4 \nu c x^{3/4} \xi \left(c \frac{y}{x^{1/4}} \right) \right]$$

or $$u = 4 \nu c^2 x^{1/2} \xi' \qquad \cdots (39)$$

and

$$v = -\frac{\partial \psi}{\partial x} = -\frac{\partial}{\partial x} \left[4 \nu c x^{3/4} \xi \left(c \frac{y}{x^{1/4}} \right) \right]$$

$$= -\left[4 \nu c \frac{3}{4} x^{-1/4} \xi - 4 \nu c x^{3/4} \frac{1}{4} x^{-\frac{5}{4}} c y \xi' \right]$$

or

$$v = \nu c x^{-\frac{1}{4}} \left[\eta \xi' - 3 \xi \right] \qquad \cdots (40)$$

Substituting these values in equation (34), we get the following differential equations

$$4\nu c^2 x^{1/2}\zeta'\left[4\nu c^2 \frac{1}{2} x^{-1/2}\zeta' - 4\nu c^2 x^{1/2}\frac{1}{4}x^{-5/4} c y \zeta''\right]$$

$$+ \nu c x^{-1/4}(\eta\zeta' - 3\zeta)\, 4\nu c^2 x^{1/4}\frac{c}{x^{1/4}}\zeta''$$

$$= \nu\, 4\nu c^2 x^{1/4} c \times \frac{c}{x^{1/4}}\zeta'''$$

$$+ \frac{g\cos\phi(t_w - t_\infty)}{t_\infty}\theta$$

or $$2\zeta'^2 - \eta\zeta'\zeta'' + \eta\zeta'\zeta'' - 3\zeta\zeta''$$

$$= \zeta''' + \theta$$

or $$\zeta''' + 3\zeta\zeta'' - 2\zeta'^2 + \theta = 0 \quad \cdots (41)$$

and substituting in equation(35) we get:

$$\because \frac{\partial\theta}{\partial x} = \frac{\partial\theta}{\partial\eta}\frac{\partial\eta}{\partial x} = -cy\frac{1}{4}x^{-5/4}\frac{\partial\theta}{\partial\eta}$$

$$= -\frac{1}{4x}\eta\frac{\partial\theta}{\partial\eta}$$

and $$\frac{\partial\theta}{\partial y} = \frac{\partial\theta}{\partial\eta}\cdot\frac{\partial\eta}{\partial y} = \frac{c}{x^{1/4}}\frac{\partial\theta}{\partial\eta}$$

$$\therefore 4\nu x^{1/2} c^2 \zeta' \left(-\frac{1}{4x}\eta\frac{\partial\theta}{\partial\eta}\right) + \nu c\, x^{-1/4}(\eta\zeta' - 3\zeta) \times$$

$$\left(\frac{c}{x^{1/4}}\frac{\partial\theta}{\partial\eta}\right) = \frac{k}{g\rho C_p}\frac{c^2}{x^{1/2}}\frac{\partial^2\theta}{\partial\eta^2}$$

$$\therefore -\nu\eta\zeta'\frac{\partial\theta}{\partial\eta} + \nu\eta\zeta\frac{\partial\theta}{\partial\eta} - 3\nu\zeta\frac{\partial\theta}{\partial\eta}$$

$$= \alpha\frac{\partial^2\theta}{\partial\eta^2}$$

or $$\frac{\partial^2\theta}{\partial\eta^2} + \frac{3\nu}{\alpha}\zeta\frac{d\theta}{d\eta} = 0$$

or $$\theta'' + 3 P_r \zeta\theta' = 0 \qquad \cdots\cdots (42)$$

Boundary conditions now become at

$\eta = 0$; $\zeta = \zeta' = 0$ and

$\eta = \infty$; $\zeta' = 0$, $\theta = 0$ or $t = t_\infty$

Solution of the equations (41) and (42) have been obtained for hot vertical plate by E. Pohlhausen [15] for Pr = 0.73 and is shown in the fig. 4.

Now heat transferred per unit area of the plate

$$q_x = -k\left(\frac{\partial T}{\partial y}\right)_0$$

and

$$\frac{\partial T}{\partial \eta} = \frac{\partial T}{\partial\theta}\frac{\partial\theta}{\partial y} = \frac{\partial T}{\partial\theta}\frac{\partial\theta}{\partial\eta}\cdot\frac{\partial\eta}{\partial y}$$

$$= (t_w - t_\infty)\left(\frac{d\theta}{d\eta}\right)\left(c\, x^{-1/4}\right)$$

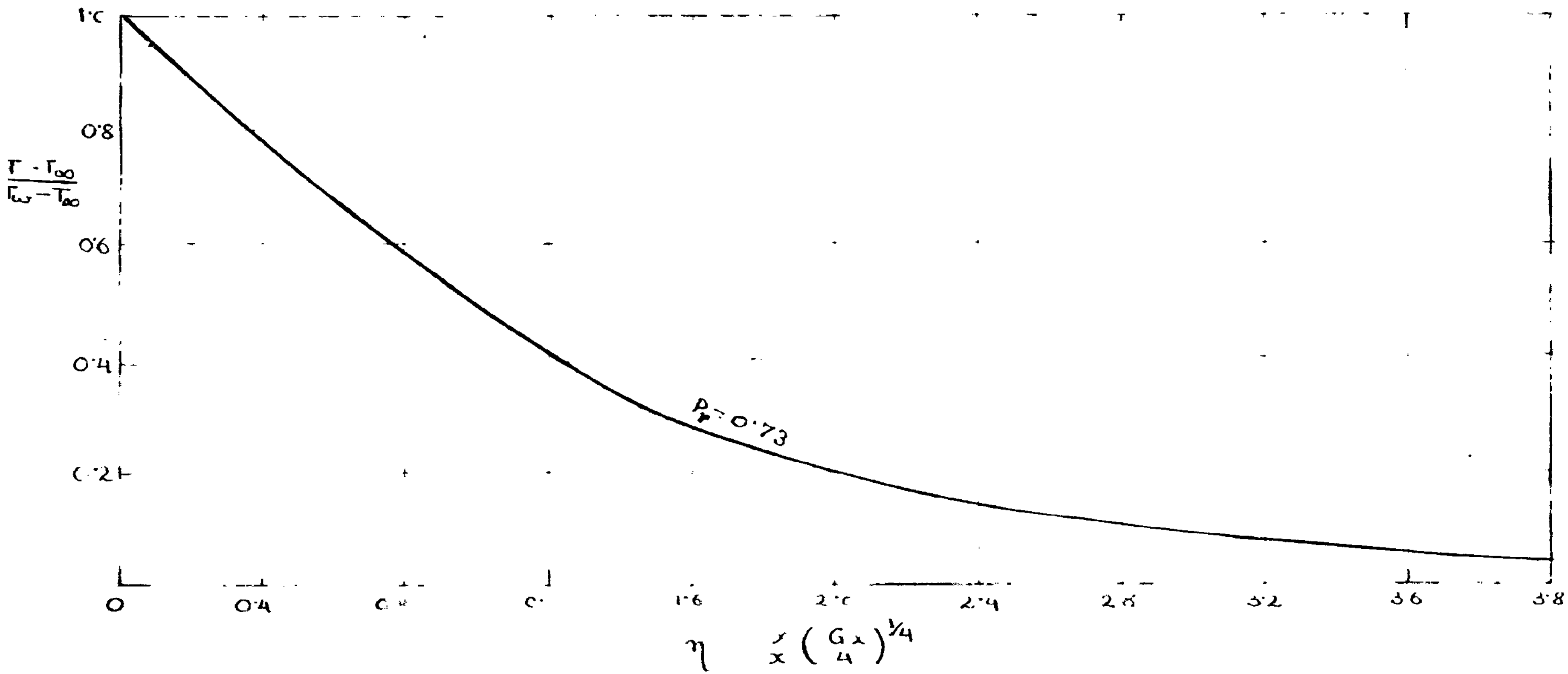


FIG. 4

TEMPERATURE DISTRIBUTION IN THE LAMINAR BOUNDARY LAYER ON A HOT VERTICAL PLATE IN NATURAL CONVECTION FOR $P_r = 0{\cdot}73$, AFTER E. POHLHAUSEN (From BOUNDARY LAYER THEORY, by SCHLICHTING)

$$\therefore q_x = -k\,c\,x^{-1/4}\left(\frac{d\theta}{d\eta}\right)_0 (t_w - t_\infty)$$

from fig. 4. for $Pr = \cdot 73$, at $y = 0$, $\eta = 0$ we get.

$$\left(\frac{\partial\theta}{\partial\eta}\right)_0 = -\cdot 508$$

Total heat transferred by the plate of length L and width b

$$Q = b\int_0^L q_x\,dx$$

$$Q = \cdot 508 \times \frac{4}{3}\,b\,L^{3/4}\,c\,k(t_w - t_\infty)$$

$$= h\,b\,L(t_w - t_\infty)$$

$$h = \frac{Q}{b\,L(t_w - t_\infty)}$$

$$Nu_{x,fp} = \frac{h\,x}{k}$$

$$= \frac{Q\,L}{k\,b\,L(t_w - t_\infty)}$$

$$= \frac{\cdot 508 \times 4 \times b\,L^{3/4}\,c\,k(t_w - t_\infty)}{3\,k\,b\,(t_w - t_\infty)}$$

$$= \frac{\cdot 508 \times 4}{3}\,c\,L^{-1/4}$$

$$= \frac{\cdot 508 \times 4}{3}\left[\frac{g\,(t_w - t_\infty)\,L^3\cos\phi}{4\,\nu^2\,T_\infty}\right]^{\frac{1}{4}}$$

$$= \cdot 478\,(Gr_x)^{1/4}(\cos\phi)^{1/4}$$

or $$Nu_{x,fp} \simeq \cdot 5\,(Gr_{x,\parallel}\cos\phi)^{1/4} \qquad \cdots (43)$$

Solutions of Inclined Flat Plate Extended to Yawed Cylinder:

Adopting the method given for vertical tube in section 2.03(ii) we expect to get a similar expression as given in equation (33) for the case of an inclined tube as follows:

$$Nu_{d,cyl.} = \frac{2}{\log\left\{1 + 4/\left(Gr_d \cos\phi \frac{d}{L}\right)^{1/4}\right\}} \quad \cdots(44)$$

This equation will not be applicable for $\phi \rightarrow 90^{\circ}$. But we can very well apply this equation upto $\phi = 45^{\circ}$. For $90^{\circ} > \phi > 45^{\circ}$ the solutions for horizontal cylinder will have to be extended in order to include the effect of inclination. Due to Eckert the equation (44) will have a modified form as follows; for this case $90^{\circ} > \phi > 45^{\circ}$ or ($\psi < 45^{\circ}$) .

$$Nu_{d,cyl} = \frac{2}{\log\left\{1 + 5/\left(Gr_d \cos\psi\right)^{1/4}\right\}} \quad \cdots(45)$$

2.04 EXPERIMENTAL DETERMINATION OF h_a :-

Experimental value of h_a will be determined by the defining equation: $Q = h_a A (T_{ta} - T_{wa})$

where $A = A_L + A_w$

$$\therefore Q = h_a (A_L + A_w)(T_{ta} - T_{wa}) \quad \cdots(46)$$

This equation is based on the tube surface temperature and includes for convective and radiative heat transfer from the entire surface of heat exchanger.

CHAPTER 3

TEST EQUIPMENT

" General criteria of selecting the various units of the test setup explained in details alongwith their function ".

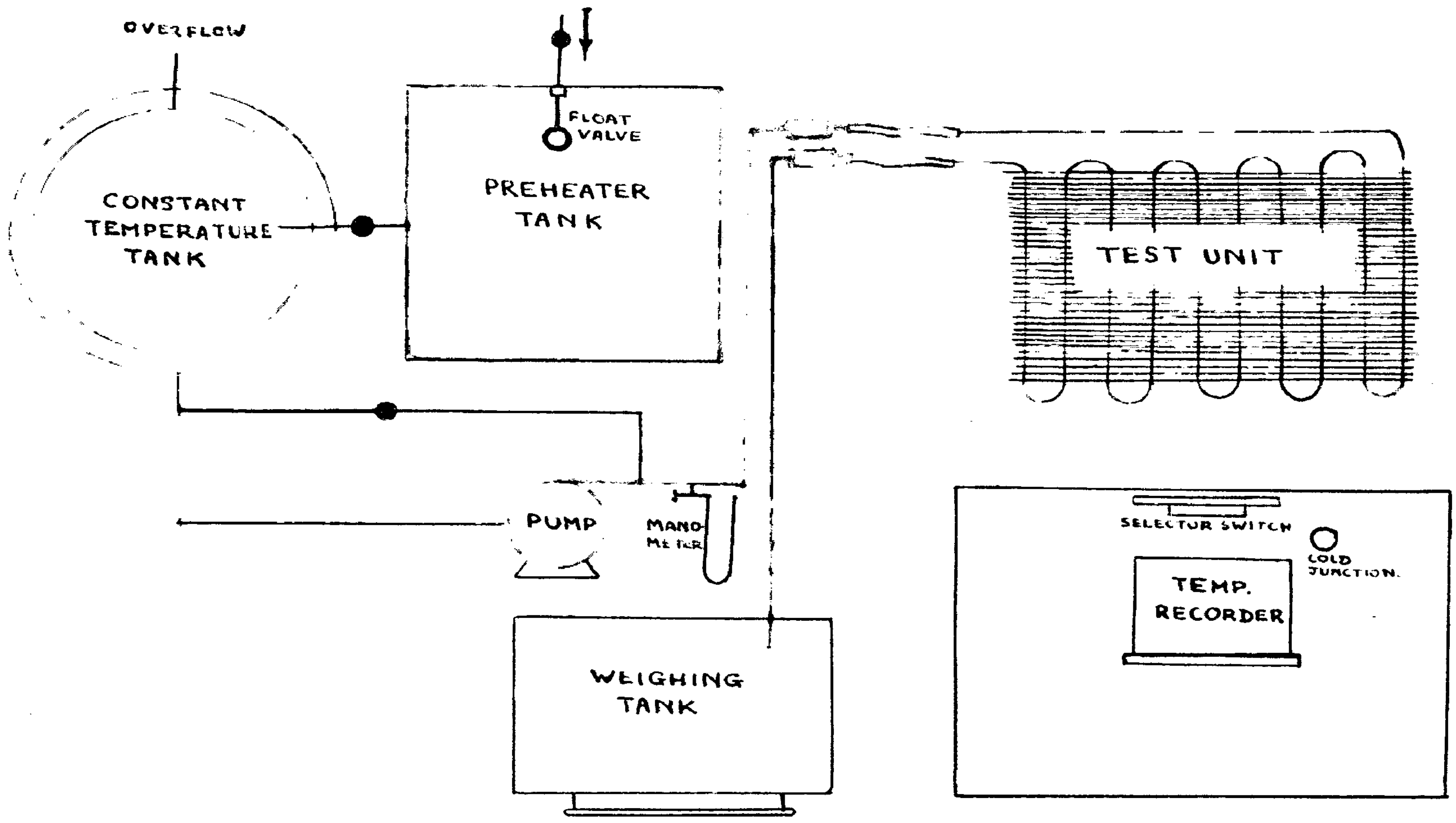
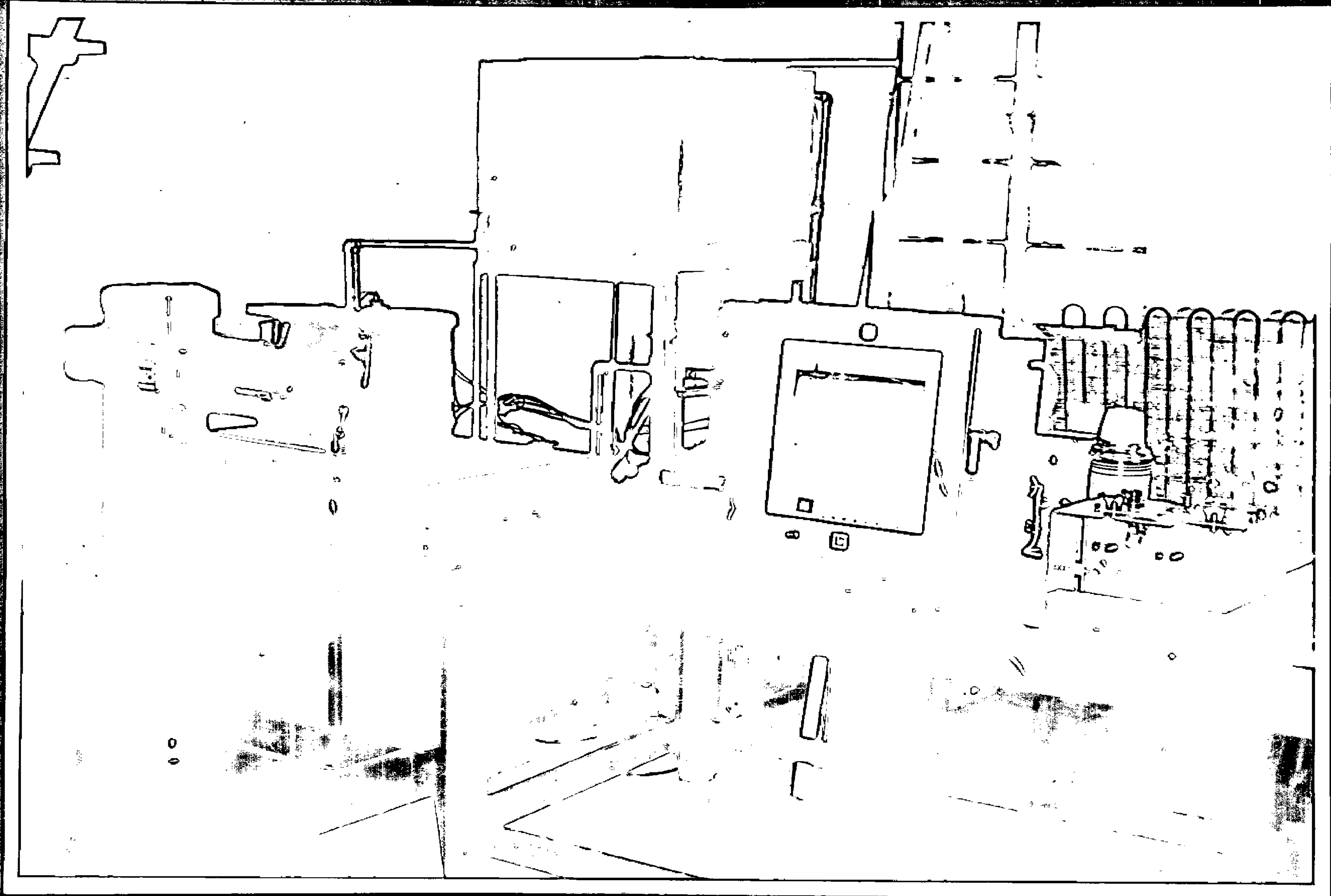


FIG. 5

GENERAL LAYOUT OF TEST SETUP



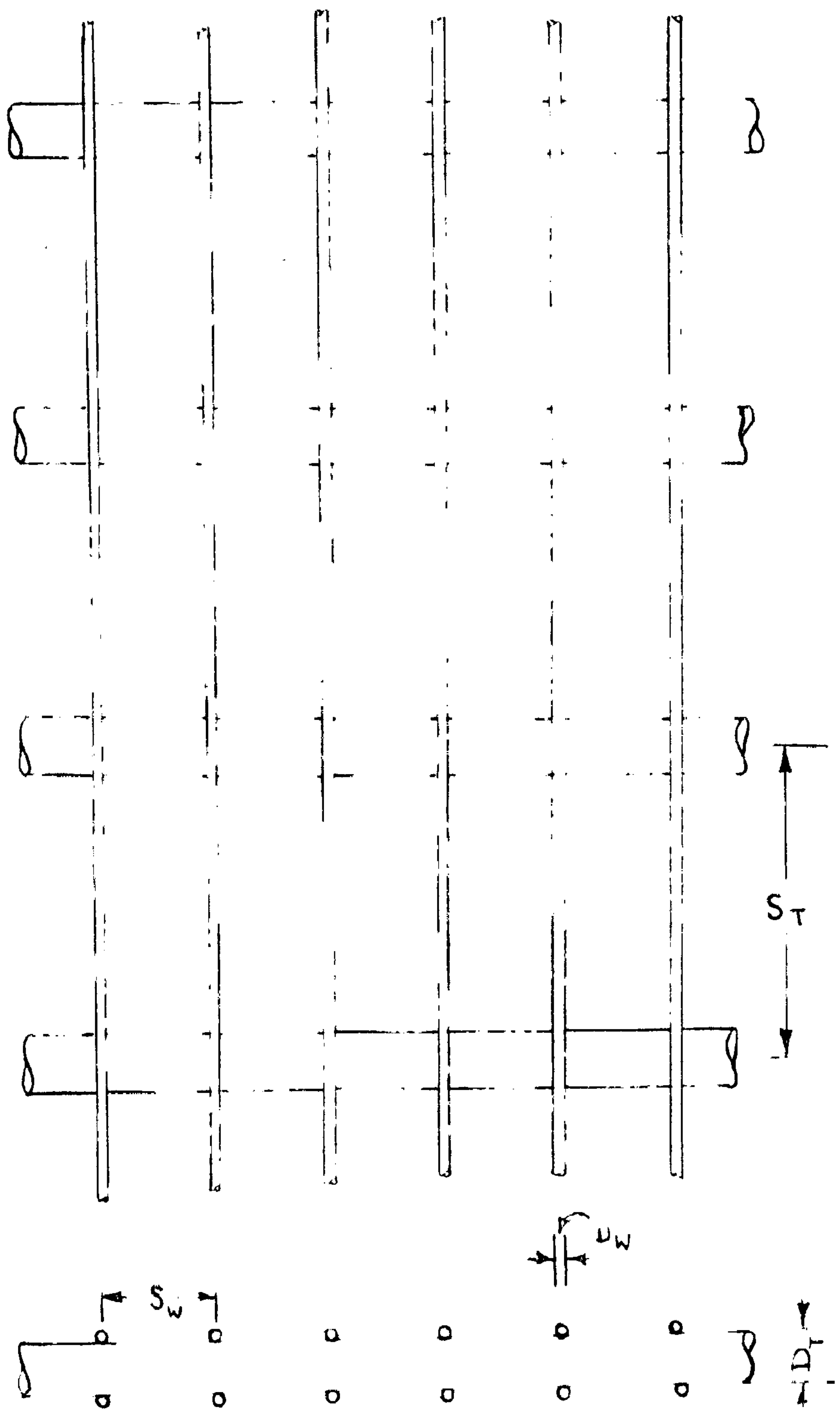
General View of Test Setup.

3.01 TEST UNIT

The size of the heat exchanger was selected arbitrarily depending upon the space which may be available in a common domestic refrigerator. The overall length and breadth, tube spacing and tube diameter were kept constant in all the test units, since effect of these factors is well known and is independent of wire tube geometry. The flow rate through the tube was also maintained constant. Variable factors were the wire diameter, wire spacing, inclination with horizontal, and spacing between the end plates in case of chimney effect.

Three different wire diameters were selected, namely 20 gauge, 16 gauge and 12 gauge which necessitated the construction of atleast three heat exchanger units. The wire spacing selected were 2", 1", ½" and ¼". This combination required only one unit for each diameter and it was possible to change over to narrower spacing by introducing one additional wire in between two wires to change the spacing from 2" to 1", 1" to ½" and ½" to ¼".

The inclination of the exchanger was also selected arbitrarily at regular interval of 15° with the horizontal. First the exchanger inclination was changed from 0° to 90°, keeping wires horizontal and then inclination was changed from 0° to 90°, keeping tubes horizontal. For determining chimney effect the exchanger was in vertical position confined between a duct made of two vertical plates, the



FIG

TEST UNIT DETAILS

spacing between which was varied from 2" to 3" to 4" and to 5". Each unit consists of ½" I.D. steel tubes with 2" spacing between them, and ends joined alternately so that one continuous tube is in zig-zag shape. Steel wires have been spot welded at the diametrically opposite ends of the tube. The whole exchanger was painted with black paint in order to increase the radiative heat transfer coefficient and to simulate the actual condition in which it is used in practice. The exchanger was suspended on a stand about 7' high, so as to provide the facility of changing the angular positions of the exchanger.

3.02 <u>OTHER EQUIPMENTS</u>

Additional provision was made in the test apparatus as follows:

1. <u>Hot & Fixed Temperature Water Supply</u>.- This was achieved by providing one preheater tank and one constant temperature tank, the capacities of which were selected so that they can supply water for about 1½ hrs. continuous run of the test. In the preheater tank the water was heated upto about 150 to 160° F, which passed on to the constant temperature tank where the temperature was maintained constant at about 180° F. Two thousand walts heaters were used to heat incoming water in preheater tank and to maintain the water in constant temperature tank at desired temperature. Preheater tank was of 45 gallons capacity and of the size 2' x 2' x 2' made of 1/8" thick

M.S. Sheet. A float valve at the water inlet of the pre-heater tank provided constant level in the preheater tank. The preheater tank was placed on a 4½' high stand so as to provide gravity flow of water from it to the constant temperature tank.

Constant temperature tank consists of two tanks, one of smaller diameter of 1½' and 3' deep and the other of larger diameter of 1' 10" and 3½' deep. Smaller one was placed in the bigger one and the annulus was insulated with 2" thick cork powder (coarse) and felt, so as to minimise the heat leakage from this tank. Smaller tank had a water capacity of 30 gallons. This tank was also provided with two thousand watts heater and a thermostat in order to maintain constant temperature. An over flow pipe was also provided in the constant temperature tank, the over-flow from which was so regulated by means of a hand set up valve, that the inflow into the tank equals the outflow. This arrangement provided constant temperature water supply to the exchanger within a tolerance of ± 2°F.

ii. <u>Supply of Water at Constant Rate of Flow</u>- The flow rate from the exchanger was maintained constant because this factor is also independent of the wire tube geometry. This was achieved by regulating manually the inlet pressure by means of a bypass valve fitted between the inlet and outlet of the water pump. The water pump used, had the following specifications

Make - Hanse, Denmark

H.P. = $\frac{1}{2}$

Capacity = 30 g.p.m.

Static head = 30 ft. of water

Single phase motor driven.

The water was supplied at a constant pressure indicated by a manometer connected just before the inlet mixing cup.

iii. Measurement of the Flow Rate of Water:- Water flow rate was measured by weighing the water collected in the weighing tank after certain interval of time. The size of weighing tank was selected so as to provide the collection for about two hours of continuous run. The tank was of 70 gallons capacity and was kept on an Avery weighing machine of 5 cwt capacity.

iv. Measurement of Inlet and Outlet Temperatures:- Special mixing cups were designed in an attempt to measure the mean bulk temperature of water passing through the cross-sectional area of the pipe. Two mixing cups as shown in fig. 7 (6" long & 1$\frac{1}{4}$" dia) were made of brass with 11/16" inside bore. At the inlet mixing was obtained by sudden expansion of liquid from a diameter of 3/16" to 11/16", and at the outlet mixing is obtained by expansion of liquid from $\frac{1}{4}$" dia to 11/16" dia.

Mixing cups were connected to the heat exchanger inlet and outlet by two rubber hoses, inorder to provide flexibility for tilting the heat exchanger in different position.

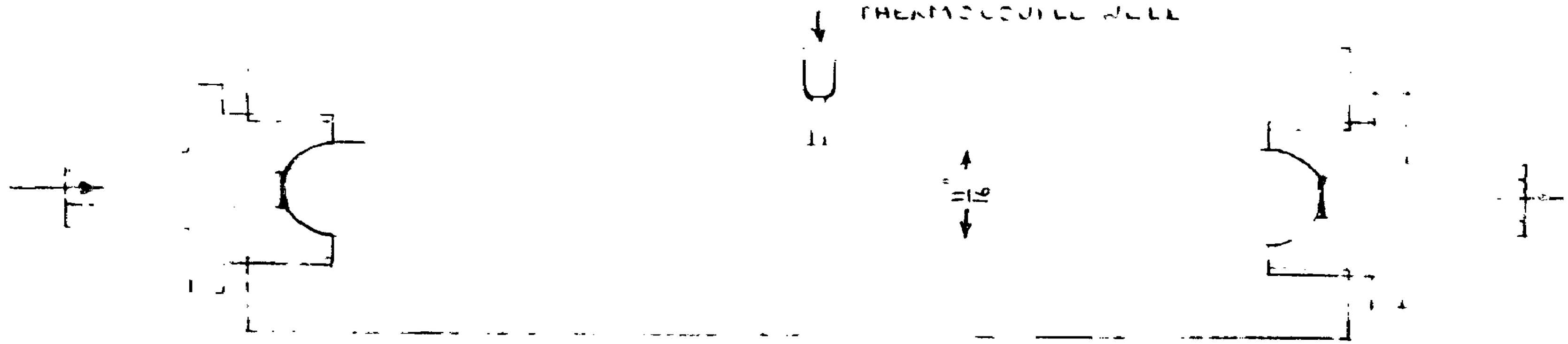
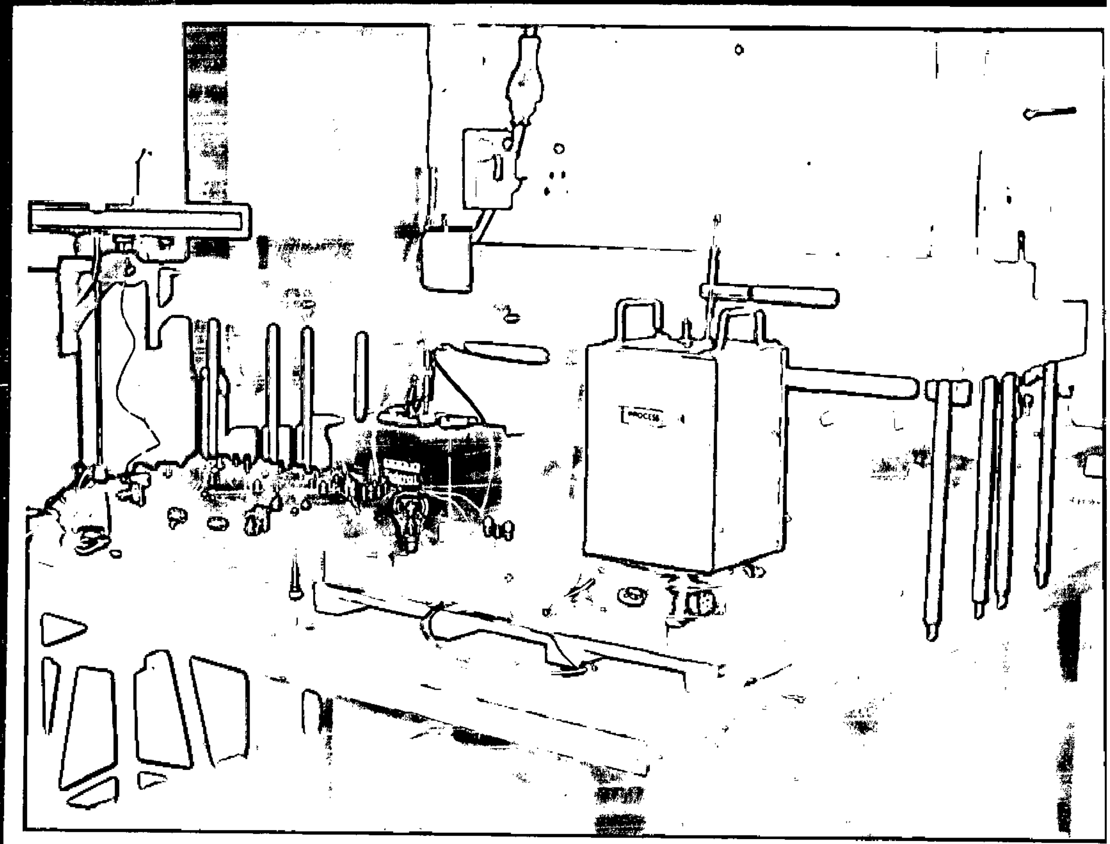
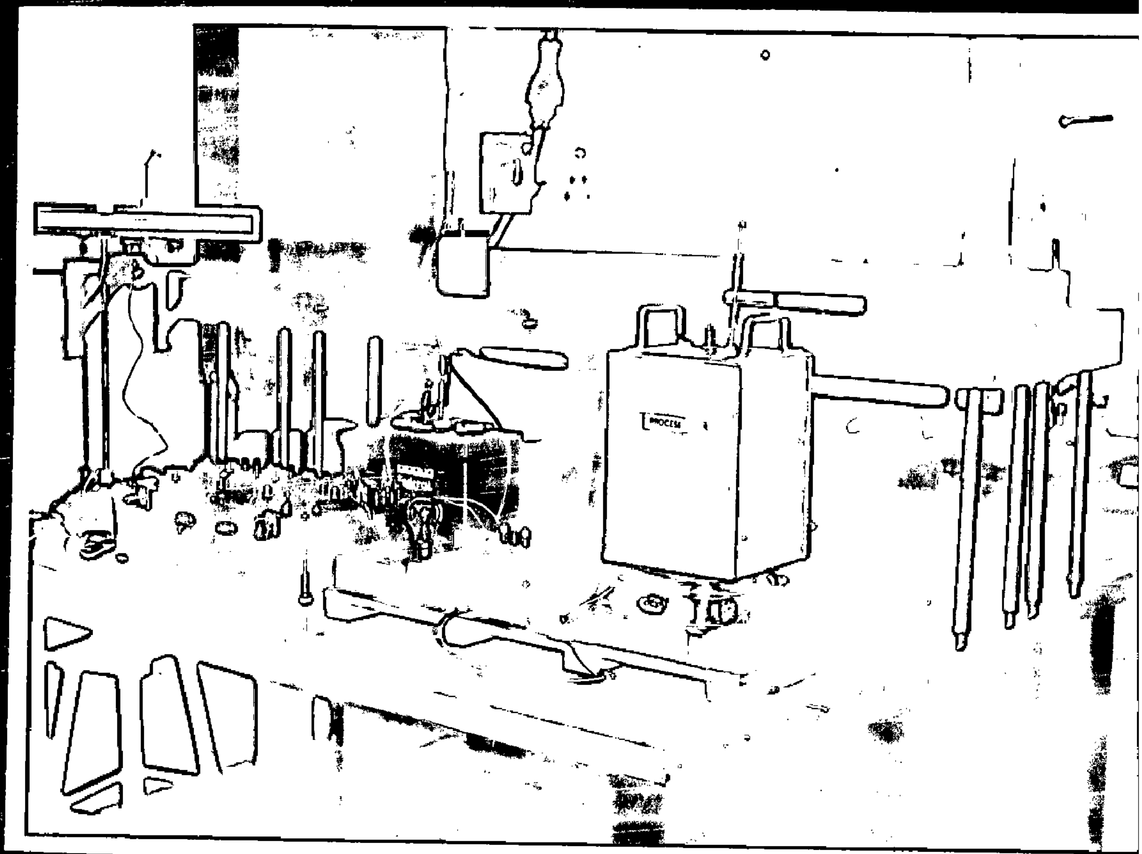


FIG - 7

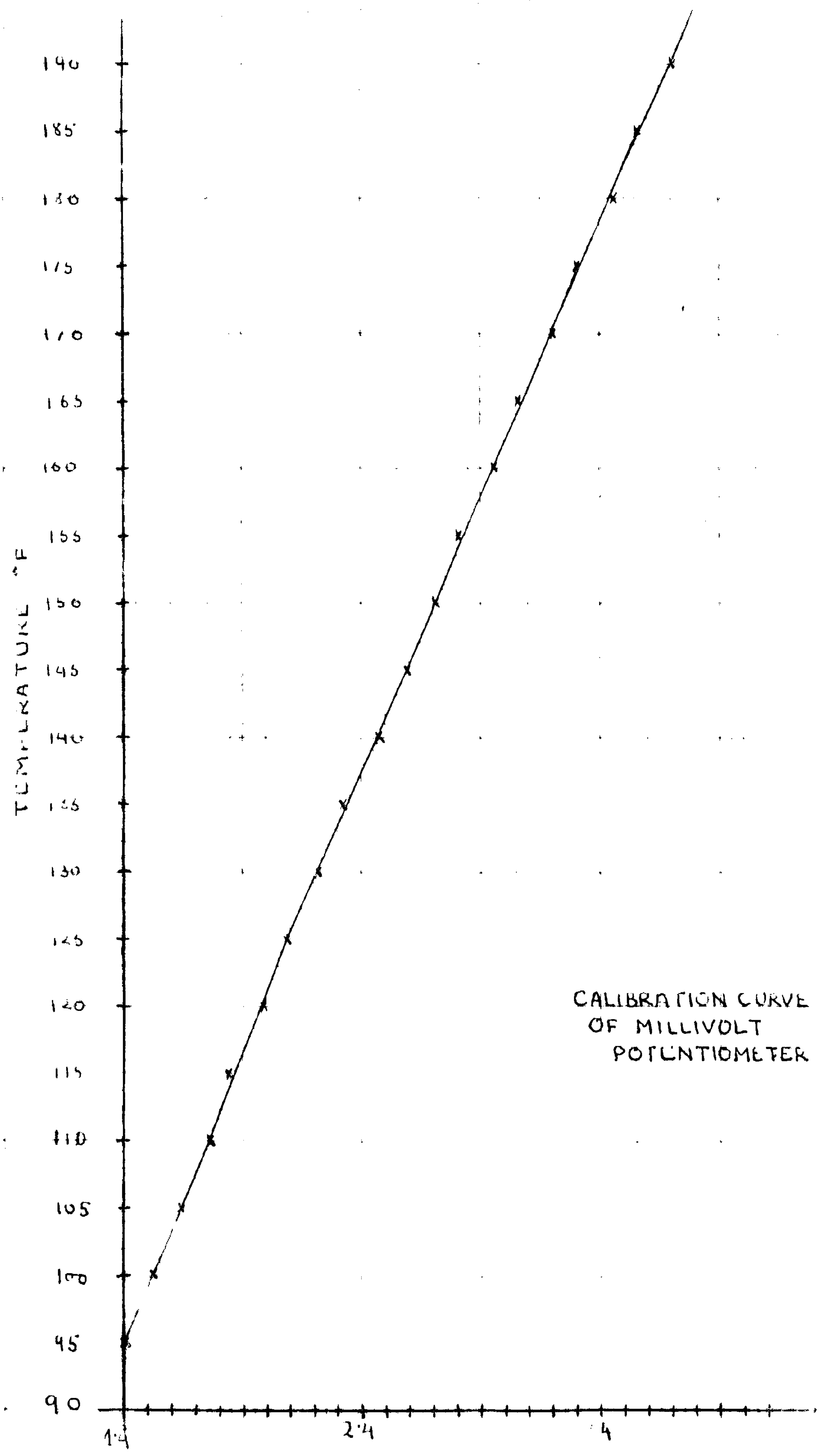
MIXING CUP USED AT INLET AND OUTLET



Calibration Setup for Millivolt Potentiometer.



Calibration Setup for Millivolt Potentiometer.



190
185
180
175
170
165
160
155
150
145
140
135
130
125
120
115
110
105
100
95
90
TEMPERATURE °F
1·4
2·4
4
CALIBRATION CURVE
OF MILLIVOLT
POTENTIOMETER

Both mixing cups and rubber hoses were heavily insulated by asbestos rope in order to restrict any leakage of heat from mixing cups and exchanger inlet and outlet.

v. <u>Heating and Electric Circuits</u>.- In the preheater tank, 2000 watts heater coils were directly connected to 220 volts A.C. mains and remained operating for the entire period of the run. In the constant temperature tank the heater coils of 2000 watts were kept in series with a thermostat and then connected to the 220 volts A.C. mains. This operation provided the heating of the water in the tank up to the temperature setting of thermostat, and as soon as particular temperature reached, the circuit was disconnected automatically by the thermostat. A red lamp was connected between the off - on point of the thermostat and the heater, such that the bulb remained off when the heater was on and it was glowing when the heater was off. This indicated the proper operation of heater coils.

vi. <u>Temperature Measuring Devices</u>.- In the initial part of the work the temperatures were recorded by means of the available Kaycee direct reading potentiometer, having the least count of .005 m.v. The potentiometer readings were calibrated for the desired range. Nine thermocouple junction of copper and constantan were placed on the tube surface to find out the average tube surface temperature. Also nine thermocouple junctions were placed on wires in between the two tubes in order to find out average mean wire temperature. All these junctions together with inlet and outlet tempera-

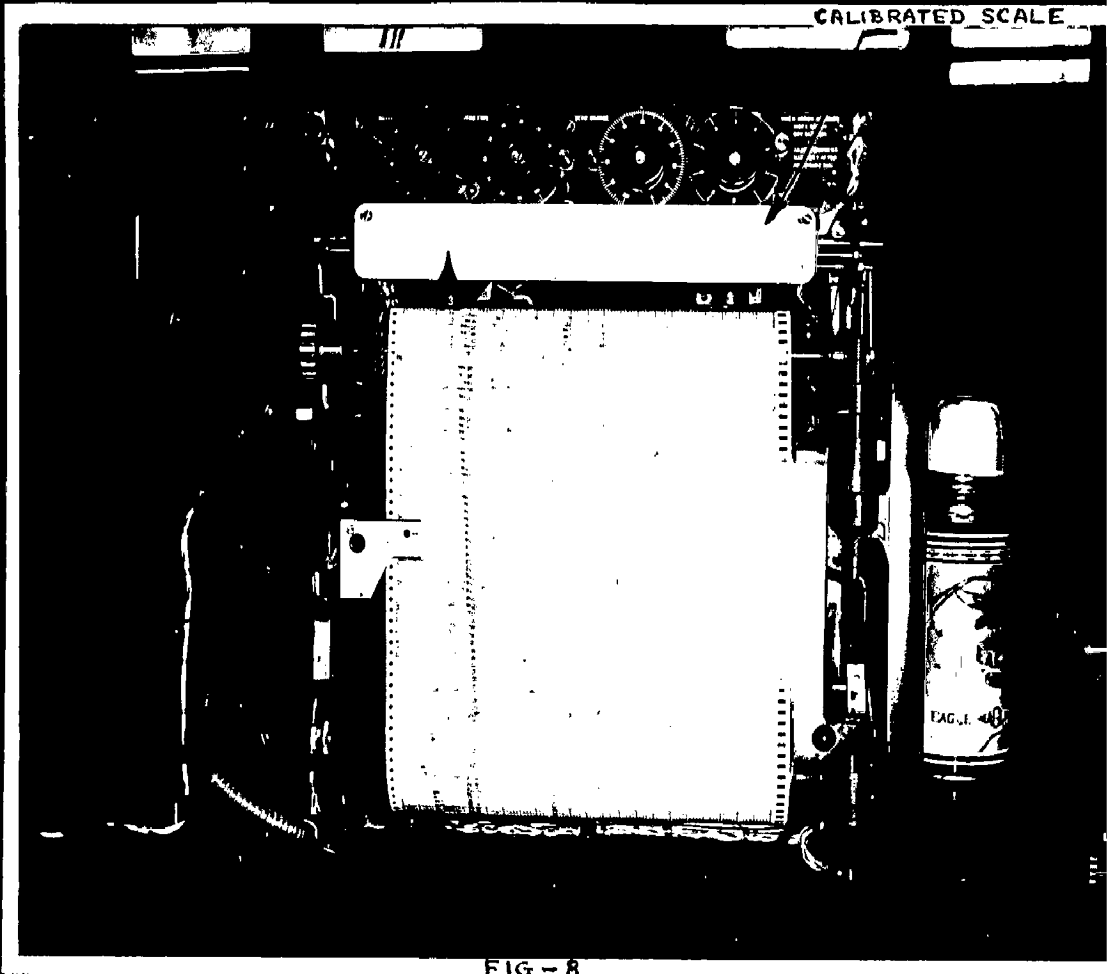


FIG - 8

Calibration of 10 Point Temperature Recorder.

ture junctions were connected turn by turn with the help of a selector switch. After the first few run we received a ten point temperature recorder of Leeds Northrup Co. of U.S.A. which had the special feature of adjustable zero and adjustable range (AZAR). Since the previous potentiometric method was much time consuming, it was decided to use this ten point temperature recorder. The recorder was calibrated with the particular type of copper constantan thermocouple for the required temperature range (85° F to 120° F). Though the accuracy of measurement with the recorder is comparatively very less but it was good enough for the accuracy required in this work i.e. ± .25° F. Fig. 8 shows the the calibration set up of the temperature recorder.

vii. Confining Chambers- For the investigation of Chimney effect two plywood sheets of the size 6' x 3' x ½" thick were placed on both the sides of heat exchanger, ends were closed by spacers of various width so as to vary the spacing between the two plywood sheets. The upper and bottom ends remain open for the natural circulation of air. The exchanger was kept in vertical position between the two plates. Four wood spacers of 2", 3", 4" & 5" width were used for changing the spacing between the plates.

CHAPTER 4

E X P E R I M E N T A T I O N

" Full procedure of starting and conducting the test explained alongwith the precautionary measures to be taken during the test."

4.01 PREPARING FOR THE TEST

1) Both the water tanks were cleaned and valves were checked for proper operation. Then the tanks were filled up to the maximum capacity.

ii) Electrical connections were then carefully checked and heaters in preheater tank and constant temperature tank were switched on.

iii) Water in the preheater tank was allowed to reach nearly 160°F of temperature, while that in constant temperature tank was heated till the red pilot lamp started glowing.

iv) A check of the temperature of water in constant temperature tank was made by a mercury-in-glass thermometer. This indicated the correct operation of thermostat within the specified range.

v) Temperature recorder was then checked for the proper operation. For this all terminals of thermocouples were short circuited and zero error of the recorder, if found, was removed by coarse and fine adjustment knobs. Range of the recorder was adjusted according to required temperature range.

4.02 TEST PROCEDURE

1) The bypass valve and exchanger inlet valves were fully opened and then the water pump was switched on.

ii) The inlet pressure was regulated by means of bypass valve at 18" of Hg.

iii) The hand setup valve at the inlet of constant temperature tank was so regulated that the inflow into the constant temperature tank was equal to the water pumped out of the tank. This condition was approximated when the overflow from the tank was minimum.

iv) The exchanger, was set in the desired position. The help of spirit level was taken for keeping the exchanger exactly horizontal. Angular position was then adjusted by keeping the vertical and horizontal ordinates such that division of the two coordinates gave the value of tan ψ where ψ is required angle with the horizontal.

v) Whole test set up was left operating in this condition for about an hour so that the steady state in surroundings and whole apparatus is reached. This was checked by means of a room thermometer suspended just near the test set-up which also indicated the room temperature.

vi) It was found that for each position of the exchanger the steady state was reached within 15 to 20 minutes, after which the temperatures could be noted down. Water flow was also measured for this interval and then the position of exchanger was changed.

vii) After the above precautions the test run was started. The temperatures of tube surface were taken by nine thermocouples spread all over the exchanger. The arithmetic mean of these temperature was considered as average tube surface temperature. The junctions of thermocouples were mercury flash welded, and were placed on the tube surface by winding its one turn on the tube periphery at a cross-section. Thin sticking paper tape was also used to keep it in place. The error caused by this was assumed to be negligible.

The average wire temperature was also determined by taking the arithmetic mean of readings of nine thermocouples spread all over the exchanger wire segments. The junction was placed in the middle of the segment so as to give the mean wire temperature. Some of the junctions were placed on the wires on one side of the exchanger and some of them on the other side.

Inlet and outlet temperatures were taken by thermocouples placed in the mixing cups.

CHAPTER 5

TEST RESULTS

" The charscteristic curves plotted, the results discussed and the conclusions drawn out of the obtained results".

NOTE:- Following representation has been adopted in the Characteristic Plots:

Theoretical curve for 12 S.W.G. wire.

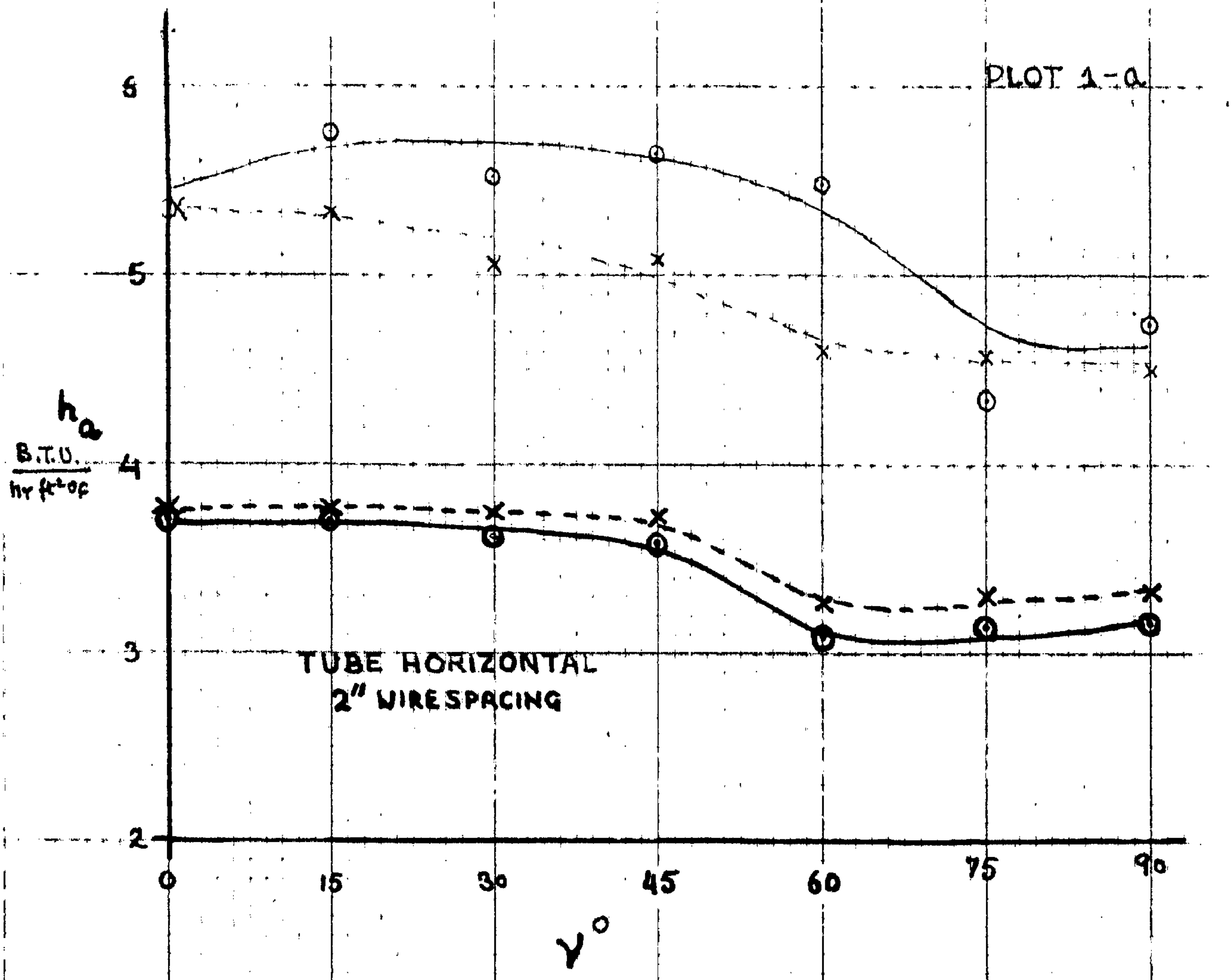
Experimental curve for 12 S.W.G. wire.

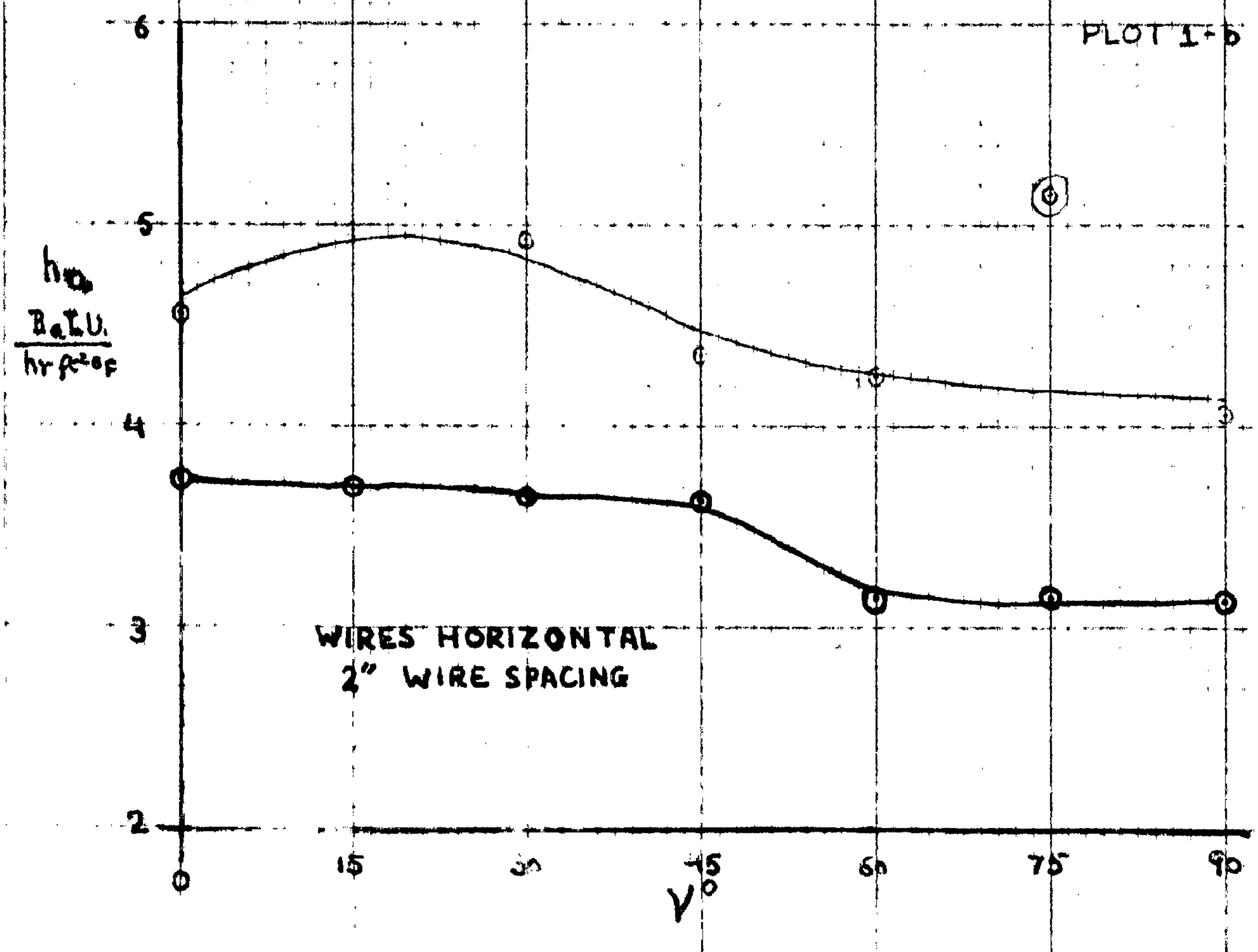
Theoretical curve for 16 S.W.G. wire.

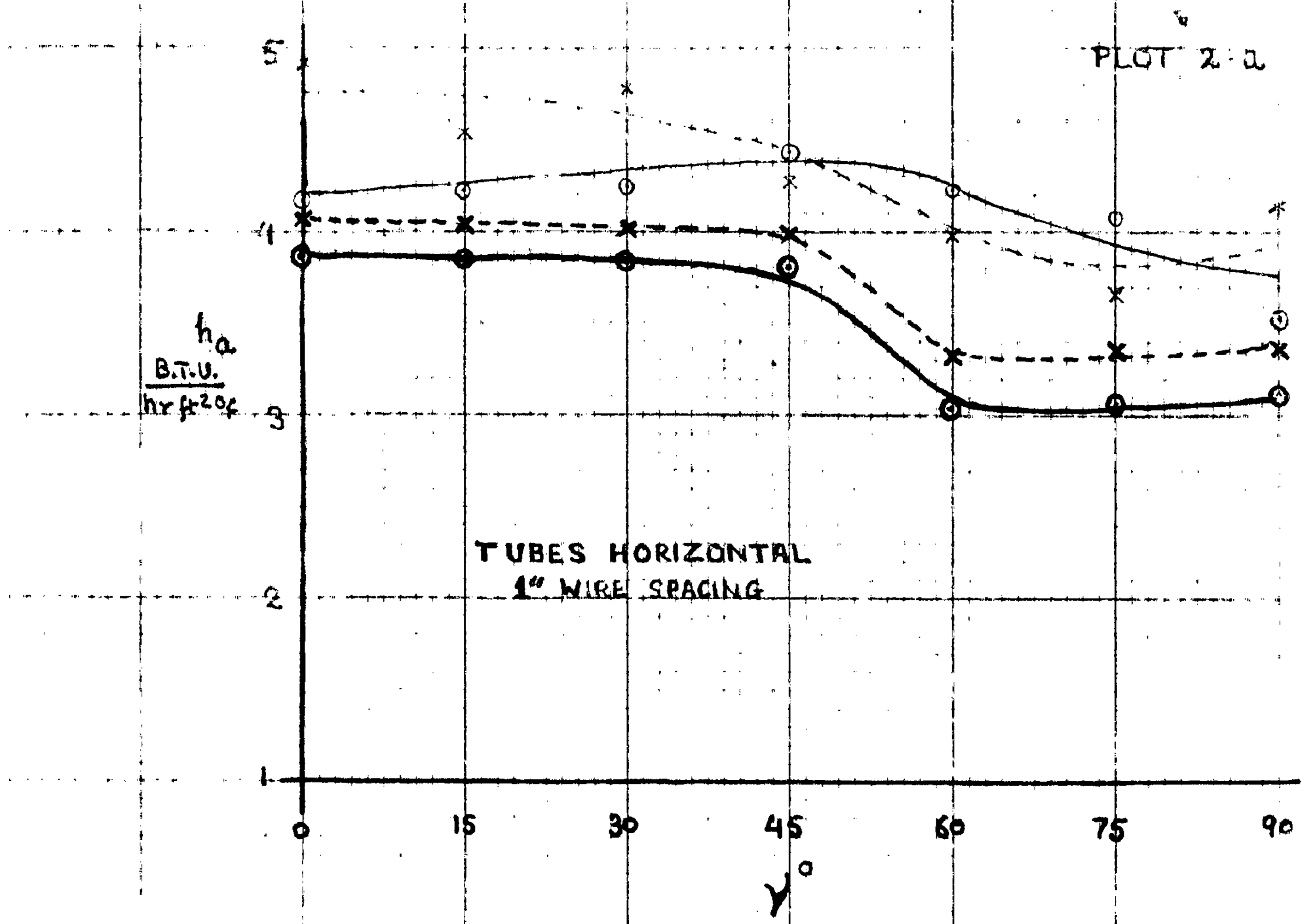
Experimental curve for 16 S.W.G. wire.

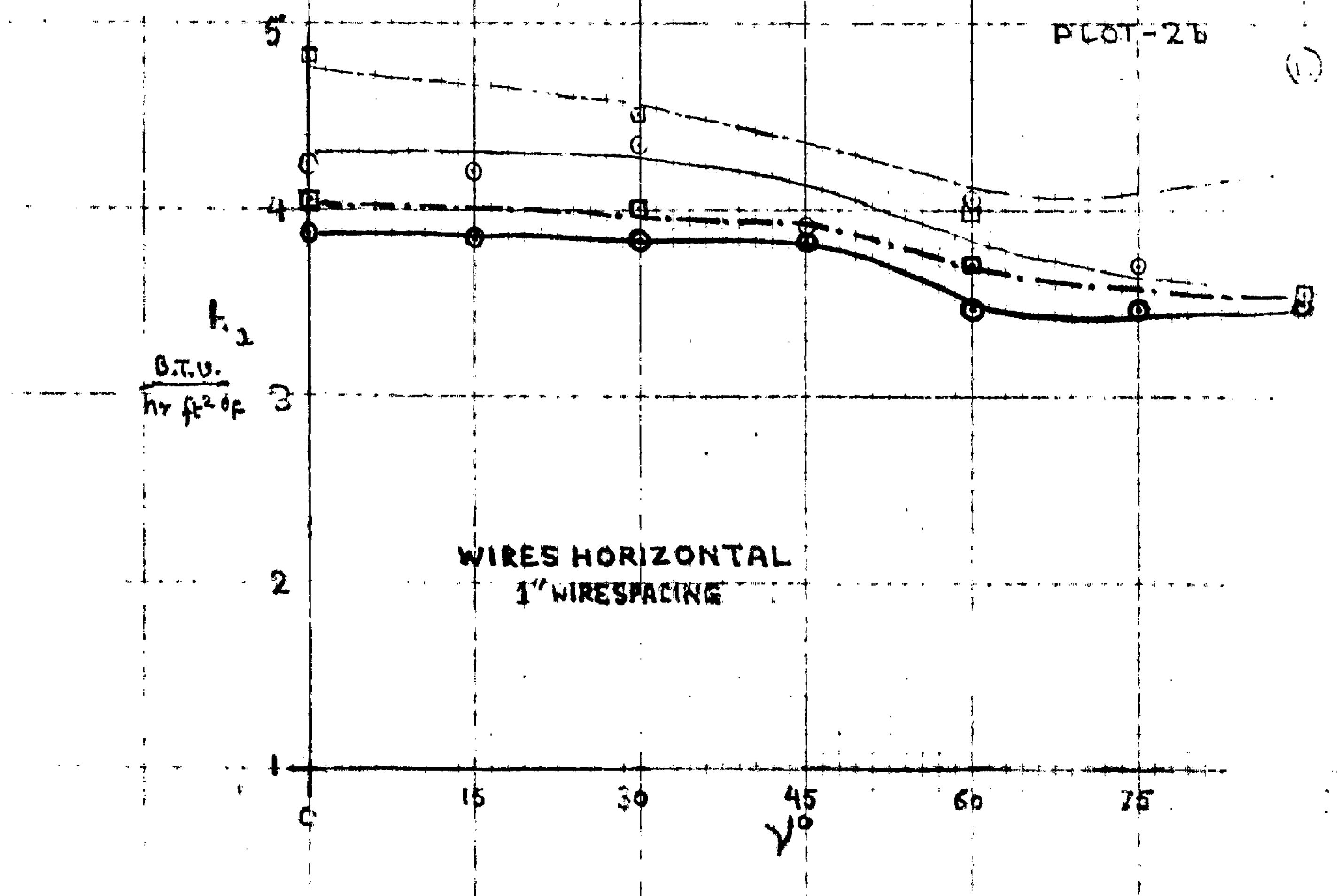
Theoretical curve for 20 S.W.G. wire.

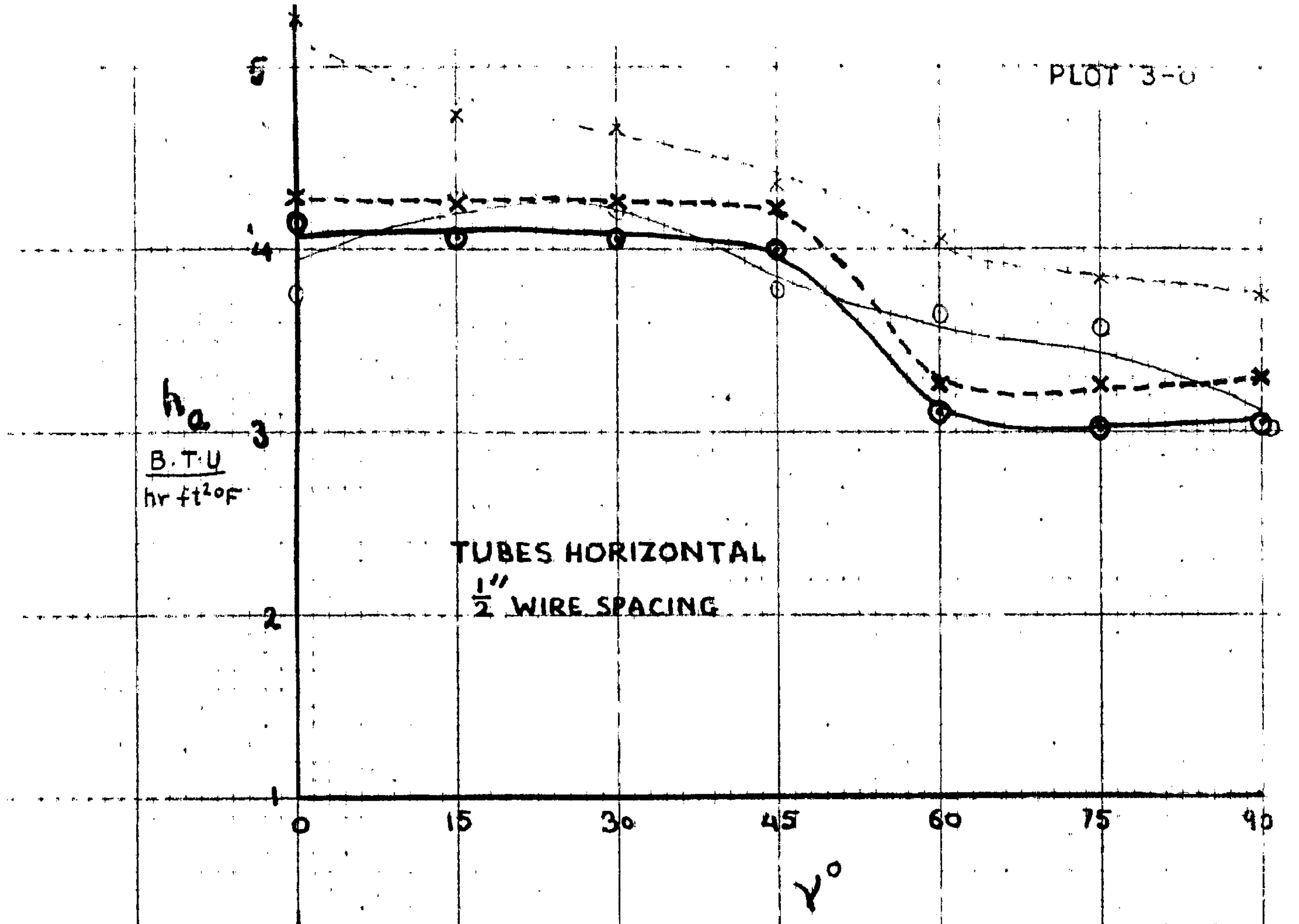
Experimental curve for 20 S.W.G. wire.

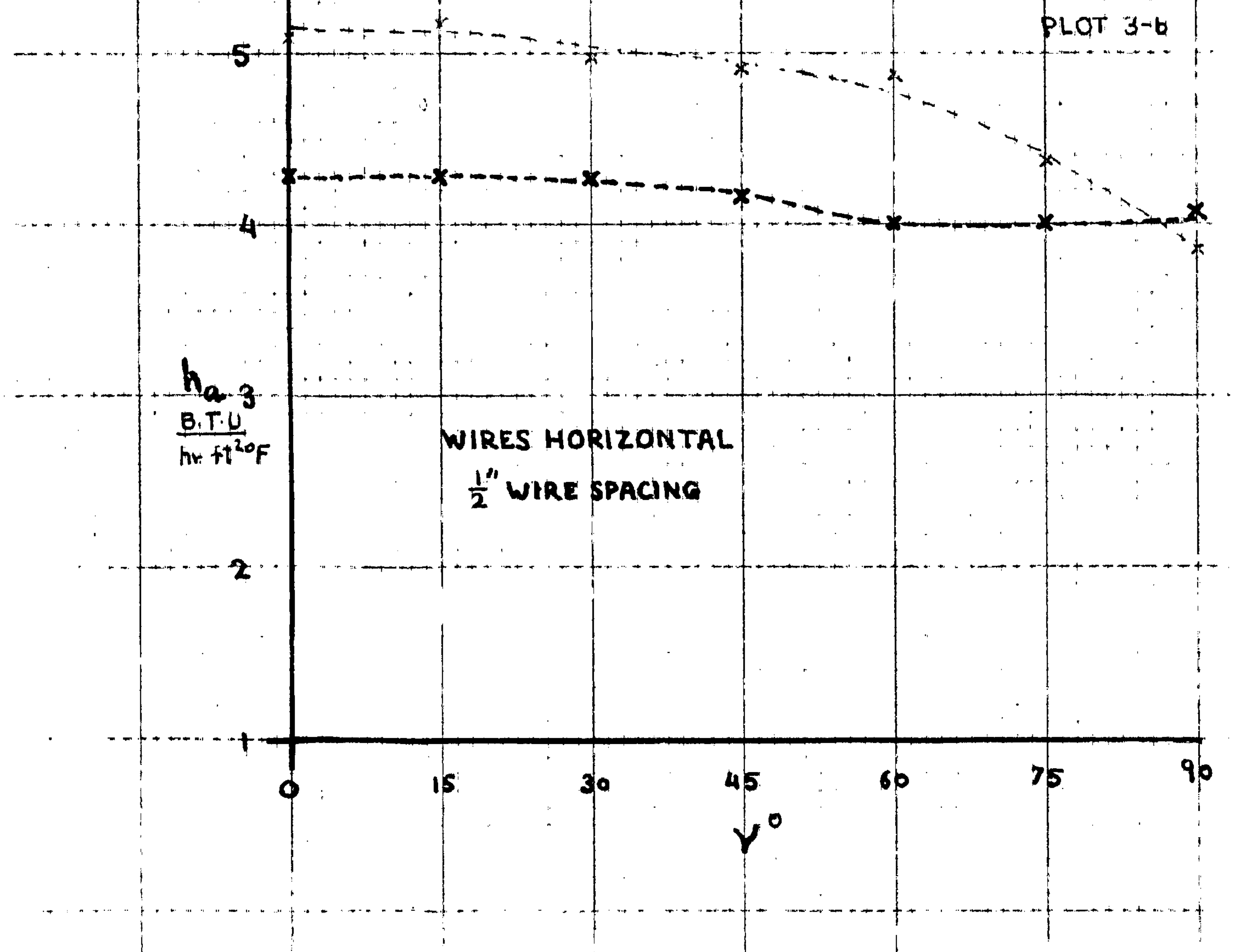

PLOT 1-a
6
5
4
3
2
ha
B.T.U.
hr ft2 °F
TUBE HORIZONTAL
2" WIRESPACING
0
15
30
45
60
75
90
γ°

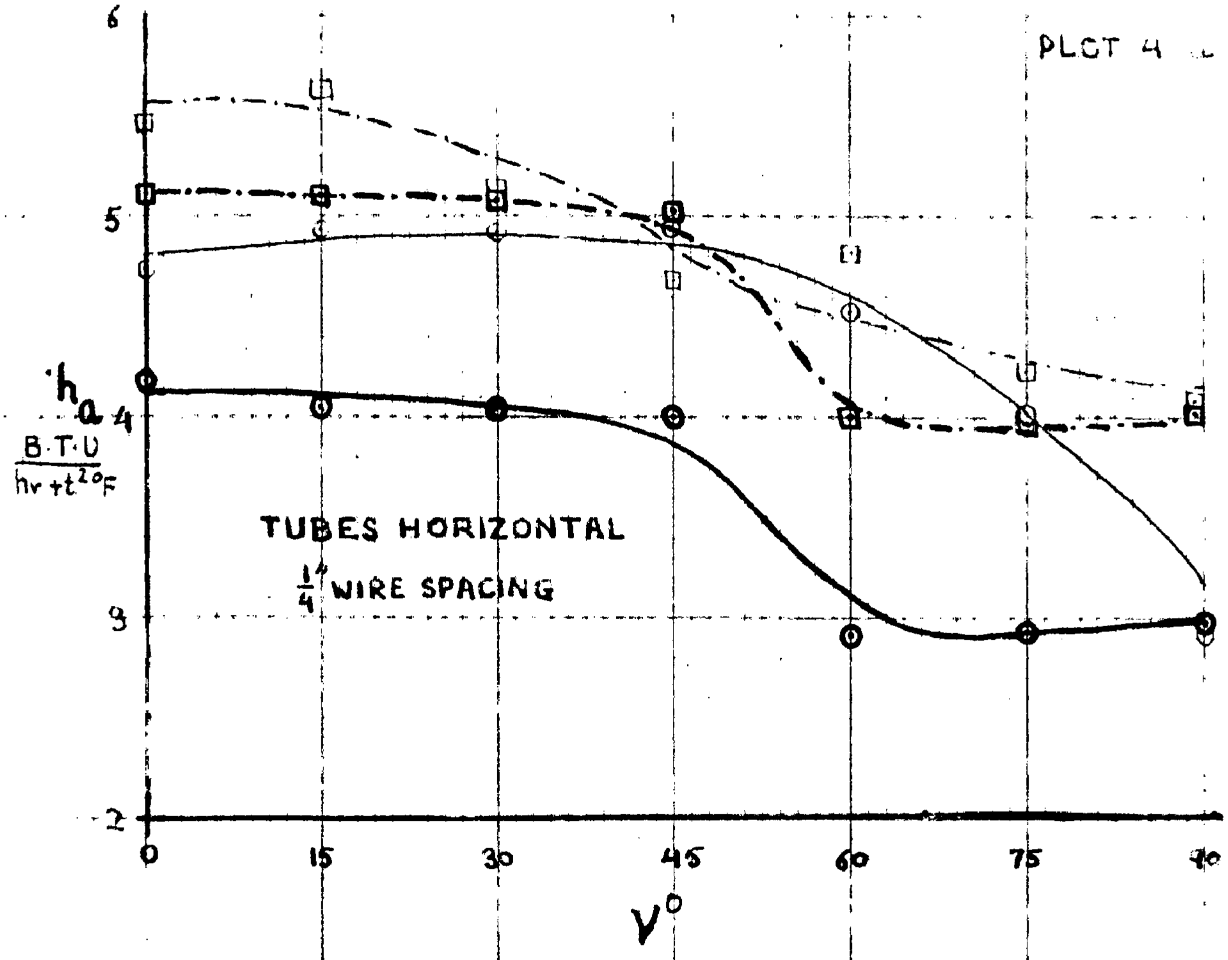

PLOT 1-b
6
5
4
3
2
ha
B.T.U.
hr ft2 °F
WIRES HORIZONTAL
2" WIRE SPACING
0
15
30
45
60
75
90
γ°


PLOT 2·a
5
4
3
2
1
h_a
B.T.U. / hr ft² °F
TUBES HORIZONTAL
1" WIRE SPACING
0
15
30
45
60
75
90
γ°

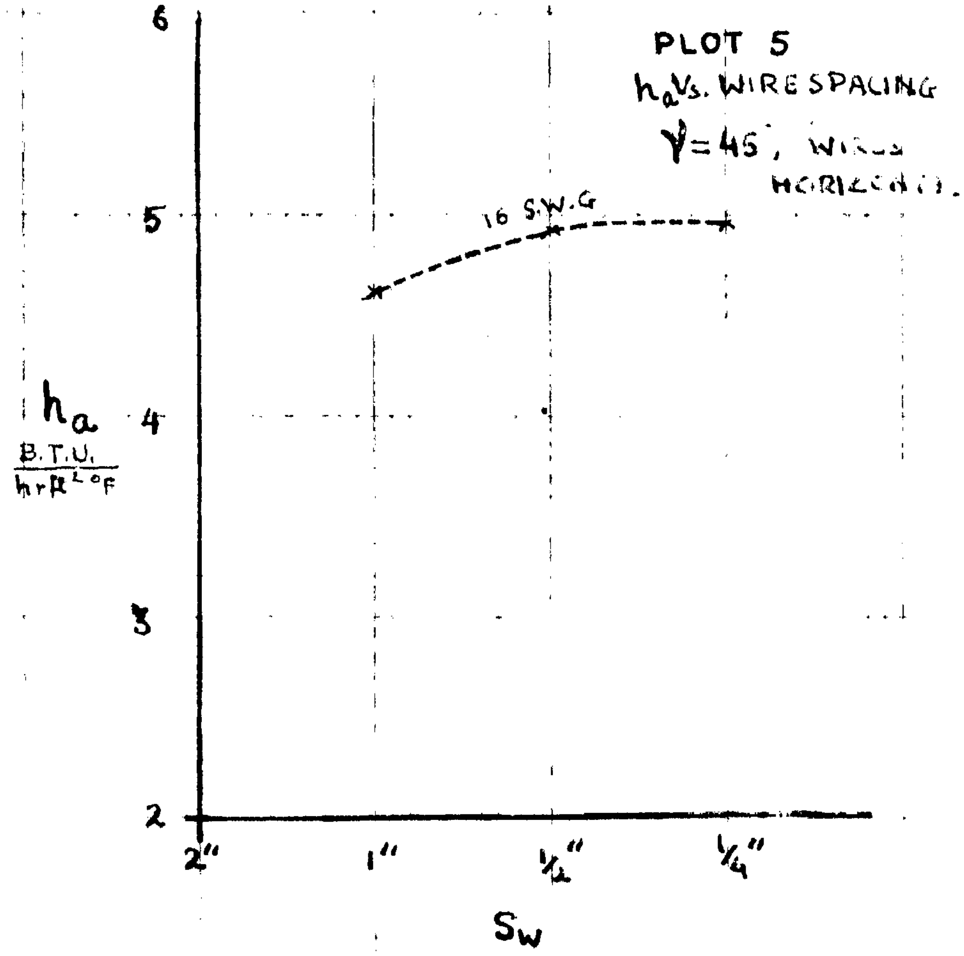

PLOT-2b
5
4
3
2
1
B.T.U. / hr ft² °F
WIRES HORIZONTAL
1" WIRESPACING
0
15
30
45
60
75
γ°

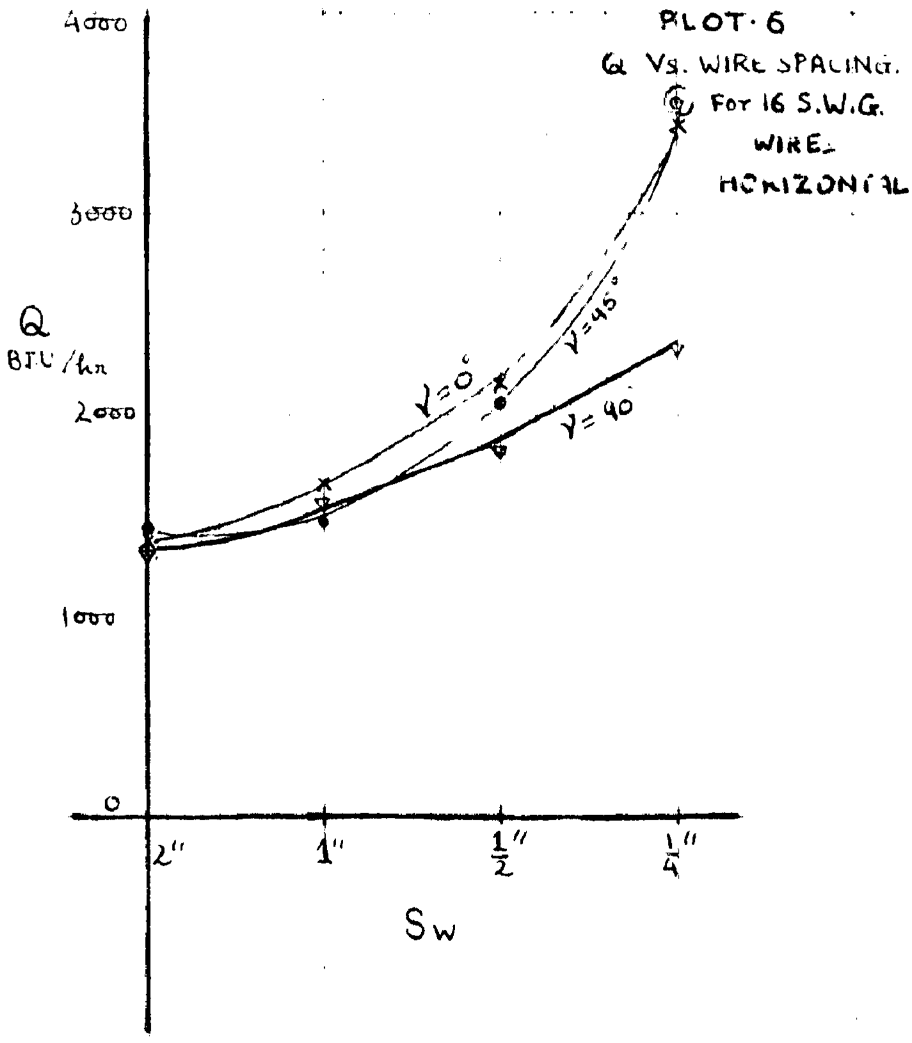

PLOT 3-a
5
4
3
2
1
h_a
B.T.U / hr ft²°F
TUBES HORIZONTAL
1/2" WIRE SPACING
0
15
30
45
60
75
90
γ°

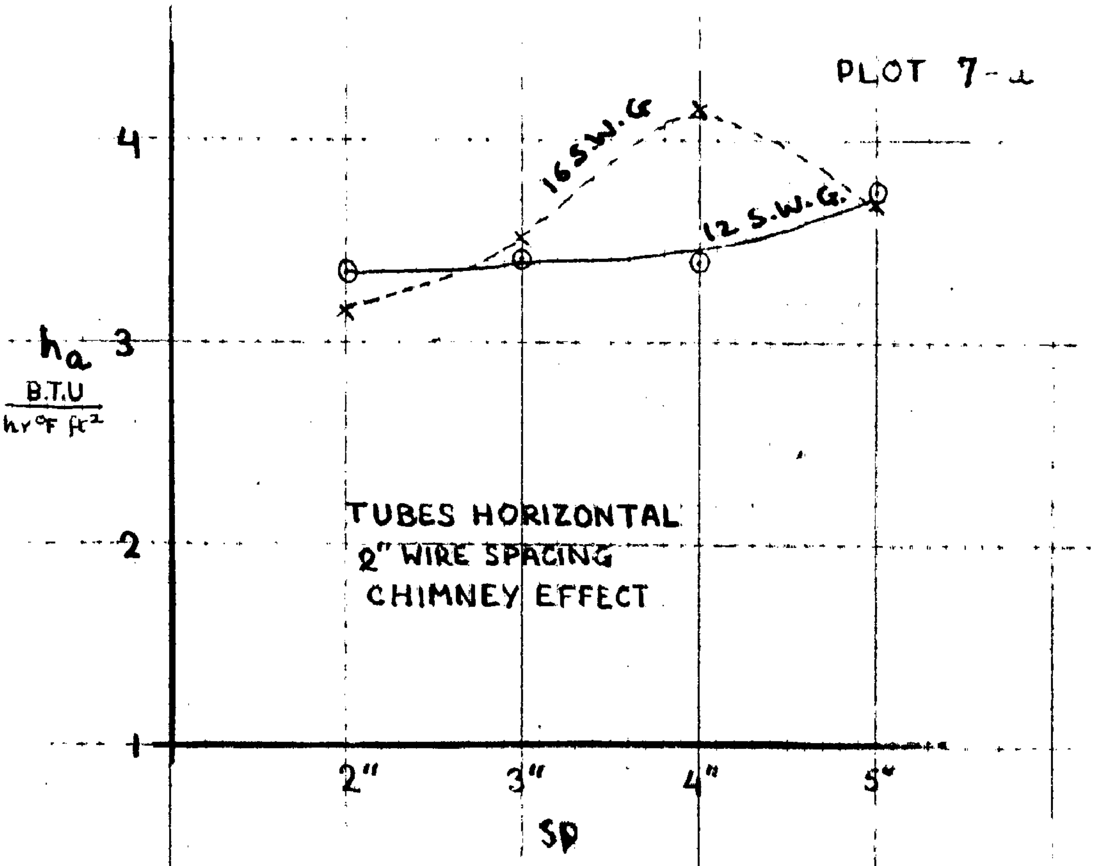

PLOT 3-b
5
4
3
2
1
h_a
B.T.U / hr ft²°F
WIRES HORIZONTAL
1/2" WIRE SPACING
0
15
30
45
60
75
90
γ°

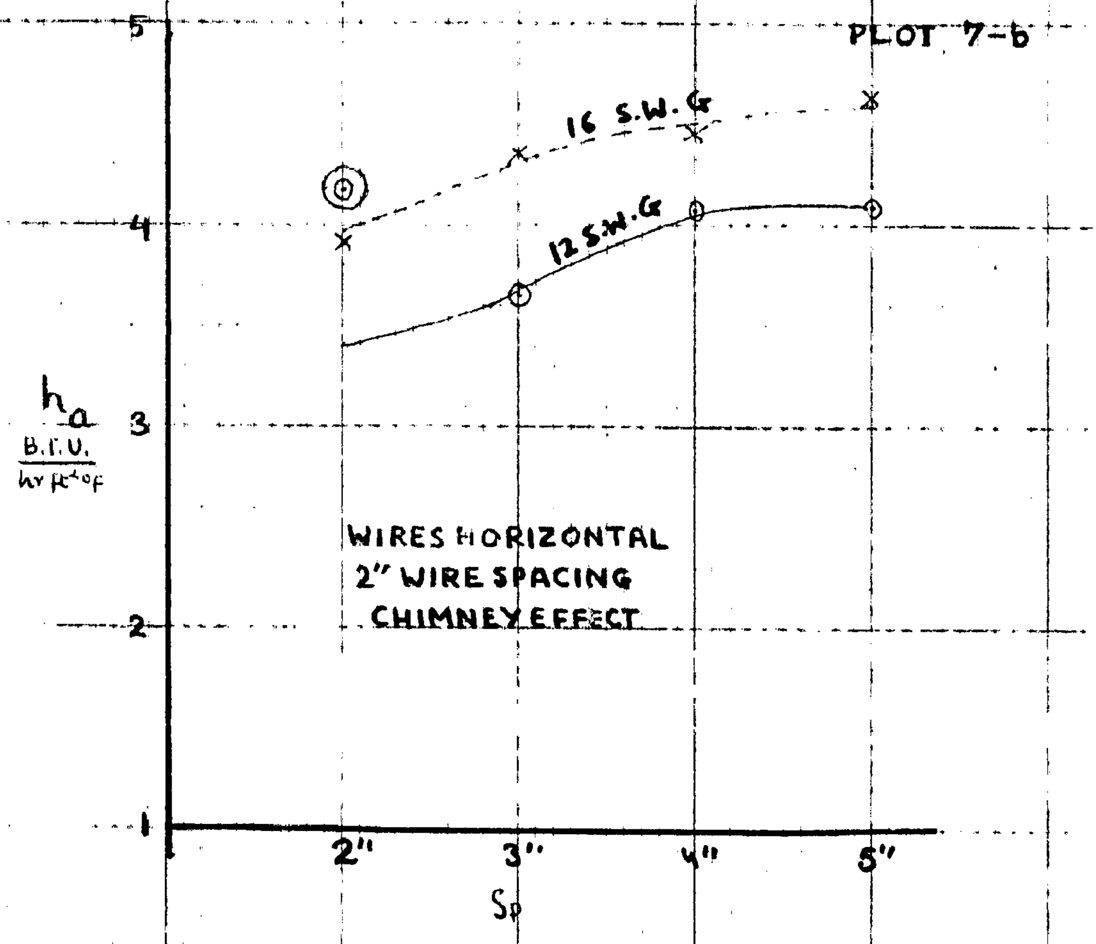


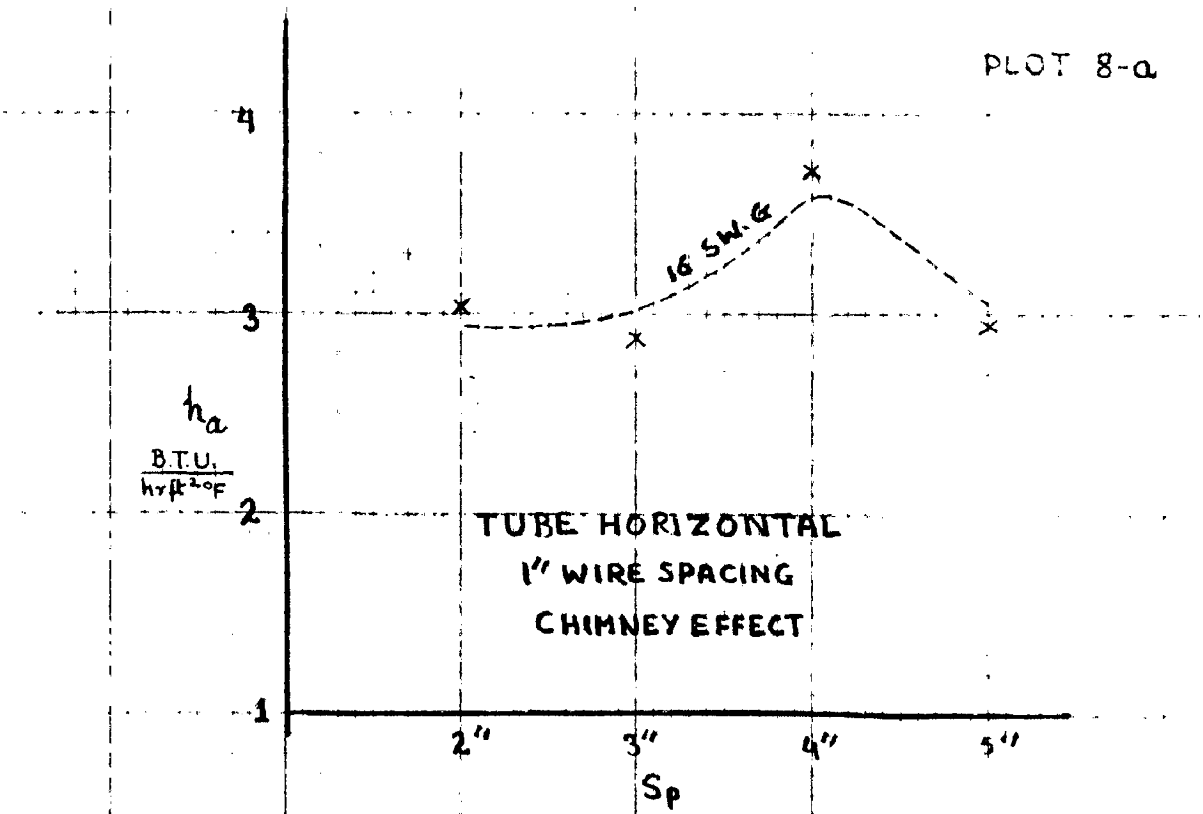
PLOT 4
TUBES HORIZONTAL
1/4" WIRE SPACING
h_a
B.T.U / hr ft² °F
6
5
4
3
2
0
15
30
45
60
75
90
γ°

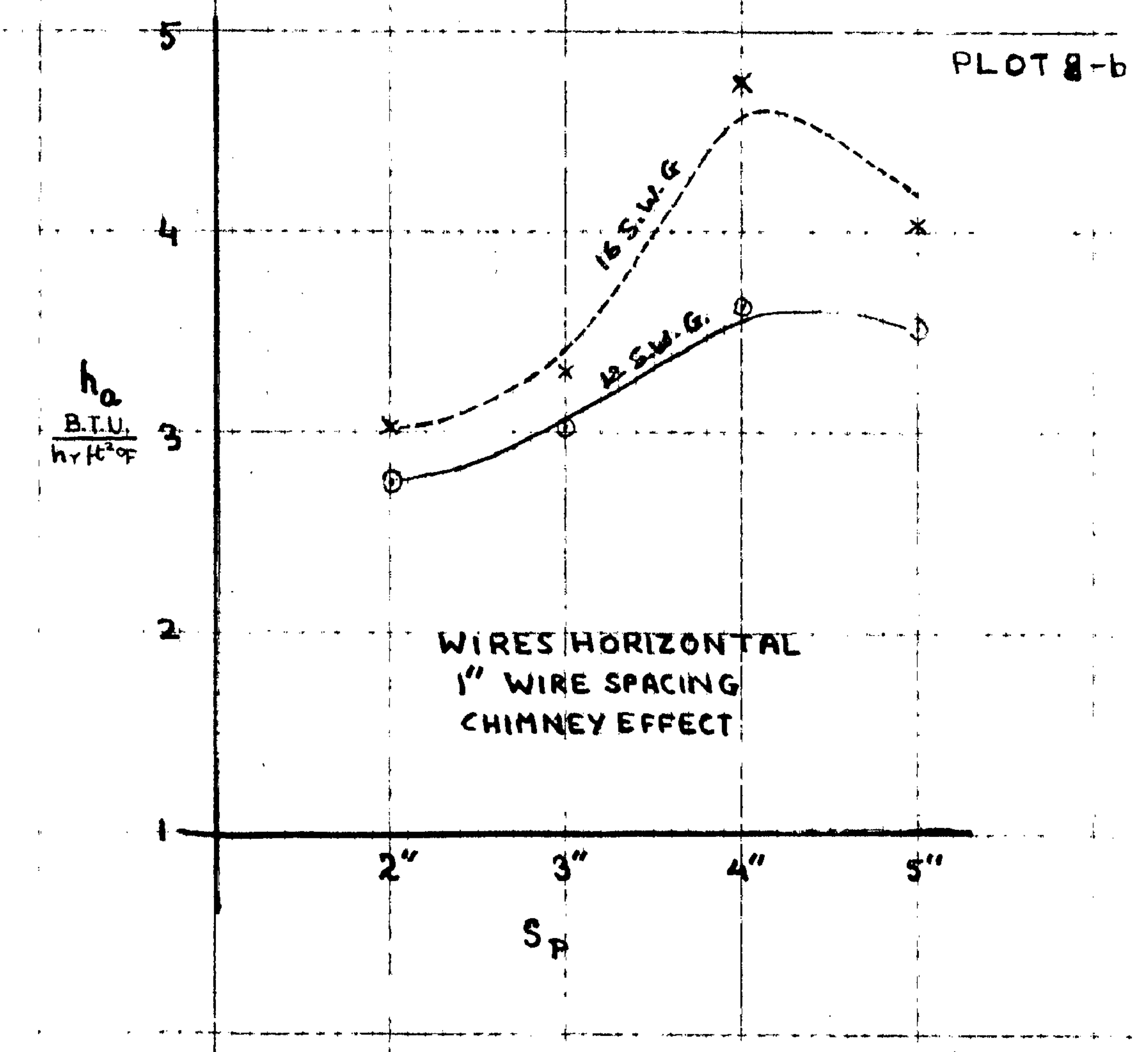

PLOT 5
h_a Vs. WIRE SPACING
γ = 45°, WIRES HORIZONTAL
16 S.W.G.
h_a
B.T.U./hr ft² °F
6
5
4
3
2
2"
1"
1/2"
1/4"
S_w

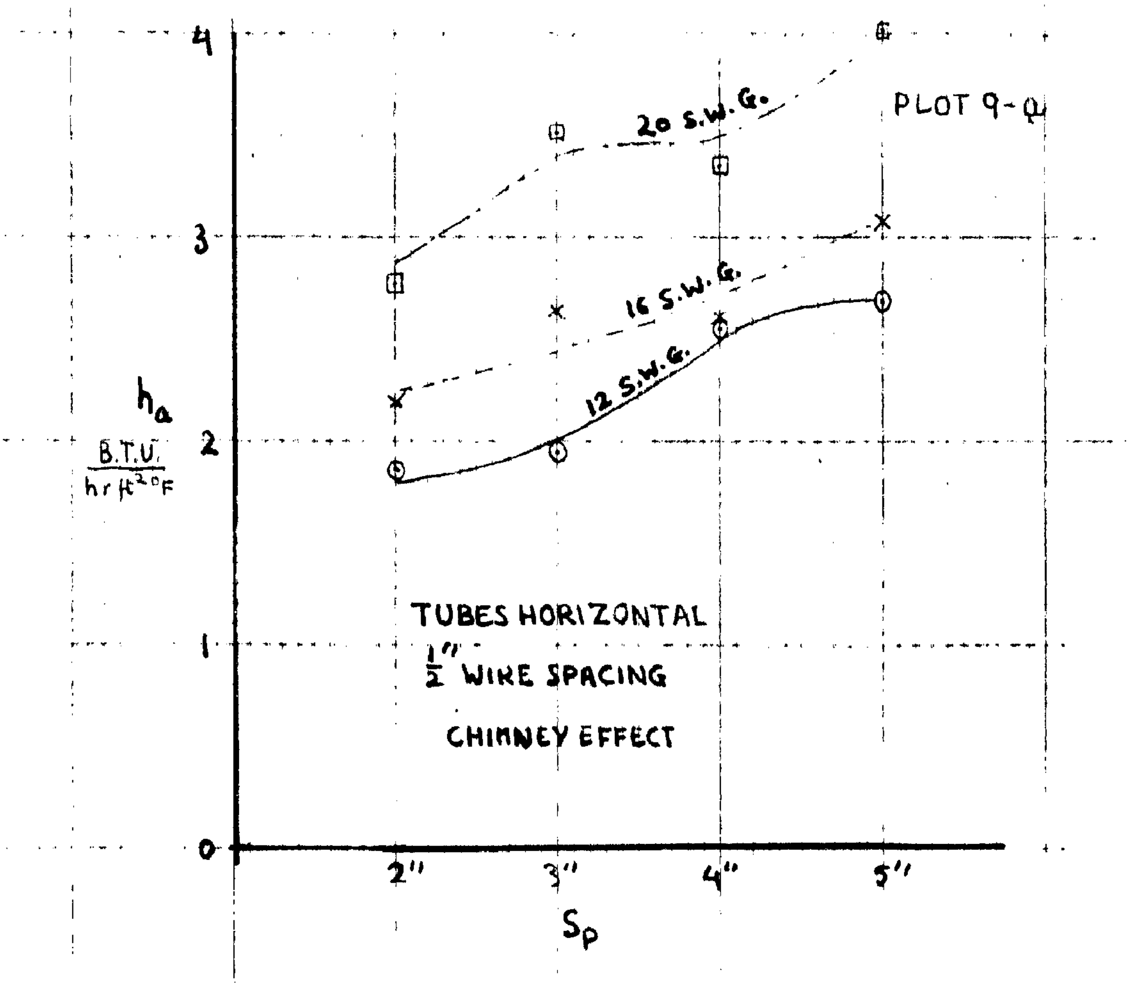

PLOT 6
Q Vs. WIRE SPACING
For 16 S.W.G. WIRE
HORIZONTAL
Q
BTU/hr
4000
3000
2000
1000
0
γ = 0°
γ = 45°
γ = 90°
2"
1"
1/2"
1/4"
Sw

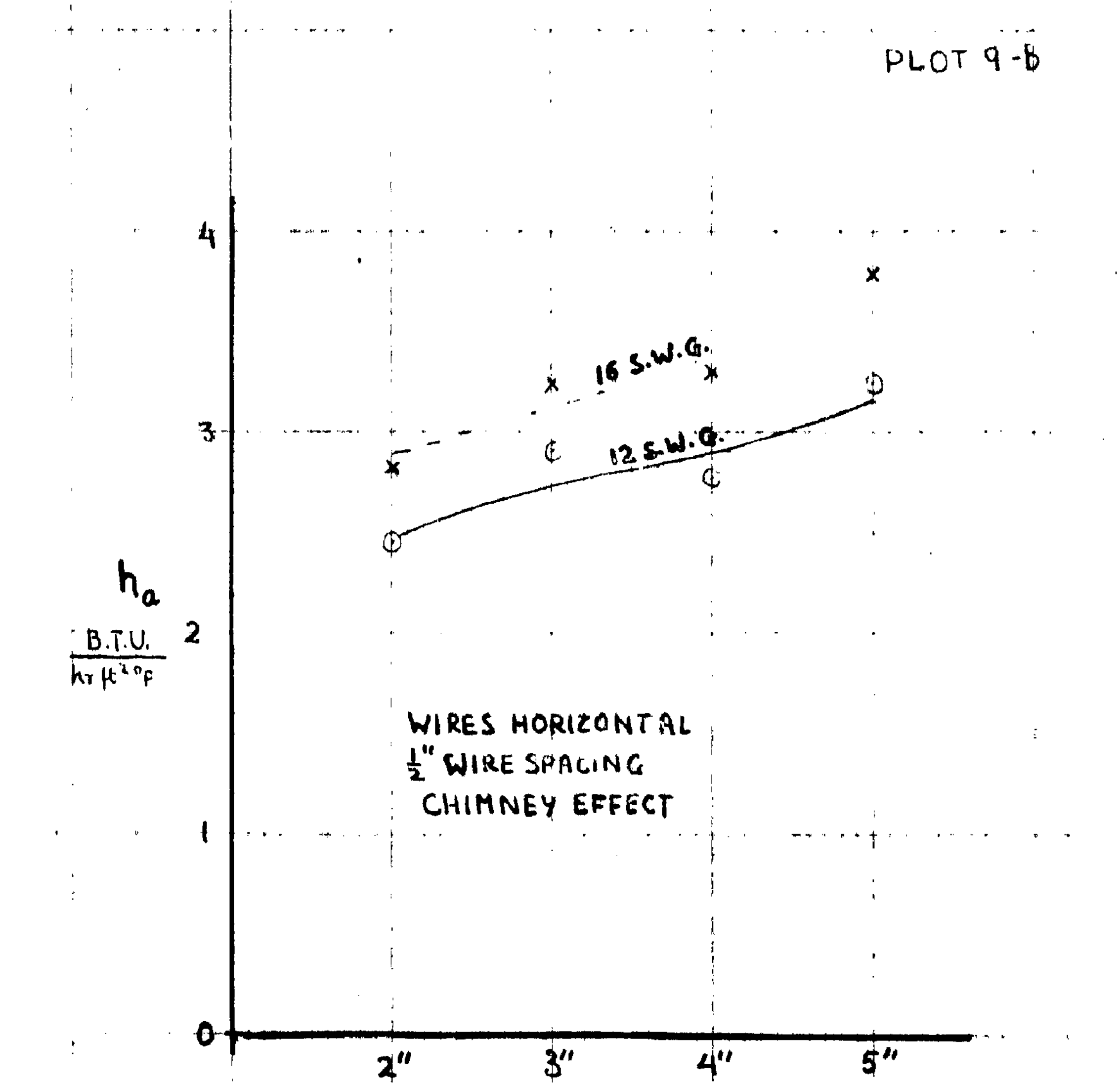

PLOT 7-a
16 S.W.G
12 S.W.G.
4
3
2
1
h_a B.T.U / hr °F ft²
TUBES HORIZONTAL
2" WIRE SPACING
CHIMNEY EFFECT
2"
3"
4"
5"
Sp

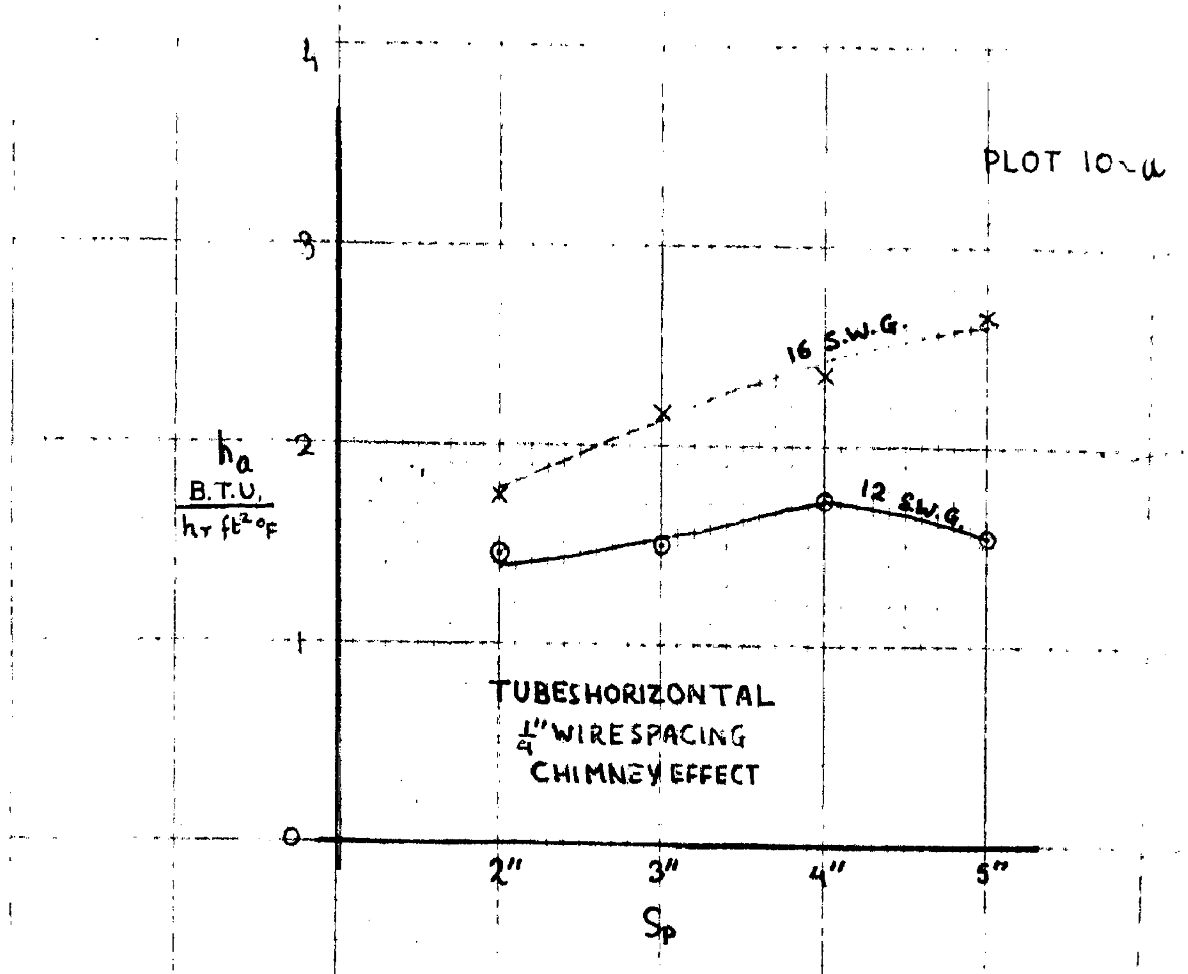

PLOT 7-b
16 S.W.G
12 S.W.G
5
4
3
2
1
h_a B.T.U. / hr ft² °F
WIRES HORIZONTAL
2" WIRE SPACING
CHIMNEY EFFECT
2"
3"
4"
5"
Sp


PLOT 8-a
4
3
2
1
h_a
B.T.U.
hr ft² °F
16 S.W.G
TUBE HORIZONTAL
1" WIRE SPACING
CHIMNEY EFFECT
2"
3"
4"
5"
Sp

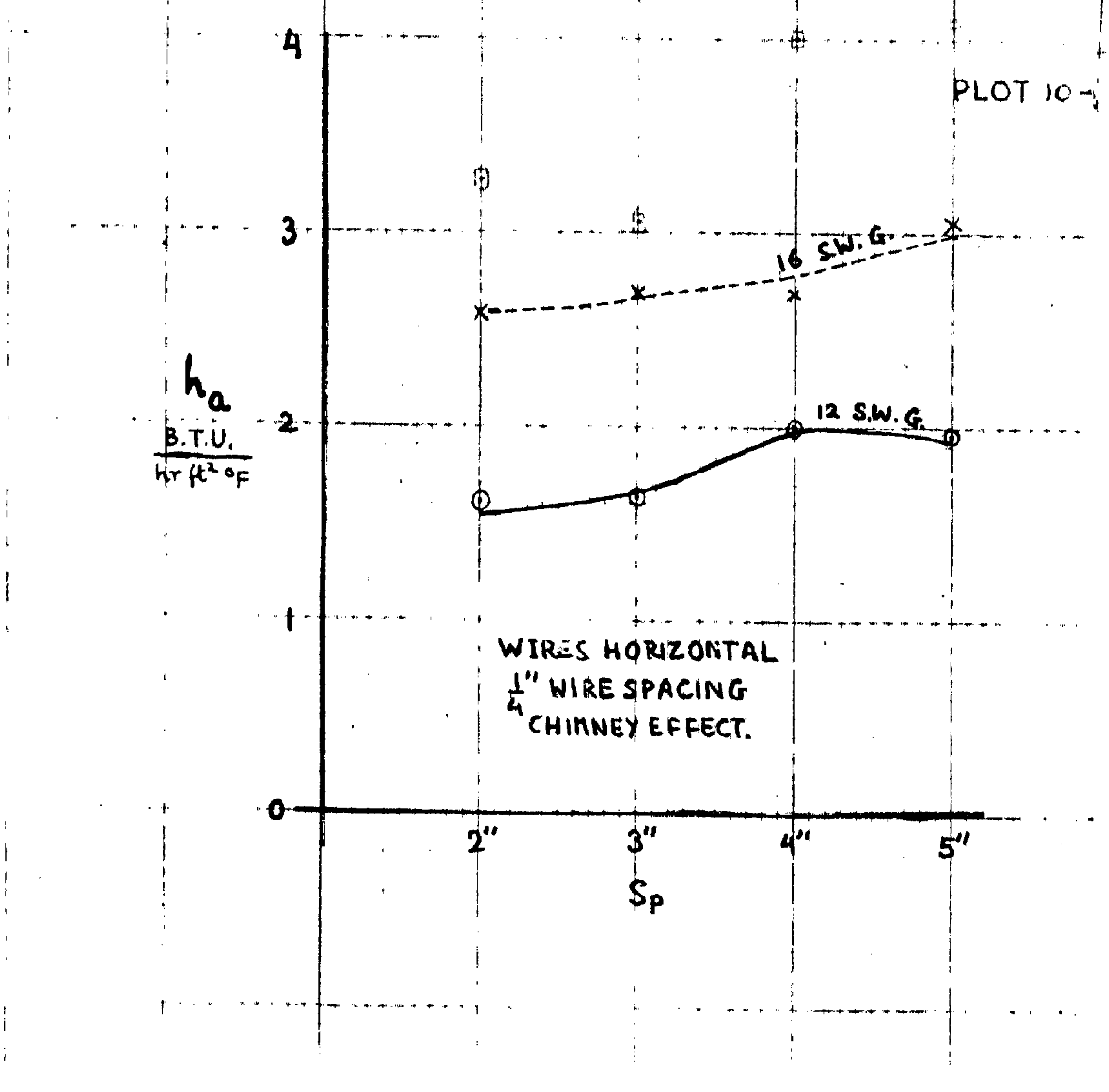

PLOT 8-b
5
4
3
2
1
h_a
B.T.U.
hr ft² °F
16 S.W.G
12 S.W.G.
WIRES HORIZONTAL
1" WIRE SPACING
CHIMNEY EFFECT
2"
3"
4"
5"
Sp


PLOT 9-a
20 S.W.G.
16 S.W.G.
12 S.W.G.
h_a
B.T.U. / hr ft² °F
TUBES HORIZONTAL
½" WIRE SPACING
CHIMNEY EFFECT
0
1
2
3
4
2"
3"
4"
5"
S_p


PLOT 9-b
16 S.W.G.
12 S.W.G.
h_a
B.T.U. / hr ft² °F
WIRES HORIZONTAL
½" WIRE SPACING
CHIMNEY EFFECT
0
1
2
3
4
2"
3"
4"
5"



PLOT 10-a
16 S.W.G.
12 S.W.G.
h_a B.T.U./hr ft² °F
TUBES HORIZONTAL
1/4" WIRE SPACING
CHIMNEY EFFECT
0
1
2
3
4
2"
3"
4"
5"
Sp



PLOT 10-b
16 S.W.G.
12 S.W.G.
h_a B.T.U./hr ft² °F
WIRES HORIZONTAL
1/4" WIRE SPACING
CHIMNEY EFFECT.
0
1
2
3
4
2"
3"
4"
5"
Sp

5.01 DISCUSSION

Both theoretically and experimentally determined values of h_a have been plotted against $\sqrt{Q}$ wire spacing to show the characteristics of the wire and tube heat exchanger. The results obtained may be interpretted as follows:

1. The effect of yawing is demonstrated by the curves of plot nos. 1, 2, 3 & 4. The curves in upper half of these plots show the effect of yawing when the rotation of the plane of exchanger is about a horizontal tube, and the lower half shows the effect of yawing when rotation is about horizontal wire.

i. Tube Horizontal:- The results from plots 1(a), 2(a), 3(a) and 4(a) indicate for the case of horizontal tubes that there is about 20 to 28% reduction of heat transfer coefficient, by a change in position from horizontal to vertical, for different wire spacings. This percentage reduction is seen to be increasing as the wire spacing decreases. There is nearly 20 percent reduction with 2" wire spacing, 22.5 per cent with 1" wire spacing, 25.0 per cent with ½" wire spacing and 28 per cent with ¼" wire spacing.

ii. Wires Horizontal:- The results from plots 1(b), 2(b) and 3(b) indicate for the case of horizontal wires, that the percentage reduction in heat transfer, by a change in position from horizontal to vertical, is comparatively less serious and we find a more uniform change in the value of heat transfer coefficient for this case. The percentage reduction seems to decrease with the decrease in wire spacing. The reduction seems to take place from about 16 percent to 10 percent; more specifically it is nearly 16 percent with 2" wire spacing, 13.5 percent with 1" wire spacing and 12 percent with ½" wire spacing. Due to practical difficulties the data for ¼" wire spacing is not shown.

iii. Combined Effects:- In both cases we find that the change in h_o is more serious with in certain range of change in inclination. When the tubes remain horizontal the change is more effective between 45° and 60° yaw angle. For the case of wires remaining horizontal practically the change seems to be effective from the earlier stages that is nearly 30 to 45°. This may be probably due to the fact that the blockage of flow with change in inclination is not so serious for the case of horizontal tubes as it is for the case of horizontal wires.

2. Effect of wire spacing is shown in plot no. 5 for 16 gauge wire. The value of h_o is found to increase with the decrease in wire spacing but change in the value of h_o decreases with the decrease in wire spacing. This may be due to the fact that as the wire spacing decreases, the boundary layer effects on the adjacent wire predominate more and more. In no case the wire spacing should be so close that the boundary layers of the two adjacent wires may

intersect each other, in which case flat plate condition is achieved.

3. Effect of wire spacing on Q is shown in plot no. 6, for three different exchanger positions. It is seen that heat transfer increases with the decrease in wire spacing. In the horizontal position the increase in the heat transfer is found to increase at a faster rate with the decrease in wire spacing. As the exchanger approaches vertical position the rate of increase in the heat transfer is comparatively less, with the wire spacing.

4. Chimney effect is shown on the plot nos. 7, 8, 9 & 10. The upper part (a) shows effect when the tubes were kept horizontal and the lower part (b) shows the effect when wires were kept horizontal. From all the plots we can conclude that the value of h_o increases with the plate spacing. Particularly for 12 and 16 S.W.G. wire, plots 7, 8 & 10 indicate that at 4" plate spacing the heat transfer coefficient is either maximum or beyond 4" spacing the increase in the value of h_o is very little affected. It is due to the fact that probably with this plate spacing the convection due to the chimney action is most effective.

5.02 THEORETICAL RESULTS COMPARED

Theoretically the values of h_o were calculated with the help of defining equation (3). Total convective coefficients for wire and tubes both were determined with the help of combining equation (11). Convective coefficients for wires and tubes in different positions separately were determined with the help of equations (23a), (32), (44) and (45). Radiative coefficient was found with the help of equation (6) in which the configuration factor for the exchanger is assumed unity.

This assumption did not affect the results at all since the variation in the value of radiative coefficient for the required temperature range was found to be negligible, which were calculated separately for each case.

Though the theoretically calculated values did not fully agree with the experimental values due to theoretical and practical discrepancies unaccounted for, a good agreement is found to exist in the variation of theoretically and experimentally determined values.

6.03 CONCLUSIONS

Following conclusions may be drawn from the study:-

1. The wire and tube heat exchanger may be inclined upto about 45° without affecting its performance appreciably when the tubes remain horizontal.

2. Change in the heat transfer coefficient is less in the case of horizontal wires than that of horizontal tubes, for the vertical position of the heat exchanger.

3. There is a particular wire spacing for particular diameter of wire, for which the heat transfer coefficient is

maximum. A further decrease in wire spacing does not affect the heat transfer coefficient appreciably.

4. For any wire spacing the heat transfer is maximum for horizontal position.

5. The chimney surrounding the exchanger is most effective when the plate spacing is at a particular value.

APPENDIX - A

NOMENCLATURE

NOMENCLATURE

A_t	Total area of tubes. sq ft
A_w	Total area of wires. sq ft
d	Diameter of hypothetical cylinder ft
D_w	Diameter of wire. ft.
D_c	Characteristic diameter. ft
U	Overall heat transfer coefficient for the exchanger. B.T.U /sq ft hr °F.
A	Area of the exposed surfaces. sq. ft.
θ	Temperature difference between inside fluid and outside fluid.
h_i	Convective heat transfer coefficient for inside tube surface. B.T.U./hr ft²°F.
h_c	Convective heat transfer coefficient for outside tube surface. B.T.U./hr ft² °F.
h_r	Radiative heat transfer coefficient for outer surface. B.T.U /hr ft²°F
k_t	Tube wall thermal conductivity. B.T.U /hr ft °F.
r_o	Outside radius of tube. ft
r_i	Inside tube radius. ft
L	Tube length. ft
A_c	Outside area where convection heat transfer exists. sq ft
A_i	Inside tube area. sq ft
V	Velocity ft/sec.
ρ	Fluid density lbs/cu ft.
μ	Viscosity of fluid. lbs/sec ft.

k	Thermal conductivity of fluid. B.T.U/hr ft °F
C_p	Specific heat of fluid. B.T.U/lb °F
ϵ	Emissivity of outer surface.
σ	Universal gas constant. $.174 \times 10^{-8}$
M	Mass flow rate of water. lbs/hr
η	Fin effectiveness.
Nu_x	Nusselt number based on x
Nu_d	Nusselt number based on d
Gr_x	Grashof number based on x
Gr_d	Grashof number based on d
r_w	Radius of wire. ft
u	Velocity component in x direction.
v	velocity component in y direction.
x	Co-ordinate measuring longitudinal axis.
α	Thermal diffusivity = $k/\rho C_p$ ft²/hr
β	Coefficient of thermal expansion.
g	Acceleration due to gravity. ft²/sec²
t_w	Wall temperature.
t_∞	Ambient temperature
t	static temperature.
T_{wa}	Mean wire temperature (average).
T_{ta}	Average tube surface temperature.
φ	Angle made with vertical plane.
γ	Angle made with horizontal plane.

P_r	Prandtl number.
q_x	Heat transfer per unit area. BTU/hr sq ft
q_R	Radiative heat transfer rate. BTU/hr sq ft
Q	Total heat transfer BTU/hr
$Gr_{x,fp}$	Grashof number based on x for flat plate.
$Gr_{d,cyl}$	Grashof number based on d for cylinder.
$Nu_{x,fp}$	Nusselt number based on x for flat plate.
$Nu_{d,cyl}$	Nusselt number based on d for cylinder.
D_T	Diameter of tubes(outside). ft
S_W	Centre to centre wire spacing. in
S_T	Centre to centre tube spacing. in.
S_P	Plate spacing (in case of chimney effect). in.
C	Fin circumference. ft
h_a	Overall heat transfer coefficient(= h_c+ h_r).
T_i	Inlet mixing-cup temperature
T_o	Outlet mixing-cup temperature
T_s	Surface temperature.

APPENDIX - C

SAMPLE CALCULATION

SAMPLE CALCULATION

The method used for calculating the theoretical and experimental values of h_a has been shown below for a particular run.

Observation sheet no. 1.

Run no. 2, Tubes remaining horizontal

Wire diameter	= 12 S.W.G. (.104")
Wire spacing (centre to centre)	= 1/4"
Yaw angle ψ	= 15°
Average tube surface temperature	= 142.6°F
Average mean wire temperature	= 133.55°F
Ambient temperature	= 89°F
Inlet temperature	= 181.6°F
Outlet temperature	= 150.8°F
Flow rate	= 157 lbs/hr.

Convective coefficient is determined by the equation (11). Since in this case tubes remain horizontal and inclination of wires is changed, equation (23a) will be used to determine h_{c_t}, and equation (46) for determining h_w, because it is applicable upto 45° of yaw angle.

Evaluation of h_{c_t}.

Mean air temperature $t_{ma} = \dfrac{142.6 + 89}{2}$

$= 115.8\,°F = 575.8\,°R$

For air 115°F, $\nu = .18944 \times 10^{-3}\ ft^2/sec$

& $k = .015716\ BTU/hr\,ft\,°F$

Now since $Gr_d = \dfrac{g\beta(t_w - t_\infty)d^3}{\nu^2}$

$$= \frac{32.2 \times (142.6 - 89)(.026)^3}{575.8 \times (.18444)^2 \times (10^{-3})^2}$$

$$= 1471.5$$

$\therefore$ $$Nu \doteq \frac{2}{\log_e\left[1 + \dfrac{5}{(Gr_d)^{1/4}}\right]}$$

$$= \frac{2}{\log_e\left[1 + \dfrac{5}{(1471.5)^{1/4}}\right]} = \frac{2}{\log_e 1508}$$

or $$\frac{h_t D_t}{k} = \frac{2}{\log_e 1.808}$$

$$h_t = \frac{2}{\log_e 1.808} \times \frac{.015716}{.026}$$

$$= 2045 \ \text{BTU/hr ft}^2\ {}^\circ\text{F}$$

Evaluation of h_{ws}.

Mean air temperature $= \dfrac{138.55 + 89.0}{2}$

$= 113.775\,^\circ\text{F} = 573.775\ \text{R}$

For air at 113.775 [illegible]

$\nu = 1\cdot 05 \times 10^{-}$ ft^2/sec.

$k = .015675$ BTU/hr ft² F

$$G_{rd} = \frac{32.2\,(138.55 - 89.0)\,([illegible])^3}{573.775 \times (.1865)^2 (10^{-})^2}$$

$$= 50.820$$

Now $$Nu_d = \frac{2}{\log_e \left\{ 1 + \frac{5}{(Gr_d)^{1/4}(\cos\psi)^{1/4}} \right\}}$$

$$= \frac{2}{\log_e \left\{ 1 + \frac{5}{(50.82 \cos 15)^{1/4}} \right\}}$$

$$\frac{h_w d_w}{k} = \frac{2}{\log_e 2.9855}$$

$$h_w = \frac{2}{\log_e 2.9855} \times \frac{.015675}{.104/12}$$

$$= 3.305 \ \text{BTU/hr ft}^2 \ {}^\circ\text{F}$$

Fin Effectiveness –

$$\eta = \frac{\tanh ml/2}{ml/2}$$

where $$m = \sqrt{\frac{4 h_c}{k_w D_w}} = \sqrt{\frac{4 \times 2.045 \times 12}{26.23 \times .104}}$$

$$= 6.012$$

$$\eta = \frac{\tanh 6.012 \times \frac{2}{12 \times 2}}{6.012 \times \frac{2}{12 \times 2}} = \frac{.4621}{.501}$$

$$= .925$$

Convective coefficient h_c – from eq(11)

$$h_c = \frac{3.305 \times 15.23 \times .925 + 2.045 \times 3.485}{(15.23 + 3.485)}$$

$$= 2.872 \ \text{BTU/hr ft}^2 \ {}^\circ\text{F}$$

Evaluation of hr :-

$$h_r = \sigma \epsilon (T_s^2 + T_e^2)(T_s + T_e)$$

For black painted surface $\epsilon = .89$

and T_s = average Surface temperature

$$= \frac{142.6 + 138.55}{2}$$

$$= 140.575\ F = 600.575\ R$$

$$T_e = 89^\circ F = 549^\circ R$$

$$h_r = .174 \times 10^{-8} (.89)(600.575^2 + 549^2) \times (600.575 + 549)$$

$= 1.177$ BTU/hr ft^2 $^\circ$F

Theoretical value of ha :-

$$h_a = h_c + h_r$$

$$= 2.872 + 1.177$$

$= 4.049$ B.T.U/hr ft^2 $^\circ$F

Experimental value of ha

Total heat transfer $= Q = 157(181.5 - 150)$

$= 4945.5$ BTU/hr

From eq (11)

$$4945.5 = h_a (142.6 - 89)(15.2 + 3.485)$$

$$h_a = \frac{4945.5}{53.6 \times 18.72}$$

$= 4.94$ BTU/hr ft^2 $^\circ$F

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APPENDIX - B

DATA RECORD

EXCHANGER DETAILS

Tube diameter (inside) = 1/4"

Tube diameter (outside) = 5/16"

Tube spacing (Centre to centre) = 2"

Total tube length = 41.5ft.

Total tube surface area (A_t) = 3.486 sq. ft.

Overall length of heat exchanger = 38"

Overall width of heat exchanger = 23"

Wire length = 38"

TABLE OF COMBINATIONS OF WIRE SPACINGS AND WIRE DIAMETERS USED.

S.No.	Details	WIRE DIAMETER										
		12 S.W.G. (.104"d)				16 S.W.G. (.064"d)				20 S.W.G. (.036"d)		
1.	Wire spacing	2"	1"	½"	¼"	2"	1"	½"	¼"	1"	½"	¼"
2.	No. of wire pairs.	12	23	46	89	12	23	46	89	23	46	89
3.	Total no. of wires.	23	46	89	178	23	46	89	178	46	89	178

OBSERVATION SHEET No.1

Wire Gauge 13

Wire Spacing - 4d

Tubes Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	157.0	157.0	159.0	159.0	157.0	157.5	158.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	69	69	69	69	69	69	69
Inlet Temp. °F	181.0	181.5	179.0	181.4	182.0	179.5	180.5
Outlet Temp. °F	151.0	150.0	[illegible]	150.5	152.0	151.5	150.0
OUTSIDE TUBE SURFACE TEMPERATURE T_1	159.0	156.0	[illegible]	158.0	159.5	159.5	[illegible]
T_2	140.0	140.0	141.0	141.0	153.0	[illegible]	157.5
T_3	142.0	[illegible]	140.0	159.5	142.0	[illegible]	[illegible]
T_4	144.0	140.0	141.0	142.0	144.0	[illegible]	150.0
T_5	[illegible]	141.5	142.5	142.5	[illegible]	147.0	151.5
T_6	144.0	157.0	[illegible]	141.5	[illegible]	144.0	[illegible]
T_7	[illegible]	143.0	142.0	141.0	[illegible]	147.0	153.0
T_8	143.0	143.0	144.0	144.5	147.0	[illegible]	[illegible]
T_9	[illegible]	141.5	140.0	141.5	144.0	[illegible]	150.0
T_A	[illegible]	142.6	142.6	142.5	[illegible]	147.7	152.7
U_1	144.0	131.5	140.0	142.0	[illegible]	[illegible]	150.0
U_2	125.0	128.5	123.0	124.0	[illegible]	132.0	142.0
U_3	144.0	141.5	141.0	142.5	[illegible]	[illegible]	151.0
[illegible] TEMPERATURE U_4	147.0	[illegible]	144.0	[illegible]	147.0	150.0	155.0
U_5	125.0	134.0	122.5	122.0	125.0	[illegible]	150.0
U_6	[illegible]	144.0	142.0	144.0	[illegible]	[illegible]	152.5
U_7	142.5	[illegible]	140.0	140.0	143.0	144.5	[illegible]
U_8	142.0	140.0	141.0	141.5	142.5	[illegible]	[illegible]
U_9	[illegible]	140.5	142.5	144.0	[illegible]	[illegible]	155.0
U_A	140.0	[illegible]	157.5	[illegible]	141.1	142.5	150.4

OBSERVATION SHEET No. 3

Wire Gage 18 Wire Spacing - 1/4" Wire Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	180.0	180.0	[illegible]	[illegible]	175.0	[illegible]	180.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	80	80	80	80	80	80	80
Inlet Temp. °F	180.0	181.5	182.5	182.5	184.5	180.0	181.0
Outlet Temp. °F	153.0	154.0	155.0	155.5	150.5	150.0	152.0
OUTSIDE TUBE SURFACE TEMPERATURE T_1	151.5	150.0	151.0	150.0	153.5	153.5	150.0
T_2	164.0	[illegible]	[illegible]	159.0	151.0	153.0	157.5
T_3	155.5	157.0	158.0	150.0	151.0	154.5	152.0
T_4	161.5	162.5	164.0	[illegible]	150.0	154.0	159.0
T_5	160.0	162.0	[illegible]	[illegible]	153.0	155.0	150.0
T_6	[illegible]	167.5	[illegible]	153.5	150.5	157.0	150.0
T_7	164.0	[illegible]	[illegible]	152.0	151.0	155.5	150.0
T_8	163.5	[illegible]	[illegible]	150.0	152.0	153.0	150.0
T_9	162.5	169.0	168.5	[illegible]	[illegible]	152.0	151.0
T_A	[illegible]	161.1	[illegible]	153.0	153.1	155.6	150.2
MESH WIRE TEMPERATURE W_1	162.5	164.0	164.0	[illegible]	153.0	153.0	150.0
W_2	157.5	[illegible]	158.0	164.0	167.0	[illegible]	[illegible]
W_3	163.5	164.0	163.5	[illegible]	152.0	155.5	159.0
W_4	[illegible]	167.0	[illegible]	151.5	155.0	157.0	151.5
W_5	161.0	161.0	162.0	[illegible]	163.0	167.0	158.0
W_6	164.5	[illegible]	[illegible]	150.0	152.0	153.0	150.0
W_7	162.5	[illegible]	[illegible]	[illegible]	150.0	164.0	157.0
W_8	[illegible]	167.5	[illegible]	150.0	154.0	157.0	151.0
W_9	163.0	[illegible]	167.5	164.0	153.0	153.0	150.0
W_A	162.9	164.1	154.7	167.6	151.0	154.0	158.1

Exchanger No. 1

Wire Gage 12

Wire Spacing - 3/8"

Chimney Effect

		Tubes Horizontal				Wires Horizontal			
Run No.		1	2	3	4	1	2	3	4
Flow Rate lbs/hr.		107.0	112.0	125.0	107.5	150.0	150.0	150.0	155.0
Plate Spacing		2°	3°	4°	5°	2°	3°	4°	5°
Ambient Temp. °F		80	80	80	80	90	90	90	90
Inlet Temp. °F		185.0	188.0	184.5	182.0	180.5	181.0	182.5	181.0
Outlet Temp. °F		157.0	159.0	156.0	153.0	157.0	150.0	158.5	154.5
Outside Tube Surface Temperature	T_1	150.0	155.0	152.0	159.0	154.0	171.0	159.0	155.0
	T_2	150.0	150.0	150.0	157.0	159.5	157.0	158.0	157.0
	T_3	159.5	160.0	153.0	151.0	151.0	150.5	151.5	150.0
	T_4	150.5	156.5	153.0	150.5	152.0	151.0	151.0	159.0
	T_5	160.5	157.5	154.0	152.0	152.5	152.5	153.0	152.0
	T_6	150.0	153.0	159.0	157.5	152.0	152.5	153.0	151.0
	T_7	151.5	150.0	159.0	152.0	153.0	153.0	151.0	155.0
	T_8	160.5	157.5	153.0	152.0	153.0	152.5	154.0	154.0
	T_9	150.0	157.5	152.0	151.0	150.5	159.0	157.0	155.0
	T_A	150.2	153.3	151.0	151.3	151.8	152.1	150.8	150.5
Wire Temperature	U_1	159.5	154.5	159.5	150.0	159.0	150.0	158.0	150.0
	U_2	159.0	160.0	157.0	150.0	164.0	157.0	152.0	158.0
	U_3	150.5	157.0	153.0	159.5	155.0	154.0	158.0	154.5
	U_4	151.5	158.0	154.0	153.0	152.0	152.0	153.0	151.5
	U_5	150.5	159.5	150.0	157.0	150.5	150.5	158.0	157.5
	U_6	150.0	157.0	152.0	151.5	151.0	150.0	151.5	151.0
	U_7	150.0	157.0	152.0	151.5	151.0	150.5	151.5	151.0
	U_8	156.0	165.0	160.0	159.0	152.0	152.0	155.0	154.0
	U_9	159.0	157.5	151.5	151.0	157.5	152.5	150.5	150.5
	U_A	150.4	154.9	158.0	155.5	150.2	159.3	159.0	158.0

OBSERVATION SHEET NO. 4

Wire Gage 18   Wire Spacing - 1/2"   Tubes Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	157.0	159.0	165.0	155.0	170.0	174.0	171.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	93	93	93	93	93	93	93
Inlet Temp. °F	183.0	170.0	185.0	185.0	170.0	170.5	180.0
Outlet Temp. °F	157.5	153.8	157.5	158.5	154.0	156.0	157.5
OUTSIDE TUBE SURFACE TEMPERATURE T_1	157.5	153.0	156.0	158.0	154.0	155.0	153.0
T_2	151.0	160.0	153.0	150.0	151.5	152.0	154.5
T_3	153.0	153.0	156.0	153.0	152.5	151.0	157.0
T_4	150.0	153.0	152.0	150.0	160.0	160.0	151.0
T_5	153.0	150.0	154.0	151.0	160.0	160.0	157.0
T_6	156.0	152.0	150.0	155.5	153.0	152.5	157.0
T_7	162.0	156.0	164.0	164.0	157.5	159.0	157.0
T_8	158.0	160.0	151.0	150.5	150.0	167.0	154.0
T_9	155.0	151.5	154.0	154.0	152.5	150.0	153.0
T_{10}	154.0	151.9	155.4	155.0	151.8	151.5	155.9
WIRE SURFACE TEMPERATURE W_1	156.3	152.0	155.3	153.0	158.0	152.0	159.0
W_2	153.0	150.5	157.0	158.0	158.0	152.0	158.0
W_3	151.0	167.0	157.3	153.0	154.0	152.0	154.0
W_4	158.0	167.0	150.8	163.0	152.9	160.0	151.0
W_5	159.0	158.5	150.0	190.0	153.0	153.0	159.0
W_6	153.0	151.0	154.0	152.0	151.5	152.0	155.0
W_7	163.0	140.0	144.0	148.0	165.0	163.0	150.0
W_8	160.0	160.0	152.0	153.0	160.0	169.0	151.0
W_9	163.5	144.0	167.0	163.0	144.0	144.0	152.0
W_{10}	152.4	163.2	152.9	151.6	151.0	153.1	154.2

	Run No.	1	2	3	4	5	6	7
	Flow Rate lbs/hr.	171.0	160.0	164.0	152.5	153.0	154.0	157.0
	Yaw Angle	0	15	30	45	60	75	90
	Ambient Temp. °F	93	93	93	93	93	93	93
	Inlet Temp. °F	180.0	181.0	185.0	183.0	181.0	170.0	182.0
	Outlet Temp. °F	164.0	154.0	157.5	156.0	155.0	152.0	150.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	153.5	154.5	157.0	155.0	158.0	150.0	154.0
	T_2	152.0	151.5	154.0	152.5	155.0	154.0	151.0
	T_3	167.0	163.0	160.5	150.0	152.5	150.5	159.0
	T_4	151.5	152.0	154.0	154.0	155.0	158.0	152.0
	T_5	151.0	152.0	160.5	150.0	150.0	158.0	150.0
	T_6	151.5	152.5	155.0	154.0	150.0	150.0	151.0
	T_7	158.0	159.0	153.0	161.0	153.0	158.0	159.0
	T_8	167.0	160.0	151.0	151.0	153.0	150.0	150.0
	T_9	150.0	151.0	152.0	152.0	155.0	151.5	150.0
	T_A	151.3	152.1	154.0	153.5	155.1	153.1	150.3
HEAT ... TEMPERATURE	W_1	163.0	151.0	152.0	153.5	155.0	157.0	167.5
	W_2	152.0	152.0	154.0	154.0	157.0	151.5	150.0
	W_3	151.0	150.0	167.0	160.0	167.5	160.0	167.0
	W_4	163.0	167.0	167.5	167.0	160.0	167.0	152.0
	W_5	154.0	154.0	157.0	154.5	154.0	153.3	150.0
	W_6	151.0	150.5	158.0	151.5	154.0	154.0	159.0
	W_7	163.0	153.0	150.0	161.0	152.0	150.0	157.0
	W_8	163.0	163.0	163.0	151.5	151.0	167.0	152.0
	W_9	160.5	163.0	167.5	152.0	154.5	152.0	150.0
	W_A	160.3	163.3	160.5	150.4	152.0	160.3	159.0

Wire Horizontal

Wire Spacing - [illegible]°

Wire Gauge 22

[illegible] TUBE No. 5

Chimney Effect

Tube Spacing - 1/2"

	Tubes Horizontal				Wires Horizontal			
Run No.	1	2	3	4	1	2	3	4
Flow Rate lbs/hr.	173.0	159.0	173.0	159.0	158.0	171.5	158.0	170.0
Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
Ambient Temp. °F	90	90	90	90	90	90	90	90
Inlet Temp. °F	183.5	183.5	179.5	182.0	184.0	180.0	182.0	180.0
Outlet Temp. °F	174.5	174.0	158.5	170.0	172.0	157.0	169.0	156.0
T_1	166.0	163.5	150.0	151.0	160.0	151.0	152.0	150.0
T_2	165.0	164.0	150.0	150.0	154.0	160.0	162.0	150.0
T_3	162.0	159.5	151.5	152.0	155.5	160.0	152.0	156.0
T_4	163.0	161.0	156.0	150.0	154.0	158.0	160.0	150.0
T_5	170.0	164.0	150.0	160.0	154.0	159.0	161.0	157.5
T_6	154.5	156.0	152.5	152.5	150.0	155.5	158.5	154.0
T_7	164.0	153.0	158.0	159.0	154.0	157.5	150.0	156.0
T_8	162.0	162.0	157.0	157.0	152.0	157.5	159.0	155.0
T_9	163.0	163.0	157.0	158.0	154.0	159.0	160.0	157.0
T_A	164.6	162.0	153.0	157.3	153.7	158.0	160.5	153.0
U_1	160.0	165.0°	159.0	160.0	162.5	158.0	160.0	157.0
U_2	165.0	166.6°	151.0	162.0	158.0	160.0	162.0	159.0
U_3	165.0	164.0	158.0	159.0	155.0	160.0	162.0	159.0
U_4	164.0	161.0	153.0	155.5	150.5	161.5	163.5	151.0
U_5	163.9°	150.5°	152.5°	151.0°	150.0	153.0	153.5	157.5
U_6	152.0	150.0	155.0	157.0	152.0	157.0	158.0	155.0
U_7	163.0	153.0	147.0	150.0	152.0	150.0	156.0	153.0
U_8	156.0	156.0	150.0	153.0	152.5	163.5	165.0	164.0
U_9	150.0	156.0	158.0	157.0	158.0	160.0	161.0	159.0
U_A	162.0	161.6	155.5	157.1	161.0	157.4	153.5	155.0

OUTSIDE TUBE SURFACE TEMPERATURE (T_1–T_A)

INSIDE TUBE SURFACE TEMPERATURE (U_1–U_A)

CONDITION SERIES No. 7

Tubes Insulated

Wire Spacing - 1"

Wire Gage 12

		1	2	3	4	5	6	7
Run No.		1	2	3	4	5	6	7
Flow Rate lbs/hr.		181.0	179.0	177.0	182.0	182.0	170.0	180.0
Yaw Angle		0	15	30	45	60	75	90
Ambient Temp. °F		80	80	80	80	80	80	80
Inlet Temp. °F		180.0	178.0	182.0	181.0	179.0	182.0	179.0
Outlet Temp. °F		159.0	157.0	170.5	159.5	158.0	171.0	150.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	157.0	150.0	151.0	151.0	[illegible]	150.0	150.0
	T_2	167.0	167.0	[illegible]	[illegible]	[illegible]	[illegible]	155.0
	T_3	[illegible]	[illegible]	150.0	151.0	152.0	155.0	155.0
	T_4	[illegible]	[illegible]	167.0	167.0	[illegible]	[illegible]	150.5
	T_5	150.0	157.0	150.0	158.5	150.0	150.0	152.0
	T_6	150.0	157.0	150.0	158.5	[illegible]	150.0	152.0
	T_7	159.0	[illegible]	159.5	157.0	157.5	150.5	151.0
	T_8	155.0	150.5	[illegible]	155.0	155.0	[illegible]	150.0
	T_9	152.0	150.0	151.0	[illegible]	151.0	153.0	155.0
	T_A	152.4	151.0	153.6	152.7	152.9	153.5	157.0
	W_1	[illegible]	167.0	161.0	160.0	150.0	158.0	157.5
	W_2	152.0	151.0	154.0	158.0	152.0	154.0	157.0
	W_3	[illegible]	168.0	160.5	[illegible]	160.5	[illegible]	[illegible]
	W_4	162.5	130.0	161.0	161.0	161.0	167.0	167.0
	W_5	152.0	150.0	151.0	158.0	152.0	150.0	[illegible]
	W_6	129.0	120.0	133.0	132.0	131.0	134.0	137.0
	W_7	134.0	134.5	133.0	[illegible]	[illegible]	[illegible]	141.0
	W_8	131.0	129.0	129.0	130.0	130.0	131.0	132.0
	W_9	124.0	125.0	125.0	[illegible]	132.0	130.0	140.5
	W_A	[illegible]	139.7	161.3	162.0	161.8	162.0	[illegible]

TEST SECTION NO. 2

Wire Gage 18

Wire Spacing - 1"

Wire Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	184.0	181.0	183.0	175.0	177.0	170.0	170.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	69	69	69	69	69	69	69
Inlet Temp. °F	179.0	183.0	182.0	188.0	184.0	179.8	182.0
Outlet Temp. °F	166.0	171.5	170.8	172.0	173.0	166.6	172.9
OUTSIDE TUBE SURFACE TEMPERATURE T_1	155.0	150.0	150.0	150.5	151.0	150.0	154.0
T_2	[illegible]	152.0	[illegible]	[illegible]	[illegible]	[illegible]	151.0
T_3	150.0	153.0	151.0	[illegible]	155.0	153.0	153.0
T_4	148.0	154.0	153.0	152.0	151.0	150.0	155.0
T_5	157.0	159.0	159.0	161.0	162.0	160.0	161.0
T_6	157.0	159.0	159.0	161.0	162.0	160.0	161.0
T_7	155.0	159.0	156.0	160.0	160.0	160.0	162.0
T_8	153.0	155.0	152.0	154.0	157.0	153.0	154.0
T_9	[illegible]	[illegible]	[illegible]	147.0	147.5	151.0	155.0
T_A	153.0	155.7	154.2	154.6	155.1	154.9	157.0
[illegible] TEMPERATURE W_1	[illegible]	150.5	[illegible]	[illegible]	[illegible]	151.0	153.0
W_2	151.0	153.0	152.0	154.0	155.0	153.0	[illegible]
W_3	143.0	143.5	144.0	145.0	[illegible]	[illegible]	151.0
W_4	141.0	143.0	141.0	144.0	144.0	142.5	144.0
W_5	[illegible]	151.0	152.0	[illegible]	157.0	154.0	[illegible]
W_6	131.0	132.0	130.0	134.0	[illegible]	134.5	134.0
W_7	[illegible]	140.0	[illegible]	140.0	137.0	[illegible]	[illegible]
W_8	[illegible]	133.5	133.0	137.0	[illegible]	[illegible]	[illegible]
W_9	[illegible]	123.0	129.0	130.0	130.0	130.0	134.0
W_A	140.3	141.6	140.9	143.1	143.1	142.6	[illegible]

Chimney Effect — Wire Spacing 1" — Wire Gap 12

	Tubes Horizontal				Wires Horizontal			
Run No.	1	2	3	4	1	2	3	4
Flow Rate lbs/hr.	187.0	174.0	177.0	177.0	171.0	180.0	172.0	170.0
Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
Ambient Temp. °F	90	90	90	90	90	90	90	90
Inlet Temp. °F	182.0	184.5	181.0	179.0	[illegible].0	181.0	170.0	182.5
Outlet Temp. °F	174.0	173.5	173.0	171.0	170.0	172.0	168.0	172.0
Outside Tube Surface Temperature T_1	166.0	160.0	166.0	160.0	162.0	152.0	158.0	153.0
T_2	158.0	165.0	151.0	159.0	155.0	150.0	153.0	151.0
T_3	164.0	157.0	160.0	156.0	155.0	151.0	1[illegible].0	1[illegible].0
T_4	158.0	153.0	155.0	152.0	1[illegible].0	1[illegible].5	164.0	151.0
T_5	163.0	168.0	165.0	152.0	150.0	152.0	157.0	151.0
T_6	165.0	168.0	168.0	153.0	150.0	153.0	150.0	154.5
T_7	154.0	157.5	155.0	152.0	159.0	151.0	155.5	150.5
T_8	154.0	154.0	153.0	150.0	159.0	150.0	157.0	151.0
T_9	154.0	153.0	154.0	151.0	154.0	153.5	151.0	159.0
T_A	161.7	164.4	151.0	158.2	150.0	150.2	153.9	158.3
Wire Temperature W_1	153.0	164.0	151.0	1[illegible].0	153.0	1[illegible].0	1[illegible].0	167.0
W_2	159.0	160.0	156.0	166.0	150.0	153.0	167.0	153.0
W_3	151.0	151.0	158.0	155.0	153.5	152.0	1[illegible].5	153.0
W_4	150.0	150.0	155.0	155.0	151.0	154.0	1[illegible].5	154.0
W_5	150.0	157.0	158.0	153.0	157.5	158.5	155.0	157.5
W_6	154.0	165.0	150.0	150.0	162.0	164.5	153.0	1[illegible].0
W_7	153.0	154.0	167.0	1[illegible].0	162.0	164.0	160.0	163.0
W_8	157.0	153.0	153.0	157.0	161.5	1[illegible].0	160.0	1[illegible].0
W_9	153.0	153.0	164.0	152.0	162.0	164.0	1[illegible].0	164.0
W_A	154.1	155.0	151.0	1[illegible].0	1[illegible].0	1[illegible].3	162.4	167.0

OBSERVATION SHEET NO. 19

Tube Gap 12 — Tube Spacing = 3D — Tubes Horizontal

		1	2	3	4	5	6	7
Run No.		1	2	3	4	5	6	7
Flow Rate lbs/hr.		187.0	[illegible]	188.0	[illegible]	187.0	182.0	182.0
Yaw Angle		0	15	30	45	60	75	90
Ambient Temp. °F		81	81	81	81	81	81	81
Inlet Temp. °F		170.0	167.5	170.0	170.0	169.0	172.0	173.5
Outlet Temp. °F		151.0	157.5	151.0	151.0	150.0	[illegible]	[illegible]
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	147.0	[illegible]	142.5	141.0	147.0	[illegible]	158.5
	T_2	150.0	[illegible]	[illegible]	148.0	[illegible]	150.0	[illegible]
	T_3	151.0	150.0	147.0	[illegible]	147.0	152.0	[illegible]
	T_4	152.5	151.0	[illegible]	147.0	[illegible]	152.0	153.0
	T_5	151.0	150.5	[illegible]	[illegible]	[illegible]	[illegible]	150.5
	T_6	150.5	[illegible]	[illegible]	[illegible]	147.5	151.0	152.5
	T_7	152.0	151.5	[illegible]	[illegible]	147.0	152.5	156.0
	T_8	150.0	[illegible]	[illegible]	[illegible]	147.0	151.0	153.0
	T_9	152.5	152.0	[illegible]	147.5	[illegible]	152.0	153.5
	T_A	150.7	[illegible]	[illegible]	[illegible]	147.2	151.2	153.1
MEAN HEAT TEMPERATURE	H_1	[illegible]	[illegible]	[illegible]	142.0	147.0	[illegible]	152.0
	H_2	[illegible]	148.0	[illegible]	148.5	[illegible]	148.5	148.0
	H_3	150.0	150.0	147.0	[illegible]	147.0	150.5	153.5
	H_4	152.0	151.0	[illegible]	147.0	[illegible]	152.0	[illegible]
	H_5	[illegible]	153.0	147.5	[illegible]	[illegible]	147.0	[illegible]
	H_6	157.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	H_7	[illegible]	141.0	[illegible]	[illegible]	[illegible]	141.0	[illegible]
	H_8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	H_9	152.0	150.5	147.0	155.0	157.0	150.5	150.0
	H_A	[illegible]	[illegible]	142.8	[illegible]	[illegible]	147.2	147.2

Condenser No. 11

Wire Gage 12 — Wire Spacing - 2 — Wire Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	201.0	232.0	194.0	179.0	182.0	188.0	174.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	90	90	90	90	90	90	90
Inlet Temp. °F	174.0	172.5	171.2	170.5	170.5	172.5	171.5
Outlet Temp. °F	150.0	154.0	153.0	152.5	152.5	153.5	154.0
OUTSIDE TUBE SURFACE TEMPERATURE T_1	152.5	[illegible]	147.0	[illegible]	150.5	[illegible]	[illegible]
T_2	152.0	151.5	[illegible]	150.5	150.0	[illegible]	[illegible]
T_3	154.5	152.0	[illegible]	150.0	152.5	150.0	[illegible]
T_4	155.5	154.0	150.0	151.0	152.5	151.0	151.0
T_5	151.0	150.0	[illegible]	147.5	150.0	[illegible]	[illegible]
T_6	153.0	152.0	147.5	[illegible]	151.0	150.0	150.0
T_7	155.5	152.0	150.0	151.5	154.0	[illegible]	[illegible]
T_8	151.5	150.5	[illegible]	147.5	150.0	[illegible]	[illegible]
T_9	155.2	154.0	150.0	151.5	154.0	151.0	151.0
T_A	152.7	152.1	[illegible]	[illegible]	151.7	147.0	[illegible]
W_1	152.5	[illegible]	147.5	[illegible]	150.0	[illegible]	[illegible]
W_2	153.0	151.0	[illegible]	150.0	[illegible]	[illegible]	[illegible]
W_3	154.0	152.8	[illegible]	150.5	151.5	[illegible]	[illegible]
W_4	154.5	152.5	150.5	151.5	152.0	150.0	151.0
W_5	151.0	137.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
W_6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
W_7	[illegible]	147.7	[illegible]	[illegible]	150.0	[illegible]	[illegible]
W_8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
W_9	150.0	[illegible]	[illegible]	[illegible]	147.5	147.0	[illegible]
W_A	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

OBSERVATION SHEET NO. 13

Wire Gage 18 | Wire Spacing 3" | Chimney Effect

		Tubes Horizontal				Wires Horizontal			
	Run No.	1	2	3	4	1	2	3	4
	Flow Rate lbs/hr.	180.0	170.0	173.5	173.0	175.0	178.0	170.0	195.0
	Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
	Ambient Temp. °F	92	92	92	92	92	92	92	92
	Inlet Temp. °F	175.0	173.5	174.0	173.0	173.5	173.0	170.0	175.0
	Outlet Temp. °F	158.0	170.0	157.0	160.5	159.0	159.0	171.0	157.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	163.0	167.0	151.0	151.0	161.5	164.0	160.0	163.0
	T_2	150.0	158.0	159.0	159.0	151.0	152.0	154.0	155.0
	T_3	160.0	154.0	155.0	158.0	151.5	153.0	153.5	155.0
	T_4	150.0	155.5	155.5	153.0	151.5	154.0	154.0	150.5
	T_5	164.5	164.0	162.5	160.0	160.0	160.0	158.0	154.5
	T_6	150.0	154.0	155.0	156.0	160.0	154.0	154.5	154.0
	T_7	151.0	153.0	157.0	159.0	151.0	154.0	155.0	153.0
	T_8	167.0	153.0	158.0	150.0	163.0	151.0	163.0	164.0
	T_9	Thermocouple junction found broken							
	T_A	163.4	152.7	153.0	155.8	163.0	151.0	152.1	153.0
MEAN WIRE TEMPERATURE	W_1	148.2	163.5	164.3	151.5	161.0	164.0	161.0	163.5
	W_2	164.0	163.6	160.5	163.6	163.0	152.0	151.0	155.0
	W_3	160.0	164.0	163.0	163.0	163.0	163.5	163.5	164.5
	W_4	161.0	163.5	167.4	152.0	150.0	160.0	167.0	163.0
	W_5	160.0	167.0	167.0	150.0	150.0	158.0	152.5	160.0
	W_6	160.0	167.0	167.0	150.0	160.0	160.0	167.0	163.0
	W_7	160.0	162.5	162.0	160.0	167.0	160.0	160.0	160.0
	W_8	160.0	160.0	167.0	151.0	150.0	161.0	150.0	150.0
	W_9	162.0	160.5	160.0	153.5	167.5	151.0	151.0	151.0
	W_A	162.3	160.0	160.3	150.0	164.9	162.2	163.0	164.7

Tube Horizontal — Fin Spacing - 1/2" — Fin Size D

EXPERIMENTAL DATA No. 13

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	155.0	150.0	155.0	157.0	157.0	152.0	155.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	87.5	87.5	87.5	87.5	87.5	87.0	87.5
Inlet Temp. °F	180.0	181.5	183.5	183.5	182.5	181.5	180.5
Outlet Temp. °F	157.5	159.0	158.5	159.5	158.0	157.5	155.0
Outside Tube Surface Temperature T_1	167.5	[illegible]	158.5	[illegible]	[illegible]	[illegible]	[illegible]
T_2	166.5	166.5	167.5	[illegible]	168.5	[illegible]	166.0
T_3	161.5	168.0	[illegible]	[illegible]	168.5	[illegible]	[illegible]
T_4	166.0	166.0	[illegible]	[illegible]	[illegible]	[illegible]	168.0
T_5	168.0	168.5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
T_6	157.0	[illegible]	[illegible]	[illegible]	[illegible]	151.0	[illegible]
T_7	167.0	158.0	150.5	[illegible]	[illegible]	[illegible]	[illegible]
T_8	[illegible]	163.5	151.5	[illegible]	166.0	168.5	168.0
T_9	[illegible]	[illegible]	166.5	[illegible]	166.0	[illegible]	[illegible]
T_A	166.5	[illegible]	[illegible]	162.7	162.8	[illegible]	[illegible]
Fin Root Temperature U_1	167.5	[illegible]	150.5	[illegible]	168.5	[illegible]	166.0
U_2	156.5	156.0	157.0	158.0	151.0	[illegible]	151.0
U_3	167.0	[illegible]	150.5	[illegible]	166.0	168.0	[illegible]
U_4	168.5	162.0	[illegible]	[illegible]	[illegible]	[illegible]	151.0
U_5	158.5	163.5	156.5	161.5	[illegible]	[illegible]	[illegible]
U_6	168.5	151.0	[illegible]	168.5	161.0	161.0	[illegible]
U_7	[illegible]	168.0	168.0	[illegible]	[illegible]	[illegible]	[illegible]
U_8	[illegible]	[illegible]	150.0	167.5	166.5	[illegible]	166.0
U_9	166.5	167.0	[illegible]	168.0	[illegible]	[illegible]	[illegible]
U_A	161.0	161.5	166.7	162.0	[illegible]	[illegible]	[illegible]

OBSERVATION SHEET NO. 1

Wire Gauge D

Wire Spacing - 1/4"

Wires Horizontal

Run No.		1	2	3	4	5	6	7
Flow Rate lbs/hr.		190.0	193.5	194.0	193.0	193.0	193.0	199.0
Yaw Angle		0	15	30	45	60	75	90
Ambient Temp. °F		88	88	89	88	88	88	89
Inlet Temp. °F		183.5	180.0	181.5	182.0	180.0	181.0	181.5
Outlet Temp. °F		152.0	159.0	159.5	160.0	159.5	158.0	157.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	180.0	147.0	[illegible]	150.0	180.5	155.8	180.0
	T_2	[illegible]	[illegible]	147.0	[illegible]	[illegible]	158.5	157.0
	T_3	144.5	142.0	143.0	149.0	144.5	158.9	157.0
	T_4	147.0	150.0	150.5	[illegible]	[illegible]	152.0	157.0
	T_5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	158.0	157.0
	T_6	[illegible]	[illegible]	141.0	[illegible]	[illegible]	147.0	152.0
	T_7	150.0	[illegible]	147.0	[illegible]	[illegible]	158.0	158.5
	T_8	141.5	141.0	140.5	142.5	142.0	150.0	154.0
	T_9	140.0	[illegible]	140.0	140.0	141.5	[illegible]	154.0
	T_A	144.8	144.0	[illegible]	144.8	[illegible]	151.7	155.6
HEAD WALL TEMPERATURE	W_1	[illegible]	[illegible]	147.0	[illegible]	[illegible]	153.0	159.0
	W_2	157.0	154.5	[illegible]	[illegible]	[illegible]	161.0	167.0
	W_3	157.5	[illegible]	147.5	149.5	[illegible]	158.0	150.0
	W_4	[illegible]	142.5	142.5	142.0	148.5	[illegible]	[illegible]
	W_5	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	W_6	142.5	140.0	144.0	[illegible]	[illegible]	150.0	[illegible]
	W_7	142.0	142.0	142.0	142.0	142.0	150.0	155.0
	W_8	[illegible]	147.0	[illegible]	[illegible]	[illegible]	154.0	158.0
	W_9	[illegible]	144.0	[illegible]	[illegible]	[illegible]	152.0	157.0
	W_A	142.8	141.7	141.6	142.6	142.0	[illegible]	155.2

DATA SHEET NO. 15

Wire Gauge 20

Wire Spacing - 4"

Chimney Effect

	Wires Horizontal				Tubes Horizontal			
Run No.	1	2	3	4	1	2	3	4
Flow Rate lbs/hr.	154.0	150.5	150.0	151.5	158.0	154.0	150.0	159.0
Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
Ambient Temp. °F	87	87	89	87	87	87	87	87
Inlet Temp. °F	180.5	188.0	182.0	180.0	182.0	188.5	180.0	182.0
Outlet Temp. °F	168.0	158.0	157.5	154.5	172.0	171.0	157.5	158.5
OUTSIDE TUBE SURFACE TEMPERATURE T_1	151.5	154.0	152.0	1[illegible].5	157.0	150.0	154.0	155.5
T_2	150.0	153.0	152.0	147.5	154.5	159.0	152.5	154.0
T_3	1[illegible].0	159.0	155.0	1[illegible].0	157.0	150.0	157.0	1[illegible].0
T_4	151.0	152.0	151.0	1[illegible].5	150.5	152.0	154.5	155.0
T_5	1[illegible].5	150.0	158.0	151.0	157.0	157.0	152.5	150.0
T_6	1[illegible].0	152.0	151.0	147.0	152.0	153.0	147.0	1[illegible].0
T_7	144.5	147.0	154.0	154.5	159.0	155.0	153.0	150.0
T_8	1[illegible].5	151.0	150.0	158.0	15[illegible].5	159.0	153.0	1[illegible].0
T_9	147.0	150.0	147.0	144.0	158.0	161.5	15[illegible].0	158.0
T_A	1[illegible].4	152.7	153.9	150.9	157.7	157.8	158.3	154.7
WIRE TEMPERATURE W_1	150.5	158.0	151.0	147.0	154.5	157.8	151.0	152.0
W_2	1[illegible].0	1[illegible].0	144.0	140.5	154.0	15[illegible].0	151.0	153.0
W_3	151.5	154.0	151.0	1[illegible].0	150.0	151.0	155.0	15[illegible].0
W_4	147.0	152.0	1[illegible].0	1[illegible].0	157.0	157.0	1[illegible].0	1[illegible].0
W_5	1[illegible].0	1[illegible].0	1[illegible].0	1[illegible].5	155.0	157.0	152.0	158.0
W_6	1[illegible].0	150.5	150.5	1[illegible].0	155.0	157.5	152.0	158.0
W_7	1[illegible].5	150.5	147.5	144.0	151.0	152.0	1[illegible].5	1[illegible].5
W_8	1[illegible].0	151.0	150.5	150.5	144.0	1[illegible].0	1[illegible].5	1[illegible].5
W_9	1[illegible].0	1[illegible].0	1[illegible].5	144.0	150.0	157.0	151.0	152.0
W_A	1[illegible].9	1[illegible].5	1[illegible].2	1[illegible].9	158.7	15[illegible].1	150.2	151.4

Tubes Horizontal

Pipe Spacing - 4"

Pipe Gap 3

		1	2	3	4	5	6	7
Run No.		1	2	3	4	5	6	7
Flow Rate lbs/hr.		150.0	150.0	150.0	150.0	150.0	150.0	150.0
Yaw Angle		0	15	30	45	60	75	90
Ambient Temp. °F		91	91	91	91	91	91	91
Inlet Temp. °F		180.0	182.5	180.0	184.5	181.0	184.0	182.5
Outlet Temp. °F		170.5	170.0	157.0	171.5	170.0	172.0	171.5
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	140.5	[illegible]	[illegible]	[illegible]	[illegible]	152.5	151.0
	T_2	148.0	147.5	147.0	[illegible]	[illegible]	154.0	153.0
	T_3	140.0	[illegible]	[illegible]	[illegible]	147.0	158.0	152.0
	T_4	142.0	[illegible]	[illegible]	[illegible]	147.5	152.5	152.0
	T_5	154.5	154.5	154.0	157.5	155.5	155.0	158.0
	T_6	120.0	137.0	[illegible]	142.5	155.5	157.5	155.5
	T_7	140.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	151.0
	T_8	142.0	147.0	[illegible]	[illegible]	[illegible]	151.0	152.5
	T_9	123.5	140.0	142.0	[illegible]	148.5	[illegible]	[illegible]
	T_A	140.7	[illegible]	[illegible]	[illegible]	[illegible]	152.1	152.0
INSIDE TUBE TEMPERATURE	W_1	130.0	140.5	142.0	[illegible]	144.0	[illegible]	150.0
	W_2	137.0	140.5	141.0	143.5	141.5	[illegible]	[illegible]
	W_3	[illegible]	131.0	134.0	140.5	137.0	142.5	140.0
	W_4	131.0	132.0	[illegible]	134.5	133.5	132.0	140.0
	W_5	[illegible]	[illegible]	132.5	132.5	130.0	[illegible]	[illegible]
	W_6	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	132.0	[illegible]
	W_7	[illegible]	[illegible]	[illegible]	133.5	[illegible]	[illegible]	141.0
	W_8	140.5	[illegible]	141.5	143.5	142.0	137.0	152.0
	W_9	142.0	120.5	120.0	121.5	122.0	[illegible]	[illegible]
	W_A	133.5	134.7	133.0	132.8	[illegible]	[illegible]	144.7

OBSERVATION SHEET No. 37

Wire Gage 18 Wire Spacing - 1/2" Wire Horizontal

Run No.		1	2	3	4	5	6	7
Flow Rate lbs/hr.		159.0	157.0	158.0	160.0	157.0	164.0	164.0
Yaw Angle		0	15	30	45	60	75	90
Ambient Temp. °F		91	91	91	91	91	91	91
Inlet Temp. °F		180.0	181.0	178.0	178.0	181.0	178.0	181.0
Outlet Temp. °F		166.5	157.0	155.0	156.0	157.5	157.0	170.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	140.5	140.0	140.0	140.0	142.0	143.0	147.0
	T_2	143.0	143.0	142.0	142.5	143.0	143.0	140.5
	T_3	140.0	140.0	139.5	139.0	142.0	143.5	143.0
	T_4	142.0	141.5	141.0	141.5	144.5	143.0	148.5
	T_5	154.5	155.0	151.9	152.5	154.0	154.0	150.5
	T_6	Thermocouple found broken						
	T_7	140.0	141.0	140.5	140.5	142.0	143.0	143.0
	T_8	142.0	143.0	142.0	144.0	144.5	147.0	150.5
	T_9	133.5	134.5	134.0	135.0	135.5	141.5	143.0
	T_A	142.2	142.0	141.3	142.0	143.7	145.6	143.1
MEAN WIRE TEMPERATURE	W_1	130.0	134.5	133.0	137.5	141.0	140.0	145.0
	W_2	137.0	137.0	134.5	133.5	140.0	140.0	143.0
	W_3	143.0	142.0	143.0	143.5	148.0	148.5	152.5
	W_4	132.0	129.0	122.0	129.0	132.5	134.0	134.5
	W_5	120.0	120.0	130.0	127.0	130.5	132.0	137.0
	W_6	133.0	132.0	132.0	131.5	135.0	133.0	134.0
	W_7	123.0	125.0	123.0	125.0	129.0	123.0	132.5
	W_8	140.5	140.0	150.0	133.0	148.0	150.0	151.0
	W_9	142.0	135.0	135.0	130.0	137.5	142.0	147.5
	W_A	133.5	134.6	132.6	133.7	137.4	130.8	142.8

Chimney Effect

Wire Spacing = 1/2"

Wire Gage 19

		Tubes Horizontal				Wires Horizontal			
	Run No.	1	2	3	4	1	2	3	4
	Flow Rate lbs/hr.	151.0	152.0	159.0	150.0	159.0	159.0	154.0	151.0
	Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
	Ambient Temp. °F	80	80	80	80	80	80	80	80
	Inlet Temp. °F	180.0	180.5	181.0	180.0	185.0	184.0	181.0	180.0
	Outlet Temp. °F	172.0	171.5	172.0	170.0	175.0	173.0	170.0	168.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	153.0	157.0	158.5	152.0	159.0	153.0	151.0	163.0
	T_2	153.0	159.0	160.5	154.5	150.0	155.0	153.5	150.0
	T_3	153.0	157.0	157.5	153.0	157.0	153.0	151.0	160.0
	T_4	153.0	158.0	159.5	153.0	159.0	155.8	157.5	160.0
	T_5	160.0	150.0	160.5	156.5	150.5	152.5	150.0	154.0
	T_6	159.5	153.5	16.5	151.5	155.0	154.0	158.5	153.0
	T_7	159.5	157.0	156.5	151.0	154.5	151.0	160.0	16.0
	T_8	163.0	160.0	159.5	155.0	150.0	155.0	153.5	150.0
	T_9	160.0	155.5	154.5	16.5	157.5	154.0	151.0	10.0
	T_A	158.7	155.0	152.0	151.8	151.3	157.4	157.0	153.0
WIRE SURFACE TEMPERATURE	W_1	153.0	154.0	153.5	16.0	153.0	16.0	16.0	162.0
	W_2	156.0	153.0	150.0	151.0	153.5	167.5	16.0	162.0
	W_3	157.5	151.5	152.5	16.5	16.0	162.0	164.0	10.0
	W_4	158.5	151.0	151.5	164.5	158.5	150.0	16.5	162.0
	W_5	155.5	151.5	151.5	16.5	154.0	150.0	16.0	160.0
	W_6	155.0	153.0	153.0	16.0	154.0	150.5	16.5	160.0
	W_7	167.5	164.5	16.0	10.0	163.0	161.0	15.0	15.0
	W_8	155.0	157.5	157.0	151.0	154.5	158.5	150.5	164.0
	W_9	16.0	10.5	10.0	157.5	152.0	164.5	162.5	15.5
	W_A	155.7	151.7	150.8	16.0	151.5	167.4	16.1	161.9

CONDENSER NO. 10

[illegible] Heat Exchanger No. [illegible]

Fin Gap [illegible] Fin Spacing - 1°

Tubes Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	153.0	156.0	150.0	158.0	152.0	152.0	155.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	80	80	80	80	80	80	80
Inlet Temp. °F	182.5	178.5	[illegible]	170.5	205.0	191.0	201.5
Outlet Temp. °F	172.0	[illegible]	[illegible]	171.0	[illegible]	173.0	174.0
[Outside Tube Surface Temperature] T_1	153.0	167.0	[illegible]	[illegible]	152.0	153.0	157.5
T_2	[illegible]	164.5	164.0	167.0	150.0	152.0	154.0
T_3	150.0	[illegible]	[illegible]	[illegible]	[illegible]	151.0	154.0
T_4	168.0	155.5	154.0	167.0	157.0	[illegible]	155.0
T_5	150.0	[illegible]	[illegible]	[illegible]	150.0	157.0	151.0
T_6	[illegible]	167.0	[illegible]	[illegible]	152.0	153.0	155.5
T_7	152.0	[illegible]	[illegible]	167.0	152.0	153.0	155.0
T_8	152.0	161.5	164.0	[illegible]	151.0	152.5	151.0
T_9	[illegible]	[illegible]	[illegible]	[illegible]	150.0	152.0	155.0
T_{10}	[illegible]	[illegible]	[illegible]	[illegible]	151.0	153.0	154.8
[Head Wall Temperature] W_1	155.0	151.5	150.0	151.0	[illegible]	[illegible]	[illegible]
W_2	[illegible]	[illegible]	168.0	164.0	150.5	150.0	151.0
W_3	153.0	150.0	[illegible]	[illegible]	155.0	[illegible]	[illegible]
W_4	154.0	151.0	[illegible]	151.0	157.0	[illegible]	155.0
W_5	[illegible]	[illegible]	[illegible]	161.0	167.0	[illegible]	167.0
W_6	[illegible]	[illegible]	[illegible]	161.5	167.0	[illegible]	153.0
W_7	157.5	153.5	151.0	153.0	150.0	[illegible]	151.0
W_8	133.0	128.0	131.0	[illegible]	[illegible]	[illegible]	[illegible]
W_9	124.0	128.0	[illegible]	134.0	[illegible]	141.0	[illegible]
W_{10}	[illegible]	142.0	141.4	144.5	[illegible]	[illegible]	[illegible]

Wire horizontal

Wire Spacing = 1"

Wire Gage 9

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	164.0	154.0	163.5	153.5	154.0	158.0	150.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	90	90	90	90	90	90	90
Inlet Temp. °F	183.0	180.0	181.5	182.0	175.5	178.0	180.0
Outlet Temp. °F	173.0	171.0	172.0	173.0	157.0	160.0	170.0
T_1	[illegible]	167.5	163.0	150.0	167.0	167.0	[illegible]
T_2	164.0	162.0	162.0	163.0	163.0	164.0	167.0
T_3	163.0	167.0	167.5	150.0	167.0	167.0	163.5
T_4	167.0	159.0	150.0	152.0	158.0	159.0	151.0
T_5	[illegible]	162.0	162.0	164.0	162.0	161.5	161.5
T_6	158.0	163.0	167.0	160.0	163.5	163.0	160.0
T_7	160.0	163.5	167.0	160.0	167.0	163.5	163.5
T_8	163.0	164.0	163.5	167.0	167.0	163.0	167.0
T_9	163.5	162.0	164.0	165.0	165.0	163.0	167.0
T_A	163.5	163.0	167.0	163.0	167.3	163.8	163.0
W_1	151.5	163.0	151.0	151.5	163.5	163.0	163.0
W_2	162.5	160.0	164.0	164.0	163.0	163.0	163.0
W_3	153.0	151.0	152.0	153.0	151.0	152.0	152.0
W_4	154.0	160.0	163.0	163.5	162.5	164.5	163.0
W_5	163.0	113.0	133.0	133.5	137.0	132.0	134.0
W_6	163.5	162.0	167.0	167.0	163.0	163.0	163.0
W_7	152.0	163.0	163.0	153.0	153.0	150.0	150.5
W_8	134.0	132.0	137.0	137.0	133.0	137.0	133.0
W_9	133.5	132.0	139.0	142.0	141.5	134.0	133.0
W_A	163.0	160.0	164.0	163.2	163.0	162.0	162.1

Wire Spacing - 1"

	Tubes Horizontal				Wires Horizontal			
Run No.	1	2	3	4	1	2	3	4
Flow Rate lbs/hr.	174.0	172.0	173.0	170.0	171.0	172.5	171.0	171.0
Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
Chimney Effect								
Ambient Temp. °F	80	80	80	80	80	80	80	80
Inlet Temp. °F	177.5	180.0	178.0	181.0	182.0	178.0	180.0	179.5
Outlet Temp. °F	170.0	172.0	169.5	174.0	175.0	171.0	170.5	171.5
Outside Tube Surface Temperatures								
T_1	154.0	157.5	159.5	151.0	157.0	152.0	167.0	[illegible]
T_2	153.0	152.0	155.0	150.0	159.0	151.0	[illegible]	164.0
T_3	152.0	151.0	155.0	150.0	150.0	151.0	[illegible]	[illegible]
T_4	152.0	157.0	151.0	155.5	153.0	150.0	150.0	154.0
T_5	164.0	153.0	150.0	150.0	157.0	150.0	150.0	[illegible]
T_6	158.0	153.5	159.0	160.5	157.0	151.0	167.0	[illegible]
T_7	153.0	152.5	158.0	150.0	155.5	151.0	[illegible]	[illegible]
T_8	152.0	150.0	158.0	158.0	154.0	[illegible]	164.5	164.0
T_9	151.5	151.0	157.0	160.0	150.0	[illegible]	[illegible]	[illegible]
T_A	152.0	150.0	157.1	158.7	150.8	151.2	167.6	167.6
Wire Surface Temperatures								
W_1	154.0	154.5	150.0	158.0	158.0	158.0	[illegible]	[illegible]
W_2	151.0	151.0	155.0	150.0	155.0	[illegible]	164.0	[illegible]
W_3	154.0	150.0	151.0	151.0	153.0	158.0	[illegible]	[illegible]
W_4	158.0	161.0	157.0	[illegible]	152.0	162.0	161.0	168.0
W_5	150.0	151.0	157.0	155.5	[illegible]	167.0	[illegible]	164.0
W_6	152.0	153.5	158.0	161.0	150.0	154.0	167.0	[illegible]
W_7	157.0	151.0	158.0	152.0	155.8	[illegible]	167.0	[illegible]
W_8	152.0	151.0	[illegible]	[illegible]	151.0	[illegible]	[illegible]	[illegible]
W_9	155.0	151.5	160.0	[illegible]	151.5	[illegible]	[illegible]	161.0
W_A	156.7	157.0	151.6	154.1	155.4	[illegible]	169.0	[illegible]

OBSERVATIONS RUN NO. [illegible]

Tubes Horizontal

Wire Spacing - 2"

Wire Gauge [illegible]

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	180.0	177.0	181.0	175.0	178.0	173.0	170.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temperature °F	88	88	88	88	88	88	88
Inlet Temp. °F	181.0	181.5	178.0	181.0	178.0	182.0	179.5
Outlet Temp. °F	172.8	172.0	170.5	173.0	171.0	174.5	172.0
OUTSIDE TUBE SURFACE TEMPERATURE							
T_1	[illegible]	[illegible]	164.5	167.0	164.0	150.0	152.0
T_2	151.0	150.0	[illegible]	150.0	[illegible]	151.0	151.0
T_3	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
T_4	147.5	[illegible]	144.0	[illegible]	[illegible]	[illegible]	[illegible]
T_5	151.0	150.0	[illegible]	140.0	144.0	[illegible]	150.5
T_6	142.5	141.0	[illegible]	141.0	[illegible]	147.5	[illegible]
T_7	150.5	150.0	147.5	151.0	[illegible]	152.0	152.0
T_8	[illegible]	152.0	141.0	144.0	[illegible]	[illegible]	152.0
T_9	153.0	[illegible]	144.0	[illegible]	144.0	[illegible]	[illegible]
T_A	[illegible]	147.7	144.7	[illegible]	144.0	[illegible]	[illegible]
MEAN WIRE TEMPERATURE							
W_1	[illegible]	[illegible]	148.0	141.0	[illegible]	150.0	150.5
W_2	[illegible]	150.0	147.0	150.0	[illegible]	151.0	150.0
W_3	147.0	[illegible]	[illegible]	[illegible]	147.0	148.0	147.5
W_4	[illegible]	[illegible]	148.5	[illegible]	[illegible]	[illegible]	[illegible]
W_5	[illegible]	[illegible]	148.0	141.0	144.0	[illegible]	[illegible]
W_6	153.0	152.5	150.5	153.0	152.5	154.0	153.0
W_7	151.0	151.0	147.5	151.0	[illegible]	153.0	151.0
W_8	[illegible]	140.0	[illegible]	[illegible]	140.0	142.0	142.5
W_9	[illegible]	131.0	[illegible]	137.0	[illegible]	[illegible]	[illegible]
W_A	142.0	[illegible]	142.7	144.5	144.5	147.5	[illegible]

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	185.0	180.0	181.5	177.0	191.0	180.0	[illegible]
Yaw Angle	0	15	30	[illegible]	60	75	90
Ambient Temp. °F	88	88	88	88	88	[illegible]	[illegible]
Inlet Temp. °F	179.0	182.0	179.5	180.0	180.0	179.5	183.0
Outlet Temp. °F	172.0	174.0	172.0	172.0	173.0	172.0	175.5
T_1	[illegible]	[illegible]	147.0	150.0	[illegible]	151.0	153.0
T_2	151.0	151.5	150.0	151.0	151.5	152.0	153.0
T_3	[illegible]	[illegible]	147.0	[illegible]	[illegible]	[illegible]	150.0
T_4	[illegible]	147.0	[illegible]	150.5	151.0	150.0	152.0
T_5	[illegible]	[illegible]	[illegible]	147.0	147.0	[illegible]	[illegible]
T_6	[illegible]	147.0	147.0	[illegible]	[illegible]	[illegible]	[illegible]
T_7	[illegible]	153.0	150.0	151.0	151.0	152.0	153.0
T_8	152.0	152.5	[illegible]	150.0	151.0	[illegible]	153.0
T_9	151.0	151.0	147.0	[illegible]	[illegible]	[illegible]	[illegible]
T_A	[illegible]	[illegible]	147.0	[illegible]	[illegible]	[illegible]	150.0
W_1	[illegible]	[illegible]	147.0	[illegible]	[illegible]	[illegible]	152.5
W_2	151.0	151.5	[illegible]	151.0	151.5	151.0	152.5
W_3	147.0	[illegible]	147.0	[illegible]	[illegible]	[illegible]	150.0
W_4	[illegible]	147.5	[illegible]	150.0	151.0	[illegible]	152.0
W_5	[illegible]	150.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
W_6	151.5	153.0	150.0	151.0	151.0	151.0	153.0
W_7	152.5	153.0	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
W_8	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	147.0
W_9	132.0	132.0	131.0	[illegible]	[illegible]	[illegible]	[illegible]
W_A	[illegible]	147.2	[illegible]	[illegible]	[illegible]	147.4	[illegible]

OUTSIDE TUBE SURFACE TEMPERATURE

HEAT ... TEMPERATURE

Chimney Effect — Wire Spacing = 3"

		Tubes Horizontal				Wires Horizontal			
	Run No.	1	2	3	4	1	2	3	4
	Flow Rate lbs/hr.	192.0	191.5	197.0	195.0	202.0	197.5	197.5	197.0
	Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
	Ambient Temp. °F	80	80	80	80	80	80	80	80
	Inlet Temp. °F	180.0	177.0	181.5	177.5	178.0	170.0	180.0	177.0
	Outlet Temp. °F	172.5	171.0	174.5	171.5	172.0	172.5	172.5	170.0
OUTSIDE TUBE SURFACE TEMPERATURE	T_1	157.5	155.0	154.0	167.0	150.0	163.0	164.0	162.0
	T_2	151.0	150.0	150.0	155.0	153.0	153.0	152.0	160.0
	T_3	150.0	157.0	157.0	153.0	154.0	150.0	160.0	163.0
	T_4	155.0	153.0	152.5	150.0	160.0	157.0	151.0	167.0
	T_5	150.0	150.0	160.5	167.0	151.0	160.0	152.5	150.0
	T_6	151.0	150.0	150.0	153.0	157.0	153.0	151.0	160.0
	T_7	154.0	153.0	151.0	157.0	153.5	154.0	152.5	151.0
	T_8	157.0	159.0	155.0	152.0	154.0	160.0	163.0	163.0
	T_9	152.5	151.0	151.0	154.0	159.0	154.0	150.0	163.0
	T_A	153.6	157.6	155.4	152.3	154.1	151.0	163.6	163.4
HEAT WIRE TEMPERATURE	W_1	157.0	155.0	154.0	160.0	150.0	163.0	163.0	162.0
	W_2	150.0	159.0	158.5	155.0	155.0	153.5	151.5	163.0
	W_3	150.5	150.0	157.0	153.0	154.0	150.0	160.0	160.0
	W_4	153.0	154.0	152.5	150.0	160.0	153.0	151.0	167.0
	W_5	150.0	157.0	159.0	157.0	155.0	155.0	153.0	160.0
	W_6	152.5	158.0	154.0	159.0	151.0	163.0	160.0	153.0
	W_7	153.5	151.0	151.0	158.0	150.0	153.0	154.0	151.0
	W_8	163.0	164.0	163.0	163.0	167.0	162.0	160.0	160.0
	W_9	163.0	162.0	162.0	153.0	161.0	152.0	157.0	157.0
	W_A	155.5	154.0	154.7	151.3	151.4	167.0	160.5	160.0

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	153.0	150.0	131.0	123.0	140.0	132.0	125.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	89	89	89	80	80	80	80
Inlet Temp. °F	175.0	182.8	184.8	183.5	170.0	174.0	173.0
Outlet Temp. °F	150.0	150.2	152.5	152.0	151.5	153.5	150.0
T_1	2.020	2.690	3.000	3.025	3.000	2.770	2.725
T_2	2.873	3.000	2.045	2.740	2.720	2.550	2.400
T_3	2.750	2.070	2.800	2.003	2.705	2.720	2.510
T_4	2.570	2.020	2.825	2.740	2.020	2.035	2.770
T_5	2.740	2.010	2.050	2.015	2.625	2.735	2.400
T_6	2.420	2.445	2.520	2.473	2.225	2.505	2.603
T_7	2.220	2.230	2.340	2.650	2.520	2.545	2.670
T_8	2.535	2.640	2.090	2.740	2.730	2.090	2.720
T_9	2.020	2.610	2.075	2.710	2.320	2.570	2.070
T_A	145.2	140.7	154.2	152.2	140.0	147.6	147.5
W_1	2.340	2.520	2.620	2.430	2.600	2.440	2.535
W_2	3.020	2.640	2.720	2.750	2.720	2.640	2.700
W_3	3.020	2.200	2.250	2.290	2.025	2.340	2.525
W_4	2.150	2.545	2.620	2.630	2.525	2.705	2.600
W_5	2.570	2.210	2.230	2.225	2.400	2.020	2.605
W_6	2.233	2.420	2.420	2.405	2.600	2.740	2.705
W_7	2.200	2.155	2.300	2.645	2.050	2.575	2.570
W_8	2.440	2.525	2.590	2.340	2.000	2.520	2.520
W_9	Thermocouple found broken						
W_A	137.0	137.8	123.7	140.5	130.6	130.0	141.5

OBSERVATION SHEET NO. [illegible]

Wire Gauge = 20   Wire Spacing - 1/4"   Wires Horizontal

Run No.	1	2	3	4	5	6	7
Flow Rate lbm/hr.	155.0	161.0	153.0	155.0	164.0	163.0	180.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	88	80	89	83	80	80	83
Inlet Temp. °F	180.3	181.9	179.1	180.0	179.4	184.2	170.0
Outlet Temp. °F	161.0	159.9	160.1	161.0	161.3	160.0	150.0
Outside Tube Surface Temperature							
T_1	2.070	2.880	2.540	2.020	2.005	2.200	2.020
T_2	2.240	2.295	2.235	2.535	2.580	2.750	2.900
T_3	2.675	2.720	2.834	2.015	2.625	2.240	2.870
T_4	2.000	2.935	2.520	2.030	2.020	2.050	2.020
T_5	2.700	2.380	2.655	2.040	2.005	2.520	2.750
T_6	2.120	2.375	2.265	2.800	2.540	2.050	2.500
T_7	2.020	2.330	2.330	2.640	2.000	2.730	2.040
T_8	2.205	2.280	2.365	2.740	2.700	2.630	2.750
T_9	2.475	2.435	2.550	2.700	2.500	2.002	2.740
T_A	162.0	161.9	160.2	151.9	160.0	153.0	151.2
Mean Wire Temperature							
U_1	1.060	2.210	1.730	2.590	2.050	2.080	2.009
U_2	2.940	2.410	2.010	2.075	2.780	2.045	2.700
U_3	1.500	1.940	2.335	2.570	2.030	2.210	2.120
U_4	2.005	2.340	2.200	2.040	2.000	2.950	2.040
U_5	1.055	1.910	2.015	1.009	2.345	2.470	2.420
U_6	2.330	2.800	2.205	1.720	1.780	2.120	2.340
U_7	Thermocouple found broken						
U_8	2.195	2.010	2.215	2.425	1.700	1.010	2.240
U_9	1.970	2.130	2.300	1.730	2.830	2.715	2.550
U_A	184.0	180.2	183.4	180.3	183.2	157.0	183.0

Chimney Effect

Wire Spacing = 1/8

Wire Gage [illegible]

OVERALL [illegible] RUN NO. [illegible]

	Tubes Horizontal				Wires Horizontal			
Run No.	1	2	3	4	1	2	3	4
Flow Rate lb/hr.	101.0	102.0	122.0	[illegible]	101.0	138.0	102.0	[illegible]
Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
Ambient Temp. °F	89	89	[illegible]	80	89	80	[illegible]	[illegible]
Inlet Temp. °F	178.0	178.5	173.0	177.5	173.0	172.7	171.9	172.0
Outlet Temp. °F	130.5	153.5	152.5	154.3	154.0	151.8	150.0	150.0
T_1	2.030	2.7[illegible]	2.080	2.020	2.592	2.087	2.000	2.000
T_2	2.070	2.[illegible]	2.0[illegible]	2.000	2.[illegible]0	2.[illegible]	2.[illegible]	2.[illegible]
T_3	2.525	2.[illegible]	2.[illegible]0	2.[illegible]8	2.[illegible]	2.[illegible]	2.[illegible]5	2.[illegible]
T_4	2.210	2.[illegible]9	2.000	2.74[illegible]	2.010	2.[illegible]4	2.0[illegible]0	2.320
T_5	2.[illegible]	2.[illegible]0	2.030	2.043	2.710	2.820	2.720	2.017
T_6	2.74[illegible]	2.04[illegible]	2.020	2.0[illegible]	2.[illegible]	2.890	2.[illegible]5	2.[illegible]
T_7	2.[illegible]5	2.[illegible]	2.570	2.590	2.[illegible]7	2.[illegible]	2.578	2.[illegible]0
T_8	2.74[illegible]	2.100	2.000	2.898	2.[illegible]0	2.414	2.030	2.039
T_9	2.[illegible]3	2.6[illegible]	2.795	2.820	2.[illegible]8	2.809	2.[illegible]	2.[illegible]
T_Δ	152.0	140.0	151.0	151.8	140.0	14[illegible].1	14[illegible].9	14[illegible]
U_1	2.94[illegible]	2.[illegible]0	2.820	2.0[illegible]	2.[illegible]	2.[illegible]0	2.[illegible]	2.[illegible]
U_2	2.052	2.[illegible]5	2.9[illegible]	2.875	2.[illegible]0	2.090	2.0[illegible]	2.050
U_3	2.718	2.[illegible]5	2.0[illegible]	2.[illegible]	2.[illegible]	2.040	2.[illegible]4	2.0[illegible]
U_4	2.[illegible]	2.[illegible]°	2.[illegible]°	2.1[illegible]	2.[illegible]0	2.[illegible]	2.[illegible]0	2.[illegible]7
U_5	2.008	2.[illegible]0	2.005	2.043	2.[illegible]	2.938	2.[illegible]	2.[illegible]0
U_6	2.919	2.[illegible]	2.7[illegible]	2.7[illegible]	2.[illegible]0	2.594	2.9[illegible]	2.927
U_7	2.7[illegible]	2.[illegible]0	2.730	2.025	2.0[illegible]	2.007	2.572	2.0[illegible]
U_8	2.705	2.020	2.095	2.095	2.970	2.7[illegible]	2.0[illegible]	2.007
U_9	2.020	2.040	1.709	2.009	2.1[illegible]	2.090	1.7[illegible]	1.040
U_Δ	1[illegible].6	157.0	14[illegible].0	1[illegible].5	1[illegible].7	14[illegible].9	1[illegible]7.1	1[illegible].8

OUTSIDE TUBE SURFACE TEMPERATURE

INSIDE TUBE WALL TEMPERATURE

[illegible] No. 2[illegible]

Wire Gage 20 Wire Spacing - 1/2" Tube Insulated

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	130.0	125.0	128.5	124.5	130.5	130.0	123.0
Yaw Angle	0	15	30	45	60	75	90
Ambient Temp. °F	98	98	98	98	98	98	98
Inlet Temp. °F	182.0	182.1	182.5	184.0	185.0	181.0	185.0
Outlet Temp. °F	168.5	160.0	168.2	171.0	170.6	167.7	171.5
OUTSIDE TUBE SURFACE TEMPERATURE T_1	2.015	2.600	2.055	2.420	2.425	2.130	2.093
T_2	2.620	2.310	2.340	2.345	2.340	2.320	2.225
T_3	2.440	2.600	2.600	2.025	2.075	2.745	2.600
T_4	2.415	2.313	2.435	2.390	2.325	2.340	2.470
T_5	2.330	2.310	2.320	2.325	2.335	2.060	2.340
T_6	2.233	2.310	2.780	2.340	2.025	2.030	2.435
T_7	2.723	2.723	2.520	2.070	2.605	2.365	2.033
T_8	2.375	2.200	2.205	2.290	2.320	2.275	2.225
T_9	2.420	2.523	2.520	2.300	2.630	2.573	2.305
T_A	142.0	143.5	143.0	142.5	144.6	141.6	143.5
U_1	2.290	2.000	2.200	2.000	2.090	1.920	1.900
U_2	2.570	2.323	2.420	2.470	2.340	2.370	2.370
U_3	2.330	2.393	2.010	2.640	2.303	2.550	2.320
U_4	2.200	2.230	2.133	2.430	2.520	2.430	2.420
[illegible] TEMPERATURE U_5	2.545	2.700	2.033	2.040	2.775	2.745	2.033
U_6	2.020	2.600	2.625	2.690	2.090	2.710	2.330
U_7	1.963	1.740	1.050	1.440	1.020	1.700	1.700
U_8	2.605	2.700	2.533	2.600	2.300	2.370	2.340
U_9	2.440	2.323	2.700	2.950	2.420	2.520	2.003
U_A	153.0	153.6	157.0	153.6	153.0	157.0	153.0

Run No.	1	2	3	4	5	6	7
Flow Rate lbs/hr.	114.0	114.0	115.2	112.0	109.0	119.0	111.0
Fan Angle	0	15	30	45	60	75	90
Ambient Temp. °F	83	83	86	85	83	83	85
Inlet Temp. °F	178.5	159.5	157.5	156.0	153.0	157.5	150.0
Outlet Temp. °F	150.5	150.5	154.3	152.5	150.5	152.2	152.5
T_1	2.100	1.670	1.638	1.293	2.020	1.775	1.780
T_2	2.440	2.238	2.170	2.110	1.630	2.020	2.150
T_3	1.720	2.305	2.358	2.543	2.403	1.723	2.125
T_4	2.303	2.009	1.967	2.343	1.538	2.000	2.703
T_5	2.430	2.100	2.043	1.955	1.923	2.003	2.143
T_6	2.100	2.100	1.900	2.000	2.025	2.417	2.304
T_7	2.095	2.050	2.030	1.940	1.900	2.058	2.120
T_8	1.840	2.091	2.285	1.947	1.920	2.020	2.095
T_9	2.173	2.140	2.030	1.997	1.973	2.140	2.330
T_A	123.0	127.0	122.0	121.5	110.0	124.8	123.6
H_1	2.220	2.243	2.190	2.157	2.138	2.231	2.237
H_2	1.035	1.420	1.708	1.800	1.910	2.090	2.131
H_3	1.624	1.530	1.980	1.530	1.718	1.630	1.757
H_4	2.200	2.070	2.700	2.038	1.950	1.840	2.018
H_5	2.220	2.320	2.145	2.043	2.110	2.230	2.238
H_6	1.432	1.590	2.315	2.220	2.210	1.430	2.143
H_7	1.230	1.500	1.530	1.240	1.220	1.240	1.430
H_8	2.009	2.538	2.240	2.208	1.950	2.234	2.181
H_9	2.073	2.072	1.925	1.920	1.740	2.115	2.130
H_A	114.2	127.0	111.7	117.6	117.5	120.0	122.4

Chimney Effect

Plate Spacing - 1/2"

Run No.	Tubes Horizontal 1	2	3	4	Wires Horizontal 1	2	3	4
Flow Rate lbs/hr.	123.0	132.0	117.0	115.0	121.0	120.0	122.5	122.0
Plate Spacing	2"	3"	4"	5"	2"	3"	4"	5"
Ambient Temp. °F	83	86	86	83	86	89	83	80
Inlet Temp. °F	203.2	204.4	204.0	202.5	203.5	203.0	202.6	201.0
Outlet Temp. °F	175.0	175.0	173.8	172.0	174.0	171.5	171.0	170.0
Outside Tube Surface Temperature T_1	2.023	2.200	2.610	2.320	1.710	2.200	2.023	2.320
T_2	2.120	2.095	2.015	2.600	2.453	2.703	2.700	2.040
T_3	2.595	1.8450	2.020	2.600	2.130	2.703	2.243	2.320
T_4	3.030	2.700	2.840	2.130	2.683	2.040	2.233	2.530
T_5	3.030	2.800	2.000	2.640	2.230	2.020	2.610	2.600
T_6	2.120	2.010	2.620	2.000	2.200	2.900	3.130	2.020
T_7	3.030	2.730	2.600	2.500	2.230	2.020	2.020	2.535
T_8	Thermocouple found broken							
T_9	2.110	2.030	2.020	2.040	2.540	2.080	2.020	2.020
T_A	130.7	193.0	154.2	10.0	123.3	10.3	104.5	102.5
[illegible] Temperature H_1	2.220	2.940	2.940	2.720	2.520	2.830	2.703	2.780
H_2	2.005	2.110	2.030	2.530	2.000	2.293	2.430	2.590
H_3	3.120	2.075	2.070	2.075	2.375	2.040	2.500	2.403
H_4	2.120	2.840	2.010	2.700	2.230	2.720	2.505	2.535
H_5	2.120	2.000	2.040	2.710	2.403	2.020	2.705	2.005
H_6	1.210	2.900	2.920	2.770	2.200	1.030	1.085	2.020
H_7	2.040	2.432	2.100	2.120	1.840	1.030	1.700	1.005
H_8	3.035	2.640	2.700	2.590	2.530	2.035	2.420	2.030
H_9	2.070	2.045	2.700	2.420	1.955	2.800	2.255	2.020
H_A	195.5	130.2	10.0	104.0	124.3	100.0	123.3	123.3

Plate Spacing 3"

[illegible] No. 2

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Wires Horizontal
Tubes Horizontal

Wire Spacing - 1"

Run No.	Wires Horizontal 1	2	3	4	Tubes Horizontal 1	2	3	4
Flow Rate lbs/hr.	175.0	173.0	158.0	167.0	190.0	182.0	157.0	184.0
Yaw Angle	0	30	60	90	0	30	60	90
Ambient Temp. °F	90	90	90	90	90	90	90	90
Inlet Temp. °F	176.5	182.5	183.4	186.0	179.3	170.0	180.5	179.0
Outlet Temp. °F	180.0	173.3	173.3	175.2	170.0	170.0	171.0	157.3
OUTSIDE TUBE SURFACE TEMPERATURES								
T_1	2.012	2.090	3.240	2.290	2.940	2.023	2.940	2.016
T_2	2.190	2.190	2.427	3.239	2.322	2.242	2.202	2.046
T_3	2.103	2.010	2.797	2.940	2.093	2.070	2.000	2.004
T_4	2.123	2.072	2.230	2.310	3.063	3.212	2.093	2.996
T_5	2.010	2.604	2.040	2.030	3.185	2.019	2.940	2.536
T_6	2.023	2.174	3.191	2.070	2.030	2.954	2.071	3.070
T_7								
T_8	Only six thermocouple junctions were placed.							
T_9								
T_A	198.5	184.3	188.8	158.6	193.2	182.6	182.5	184.5
HEAT FLUX TEMPERATURES								
U_1	1.751	1.742	1.872	1.833	1.730	1.820	1.690	1.813
U_2	1.001	1.723	1.732	1.830	1.600	1.778	1.030	1.790
U_3	1.013	1.740	1.031	1.913	1.730	1.770	1.076	1.933
U_4	2.192	2.090	2.307	2.313	1.740	1.990	1.019	1.706
U_5	1.070	1.702	1.702	1.040	1.702	1.090	1.030	1.940
U_6	1.803	1.855	1.072	1.992	1.003	1.033	1.801	1.855
U_7								
U_8	Only six thermocouple junctions were placed.							
U_9								
U_A	112.3	114.2	119.4	120.4	107.3	113.5	100.5	114.3

Wire Gap 2D

ORIENTATION NO. 3