# OPTIMIZATION OF THE DESIGN OF AN EXTENDED SURFACE WITH FINNED PINS

by

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# I. INTRODUCTION

In order to increase the rate of heat transfer from a primary surface, extended surfaces in the form of fins of different shapes and sizes have been widely used.

In recent years pins have been used instead of fins to increase the rate of heat transfer. Hsieh (1), working on the original idea of Professor Hsu has proved that the rate of heat transfer through a pin can be further increased by the addition of annular fins on the pin.

The objective of this thesis is to optimize the design of an extended flat surface with finned pins and determine the improvement in the rate of heat transfer.

The general procedure to be followed is as follows:

(1) Theoretical analysis of the heat transfer characteristics of various designs of pins and finned pins.

(2) Optimization of the design for a given primary surface using plain pins and finned pins.

(3) Experimental measurements of heat transfer rate for finned pin, plain pin and primary surface.

(4) Comparison of rate of heat transfer between an extended surface with finned pins and plain pins.

# II. REVIEW OF LITERATURE

Extended surfaces are commonly found in the form of fins attached to the surface of a machine part for the express purpose of increasing the rate of heat transfer between the surface and an ambient fluid. It is on this principle that fins find numerous applications in electrical apparatus, heat exchangers, radiators, and so on. Fins are made in various profiles and shapes. For any particular application, the problem is to select a fin which will give maximum rate of cooling, minimum material, minimum resistance to air flow, adequate strength and ease of manufacture. Schneider (2) and Jackob (3) have discussed heat transfer rate, efficiency and temperature distribution of various types of circumferential fins and spines.

McManus and Starner (4) determined the average heat transfer coefficients for the rectangular fin arrays. They plotted curves for temperature vs. average heat transfer coefficients. These coefficients were determined for various fin positions. Schryber (5) provided heat transfer coefficient data on a serrated type of finned surface and also showed the ease of fabrication and the flexibility of sizes.

Kays (6) adopted small diameter circular pins in contrast to fins on the heat transfer surface and proved that heat exchangers with pinned and finned surfaces are competitive, so far as volume and weight are concerned. Norris and Spofford (7) presented test results for a group of small discontinuous fins and pins and proved that the heat transfer coefficient can be almost twice as high as that for continuous fins.

Avrami and Little (8) studied the temperature gradients in two dimensions with thick fins of rectangular profile, and also established the critical Nusselt number below which straight rectangular fins are more effective. Carrier and Anderson (9) presented solutions in terms of infinite series for circular fins of rectangular and hyperbolic profile.

Gray, Mathew and McRobert (10) derived the equations for heat transfer through circular disc fins which were later modified by Murray (11) for special cases. Transawa (12) gives calculation of heat transfer rate in simple shape fins including cases in which thicker and shorter fins are exposed to flowing liquid. Charts for evaluating mathematical expressions are given, from which heat dissipation from the fins can be calculated.

Schmidt (13) introduced the apparent coefficient of heat transfer as a function of the dimensions and the mean coefficient of heat transfer in order to facilitate the calculation of heat transmission from or to finned surfaces. Keller and Sommers (14) plotted curves for the efficiency of an annular fin of constant thickness.

Tate and Cartinhour (15) described four types of heat exchangers with disc-on-tube as the extended surface. Kays and London (16) presented basic heat transfer and flow friction design data for thirteen plate-fin type and finned flat-tube type surfaces. The various surfaces were compared on the basis of heat transfer coefficient and flow friction horsepower. Kays (17) has also worked on six compact high-performance heat transfer surfaces.

Kayan and Gates (18) dealt most comprehensively with the analysis of finned structures found in many engineering application.

Dusinberre (19) and (20) showed a trial and error procedure for getting local surface coefficient, and gave an approximate form of fin efficiency for four different types of fins.

The various types of heat transfer surfaces used in most heat exchangers have been illustrated by Hsu (21). He has also given in detail, the mathematics involved in the design of heat exchangers.

Following the original idea of Professor Hsu, Hseih (1) has added a new type of extended surface which is known as a finned pin. It was found that the heat transfer rate can be increased by 61 per cent by a single finned pin compared to a plain pin of the same diameter.

He derived a mathematical expression for a pin with two fins, which could be modified for any number of fins. In the following chapters, the modified mathematical equations have been used extensively.

Reiher (22) proved that the staggered arrangement gave substantially higher coefficients of heat transfer than an in-line arrangement. McAdams (23) described the work done by numerous investigators on staggered tubes and stated that the heat transfer coefficient is somewhat higher for the staggered arrangement than for an in-line arrangement. The increase in heat transfer coefficient for the rows in the rear of the bank over those in the front row is due to increased turbulence.

# III. THEORETICAL INVESTIGATIONS

## (1) HEAT TRANSFER CHARACTERISTICS OF A PIN

The variables that affect the rate of steady state heat transfer between a plain pin and the ambient fluid are:

1. Diameter of pin
2. Difference in temperature between pin and ambient air
3. Length of pin
4. Thermal conductivity of the pin material

For unsteady state heat transfer two more variables, the density and the specific heat of the material, will also have to be considered.

In analyzing these variables, if we keep the thermal conductivity of the pin material, the convective film coefficient and the temperature difference between root of the pin and ambient air constant, we are left with only two principal variables, viz. diameter and the length of the pin. Therefore, the curves can be plotted with the diameter of the pin against heat flux for various lengths of the pin.

An equation for the heat transfer rate through a pin projecting from a primary surface is given by Kreith (24) as follows:

$$Q = kAm\theta_o \frac{\sinh mL + H\cosh mL}{\cosh mL + H \sinh mL} \qquad (3\text{-}1)$$

$$q = \frac{Q}{A} = km\theta_o \frac{\sinh mL + H \cosh mL}{\cosh mL + H \sinh mL} \qquad (3\text{-}2)$$

where,

$Q$ = Rate of heat flow from pin to fluid (Btu/hr)

$q$ = Rate of heat flow per unit root area or heat flux at the root of the pin ($Btu/ft^2hr$)

$P$ = Perimeter of the pin (ft)

$h$ = Average convective heat transfer coefficient ($Btu/hr\ ft^2\ F$)

$k$ = Thermal conductivity of the pin (Btu/hr ft F)

$A$ = Cross sectional area of the pin ($ft^2$)

$t_o$ = Temperature at the root of the pin (F)

$t_a$ = Ambient temperature of air (F)

$\theta_o$ = Temperature excess at the root of the pin $= t_o - t_a$

$m = \sqrt{\frac{hP}{kA}}$

$L$ = Length of the pin

$H = \frac{h}{mk}$

The convective heat transfer coefficient for natural convection is given by McAdams (23) as:

$$h = .27 \left(\frac{\Delta T}{d}\right)^{\frac{1}{4}}$$

$$\text{for } 10^3 < G_R < 10^9 \qquad (3\text{-}3)$$

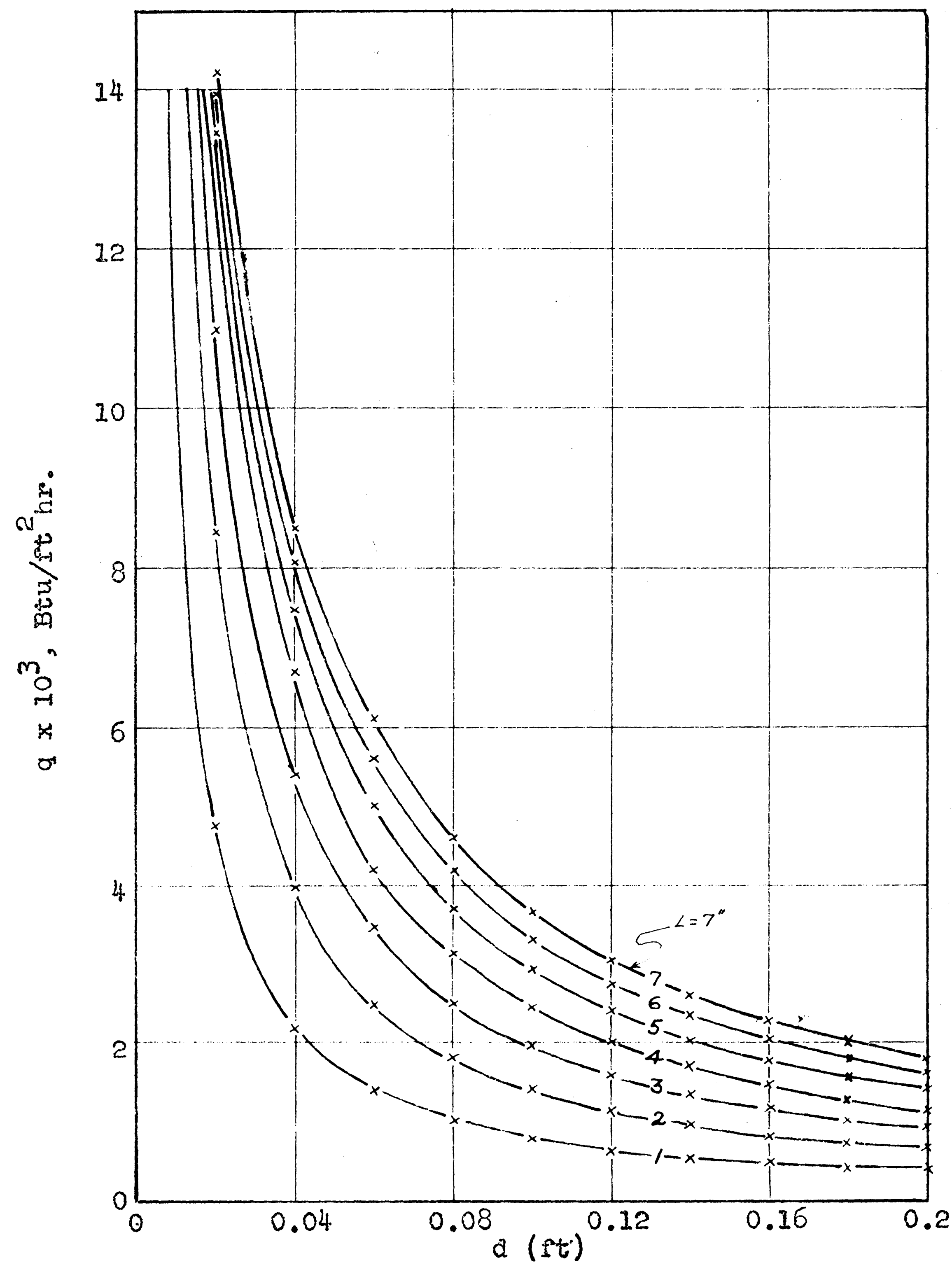



Fig. 1 Heat transfer characteristics of plain pin fin

where,

$G_R$ = Grashof number

$\Delta T$ = Difference in temperature between the pin and ambient air (F)

d = Diameter of the pin (ft)

By means of a computer (IBM 1620), a family of curves of q vs. d are plotted as shown in the fig. 1 with T = 124.2 F and k = 30 Btu/hr ft F. The data for fig. 1 are shown in Table A-1, in the Appendix A.

From these curves it can be seen that:

1. With decrease in diameter of the pin, the heat transfer rate increases. The increase is notable between the range $0 < d < .08$ and then the slope of the curve gradually decreases for $d > .08$. The increase in heat transfer is due to the improvement in h with decrease in the value of the denominator in equation (3-3).
2. For a given diameter, the heat transfer rate increases with increase in length. On the other hand there is a limit to which we can increase the heat transfer rate with increase in length.

In view of the above discussion it can be seen that for a given heat transfer rate, the design of a pin can be optimized by determining the ideal combination of length and diameter of the pin.

(2) HEAT TRANSFER CHARACTERISTICS OF A FINNED PIN

In the analysis of a finned pin, more variables are involved.

$$Q = f\ (d, D, b, s, L, n) \qquad (3\text{-}4)$$

where,

$Q$ = Heat flux (Btu/$ft^2$hr)

$d$ = Diameter of pin (ft)

$D$ = Outside diameter of fin (ft)

$b$ = Thickness of fin (ft)

$L$ = Length of pin (ft)

$n$ = Number of fins (ft)

$s$ = Spacing of fins (ft)

It would be rather complicated to vary one of the above variables and hold the rest of them constant. For a given value of d and D, if b is doubled, the volume of the material will be doubled without appreciable increase in the surface area. On the other hand, two fins with thickness b will have two times the surface area compared to one fin with 2b thickness. Therefore, instead of one thick fin, a greater number of thinner fins will be preferable. So we may choose a minimum thickness for the fin and assume that it be constant. Secondly, from the previous analysis of a plain pin, we know that smaller diameter is better for increasing the heat transfer rate, but a pin cannot be too small to be practical. So a suitable diameter is selected for the pins. Thirdly, fins will be equally spaced over the entire length of the pin. So two variables s and n will merge into a single variable. Finally, the variables involved are D, L and n.

## (3) MATHEMATICAL EQUATIONS FOR HEAT TRANSFER FROM A FINNED PIN

The mathematical equations for the two disced finned pins were derived in detail by Hsieh (1). In the following discussion a summary of the derivation of these equations is given.

The derivation of the equations was based on the principal assumption that the temperature of the ambient air, thermal conductivity of the material and convective heat transfer coefficient are constant. It was also assumed that the heat transfer is by convection only.

Nomenclature:

h = Average convective heat transfer coefficient (Btu/hr ft$^2$ F)

k = Thermal conductivity of finned pin (Btu/hr ft F)

d = Diameter of pin (ft)

D = Outside diameter of fin (ft)

L = Length of pin

s = Spacing or pitch of fin (ft)

n = Number of fins

t = Thickness of fin (ft)

$t_o$ = Temperature at the root of the pin (F)

$t_a$ = Ambient temperature of air (F)

$\theta_o$ = Temperature excess at the root of the fin

= $t_o - t_a$ (F)

$r_1$ = Radius of pin (ft) = $\frac{d}{2}$

$r_2$ = Outside radius of fin (ft) = $\frac{D}{2}$

$Q_1, Q_2, Q_3 \ldots\ldots Q_n$ = Rate of heat transfer at the root of the pin with 1, 2, 3 ...... n fins spaced equidistant from each other.

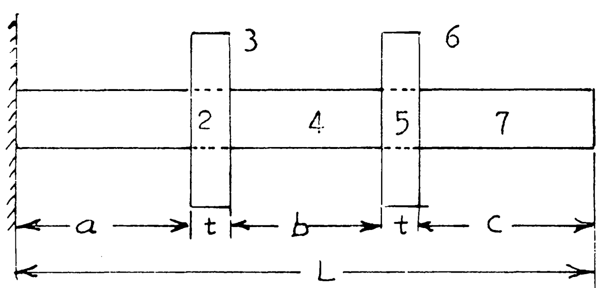



Fig. 2a A pin with two fins

The finned pin is divided into pins and fins, and are numbered as shown in Figure 2a.

Heat flux from the pin 7 is given by equation (3-1) as:

$$Q_{7-0} = kAm\, \theta_{7-0} \frac{\tanh mc + H_1}{1 + H_1 \tanh mc} \qquad (3\text{-}5)$$

$$= kAm\, \theta_{7-0} B_1$$

where,

$Q_{7-0}$ = Heat flux from pin 7

$\theta_{7-0} = t_{7-0} - t_a$

$t_{7-0}$ = Root temperature of pin 7

$m = \sqrt{\frac{4h}{kd}}$

$H_1 = \frac{h}{mk}$

$B_1 = \frac{\tanh mc + H_1}{1 + H_1 \tanh mc}$

Heat flux from fin 6 is given by Schneider (2) as:

$$Q_{6-0} = 2\pi kNtr_1\, \theta_{6-0} \frac{K_1(Nr_1)I_1(Nr_2) - I_1(Nr_1)K_1(Nr_2)}{K_0(Nr_1)I_1(Nr_2) + I_0(Nr_1)K_1(Nr_2)}$$

$$= B_2\theta_{6-0} \qquad (3\text{-}6)$$

where,

$Q_{6-0}$ = Heat flux from fin 6

$\theta_{6-0} = t_{6-0} - t_a$

$t_{6-0}$ = Average root temperature of fin 6.

$N = \sqrt{\frac{2h}{kt}}$

$K_0$ = Zero order Modified Bessel Function, 2nd Kind

$K_1$ = First order Modified Bessel Function, 2nd Kind

$I_0$ = Zero order Modified Bessel Function, 1st Kind

$I_1$ = First order Modified Bessel Function, 1st Kind

$$B_2 = 2\pi kNtr_1 \frac{K_1(Nr_1)I_1(Nr_2) - I_1(Nr_1)K_1(Nr_2)}{K_0(Nr_1)I_1(Nr_2) + I_0(Nr_1)K_1(Nr_2)}$$

For determining the heat flux in pin 5 let us assume that pin 5 is surrounded by a fictitious fluic having a heat transfer coefficient equal to $h_1$, then

$$Q_{6-0} = h_1 S\,\theta_{6-0}$$
$$= h_1(\pi dt)\,\theta_{6-0} \qquad (3\text{-}7)$$

Equating equations (3-6) and (3-7), and rearranging

$$h_1 = \frac{B_2}{\pi dt}$$

Now pin 5 can be considered as an individual pin with the following boundary conditions.

$$Q_{5-t} = Q_{7-0} \text{ and } \theta_{5-t} = \theta_{7-0} \text{ at } x = t$$
$$\theta = \theta_{5-0} \text{ at } x = 0$$

where,

$Q_{5-t}$ = Heat flux from the end of pin 5

From the heat balance of the differential element of pin 5, we arrive at the following equation

$$\frac{d^2\theta}{dx^2} - m_1^2\theta = 0 \qquad \left[m_1 = \sqrt{\frac{4h_1}{kd}}\right] \qquad (3\text{-}8)$$

The solution of this equation after putting the boundary condition for pin 5 is:

$$\frac{\theta}{\theta_{5-0}} = \frac{\cosh m_1(t-x) + H_2 \sinh m_1 (t-x)}{\cosh m_1 t + H_2 \sinh m_1 t} \qquad (3\text{-}9)$$

where,

$$H_2 = \frac{m}{m_1} B_1$$

For pin 5 at $x = t$, $\theta = \theta_{5-t} = \theta_{7-0}$

Therefore, equation (3-9) becomes:

$$\theta_{7-0} = \frac{\theta_{5-0}}{\cosh m_1 t + H_2 \sinh m_1 t} \qquad (3\text{-}10)$$

where,

$$B_3 = \frac{1}{\cosh m_1 t + H_2 \sinh m_1 t}$$

By differentiating equation (3-9) and putting $x=0$ we get,

$$\left.\frac{d\theta}{dx}\right|_{x=0} = -m_1 \theta_{5-0} \frac{\sinh m_1 t + H_2 \cosh m_1 t}{\cosh m_1 t + H_2 \sinh m_1 t}$$

$$Q_{5-0} = -kA \left.\frac{d\theta}{dx}\right|_{x=0}$$

$$= kAm_1\theta_{5-0} \frac{\tanh m_1 t + H_2}{1 + H_2 \tanh m_1 t}$$

$$= kAm_1\theta_{5-0} B_4 \qquad (3\text{-}11)$$

where,

$$B_4 = \frac{\tanh m_1 t + H_2}{1 + H_2 \tanh m_1 t}$$

for pin 4

let $Q_{4-b}$ = Heat flux from the end of the pin 4 at $x = b$

$\theta_{4-b}$ = Temperature difference at the end of pin 4 at $x = b$

then

$$Q_{4-b} = Q_{5-0}$$

$$\theta_{4-b} = \theta_{5-0}$$

$$Q_{4-b} = -kA \left.\frac{dt}{dx}\right|_{x=b} = -kA \left.\frac{d\theta}{dx}\right|_{x=b} \qquad (3\text{-}12)$$

Equating equations (3-11) and (3-12) and rearranging

$$\frac{d\theta_{4-b}}{dx} = -m_1 B_4 \theta_{5-0} \qquad (3\text{-}13)$$

Recall that the heat balance equation for a differential element of a pin is

$$\frac{d^2\theta}{dx^2} - m^2\theta = 0 \qquad (3\text{-}14)$$

The boundary conditions for pin 4 are:

at $x = 0$, $\theta = \theta_{4-0}$

at $x = b$ $\theta = \theta_{4-b}$

With the help of equation (3-11) and the boundary conditions for pin 4 the solution of equation (3-1[illegible]) is:

$$\frac{\theta}{\theta_{4-0}} = \frac{\cosh m(b-x) + H_3 \sinh m(b-x)}{\cosh mb + H_3 \sinh mb} \qquad (3\text{-}15)$$

where $H_3 = \frac{m_1}{m} B_4$

$$Q_{4-0} = kA \left.\frac{d\theta}{dx}\right|_{x=0}$$

where

$Q_{4-0}$ = Heat flux through pin 4 at $x = 0$

$= Q_1$

$\left.\frac{d\theta}{dx}\right|_{x=0}$ is obtained by differentiating equation (3-15) and putting x=0

therefore,

$$Q_1 = Q_{4-0} = kAm\theta_{4-0}\,\frac{\tanh mb + H_3}{1 + H_3 \tanh mb} \tag{3-16}$$

Next, pin 2 comes into consideration. Since the conditions of pin 2 are similar to pin 5 we can obtain the solution for the determination of heat transfer rate on the same pattern.

$$\frac{\theta}{\theta_{2-0}} = \frac{\cosh m_1(t-x) + H_4 \sinh m_1(t-x)}{\cosh m_1 t + H_4 \sin m_1 t} \tag{3-17}$$

where $H_4 = \frac{m}{m_1} B_6$

$$B_6 = \frac{\tanh mb + H_3}{1 + H_3 \tanh mb}$$

The heat flux of pin 2 is analogous to equation (3-11)

$$Q_{2-0} = kAm_1B8\theta_{2-0} \tag{3-18}$$

where

$$B8 = \frac{\tanh m_1 t + H_4}{1 + H_4 \tanh m_1 t}$$

The heat flux of pin 1 analogous to equation (3-16) is

$$Q_2 = Q_{1-0} = kAm\theta_{1-0}\,\frac{\tanh ma + H_5}{1 + H_5 \tanh ma}$$

$$= kAm\theta_{1-0}B_{10} \tag{3-19}$$

Where $Q_2 = Q_{1-0}$ = Heat flux through the root of pin 1

$$B_{10} = \frac{\tanh ma + H_5}{1 + H_5 \tanh ma}$$

$$H_5 = \frac{m_1}{m} B_8$$

The equations can be similarly modified for any number of fins by the similar process. Following are the modified equations giving heat flux for a pin with a maximum of ten fins equally spaced.

$$s = \frac{L - nt}{n+1}$$

Now,

$$ma = mb = mc = ms$$

$$T = \tanh ms$$

$$T_i = \tanh m_i t$$

$$H_6 = B_{10} \frac{m}{m_i} \quad (3\text{-}20)$$

$$B_{12} = \frac{T_i + H_6}{1 + T_i H_6} \quad (3\text{-}21)$$

$$H_7 = B_{12} \frac{m_i}{m} \quad (3\text{-}22)$$

$$B_{14} = \frac{T + H_7}{1 + TH_7} \quad (3\text{-}23)$$

Therefore,

$$Q_3 = kAm\theta_o B_{14} \quad (3\text{-}24)$$

Let,

$$H_8 = B_{14} \frac{m}{m_i} \quad (3\text{-}25)$$

$$B_{16} = \frac{T_i + H_8}{1 + T_i H_8} \quad (3\text{-}26)$$

$$H_9 = \frac{m_i}{m} \quad (3\text{-}27)$$

$$B_{18} = \frac{T + H_9}{1 + TH_9} \quad (3\text{-}28)$$

Therefore,

$$Q_4 = kAm\theta_o B_{18} \tag{3-29}$$

Let,

$$H_{10} = B_{18} \frac{m}{m_i} \tag{3-30}$$

$$B_{20} = \frac{T_i + H_{10}}{1 + T_i H_{10}} \tag{3-31}$$

$$H_{11} = B_{20} \frac{m_i}{m} \tag{3-32}$$

$$B_{22} = \frac{T + H_{11}}{1 + TH_{11}} \tag{3-33}$$

Therefore,

$$Q_5 = kAm\theta_o B_{22} \tag{3-34}$$

Let,

$$H_{12} = B_{22} \frac{m}{m_i} \tag{3-35}$$

$$B_{24} = \frac{T_i + H_{12}}{1 + T_i H_{12}} \tag{3-36}$$

$$H_{13} = B_{24} \frac{m_i}{m} \tag{3-37}$$

$$B_{26} = \frac{T + H_{13}}{1 + TH_{13}} \tag{3-38}$$

Therefore,

$$Q_6 = kAm\theta_o B_{26} \tag{3-39}$$

Let,

$$H_{14} = B_{26} \frac{m}{m_i} \tag{3-40}$$

$$B_{28} = \frac{T_i + H_{14}}{1 + T_i H_{14}} \tag{3-41}$$

$$H_{15} = B_{28} \frac{m_i}{m} \tag{3-42}$$

$$B_{30} = \frac{T + H_{15}}{1 + TH_{15}} \qquad (3\text{-}43)$$

Therefore,

$$Q_7 = kAm\theta_o B_{30} \qquad (3\text{-}44)$$

Let,

$$H_{16} = B_{30} \frac{m}{m_i} \qquad (3\text{-}45)$$

$$B_{32} = \frac{T_i + H_{16}}{1 + T_i H_{16}} \qquad (3\text{-}46)$$

$$H_{17} = B_{32} \frac{m_i}{m} \qquad (3\text{-}47)$$

$$B_{34} = \frac{T + H_{17}}{1 + TH_{17}} \qquad (3\text{-}48)$$

Therefore,

$$Q_8 = kAm\theta_o B_{34} \qquad (3\text{-}49)$$

Let,

$$H_{18} = B_{34} \frac{m}{m_i} \qquad (3\text{-}50)$$

$$B_{36} = \frac{T_i + H_{18}}{1 + T_i H_{18}} \qquad (3\text{-}51)$$

$$H_{19} = B_{36} \frac{m_i}{m} \qquad (3\text{-}52)$$

$$B_{38} = \frac{T + H_{19}}{1 + TH_{19}} \qquad (3\text{-}53)$$

Therefore,

$$Q_9 = kAm\theta_o B_{38} \qquad (3\text{-}54)$$

Let,

$$H_{20} = B_{38} \frac{m}{m_i} \qquad (3\text{-}55)$$

$$B_{40} = \frac{T_i + H_{20}}{1 + T_i H_{20}} \qquad (3\text{-}56)$$

$$H_{21} = B_{40} \frac{m_1}{m} \qquad (3\text{-}57)$$

$$B_{42} = \frac{T + H_{21}}{1 + TH_{21}} \qquad (3\text{-}58)$$

Therefore,

$$Q_{10} = kAm\theta_o B_{42} \qquad (3\text{-}59)$$

The equations presented in this thesis are specially adaptable for the computer programming. A sample calculation on page 45 will serve to illustrate the use of the equations given above.

In evaluating the values of Q, computer (IBM 1620) was extensively used. For a given value of L and D, q vs. n is plotted. A maximum of 10 fins were used in the analysis. For d = 1/2 in and L = 1/2 in., Figure 2 shows Q vs. n for D = 3/4 in to D = 1 3/4 in increasing in the steps of 1/4 in. With the same parameters as in Figure 32, sets of curves are plotted in Figure 3 to 9 with d = 1/2 in and L taking on value of 1 in, 1 1/2 in, 2 in, 3 in, 4 in, 5 in and 6 in. The data for these curves are in Appendix A. From these curves it can be seen that:

1. The heat transfer rate increases with increase in outside diameter, the increase is appreciable for smaller values of D but it is not significant for large values of D.

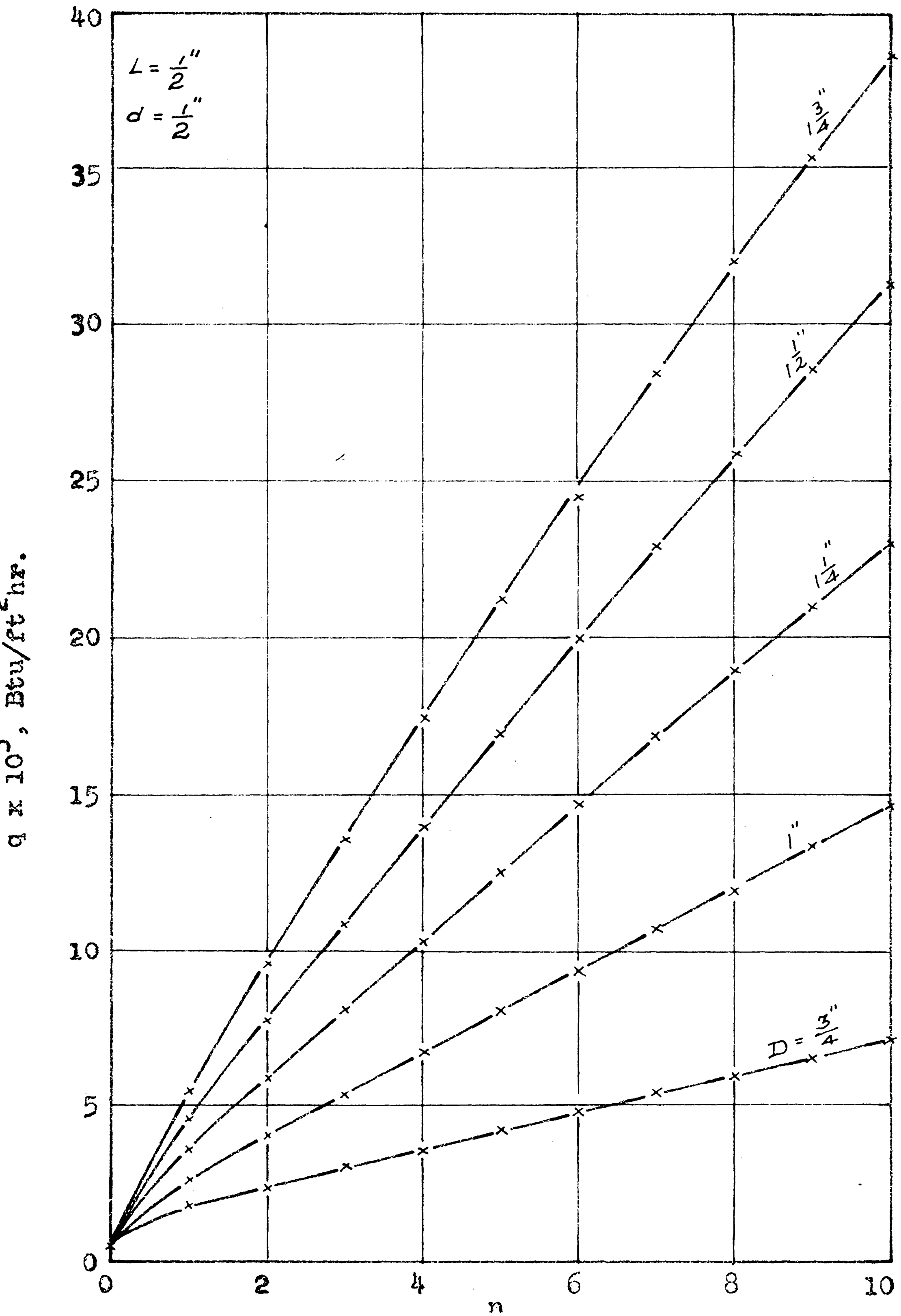



Fig. 2 Heat transfer characteristics of a finned pin($L=\frac{1}{2}$")

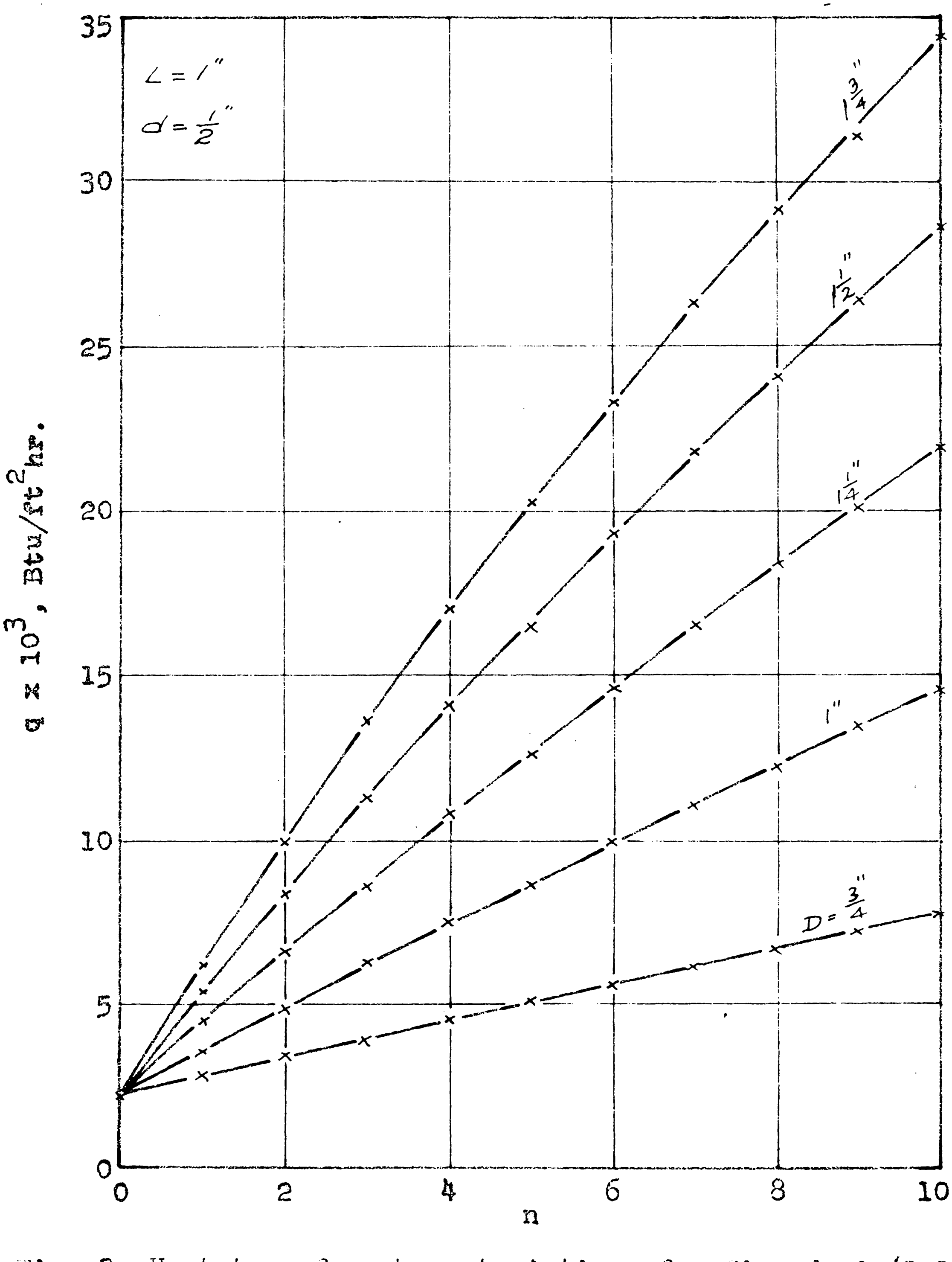



Fig. 3 Heat transfer characteristics of a finned pin(L=1")

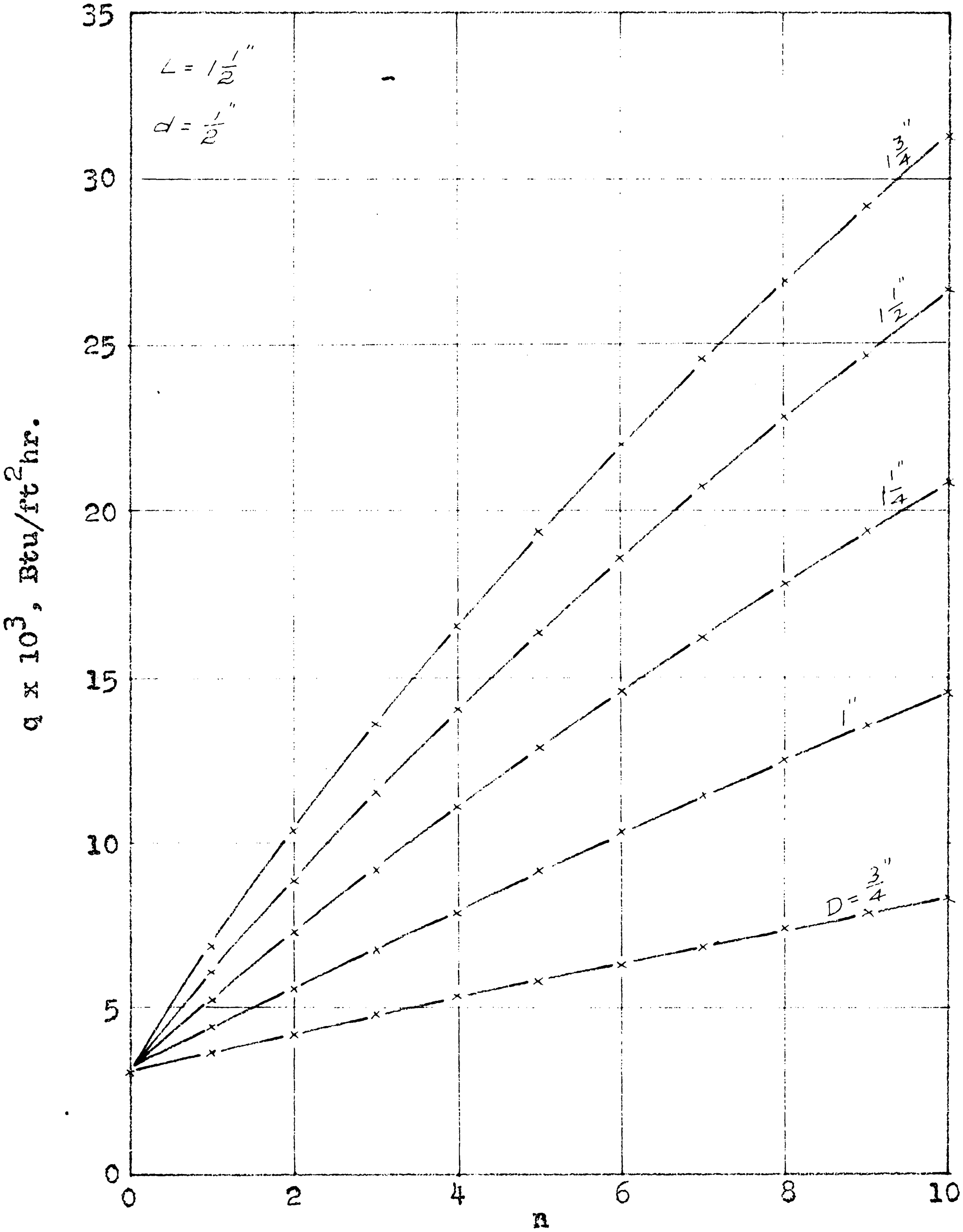



Fig. 4 Heat transfer characteristics of a finned pin(L=1½")

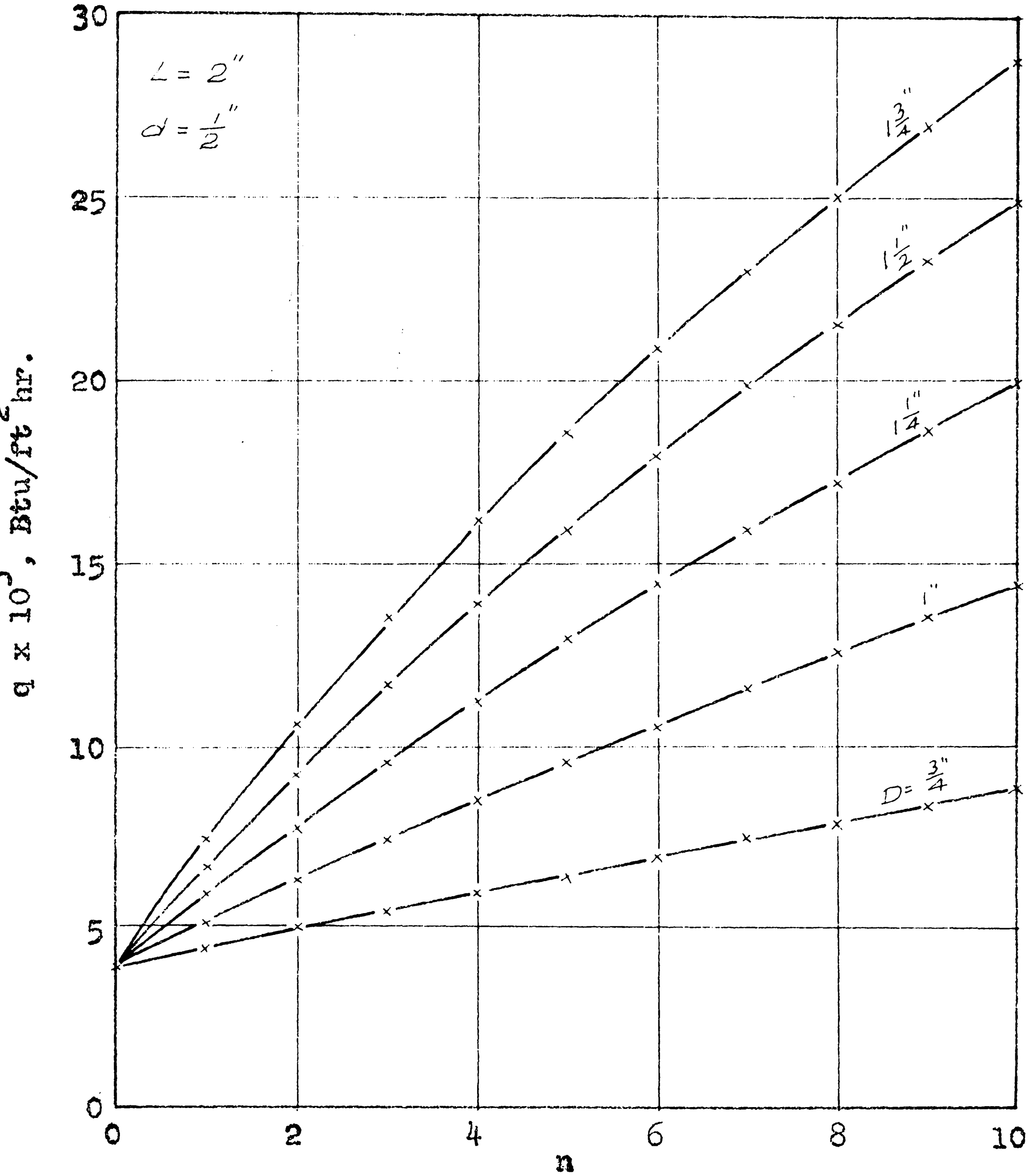



Fig. 5 Heat transfer characteristics of a finned pin(L=2")

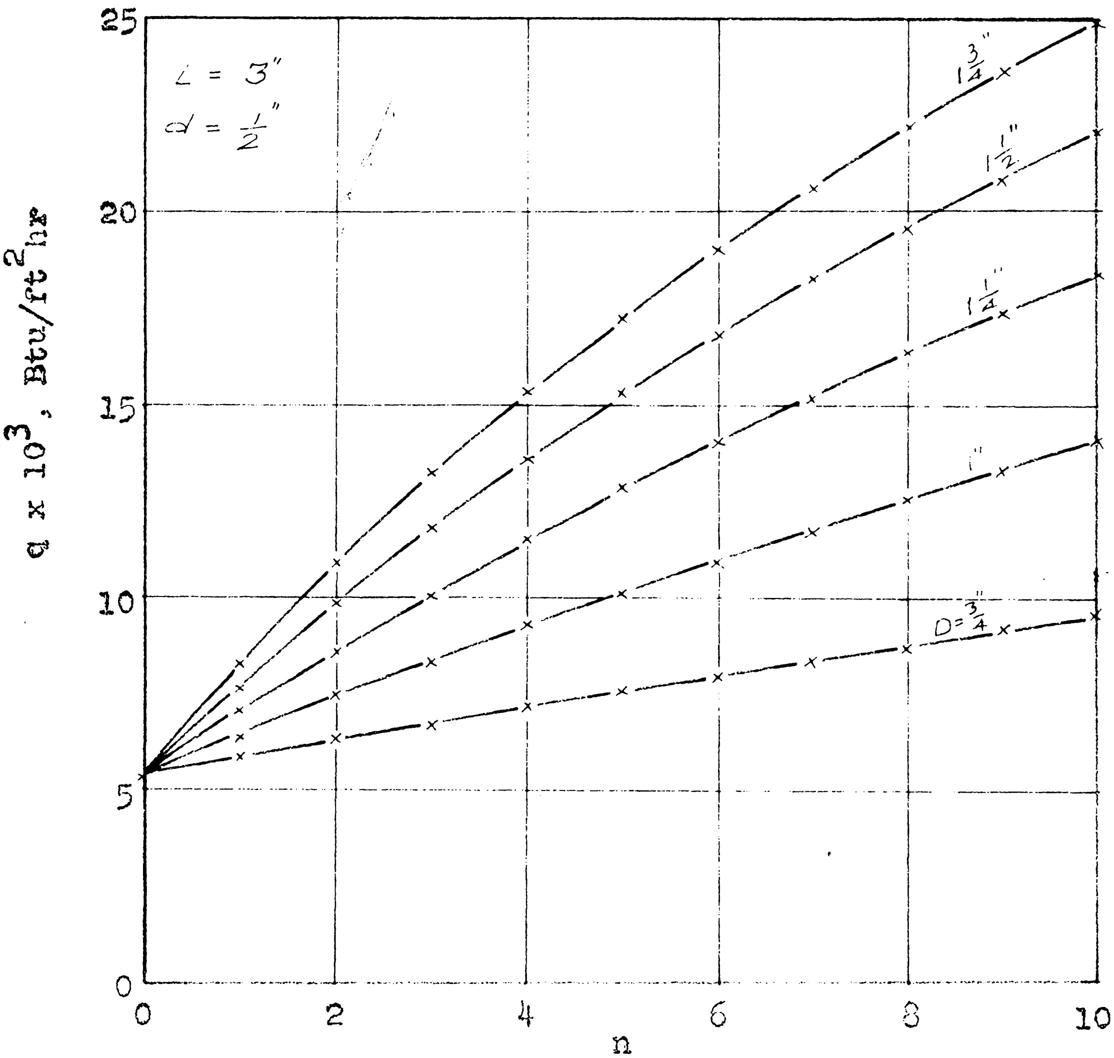



Fig. 6 Heat transfer characteristics of a finned pin(L=3")

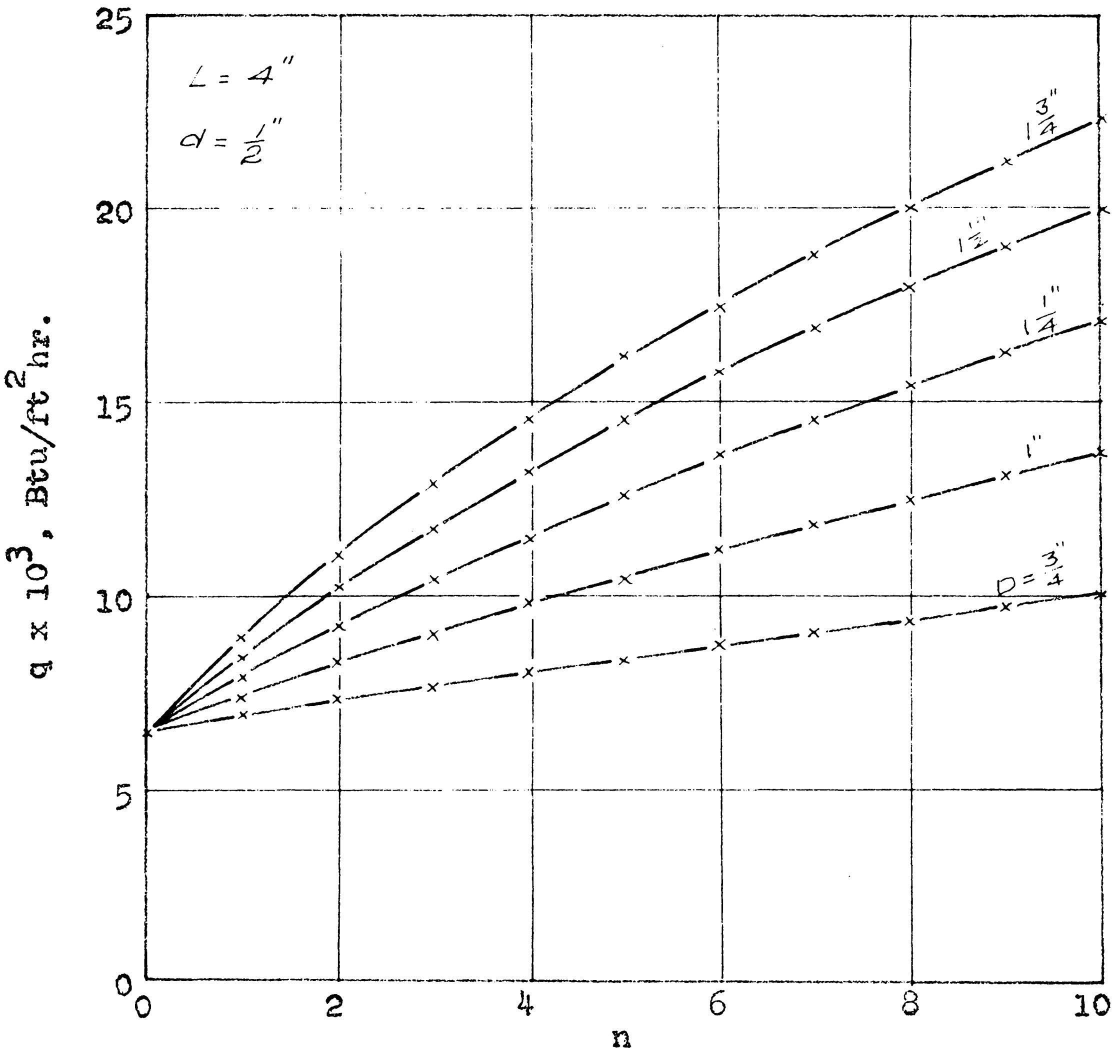



Fig. 7 Heat transfer characteristics of a finned pin(L=4")

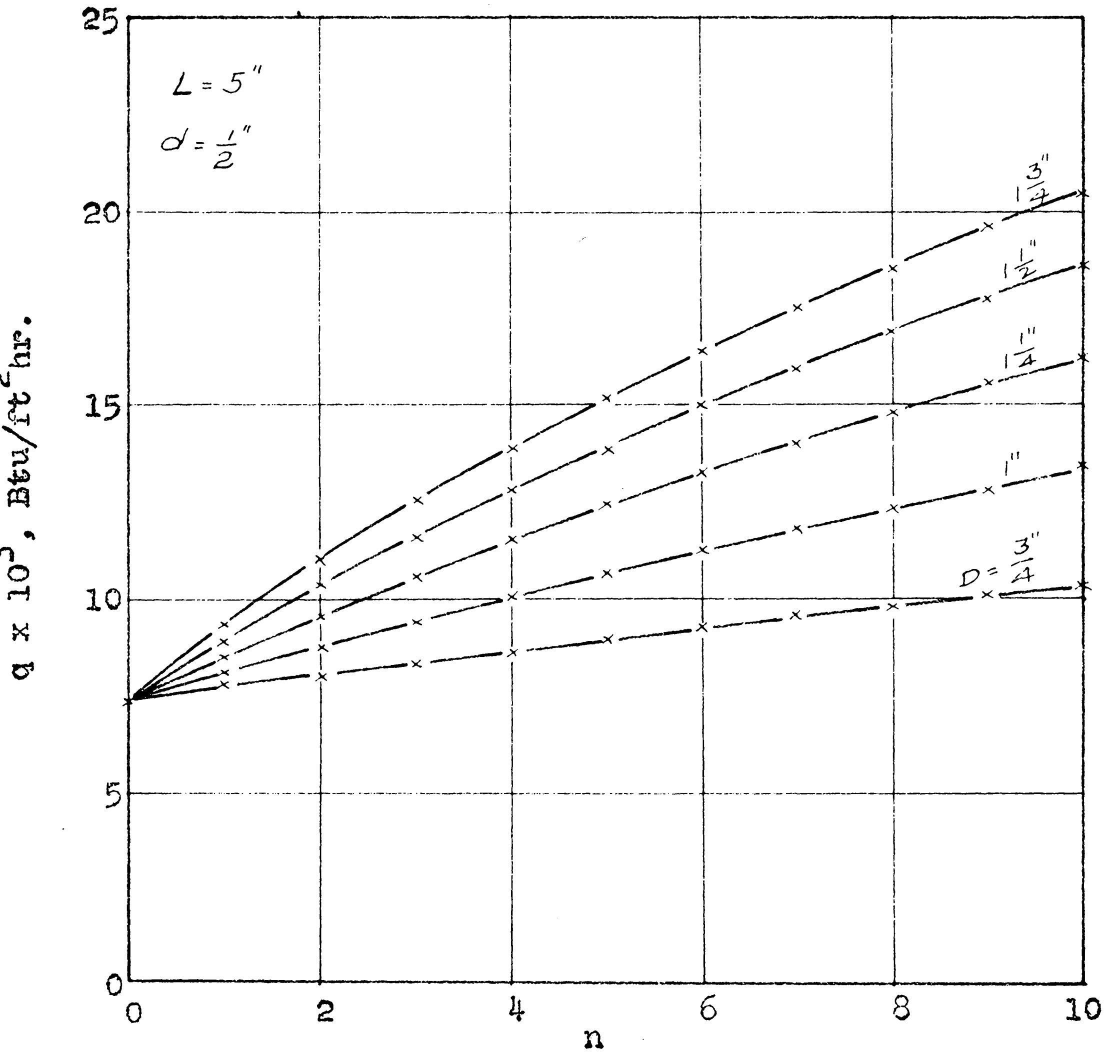



Fig. 8 Heat transfer characteristics of a finned pin(L=5")

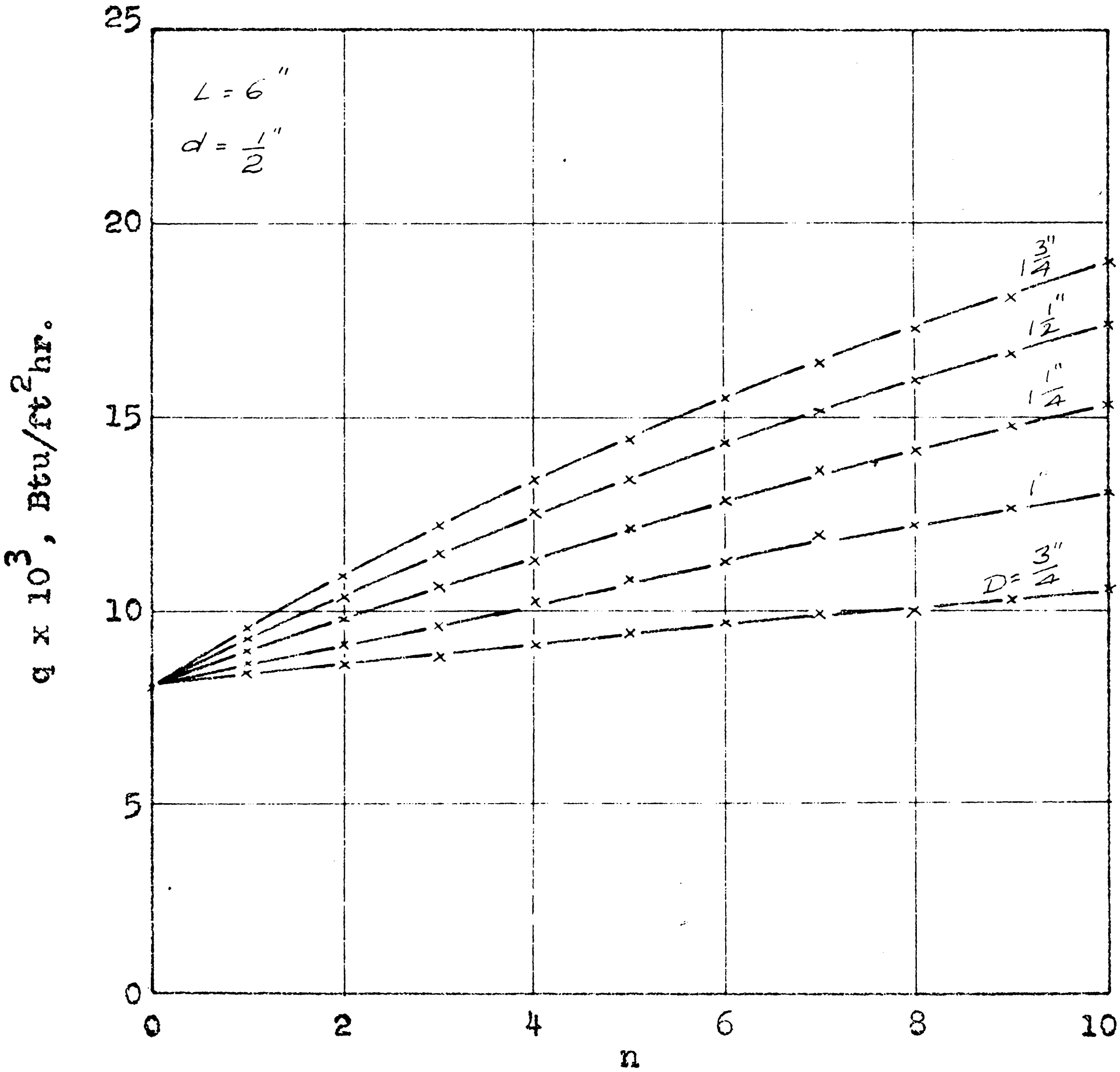



Fig. 9 Heat transfer characteristics of a finned pin(L=6")

2. Heat transfer rate increases uniformly with increase in number of fins.

3. D and n remaining same, heat transfer decreases with increase in length.

In view of the above discussion we can say that a short pin with more number of fins and as big an outside diameter as permissible would be most ideal.

When many finned pins are assembled on a surface, the outside diameter of fins is limited by the spacing of the pins. For a given length of the pin, the boundary layer thickness and the thickness of free convection control the spacing of fins.

## (4) OPTIMIZATION OF DESIGN OF FINNED PIN AND PLAIN PIN

A detailed theoretical investigation of the heat transfer characteristics of a finned pin and a plain pin led to the optimization of their design. Since it had been proven that a finned pin was the best among the extended surfaces for increasing the heat transfer rate, the next step was to optimize its design. For the purpose of comparison an8 in x 4 1/2 in. primary surface was considered most convenient because it has sufficient area and the building up of finned pins and plain pins will not be too difficult.

Design of pins

Design of heat transfer surface with pins was based on the following assumptions.

1. The temperature of air around all the pins was assumed constant.
2. All the pins were at the same root temperature.
3. The heat transfer from pin to air was by convection only.

Since the surfaces of pins and finned pins are polished, the emissivity will be low. The temperature difference for which we will design is 100 F, which is not much for considering radiation. In a compact design of pins and finned pins, most of these pins will be surrounded by pins at the same temperature and this will reduce radiation. Only effective radiation will be from those pins that are exposed to free atmosphere and such pins are much less compared to the total number of pins. We can also determine equivalent radiation convective heat transfer coefficient to check whether it is considered significant.

$$h_r = \sigma \epsilon \frac{T_2^4 - T_1^4}{T_2 - T_1} \qquad \text{(McAdams)} \qquad (3\text{-}60)$$

where,

$h_r$ = Equivalent radiation convective heat transfer coefficient (Btu/hr ft$^2$F)

$\sigma$ = Stefan - Boltzmann constant = .171 x $10^{-8}$

$\epsilon$ = Emissivity of the surface

$T_2$ = Absolute temperature of radiating surface (K)

$T_1$ = Absolute temperature of ambient air (K)

Room Temp. = 80 F = 540 K

Surface temperature of pins = 100 + 80 = 180 F = 640 K

$\epsilon$ = .04 for polished copper from Hsu (21)

$$h_r = .171\ (.04)\ \frac{\left(\frac{640}{100}\right)^4 - \left(\frac{540}{100}\right)^4}{640 - 540}$$

= .0562 which is considered negligible

For the design of pins an important consideration is to determine spacing of various size pins which will be checked for heat transfer rate. The boundary layer thickness of free convection will give some idea about the spacing but as we go in the upper rows the boundary layer will be turbulent as explained on page 11. In view of the complex nature of the conditions, it was very difficult to arrive at a value of the clearance between two successive pins. Since the diameters of the pins that were to be considered were small, an average value of 3/16 in. clearance was considered a good assumption. The total number of particular diameter pin in rows and columns were found from the geometrical considerations as shown in Figure 10.

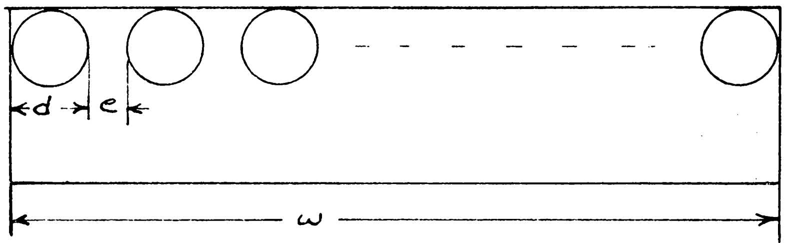



Fig. 10 An arrangement of pins in a row.

The general equation from Figure 10 can be written as:

$$w = (n-1)e + nd \qquad (3\text{-}61)$$

where,

$n$ = Number of pins

$e$ = 3/16"

The number of pins and their spacing were found for each diameter of pin. Length of the pin was judged from Figure 1. Heat transfer rate was determined by the equation (3-1) with k = 220 Btu/hr ft F (for copper) and $\theta_o$ = 100 F was considered an average value of temperature for the temperature range which will be covered while testing. The entire computation was done on the computer.

Table 1 gives the number of pins on the primary surface, length, diameter and total heat transfer rate from an 8 in x 4 1/2 in. primary surface.

Table 1. Various Designs of Plain Pin

| L (inches) | Number of pins | Dia. of pin (in.) | Q/pin (Btu/hr.) | Total Q (Btu/hr.) |
|---|---|---|---|---|
| 2 | 383 | 1/8 | 1.4171 | 538 |
| 2.5 | 246 | 3/16 | 2.4137 | 595 |
| 3 | 165 | 1/4 | 3.6 | 592 |
| 4 | 88 | 3/8 | 6.5025 | 572 |

From the four designs given above, the one with 3/16 in. diameter pin gives the maximum heat transfer rate, so this was to be tested experimentally. Further details of this design are:

Centre to center distance between consecutive pins in row = 3/8 in.

Centre to center distance between two consecutive rows = 3/8 in.

Total Q for two 8 in x 4 1/2 in surface with 3/16 in pin = 2 x 246 x 2.4137 = 1190 Btu/hr.

Figure 11 shows the assembly of pins.

Design of Finned Pins:

The assumptions in the design of finned pins are the same as those made in the design of plain pins.

In case of finned pins the assembly was not so easy as pins because to put more number of finned pins we had

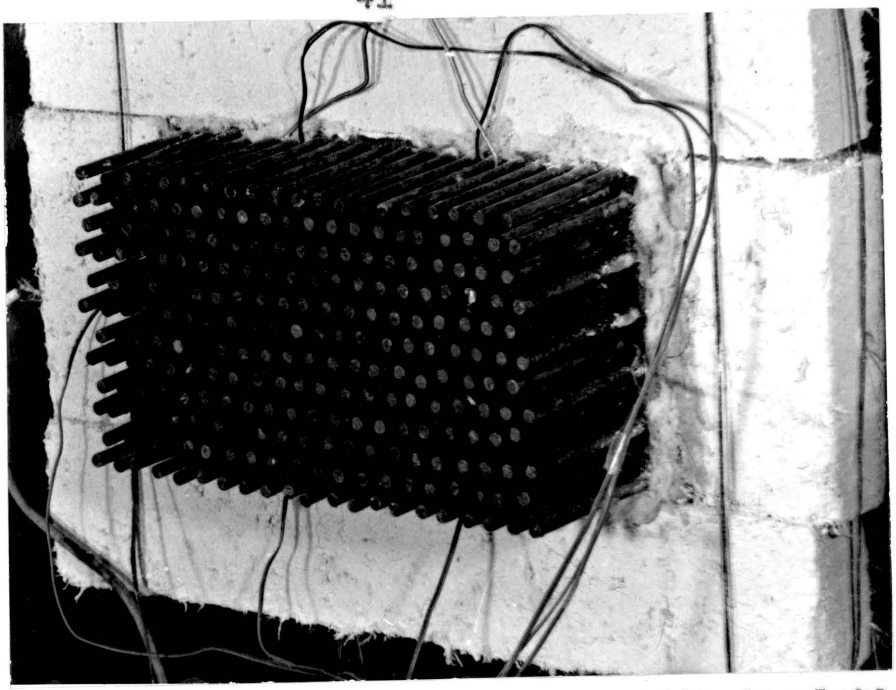


Fig. 11 Assembly of plain pins with insulation

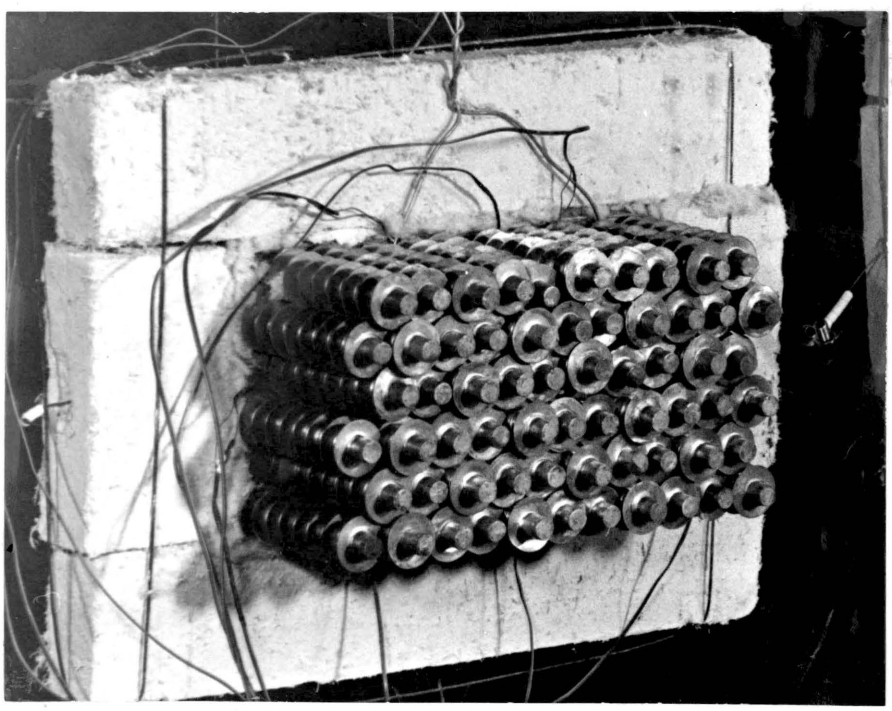


Fig. 12 Assembly of finned pin with insulation

to arrange them in such a way that they overlap on each other, leaving a clearance of 1/8 in. which was considered necessary for the free movement of air between two overlapping fins. This was done by having three different size of pins whose lengths were 1/8 in. greater than the other. From the curves on Figure 2 to 9, eight fins were considered adequate. The pitch of the fins, on the basis of a clearance of 1/8 in. was found to be 3 x 1/8 = 3/8 in. The short pin extending from the last fin was also kept 3/8 in. Figure 13 shows the details of three different types of finned pins. Total number of particular diameter pins were determined from the geometrical considerations as shown in Figure 14.

The general equation for finned pin can be written as:

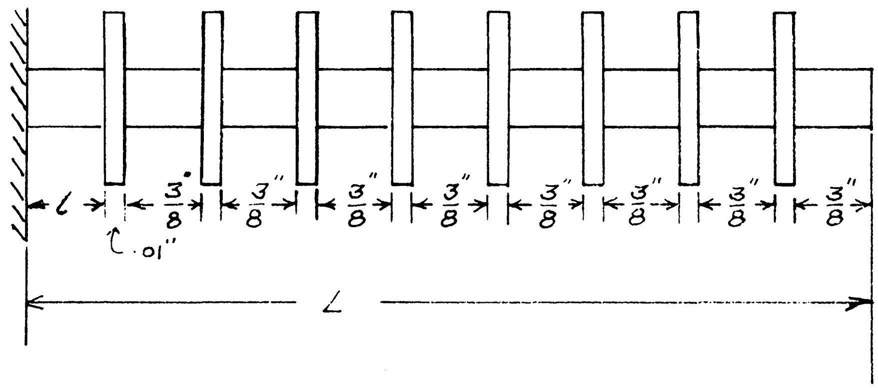
$$w = nd + (n-1)f + (n-1)e \qquad (3\text{-}62)$$

where,

$n$ = number of pins

$f = 1/8''$

The number of pins and their spacing were found for each given size of a finned pin. Heat transfer rate was determined from the equation (3-49). The Table 2 gives the description of various combinations of finned pins that were tried to maximize the heat transfer rate from an 8 in x 4 1/2 in. surface.




l = 1/8" for pin # 1

l = 1/4" for pin # 2

l = 3/8" for pin # 3

Fig. 13 Dimensions of three types of finned pin.

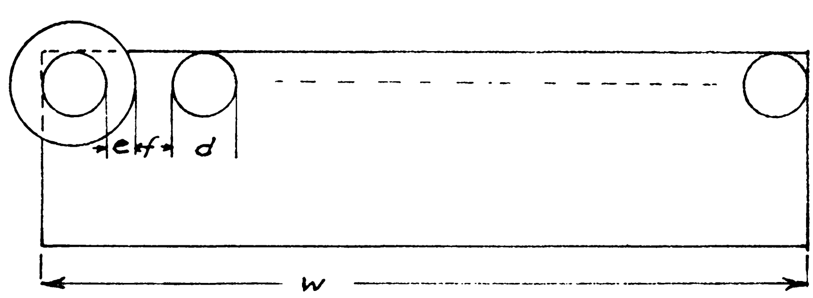



Fig. 14 An arrangement of finned pins in a row.

Table 2. Various Designs of Finned Pin

| d in. | D in. | Pin #1 No. of pins | Pin #1 Q/pin | Pin # 2 No. of pins | Pin # 2 Q/pin | Pin # 3 No. of pins | Pin # 3 Q/pin | Total Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|
| 3/16 | 7/16 | 60 | 5.584 | 55 | 5.44 | 60 | 5.44 | 960 |
| 3/16 | 11/16 | 36 | 9.335 | 36 | 9.634 | 36 | 9.634 | 1030 |
| 1/4 | 1/2 | 35 | 7.18 | 32 | 6.93 | 35 | 6.93 | 715 |
| 1/4 | 3/4 | 32 | 11.794 | 28 | 11.924 | 28 | 11.924 | 1046 |
| 3/8 | 5/8 | 32 | 10.222 | 28 | 9.786 | 28 | 9.786 | 874 |
| 3/8 | 7/8 | 21 | 16.588 | 21 | 16.474 | 21 | 16.474 | 1041 |

From the pin designs given above it is seen that the design with d = 1/4 in. and D = 3/4 in. gives the maximum heat transfer rate, but the design with d = 3/8 in and D = 7/8 in gives 5 Btu/hr less, which is small compared to 1041 Btu/hr. Since it would be much easier to make a primary surface with a lesser number of finned pins, the latter design was tested experimentally. Further details of the design are:

Center to center distance between consecutive pins in row = 3/4 in.

Center to center distance between two consecutive rows = 3/4 in.

Total Q for two 8 in x 4 1/2 in surface with d = 3/8 in and D = 7/8 in finned pin = 2 x 1041 = 2082 Btu/hr.

Figure 12 shows the details of finned pin assembly.

Design of Surface Without Pins and Finned Pins:

Heat transfer from a plate was considered a basis for comparing pins and finned pins.

For low temperature and moderate size McAdams (23) gives:

$$h_c = .29\ (\Delta T/L)^{.25}$$

where,

$h$ = Average convective heat transfer coefficient (Btu/hr ft$^2$F)

$\Delta T$ = Difference in temperature between the plate and air (F) = 100 °F

$L$ = Length of the plate (ft) = 4.5/12

$$h = .29\ (100/\tfrac{4.5}{12})^{.25}$$

$$= .29\ (1200/4.5)^{.25}$$

$$= 1.176$$

$$Q = h\ \theta_o A$$

$$= 1.176 \times 100\ \left(\frac{8 \times 4.5}{144}\right)$$

$$= 29.5 \text{ Btu/hr}$$

## (5) SAMPLE CALCULATION OF HEAT TRANSFER

### 1. Finned Pin

Given data:

$k$ = 220 Btu/hr ft F

$d$ = 3/8" = 1/32'

$b$ = 1/100" = 1/1200'

$$D = 7/8''$$

$$\theta_o = 100\ {}^oF$$

$$n = 8$$

$$s = 3/8''$$

Now,

$$h = .27 \left(\frac{\Delta T}{d}\right)^{.25}$$

$$= .27 \left(\frac{100}{1/32}\right)^{.25}$$

$$= 2.032$$

$$m = \sqrt{\frac{4h}{kd}} = \sqrt{\frac{4(2.032)}{220\ (1/32)}}$$

$$= 1.088$$

$$S = ms$$

$$= 1.088(1/32) = 0.034$$

$$H_1 = \frac{h}{mk} = \frac{2.032}{(1.088)\ 220}$$

$$= 0.0085$$

$$T = \text{Tanh } S = \tanh\ (0.034)$$

$$= 0.034$$

$$B_1 = \frac{T + H_1}{1 + TH_1}$$

$$= \frac{0.034 + 0.0085}{1 + 0.034(0.0085)} = 0.0425$$

$$N = \sqrt{\frac{2h}{kb}} = \sqrt{\frac{2(2.032)}{220\ (1/1200)}} = 4.71$$

$$Nr_1 = \frac{4.71}{64} = 0.0736$$

$$Nr_2 = \frac{4.71(7)}{(192)} = 0.172$$

$$B_2 = \pi kNbd \; \frac{K_1(Nr_1)I_1(Nr_2) - I_1(Nr_1)K_1(Nr_2)}{K_0(Nr_1)I_1(Nr_2) + I_0(Nr_1)K_1(Nr_2)}$$

$$= 3.14(220)(4.71)(1/1200)(1/32)$$

$$\frac{12.864(0.0914) - (0.038)\,5.282}{2.685\,(0.0914) + (1.0015)5.282} = 0.0158$$

$$h_1 = \frac{B_2}{\pi db} = \frac{0.0158}{3.14(1/32)(1/1200)}$$

$$= 193.4$$

$$m_1 = \sqrt{\frac{4h_1}{kd}} = \sqrt{\frac{4(193.4)}{220(1/32)}}$$

$$= 10.62$$

$$H_2 = \frac{m}{m_1} B_1 = \frac{1.088}{10.62} \; 0.0425$$

$$= 0.0044$$

$$H = m_1 b = \frac{10.62}{1200} = 0.00885$$

$$T_1 = \text{Tanh}H = 0.00885$$

$$B_4 = \frac{T_1 + H_2}{1 + T_1 H_2} = \frac{0.00885 + 0.0425}{1 + (0.00885)0.0425}$$

$$= 0.0132$$

$$H_3 = \frac{m_1}{m} \; B_4$$

$$= \frac{10.62(0.0132)}{1.088} = 0.1288$$

$$B_6 = \frac{T + H_3}{1 + TH_3}$$

$$= \frac{0.034 + 0.1288}{1 + 0.034(0.1288)} = 0.162$$

$$H_4 = \frac{m}{m_i} B_6 = \frac{1.088(0.162)}{10.62}$$

$$= 0.0166$$

$$B_8 = \frac{T_i + H_4}{1 + T_i H_4} = \frac{0.00885 + 0.0166}{1 + 0.00885(0.0166)}$$

$$= 0.0255$$

$$H_5 = \frac{m_i}{m} B_8$$

$$= \frac{10.62(0.0255)}{1.088} = 0.2483$$

$$B_{10} = \frac{T + H_5}{1 + TH_5} = \frac{0.034 + 0.2483}{1 + (0.034)0.2483} = 0.2799$$

$$H_6 = \frac{m}{m_i} B_{10}$$

$$= \frac{1.088(0.2799)}{10.62} = 0.0287$$

$$B_{12} = \frac{T_i + H_6}{1 \quad T_i H_6}$$

$$= \frac{0.00885 + 0.0287}{1 + 0.00885(0.0287)} = 0.0375$$

$$H_7 = \frac{m_i}{m} B_{12}$$

$$= \frac{10.62\ (0.0375)}{1.088} = 0.3661$$

$$B_{14} = \frac{T + H_7}{1 + TH_7}$$

$$= \frac{0.034 + 0.3661}{1 + 0.034\ (0.3661)} = 0.3952$$

$$H_8 = \frac{m}{m_1} B_{14}$$

$$= \frac{1.088(0.3952)}{10.62} = 0.0405$$

$$B_{16} = \frac{T_1 + H_8}{1 + T_1 H_8}$$

$$= \frac{0.00885 + 0.0405}{1 + 0.00885(0.0405)} = 0.0493$$

$$H_9 = \frac{m_1}{m} B_{16}$$

$$= \frac{10.62(0.0493)}{1.088} = 0.4813$$

$$B_{18} = \frac{T + H_9}{1 + TH_9}$$

$$= \frac{0.034 + 0.4813}{1 + 0.034(0.4813)} = 0.507$$

$$H_{10} = \frac{m}{m_1} B_{18}$$

$$= \frac{1.088(0.507)}{10.62} = 0.052$$

$$B_{20} = \frac{T_1 + H_{10}}{1 + T_1 H_{10}}$$

$$= \frac{0.00885 + 0.052}{1 + 0.00885\ (0.052)} = 0.0608$$

$$H_{11} = \frac{m_1}{m} B_{20}$$

$$= \frac{10.62\ (0.0608)}{1.088} = 0.5931$$

$$B_{22} = \frac{T + H_{11}}{1 + TH_{11}}$$

$$= \frac{0.034 + 0.5931}{1 + (0.034)\ 0.5931} = 0.6147$$

$$H_{12} = \frac{m}{m_1} B_{22}$$

$$= \frac{1.088\ (0.6147)}{10.62} = 0.063$$

$$B_{24} = \frac{T_1 + H_{12}}{1 + T_1 H_{12}}$$

$$= \frac{0.00885 + 0.063}{1 + 0.00885\ (0.063)} = 0.0718$$

$$H_{13} = \frac{m_1}{m} B_{24}$$

$$= \frac{10.62\ (0.0718)}{1.088} = 0.7006$$

$$B_{26} = \frac{T + H_{13}}{1 + TH_{13}}$$

$$= \frac{0.034 + 0.7006}{1 + 0.034\ (0.7006)} = 0.7175$$

$$H_{14} = \frac{m}{m_1} B_{26}$$

$$= \frac{1.088\ (0.7175)}{10.62} = 0.0735$$

$$B_{28} = \frac{T_1 + H_{14}}{1 + T_1 H_{14}}$$

$$= \frac{0.00885 + 0.0735}{1 + 0.00885\ (0.0735)} = 0.0823$$

$$H_{15} = \frac{m_1}{m} B_{28}$$

$$= \frac{10.62\ (0.0823)}{1.088} = 0.8033$$

$$B_{30} = \frac{T + H_{15}}{1 + TH_{15}}$$

$$= \frac{0.034 + 0.8033}{1 + 0.034\ (0.8033)} = 0.815$$

$$H_{16} = \frac{m}{m_1} B_{30}$$

$$= \frac{1.088\ (0.815)}{10.62} = 0.0835$$

$$B_{32} = \frac{T_1 + H_{16}}{1 \quad T_1 H_{16}}$$

$$= \frac{0.00885 + 0.0835}{1 + 0.00885\ (0.0835)} = 0.0923$$

$$H_{17} = \frac{m_1}{m} B_{32}$$

$$= \frac{10.62\ (0.0923)}{1.088} = 0.9006$$

$$B_{34} = \frac{T + H_{17}}{1 + TH_{17}}$$

$$= \frac{0.034 + 0.9006}{1 + 0.034\ (0.9006)} = 0.9069$$

$$Q = kAm\theta_o B_{34}$$

$$= 220\left(\frac{\pi}{4}\right)\left(\frac{1}{32}\right)^2 (100)\ (0.9069)$$

$$= 16.588 \text{ Btu/hr}$$

2. Plain Pin

Given data:

$\Delta T = 56.2$ F

$k = 220$ Btu/hr ft F

$L = 2.5$ in.

$d = 3/16"$

$$h = .27\left(\frac{\Delta T}{d}\right)^{.25}$$

$$= .27\left(\frac{56.2}{3/192}\right)^{.25} = 2.091$$

$$m = \sqrt{\frac{4h}{kd}} = \sqrt{\frac{4(2.091)}{220\ (3/192)}}$$

$$= 1.56$$

$$g = mL = 1.56\ (5/24)$$

$$= 0.325$$

$$T = \tanh 0.325 = 0.314$$

$$H = \frac{h}{mk} = \frac{2.091}{1.56(220)} = .0061$$

$$A = 0.785d^2$$

$$Q = kAm\theta_o \frac{T + H}{1 + TH}$$

$$= 220(0.785)(3/192)^2(1.56)(124.2) \frac{0.314 + 0.0061}{1 + 0.314(0.0061)}$$

$$= 1.1808 \text{ Btu/hr}$$

# IV. EXPERIMENTAL INVESTIGATIONS

## (1) OBJECTIVE OF INVESTIGATION

From the theoretical considerations of the preceding paragraphs it is evident that the rate of heat transfer is greater for the finned pin than for a pin. The objective of the investigation is to verify the principle experimentally.

## (2) CONSTRUCTION OF APPARATUS

### Heater

A separate heater was made for finned pins, pins and plates. The heaters were designed to give a uniform heating of the primary surface. Nichrome wire was wrapped around an asbestos sheet as shown in Figure 15.

### Plates, Pins and Finned Pins

The construction of plates and pinned surfaces was quite simple, but the finned pin surface was difficult to make. Some of the important considerations in the construction of the finned pin surfaces were:

1. The fins should fit tightly on the pin and the assembly of finned pins must be dipped in solder to ensure a metal to metal contact at the junction of a pin and a fin.
2. A higher percentage of tin in the solder will give a good finish to the finned pin surface.

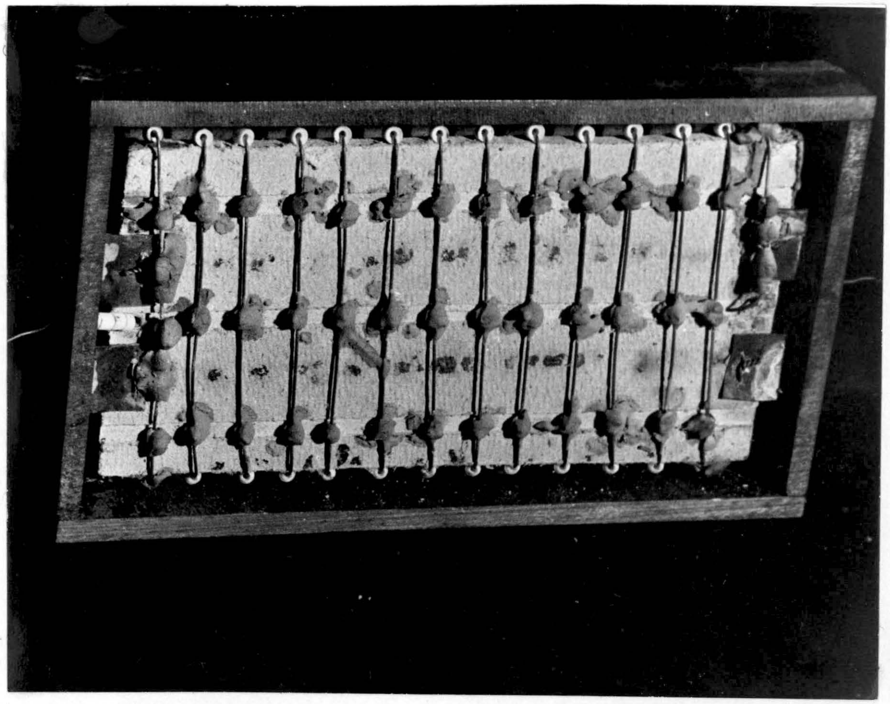


Fig. 15 Electric heater used for heating the front plates

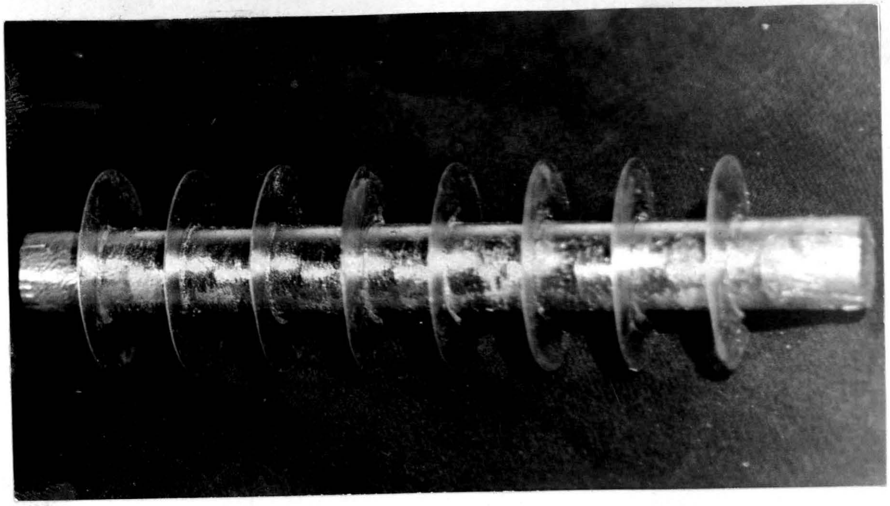


Fig. 16 Finished assembly of finned pin

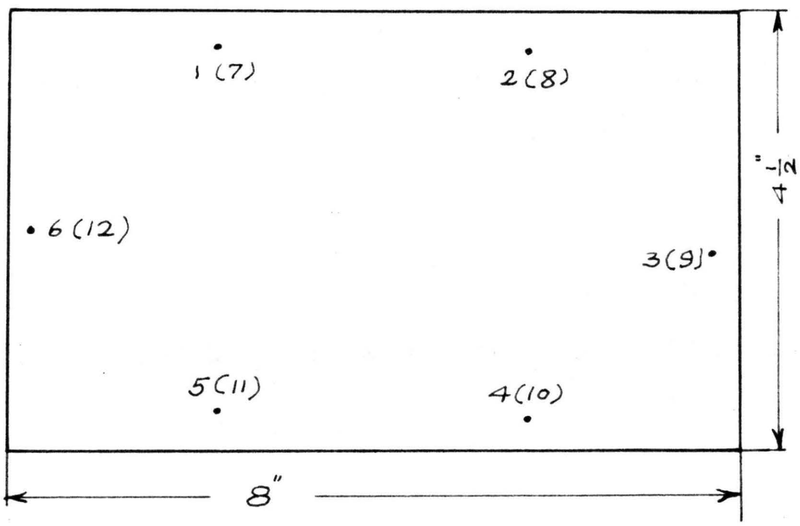



Fig. 17 An arrangement and numbering of the thermocouples. (Figures in parentheses indicate thermocouples on the other side of the plate.)

A minimum of 60 per cent tin and 40 per cent lead was considered permissible.

Figure 16 shows the finished assembly of a finned pin.

The thermocouples were located as shown in Figure 17 for all the three arrangements to get a good average root or plate temperature. Since the temperature of the thermocouples was to go as high as 400 F, they were brazed on pins and plates.

(3) LIST OF MATERIAL

The following materials were used in the experiment:

Copper Materials:

16, 3/16 in dia. x 12 ft long rods for plain pins

4, 3/8 in dia. x 12 ft long for making pins for finned pins

.01 in x 12 ft x 14 ft coil was used to make fins

20 in x 20 in x 1/4 in plate was used for front plates and side plates of heater box.

Insulation:

Porcelin insulator beads

1/8 in thick asbestos sheet for winding the heater wire

2 1/2 in thick insulation for sides of the heater box.

Thermocouple Wire:

Matched 30 gauge copper-constantan wire with plastic insulation was used.

Solder:

Solder containing 60 per cent tin and 40 per cent lead was used.

Heater:

Nichrome wire with .652 $\Omega$/ft resistance was used

(4) LIST OF APPARATUS

The following apparatus was used in this investigation:

Ammeters:

Weston type, Range 0-5 amps. 25-500 c/s, manufactured by Daystrom, Inc., Weston Instrument Division, Newark, New Jersey.

Weston type, 0-3 amp., 25-500 c/s, manufactured by Daystrom, Inc.

Potentiometer:

Number 2745, Range 0-75 mV, portable type, manufactured by Minneapolis-Honeywell Reg. Co., Rubicon Instruments, Philadelphia 32, Pennsylvania.

Voltmeter:

Model 912, Weston type, Range 0-300 V.

Variac:

Type W20MT3, one side common to line and load, line

120 V, 50-60 c/s, load 0-140 V, 20 amps. Manufactured by General Radio Company, Concord, Mass.

(5) EXPERIMENTAL OPERATION

Three different heat transfer surfaces, viz. plate, pins and finned pins, as shown in Figure 18, Figure 11 and Figure 12 respectively, were to be tested. The experimental procedure adopted for each one of them was the same. Since these surfaces were to be tested for free convection, the testing was done in a small, closed room so that there would not be any air currents. To enhance free convection, the assembly was hung by a thin wire. Figure 19 shows the heater circuit and Figure 20 shows a complete set-up of the experiment.

The heater supplied heat at a uniform rate. From time to time the thermocouple readings were checked and when the readings remained constant for at least fifteen minutes, it was considered that the steady state was reached. Then the readings were noted as tabulated in the Appendix B.

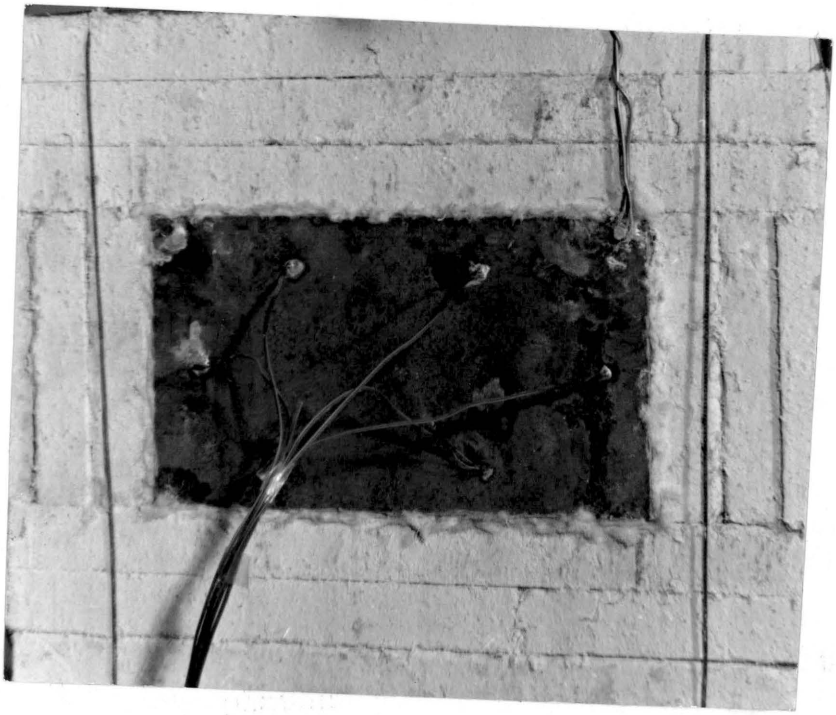


Fig. 18 Assembly of primary surface with six thermocouples on either side

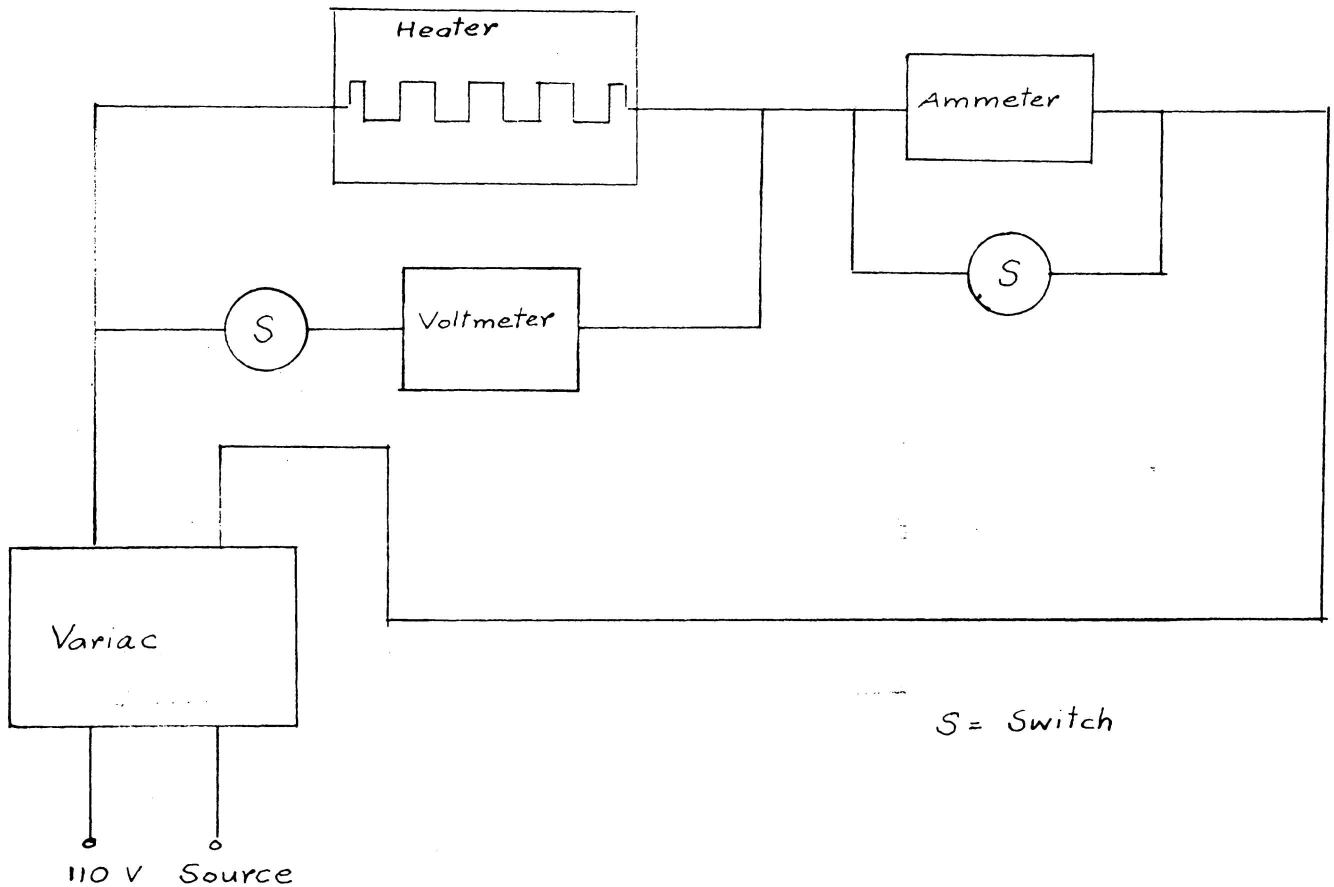



Fig. 19 Sketch of Heater Circuit

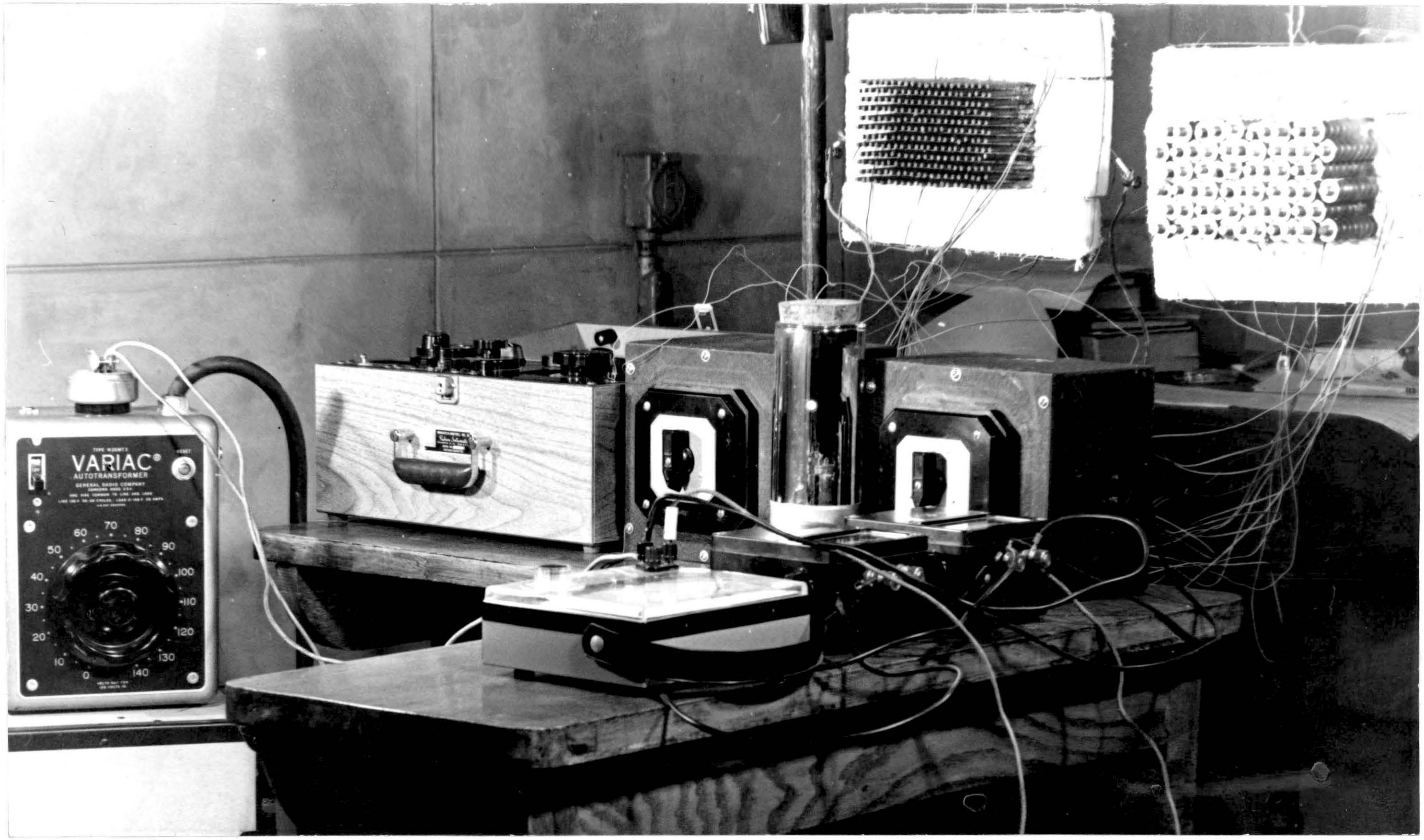



Fig. 20 Experimental set up for the heat transfer measurements of finned pin, pin and plate

# DATA AND RESULTS

Notations:

W = Rate of electric energy supply to the heater in Watts

Q = Rate of electric energy supply to the heater in Btu/hr.

$v_1, v_2, \ldots v_{12}$ = Potentiometer reading of the thermocouples 1, 2,...12. (Millivolts)

$v_m$ = Mean potentiometer reading of all the twelve thermocouples

$t_o$ = Temperature at root of the pin or plate as the case may be (F)

$t_a$ = Ambient temperature of air (F)

$\theta_o$ = Temperature excess at the root of the pin or plate = $t_o - t_a$

V = Voltage across the heater (Volts)

I = Current passing through the heater wire (Amps.)

Four sets of data were taken for various $\theta_o$ for the finned pin, pin and plate. The data for all the three arrangements are given in a tabular form in the Appendix B. Table B-1, B-2, B-3 and B-4 represent the experimental measurements of the heat transfer rates for various $\theta_o$ for finned pins. Table B-5, B-6, B-7 and B-8 represent the experimental measurements of heat transfer rate for various $\theta_o$ for pins. Table B-9, B-10, B-11 and B-12 represent the experimental measurements of heat transfer rate for various $\theta_o$ for plate.

# V. DISCUSSION

## EXPERIMENTAL ACCURACY

The data obtained from three different arrangements showed variation in temperature at the root of the pin, from one row to the next. The temperature of the upper bank of pins was slightly higher than those in the lower banks. This difference in temperature went on increasing as $\theta_0$ was increased. The temperature variation between top and bottom bank of pins was 40 F. when the average root temperature was maximum at 364 F. The nature of variation was the same, both in the case of pin and finned pin. As the hot air from the lower banks of pins moved upwards it became hotter and hotter and was hottest when it moved past the top row, which resulted in the large variation in temperature. An average root temperature of all the twelve thermocouples was considered acceptable.

The room temperature varied from 70 to 85 F during the entire testing of plate, pins and finned pins. Since we were only concerned with the temperature excess at the root of the pin, $\theta_0$, the variation did not introduce any error.

Determination of Average h and Difference Between the Temperature at the Root of the Pin and the Average Bulk Temperature.

The temperature at the immediate vicinity of a pin or a finned pin is higher than the room temperature because of the compact arrangement. In order to determine this temperature for given Q and $\theta_o$, let us first analyze the equations for a pin and a finned pin. The equations show that both the variables $\Delta T$ and h affect the heat transfer rate. So a trial and error method can be used to determine the value of $\Delta T$ at the condition that an experimental value of Q is equal to the calculated value of Q. From the value of $\Delta T$, an average value of h can be calculated from the equation (3-3). The trial and error for computing $\Delta T$ was done on the computer using equations for pin and finned pin for $\theta_o$ = 100 F and for corresponding values of Q for pin and finned pin obtained from Figure 24. The results are as follows:

(i) For Pins

Given data: $\theta_o$ = 100 F

Average value of h = 2.091 Btu/ft$^2$hrF

$\Delta T$ = 56.2 F

(ii) For Finned Pins

Given data: $\theta_o$ = 100 F

Average value of h = 1.648 $Btu/ft^2hrF$

$\Delta T = 43.04$ F

The results show that h was higher in case of pin than finned pin. One of the reasons would be that there was more resistance to air flow for finned pin than pins.

Comparison of Heat Transfer Rate of Finned Pin, Pin and Plate.

The curves drawn in Figures 21, 22 and 23 show the heat transfer rate vs. $\theta_o$ for finned pin, pin and plate respectively. These curves indicate that the experimental results were within $\pm 4$ per cent of the average curve. Figure 24 shows the grouping of the curves drawn in Figures 21, 22 and 23 for the purpose of comparing their heat transfer rate for various $\theta_o$. Curves in Figure 24 show that the heat transfer rate is highest for finned pins, little less for plain pins and much more less for a plate. The heat transfer rate increases rapidly for lower values of $\theta_o$ but it almost follows a straight line for the higher values of $\theta_o$.

Effectiveness

The effectiveness for various arrangements is calculated for $\theta_o$ from Figure 24. The procedure for the calculation of the per cent increase in the effectiveness is as follows:

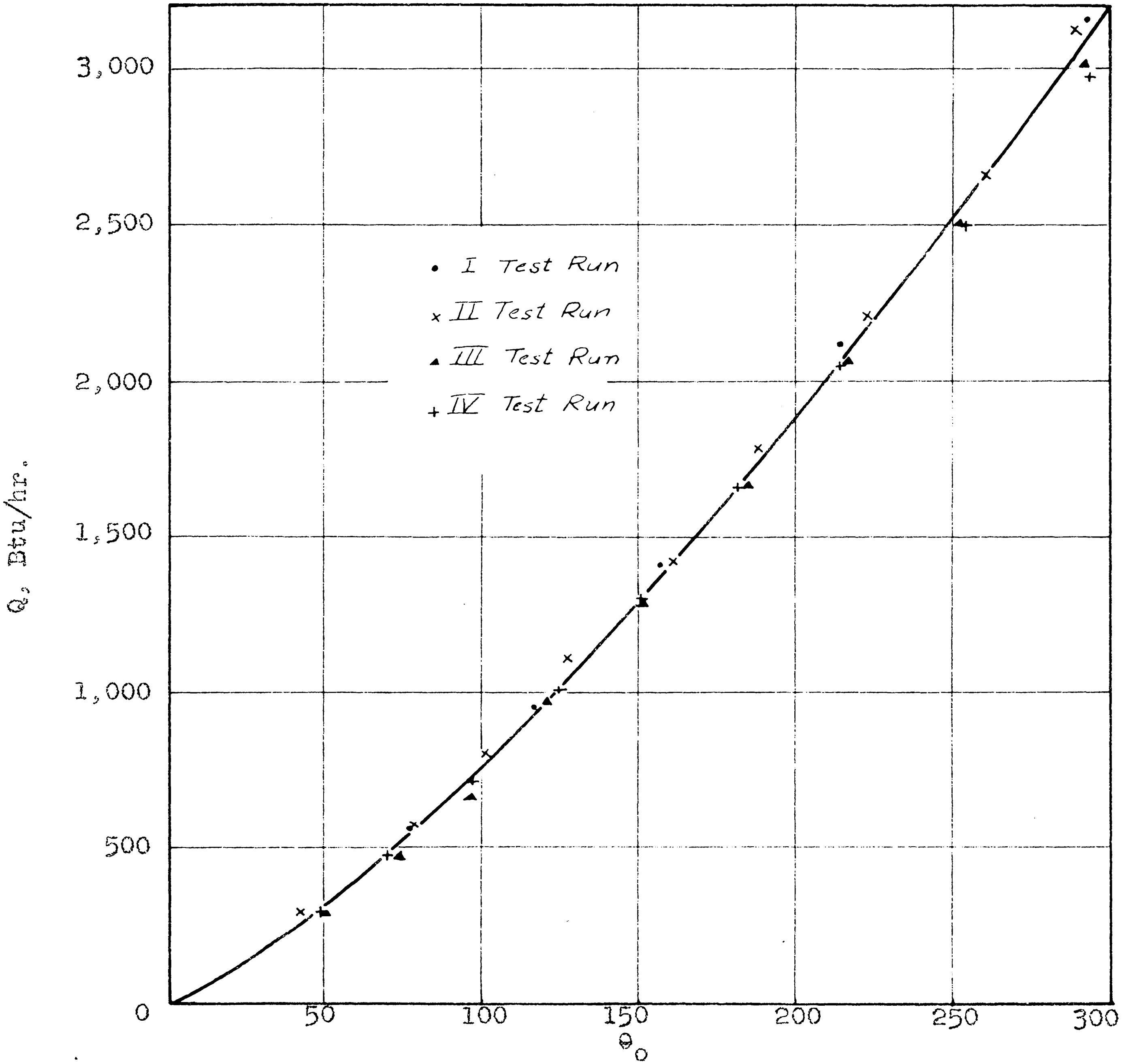



Fig. 21 Experimental measurements of heat transfer rate for finned pins

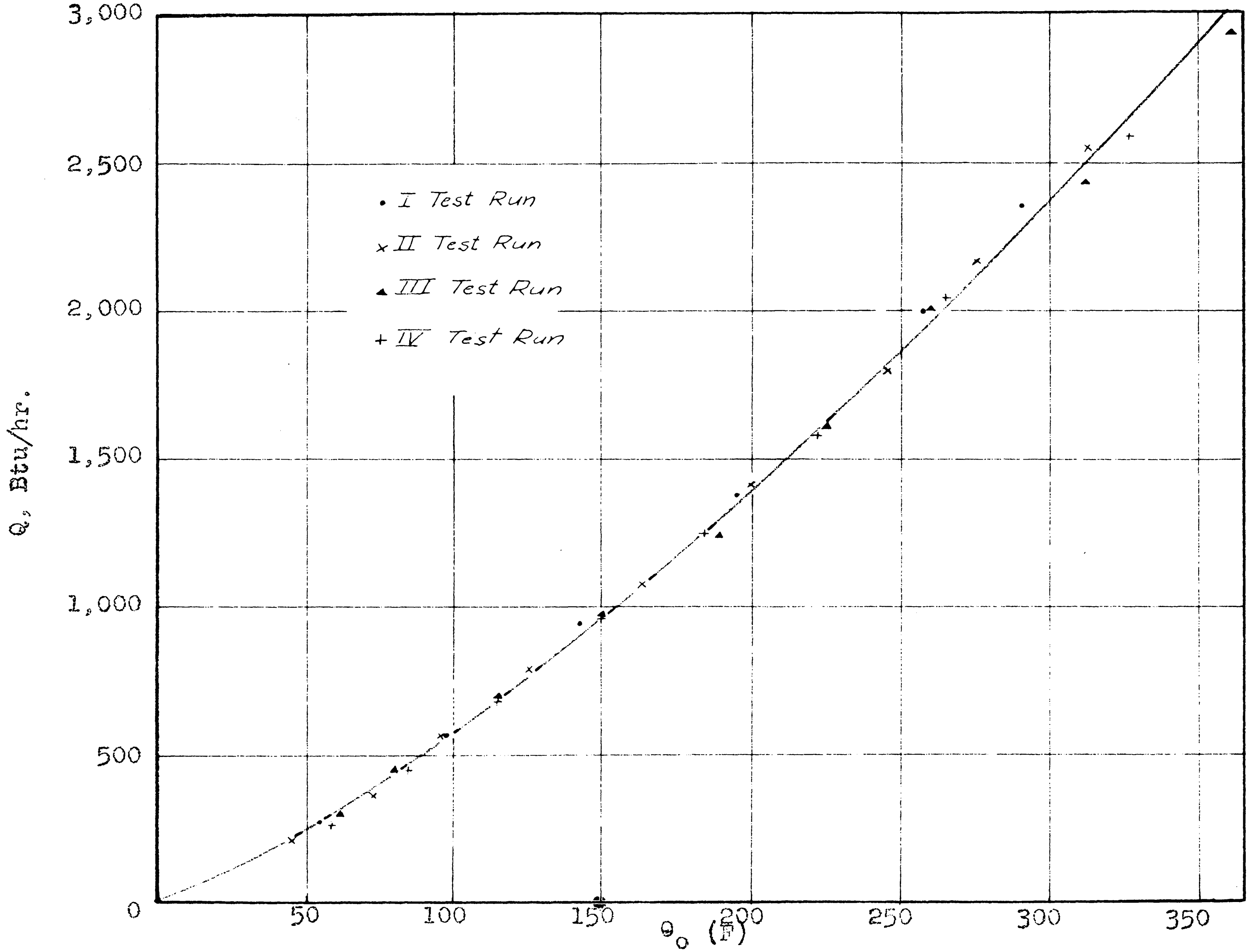



Fig. 22 Experimental measurements of heat transfer rate for pins

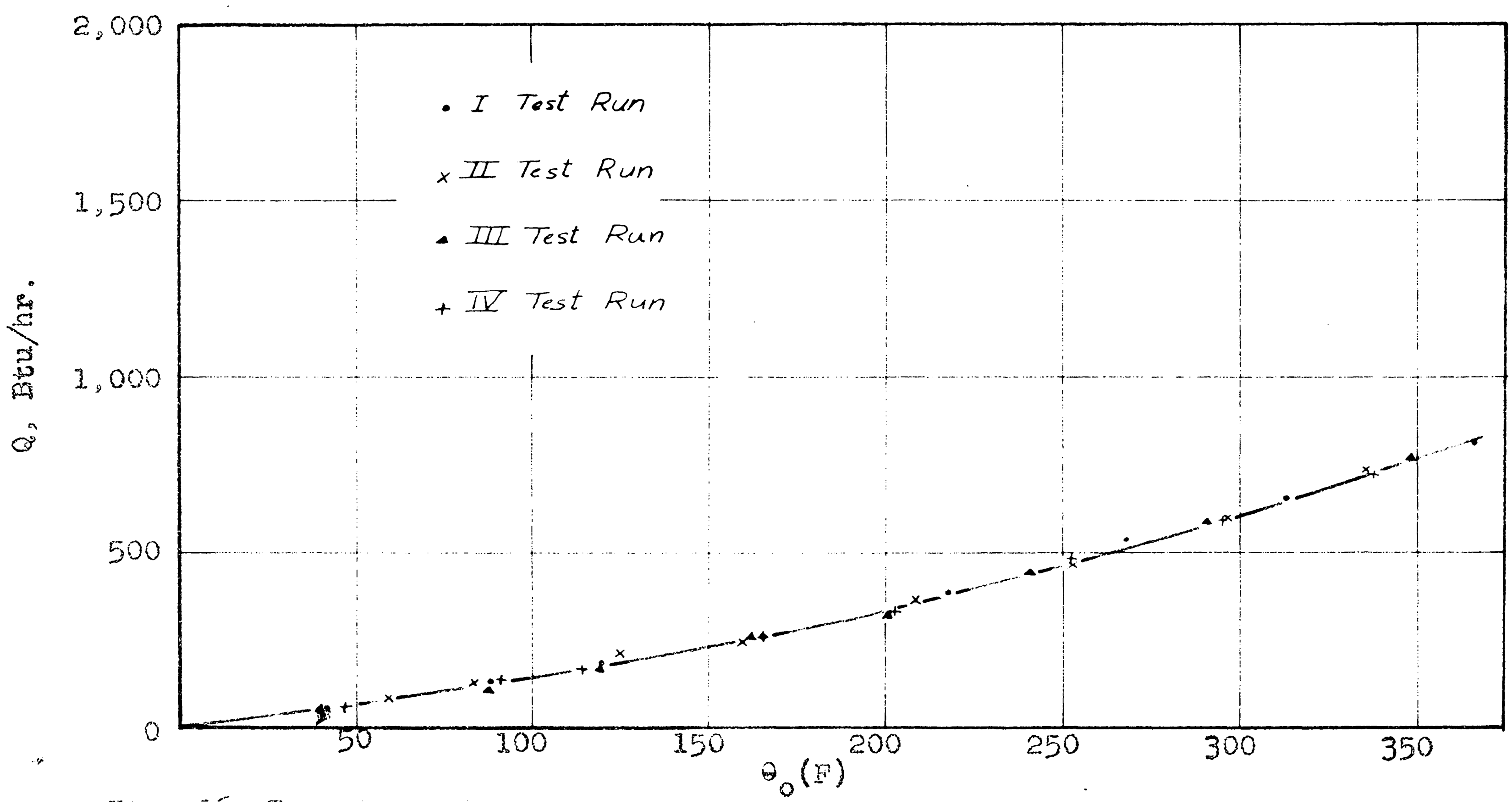



Fig. 23 Experimental measurements of heat transfer rate for a plate

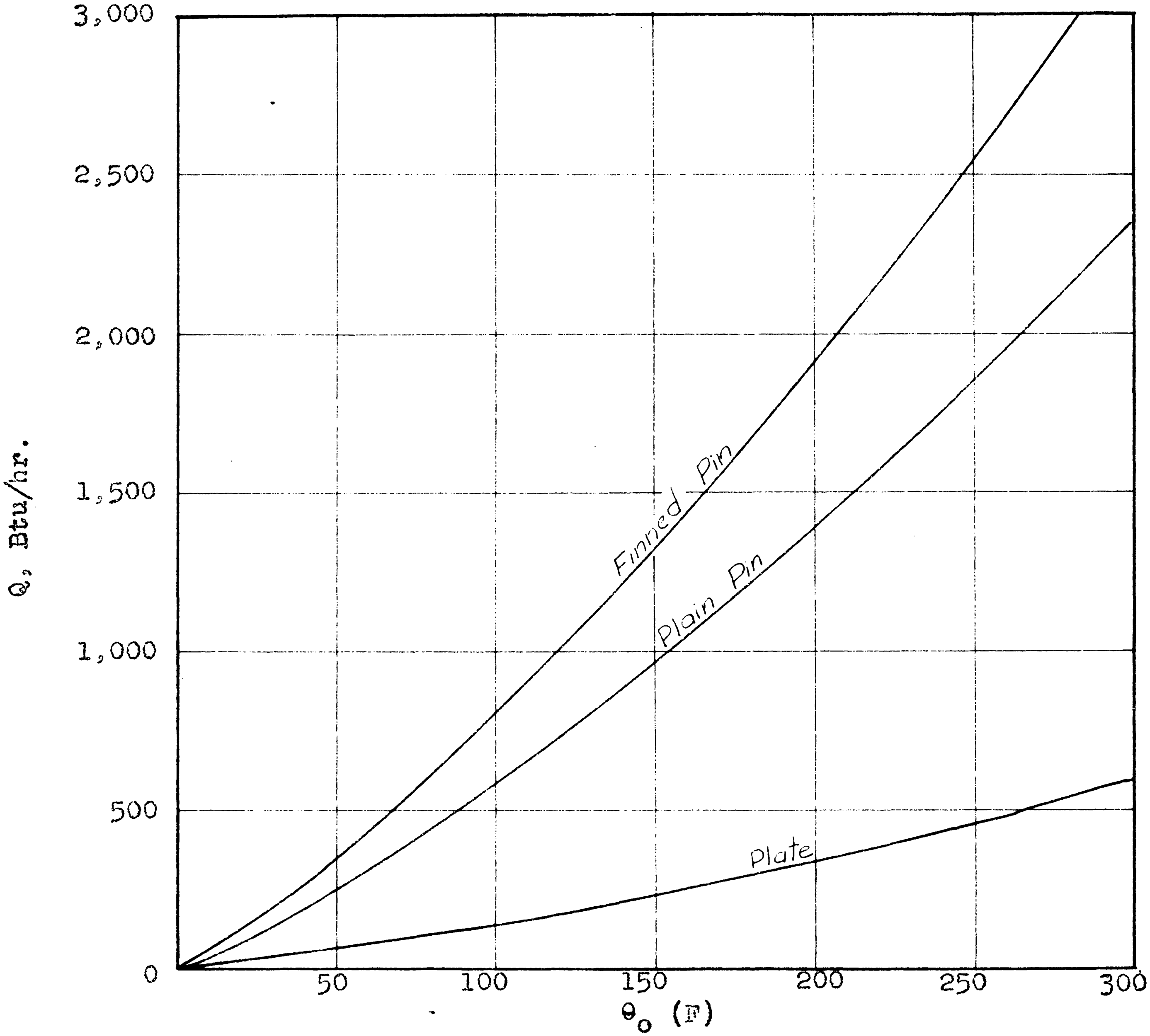



Fig. 24 Comparison of experimental measurements of heat transfer rate for plate, pins and finned pins

per cent increase in effectiveness of finned pin over plate $= \frac{Q_{finned\ pin} - Q_{plate}}{Q_{plate}} \times 100$

per cent increase in effectiveness of pins over plate $= \frac{Q_{pin} - Q_{plate}}{Q_{plate}} \times 100$

per cent increase in effectiveness of finned pin over pins $= \frac{Q_{finned\ pin} - Q_{pin}}{Q_{pin}} \times 100$

Curves in Figure 25 show the per cent increase in the effectiveness of finned pins and pins over a plate. These curves indicate that the effectiveness is highest for finned pins and little less for pins. The other point of interest is that both for finned pin and plain pin the percent increase in the effectiveness increases sharply as $\theta_o$ increases but that the increase is small, it reaches a maximum value and takes a downward trend. The downward trend may be due to the decrease in the heat transfer rate due to increased air resistance which becomes more significant on higher temperature range for finned pins and pinned surfaces.

Figure 26 shows the per cent increase in the effectiveness of finned pin over pin. The curve shows that as $\theta_o$ starts increasing the per cent increase in effectiveness increases but the rate of increase is very much less as $\theta_o$ goes high. It almost becomes steady at 36 per cent when $\theta_o$ is 300 F.

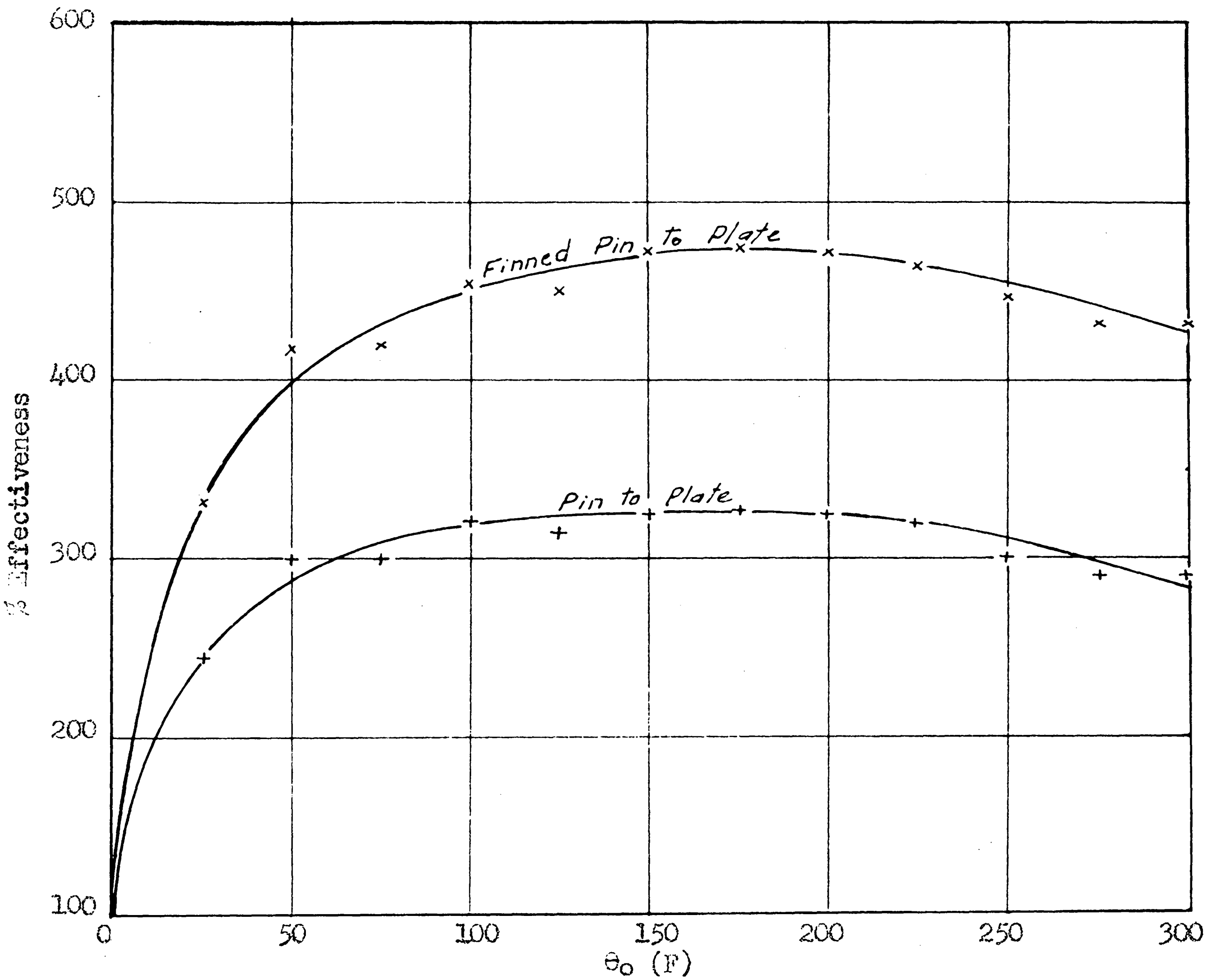



Fig. 25 Effectiveness of finned pins and pins over a plate

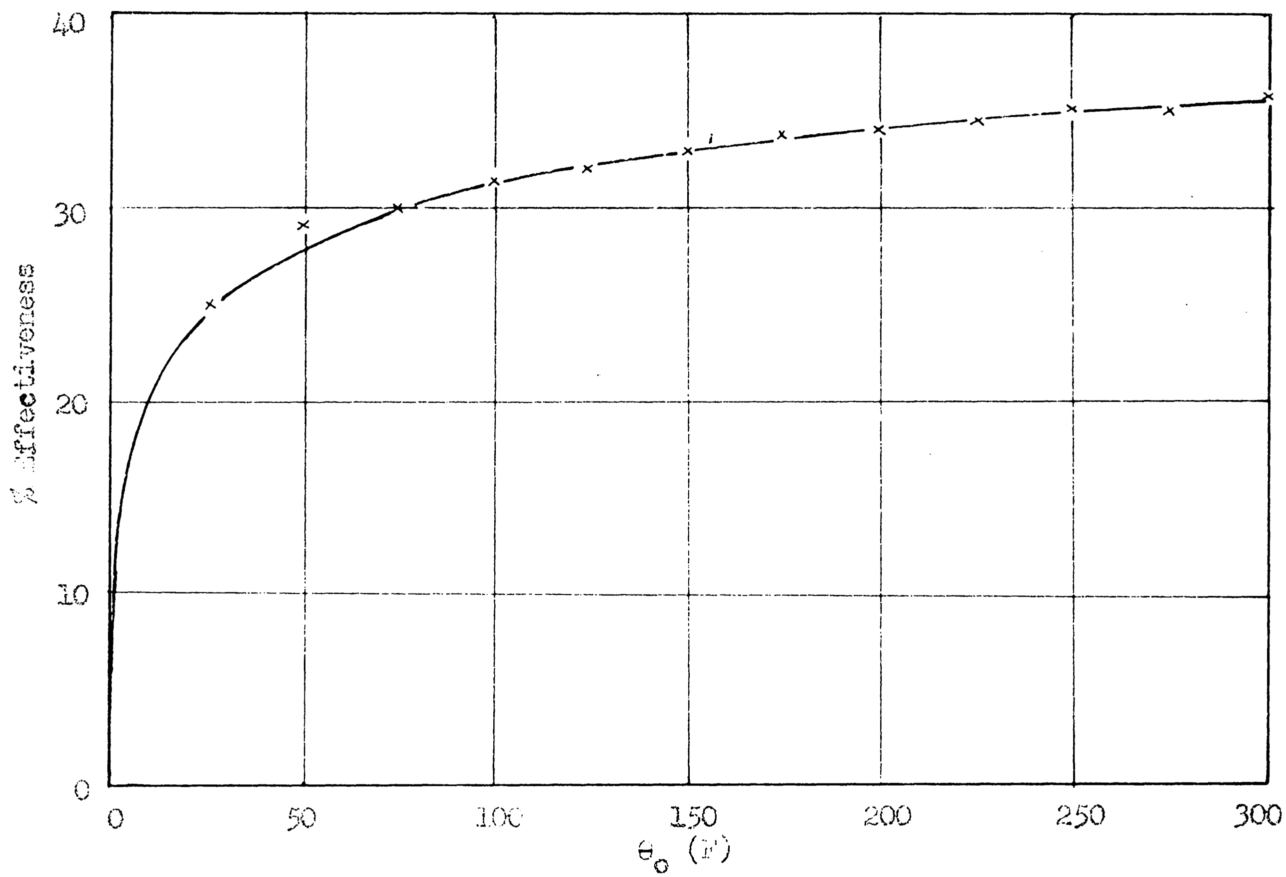



Fig. 26 Effectiveness of finned pins over pins

Comparison of Volume of Finned Pin and Pin

Volume of Pins

$V_{pin}$ = (No. of pins)(Volume of one pin)

$= 492\ (2.5)(\frac{\pi}{4})(\frac{3}{16})^2$

= 34 cu in.

Volume of plates = (No. of plates (Volume of plate)

$= 2(8)\ (\frac{9}{2})(\frac{1}{4})$

= 18 cu in.

Total Volume of Pins = 34 + 18 = 52 cu in.

Volume of Finned Pins

Volume of fins = (No. of fins)(Volume of one fin)

$= 1008 \left[ .01(\frac{\pi}{4}) \left\{ (\frac{7}{8})^2 - (\frac{3}{8})^2 \right\} \right]$

$= 10.08\ (\frac{\pi}{4})(\frac{1}{64})\ (49 - 9)$

= 4.94 cu in.

Volume of pins

= No. pins (x-sectional area of pin)(total length of three pins)

$= 42(\frac{\pi}{4})(\frac{3}{8})^2(3.125 + 3.25 + 3.375)$

= 45.2 cu in.

Total volume of finned pins

= Volume of fins + Volume of pins + Volume of plates

= 4.94 + 45.2 + 18

= 68.14 cu in.

Per cent increase in volume of finned pin over pin

$$= \frac{68.14 - 52}{52} \times 100$$

$$= 31\%$$

## VI. SUMMARY AND CONCLUSIONS

Objective of the thesis was achieved. It was proved experimentally that finned pin extended surface was superios over a plain pin, which was considered efficient means to transfer heat from a primary surface.

The true temperature difference between the root of the pin and ambient air is much lower than $\theta_o$. The reason for this difference is that as the cold air moves up it is gradually heated which reduces the difference in temperature.

The increase in effectiveness of finned pin over plain pin is almost constant on medium to higher temperature range. The maximum per cent increase in effectiveness of finned pin over plain pin is 36 per cent.

## VII. RECOMMENDATIONS

1. Various designs of pin and finned pin may be tested experimentally to see if there is any further improvement in heat transfer rate.
2. Different sizes of primary surface may be tested.
3. Forced convection may be employed.

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# APPENDICES

# XI APPENDICES

## APPENDIX A

### CALCULATED DATA ON HEAT TRANSFER CHARACTERISTICS OF PIN AND FINNED PIN

Table A-1 Data on Heat Transfer Characteristics of a pin

| Serial No. | q, Heat flux in Btu/ft$^2$ hr. | | | | | | | | | | Length of pin (in.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | d=.02 | d=.04 | d=.06 | d=.08 | d=.1 | d=.12 | d=.14 | d=.16 | d=.18 | d=.2 | |
| 1 | 4,794 | 2173 | 1388 | 1021 | 811 | 676 | 583 | 514 | 462 | 421 | 1 |
| 2 | 8,460 | 3932 | 2491 | 1805 | 1411 | 1157 | 981 | 853 | 755 | 678 | 2 |
| 3 | 10,992 | 5411 | 3479 | 2530 | 1975 | 1614 | 1363 | 1178 | 1038 | 928 | 3 |
| 4 | 12,552 | 6574 | 4325 | 3177 | 2491 | 2040 | 1722 | 1488 | 1309 | 1168 | 4 |
| 5 | 13,446 | 7443 | 5023 | 3738 | 2953 | 2428 | 2055 | 1777 | 1564 | 1395 | 5 |
| 6 | 13,937 | 8067 | 5582 | 4214 | 3358 | 2776 | 2358 | 2045 | 1802 | 1609 | 6 |
| 7 | 14,201 | 8503 | 6017 | 4608 | 3706 | 3084 | 2631 | 2289 | 2021 | 1808 | 7 |

Table A-2: Data on Heat Transfer Characteristics of Finned Pin, $L = \frac{1}{2}$"

| No. of Fins | q, heat flux in $Btu/ft^2hr.$ | | | | |
|---|---|---|---|---|---|
| | $D = \frac{3}{4}$" | D = 1" | $D = 1\frac{1}{4}$" | $D = 1\frac{1}{2}$" | $D = 1\frac{3}{4}$" |
| 1 | 1,837 | 2,635 | 3,580 | 4,564 | 5,484 |
| 2 | 2,436 | 4,022 | 5,886 | 7,814 | 9,605 |
| 3 | 3,033 | 5,395 | 8,154 | 10,988 | 13,602 |
| 4 | 3,628 | 6,754 | 10,384 | 14,088 | 17,483 |
| 5 | 4,219 | 8,100 | 12,577 | 17,117 | 21,253 |
| 6 | 4,808 | 9,432 | 14,735 | 20,079 | 24,918 |
| 7 | 5,395 | 10,752 | 16,859 | 22,975 | 28,483 |
| 8 | 5,979 | 12,058 | 18,948 | 25,809 | 31,954 |
| 9 | 6,561 | 13,351 | 21,006 | 28,583 | 35,334 |
| 10 | 7,140 | 14,633 | 23,031 | 31,299 | 38,629 |

Table A-3: Data on Heat Transfer Characteristics of Finned Pin L = 1"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D= $\frac{3}{4}$" | D= 1" | D=1$\frac{1}{4}$" | D=1$\frac{1}{2}$" | D=1$\frac{3}{4}$" |
| 1 | 2,778 | 3,547 | 4,447 | 5,375 | 6,235 |
| 2 | 3,358 | 4,875 | 6,631 | 8,417 | 10,049 |
| 3 | 3,933 | 6,179 | 8,746 | 11,326 | 13,655 |
| 4 | 4,504 | 7,457 | 10,796 | 14,110 | 17,070 |
| 5 | 5,070 | 8,712 | 12,783 | 16,780 | 20,313 |
| 6 | 5,631 | 9,943 | 14,712 | 19,344 | 23,400 |
| 7 | 6,188 | 11,151 | 16,585 | 21,809 | 26,344 |
| 8 | 6,739 | 12,337 | 18,405 | 24,183 | 29,159 |
| 9 | 7,287 | 13,503 | 20,175 | 26,472 | 31,854 |
| 10 | 7,830 | 14,647 | 21,898 | 28,682 | 34,440 |

Table A-4: Data on Heat Transfer Characteristics of Finned Pin, L = $1\frac{1}{2}$"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D= $\frac{3}{4}$" | D= 1" | D=$1\frac{1}{4}$" | D=$1\frac{1}{2}$" | D=$1\frac{3}{4}$ |
| 1 | 3,666 | 4,394 | 5,241 | 6,104 | 6,896 |
| 2 | 4,219 | 5,651 | 7,285 | 8,921 | 10,396 |
| 3 | 4,767 | 6,874 | 9,239 | 11,568 | 13,633 |
| 4 | 5,308 | 8,064 | 11,109 | 14,062 | 16,642 |
| 5 | 5,842 | 9,223 | 12,902 | 16,417 | 19,451 |
| 6 | 6,371 | 10,352 | 14,623 | 18,649 | 22,085 |
| 7 | 6,893 | 11,452 | 16,277 | 20,768 | 24,564 |
| 8 | 7,409 | 12,525 | 17,869 | 22,787 | 26,906 |
| 9 | 7,919 | 13,571 | 19,403 | 24,714 | 29,126 |
| 10 | 8,423 | 14,593 | 20,884 | 26,558 | 31,237 |

Table A-5: Data on Heat Transfer Characteristics of Finned Pin, L = 2"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D= $\frac{3}{4}$" | D= 1" | D=1$\frac{1}{4}$" | D=1$\frac{1}{2}$" | D=1$\frac{3}{4}$" |
| 1 | 4,486 | 5,167 | 5,952 | 6,746 | 7,468 |
| 2 | 5,008 | 6,342 | 7,846 | 9,333 | 10,655 |
| 3 | 5,523 | 7,479 | 9,638 | 11,730 | 13,556 |
| 4 | 6,030 | 8,578 | 11,337 | 13,959 | 16,213 |
| 5 | 6,530 | 9,641 | 12,950 | 16,043 | 18,664 |
| 6 | 7,023 | 10,670 | 14,485 | 17,998 | 20,939 |
| 7 | 7,508 | 11,668 | 15,950 | 19,840 | 23,063 |
| 8 | 7,986 | 12,635 | 17,350 | 21,581 | 25,056 |
| 9 | 8,458 | 13,574 | 18,691 | 23,232 | 26,933 |
| 10 | 8,922 | 14,486 | 19,978 | 24,803 | 28,710 |

Table A-6: Data on Heat Transfer Characteristics of Finned Pin, L = 3"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D = $\frac{3}{4}$" | D = 1" | D = $1\frac{1}{4}$" | D = $1\frac{1}{2}$" | D = $1\frac{3}{4}$" |
| 1 | 5,892 | 6,468 | 7,122 | 7,773 | 8,357 |
| 2 | 6,342 | 7,468 | 8,710 | 9,913 | 10,962 |
| 3 | 6,786 | 8,428 | 10,195 | 11,863 | 13,288 |
| 4 | 7,221 | 9,349 | 11,585 | 13,652 | 15,386 |
| 5 | 7,648 | 10,232 | 12,891 | 15,302 | 17,298 |
| 6 | 8,067 | 11,081 | 14,121 | 16,835 | 19,056 |
| 7 | 8,479 | 11,897 | 15,284 | 18,267 | 20,686 |
| 8 | 8,882 | 12,683 | 16,388 | 19,613 | 22,208 |
| 9 | 9,278 | 13,442 | 17,439 | 20,883 | 23,638 |
| 10 | 9,667 | 14,174 | 18,442 | 22,086 | 24,989 |

Table A-7: Data on Heat Transfer Characteristics of Finned Pin, L = 4"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D= $\frac{3}{4}$" | D= 1" | D=1$\frac{1}{4}$" | D=1$\frac{1}{2}$" | D=1-$\frac{3}{4}$" |
| 1 | 6,978 | 7,447 | 7,974 | 8,493 | 8,953 |
| 2 | 7,355 | 8,277 | 9,281 | 10,239 | 11,063 |
| 3 | 7,727 | 9,075 | 10,500 | 11,826 | 12,942 |
| 4 | 8,093 | 9,838 | 11,638 | 13,276 | 14,633 |
| 5 | 8,451 | 10,567 | 12,703 | 14,610 | 16,171 |
| 6 | 8,802 | 11,266 | 13,703 | 15,848 | 17,587 |
| 7 | 9,145 | 11,936 | 14,648 | 17,004 | 18,901 |
| 8 | 9,482 | 12,580 | 15,543 | 18,091 | 20,131 |
| 9 | 9,812 | 13,200 | 16,393 | 19,117 | 21,289 |
| 10 | 10,135 | 13,797 | 17,205 | 20,091 | 22,386 |

Table A-8: Data on Heat Transfer Characteristics of Finned Pin, L = 5"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D= $\frac{3}{4}$" | D= 1" | D=1$\frac{1}{4}$" | D=1$\frac{1}{2}$" | D=1$\frac{3}{4}$" |
| 1 | 7,773 | 8,147 | 8,563 | 8,969 | 9,326 |
| 2 | 8,084 | 8,828 | 9,630 | 10,388 | 11,037 |
| 3 | 8,393 | 9,487 | 10,633 | 11,690 | 12,575 |
| 4 | 8,698 | 10,119 | 11,572 | 12,885 | 13,967 |
| 5 | 8,996 | 10,724 | 12,453 | 13,989 | 15,242 |
| 6 | 9,289 | 11,304 | 13,283 | 15,017 | 16,422 |
| 7 | 9,575 | 11,860 | 14,067 | 15,981 | 17,522 |
| 8 | 9,856 | 12,396 | 14,812 | 16,890 | 18,557 |
| 9 | 10,131 | 12,911 | 15,522 | 17,752 | 19,536 |
| 10 | 10,400 | 13,408 | 16,201 | 18,573 | 20,467 |

Table A-9: Data on Heat Transfer Characteristics of Finned Pin, L = 6"

| No. of Fins | q, heat flux in Btu/ft$^2$hr. | | | | |
|---|---|---|---|---|---|
| | D= $\frac{3}{4}$" | D= 1" | D=1$\frac{1}{4}$" | D=1$\frac{1}{2}$" | D=1$\frac{3}{4}$" |
| 1 | 8,334 | 8,627 | 8,951 | 9,267 | 9,542 |
| 2 | 8,589 | 9,185 | 9,824 | 10,426 | 10,938 |
| 3 | 8,845 | 9,731 | 10,656 | 11,506 | 12,217 |
| 4 | 9,099 | 10,259 | 11,442 | 12,509 | 13,389 |
| 5 | 9,349 | 10,766 | 12,183 | 13,443 | 14,473 |
| 6 | 9,594 | 11,253 | 12,885 | 14,318 | 15,483 |
| 7 | 9,834 | 11,723 | 13,551 | 15,144 | 16,432 |
| 8 | 10,070 | 12,175 | 14,187 | 15,926 | 17,329 |
| 9 | 10,301 | 12,612 | 14,795 | 16,672 | 18,183 |
| 10 | 10,528 | 13,035 | 15,378 | 17,385 | 18,998 |

APPENDIX B

MEASURED DATA OF HEAT TRANSFER RATE THROUGH FINNED PIN, PIN AND PLATE

Table B-1 Measurement of Heat Transfer Rates for Various $\theta_o$ for Finned Pin, Set I

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.818 | 2.785 | 2.485 | 2.555 | 2.54 | 2.6 | 2.818 | 2.785 | 2.77 | 2.675 | 2.47 | 2.85 | 2.727 | 150 | 72 | 78 | 50 | 3.25 | 162.5 | 554 |
| 3.925 | 3.85 | 3.76 | 3.475 | 3.45 | 3.52 | 3.925 | 3.85 | 3.775 | 3.64 | 3.31 | 3.9 | 3.698 | 189 | 72 | 117 | 65 | 4.25 | 276 | 941 |
| 5.12 | 5.005 | 4.328 | 4.46 | 4.44 | 4.54 | 5.10 | 5.005 | 4.857 | 4.675 | 4.2 | 5.04 | 4.73 | 230 | 73 | 157 | 80 | 5.17 | 414 | 1412 |
| 6.94 | 6.775 | 5.82 | 5.99 | 5.95 | 6.105 | 6.94 | 6.775 | 6.48 | 6.27 | 5.525 | 6.8 | 6.364 | 290 | 76 | 214 | 100 | 6.23 | 623 | 2123 |
| 9.44 | 9.28 | 7.87 | 8.125 | 8.07 | 8.283 | 9.44 | 9.28 | 8.657 | 8.432 | 7.3 | 9.2 | 8.615 | 369 | 76 | 293 | 120 | 7.74 | 930 | 3170 |

Table B-2 Measurement of Heat Transfer Rates for Various $\theta_o$ for Finned Pin, Set II

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.98 | 1.955 | 1.837 | 1.85 | 1.845 | 1.85 | 1.9 | 1.884 | 1.97 | 1.9 | 1.805 | 1.994 | 1.897 | 116 | 72 | 44 | 34.2 | 2.242 | 83 | 283 |
| 2.89 | 2.838 | 2.607 | 2.615 | 2.615 | 2.625 | 2.838 | 2.677 | 2.845 | 2.772 | 2.532 | 2.905 | 2.725 | 150 | 73 | 77 | 50 | 3.315 | 165.8 | 565 |
| 3.53 | 3.455 | 3.144 | 3.15 | 3.15 | 3.17 | 3.455 | 3.228 | 3.435 | 3.28 | 3.015 | 3.526 | 3.295 | 174 | 73 | 101 | 60 | 3.935 | 236.1 | 804 |
| 4.31 | 4.205 | 3.786 | 3.79 | 3.795 | 3.816 | 4.2 | 3.91 | 4.16 | 3.96 | 3.61 | 4.275 | 3.985 | 200 | 72 | 128 | 71 | 4.59 | 326 | 1110 |
| 5.22 | 5.08 | 4.55 | 4.55 | 4.56 | 4.588 | 5.01 | 4.775 | 4.984 | 4.745 | 4.287 | 5.145 | 4.874 | 235 | 74 | 161 | 80 | 5.19 | 415.2 | 1415 |
| 6.228 | 6.068 | 5.413 | 5.405 | 5.415 | 5.46 | 6.068 | 5.632 | 5.955 | 5.665 | 5.005 | 6.15 | 5.705 | 265 | 76 | 189 | 90 | 5.85 | 526.5 | 1795 |
| 7.35 | 7.129 | 6.33 | 6.324 | 6.324 | 6.385 | 7.11 | 6.58 | 6.937 | 6.602 | 5.785 | 7.19 | 6.67 | 297 | 76 | 223 | 100 | 6.55 | 655 | 2230 |
| 8.455 | 8.245 | 7.23 | 7.249 | 7.24 | 7.296 | 8.1 | 7.81 | 7.94 | 7.555 | 6.605 | 8.25 | 7.656 | 336 | 76 | 260 | 110 | 7.14 | 784 | 2670 |
| 9.325 | 9.1 | 7.96 | 7.96 | 7.96 | 8.025 | 8.61 | 8.53 | 8.69 | 8.26 | 8.17 | 9.065 | 8.471 | 364 | 75 | 289 | 120 | 7.66 | 920 | 3134 |

Table B-3. Measurement of Heat Transfer for Various $\theta_o$ for Finned Pin, Set III

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.292 | 2.28 | 2.138 | 2.155 | 2.15 | 2.128 | 2.28 | 2.305 | 2.3 | 2.221 | 2.1 | 2.315 | 2.222 | 130 | 80 | 50 | 35 | 2.43 | 85.1 | 290.4 |
| 2.91 | 2.88 | 2.65 | 2.67 | 2.66 | 2.655 | 2.87 | 2.911 | 2.886 | 2.76 | 2.58 | 2.915 | 2.779 | 153 | 80 | 73 | 45 | 3.044 | 136.8 | 467 |
| 3.55 | 3.52 | 3.20 | 3.22 | 3.215 | 3.2 | 3.52 | 3.565 | 3.51 | 3.345 | 3.09 | 3.55 | 3.374 | 177 | 80 | 97 | 55 | 3.495 | 192.3 | 656 |
| 4.31 | 4.264 | 3.828 | 3.845 | 3.84 | 3.828 | 4.26 | 4.315 | 4.231 | 4.00 | 3.66 | 4.278 | 4.055 | 201 | 80 | 121 | 65.5 | 4.38 | 287 | 980 |
| 5.15 | 5.098 | 4.525 | 4.548 | 4.532 | 4.525 | 5.09 | 5.176 | 5.04 | 4.75 | 4.294 | 5.095 | 4.819 | 233 | 80 | 153 | 75 | 5.04 | 378.2 | 1290 |
| 6.115 | 6.037 | 5.328 | 5.35 | 5.34 | 5.334 | 6.03 | 6.127 | 5.956 | 5.594 | 5.00 | 6.018 | 5.686 | 265 | 80 | 185 | 85 | 5.71 | 486 | 1659 |
| 7.19 | 7.025 | 6.138 | 6.192 | 6.18 | 6.165 | 7.02 | 7.106 | 6.916 | 6.466 | 5.7 | 6.995 | 6.591 | 298 | 81 | 217 | 95 | 6.38 | 607 | 2070 |
| 8.26 | 8.16 | 7.09 | 7.146 | 7.124 | 7.115 | 8.12 | 8.23 | 7.98 | 7.45 | 6.505 | 8.065 | 7.604 | 334 | 81 | 253 | 105 | 7.0 | 735 | 2510 |
| 9.54 | 9.431 | 8.173 | 8.23 | 8.203 | 8.192 | 9.41 | 9.5 | 9.152 | 8.57 | 7.43 | 9.3 | 8.761 | 374 | 82 | 292 | 115 | 7.68 | 884 | 3020 |

Table B-4. Measurement of Heat Transfer for Various $\theta_o$ for Finned Pin, Set IV

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.287 | 2.274 | 2.115 | 2.139 | 2.136 | 2.13 | 2.27 | 2.28 | 2.289 | 2.208 | 2.085 | 2.305 | 2.21 | 129 | 80 | 49 | 35 | 2.42 | 84.6 | 288.6 |
| 2.899 | 2.872 | 2.635 | 2.658 | 2.652 | 2.644 | 2.87 | 2.885 | 2.88 | 2.755 | 2.568 | 2.9 | 2.768 | 152 | 81 | 71 | 45 | 3.1 | 139.4 | 476 |
| 3.595 | 3.565 | 3.22 | 3.255 | 3.251 | 3.24 | 3.56 | 3.53 | 3.55 | 3.38 | 3.114 | 3.59 | 3.404 | 178 | 81 | 97 | 55 | 3.745 | 206 | 702.5 |
| 4.418 | 4.373 | 3.9 | 3.943 | 3.939 | 3.928 | 4.37 | 4.346 | 4.328 | 4.1 | 3.73 | 4.374 | 4.146 | 207 | 82 | 125 | 66 | 4.445 | 293 | 1000 |
| 5.194 | 5.14 | 4.53 | 4.589 | 4.584 | 4.57 | 5.13 | 5.129 | 5.087 | 4.795 | 4.31 | 5.155 | 4.851 | 234 | 82 | 152 | 76 | 5.094 | 382.4 | 1305 |
| 6.1 | 6.017 | 5.27 | 5.34 | 5.333 | 5.316 | 6.00 | 6.007 | 5.946 | 5.585 | 4.963 | 6.017 | 5.658 | 264 | 82 | 182 | 85 | 5.7 | 485 | 1655 |
| 7.06 | 6.962 | 6.065 | 6.126 | 6.116 | 6.11 | 6.92 | 6.956 | 6.84 | 6.409 | 5.64 | 6.925 | 6.511 | 295 | 80 | 215 | 95 | 6.35 | 602.5 | 2054 |
| 8.377 | 8.267 | 7.29 | 7.259 | 7.224 | 7.23 | 8.26 | 8.24 | 8.06 | 7.56 | 6.59 | 8.185 | 7.714 | 338 | 84 | 254 | 104 | 7.04 | 732.5 | 2500 |
| 9.712 | 9.589 | 8.435 | 8.386 | 8.37 | 8.347 | 9.58 | 9.57 | 9.297 | 8.744 | 7.576 | 9.47 | 8.923 | 380 | 86 | 294 | 113 | 7.7 | 870 | 2970 |

Table B-5. Measurement of Heat Transfer for Various $\theta_o$ for Plain Pin, Set I

| $V_1$ (mv) | $V_2$ (mv) | $V_3$ (mv) | $V_4$ (mv) | $V_5$ (mv) | $V_6$ (mv) | $V_7$ (mv) | $V_8$ (mv) | $V_9$ (mv) | $V_{10}$ (mv) | $V_{11}$ (mv) | $V_{12}$ (mv) | $V_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.245 | 2.27 | 2.12 | 2.137 | 2.137 | 2.28 | 2.292 | 2.27 | 2.12 | 2.14 | 2.146 | 2.23 | 2.199 | 129 | 74 | 55 | 35 | 2.273 | 79.5 | 272 |
| 3.27 | 3.315 | 3.035 | 3.05 | 3.06 | 3.33 | 3.35 | 3.327 | 3.03 | 3.06 | 3.07 | 3.23 | 3.177 | 169 | 72 | 97 | 50 | 3.291 | 164.6 | 561 |
| 4.49 | 4.55 | 4.1 | 4.145 | 4.145 | 4.575 | 4.612 | 4.57 | 4.1 | 4.16 | 4.167 | 4.41 | 4.335 | 215 | 72 | 143 | 65 | 4.23 | 275 | 940 |
| 5.9 | 5.98 | 5.336 | 5.388 | 5.388 | 6.002 | 6.056 | 5.997 | 5.318 | 5.396 | 5.396 | 5.745 | 5.657 | 264 | 70 | 194 | 80 | 5.05 | 404 | 1380 |
| 7.78 | 7.908 | 6.764 | 7.066 | 7.066 | 7.95 | 8.005 | 7.945 | 6.955 | 7.1 | 7.08 | 7.575 | 7.432 | 328 | 71 | 257 | 95 | 6.04 | 575 | 2000 |
| 8.864 | 9.005 | 7.595 | 8.025 | 8.015 | 9.053 | 9.11 | 9.04 | 7.91 | 8.044 | 8.01 | 8.585 | 8.438 | 363 | 71 | 291 | 105 | 6.62 | 693 | 2370 |

Table B-6. Measurement of Heat Transfer for Various $\theta_o$ for Plain Pin, Set II

| $V_1$ (mv) | $V_2$ (mv) | $V_3$ (mv) | $V_4$ (mv) | $V_5$ (mv) | $V_6$ (mv) | $V_7$ (mv) | $V_8$ (mv) | $V_9$ (mv) | $V_{10}$ (mv) | $V_{11}$ (mv) | $V_{12}$ (mv) | $V_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.035 | 2.06 | 1.955 | 1.955 | 1.955 | 2.07 | 2.075 | 2.06 | 1.945 | 1.967 | 1.985 | 2.03 | 2.001 | 121 | 76 | 45 | 30 | 1.975 | 59.25 | 202 |
| 2.705 | 2.745 | 2.57 | 2.564 | 2.564 | 2.75 | 2.766 | 2.74 | 2.541 | 2.58 | 2.607 | 2.686 | 2.651 | 148 | 75 | 73 | 40 | 2.645 | 105.8 | 361 |
| 3.25 | 3.3 | 3.05 | 3.038 | 3.043 | 3.312 | 3.33 | 3.3 | 3.0 | 3.06 | 3.095 | 3.21 | 3.166 | 168 | 73 | 95 | 50 | 3.235 | 161.8 | 552 |
| 4.079 | 4.138 | 3.788 | 3.774 | 3.774 | 4.15 | 4.175 | 4.135 | 3.725 | 3.804 | 3.85 | 4.0 | 3.949 | 199 | 74 | 125 | 60 | 3.825 | 229.5 | 783 |
| 5.18 | 5.26 | 4.785 | 4.764 | 4.768 | 5.273 | 5.312 | 5.259 | 4.695 | 4.8 | 4.864 | 5.075 | 5.002 | 239 | 76 | 163 | 70 | 4.48 | 313.6 | 1070 |
| 6.22 | 6.323 | 5.71 | 5.692 | 5.692 | 6.345 | 6.382 | 6.32 | 5.59 | 5.74 | 5.815 | 6.078 | 5.992 | 276 | 76 | 200 | 80 | 5.13 | 410.4 | 1404 |
| 7.44 | 7.605 | 6.861 | 6.82 | 6.814 | 7.647 | 7.68 | 7.6 | 6.67 | 6.869 | 6.96 | 7.286 | 7.188 | 319 | 75 | 244 | 90 | 5.82 | 523.8 | 1790 |
| 8.46 | 8.643 | 7.44 | 7.7 | 7.695 | 8.677 | 8.715 | 8.63 | 7.55 | 7.772 | 7.863 | 8.26 | 8.177 | 352 | 76 | 276 | 100 | 6.34 | 634 | 2170 |
| 9.756 | 9.977 | 8.732 | 8.866 | 8.853 | 10.023 | 9.0 | 9.946 | 8.67 | 8.935 | 9.05 | 9.5 | 9.276 | 392 | 79 | 313 | 109 | 6.86 | 749 | 2555 |

Table B-7. Measurement of Heat Transfer for Various $\theta_o$ for Plain Pin, Set III

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.635 | 2.673 | 2.507 | 2.52 | 2.52 | 2.68 | 2.687 | 2.671 | 2.505 | 2.53 | 2.555 | 2.622 | 2.592 | 145 | 83 | 62 | 36 | 2.398 | 86 | 294 |
| 3.195 | 3.244 | 2.996 | 3.01 | 3.01 | 3.251 | 3.263 | 3.239 | 2.985 | 3.034 | 3.07 | 3.166 | 3.122 | 167 | 81 | 86 | 45 | 2.95 | 132.6 | 454 |
| 4.065 | 4.131 | 3.763 | 3.79 | 3.79 | 4.14 | 4.159 | 4.125 | 3.746 | 3.823 | 3.875 | 4.012 | 3.952 | 199 | 84 | 115 | 56 | 3.63 | 203.5 | 695 |
| 5.041 | 5.135 | 4.606 | 4.661 | 4.653 | 5.138 | 5.16 | 5.115 | 4.59 | 4.702 | 4.769 | 4.96 | 4.878 | 235 | 84 | 151 | 66 | 4.33 | 286 | 980 |
| 6.128 | 6.24 | 5.6 | 5.633 | 5.618 | 6.25 | 6.27 | 6.21 | 5.28 | 5.675 | 5.759 | 6.003 | 5.889 | 273 | 84 | 189 | 75 | 4.95 | 371.5 | 1270 |
| 7.125 | 7.265 | 6.475 | 6.537 | 6.52 | 7.285 | 7.31 | 7.237 | 6.414 | 6.583 | 6.686 | 6.984 | 6.868 | 308 | 84 | 224 | 85 | 5.542 | 472 | 1610 |
| 8.215 | 8.381 | 7.438 | 7.505 | 7.483 | 8.416 | 8.442 | 8.355 | 7.337 | 7.568 | 7.684 | 8.044 | 7.906 | 344 | 83 | 261 | 95 | 6.19 | 588 | 2010 |
| 9.798 | 10.006 | 8.832 | 8.916 | 8.869 | 10.055 | 10.07 | 9.96 | 8.708 | 8.979 | 9.122 | 9.567 | 9.407 | 396 | 84 | 312 | 104.2 | 6.84 | 712 | 2435 |
| 11.355 | 11.595 | 10.161 | 10.292 | 10.24 | 11.656 | 11.656 | 11.528 | 10.05 | 10.37 | 10.532 | 11.062 | 10.875 | 445 | 84 | 361 | 115 | 7.52 | 864 | 2950 |

Table B-8. Measurement of Heat Transfer for Various $\theta_o$ for Plain Pin, Set IV

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.48 | 2.507 | 2.355 | 2.365 | 2.365 | 2.514 | 2.52 | 2.505 | 2.346 | 2.38 | 2.402 | 2.463 | 2.434 | 139 | 80 | 59 | 35 | 2.33 | 81.5 | 279 |
| 3.131 | 3.177 | 2.935 | 2.953 | 2.953 | 3.182 | 3.196 | 3.171 | 2.925 | 2.977 | 3.01 | 3.102 | 3.059 | 164 | 82 | 82 | 44.5 | 2.9 | 129 | 441 |
| 4.019 | 4.085 | 3.735 | 3.755 | 3.755 | 4.092 | 4.11 | 4.075 | 3.712 | 3.785 | 3.832 | 3.966 | 3.91 | 198 | 82 | 116 | 55 | 3.603 | 198 | 678 |
| 4.927 | 5.014 | 4.6 | 4.545 | 4.517 | 5.002 | 5.03 | 4.981 | 4.478 | 4.59 | 4.65 | 4.83 | 4.764 | 231 | 82 | 149 | 66 | 4.275 | 282 | 965 |
| 5.917 | 6.03 | 5.384 | 5.44 | 5.426 | 6.039 | 6.064 | 6.006 | 5.347 | 5.485 | 5.566 | 5.802 | 5.709 | 266 | 82 | 184 | 75 | 4.885 | 366 | 1250 |
| 7.02 | 7.155 | 6.347 | 6.415 | 6.386 | 7.161 | 7.19 | 7.12 | 6.304 | 6.47 | 6.567 | 6.859 | 6.75 | 304 | 82 | 222 | 84.8 | 5.49 | 465 | 1588 |
| 8.35 | 8.52 | 7.505 | 7.6 | 7.569 | 8.54 | 8.567 | 8.478 | 7.441 | 7.673 | 7.795 | 8.16 | 8.017 | 348 | 82 | 266 | 96 | 6.24 | 600 | 2050 |
| 10.28 | 10.5 | 9.234 | 9.345 | 9.3 | 10.55 | 10.569 | 10.45 | 9.119 | 9.422 | 9.564 | 10.029 | 9.864 | 411 | 85 | 326 | 108 | 7.05 | 760 | 2600 |

Table B-9. Measurement of Heat Transfer for Various $\theta_o$ for Plate, Set I

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.069 | 2.091 | 2.084 | 2.09 | 2.056 | 2.02 | 2.037 | 2.03 | 2.105 | 2.045 | 2.1 | 2.024 | 2.063 | 123 | 80 | 43 | 10.2 | 1.592 | 16.21 | 55.48 |
| 3.269 | 3.3 | 3.0 | 3.295 | 3.224 | 3.14 | 3.19 | 3.175 | 3.34 | 3.198 | 3.325 | 3.146 | 3.216 | 170 | 81 | 89 | 15.4 | 2.42 | 37.2 | 127 |
| 4.06 | 4.11 | 4.095 | 4.096 | 4.022 | 3.886 | 3.954 | 3.925 | 4.159 | 3.97 | 4.141 | 3.884 | 4.025 | 202 | 81 | 121 | 18 | 2.892 | 52 | 177.6 |
| 4.994 | 5.025 | 5.026 | 5.024 | 4.912 | 4.745 | 4.82 | 4.79 | 5.095 | 4.834 | 5.07 | 4.73 | 4.922 | 237 | 81 | 156 | 22 | 3.395 | 74.8 | 255.5 |
| 6.72 | 6.825 | 6.798 | 6.831 | 6.625 | 6.365 | 6.505 | 6.442 | 6.905 | 6.538 | 6.88 | 6.37 | 6.65 | 300 | 82 | 218 | 27.2 | 4.16 | 113.4 | 387.5 |
| 8.098 | 8.219 | 8.189 | 8.2 | 7.965 | 7.638 | 7.82 | 7.72 | 8.319 | 7.865 | 8.285 | 7.645 | 7.997 | 348 | 81 | 267 | 32.6 | 4.74 | 154.6 | 529 |
| 9.545 | 9.722 | 9.651 | 9.665 | 9.44 | 8.98 | 9.205 | 8.114 | 9.81 | 9.268 | 9.76 | 8.97 | 9.344 | 394 | 81 | 313 | 36 | 5.29 | 190 | 650 |
| 11.141 | 11.282 | 11.19 | 11.224 | 10.939 | 10.411 | 10.696 | 10.56 | 10.461 | 10.735 | 11.345 | 10.388 | 10.864 | 445 | 81 | 364 | 40 | 5.95 | 238 | 814 |

Table B-10. Measurement of Heat Transfer for Various $\theta_o$ for Plate, Set II

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.515 | 2.53 | 2.529 | 2.529 | 2.49 | 2.43 | 2.455 | 2.447 | 2.555 | 2.465 | 2.54 | 2.425 | 2.493 | 141 | 81 | 60 | 11.8 | 1.866 | 22 | 75.2 |
| 3.1 | 3.135 | 3.135 | 3.134 | 3.07 | 2.996 | 3.036 | 3.033 | 3.175 | 3.044 | 3.16 | 3.0 | 3.085 | 165 | 81 | 84 | 15.0 | 2.375 | 35.6 | 121.9 |
| 4.14 | 4.171 | 4.166 | 4.17 | 4.081 | 3.948 | 4.012 | 3.978 | 4.215 | 4.022 | 4.2 | 3.94 | 4.087 | 205 | 81 | 124 | 18.4 | 2.875 | 52.9 | 181 |
| 5.14 | 5.19 | 5.169 | 5.184 | 5.037 | 4.878 | 4.966 | 4.914 | 5.245 | 4.997 | 5.225 | 4.872 | 5.068 | 242 | 81 | 161 | 21.6 | 3.339 | 72.1 | 246.5 |
| 6.395 | 6.492 | 6.484 | 6.474 | 6.311 | 6.057 | 6.191 | 6.116 | 6.557 | 6.241 | 6.535 | 6.05 | 6.325 | 288 | 80 | 208 | 26.3 | 4.036 | 106 | 361.8 |
| 7.68 | 7.76 | 7.71 | 7.729 | 7.545 | 7.205 | 7.37 | 7.296 | 7.828 | 7.406 | 7.789 | 7.2 | 7.543 | 332 | 80 | 252 | 29.8 | 4.5 | 134 | 458 |
| 8.861 | 9.005 | 8.945 | 8.945 | 8.737 | 8.376 | 8.55 | 8.465 | 9.9 | 8.609 | 9.07 | 8.336 | 8.817 | 376 | 80 | 296 | 34 | 5.078 | 172.6 | 590 |
| 10.18 | 10.35 | 10.278 | 10.294 | 10.012 | 9.579 | 9.805 | 9.66 | 10.45 | 9.88 | 10.405 | 9.55 | 10.04 | 417 | 82 | 335 | 38 | 5.66 | 215 | 734 |

Table B-11 Measurement of Heat Transfer for Various $\theta_o$ for Plate, Set III

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.96 | 1.977 | 1.977 | 1.985 | 1.95 | 1.913 | 1.927 | 1.92 | 1.992 | 1.94 | 1.99 | 1.915 | 1.954 | 119 | 79 | 40 | 10 | 1.505 | 15.05 | 51.4 |
| 2.947 | 2.985 | 2.975 | 2.98 | 2.924 | 2.85 | 2.88 | 2.868 | 3.015 | 2.895 | 3.0 | 2.845 | 2.93 | 159 | 80 | 79 | 14 | 2.19 | 30.66 | 104.7 |
| 3.972 | 4.029 | 4.02 | 4.02 | 4.025 | 3.94 | 3.814 | 3.87 | 4.075 | 3.892 | 4.054 | 3.805 | 3.96 | 200 | 79 | 121 | 18 | 2.815 | 50.7 | 173 |
| 5.07 | 5.126 | 5.11 | 5.125 | 5.0 | 4.83 | 4.906 | 4.832 | 5.184 | 4.935 | 5.165 | 4.807 | 5.008 | 240 | 78 | 162 | 22 | 3.365 | 74 | 252.8 |
| 6.168 | 6.25 | 6.225 | 6.225 | 6.065 | 5.859 | 5.957 | 5.909 | 6.311 | 5.997 | 6.29 | 5.835 | 6.091 | 280 | 78 | 202 | 25.8 | 3.94 | 101.6 | 346.8 |
| 7.24 | 7.367 | 7.329 | 7.349 | 7.16 | 6.868 | 7.023 | 6.932 | 7.46 | 7.06 | 7.432 | 6.871 | 7.174 | 319 | 78 | 241 | 29.4 | 4.465 | 131.3 | 448 |
| 8.87 | 8.976 | 8.926 | 8.953 | 8.713 | 8.328 | 8.517 | 8.45 | 9.075 | 8.584 | 9.035 | 8.31 | 8.728 | 373 | 81 | 292 | 34 | 5.09 | 173 | 590.5 |
| 10.547 | 10.71 | 10.64 | 10.685 | 10.36 | 9.924 | 10.15 | 10.03 | 10.82 | 10.224 | 10.778 | 9.875 | 10.395 | 429 | 82 | 347 | 38.5 | 5.86 | 225.9 | 771 |

Table B-12 Measurement of Heat Transfer for Various $\theta_o$ for Plate, Set IV

| $v_1$ (mv) | $v_2$ (mv) | $v_3$ (mv) | $v_4$ (mv) | $v_5$ (mv) | $v_6$ (mv) | $v_7$ (mv) | $v_8$ (mv) | $v_9$ (mv) | $v_{10}$ (mv) | $v_{11}$ (mv) | $v_{12}$ (mv) | $v_m$ (mv) | $t_o$ (F) | $t_a$ (F) | $\theta_o$ (F) | V (Volts) | I (Amp.) | W (Watts) | Q (Btu/hr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2.076 | 2.085 | 2.084 | 2.084 | 2.05 | 2.01 | 2.026 | 2.02 | 2.1 | 2.036 | 2.094 | 2.008 | 2.056 | 123 | 76 | 47 | 10 | 1.466 | 14.66 | 50.03 |
| 2.902 | 2.945 | 2.933 | 2.93 | 2.881 | 2.796 | 2.831 | 2.815 | 2.965 | 2.847 | 2.95 | 2.795 | 2.883 | 157 | 76 | 81 | 14.2 | 2.12 | 30.1 | 102.7 |
| 3.8 | 3.836 | 3.835 | 3.83 | 3.737 | 3.635 | 3.68 | 3.661 | 3.871 | 3.693 | 3.855 | 3.616 | 3.754 | 192 | 78 | 114 | 18 | 2.76 | 49.6 | 169.6 |
| 5.02 | 5.085 | 5.067 | 5.08 | 4.944 | 4.769 | 4.856 | 4.762 | 5.136 | 4.89 | 5.108 | 4.77 | 4.957 | 238 | 78 | 160 | 22 | 3.33 | 73.25 | 250 |
| 6.165 | 6.26 | 6.211 | 6.228 | 6.07 | 5.848 | 5.955 | 5.89 | 6.319 | 6.0 | 6.29 | 5.83 | 6.089 | 280 | 78 | 202 | 25.8 | 3.895 | 100.5 | 343 |
| 7.565 | 7.678 | 7.642 | 7.649 | 7.455 | 7.159 | 7.304 | 7.234 | 7.771 | 7.349 | 7.73 | 7.116 | 7.471 | 329 | 77 | 252 | 31 | 4.58 | 142 | 485 |
| 8.805 | 8.957 | 8.895 | 8.91 | 8.69 | 8.312 | 8.483 | 8.4 | 9.041 | 8.529 | 9.009 | 8.284 | 8.693 | 372 | 78 | 294 | 34 | 5.03 | 171.2 | 584 |
| 10.16 | 10.311 | 10.277 | 10.27 | 10.005 | 9.563 | 9.77 | 9.67 | 10.415 | 9.842 | 10.366 | 9.52 | 10.014 | 416 | 79 | 337 | 38 | 5.6 | 213 | 726.5 |

## ABSTRACT

Numerous types of extended surfaces have been used in the past but those with finned pins have proved to be unique in increasing the rate of heat transfer. Hsieh working on the original idea of professor Hsu proved that heat transfer rate can be further increased by putting annular fins on a pin.

In this thesis the design of finned pin was optimized to give maximum heat transfer rate from a given primary surface, and an experimental investigation was conducted to verify the results.

1. Theoretical Investigation consists of:
   (1) Reproduction of mathematical equations for pin and finned pin.
   (2) Study of heat transfer characteristics of pin and finned pin.
   (3) Optimization of the design of pin and finned pin.
   (4) Sample calculations of heat flow rate for pin and finned pin.
2. Experimental investigation consists of:
   (1) Construction of finned pin, pin and primary surfaces.
   (2) Set-up of experimental equipment.

(3) Comparison of heat flow rate for finned pin, pin and plate.

3. Conclusions: The conclusions were based on the comparison of finned pin and pin. The heat transfer rate from 8" x $4\frac{1}{2}$" surface was increased by employing finned pin. The maximum increase was 36%.