DEPARTMENT OF CHEMICAL AND METALLURGICAL ENGINEERING

Heat Transfer Laboratory

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THE CONDENSING OF LOW PRESSURE STEAM ON HORIZONTAL TITANIUM TUBES

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ABSTRACT

Heat transfer data are presented for condensing steam at 2 inches of mercury absolute pressure on the outside of 9 copper and 9 titanium horizontal tubes in a vertical row. The condensing coefficient correction factor was maximum for the top titanium tube and was 46 per cent higher than the correction factor for the top copper tube. The difference between the correction factors for titanium and copper tubes diminished with the number of tubes in a vertical row to 8 per cent higher than the correction factor for copper tubes with 6 to 9 tubes in a vertical row.

OBJECTIVE

The purpose of this investigation was to determine the low pressure steam condensing characteristics of horizontal titanium tubes placed in a vertical row where inundation of condensate occurs. Because of the generally low wettability surface characteristics of titanium, it was surmised that condensing heat transfer coefficients would be considerably higher with the possibility of dropwise condensation. The investigation was to further include the condensing characteristics of copper tubes. The copper tube results were to be used as a reference in evaluating the titanium tube condensing behavior.

REVIEW OF THE LITERATURE

In 1916, Nusselt (1) derived the equations governing the condensation of pure saturated vapors on wettable condensing surfaces. Nusselt postulated that the resistance to heat transfer was due solely to conduction across the continuous condensate film formed during the condensation process. By considering a force balance between the shear forces resulting from the viscosity of the condensate and gravitational forces resulting from the mass of the condensate, an equation was derived which predicted the thickness of the condensate layer as a function of the angle of the surface with a horizontal plane. Laminar flow and zero vapor velocity were assumed. Using the expression for the condensate film thickness, an equation was derived for the change in heat duty with position for a horizontal tube. By suitable integration of the expression, an equation was developed for the mean heat transfer coefficient for condensation of a pure saturated vapor on the surface of a horizontal tube which is lower in temperature than the saturated vapor. Equation (1) was the equation obtained.

$$h_m = 0.725 \left[\frac{k^3 \rho^2 g \lambda}{\mu D \Delta t_f} \right]^{1/4} \qquad (1)$$

where

h_m = mean condensing heat transfer coefficient, BTU/hr.-sq.ft.- °F

k = thermal conductivity of condensate evaluated at film temperature, BTU/hr.-sq.ft.- °F/ft.

ρ = density of condensate evaluated at film temperature, lb./cu.ft.

g = acceleration due to gravity, taken as 4.17×10^8 ft./hr.^{2}

λ = latent heat at saturation temperature, BTU/lb.

μ = viscosity of condensate evaluated at film temperature, lb./ft.-hr.

D = outside diameter of tube, ft.

Δt_f = temperature drop across condensate film, $t_{sv} - t_s$, °F

t_s = outside wall temperature of the tube, °F

t_{sv} = temperature of the saturated vapor, °F

For laminar flow of condensate, the film temperature, t_f, is given by

$$t_f = t_{sv} - \frac{3}{4} \Delta t_f \qquad (2)$$

Experimental investigations of the condensation of pure saturated vapors on single horizontal tubes indicate that Equation (1) predicts values generally within $\pm 10\%$ of the experimental condensing coefficients.[1] The experimental coefficients are most often higher than the theoretical values. This is attributable to turbulence or rippling in the condensate layer. The average film temperature is often evaluated using Equation (3) when turbulent flow of the condensate is expected.[2]

$$t_f = t_{sv} - \frac{1}{2} \Delta t_f \qquad (3)$$

When several horizontal tubes are placed in a vertical row such that condensate from the upper tubes drops onto the lower tubes, the mean thickness of the condensate film on a particular tube increases from the top tube to the bottom tube. By accounting for the accumulation of condensate from tube to tube, but still assuming laminar flow of the condensate, Equation (4) was derived to predict the average condensing coefficient, h_m, for n tubes located in a vertical row.[1]

$$h_m = 0.725 \left[\frac{k^3 \rho^2 g \lambda}{n \mu D \Delta t_f} \right]^{1/4} \qquad (4)$$

where

n = number of tubes in a vertical row

Equation (3) would be used for calculating t_f if turbulent flow of condensate is expected. Experimental data taken on multiple horizontal tubes in a vertical row by Katz and Geist[3], Short and Brown[4], and Young and Wohlenberg[5] indicate that Equation (4) is very conservative. The correction for multiple tube rows of $(1/n)^{1/4}$ is much too severe in view of the high degree of turbulence and splashing with condensate dropping from tube to tube. A turbulence correction factor, C_n, was added to Equation (4) by Katz, Young and Balekjian[2] to give Equation (5).

$$h_m = 0.725\, C_n \left[\frac{k^3 \rho^2 g \lambda}{n \mu D \rho t_f} \right]^{1/4} \qquad (5)$$

Equation (5) corrects the basic theoretical Nusselt model with the correction factor, C_n, and gives a means of correlating experimental condensing data for multiple tube arrangements.[2] The correction factor, C_n, varies with the number of tubes in a vertical row and with the physical properties of the material being condensed. The surface tension of the condensate film is extremely important.

Whenever the cooling surface is not wetted, the condensing vapor tends to form very fine drops which roll off the condensing surface due to the influence of gravity. This phenomena is called dropwise condensation. In dropwise condensation the drops normally agglomerate to form larger drops. Since a significant portion of the cooling surface is always free of liquid, the net resistance to heat transfer is lower than for film condensation. Dropwise condensation is generally associated with the existence of a contaminant on the tube surface. Mercaptans and fatty acids are effective promoters of dropwise condensation.[1] Where tube surfaces are mildly contaminated, mixed condensation may exist. Part of the surface will exhibit filmwise condensation while the remainder of the surface is condensing vapor in a dropwise fashion. This frequently happens with condenser tubes which have been in continuous condensing service for a long time.

The existence of any non-condensible gas in the condensing vapor significantly affects the rate of heat transfer due to the buildup of a non-condensible gas around the cooling surface. The concentration of a non-condensible gas around the tube surface forms a barrier through which the condensing vapor must diffuse prior to condensing. The temperature of the free surface of the condensate film will be equal to the saturation temperature of the condensing vapor at a pressure equal to the partial pressure of the condensing vapor at the outer film surface.

As the saturation temperature decreases with the decreased partial pressure due to the non-condensible gas, the temperature driving force for heat transfer across the condensing film decreases. The rate of heat transfer also decreases. Experimental work by Othmer[6] and Hampson indicates that as little as 1.5 % air by volume can reduce the condensing coefficient by 50 %. The greatest effects occur when there is little motion of vapor across the tubes. Under these conditions, most of the non-condensible gases eventually migrate to the vicinity of the tube surface.

An extensive experimental program was recently completed by the British Admiralty in which condensing heat transfer data were obtained for multiple tube arrangements with film and dropwise condensation of steam.[7] Photographic studies indicated that heat fluxes six times the average heat flux were obtained in the drop tracks formed in dropwise condensation when large drops rolled across the surface leaving a "bare" metal surface. About one-fifth of the surface had fresh drop tracks at all times. They concluded that high heat fluxes are sustained for times in the order of seconds in very narrow width tracks. The heat flow through these tracks then diverged in crossing the tube wall because the entire internal surface is utilizable for heat transfer. Because of this, they concluded that very thin metal walls would limit the effectiveness of dropwise condensation.

The investigators further determined the effect of condensate inundation on the condensing heat transfer coefficient. By pumping condensate through a perforated tube placed above the test section, the tube on which data were taken could effectively simulate any tube in a vertical row of 22 tubes. For filmwise condensation, the condensing coefficient first decreased with inundation due to a thicker condensate film, and then reversed the trend due to increased turbulence at about the 14th or 15th tube.

In dropwise condensation, the effect of inundation was to first increase the condensing coefficient due to enhanced wiping action for the top 6 or 7 tubes followed by a gradual decrease. The coefficient for the simulated 22nd tube in a vertical row was higher than for the top tube.

EQUIPMENT

The equipment in this investigation consisted of a condenser, inlet and outlet water headers, reboiler, make-up tank, water preheater pump, steam jet ejector and automatic controllers. Figures 1 and 2 give two views of the equipment and Figure 3 gives a line diagram showing the flow of steam and water. An elevation drawing of the condenser, reboiler and make-up tank is given in Figure 4. Steam was generated by boiling distilled water in the reboiler with 150 psig steam. The vapor flowed upward through an 8 inch line to the condenser where it condensed on the test tubes. The condensate returned to the reboiler through a 2 inch line. Water from the cooling tower system was used as the coolant.

The condenser was constructed of a 6 foot length of 18 inch diameter standard gauge commercial steel pipe. Ring flanges were welded to each end of the pipe. The flanges were made from 2 inch thick plate steel with a bolt circle identical to a standard 18 inch, 150 pound flange. Tube sheets were constructed from 2 inch plate steel with both sides surface ground to give a flat surface. Figure 5 gives a detailed drawing of the tube-sheets showing the tube layout and double O-ring grooves. The tube sheets were constructed to accommodate 25 tubes placed in 3 vertical rows with the tubes on a 7/8 inch equilateral triangular pitch. O-rings were used to seal the tubes in the tube sheet. An 8 inch by 60 inch section was removed from the top of the condenser. An 8 inch welding tee and two pieces of 8 inch pipe with the bottom half cut off was then welded to the condenser over the open section, as shown in Figure 6. This formed the steam inlet to the condenser. An impingement baffle consisting of a piece of 3 inch pipe cut in half was placed over and 2 inches above the tubes in the condenser. This prevented direct impingement of steam onto the tubes. A 2 inch diameter pipe located at the bottom of the condenser returned the condensate produced in the condenser to the reboiler. Sight glasses were provided for visual observation. These can be seen in Figures 1 and 2. Corrugated metal asbestos gaskets were used between the tube sheets and ring flanges.

The inlet and outlet water headers consisted of 1 foot lengths of 14 inch standard gauge steel pipe with 1 inch steel plates welded to the pipe. The plates closest to the condenser contained tube holes in a pattern identical to the condenser tube sheets. Single O-ring grooves were cut in each hole. A section of 3 inch pipe extended into the other plates approximately 6 inches. These pipes served as the inlet and outlet water lines. The ends of the pipe within the headers were blanked off and sections cut out of the pipe wall. This was done to insure a more nearly uniform distribution of water flow within the tubes. The inlet and outlet water headers were placed approximately 5 and 25 inches from the condenser respectively. In these positions, 8 foot tubes with a 9 inch orifice holder could be placed in the condenser such that the tubes extended into the headers approximately 1 inch.

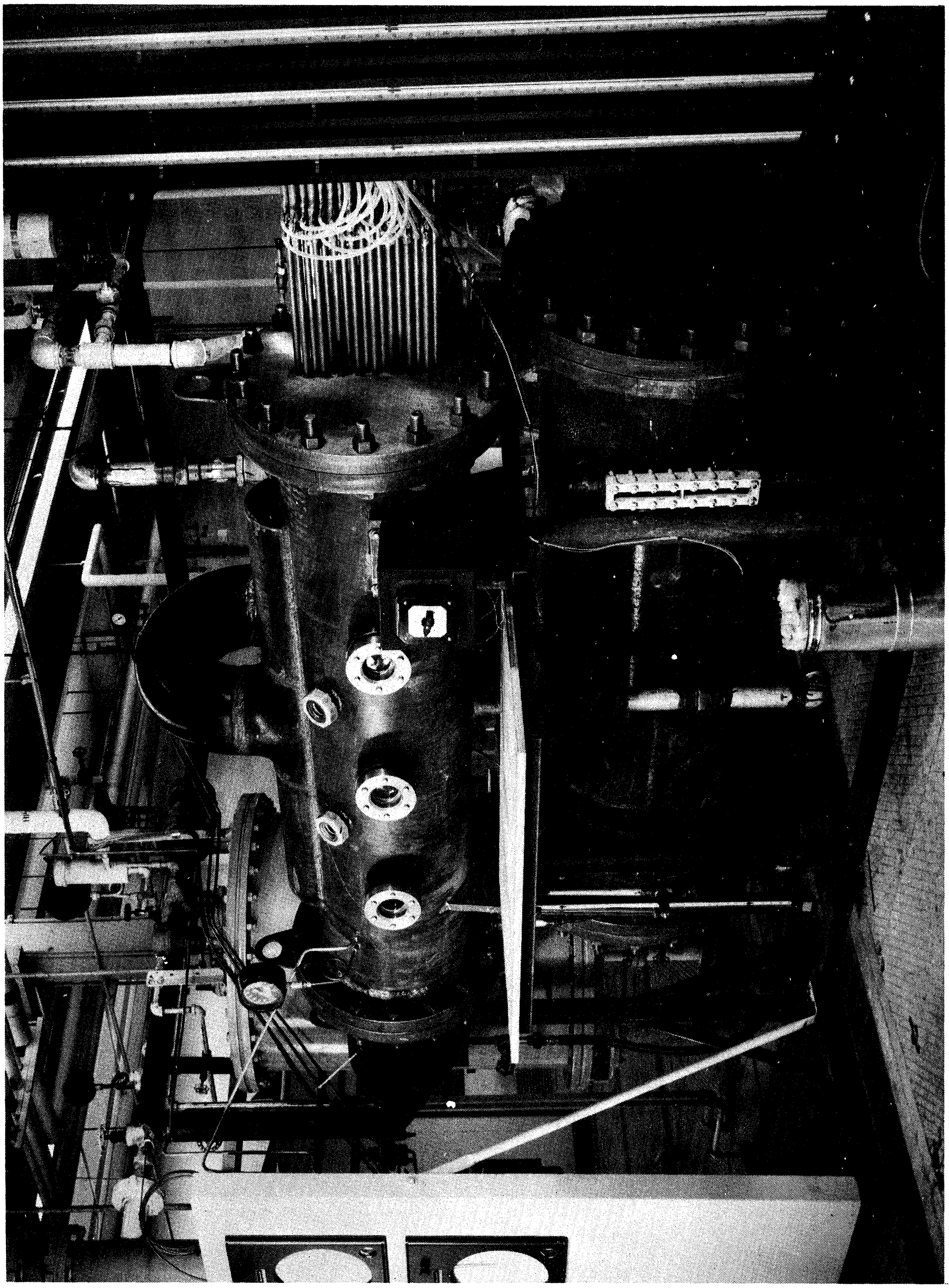

Figure 1. Overall View of Equipment Showing Test Tubes in the Tube Sheet

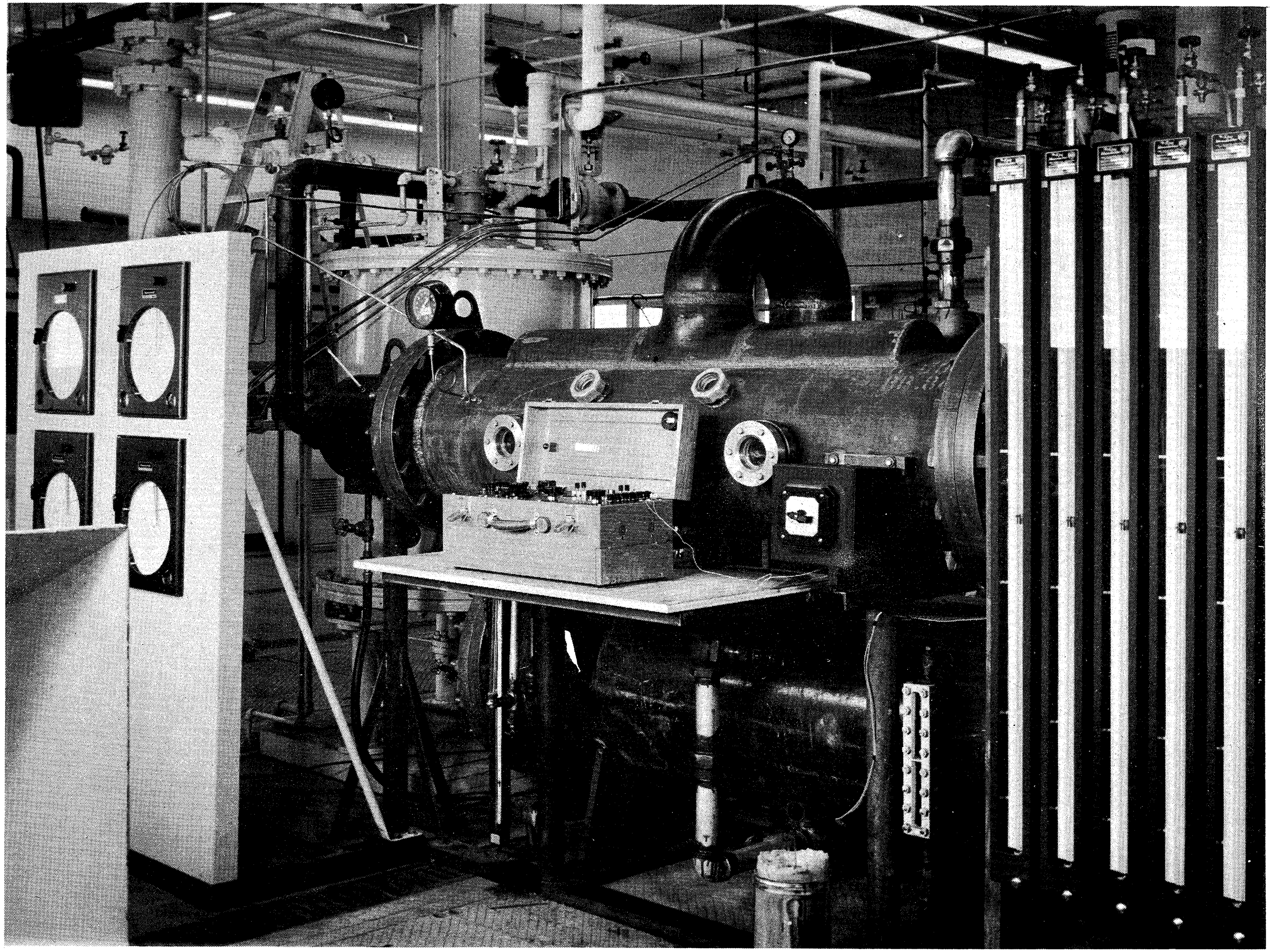

Figure 2. Overall View of Equipment Showing Automatic Controlled, Potentiometer, and Manometers

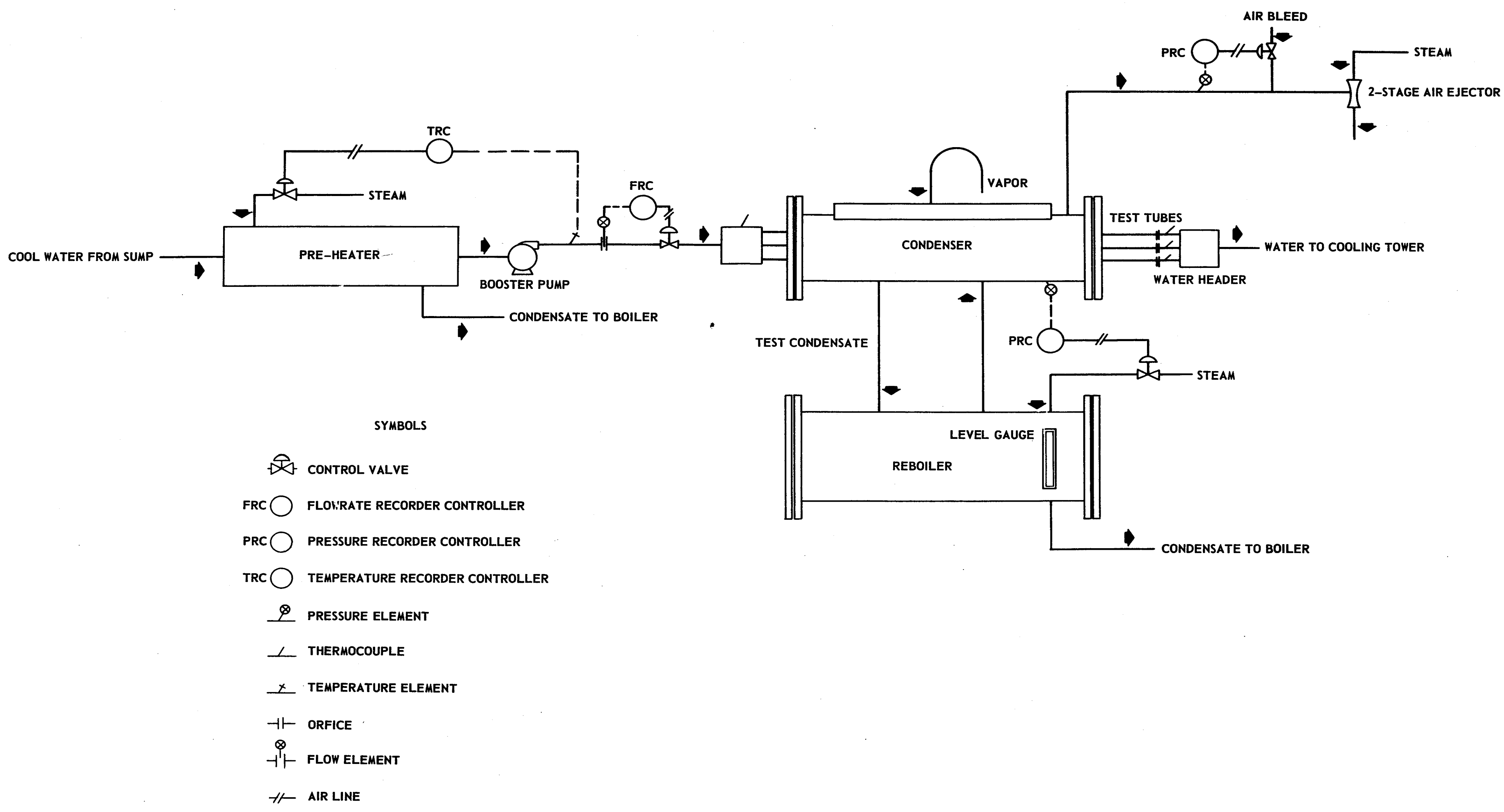

Figure 3. Line Diagram of Equipment Show the Flow of Steam and Water

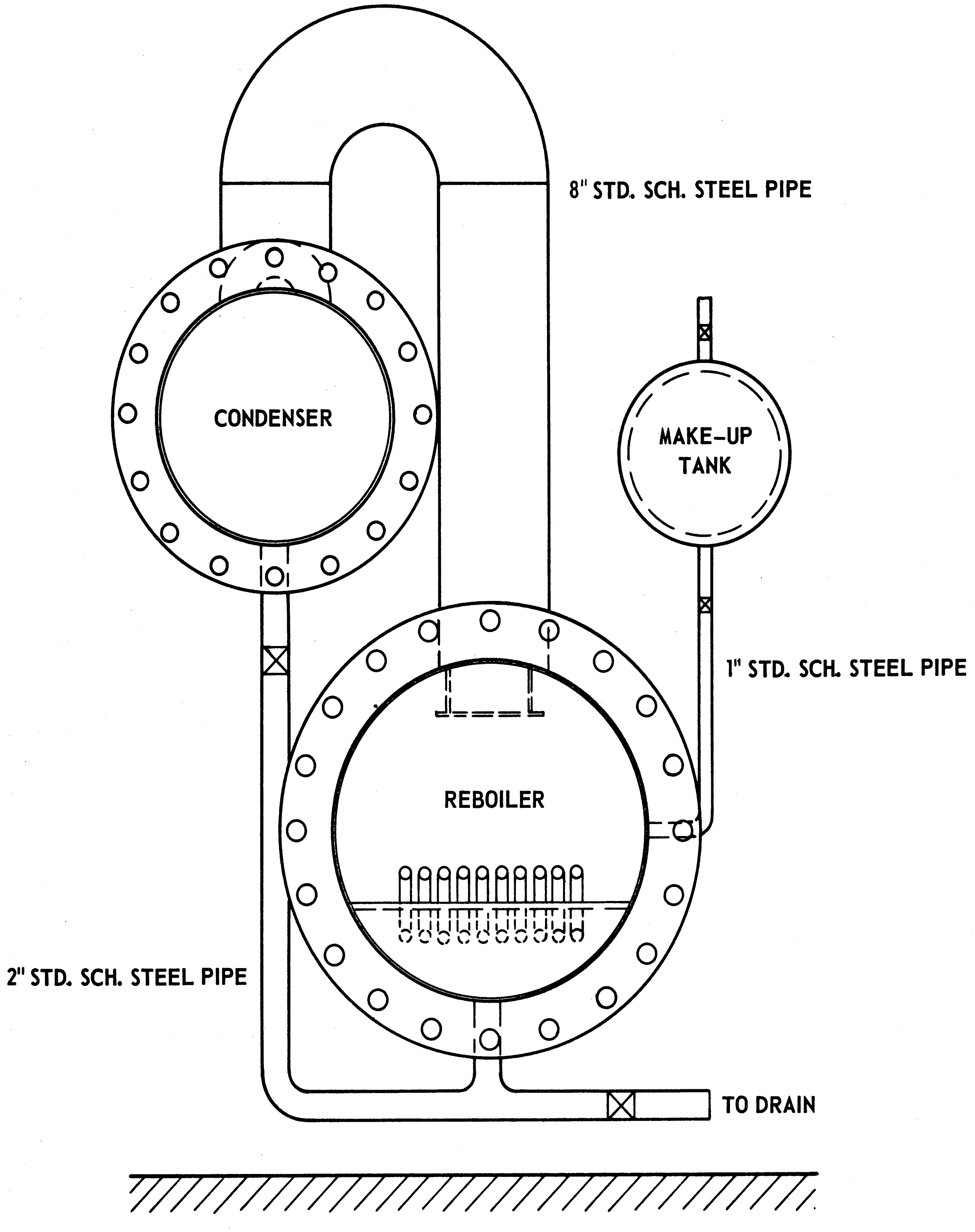

Figure 4. Elevation Drawing of Condenser, Reboiler, and Make-up Tank with the Condenser Tube Sheets and Reboiler Blind Flanges Removed

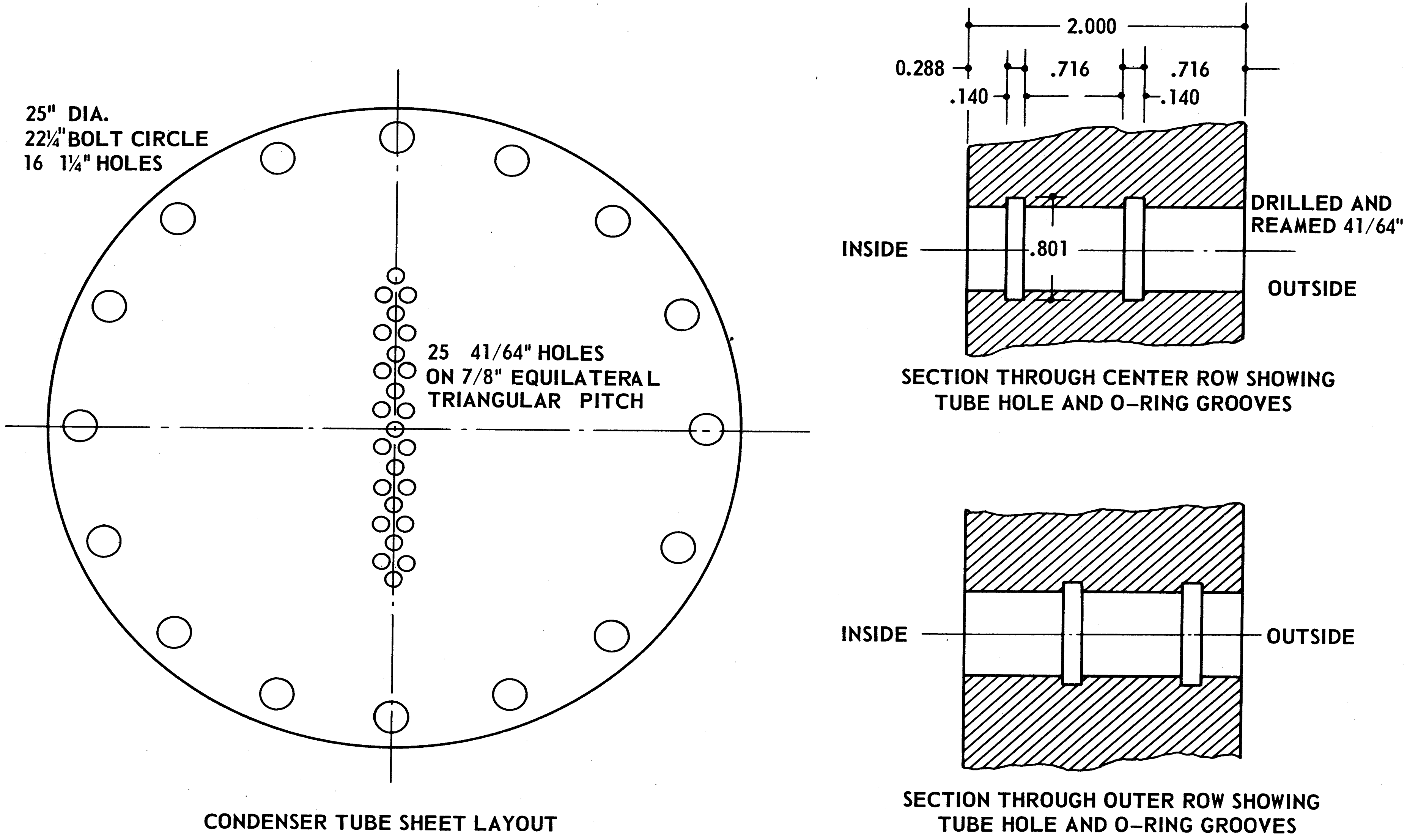

Figure 5. Detailed Drawing of Condenser Tube-Sheets and O-Ring Grooves

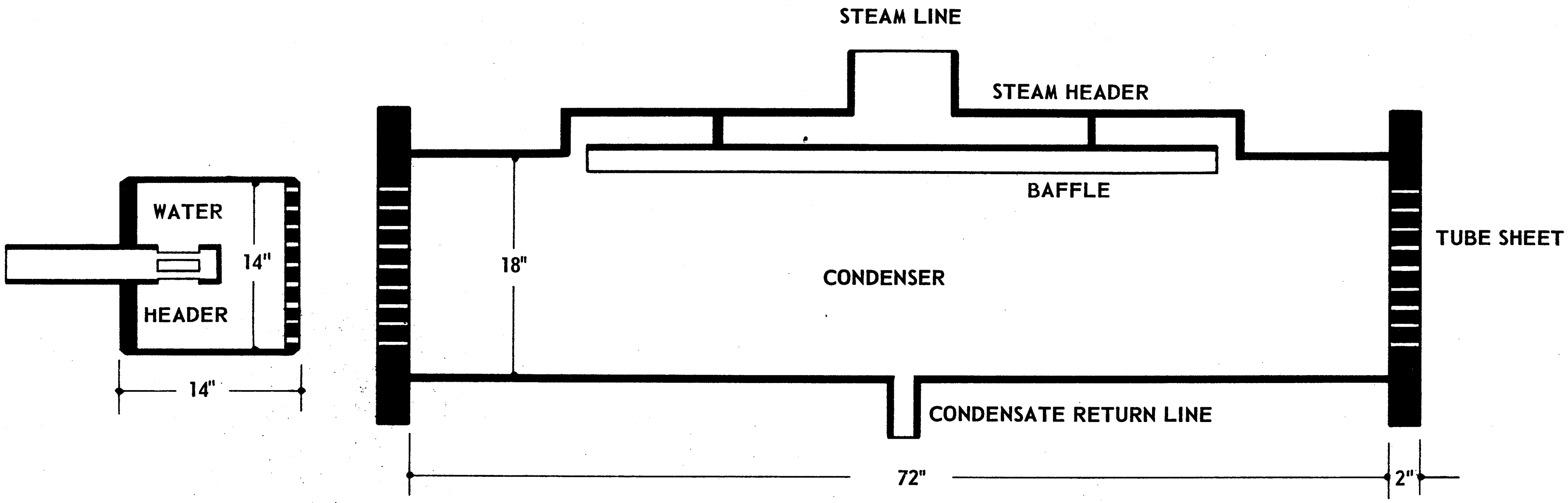

Figure 6. Cross-Sectional Drawing of Condenser and Inlet Water Header

The reboiler was constructed of a 6 foot length of 24 inch diameter standard gauge commercial steel pipe. Ring flanges were welded to each end of the pipe. The flanges were constructed from 2 inch plate steel with a bolt circle identical to a standard 24 inch, 150 pound flange. Companion blind flanges were constructed of similar material. The flanges were bolted together with a corrugated metal asbestos gasket placed between the two flanges. A 2 inch thick steel tube sheet was constructed and welded into place 6 inches within the shell. The tube sheet was made to accommodate 10, 10 foot long, 3/4 inch O.D. U-bend tubes. The layout is shown in Figure 4. Type S/T copper trufin U-bend tubes were rolled into the tube sheets. Tube supports were provided within the reboiler. A partition plate was welded to the tube sheet between the tube inlet and outlet. An additional piece of metal was welded to the partition plate to form a box such that the condensate could be kept separate from the entering steam. High pressure steam (150 psig) was used to vaporize the water in the reboiler. The condensate was returned to the high pressure boiler through a steam trap. A Jergensen gauge installed on the front of the reboiler made it possible to determine the water level in the reboiler.

A 25 gallon water make-up tank was located immediately above and slightly behind the reboiler as shown in Figure 4. A 1 inch diameter pipe with a valve connected the make-up tank to the reboiler and permitted the transfer of water to the reboiler during operation. A sparged steam line in the make-up tank made it possible to preheat and partially de-gas the water before it was allowed to enter the reboiler.

A 12 foot long, 15 inch diameter heat exchanger was installed in the inlet water line to permit the preheating of the cooling water to the desired temperature. The heat exchanger was converted from a two-tube pass until to a single tube pass unit to reduce the pressure drop. High pressure steam was condensed on the outside of the tubes. The condensate was returned to the high pressure boiler through a steam trap.

A 300 gpm submersible pump was modified and installed in the cooling water line immediately after the water preheater. The pump was used during high velocity runs when the main cooling water pump had insufficient head to give the desired water flow rate.

A two stage jet ejector with interstage condenser was used to evacuate the condenser-reboiler system on start-up and also permitted the removal of non-condensible gases which leaked into the system during operation. The ejector was connected to the reboiler with a 2 inch diameter pipe containing a 2 inch globe valve. The ejector operated on high pressure steam and process cooling water.

Four automatic controllers were installed to assist in the operation of the equipment when taking data. The controllers can be seen in Figure 2. One instrument controlled the water flow rate. A 2 inch diameter orifice flange with orifice was installed in the inlet water line. The pressure drop across the orifice served as the input signal to the controller. The controller pneumatically actuated a 2 inch globe valve which kept the flow rate at the desired value. A second instrument was an inlet cooling water temperature controller. A mercury filled bulb installed in the water line served as the sensing element for the controller. The controller pneumatically actuated a steam valve which regulated the amount of steam entering the water preheater. The remaining two instruments were absolute pressure controllers. One sensing element was connected to the condenser. The controller used the pressure signal to regulate the amount of steam entering the reboiler through a 3/4 inch pneumatically operated valve so that the desired pressure in the condenser could be maintained. The second pressure controller was installed in the steam jet ejector system to minimize fluctuations in pressure at the ejector due to variations in the steam flow rate. The control instrument controlled a small bleed valve. By bleeding in small amounts of air, the pressure in the ejector header could be kept relatively constant.

The water flow rates in each tube were measured by calibrated orifices placed in orifice holders which were located at the outlet end of the test tubes between the condenser and the exit water header. Figure 7 shows the orifice assembly. The orifices were calibrated for each tube tested. The pressure drop across the orifices were measured with water over mercury manometers. Both 50 inch and 100 inch manometers were used. A manifolded system permitted the same manometer to be used for several orifices. The accuracy of the flow rate measurement was between 1/4 and 1/2 percent.

Inlet water, outlet water, and condenser steam temperatures were measured with calibrated 30 gauge copper constantan thermocouples using a Leeds and Northrup K-3 potentiometer. Temperatures could be measured to 0.01 °F. The inlet water thermocouple was placed in the inlet water header. The exit water thermocouples were located in the orifice holder assemblies as shown in Figure 7. The stainless steel sheath extended up-stream along the tube axis for 1 inch. Thermocouples were placed in two places in the back of the condenser to permit the measurement of the steam temperature.

The condenser absolute pressure was determined with a mercury manometer and calibrated barometer.

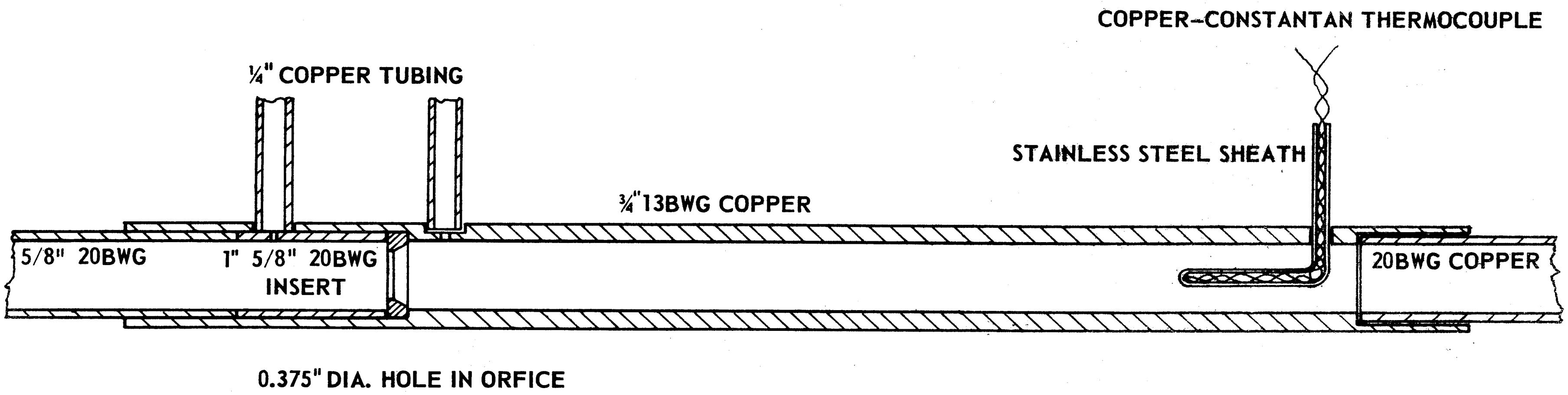

Figure 7. Cross-Sectional Drawing of Orifice Holder Assembly

TEST PROCEDURE

The test equipment was thoroughly degreased upon completion of the construction phase of the investigation. To do this, 9 foot long, 5/8 inch diameter, plain copper tubes were inserted into the condenser through the O-rings in the condenser tube sheets. Each tube sheet had two O-rings. The inlet water heater was placed into position and the tubes pushed into the header through the tube holes containing single O-rings. The tubes were pushed into the header approximately 6 inches. The outlet water header was then placed into position and the tubes pulled back into the outlet water header, leaving approximately 3/4 to 1 inch of tube extending into the headers at both ends. A 55 gallon barrel of trichlorethylene was added to the reboiler and the steam line to the reboiler was opened. Cooling water was allowed to flow through the tubes. Trichloroethylene was boiled in the reboiler, condensed on the copper tubes and returned to the reboiler. Since the trichlorethylene temperature was higher than the ambient temperature, some condensation occurred throughout the entire system. This insured a thorough cleaning throughout. The used trichlorethylene was transferred to an empty barrel and a clean barrel of trichlorethylene added for a final cleaning. Upon completion of cleaning, the copper tubes were removed. The orifice assemblies were attached to the test tubes with soft solder in the case of copper tubes and with epoxy resin in the case of titanium tubes. The tubes were wiped with trichlorethylene and placed into the condenser and headers as previously described. Vacuum putty was placed around each tube in the condenser to reduce the amount of air leakage into the system. The thermocouple circuit was wired up and the manometer tubing installed. A 24 point thermocouple selector switch was used. Fiber glass insulation was placed around the tubes to minimize heat loss.

During normal operation, the reboiler was 1/2 to 2/3 filled with distilled water through the water make-up tank. Once the reboiler was filled to the desired level, steam and water to the steam jet ejector were turned on and adjusted to give the maximum evacuation rate. The ejector was allowed to operate for approximately 30 - 45 minutes to thoroughly evacuate non-condensible gases from the condenser-reboiler system. The pressure in the condenser rapidly approached the vapor pressure of the water in the reboiler during this period. With the ejector still pulling a vacuum on the system, the condenser pressure controller was set at the desired pressure setting. The automatically controlled steam valve in the reboiler steam line then opened allowing the water in the reboiler to be heated until the vapor pressure of the water equalled the set point pressure. The system was operated under these conditions for approximately 20 - 30 minutes. This further assisted in degassing the water and evacuating the system. The cooling water controller was next set to the desired total water flow rate and the inlet water temperature controller set at the desired inlet water temperature. The steam jet ejector manifold pressure controller was set at a pressure somewhat below the condenser pressure. This minimized the air bleed and permitted maximum removal of non-condensibles during the period when data were taken. There was always a small amount of air leakage into the system. Prior to taking data, the saturated steam temperature was calculated and compared to the steam temperature measured with a thermocouple. If the two temperatures agreed within 1/2 °F, the system was considered ready for taking data. If the temperature calculated from the pressure was greater than 1/2 °F above the measured temperature, an excessive amount of air still remained in the system and evacuation was continued until satisfactory agreement was obtained.

Heat transfer data were taken when the automatic controllers had stabilized all the control variables at the desired set points. The method of taking data depended upon its eventual use. If Wilson plot data were to be taken on the top tube only, the following readings were taken in order: inlet water thermocouple, exit water thermocouple, water flow rate manometer reading, condenser steam thermocouple, and condenser pressure manometer. A total of 10 sets of data were taken for each set point and the readings averaged. If heat transfer data were to be taken on all 9 tubes in the vertical row, the following readings were taken in order: inlet water thermocouple, exit water thermocouple for tube 1, condenser steam thermocouple, exit water thermocouple for tube 2, exit water thermocouple for tube 3, inlet water thermocouple, condenser steam thermocouple, exit water thermocouple for tube 4, exit water thermocouple for tube 5, exit water thermocouple for tube 6, inlet water thermocouple, condenser steam thermocouple, exit water thermocouple for tube 7, exit water thermocouple for tube 8, exit water thermocouple for tube 9, inlet water thermocouple, and condenser steam thermocouple. The pressure drop across the orifice for each tube was measured with a manometer approximately at the same time as the exit water temperature was being measured for the same tube. The condenser pressure relative to atmospheric measure was measured with a mercury manometer 2 or 3 times during the run. Barometer readings were made before and after the runs. The inlet water and condenser steam temperatures were plotted as a function of time in order that the exact values of those temperatures existing when the exit water temperatures were measured could be determined. This procedure was necessary to obtain the most accurate temperature differences between inlet and outlet water temperatures and the most accurate logarithmic temperature differences. The water temperature rise was used with the water flow rate to determine the heat duty. Usually three complete sets of data were taken for each set condition. During the course of a run which lasted about 5 - 10 minutes, the inlet water temperature varied approximately $\pm$ 0.2 °F and the condenser steam temperature varied by approximately $\pm$ 0.3 °F.

Whenever the water level in the reboiler dropped below 1/4 of the reboiler diameter, make-up water was added from the make-up water tank. The water was heated with steam and at least partially de-gassed before allowing it to flow into the reboiler. A small amount of water was always retained in the make-up tank in order to maintain a vacuum seal.

WILSON PLOT PROCEDURE AND RESULTS

The main purpose of this investigation was to measure the condensing coefficient for steam on various horizontal tubes at different operating conditions. Direct measurement of the condensing coefficient is a difficult undertaking. To do this, it is necessary to accurately measure the outside wall temperature at several locations. Since only a finite number of measurements can be made, only local coefficients are determined.

An alternative procedure is to calculate the condensing coefficient from the overall heat transfer coefficient. The overall heat transfer coefficient is calculated from

$$U_o = \frac{Q}{A_o \, \Delta T_m} \tag{6}$$

where

U_o = overall heat transfer coefficient, Btu/hr.-sq.-ft.- °F
Q = total heat transfer, Btu/hr.
A_o = total external heat transfer area, sq.ft.
ΔT_m = logarithm temperature difference °F

The heat duty, Q, is obtained experimentally from

$$Q = W c_p (t_{out} - t_{in}) \tag{7}$$

where

W = water flow rate-lb./hr.
c_p = specific heat of water - Btu/lb.- °F
t_{out} = outlet water temperature, °F
t_{in} = inlet water temperature, °F

The condensing coefficient can be obtained by rearranging the expression for the overall coefficient in terms of the individual resistances. This gives

$$\frac{1}{h_m} = \frac{1}{U_o} - \frac{A_o}{A_i h_i} - r_m \qquad (8)$$

where

h_m = mean condensing coefficient, Btu/hr.-sq.ft.- °F
A_i = total internal heat transfer surface, sq.ft.
h_i = inside heat transfer coefficient
r_m = metal resistance, hr.-sq.ft.(outside area) °F/Btu

The metal resistance, r_m, is easily calculated from the thermal conductivity of the metal and the tube dimensions. Empirical expressions are available for the calculation of h_i but they are not sufficiently good for accurate heat transfer work. This is attributable to entrance and exit effects, and other system idiosyncracies. A satisfactory equation as regards to form is the Sieder-Tate Equation, Equation (9).

$$\frac{h_i D}{k} = C_i \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]^{0.14} \qquad (9)$$

where

D_i = tube inside diameter, ft.
k = water thermal conductivity at bulk water temperature, Btu/hr.-sq.ft.- °F/ft.
C_i = inside heat transfer coefficient constant, dimensionless
G = mass flow rate, lb./hr.-sq.ft.
μ = water viscosity at bulk water temperature, lb./ft.-hr.
μ_w = water viscosity at average wall temperature, lb./ft.-hr.

The constant, C_i, must be obtained experimentally.

A familiar method for determining individual coefficients from the overall coefficient is known as the Wilson Plot technique.[8] The general scheme is to hold either the inside or outside coefficient constant while varying the other coefficient. The variation of the overall coefficient is, thereby, due to the varying heat transfer coefficient alone. If the expression for the overall heat transfer coefficient is written as

$$\frac{1}{U_o} - r_m = \frac{1}{h_m} + \frac{A_o}{A_i h_i} \tag{10}$$

and the condensing coefficient is assumed to be constant, then Equation (10) takes on the form

$$y = m x + b \tag{11}$$

where

$$y = \frac{1}{U_o} - r_m$$

$$b = \frac{1}{h_m}$$

$$m = \frac{1}{C_i}$$

$$x = \frac{A_o}{A_i \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]^{0.14} \left[\frac{k}{D_i}\right]}$$

By plotting

$$\left[\frac{1}{U_o} - r_m\right] \quad \text{versus} \quad \frac{A_o}{A_i \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]^{0.14} \left[\frac{k}{D_i}\right]}$$

the slope of the resulting straight line through the data equals $1/C_i$ and the intercept equals $1/h_m$. The intercept value corresponds to an infinite inside heat transfer coefficient.

Experimentally, it is very difficult to hold h_m constant since as the inside heat transfer coefficient changes, the wall temperature changes, and consequently, the temperature drop across the condensing film will also change. A modification of the Wilson plot technique can be made to eliminate this problem.

Equation (10) is first written in terms of the complete expressions for h_m and h_i

$$\frac{1}{U_o} - r_m = \frac{1}{C\left[\frac{k^3 \rho^2 g \lambda}{\mu D \Delta t_f}\right]^{1/4}} + \frac{A_o D_i}{A_i C_i k \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]_i^{0.14}} \qquad (12)$$

where C is the experimentally determined constant to replace the value of 0.725 in Equation (1).

In the expression for h_m, the variables

$$\left[\frac{k^3 \rho^2}{\mu \Delta t_f}\right]^{1/4}$$

will vary with changes in the inside heat transfer coefficient. Multiplying

Equation (12) by this group, Equation (13) is obtained.

$$\left[\frac{1}{U_o} - r_m\right]\left[\frac{k^3 \rho^2}{\mu \, \Delta t_f}\right]^{1/4} = \frac{1}{C\left[\frac{g \lambda}{D}\right]^{1/4}} + \frac{A_o D_i \left[\frac{k^3 \rho^2}{\mu \, \Delta t_f}\right]^{1/4}}{A_i C_i k \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]^{0.14}} \tag{13}$$

The group,

$$\frac{1}{C\left[\frac{g \lambda}{D}\right]^{1/4}}$$

can be held sufficiently constant so that Equation (13) has the form

$$y = m x + b \tag{11}$$

which is necessary in the Wilson plot technique.

If

$$\left[\frac{1}{U_o} - r_m\right]\left[\frac{k^3 \rho^2}{\mu \, \Delta t_f}\right]^{1/4}$$

is plotted versus

$$\frac{A_o D_i \left[\frac{k^3 \rho^2}{\mu \Delta t_f}\right]^{1/4}}{A_i k \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]^{0.14}}$$

for each data point and a straight line placed through the data in a least square sense, the intercept of the line with the ordinate is

$$\frac{1}{C \left[\frac{g \lambda}{D}\right]^{1/4}}$$

and the slope of the line is $1/C_i$. To obtain the correct values of the function to be plotted requires an iterative procedure. The first step is to assume a value for the inside heat transfer coefficient, C_i. From the water flow rate and temperatures, the Reynolds number and the water physical properties can be obtained. If

$$\left[\frac{\mu}{\mu_w}\right]^{0.14}$$

is initially taken equal to 1.0, an approximate value of h_i can be calculated from

$$h_i = \frac{k C_i}{D_i} \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu}{\mu_w}\right]^{0.14} \qquad (14)$$

The inside tube wall temperature is next calculated using Equation (15).

$$t_{wi} = t_{wa} + \frac{Q}{A_i h_i} \tag{15}$$

where

t_{wi} = average inside wall temperature, °F
t_{wa} = average bulk water temperature, °F

The wall temperature, t_{wi}, is used to evaluate μ_w and a more correct value of h_i obtained from Equation (14). Equation (15) is again evaluated to determine if the previous inside wall temperature is sufficiently accurate. If it is not, then the procedure is continued until satisfactory agreement is obtained. Once h_i is calculated for the assumed value of C_i, the condensing coefficient can be calculated from Equation (8). The temperature drop across the condensing film, Δt_f, is then calculated from

$$\Delta t_f = \frac{U_o \, \Delta T_m}{h_m} \tag{16}$$

and the film temperature, t_f, from

$$t_f = t_{sv} - \frac{1}{2} \Delta t_f \tag{3}$$

where

t_f = average condensing film temperature, °F
t_{sv} = temperature of saturated vapor, °F

The group

$$\left[\frac{k^3 \rho^2}{\mu \, \Delta t_f}\right]^{1/4}$$

is a function of t_f. With the value of that quantity known, the two functions required for the Wilson plot can be evaluated and plotted. A line is placed through the data in a least mean sense and the slope of the line evaluated. The reciprocal of the slope is the constant C_i. If the calculated value of C_i differs significantly from the assumed value, the calculated value is taken and the whole procedure repeated until there is sufficient agreement between the assumed and calculated values of C_i.

The average condensing coefficient constant for all the data can be calculated from the intercept value

$$C = \frac{1}{\text{intercept} \left[\frac{g \lambda}{D}\right]^{1/4}} \tag{17}$$

The actual values of the condensing coefficient and the individual values of C are obtained in the process of determining C_i.

A program was prepared for the University of Michigan IBM 7090 digital computer and all the Wilson plot data were processed using that program. The input data to the program were the water flow rate, inlet and outlet water temperatures, steam temperature, tube dimensions, thermal conductivity of the tube metal and an initial estimate for the inside heat transfer coefficient constant, C_i. The necessary physical properties of steam and water were written into the program. The program took the value of C_i, went through the process outlined and obtained the values of the two functions necessary for the modified Wilson plot. A least square subroutine was then used to compute the slope of the best straight line through the processed data and the intercept. The reciprocal of the slope is C_i. The assumed value of C_i was compared to the calculated value and if it differed by more than 0.1 per cent, the calculated value was used and the process repeated until the assumed and calculated values agreed within 0.1 per cent.

Four sets of Wilson plot data were processed. All the data were taken with a steam pressure of 2 inches of mercury absolute pressure and an inlet water temperature of 75 °F. The tube dimensions appear in Table I and the heat transfer data appear in Appendix A. Two sets of data were on a copper tube and two sets were on a titanium tube. In each set the heat transfer data were taken on the top tube in the center vertical row. The first sets of data for the copper and titanium tubes were taken with 25 tubes located in the condenser. The second sets of data were taken with only the 9 tubes in the center vertical row present. Rubber stoppers were used to plug the tube sheet holes not used in the latter runs.

The Wilson plot results for the four sets of data are presented graphically in Figures 8-11. The calculated values of the inside heat transfer constant, C_i, and the condensing coefficient constant, C, obtained from the intercept are given in Table II. As can be seen in Table II, the condensing constants in the second sets were higher than in the first. This is attributable to a reduction in the amount of non-condensibles present in the condenser by a factor of 2. Accurate leak rate curves were obtained for the system. Measurements of ejector evacuation rates were also made but they were not very accurate because of the rapid changes in the system pressure. It is estimated that the amounts of non-condensibles present in the first and second sets were less than 0.50 and 0.25 per cent by volume, respectively.

The average value of the inside heat transfer coefficient constants appearing in Table II is 0.02468 with maximum deviations of -2.5 per cent and + 3.5 per cent. Most, if not all, the deviation from the average can be attributed to experimental error since straight lines placed through the data in Figures 8-11 with slopes equal to 1/0.02468 appear as reasonable as the least square lines. To determine if the calculated values of the condensing coefficient constant would be reasonable if the inside heat transfer coefficient constant were to be taken as 0.02468, the Wilson plot data were reanalyzed. The results of the analysis are given in Figure 12 with the calculated values of the condensing coefficient plotted versus the amount of condensate produced on the tube in pounds per hour. The amount of condensate produced per hour is directly related to the tube-side water velocity. Exclusive of experimental errors, a trend in the condensing coefficient with the condensate loading can result from an error in the inside heat transfer coefficient due to the wrong coefficient or from an increase in the condensate turbulent level. Any trend due to variations in condensate turbulence is likely to be small. Since there is no obvious trend in the data of each set, the average value for C_i adequately represents the data.

The computer program and a set of typical output data are given in Appendix B.

TABLE I

Tube Dimensions and Characteristics

	Copper		Titanium	
	Top Tube	Average for Middle Row	Top Tube	Average for Middle Row
Tube type	plain	plain	plain	plain
Tube outside diameter, in.	0.6252	0.6252	0.5287	0.6271
Tube inside diameter, in.	0.5550	0.5550	0.5592	0.5581
Tube wall thickness, in.	0.0351	0.0351	0.0347	0.0345
Tube length, in.	72.156	72.156	72.156	72.156
Thermal conductivity, BTU/hr.-ft.^{2}- °F/ft.	196	196	10	10

TABLE II

Computed Values of the Inside Heat Transfer Coefficient Constant and the Condensing Coefficient Constant for Copper and Titanium Tubes

Set	C_i	Deviation from Average	Condensing Constant
1st Copper	0.02475	+0.3	0.7275
1st Titanium	0.02436	-1.3	1.1183
2nd Copper	0.02406	-2.5	0.9709
2nd Titanium	0.02555	+3.5	1.3223
Average	0.02468		

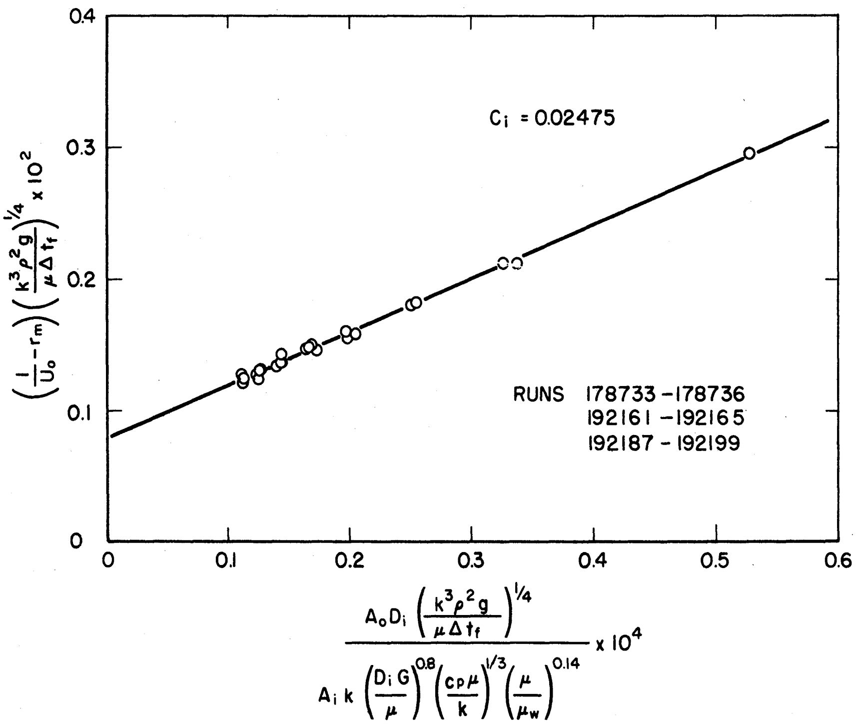

Figure 8. Modified Wilson Plot for the First Set of Copper Tube Data

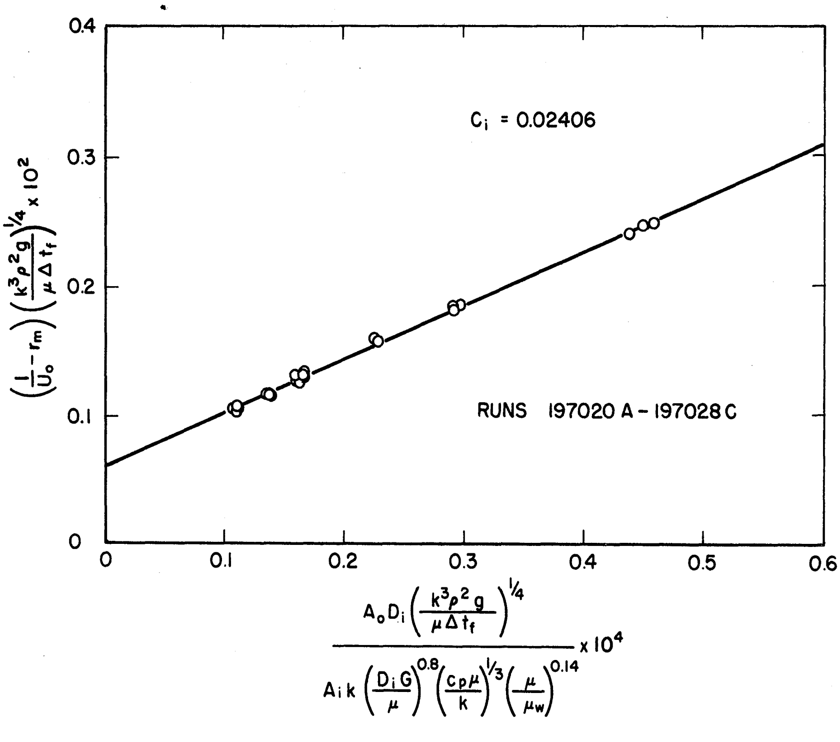

Figure 9. Modified Wilson Plot for the First Set of Titanium Tube Data

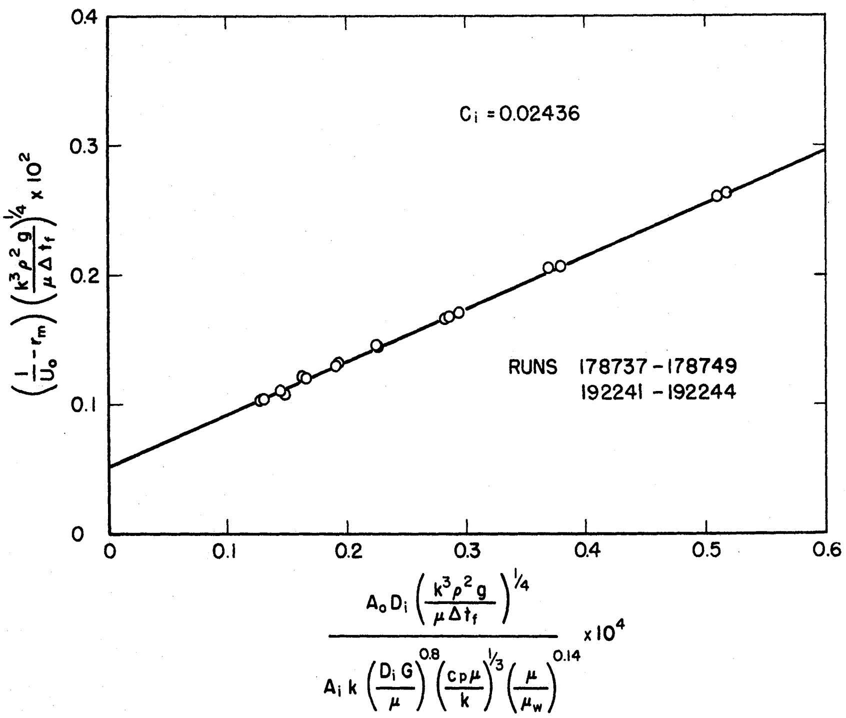

Figure 10. Modified Wilson Plot for the Second Set of Copper Tube Data

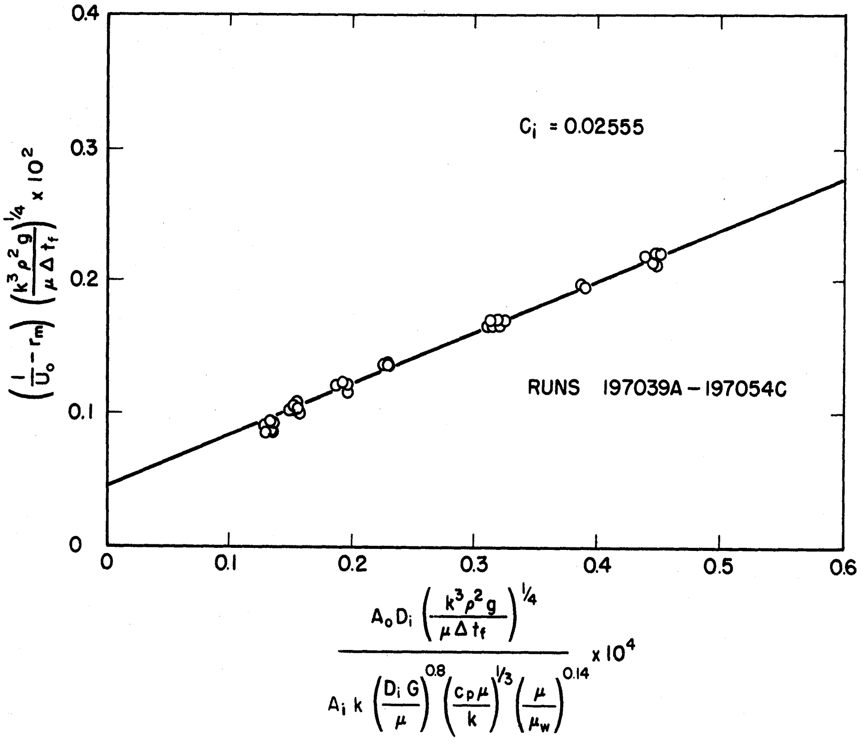

Figure 11. Modified Wilson Plot for the Second Set of Titanium Tube Data

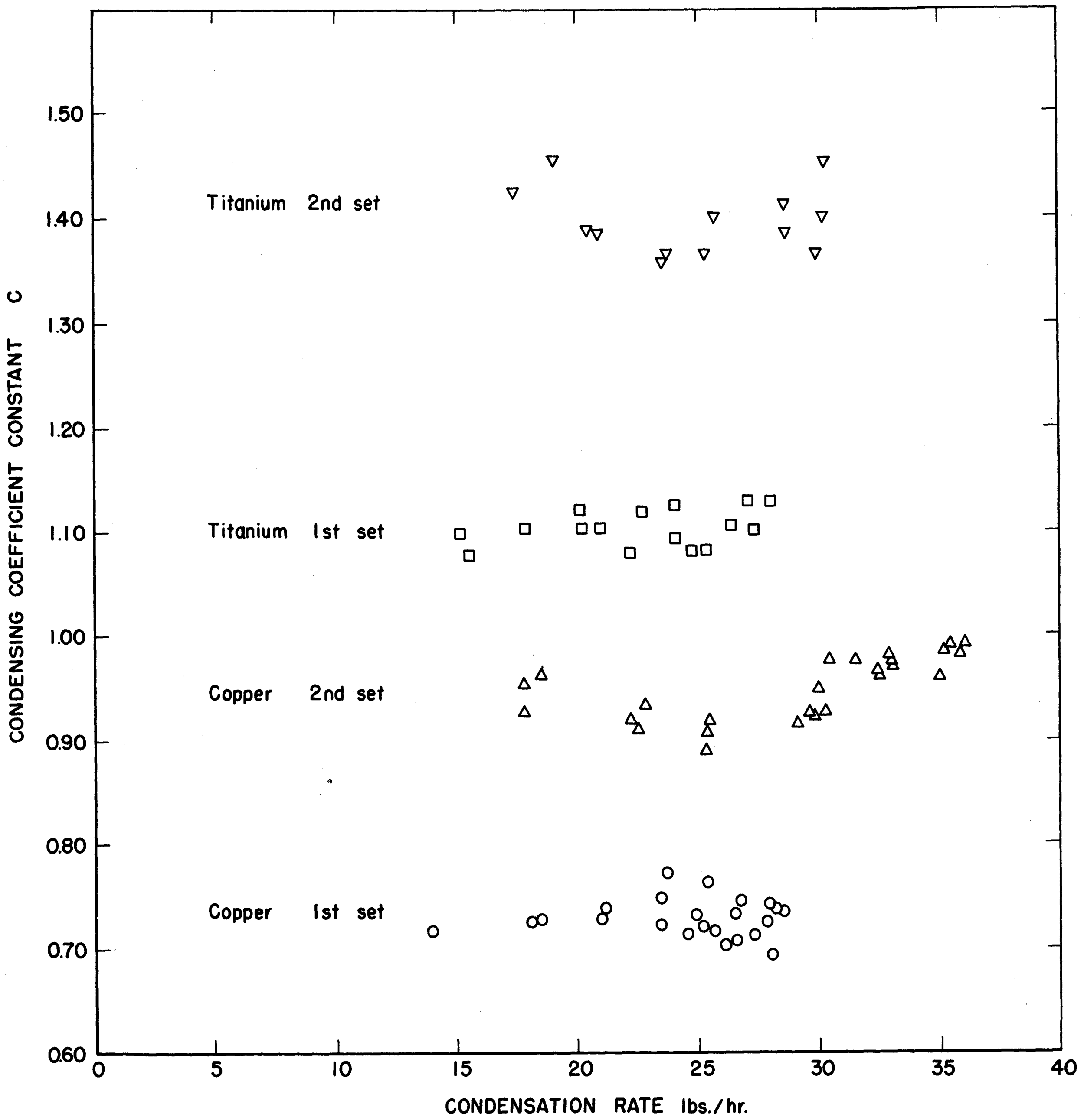

Figure 12. Condensing Heat Transfer Coefficient Constants Calculated from the Wilson Plot Data Using an Inside Heat Transfer Coefficient Constant of 0.02468

MULTIPLE TUBE DATA PROCESSING AND RESULTS

Two sets of heat transfer data were taken on the nine tubes in the center vertical row. The two side rows were excluded. The first set of data were taken on copper tubes and the second set on titanium tubes. The data appear in Appendix C.

The purpose of taking multiple tube data was to obtain the correction factor, C_n, for Equation (5), as a function of the number of tubes in a vertical row. A computer program was written for the IBM 7090 digital computer to process the data. The computer program consisted of three sections. In the first section the input data including the average value of the inside heat transfer coefficient were read into the computer and preliminary calculations made. These operations included the calculation for each tube of the heat duty, logarithmic temperature difference, overall heat transfer coefficient, water velocity, bulk water physical properties, inside heat transfer coefficients, and condensing coefficient by the method described in Equation (8). From the condensing coefficient and physical properties of the condensate film, the condensing coefficient constant for Equation (1) was calculated. The average inlet water temperature, water velocity, and steam temperature for all nine tubes were also calculated. A print out of the results completed the first section.

In the second section of the program, the average inlet water temperature, water velocity, steam temperature, and condensing coefficient constants for each tube were used to predict for each tube what the heat duty, exit water temperature, logarithmic temperature difference, overall heat transfer coefficient, inside heat transfer coefficient and condensing coefficient would have been had the inlet water temperature, water velocity and steam temperature been equal to the average values. These calculations put all the tubes on a consistent basis. A print out of the results completed the second section.

The condensing coefficient correction factor was calculated in the third section of the computer program. The correction factor is by definition that factor which makes Equation (5) an equality and is calculated from Equation (18).

$$C_n = \frac{h_m}{0.725 \left[\dfrac{k^3 \rho^2 g \lambda}{n \mu D \Delta t_f} \right]^{1/4}} \tag{18}$$

In Equation (18), the mean condensing coefficient, h_m, is the mean condensing coefficient for the top n tubes calculated from the experimental data. The correction factor for the top tube was calculated using the values of the heat duty and exit water temperature calculated in the previous section. The overall heat transfer coefficient, logarithmic temperature difference and inside heat transfer coefficients were then calculated and the mean condensing coefficient computed from Equation (8).

$$\frac{1}{h_m} = \frac{1}{U_o} - \frac{A_o}{A_i h_i} - r_m \qquad (8)$$

Equation (16) was used to calculate the temperature drop across the condensing film.

$$\Delta t_f = \frac{U_o \Delta t_m}{h_m} \qquad (16)$$

and Equation (3) used to calculate the film temperature.

$$t_f = t_{sv} - \frac{1}{2} \Delta t_f \qquad (3)$$

Once the film temperature is known, the quantity with n = 1

$$0.725 \left[\frac{k^3 \rho^2 g \lambda}{1 \mu D \Delta t_f} \right]^{1/4}$$

can be calculated and C_n computed from Equation (18) for the top tube.

To determine C_n for the top two tubes in the vertical row, the heat duties calculated in the second section for the top two rows were added to give the total heat transferred. Using mean values of the water density and heat capacity for the top two tubes, the average exit water temperature for the top two tubes was calculated. The logarithmic temperature difference, overall heat transfer coefficient and inside heat transfer coefficient were next calculated and the mean condensing coefficient calculated from Equation (8), the temperature drop across the condensing film calculated from Equation (16) and the film temperature calculated from Equation (3). The quantity

$$0.725 \left[\frac{k^3 \rho^2 g \lambda}{2 \mu D \Delta t_f} \right]^{1/4}$$

was computed and the correction factor for two tubes in a vertical row calculated from Equation (18).

The correction factors for 3, 4...9 tubes in a vertical row were calculated by adding the heat duties for the top n tubes and following the procedure previously outlined. Tables III and IV give the values of the condensing coefficient correction factors for a vertical row of 1 to 9 copper and titanium tubes respectively. The results were obtained from experimental data taken at a steam pressure of approximately 2 inches of mercury absolute and an inlet water temperature of 75 °F. Average values of C_n for each water velocity are given in Tables V and VI for copper and titanium tubes, respectively. The results are also presented in Figures 13 and 14. Average values of C_n for all the data as a function of the number of tubes in a vertical row are given in Table V for copper tubes and in Table VI for titanium tubes. These results are shown in Figure 15.

The computer program and typical calculated results can be found in Appendix D.

TABLE III

Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches Mercury Absolute Pressure on 1-9 Copper Tubes in a Vertical Row

Run No.	Vel.	C_n for n Copper Tubes in a Vertical Row: 1	2	3	4	5	6	7	8	9
197020A	6.071	1.3292	1.3060	1.3173	1.3243	1.3440	1.3780	1.3898	1.4060	1.4199
197020B	5.854	1.3171	1.3124	1.3092	1.3264	1.3446	1.3608	1.3724	1.3872	1.3985
197020C	5.879	1.2779	1.2969	1.3292	1.3360	1.3602	1.3765	1.3878	1.4055	1.4180
197021A	8.970	1.2901	1.2667	1.2946	1.3299	1.3454	1.3611	1.3687	1.3786	1.3906
197021B	8.907	1.2540	1.2614	1.2927	1.3183	1.3338	1.3502	1.3626	1.3789	1.3974
197021C	8.865	1.2651	1.2612	1.2760	1.2900	1.3098	1.3348	1.3459	1.3625	1.3799
197022A	11.616	1.2466	1.2569	1.2779	1.2926	1.3027	1.3260	1.3190	1.3330	1.3524
197022B	11.608	1.2268	1.2584	1.2652	1.2747	1.2926	1.3112	1.3196	1.3396	1.3622
197022C	11.598	1.2640	1.2586	1.2899	1.3009	1.3112	1.3332	1.3500	1.3674	1.3860
197023A	16.415	1.2723	1.2897	1.2998	1.3166	1.3484	1.3697	1.3697	1.3864	1.4067
197023B	16.393	1.3047	1.2680	1.3268	1.3596	1.3887	1.4063	1.4108	1.4246	1.4333
197023C	16.391	1.2606	1.2265	1.2447	1.2886	1.3221	1.3299	1.3487	1.3680	1.3863
197024A	20.355	1.3490	1.3331	1.3721	1.3812	1.4039	1.4237	1.4173	1.4315	1.4463
197024B	20.349	1.3337	1.3263	1.3680	1.3965	1.4217	1.4341	1.4387	1.4486	1.4614
197024C	20.330	1.3410	1.3605	1.4248	1.4608	1.4860	1.5069	1.4875	1.4947	1.5033
197025A	25.440	1.3170	1.3227	1.3610	1.3901	1.4157	1.4371	1.4379	1.4558	1.4711
197025B	25.441	1.3609	1.3523	1.3954	1.4200	1.4542	1.4761	1.4872	1.4964	1.5064
197025C	25.412	1.3461	1.3424	1.3821	1.4142	1.4444	1.4716	1.4881	1.5002	1.5149
197026A	16.888	1.3393	1.2869	1.3390	1.3664	1.3954	1.4152	1.4254	1.4318	1.4447
197026B	17.006	1.2687	1.2548	1.3164	1.3122	1.3449	1.3727	1.3790	1.3914	1.4093
197026C	17.122	1.2738	1.2902	1.2998	1.3347	1.3653	1.3759	1.3865	1.3997	1.4139
197027A	20.025	1.3417	1.3386	1.3651	1.3827	1.4054	1.4189	1.4295	1.4383	1.4500
197027B	20.012	1.3209	1.2692	1.3244	1.3578	1.3876	1.4094	1.4168	1.4256	1.4403
197027C	20.030	1.3323	1.3329	1.3694	1.3871	1.4106	1.4343	1.4252	1.4356	1.4529
197028A	25.528	1.3564	1.3473	1.3860	1.4088	1.4412	1.4682	1.4695	1.4803	1.4940
197028B	25.526	1.3605	1.3586	1.3923	1.4052	1.4293	1.4505	1.4605	1.4722	1.4877
197028C	25.509	1.3550	1.3561	1.3980	1.4251	1.4559	1.4689	1.4767	1.4870	1.5019

TABLE IV

Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches Mercury Absolute Pressure on 1-9 Titanium Tubes in a Vertical Row

		C_n for n Titanium Tubes in a Vertical Row								
Run No.	Vel.	1	2	3	4	5	6	7	8	9
197039B	6.561	2.0469	1.6098	1.6352	1.5634	1.5538	1.5496	1.5385	1.5568	1.5688
197039C	6.458	1.9287	1.5229	1.5799	1.5546	1.5538	1.5391	1.5368	1.5618	1.5788
197040A	9.390	1.8320	1.5144	1.5168	1.4904	1.4770	1.4926	1.4997	1.5201	1.5376
197040B	9.298	1.9756	1.6037	1.5480	1.5257	1.5248	1.5447	1.5425	1.5590	1.5796
197040C	9.312	1.8910	1.5661	1.5418	1.5377	1.5453	1.5582	1.5446	1.5561	1.5634
197041A	13.377	1.8025	1.4776	1.4271	1.4047	1.4071	1.4208	1.4172	1.4383	1.4576
197041B	13.362	1.9264	1.5651	1.4956	1.4615	1.4680	1.4788	1.4756	1.4932	1.5108
197043A	20.911	1.9215	1.5342	1.4751	1.4568	1.4945	1.5270	1.5156	1.5273	1.5398
197043B	20.819	1.9452	1.6350	1.5973	1.5322	1.5297	1.5250	1.4897	1.4793	1.4707
197044A	24.876	1.9854	1.6513	1.6066	1.6021	1.6203	1.6401	1.6456	1.6584	1.6692
197044B	24.884	1.9611	1.6246	1.5593	1.5695	1.5952	1.6131	1.6103	1.6275	1.6447
197044C	24.904	2.0514	1.6571	1.6309	1.6233	1.6369	1.6497	1.6501	1.6608	1.6774
197048A	13.286	1.8316	1.4979	1.4838	1.4989	1.5026	1.5047	1.5000	1.5048	1.5136
197049A	16.258	2.0196	1.2668	1.5406	1.4791	1.5051	1.4960	1.4776	1.4841	1.5315
197049B	16.270	1.8789	1.5202	1.4931	1.4552	1.4884	1.4913	1.4761	1.4810	1.4974
197049C	16.270	1.8676	1.5168	1.4700	1.4578	1.4698	1.4771	1.4520	1.4650	1.4898
197050A	21.020	1.8453	1.5460	1.5389	1.4861	1.5027	1.5013	1.4801	1.4932	1.5150
197050B	21.014	1.8632	1.5307	1.5103	1.4798	1.5032	1.5063	1.4959	1.5247	1.5489
197051A	24.842	1.8360	1.5944	1.6104	1.5915	1.7399	1.7242	1.6945	1.6896	1.6213
197051B	24.848	1.8801	1.6715	1.6510	1.6009	1.6219	1.6426	1.5961	1.6139	1.6340
197051C	24.835	1.9195	1.6065	1.5557	1.5071	1.5370	1.5471	1.5110	1.5419	1.5484
197052B	16.400	1.8383	1.4961	1.4502	1.4533	1.4794	1.4898	1.4940	1.4991	1.5152
197052C	16.364	1.9092	1.5958	1.5597	1.4906	1.4954	1.4866	1.4857	1.4893	1.5002
197053A	21.107	1.9730	1.5997	1.5426	1.4852	1.5082	1.4952	1.4849	1.4943	1.5144
197053B	21.035	1.8459	1.4895	1.4848	1.4523	1.4833	1.4953	1.4834	1.4879	1.4974
197054B	24.850	1.9551	1.6027	1.5339	1.5010	1.5360	1.5514	1.5594	1.5833	1.6054
197054C	24.846	1.8983	1.5374	1.4936	1.4726	1.4824	1.5075	1.5251	1.5459	1.5702
197047A	9.483	1.8539	1.5330	1.5143	1.4747	1.5087	1.5241	1.5302	1.5441	1.5613
197047C	9.516	1.9570	1.5970	1.5409	1.5074	1.4927	1.5016	1.4995	1.5448	1.5417

TABLE V

Average Values of Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches Mercury Absolute Pressure on 1-9 Copper Tubes in a Vertical Row

Avg. Vel. ft./sec.	C_n for n Copper Tubes in a Vertical Row								
	1	2	3	4	5	6	7	8	9
5.935	1.3081	1.3051	1.3186	1.3289	1.3496	1.3750	1.3833	1.3996	1.4121
8.914	1.2697	1.2631	1.2878	1.3094	1.3287	1.3487	1.3591	1.3733	1.3893
11.607	1.2391	1.2580	1.2777	1.2894	1.3022	1.3235	1.3295	1.3467	1.3669
16.702	1.2866	1.2694	1.3044	1.3297	1.3607	1.3783	1.3877	1.4003	1.4157
20.183	1.3364	1.3268	1.3707	1.3943	1.4192	1.4346	1.4358	1.4457	1.4590
25.476	1.3493	1.3466	1.3498	1.4106	1.4401	1.4620	1.4700	1.4819	1.4960
Average	1.3076	1.3013	1.3340	1.3356	1.3801	1.3393	1.4065	1.4195	1.4344

TABLE VI

Average Values of Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches Mercury Absolute Pressure on 1-9 Titanium Tubes in a Vertical Row

Avg. Vel. ft./sec.	C_n for n Titanium Tubes in a Vertical Row								
	1	2	3	4	5	6	7	8	9
6.510	1.9878	1.5664	1.6076	1.5590	1.5538	1.5444	1.5377	1.5593	1.5738
9.400	1.9019	1.5628	1.5324	1.5072	1.5097	1.5242	1.5233	1.5448	1.5567
13.342	1.8535	1.5135	1.4688	1.4550	1.4592	1.4681	1.4643	1.4788	1.4940
16.312	1.9027	1.5511	1.5027	1.4672	1.4876	1.4882	1.4771	1.4837	1.5068
20.984	1.8990	1.5559	1.5248	1.4821	1.5036	1.5084	1.4916	1.5011	1.5144
24.861	1.9359	1.6182	1.5802	1.5585	1.5962	1.6095	1.5990	1.6152	1.6213
Average	1.9135	1.5613	1.5361	1.5048	1.5184	1.5238	1.5155	1.5305	1.5445

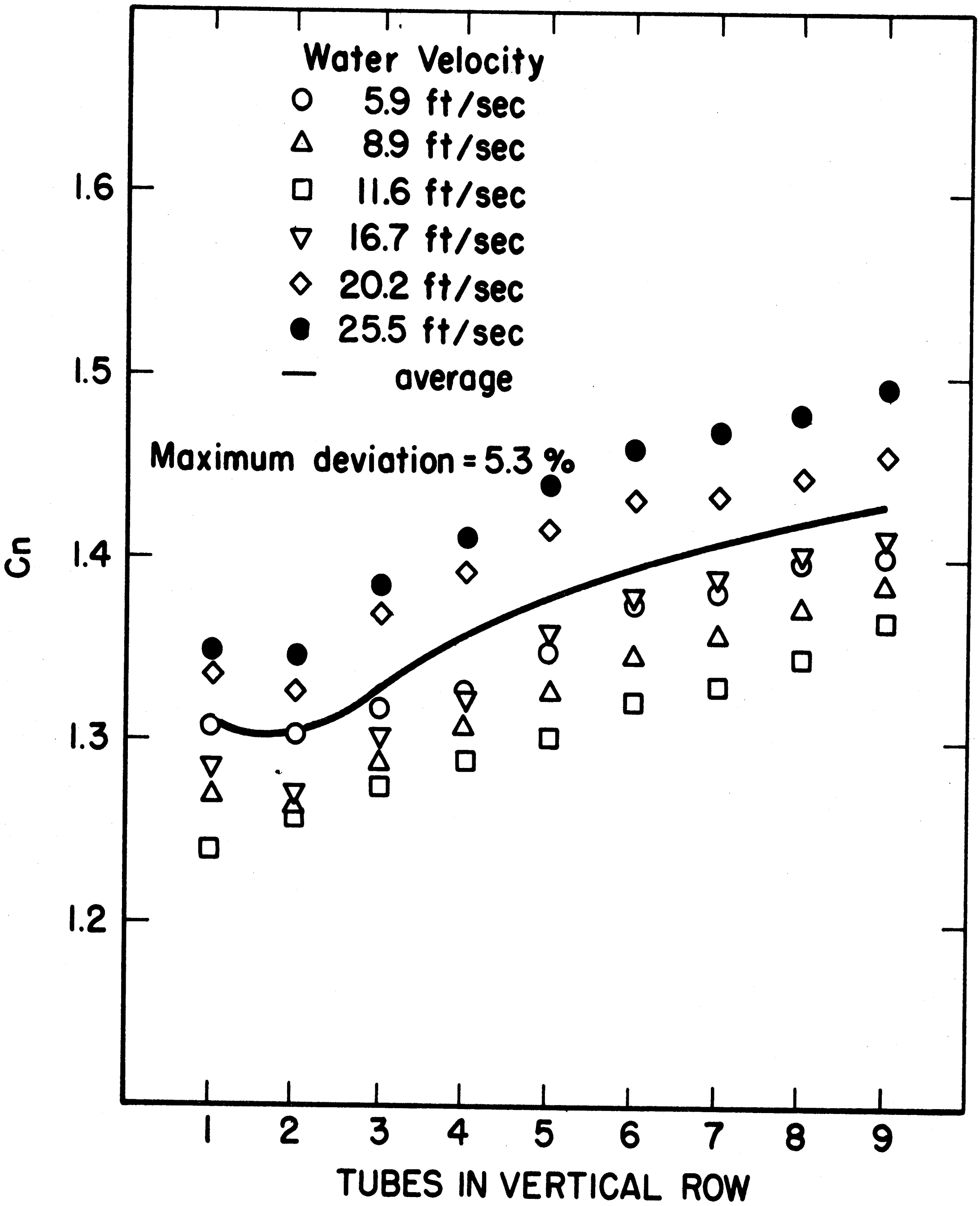

Figure 13. Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches of Mercury Absolute Pressure on 1 to 9 Copper Tubes in a Vertical Row

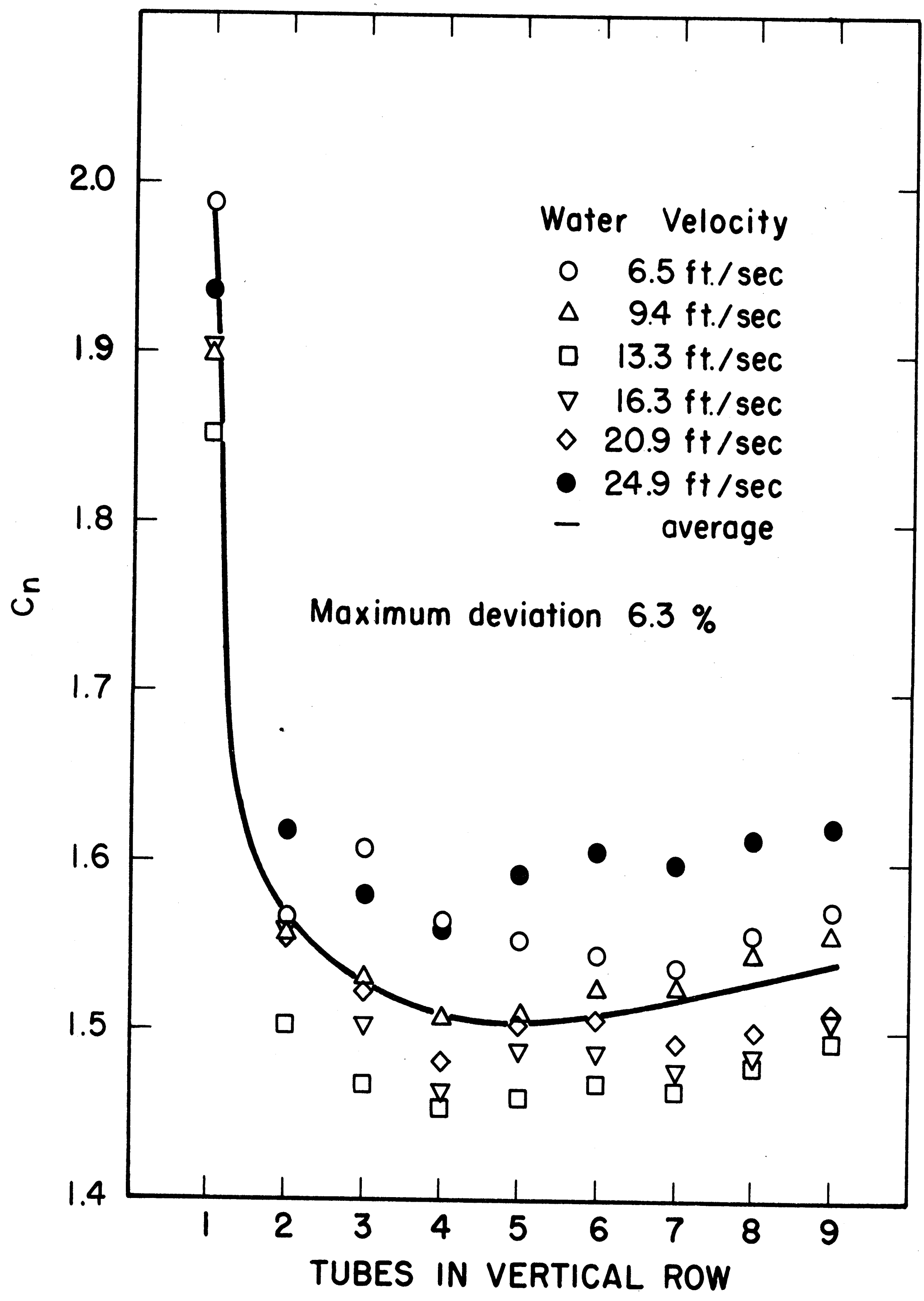

Figure 14. Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches of Mercury Absolute Pressure on 1 to 9 Titanium Tubes in a Vertical Row

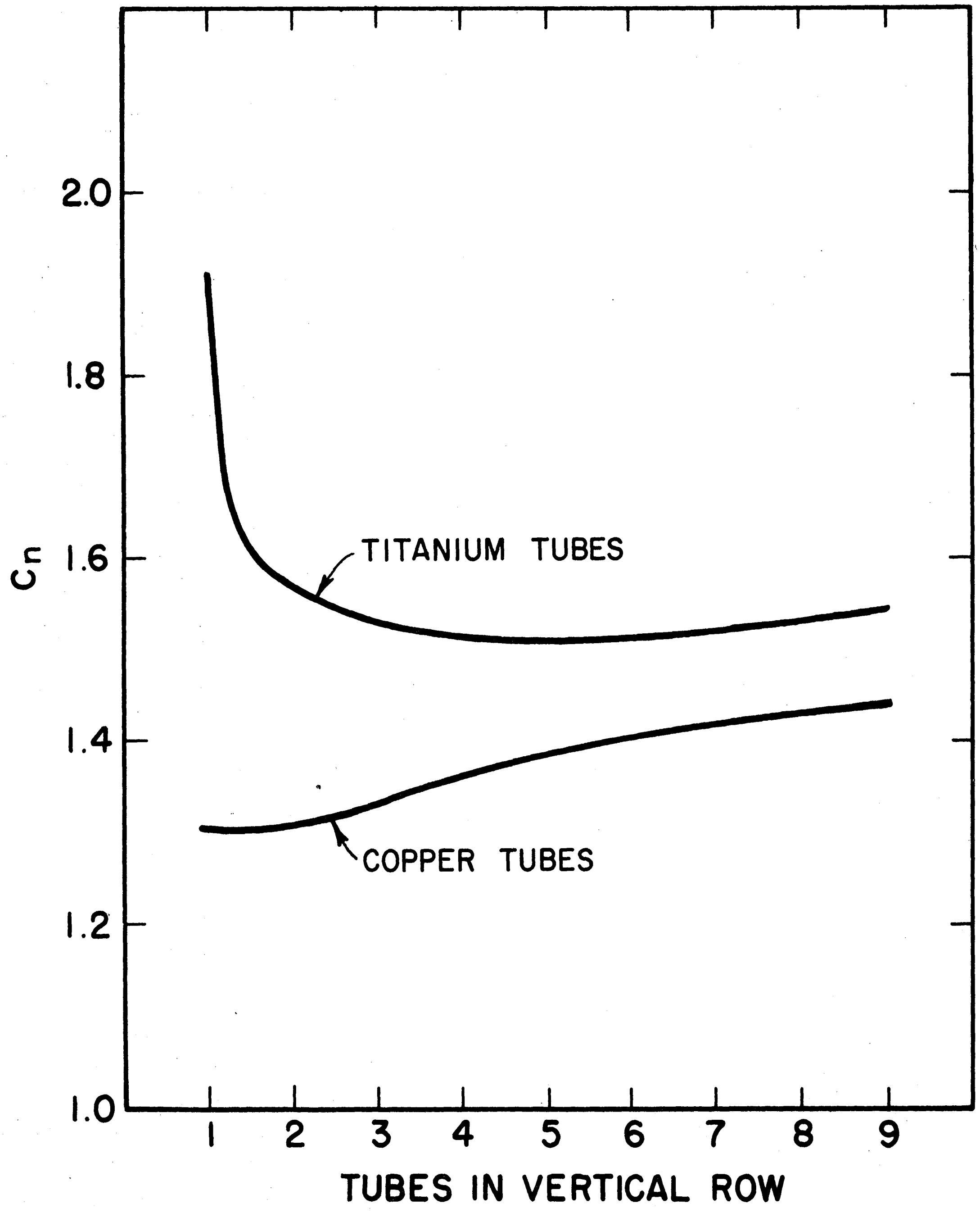

Figure 15. Mean Values of the Condensing Coefficient Correction Factors for Condensation of Steam at 2 Inches of Mercury Absolute Pressure on 1 to 9 Copper and Titanium Tubes in a Vertical Row

DISCUSSION OF RESULTS

The results of this investigation are given in Tables III - VI and Figures 13 - 15. As can be seen in Figure 15, the condensing coefficient correction factors, C_n, are higher for titanium tubes than for copper tubes. The maximum value of C_n for titanium tubes occurs for the top tube where C_n is 46 per cent higher than the value for the top copper tube. The difference in C_n diminishes to a more or a less constant value of approximately 8 per cent greater with 6 to 9 tubes in a vertical row. Inundation drastically reduces the effectiveness of titanium tubes with essentially all the improvement being a result of the increase on the top tube.

In Figures 12, 13 and 14, there appears to be a consistent trend in which for a given number of tubes in a vertical row C_n varies with the tube-side water velocity (or condensate loading as both are directly related). For low and high velocities the correction factor is higher than for intermediate velocities. This might be attributable in part to an error in the average heat transfer coefficient and in part to varying degrees of turbulence in the condensate film depending upon the tube condensate flow rate. These two factors are closely coupled since it is tentatively assumed that the condensate turbulence effect is constant over the entire range of condensing conditions when taking Wilson plot data. The maximum deviations from the mean values in Figures 13 and 14 are 5.3 and 6.3 per cent, respectively.

Visual observation of low pressure steam condensing on the nine titanium tubes in vertical row revealed that as could best be seen, only filmwise condensation was occurring. Visual observation of the top tube was limited and it could be possible that partial dropwise condensation was occurring on this tube. The generally lower wettability of the titanium tube surface increases the condensing coefficient but not to the point where dropwise condensation will persist for multiple tube arrangements.

CONCLUSIONS AND RECOMMENDATIONS

The slightly higher average condensing coefficients obtainable for titanium tubes (8-10 percent) are compensated to a certain extent by the low thermal conductivity of the metal (approximately 10 Btu/hr.-sq.ft.-°F/ft.) when compared to copper or admiralty condenser tubes. Full advantage of titanium tubes can be realized when compared to the lower thermal conductivity alloy condenser tubes such as cupro-nickel and stainless steel. The greater allowable design stresses permissible with titanium tubes compared to those for the cupro-nickel alloys makes it possible to use considerably thinner tube walls which makes titanium tubes attractive for both improved condensing coefficients and reduced weight. The errosion and corrosion characteristics of titanium further add to the benefits of titanium tubes.

To determine if a significant advantage can be realized when using titanium tubes in steam condensing, an actual condenser should be designed with the results presented here and a comparison made to existing conventional condensers.

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APPENDIX A. TUBESIDE WILSON PLOT DATA FOR COPPER AND TITANIUM TUBES

TABLE VII

Wilson Plot Data for the Top Copper Tube in the Center Vertical Row, First Set

RUN NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
178730	8295	75.850	79.160	100.870
178732	9350	75.760	78.890	100.820
178733	5000	75.620	80.470	100.890
178734	7400	75.600	79.350	100.860
178735	9320	76.030	79.120	100.960
178736	8290	76.220	79.600	100.850
192161C	2930	74.810	81.210	100.000
192163B	3890	74.830	80.460	100.440
192164B	4840	75.070	80.160	100.760
192165B	5810	75.120	79.640	100.830
192166A	1781	74.920	83.070	100.590
192187	6935	75.050	79.000	100.960
192188	8200	74.420	78.020	101.030
192189	9320	74.880	78.000	101.080
192190	8150	75.160	78.630	101.080
192191	7000	74.770	78.650	101.060
192192	5955	74.820	79.220	101.160
192193	4980	74.920	79.820	101.070
192194	3770	75.020	80.810	101.060
192195	2890	74.940	81.610	101.020
192196	5880	74.820	79.220	101.080
192198	6100	75.660	79.880	100.930
192199	7115	75.800	79.550	101.010

TABLE VIII

Wilson Plot Data for the Top Copper Tube in the Center Vertical Row, Second Set

RUN NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197020A	2345	75.180	83.250	101.310
197020B	2240	75.200	83.350	101.170
197020C	2260	74.960	83.100	101.240
197021A	3505	75.020	81.710	101.140
197021B	3446	75.090	81.820	101.430
197021C	3421	75.320	82.020	101.320
197022A	4480	74.870	80.710	101.100
197022B	4490	75.170	80.990	101.530
197022C	4490	75.090	80.930	101.180
197023A	6315	74.930	79.780	101.250
197023B	6300	75.000	79.900	101.190
197023C	6305	75.240	80.010	101.160
197024A	7850	74.810	79.140	100.920
197024B	7850	74.960	79.310	101.350
197024C	7850	74.990	79.320	101.150
197025A	9800	75.010	78.690	101.080
197025B	9800	75.000	78.810	101.500
197025C	9800	74.960	78.740	101.410
197026A	6500	74.840	79.670	100.800
197026B	6540	74.660	79.360	100.780
197026C	6595	74.530	79.250	100.870
197027A	7735	74.730	79.070	100.720
197027B	7735	74.780	79.120	101.000
197027C	7735	74.840	79.180	100.920
197028A	9840	74.990	78.700	100.850
197028B	9840	75.040	78.760	100.910
197028C	9825	75.040	78.750	100.880

TABLE IX

Wilson Plot Data for the Top Titanium Tube in the Center Vertical Row, First Set

RUN NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
178737	4200	75.220	80.150	100.520
178738	5340	75.060	79.330	100.710
178739	6375	74.990	78.870	100.810
178740	7480	75.130	78.540	100.720
178741	8770	74.990	78.090	100.830
178742	9920	74.940	77.780	100.870
178743	3070	74.830	80.820	100.860
178744	2220	74.840	81.870	100.910
178745	4022	75.440	80.600	101.380
178746	5290	75.110	79.530	101.240
178747	6320	75.000	78.930	101.270
178748	7550	75.000	78.470	101.220
178749	8710	74.900	78.100	101.260
192241	9980	75.070	77.960	101.330
192242	4220	74.920	80.020	101.330
192243	3082	74.770	80.750	101.270
192244	2240	74.850	81.960	101.420

TABLE X

Wilson Plot Data for the Top Titanium Tube in the Center Vertical Row, Second Set

RUN NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197039A	2690	75.230	81.880	101.150
197039B	2656	74.980	81.840	101.240
197039C	2634	74.760	81.660	101.310
197040A	3818	74.950	80.560	101.200
197040B	3761	74.860	80.630	101.250
197040C	3763	74.930	80.650	101.320
197041A	5387	75.170	79.680	100.950
197041B	5368	75.310	79.890	100.990
197041C	5368	75.280	79.760	100.890
197042B	6508	75.210	79.200	101.150
197042C	6525	75.250	79.230	100.970
197043A	8420	74.680	78.180	100.940
197043B	8458	74.680	78.200	101.110
197044A	10110	74.860	77.970	101.110
197044B	10112	75.000	78.080	101.080
197044C	10112	74.990	78.100	100.960
197045A	2774	74.920	81.750	101.220
197045B	2774	74.870	81.730	101.200
197046A	3124	74.990	81.240	100.780
197046B	3098	74.830	81.180	101.100
197047A	3855	75.300	80.820	101.160
197047B	3844	74.840	80.580	101.120
197047C	3873	74.730	80.410	101.180
197048A	5340	74.930	79.490	100.780
197048B	5360	75.060	79.670	100.930
197048C	5359	75.320	79.800	100.940
197049A	6550	75.200	79.320	101.020
197049B	6540	75.350	79.380	101.050
197049C	6540	75.240	79.280	101.060
197050A	8460	75.110	78.520	101.070
197050B	8500	75.000	78.380	100.720
197051A	10110	74.740	77.780	101.060
197051B	10105	74.820	77.870	101.000
197051C	10130	74.900	77.970	101.120
197052A	6605	75.010	78.920	100.840
197052B	6605	75.250	79.230	100.950
197052C	6590	75.200	79.240	100.990
197053A	8530	75.070	78.530	101.040
197053B	8530	75.360	78.720	101.050
197053C	8480	74.900	78.360	101.120
197054A	10130	74.620	77.780	101.060
197054B	10100	74.780	77.880	101.060
197054C	10100	74.760	77.830	101.030

APPENDIX B. MODIFIED WILSON PLOT COMPUTER PROGRAM AND A SET OF TYPICAL OUTPUT

TABLE XI

Modified Wilson Plot Computer Program Written in the Michigan Algorithm Decoder Language

```
$COMPILE MAD, EXECUTE, DUMP , PUNCH OBJECT                    C-WP 001

           R  WILSON PLOT PROGRAM

           INTEGER I, RUNNO, METAL1, METAL2, C, RUNS
           DIMENSION WTUBE(50), TTUBEI(50), TTUBEO(50), VAPORT(50),
           1 TAVG(50), CPT(50), LAT(50), Q(50), LMTD(50), VISC(50),
           2 DEN(50), KT(50), PR(50), RE(50), VEL(50), TWALLA(50),
           3 VISCW(50), TWALL(50), TWALLO(50), DELTF(50), FILMT(50),
           4 KCOND(50), DCOND(50), VCOND(50), PHYGR(50), FUNCTA(50),
           5 FUNCTB(50), RUNNO(50), S(2), HI(50), HCOND(50), UO(50),
           6 A(8), D(8), E(8), F(8), G(8), H(8), K(8), L(8), CONS(50),
           7 RUN(50)
START      PRINT FORMAT TITLE
           PRINT COMMENT   $8$
           SUMLAT = 0.0
           C = 1
           READ FORMAT DATA, RUNS, ID, OD, TL, TK, CI
           READ FORMAT DATA2, METAL1, METAL2
           PRINT FORMAT OUT1, OD, ID, TL, TK, METAL1, METAL2
           THROUGH ALPHA, FOR I = 1, 1, I .G. RUNS
ALPHA      READ FORMAT DATA1, RUN(I), RUNNO(I), WTUBE(I), TTUBEI(I),
           1 TTUBEO(I), VAPORT(I)
           OD = OD/12.0
           ID = ID/12.0
           TL = TL/12.0
           AOT = 3.1416*OD*TL
           AIT = 3.1416*ID*TL
           RM = (OD-ID)/(TK*2.0)
           DM = (OD-ID)/ELOG.(OD/ID)
           AMET = 3.1416*DM*TL
           AFLOW = 3.1416*ID*ID/4.0
           PRINT FORMAT OUT2, AOT, AIT, AFLOW, RM, CI
           THROUGH BETA, FOR I = 1, 1, I .G. RUNS
           TAVG(I) = (TTUBEI(I) + TTUBEO(I))/2.0
           CPT(I) = A(0) + A(1)*TAVG(I) + A(2)*TAVG(I).P.2 +
           1 A(3)*TAVG(I).P.3 + A(4)*TAVG(I).P.4 + A(5)*TAVG(I).P.5
           VISC(I) =  EXP.( D(0) + D(1)/TAVG(I) + D(2)/TAVG(I).P.2 +
           1 D(3)/TAVG(I).P.3 + D(4)/TAVG(I).P.4 + D(5)/TAVG(I).P.5)
           DEN(I) = F(0) + F(1)*TAVG(I) + F(2)*TAVG(I).P.2 +
           1 F(3)*TAVG(I).P.3 + F(4)*TAVG(I).P.4 + F(5)*TAVG(I).P.5
           KT(I) = G(0) + G(1)*TAVG(I) + G(2)*TAVG(I).P.2 +
           1 G(3)*TAVG(I).P.3 + G(4)*TAVG(I).P.4 + G(5)*TAVG(I).P.5
           LAT(I) = E(0) + E(1)*VAPORT(I) + E(2)*VAPORT(I).P.2 +
           1 E(3)*VAPORT(I).P.3 + E(4)*VAPORT(I).P.4 + E(5)*VAPORT(I).P.5
           SUMLAT = SUMLAT + LAT(I)
           Q(I) = WTUBE(I)*CPT(I)*(TTUBEO(I) - TTUBEI(I))
           LMTD(I) = (TTUBEO(I) - TTUBEI(I))/(ELOG.((VAPORT(I) -
           1 TTUBEI(I))/(VAPORT(I) - TTUBEO(I))))
           UO(I) = Q(I)/(AOT*LMTD(I))
           PR(I) = CPT(I)*VISC(I)/KT(I)
           RE(I) = ID*WTUBE(I)/(AFLOW*VISC(I))
BETA       VEL(I) = WTUBE(I)/(AFLOW*DEN(I)*3600.0)
           AVGLAT = SUMLAT/RUNS
RET2       THROUGH GAMMA, FOR I = 1, 1, I .G. RUNS
           TWALLA(I) = TAVG(I)
RET1       VISCW(I) =  EXP.(D(0) + D(1)/TWALLA(I) + D(2)/TWALLA(I).P.2 +
           1 D(3)/TWALLA(I).P.3 + D(4)/TWALLA(I).P.4 +D(5)/TWALLA(I).P.5)
           HI(I) = CI*KT(I)*RE(I).P.0.8*PR(I).P.0.33333*(VISC(I)/
           1 VISCW(I)).P.0.14/ID
           TWALL(I) = TAVG(I) + Q(I)/(AIT*HI(I))
           WHENEVER .ABS.(TWALLA(I) - TWALL(I)) .G. 0.3
           TWALLA(I) = TWALL(I)
           TRANSFER TO RET1
           END OF CONDITIONAL
           TWALLO(I) = TWALL(I) + Q(I)*RM/AMET
           HCOND(I) = 1.0/(1.0/UO(I) -AOT*RM/AMET - AOT/(AIT*HI(I)))
           DELTF(I) = UO(I)*LMTD(I)/HCOND(I)
           FILMT(I) = VAPORT(I) - DELTF(I)/2.0
           KCOND(I) = H(0) + H(1)*FILMT(I) + H(2)*FILMT(I).P.2 +
           1 H(3)*FILMT(I).P.3 + H(4)*FILMT(I).P.4 + H(5)*FILMT(I).P.5
           DCOND(I) = K(0) + K(1)*FILMT(I) + K(2)*FILMT(I).P.2 +
           1 K(3)*FILMT(I).P.3 + K(4)*FILMT(I).P.4 + K(5)*FILMT(I).P.5
           VCOND(I) = EXP.( L(0) + L(1)/FILMT(I) + L(2)/FILMT(I).P.2 +
           1 L(3)/FILMT(I).P.3 + L(4)/FILMT(I).P.4 + L(5)/FILMT(I).P.5)
           PHYGR(I) = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
           1 (VCOND(I)*DELTF(I))).P.0.25
           CONS(I) = HCOND(I)*(OD/(LAT(I)*4.17*10.0.P.8)).P.0.25/
           1 PHYGR(I)
           FUNCTA(I) = (1.0/UO(I) - AOT*RM/AMET)*PHYGR(I)
GAMMA      FUNCTB(I) = AOT*PHYGR(I)*CI/(AIT*HI(I))
           EXECUTE LSTSQ.(FUNCTB, FUNCTA, RUNS, B, 1)
           CONDC = 1.0/(B(0)*(4.17*10.0.P.8*AVGLAT/OD).P.0.25)
           CIC = 1.0/B(1)
           PRINT FORMAT HEAD1
           THROUGH PO1, FOR I = 1, 1, I .G. RUNS
PO1        PRINT FORMAT RESLT1,RUN(I),RUNNO(I),WTUBE(I),TTUBEI(I),
           1 TTUBEO(I), TAVG(I), CPT(I), DEN(I), VISC(I)
           PRINT FORMAT HEAD2
           THROUGH PO2, FOR I = 1, 1, I .G. RUNS
PO2        PRINT FORMAT RESLT2,RUN(I),RUNNO(I),KT(I),PR(I),TWALL(I),
           1 VISCW(I), VEL(I), RE(I), HI(I)
           PRINT FORMAT HEAD3
           THROUGH PO3, FOR I = 1, 1, I .G. RUNS
PO3        PRINTFORMATRESLT3,RUN(I),RUNNO(I),VAPORT(I),LAT(I),TWALLO(I),
           1 DELTF(I), FILMT(I), KCOND(I), DCOND(I)
           PRINT FORMAT HEAD4
           THROUGH PO4, FOR I = 1, 1, I .G. RUNS
PO4        PRINT FORMAT RESLT4, RUN(I), RUNNO(I), VCOND(I), PHYGR(I),
           1  CONS(I), FUNCTA(I), FUNCTB(I)
           PRINT FORMAT HEAD5
           THROUGH PO5, FOR I = 1, 1, I .G. RUNS
PO5        PRINT FORMAT RESLT5, RUN(I), RUNNO(I), Q(I), LMTD(I), UO(I),
           1 HI(I), HCOND(I)
           PRINT COMMENT $-$
           PRINT FORMAT RESIT, C, CIC, CONDC
           WHENEVER .ABS.(CI - CIC)/CIC .G. 0.001
           CI = CIC
           C = C + 1
           TRANSFER TO RET2
           END OF CONDITIONAL
           VECTOR VALUES TITLE = $ 110H1                     WILSON
           1PLOT ANALYSIS FOR TUBE-SIDE HEAT TRANSFER COEFFICIENT CORRELA
           2TION CONSTANT                   *$
           VECTOR VALUES DATA = $ 110, 5F10.4  *$
           VECTOR VALUES DATA1 =  $ I4, C6, F10.0, 3F10.3  *$
           VECTOR VALUES DATA2 = $ 2C6  *$
           VECTOR VALUES OUT1 = $  32H TUBE OUTSIDE DIAMETER - INCHES
           1    S30, F10.4  /
           131H TUBE INSIDE DIAMETER - INCHES        S31, F10.4     /
           122H TUBE LENGTH - INCHES         S40, F10.4  /
           142H TUBE THERMAL CONDUCTIVITY - BTU/HR-FT-F       S21, F10.4  /
           112H TUBE METAL             S43, 2C6     *$
           VECTOR VALUES OUT2 = $ 43H TUBE OUTSIDE HEAT TRANSFER AREA -
           1SQFT/FT      S19, F10.4    /
           142H TUBE INSIDE HEAT TRANSFER AREA - SQFT/FT    S20, F10.4 /
           122H TUBE FLOW AREA - SQFT      S40, F13.7  /
           133H METAL RESISTANCE - BTU/HR-SQFT-F       S29, F13.7    /
           126H INSIDE COEFFICIENT CONSTANT          S35, F10.5   *$
           VECTOR VALUES RESIT = $ 7H-AFTER   I2,  18H ITERATIONS, CI =
           1   F7.5,  24H , CONDENSING CONSTANT =    F8.5  *$
           VECTOR VALUES HEAD1 =$120H2          RUN NO          W TUBE
           1 T TUBE IN      T TUBE OUT            T-AVG            T-CP
           2T-DENSITY     T-VISCOSITY    /     120H
           3LB/HR             F                F                F      BTU/
           4LB-F          LB/CUFT          LB/FT-HR       /*$
           VECTOR VALUES RESLT1 = $ I9, C6, F15.0, 6F15.3   *$
           VECTOR VALUES HEAD2 = $ 120H2            RUN NO              T-K
           1          PR       T WALL IN    TW-VISCOSITY      T-VELOCITY
           2         RE                  HI     /    120H                BTU
           3/HR-FT                                F         LB/FT-HR          F
           4T/SEC                      BTU/HR-SQFT-F       /*$
           VECTOR VALUES RESLT2 = $ I9, C6, F15.4, F15.3, 2F15.2,
           1 2F15.3, F15.2   *$
           VECTOR VALUES HEAD3 = $ 120H2           RUN NO      VAPOR TEMP
           1     LAT HEAT       T WALL OUT          DT FILM          T FILM
           2          C-K       C-DENSITY      / 120H
           3      F            BTU/LB                F                F
           4     F        BTU/HR-FT            LB/CUFT      /*$
           VECTOR VALUES RESLT3 = $ I9, C6, F15.3, F15.2, 3F15.3, F15.4,
           1 F15.3   *$
           VECTOR VALUES HEAD4 = $ 90H2            RUN NO     C-VISCOSITY
           1         PHYGR              COND C           FUNCT A          FUNCT B   /
           2 90H                             LB/FT-HR
           3                                                /*$
           VECTOR VALUES RESLT4 = $ I9, C6, 2F15.3, F15.5, 2E15.8   *$
           VECTOR VALUES HEAD5 = $ 90H2            RUN NO        HEAT DUTY
           1        LMTD                 UO                 HI          H COND   /
           2  90H                            BTU/HR                F  BTU/HR-SQ
           3FT-F  BTU/HR-SQFT-F  BTU/HR-SQFT-F       /*$
           VECTOR VALUES RESLT5 = $ I9, C6, F15.1, F15.3, 3F15.2   *$
           VECTOR VALUES A =  0.10124896E 01, -0.46678063E-03,
           1 0.58540867E-05, -0.32721741E-07, 0.72640616E-10, 0.0E0
           VECTOR VALUES D =  -0.21968738E01, 0.54722744E03,
           1 -0.41363282E05, 0.16141324E07, -0.24764542E08, 0.0E0
           VECTOR VALUES E = 1095.2, -0.5800, 0.0, 0.0, 0.0
           VECTOR VALUES F = 0.63130000E02, -0.11700000E-01, 0.0E0
           VECTOR VALUES G = 0.30377927E00, 0.25267360E-03,
           1 0.92050520E-05, -0.75847219E-07, 0.17507457E-09, 0.0E0
           VECTOR VALUES H = 0.30377927E00, 0.25267360E-03,
           1 0.92050520E-05, -0.75847219E-07, 0.17507457E-09, 0.0E0
           VECTOR VALUES K = 0.63130000E02, -0.11700000E-01, 0.0E0
           VECTOR VALUES L =  -0.21968738E01, 0.54722744E03.
           1 -0.41363282E05, 0.16141324E07, -0.24764542E08, 0.0E0
           TRANSFER TO START
           END OF PROGRAM
```

AFLOW	TUBESIDE FLOW AREA, SQ.FT.
AIT	TOTAL INSIDE HEAT TRANSFER AREA, SQ.FT.
AMET	TOTAL MEAN METAL AREA, SQ.FT.
AOT	TOTAL OUTSIDE HEAT TRANSFER AREA, SQ.FT.
A(I)	CONSTANTS FOR HEAT CAPACITY OF WATER
B(I)	CONSTANTS FOR LEAST SQUARE SUBROUNTINE
CIC	VALUE OF INSIDE HEAT TRANSFER COEFFICIENT CONSTANT CALCULATED FROM LEAST SQUARE SUBROUTINE
CI	ASSUMED VALUE OF INSIDE HEAT TRANSFER COEFFICIENT CONSTANT
CONDC	AVERAGE CONDENSING COEFFICIENT CONSTANT CALCULATED FROM INTERCEPT
CONS	CONDENSING COEFFICIENT CONSTANT TO REPLACE 0.725
CPT	SPECIFIC HEAT FOR WATER, BTU/LB-F
DCOND	DENSITY OF CONDENSATE, LB/CU.FT.
DELTF	TEMPERATURE DROP ACROSS CONDENSATE FILM, F.
DEN	DENSITY OF WATER, LB./CU.FT.
DM	MEAN METAL DIAMETER OF TUBE, IN. OR FT.
D(I)	CONSTANTS FOR VISCOSITY OF WATER
E(I)	CONSTANTS FOR LATENT HEAT OF STEAM
FILMT	CONDENSATE FILM TEMPERATURE, F.
F(I)	CONSTANTS FOR DENSITY OF WATER
FUNCTA	ORDINATE VALUE FOR WILSON PLOTS
FUNCTB	ABSCISSA VALUE FOR WILSON PLOTS
G(I)	CONSTANTS FOR THERMAL CONDUCTIVITY OF WATER
HCOND	CONDENSING COEFFICIENT, BTU/HR.-SQ.FT.-F.
HI	INSIDE HEAT TRANSFER COEFFICIENT, BTU/HR.-SQ.FT.-F.
H(I)	CONSTANTS FOR THERMAL CONDUCTIVITY OF CONDENSATE
ID	TUBE INSIDE DIAMETER, IN. OR FT.
KCOND	THERMAL CONDUCTIVITY OF CONDENSATE FILM, BTU/HR.-SQ.FT.-F./FT.
K(I)	CONSTANTS FOR DENSITY OF CONDENSATE
KT	THERMAL CONDUCTIVITY OF WATER, BTU/HR.-SQ.FT.-F./FT.
LAT	LATENT HEAT OF STEAM, BTU/LB.
LMTD	LOGARITHMIC TEMPERATURE DIFFERENCE, F.
L(I)	CONSTANTS FOR VISCOSITY OF CONDENSATE
OD	TUBE OUTSIDE DIAMETER, IN. OR FT.
PHYGR	PHYSICAL PROPERTY GROUP
PR	PRANDTL NUMBER OF WATER
Q	HEAT DUTY, BTU/HR.
RE	REYNOLDS NUMBER
RM	METAL RESISTANCE, HR.-SQ.FT.(OUTSIDE AREA)-F./BTU
SUMLAT	SUM OF LATENT HEATS FOR ALL RUNS
TAVG	AVERAGE TUBESIDE TEMPERATURE, F.
TK	THERMAL CONDUCTIVITY OF TUBE METAL, BTU/HR.-SQ.FT.-F./FT.
TL	TUBE LENGTH, IN. OR FT.
TTUBEI	INLET WATER TEMPERATURE, F.
TTUBEO	OUTLET WATER TEMPERATURE, F.
TWALLA	ESTIMATED VALUE OF INSIDE WALL TEMPERATURE, F.
TWALL	CALCULATED VALUE OF INSIDE WALL TEMPERATURE, F.
TWALLO	OUTSIDE WALL TEMPERATURE, F.
UO	OVERALL HEAT TRANSFER COEFFICIENT, BTU/HR.-SQ.FT.-F.
VAPORT	STEAM VAPOR TEMPERATURE, F.
VCOND	VISCOSITY OF CONDENSATE, LB./FT.-HR.
VEL	WATER VELOCITY, FT./SEC.
VISC	VISCOSITY OF WATER, LB./FT.-HR.
VISCW	VISCOSITY OF WATER AT WALL TEMPERATURE, LB./FT.-HR.
WTUBE	TUBESIDE FLOW RATE, LB./HR.

TABLE XII

Typical Wilson Plot Output Calculated with an IBM 7090 Digital Computer

WILSON PLOT ANALYSIS FOR TUBE-SIDE HEAT TRANSFER COEFFICIENT CORRELATION CONSTANT

TUBE OUTSIDE DIAMETER - INCHES	.6250
TUBE INSIDE DIAMETER - INCHES	.5550
TUBE LENGTH - INCHES	72.1560
TUBE THERMAL CONDUCTIVITY - BTU/HR-FT-F	196.0000
TUBE METAL	COPPER
TUBE OUTSIDE HEAT TRANSFER AREA - SQFT/FT	.9839
TUBE INSIDE HEAT TRANSFER AREA - SQFT/FT	.8737
TUBE FLOW AREA - SQFT	.0016800
METAL RESISTANCE - BTU/HR-SQFT-F	.0000149
INSIDE COEFFICIENT CONSTANT	.02500

RUN NO	W TUBE LB/HR	T TUBE IN F	T TUBE OUT F	T-AVG F	T-CP BTU/LB-F	T-DENSITY LB/CUFT	T-VISCOSITY LB/FT-HR
178730	8295	75.850	79.160	77.505	.999	62.223	2.135
178732	9350	75.760	78.890	77.325	.999	62.225	2.140
178733	5000	75.620	80.470	78.045	.999	62.217	2.121
178734	7400	75.600	79.350	77.475	.999	62.224	2.136
178735	9320	76.030	79.120	77.575	.999	62.222	2.133
178736	8290	76.220	79.600	77.910	.999	62.218	2.125
192161C	2930	74.810	81.210	78.010	.999	62.217	2.122
192163B	3890	74.830	80.460	77.645	.999	62.222	2.131
192164B	4840	75.070	80.160	77.615	.999	62.222	2.132
192165B	5810	75.120	79.640	77.380	.999	62.225	2.138
192166A	1781	74.920	83.070	78.995	.999	62.206	2.097
192187	6935	75.050	79.000	77.025	.999	62.229	2.148
192188	8200	74.420	78.020	76.220	.999	62.238	2.169
192189	9320	74.880	78.000	76.440	.999	62.236	2.163
192190	8150	75.160	78.630	76.895	.999	62.230	2.151
192191	7000	74.770	78.650	76.710	.999	62.232	2.156
192192	5955	74.820	79.220	77.020	.999	62.229	2.148
192193	4980	74.920	79.820	77.370	.999	62.225	2.139
192194	3770	75.020	80.810	77.915	.999	62.218	2.125
192195	2890	74.940	81.610	78.275	.999	62.214	2.115
192196	5880	74.820	79.220	77.020	.999	62.229	2.148
192198	6100	75.660	79.880	77.770	.999	62.220	2.128
192199	7115	75.800	79.550	77.675	.999	62.221	2.131

TABLE XII (Continued)

RUN NO	T-K BTU/HR-FT	PR	T WALL IN F	TW-VISCOSITY LB/FT-HR	T-VELOCITY FT/SEC	RE	HI BTU/HR-SQFT-F
178730	.3497	6.099	86.08	1.93	22.042	106952.392	3661.84
178732	.3495	6.115	85.64	1.94	24.844	120290.727	4023.30
178733	.3500	6.053	89.31	1.86	13.288	64892.617	2462.11
178734	.3496	6.102	86.96	1.91	19.663	95377.737	3346.49
178735	.3497	6.093	85.77	1.93	24.766	120270.862	4018.98
178736	.3499	6.065	86.64	1.92	22.030	107415.847	3671.06
192161C	.3500	6.056	91.32	1.81	7.786	38010.936	1610.50
192163B	.3498	6.087	90.09	1.84	10.337	50241.693	2012.57
192164B	.3497	6.090	89.38	1.86	12.861	62488.694	2393.90
192165B	.3496	6.110	88.25	1.88	15.438	74797.695	2762.16
192166A	.3506	5.974	94.[illegible]0	1.76	4.734	23381.446	1091.22
192187	.3494	6.141	86.91	1.91	18.426	88894.336	3169.56
192188	.3488	6.211	85.59	1.94	21.784	104074.527	3601.33
192189	.3490	6.192	84.77	1.96	24.761	118610.794	3988.92
192190	.3493	6.152	85.88	1.93	21.654	104302.220	3598.04
192191	.3492	6.168	86.46	1.92	18.598	89381.616	3185.76
192192	.3494	6.141	87.68	1.89	15.822	76327.810	2809.36
192193	.3496	6.111	88.79	1.87	13.233	64104.484	2443.70
192194	.3499	6.064	90.60	1.83	10.019	48851.906	1967.10
192195	.3502	6.034	92.08	1.81	7.681	37612.589	1596.20
192196	.3494	6.141	87.66	1.89	15.623	75366.502	2780.90
192198	.3498	6.077	88.00	1.89	16.210	78905.074	2876.51
192199	.3498	6.085	87.07	1.91	18.907	91928.070	3246.92

RUN NO	VAPOR TEMP F	LAT HEAT BTU/LB	T WALL OUT F	DT FILM F	T FILM F	C-K BTU/HR-FT	C-DENSITY LB/CUFT
178730	100.870	1036.70	86.517	14.314	93.713	.3594	62.034
178732	100.820	1036.72	86.110	14.675	93.482	.3593	62.036
178733	100.890	1036.68	89.694	11.110	95.335	.3603	62.015
178734	100.860	1036.70	87.400	13.410	94.155	.3596	62.028
178735	100.960	1036.64	86.229	14.697	93.611	.3593	62.035
178736	100.850	1036.71	87.085	13.723	93.988	.3595	62.030
192161C	100.000	1037.20	91.622	8.222	95.889	.3606	62.008
192163B	100.440	1036.94	90.437	9.887	95.497	.3604	62.013
192164B	100.760	1036.76	89.775	10.891	95.314	.3603	62.015
192165B	100.830	1036.72	88.671	12.087	94.787	.3600	62.021
192166A	100.590	1036.86	94.435	5.896	97.642	.3615	61.988
192187	100.960	1036.64	87.345	13.561	94.180	.3596	62.028
192188	101.030	1036.60	86.065	14.922	93.569	.3593	62.035
192189	101.080	1036.57	85.240	15.807	93.177	.3591	62.040
192190	101.080	1036.57	86.334	14.704	93.728	.3594	62.033
192191	101.060	1036.59	86.892	14.116	94.002	.3595	62.030
192192	101.160	1036.53	88.103	12.990	94.665	.3599	62.022
192193	101.070	1036.58	89.177	11.808	95.166	.3602	62.017
192194	101.060	1036.59	90.951	9.987	96.066	.3607	62.006
192195	101.020	1036.61	92.390	8.466	96.787	.3611	61.998
192196	101.080	1036.57	88.071	12.942	94.609	.3599	62.023
192198	100.930	1036.66	88.414	12.452	94.704	.3599	62.022
192199	101.010	1036.61	87.497	13.462	94.279	.3597	62.027

TABLE XII (Continued)

RUN NO	C-VISCOSITY LB/FT-HR	PHYGR	COND C	FUNCT A	FUNCT B
178730	1.773	1.629	.70443	.13372454E-02	.12404400E-04
178732	1.778	1.617	.73757	.12514292E-02	.11210015E-04
178733	1.742	1.746	.74779	.15863888E-02	.19775403E-04
178734	1.765	1.658	.74641	.13473484E-02	.13819548E-04
178735	1.775	1.617	.72465	.12662267E-02	.11223358E-04
178736	1.768	1.648	.74119	.13003189E-02	.12517284E-04
192161C	1.732	1.886	.72315	.21335343E-02	.32663172E-04
192163B	1.739	1.799	.73661	.18061792E-02	.24923576E-04
192164B	1.743	1.754	.77115	.15892956E-02	.20438735E-04
192165B	1.753	1.706	.76178	.14689046E-02	.17224404E-04
192166A	1.700	2.063	.71368	.29545017E-02	.52725068E-04
192187	1.764	1.654	.73060	.13939946E-02	.14551559E-04
192188	1.776	1.611	.73453	.13058577E-02	.12475508E-04
192189	1.784	1.586	.69398	.12966126E-02	.11085710E-04
192190	1.773	1.618	.71106	.13349627E-02	.12540418E-04
192191	1.768	1.636	.70338	.14160007E-02	.14323371E-04
192192	1.755	1.675	.72043	.14891278E-02	.16624985E-04
192193	1.745	1.718	.71935	.16109158E-02	.19610842E-04
192194	1.729	1.798	.72712	.18395197E-02	.25489170E-04
192195	1.715	1.879	.72493	.21381909E-02	.32825061E-04
192196	1.756	1.676	.71349	.15044321E-02	.16807294E-04
192198	1.754	1.693	.73046	.14692707E-02	.16411893E-04
192199	1.762	1.657	.71523	.13985849E-02	.14236031E-04

RUN NO	HEAT DUTY BTU/HR	LMTD F	UO BTU/HR-SQFT-F	HI BTU/HR-SQFT-F	H COND BTU/HR-SQFT-F
178730	27425.3	23.326	1195.01	3661.84	1947.42
178732	29232.3	23.460	1266.46	4023.30	2024.62
178733	24222.3	22.759	1081.74	2462.11	2215.95
178734	27718.5	23.335	1207.33	3346.49	2100.91
178735	28766.1	23.351	1252.09	4018.98	1989.34
178736	27988.2	22.898	1242.31	3671.06	2072.91
192161C	18730.6	21.834	871.92	1610.50	2315.53
192163B	21875.8	22.679	980.40	2012.57	2248.91
192164B	24607.6	23.051	1085.00	2393.90	2296.42
192165B	26231.4	23.377	1140.48	2762.16	2205.83
192166A	14498.4	21.336	690.66	1091.22	2499.20
192187	27362.3	23.881	1164.57	3169.56	2050.84
192188	29487.0	24.766	1210.12	3601.33	2008.49
192189	29045.8	24.607	1199.73	3988.92	1867.67
192190	28248.6	24.143	1189.21	3598.04	1952.62
192191	27129.5	24.298	1134.81	3185.76	1953.37
192192	26172.4	24.073	1105.03	2809.36	2047.81
192193	24374.3	23.615	1049.05	2443.70	2098.06
192194	21803.4	23.024	962.51	1967.10	2218.84
192195	19254.2	22.581	866.64	1596.20	2311.67
192196	25842.8	23.993	1094.76	2780.90	2029.58
192198	25712.7	23.096	1131.55	2876.51	2098.76
192199	26650.9	23.285	1163.32	3246.92	2012.09

AFTER 3 ITERATIONS, CI = .02475 , CONDENSING CONSTANT = .72746

APPENDIX C. CONDENSING HEAT TRANSFER DATA FOR CONDENSATION OF STEAM AT 2 INCHES OF MERCURY ABSOLUTE PRESSURE ON 9 COPPER AND 9 TITANIUM TUBES IN A VERTICAL ROW

TABLE XIII

Condensing Heat Transfer Data for Condensation of Steam at 2 Inches of Mercury Absolute Pressure on 9 Copper Tubes in a Vertical Row

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197020A	1	2345	75.180	83.250	101.310
197020A	2	2261	75.280	82.550	101.290
197020A	3	2232	75.320	82.370	101.270
197020A	4	2250	75.380	82.150	101.220
197020A	5	2268	75.390	82.100	101.200
197020A	6	2383	75.390	82.030	101.170
197020A	7	2290	75.420	81.880	101.170
197020A	8	2293	75.440	81.920	101.180
197020A	9	2236	75.460	81.960	101.200

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197020B	1	2240	75.200	83.350	101.170
197020B	2	2192	75.170	82.580	101.140
197020B	3	2124	75.150	82.300	101.110
197020B	4	2200	75.150	82.080	101.080
197020B	5	2196	75.170	82.000	101.080
197020B	6	2196	75.190	81.920	101.080
197020B	7	2254	75.170	81.680	101.040
197020B	8	2254	75.120	81.630	101.000
197020B	9	2167	75.070	81.620	100.960

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197020C	1	2260	74.960	83.100	101.240
197020C	2	2221	75.020	82.460	101.240
197020C	3	2196	75.050	82.310	101.230
197020C	4	2200	75.100	82.030	101.230
197020C	5	2203	75.110	82.060	101.230
197020C	6	2214	75.120	81.900	101.220
197020C	7	2214	75.140	81.780	101.180
197020C	8	2232	75.140	81.790	101.150
197020C	9	2167	75.140	81.770	101.120

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197021A	1	3505	75.020	81.710	101.140
197021A	2	3370	75.040	80.850	101.070
197021A	3	3341	75.050	80.730	101.010
197021A	4	3341	75.030	80.640	100.960
197021A	5	3312	75.000	80.410	100.970
197021A	6	3384	74.970	80.240	100.980
197021A	7	3359	74.960	80.100	101.070
197021A	8	3384	74.980	80.080	101.160
197021A	9	3384	75.010	80.110	101.250

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197021B	1	3446	75.090	81.820	101.430
197021B	2	3330	75.040	81.600	101.340
197021B	3	3312	75.020	80.800	101.240
197021B	4	3312	75.030	80.620	101.130
197021B	5	3312	75.060	80.460	101.110
197021B	6	3359	75.100	80.380	101.100
197021B	7	3359	75.150	80.310	101.100
197021B	8	3384	75.170	80.330	101.130
197021B	9	3352	75.180	80.380	101.150

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197021C	1	3421	75.320	82.020	101.320
197021C	2	3316	75.350	81.230	101.290
197021C	3	3283	75.370	81.010	101.270
197021C	4	3305	75.410	80.830	101.230
197021C	5	3283	75.430	80.810	101.230
197021C	6	3359	75.440	80.750	101.220
197021C	7	3348	75.490	80.580	101.230
197021C	8	3366	75.520	80.630	101.230
197021C	9	3341	75.540	80.660	101.240

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197022A	1	4480	74.870	80.710	101.100
197022A	2	4345	74.910	79.990	101.250
197022A	3	4327	74.930	79.800	101.390
197022A	4	4349	74.980	79.650	101.520
197022A	5	4309	75.010	79.540	101.500
197022A	6	4388	75.040	79.580	101.480
197022A	7	4352	75.100	79.190	101.480
197022A	8	4406	75.110	79.400	101.490
197022A	9	4388	75.140	79.500	101.510

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197022B	1	4490	75.170	80.990	101.530
297022B	2	4356	75.240	80.350	101.450
197022B	3	4327	75.280	80.010	101.380
197022B	4	4338	75.330	79.850	101.280
197022B	5	4295	75.350	79.850	101.250
197022B	6	4381	75.380	79.760	101.230
197022B	7	4363	75.390	79.590	101.190
197022B	8	4406	75.390	79.590	101.170
197022B	9	4360	75.390	79.750	101.150

TABLE XIII (Continued)

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197022C	1	4490	75.090	80.930	101.180
197022C	2	4356	75.120	80.130	101.220
197022C	3	4327	75.130	80.020	101.270
197022C	4	4338	75.170	79.780	101.310
197022C	5	4270	75.200	79.720	101.310
197022C	6	4381	75.230	79.720	101.300
197022C	7	4352	75.280	79.680	101.310
197022C	8	4399	75.290	79.640	101.320
197022C	9	4370	75.310	79.680	101.330

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197023A	1	6315	74.930	79.780	101.250
197023A	2	6095	74.960	79.100	101.280
197023A	3	6116	74.970	78.800	101.310
197023A	4	6149	74.980	78.680	101.340
197023A	5	6073	74.980	78.760	101.330
197023A	6	6217	74.980	78.570	101.330
197023A	7	6178	74.950	78.260	101.320
197023A	8	6268	74.920	78.360	101.320
197023A	9	6192	74.880	78.390	101.320

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197023B	1	6300	75.000	79.900	101.190
197023B	2	6088	75.030	79.020	101.320
197023B	3	6106	75.050	79.140	101.450
197023B	4	6138	75.090	78.970	101.500
197023B	5	6073	75.120	78.940	101.420
197023B	6	6206	75.140	78.740	101.340
197023B	7	6167	75.170	78.650	101.270
197023B	8	6257	75.180	78.540	101.270
197023B	9	6192	75.190	78.540	101.270

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197023C	1	6305	75.240	80.010	101.160
197023C	2	6088	75.230	79.100	101.210
197023C	3	6106	75.220	78.950	101.260
197023C	4	6138	75.240	79.030	101.370
197023C	5	6066	75.270	79.000	101.420
197023C	6	6199	75.290	78.680	101.470
197023C	7	6167	75.330	78.800	101.450
197023C	8	6257	75.330	78.740	101.380
197023C	9	6192	75.340	78.740	101.300

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT. F	T STEAM F
197024A	1	7850	74.810	79.140	100.920
197024A	2	7546	74.860	78.430	101.160
197024A	3	7603	74.880	78.390	101.400
197024A	4	7607	74.900	78.150	101.550
197024A	5	7596	74.900	78.150	101.470
197024A	6	7693	74.910	78.050	101.400
197024A	7	7632	74.890	77.710	101.290
197024A	8	7744	74.870	77.830	101.260
197024A	9	7682	74.850	77.810	101.230

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197024B	1	7850	74.960	79.310	101.350
197024B	2	7535	74.960	78.560	101.430
197024B	3	7603	74.950	78.470	101.510
197024B	4	7603	74.970	78.340	101.530
197024B	5	7596	74.980	78.260	101.460
197024B	6	7693	75.000	78.080	101.340
197024B	7	7632	75.020	77.970	101.290
197024B	8	7744	75.030	77.950	101.270
197024B	9	7675	75.030	77.970	101.240

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197024C	1	7850	74.990	79.320	101.150
197024C	2	7520	74.910	78.590	101.100
197024C	3	7582	74.860	78.510	101.060
197024C	4	7596	74.880	78.330	100.970
197024C	5	7589	74.940	78.260	100.920
197024C	6	7690	75.000	78.200	100.870
197024C	7	7625	75.060	77.820	100.960
197024C	8	7740	75.060	78.000	101.090
197024C	9	7675	75.060	78.000	101.220

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197025A	1	9800	75.010	78.690	101.080
197025A	2	9403	75.020	78.050	101.120
197025A	3	9482	75.020	77.940	101.160
197025A	4	9529	75.020	77.820	101.250
197025A	5	9522	75.020	77.760	101.310
197025A	6	9641	75.010	77.660	101.360
197025A	7	9526	75.000	77.450	101.420
197025A	8	9684	74.990	77.540	101.430
197025A	9	9594	74.980	77.500	101.430

TABLE XIII (Continued)

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197025B	1	9600	75.000	78.810	101.500
197025B	2	9403	74.990	78.080	101.440
197025B	3	9482	74.990	78.000	101.380
197025B	4	9540	74.990	77.810	101.240
197025B	5	9515	74.980	77.810	101.160
197025B	6	9641	74.980	77.660	101.080
197025B	7	9529	74.980	77.550	101.040
197025B	8	9688	74.990	77.470	101.080
197025B	9	9587	74.990	77.470	101.130

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197025C	1	9800	74.960	78.740	101.410
197025C	2	9300	74.960	78.070	101.440
197025C	3	9490	74.970	77.960	101.480
197025C	4	9540	74.970	77.840	101.470
197025C	5	9508	74.970	77.790	101.420
197025C	6	9641	74.970	77.710	101.370
197025C	7	9529	74.970	77.610	101.290
197025C	8	9688	74.970	77.500	101.260
197025C	9	9590	74.970	77.520	101.230

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197026A	1	6500	74.840	79.670	100.800
197026A	2	6239	74.820	78.700	100.770
197026A	3	6293	74.810	78.740	100.740
197026A	4	6293	74.780	78.510	100.750
197026A	5	6243	74.780	78.490	100.770
197026A	6	6404	74.770	78.300	100.800
197026A	7	6365	74.750	78.150	100.810
197026A	8	6466	74.740	78.000	100.790
197026A	9	6404	74.730	78.060	100.760

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197026B	1	6540	74.660	79.360	100.780
197026B	2	6282	74.640	78.540	100.830
197026B	3	6336	74.630	78.580	100.870
197026B	4	6372	74.610	78.070	100.910
197026B	5	6282	74.600	78.280	100.900
197026B	6	6444	74.600	78.150	100.900
197026B	7	6404	74.590	77.880	100.870
197026B	8	6502	74.580	77.860	100.850
197026B	9	6448	74.570	77.920	100.820

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197026C	1	6595	74.530	79.250	100.870
197026C	2	6332	74.510	78.540	100.870
197026C	3	6397	74.500	78.200	100.870
197026C	4	6412	74.480	78.200	100.870
197026C	5	6271	74.460	78.170	100.880
197026C	6	6487	74.450	77.840	100.880
197026C	7	6451	74.430	77.790	100.970
197026C	8	6552	74.430	77.750	101.050
197026C	9	6509	74.430	77.750	101.040

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197027A	1	7735	74.730	79.070	100.720
197027A	2	7416	74.730	78.350	100.810
197027A	3	7484	74.730	78.180	100.910
197027A	4	7481	74.740	78.030	100.960
197027A	5	7463	74.750	78.000	100.920
197027A	6	7567	74.750	77.830	100.880
197027A	7	7513	74.760	77.770	100.840
197027A	8	7618	74.760	77.670	100.830
197027A	9	7560	74.760	77.690	100.830

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197027B	1	7735	74.780	79.120	101.000
197027B	2	7416	74.790	78.210	101.000
197027B	3	7477	74.790	78.290	101.000
197027B	4	7481	74.800	78.130	100.960
197027B	5	7452	74.800	78.070	100.930
197027B	6	7567	74.810	77.940	100.900
197027B	7	7500	74.810	77.770	100.850
197027B	8	7618	74.810	77.700	100.830
197027B	9	7546	74.810	77.760	100.800

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197027C	1	7735	74.840	79.180	100.920
197027C	2	7416	74.840	78.460	100.930
197027C	3	7477	74.850	78.340	100.930
197027C	4	7484	74.850	78.130	100.910
197027C	5	7481	74.860	78.100	100.880
197027C	6	7571	74.860	77.840	100.850
197027C	7	7513	74.860	77.860	100.850
197027C	8	7618	74.860	77.780	100.870
197027C	9	7560	74.860	77.860	100.900

TABLE XIII (Continued)

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197028A	1	9840	74.990	78.700	100.850
197028A	2	9454	75.020	78.030	100.900
197028A	3	9500	75.030	77.960	100.940
197028A	4	9570	75.040	77.800	100.980
197028A	5	9545	75.030	77.810	100.970
197028A	6	9680	75.020	77.700	100.950
197028A	7	9555	75.020	77.470	100.940
197028A	8	9710	75.020	77.480	100.940
197028A	9	9625	75.020	77.500	100.940

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197028B	1	9840	75.040	78.760	100.910
197028B	2	9454	75.040	78.080	100.920
197028B	3	9500	75.050	77.970	100.930
197028B	4	9580	75.050	77.750	100.920
197028B	5	9545	75.050	77.750	100.880
197028B	6	9680	75.040	77.650	100.850
197028B	7	9555	75.040	77.540	100.840
197028B	8	9710	75.050	77.500	100.860
197028B	9	9610	75.050	77.540	100.880

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197028C	1	9825	75.040	78.750	100.880
197028C	2	9440	75.040	78.080	100.880
197028C	3	9500	75.040	77.990	100.880
197028C	4	9610	75.050	77.840	100.930
197028C	5	9550	75.050	77.830	100.970
197028C	6	9615	75.060	77.660	101.010
197028C	7	9555	75.060	77.580	101.050
197028C	8	9700	75.060	77.530	101.040
197028C	9	9620	75.050	77.560	101.030

TABLE XIV

Condensing Heat Transfer Data for Condensation of Steam at 2 Inches of Mercury Absolute Pressure on 9 Titanium Tubes in a Vertical Row

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197039B	1	2656	74.980	81.840	101.240
197039B	2	2365	75.050	81.260	101.220
197039B	3	2594	75.080	81.100	101.200
197039B	4	2525	75.080	80.680	101.160
197039B	5	2440	75.040	80.800	101.130
197039B	6	2465	75.010	80.640	101.110
197039B	7	2365	74.940	80.560	101.070
197039B	8	2548	74.910	80.480	101.050
197039B	9	2510	74.880	80.400	101.040
197039C	1	2634	74.760	81.660	101.310
197039C	2	2335	74.800	81.020	101.300
197039C	3	2583	74.820	80.930	101.290
197039C	4	2482	74.860	80.710	101.280
197039C	5	2402	74.870	80.780	101.270
197039C	6	2420	74.890	80.560	101.270
197039C	7	2327	74.900	80.680	101.240
197039C	8	2457	74.900	80.680	101.210
197039C	9	2478	74.910	80.560	101.190
197040A	1	3818	74.950	80.560	101.200
197040A	2	3424	74.970	79.920	101.190
197040A	3	3560	74.990	79.840	101.180
197040A	4	3600	74.880	79.420	101.110
197040A	5	3521	74.760	79.260	101.050
197040A	6	3590	74.650	79.180	100.980
197040A	7	3406	74.560	79.140	100.980
197040A	8	3604	74.600	79.100	101.050
197040A	9	3638	74.640	79.070	101.110
197040B	1	3761	74.860	80.630	101.250
197040B	2	3361	74.900	80.020	101.270
197040B	3	3534	74.910	79.740	101.280
197040B	4	3588	74.950	79.580	101.270
197040B	5	3499	74.960	79.600	101.230
197040B	6	3620	74.980	79.560	101.200
197040B	7	3358	75.030	79.600	101.150
197040B	8	3555	75.060	79.560	101.150
197040B	9	3568	75.090	79.590	101.140
197040C	1	3763	74.930	80.650	101.320
197040C	2	3383	74.950	80.020	101.270
197040C	3	3527	74.950	79.820	101.220
197040C	4	3590	74.980	79.660	101.180
197040C	5	3499	75.010	79.700	101.200
197040C	6	3569	75.040	79.630	101.220
197040C	7	3380	74.970	79.440	101.070
197040C	8	3569	74.870	79.300	100.880
197040C	9	3613	74.770	79.070	100.710
197041A	1	5387	75.170	79.680	100.950
197041A	2	4908	75.190	78.970	100.960
197041A	3	5035	75.200	78.800	100.980
197041A	4	5145	75.230	78.630	100.980
197041A	5	5030	75.260	78.690	100.970
197041A	6	5145	75.280	78.650	100.960
197041A	7	4880	75.300	78.610	100.940
197041A	8	5135	75.300	78.650	100.930
197041A	9	5155	75.300	78.610	100.920
197041B	1	5368	75.310	79.890	100.990
197041B	2	4908	75.240	79.100	100.940
197041B	3	5038	75.210	78.840	100.880
197041B	4	5132	75.170	78.600	100.840
197041B	5	5042	75.160	78.670	100.850
197041B	6	5145	75.150	78.570	100.860
197041B	7	4870	75.170	78.570	100.910
197041B	8	5120	75.200	78.600	100.950
197041B	9	5145	75.230	78.600	100.980
197043A	1	8420	74.680	78.180	100.940
197043A	2	7643	74.680	77.470	101.000
197043A	3	7885	74.690	77.340	101.070
197043A	4	8045	74.680	77.210	101.130
197043A	5	7834	74.670	77.390	101.120
197043A	6	8091	74.660	77.280	101.110
197043A	7	7609	74.640	77.100	101.090
197043A	8	8010	74.620	77.080	101.070
197043A	9	8102	74.600	77.020	101.050

TABLE XIV (Continued)

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197043B	1	8458	74.680	78.200	101.110
197043B	2	7660	74.660	77.600	101.020
197043B	3	7900	74.650	77.440	100.930
197043B	4	8078	74.620	77.080	100.880
197043B	5	7884	74.610	77.190	100.930
197043B	6	7557	74.590	77.170	100.970
197043B	7	7641	74.590	76.880	101.000
197043B	8	8008	74.600	76.870	100.990
197043B	9	8138	74.610	76.800	100.980

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197044A	1	10110	74.860	77.970	101.110
197044A	2	9048	74.910	77.480	101.070
197044A	3	9352	74.930	77.360	101.030
197044A	4	9585	74.950	77.270	100.980
197044A	5	9328	74.950	77.320	100.980
197044A	6	9545	74.940	77.240	100.970
197044A	7	9048	74.940	77.240	101.010
197044A	8	9515	74.940	77.160	101.060
197044A	9	9690	74.950	77.100	101.010

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197044B	1	10112	75.000	78.080	101.080
197044B	2	9040	74.990	77.530	101.080
197044B	3	9353	74.990	77.350	101.090
197044B	4	9600	74.990	77.320	101.070
197044B	5	9316	74.990	77.370	101.050
197044B	6	9550	74.990	77.260	101.020
197044B	7	9048	74.990	77.220	101.020
197044B	8	9543	74.990	77.200	101.030
197044B	9	9685	75.000	77.170	101.040

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197044C	1	10112	74.990	78.100	100.960
197044C	2	9048	74.990	77.520	100.970
197044C	3	9390	74.990	77.450	100.990
197044C	4	9591	75.000	77.330	101.030
197044C	5	9328	75.020	77.390	101.060
197044C	6	9555	75.040	77.320	101.090
197044C	7	9050	75.060	77.340	101.120
197044C	8	9550	75.070	77.270	101.120
197044C	9	9690	75.070	77.260	101.120

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197047A	1	3655	75.300	70.820	101.160
197047A	2	3451	75.330	80.210	101.130
197047A	3	3591	75.350	80.060	101.110
197047A	4	3645	75.340	79.710	101.080
197047A	5	3535	75.310	79.980	101.070
197047A	6	3616	75.280	79.740	101.070
197047A	7	3460	75.260	79.740	101.080
197047A	8	3645	75.280	79.630	101.100
197047A	9	3680	75.300	79.630	101.120

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197047C	1	3873	74.730	80.410	101.180
197047C	2	3457	74.720	79.750	101.110
197047C	3	3588	74.710	79.470	101.040
197047C	4	3657	74.680	79.130	100.970
197047C	5	3567	74.660	79.140	100.980
197047C	6	3645	74.630	79.090	100.990
197047C	7	3444	74.610	79.090	101.030
197047C	8	3680	74.620	79.060	101.050
197047C	9	3685	74.640	79.070	101.080

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197049A	1	6550	75.200	79.320	101.020
197049A	2	5950	75.220	78.640	100.950
197049A	3	6100	75.220	78.400	100.890
197049A	4	6250	75.260	78.160	100.860
197049A	5	6125	75.300	78.450	100.910
197049A	6	6280	75.330	78.190	100.960
197049A	7	5920	75.350	78.190	101.010
197049A	8	6215	75.340	78.190	101.030
197049A	9	6300	75.320	78.480	101.050

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197049B	1	6540	75.350	79.380	101.050
197049B	2	5950	75.350	78.670	101.110
197049B	3	6125	75.340	78.580	101.160
197049B	4	6250	75.360	78.320	101.180
197049B	5	6100	75.390	78.580	101.140
197049B	6	6280	75.410	78.330	101.090
197049B	7	5945	75.460	78.300	101.030
197049B	8	6240	75.490	78.300	101.010
197049B	9	6300	75.520	78.370	100.990

TABLE XIV (Continued)

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197049C	1	6540	75.240	79.280	101.060
197049C	2	5950	75.250	78.570	101.020
197049C	3	6115	75.260	78.430	100.990
197049C	4	6260	75.270	78.290	100.990
197049C	5	6100	75.280	78.360	101.010
197049C	6	6290	75.290	78.220	101.030
197049C	7	5945	75.310	78.080	101.100
197049C	8	6250	75.320	78.200	101.150
197049C	9	6280	75.320	78.280	101.200

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197050A	1	8460	75.110	78.520	101.070
197050A	2	7680	75.120	77.930	101.050
197050A	3	7920	75.130	77.880	101.030
197050A	4	8090	75.160	77.570	101.000
197050A	5	7890	75.190	77.770	100.990
197050A	6	8100	75.210	77.600	100.990
197050A	7	7650	75.230	77.540	101.010
197050A	8	8060	75.210	77.590	101.040
197050A	9	8155	75.200	77.610	101.060

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197050B	1	8500	75.000	78.380	100.720
197050B	2	7655	75.000	77.770	100.840
197050B	3	7900	74.990	77.700	100.960
197050B	4	8090	75.030	77.510	101.110
197050B	5	7890	75.070	77.700	101.150
197050B	6	8100	75.100	77.540	101.190
197050B	7	7650	75.120	77.530	101.200
197050B	8	8050	75.100	77.630	101.180
197050B	9	8150	75.090	77.560	101.150

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197051A	1	10110	74.740	77.780	101.060
197051A	2	9010	74.730	77.320	101.070
197051A	3	9350	74.720	77.260	101.080
197051A	4	9550	74.750	77.060	101.090
197051A	5	9310	74.780	77.650	101.090
197051A	6	9530	74.810	77.060	101.080
197051A	7	9050	74.840	77.030	101.030
197051A	8	9530	74.840	76.990	100.970
197051A	9	9665	74.840	77.010	100.920

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197051B	1	10105	74.820	77.870	101.000
197051B	2	9030	74.830	77.490	101.020
197051B	3	9345	74.830	77.340	101.040
197051B	4	9550	74.850	77.090	101.060
197051B	5	9300	74.870	77.270	101.070
197051B	6	9630	74.890	77.190	101.080
197051B	7	9000	74.930	76.960	101.080
197051B	8	9510	74.960	77.180	101.080
197051B	9	9655	74.970	77.160	101.070

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197051C	1	10130	74.900	77.970	101.120
197051C	2	9000	74.950	77.500	101.110
197051C	3	9355	74.980	77.360	101.100
197051C	4	9540	75.010	77.160	101.060
197051C	5	9300	75.020	77.370	101.030
197051C	6	9530	75.030	77.220	101.000
197051C	7	9035	75.020	77.000	101.000
197051C	8	9530	75.000	77.230	101.030
197051C	9	9660	74.990	77.030	101.060

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197052B	1	6605	75.250	79.230	100.950
197052A	2	5990	75.280	78.550	100.930
197052B	3	6155	75.300	78.420	100.900
197052B	4	6305	75.350	78.380	100.910
197052B	5	6185	75.370	78.470	100.950
197052B	6	6320	75.400	78.330	100.970
197052B	7	5990	75.450	78.410	101.000
197052B	8	6270	75.460	78.280	101.000
197052B	9	6355	75.470	78.320	100.990

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197052C	1	6590	75.200	79.240	100.990
197052C	2	5990	75.180	78.600	100.970
197052C	3	6145	75.160	78.440	100.950
197052C	4	6300	75.170	78.060	100.940
197052C	5	6155	75.180	78.240	100.930
197052C	6	6308	75.200	78.050	100.920
197052C	7	5970	75.270	78.210	100.950
197052C	8	6265	75.320	78.130	100.960
197052C	9	6330	75.370	78.180	100.980

TABLE XIV (Continued)

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197053A	1	8530	75.070	78.530	101.040
197053A	2	7705	75.120	77.940	101.070
197053A	3	7945	75.150	77.820	101.100
197053A	4	8100	75.200	77.600	101.090
197053A	5	7935	75.220	77.820	101.060
197053A	6	8125	75.240	77.570	101.020
197053A	7	7690	75.260	77.630	101.090
197053A	8	8095	75.260	77.610	101.090
197053A	9	8180	75.270	77.660	101.100

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197053B	1	8530	75.360	78.720	101.050
197053B	2	7690	75.390	78.080	101.070
197053B	3	7935	75.410	78.090	101.090
197053B	4	8100	75.450	77.860	101.080
197053B	5	7920	75.470	78.060	101.050
197053B	6	8125	75.480	77.900	101.020
197053B	7	7660	75.500	77.840	100.990
197053B	8	8080	75.500	77.790	100.970
197053B	9	8015	75.490	77.800	100.960

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197054B	1	10100	74.780	77.880	101.060
197054B	2	9005	74.790	77.320	101.030
197054B	3	9350	74.790	77.130	101.000
197054B	4	9580	74.810	76.990	100.960
197054B	5	9325	74.820	77.190	100.960
197054B	6	9555	74.830	77.050	100.960
197054B	7	9045	74.820	77.070	100.970
197054B	8	9520	74.800	77.030	100.980
197054B	9	9655	74.790	76.980	100.990

RUN NO.	TUBE NO.	W WATER LB/HR	T WATER IN F	T WATER OUT F	T STEAM F
197054C	1	10100	74.760	77.830	101.030
197054C	2	9020	74.790	77.250	101.070
197054C	3	9345	74.790	77.140	101.100
197054C	4	9560	74.810	77.010	101.140
197054C	5	9310	74.810	77.070	101.130
197054C	6	9560	74.820	77.060	101.130
197054C	7	9050	74.820	77.100	101.100
197054C	8	9520	74.830	77.020	101.070
197054C	9	9655	74.840	77.020	101.040

APPENDIX D. COMPUTER PROGRAM FOR ANALYSIS OF MULTIPLE TUBE CONDENSING DATA AND TYPICAL COMPUTER CALCULATED RESULTS

TABLE XV

Computer Program Written in the Michigan Algorithm Decoder for the Analysis of Multiple Tube Condensing Data

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$COMPILE MAD, EXECUTE, DUMP, PUNCH OBJECT                        C-AN 001

         R MULTIPLE TUBE ANALYSIS PROGRAM

          INTEGER I, RUNNOA, RUNNOB, TUBENO, METAL1, METAL2
          DIMENSION WTUBE(50), TTUBEI(50), TTUBEO(50), VAPORT(50),
         1 TAVG(50), CPT(50), LAT(50), Q(50), LMTD(50), VISC(50),
         2 DEN(50), KT(50), PR(50), RE(50), VEL(50), TWALLA(50),
         3 VISCW(50), TWALL(50), TWALLO(50), DELTF(50), FILMT(50),
         4 KCOND(50), DCOND(50), VCOND(50), PHYGR(50), HI(50),
         5 DELTFA(50), QA(50), CONST(50), UO(50), TUBENO(50),
         6 CN(50), CONSTA(50), RUNNOA(50), RUNNOB(53), HCOND(50),
         7 A(8), D(8), E(8), G(8), H(8), K(8), L(8), F(8)
START     READ FORMAT DATA, ID, OD, TL, TK, CI
          READ FORMAT DATA2, METAL1, METAL2
          SUMVT = 0.0
          SUMVEL = 0.0
          STIN = 0.0
          THROUGH ALPHA, FOR I = 1, 1, I .G. 9
ALPHA     READ FORMAT DATA1, RUNNOA, RUNNOB, TUBENO(I), WTUBE(I),
         1 TTUBEI(I), TTUBEO(I), VAPORT(I)
          PRINT FORMAT TITLE    , RUNNOA, RUNNOB
          PRINT COMMENT $8$
          PRINT FORMAT OUT1, OD, ID, TL, TK, METAL1, METAL2
          OD = OD/12.0
          ID = ID/12.0
          TL = TL/12.0
          RM = (OD-ID)/(TK*2.0)
          DM = (OD-ID)/ELOG.(OD/ID)
          AOT = 3.1416*OD*TL
          AIT = 3.1416*ID*TL
          AMET = 3.1416*DM*TL
          AFLOW = 3.1416*ID*ID/4.0
          PRINT FORMAT OUT2, AOT, AIT, AFLOW, RM, CI
          THROUGH BETA, FOR I = 1, 1, I .G. 9
          TAVG(I) = (TTUBEI(I) + TTUBEO(I))/2.0
          LAT(I) = E(0) + E(1)*VAPORT(I) + E(2)*VAPORT(I).P.2 +
         1 E(3)*VAPORT(I).P.3 + E(4)*VAPORT(I).P.4 + E(5)*VAPORT(I).P.5
          CPT(I) = A(0) + A(1)*TAVG(I) + A(2)*TAVG(I).P.2 +
         1 A(3)*TAVG(I).P.3 + A(4)*TAVG(I).P.4 + A(5)*TAVG(I).P.5
          VISC(I) =  EXP.( D(0) + D(1)/TAVG(I) + D(2)/TAVG(I).P.2 +
         1 D(3)/TAVG(I).P.3 + D(4)/TAVG(I).P.4 + D(5)/TAVG(I).P.5)
          DEN(I) = F(0) + F(1)*TAVG(I) + F(2)*TAVG(I).P.2 +
         1 F(3)*TAVG(I).P.3 + F(4)*TAVG(I).P.4 + F(5)*TAVG(I).P.5
          KT(I) = G(0) + G(1)*TAVG(I) + G(2)*TAVG(I).P.2 +
         1 G(3)*TAVG(I).P.3 + G(4)*TAVG(I).P.4 + G(5)*TAVG(I).P.5
          Q(I) = WTUBE(I)*CPT(I)*(TTUBEO(I) - TTUBEI(I))
          LMTD(I) = (TTUBEO(I) - TTUBEI(I))/(ELOG.((VAPORT(I) -
         1 TTUBEI(I))/(VAPORT(I) - TTUBEO(I))))
          UO(I) = Q(I)/(AOT*LMTD(I))
          PR(I) = CPT(I)*VISC(I)/KT(I)
          RE(I) = ID*WTUBE(I)/(AFLOW*VISC(I))
          VEL(I) = WTUBE(I)/(AFLOW*DEN(I)*3600.0)
          SUMVEL = SUMVEL + VEL(I)
          STIN = STIN + TTUBEI(I)
          SUMVT = SUMVT + VAPORT(I)
          TWALLA(I) = TAVG(I)
RET1      VISCW(I) =  EXP.(D(0) + D(1)/TWALLA(I) + D(2)/TWALLA(I).P.2 +
         1 D(3)/TWALLA(I).P.3 + D(4)/TWALLA(I).P.4 +D(5)/TWALLA(I).P.5)
          HI(I) = CI*KT(I)*RE(I).P.0.8*PR(I).P.0.33333*(VISC(I)/
         1 VISCW(I)).P.0.14/ID
          TWALL(I) = TAVG(I) + Q(I)/(AIT*HI(I))
          WHENEVER .ABS.(TWALLA(I) - TWALL(I)) .G. 0.3
          TWALLA(I) = TWALL(I)
          TRANSFER TO RET1
          END OF CONDITIONAL
          HCOND(I) = 1.0/(1.0/UO(I) -AOT*RM/AMET - AOT/(AIT*HI(I)))
          DELTF(I) = UO(I)*LMTD(I)/HCOND(I)
          TWALLO(I) = VAPORT(I) - Q(I)/(AOT*HCOND(I))
          FILMT(I) = VAPORT(I)- DELTF(I)/2.0
          KCOND(I) = H(0) + H(1)*FILMT(I) + H(2)*FILMT(I).P.2 +
         1 H(3)*FILMT(I).P.3 + H(4)*FILMT(I).P.4 + H(5)*FILMT(I).P.5
          DCOND(I) = K(0) + K(1)*FILMT(I) + K(2)*FILMT(I).P.2 +
         1 K(3)*FILMT(I).P.3 + K(4)*FILMT(I).P.4 + K(5)*FILMT(I).P.5
          VCOND(I) = EXP. ( L(0) + L(1)/FILMT(I) + L(2)/FILMT(I).P.2 +
         1 L(3)/FILMT(I).P.3 + L(4)/FILMT(I).P.4 + L(5)/FILMT(I).P.5)
          PHYGR(I) = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
         1 (VCOND(I)*DELTF(I))).P.0.25
BETA      CONST(I) = HCOND(I)*(OD/(4.17*10.0.P.8*LAT(I))).P.0.25 /
         1 PHYGR(I)
          ATIN = STIN/9.0
          AVGVT = SUMVT/9.0
          AVGVEL = SUMVEL/9.0
          PRINT FORMAT TITLE1
          PRINT COMMENT $8$
          PRINT FORMAT HEAD1
          THROUGH PO1, FOR I = 1, 1, I .G. 9
PO1       PRINT FORMAT RESLT1,          I, WTUBE(I), TTUBEI(I),
         1 TTUBEO(I), TAVG(I), CPT(I), DEN(I), VISC(I)
          PRINT FORMAT HEAD2
          THROUGH PO2, FOR I = 1, 1, I .G. 9
PO2       PRINT FORMAT RESLT2,          I, KT(I), PR(I), TWALL(I),
         1 VISCW(I), VEL(I), RE(I), HI(I)
          PRINT FORMAT HEAD3
          THROUGH PO3, FOR I = 1, 1, I .G. 9
PO3       PRINT FORMAT RESLT3,          I, VAPORT(I), LAT(I), TWALLO(I),
         1 DELTF(I), FILMT(I), KCOND(I), DCOND(I)
          PRINT FORMAT HEAD4
          THROUGH PO4, FOR I = 1, 1, I .G. 9
PO4       PRINT FORMAT RESLT4,          I, VCOND(I), PHYGR(I),
         1 Q(I), LMTD(I), UO(I), HI(I), HCOND(I)
          THROUGH GAMMA, FOR I = 1, 1, I .G. 9
          TTUBEI(I) = ATIN
          VEL(I) = AVGVEL
          VAPORT(I) = AVGVT
RET4      WTUBE(I) = DEN(I)*AVGVEL*3600.0*AFLOW
          TTUBEO(I) = Q(I)/(WTUBE(I)*CPT(I)) + ATIN
          TAVG(I) = (TTUBEI(I) + TTUBEO(I))/2.0
          CPT(I) = A(0) + A(1)*TAVG(I) + A(2)*TAVG(I).P.2 +
         1 A(3)*TAVG(I).P.3 + A(4)*TAVG(I).P.4 + A(5)*TAVG(I).P.5
          VISC(I) =  EXP.( D(0) + D(1)/TAVG(I) + D(2)/TAVG(I).P.2 +
         1 D(3)/TAVG(I).P.3 + D(4)/TAVG(I).P.4 + D(5)/TAVG(I).P.5)
          DEN(I) = F(0) + F(1)*TAVG(I) + F(2)*TAVG(I).P.2 +
         1 F(3)*TAVG(I).P.3 + F(4)*TAVG(I).P.4 + F(5)*TAVG(I).P.5
          KT(I) = G(0) + G(1)*TAVG(I) + G(2)*TAVG(I).P.2     +
         1 G(3)*TAVG(I).P.3 + G(4)*TAVG(I).P.4 + G(5)*TAVG(I).P.5
          PR(I) = CPT(I)*VISC(I)/KT(I)
          RE(I) = ID*WTUBE(I)/(AFLOW*VISC(I))
          LAT(I) = E(0) + E(1)*VAPORT(I) + E(2)*VAPORT(I).P.2 +
         1 E(3)*VAPORT(I).P.3 + E(4)*VAPORT(I).P.4 + E(5)*VAPORT(I).P.5
          LMTD(I) = (TTUBEO(I) - TTUBEI(I))/(ELOG.((VAPORT(I) -
         1 TTUBEI(I))/(VAPORT(I) - TTUBEO(I))))
RET2      VISCW(I) =  EXP.(D(0) + D(1)/TWALLA(I) + D(2)/TWALLA(I).P.2 +
         1 D(3)/TWALLA(I).P.3 + D(4)/TWALLA(I).P.4 +D(5)/TWALLA(I).P.5)
          HI(I) = CI*KT(I)*RE(I).P.0.8*PR(I).P.0.33333*(VISC(I)/
         1 VISCW(I)).P.0.14/ID
          TWALL(I) = TAVG(I) + Q(I)/(AIT*HI(I))
          WHENEVER .ABS.(TWALLA(I) - TWALL(I)) .G. 0.3
          TWALLA(I) = TWALL(I)
          TRANSFER TO RET2
          END OF CONDITIONAL
          TWALLO(I) = TWALL(I) - Q(I)*RM/AMET
          DELTF(I) = VAPORT(I) - TWALLO(I)
RET3      FILMT(I) = VAPORT(I)- DELTF(I)/2.0
          KCOND(I) = H(0) + H(1)*FILMT(I) + H(2)*FILMT(I).P.2 +
         1 H(3)*FILMT(I).P.3 + H(4)*FILMT(I).P.4 + H(5)*FILMT(I).P.5
          DCOND(I) = K(0) + K(1)*FILMT(I) + K(2)*FILMT(I).P.2 +
         1 K(3)*FILMT(I).P.3 + K(4)*FILMT(I).P.4 + K(5)*FILMT(I).P.5
          VCOND(I) = EXP. ( L(0) + L(1)/FILMT(I) + L(2)/FILMT(I).P.2 +
         1 L(3)/FILMT(I).P.3 + L(4)/FILMT(I).P.4 + L(5)/FILMT(I).P.5)
          PHYGR(I) = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
         1 (VCOND(I)*DELTF(I))).P.0.25
          HCOND(I) = CONST(I)*PHYGR(I)*(4.17*10.0.P.8*LAT(I)/ OD)
         1 .P.0.25
          UO(I) = 1.0/(1.0/HCOND(I) + AOT*RM/AMET + AOT/(AIT*HI(I)))
          DELTFA(I) = UO(I)*LMTD(I)/HCOND(I)
          WHENEVER .ABS.(DELTFA(I) - DELTF(I))/DELTFA(I) .G. 0.001
          DELTF(I) = DELTFA(I)
          TRANSFER TO RET3
          END OF CONDITIONAL
          QA(I) = UO(I)*LMTD(I)*AOT
          WHENEVER .ABS.(QA(I) - Q(I))/QA(I) .G. 0.001
          Q(I) = QA(I)
          TRANSFER TO RET4
          END OF CONDITIONAL
GAMMA     CONTINUE
          PRINT FORMAT TITLE2
          PRINT COMMENT $8$
          PRINT FORMAT HEAD1
          THROUGH PO5, FOR I = 1, 1, I .G. 9
PO5       PRINT FORMAT RESLT1,          I, WTUBE(I), TTUBEI(I),
         1 TTUBEO(I), TAVG(I), CPT(I), DEN(I), VISC(I)
          PRINT FORMAT HEAD2
          THROUGH PO6, FOR I = 1, 1, I .G. 9
PO6       PRINT FORMAT RESLT2,          I, KT(I), PR(I), TWALL(I),
         1 VISCW(I), VEL(I), RE(I), HI(I)
          PRINT FORMAT HEAD3
          THROUGH PO7, FOR I = 1, 1, I .G. 9
PO7       PRINT FORMAT RESLT3,          I, VAPORT(I), LAT(I), TWALLO(I),
         1 DELTF(I), FILMT(I), KCOND(I), DCOND(I)
          PRINT FORMAT HEAD4
          THROUGH PO8, FOR I = 1, 1, I .G. 9
PO8       PRINT FORMAT RESLT4,          I, VCOND(I), PHYGR(I),
         1 Q(I), LMTD(I), UO(I), HI(I), HCOND(I)
          Q = 0.0
          SCPT = 0.0
          SDEN = 0.0
          THROUGH DELTA, FOR I = 1, 1, I .G. 9
          Q(I) = Q(I-1) + Q(I)
          SDEN = SDEN + DEN(I)
          DEN(I) = SDEN/I
          SCPT = SCPT + CPT(I)
          CPT(I) = SCPT/I
          WTUBE(I) = DEN(I)*AVGVEL*3600.0*AFLOW*I
          TTUBEO(I) = TTUBEI(I) + Q(I)/(WTUBE(I)*CPT(I))
          TAVG(I) = (TTUBEI(I) + TTUBEO(I))/2.0
          KT(I) = G(0) + G(1)*TAVG(I) + G(2)*TAVG(I).P.2 +
         1 G(3)*TAVG(I).P.3 + G(4)*TAVG(I).P.4 + G(5)*TAVG(I).P.5
          DEN(I) = F(0) + F(1)*TAVG(I) + F(2)*TAVG(I).P.2 +
         1 F(3)*TAVG(I).P.3 + F(4)*TAVG(I).P.4 + F(5)*TAVG(I).P.5
          VISC(I) =  EXP.( D(0) + D(1)/TAVG(I) + D(2)/TAVG(I).P.2 +
         1 D(3)/TAVG(I).P.3 + D(4)/TAVG(I).P.4 + D(5)/TAVG(I).P.5)
          CPT(I) = A(0) + A(1)*TAVG(I) + A(2)*TAVG(I).P.2 +
         1 A(3)*TAVG(I).P.3 + A(4)*TAVG(I).P.4 + A(5)*TAVG(I).P.5
          LAT(I) = E(0) + E(1)*VAPORT(I) + E(2)*VAPORT(I).P.2 +
         1 E(3)*VAPORT(I).P.3 + E(4)*VAPORT(I).P.4 + E(5)*VAPORT(I).P.5
          TWALLA(I) = TWALL(I)
RET5      VISCW(I) =  EXP.(D(0) + D(1)/TWALLA(I) + D(2)/TWALLA(I).P.2 +
         1 D(3)/TWALLA(I).P.3 + D(4)/TWALLA(I).P.4 +D(5)/TWALLA(I).P.5)
          HI(I) = CI*KT(I)*RE(I).P.0.8*PR(I).P.0.33333*(VISC(I)/
         1 VISCW(I)).P.0.14/ID
          TWALL(I) = Q(I)/(HI(I)*AIT*I) + TAVG(I)
          WHENEVER .ABS.(TWALLA(I) - TWALL(I)) .G. 0.3
          TWALLA(I) = TWALL(I)
          TRANSFER TO RET5
          END OF CONDITIONAL
          LMTD(I) = (TTUBEO(I) - TTUBEI(I))/(ELOG.((VAPORT(I) -
         1 TTUBEI(I))/(VAPORT(I) - TTUBEO(I))))
          UO(I) = Q(I)/(LMTD(I)*AOT*I)
          HCOND(I) = 1.0/(1.0/UO(I) -AOT*RM/AMET - AOT/(AIT*HI(I)))
          DELTF(I) = UO(I)*LMTD(I)/HCOND(I)
          FILMT(I) = VAPORT(I)- DELTF(I)/2.0
          KCOND(I) = H(0) + H(1)*FILMT(I) + H(2)*FILMT(I).P.2 +
         1 H(3)*FILMT(I).P.3 + H(4)*FILMT(I).P.4 + H(5)*FILMT(I).P.5
          DCOND(I) = K(0) + K(1)*FILMT(I) + K(2)*FILMT(I).P.2 +
         1 K(3)*FILMT(I).P.3 + K(4)*FILMT(I).P.4 + K(5)*FILMT(I).P.5
          VCOND(I) = EXP. ( L(0) + L(1)/FILMT(I) + L(2)/FILMT(I).P.2 +
         1 L(3)/FILMT(I).P.3 + L(4)/FILMT(I).P.4 + L(5)/FILMT(I).P.5)
          PHYGR(I) = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
         1 (VCOND(I)*DELTF(I))).P.0.25
          CN(I) = HCOND(I)/(0.725*PHYGR(I)*(LAT(I)*4.17*10.0.P.8/(OD*
         1 I)).P.0.25)
DELTA     CONSTA(I) = CONST(I)/0.725
          PRINT FORMAT TITLE3
          PRINT COMMENT $8$
          PRINT FORMAT HEAD1
          THROUGH PO9, FOR I = 1, 1, I .G. 9
PO9       PRINT FORMAT RESLT1,          I, WTUBE(I), TTUBEI(I),
         1 TTUBEO(I), TAVG(I), CPT(I), DEN(I), VISC(I)
          PRINT FORMAT HEAD2
          THROUGH PO10, FOR I = 1, 1, I .G. 9
PO10      PRINT FORMAT RESLT2,          I, KT(I), PR(I), TWALL(I),
         1 VISCW(I), VEL(I), RE(I), HI(I)
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TABLE XV (Continued)

```
               PRINT FORMAT HEAD3
               THROUGH PO11, FOR I = 1, 1, I .G. 9
PO11           PRINT FORMAT RESLT3,          I, VAPORT(I), LAT(I), TWALLO(I),
              1 DELTF(I), FILMT(I), KCOND(I), DCOND(I)
               PRINT FORMAT HEAD4
               THROUGH PO12, FOR I = 1, 1, I .G. 9
PO12           PRINT FORMAT RESLT4,          I, VCOND(I), PHYGR(I),
              1 Q(I), LMTD(I), UO(I), HI(I), HCOND(I)
               PRINT FORMAT HEAD5
               THROUGH PO13, FOR I = 1, 1, I .G. 9
PO13           PRINT FORMAT RESLT5, I, CONST(I), CONSTA(I), CN(I)

               VECTOR VALUES TITLE = $ 80H1
              1          CALCULATED RESULTS FOR RUN NUMBER      I2, C6    *$
               VECTOR VALUES TITLE1 = $ 83H1
              1                   CALCULATED RESULTS FOR RAW DATA          *$
               VECTOR VALUES TITLE2 = $ 125H1                  CALCULATED RESUL
              1TS FOR DATA ADJUSTED TO CONSTANT INLET WATER TEMPERATURE AND
              2CONSTANT VAPOR TEMPERATURE                              *$
               VECTOR VALUES TITLE3 = $ 99H1
              2      CALCULATED RESULTS ARE FOR AVERAGE CONDITIONS FOR TOP I
              2 TUBES                          *$
               VECTOR VALUES DATA = $ 5F10.4   *$
               VECTOR VALUES DATA1 = $ I4, C6, I10, F10.0, 3F10.3   *$
               VECTOR VALUES DATA2 = $ 2C6 *$
               VECTOR VALUES OUT1 = $  32H TUBE OUTSIDE DIAMETER - INCHES
              1     S30, F10.4  /
              131H TUBE INSIDE DIAMETER - INCHES       S31, F10.4     /
              122H TUBE LENGTH - INCHES        S40, F10.4  /
              141H TUBE THERMAL CONDUCTIVITY - BTU/HR-FT-F      S21, F10.4  /
              112H TUBE METAL             S43, 2C6     *$
               VECTOR VALUES OUT2 = $ 43H TUBE OUTSIDE HEAT TRANSFER AREA -
              1SQFT/FT      S19, F10.4    /
              142H TUBE INSIDE HEAT TRANSFER AREA - SQFT/FT    S20, F10.4 /
              122H TUBE FLOW AREA - SQFT      S40, F13.7  /
              133H METAL RESISTANCE - BTU/HR-SQFT-F        S29, F13.7  /
              128H INSIDE COEFFICIENT CONSTANT            S35, F10.5    *$
               VECTOR VALUES RESLT1 = $ S9, I6, F15.0, 6F15.3    *$
               VECTOR VALUES RESLT2 = $ S9, I6, F15.4, F15.3, 2F15.2,
              1 2F15.3, F15.2   *$
               VECTOR VALUES RESLT3 = $ S9, I6, F15.3, F15.2, 3F15.3, F15.4,
              1 F15.3   *$
               VECTOR VALUES RESLT4 = $ S9, I6, 2F15.3, F15.2, F15.3,
              1 3F15.3      *$
               VECTOR VALUES RESLT5 = $ I15, 3F15.4   *$
               VECTOR VALUES HEAD1 =$120H2          TUBE NO          W TUBE
              1 T TUBE IN      T TUBE OUT            T-AVG           T-CP
              2T-DENSITY     T-VISCOSITY    /     120H
              3LB/HR                F              F               F        BTU/
              4LB-F         LB/CUFT        LB/FT-HR         //////*$
               VECTOR VALUES HEAD2 = $ 120H2          TUBE NO              T-K
              1          PR        T WALL IN   TW-VISCOSITY    T-VELOCITY
              2         RE                HI   /   120H                      BTU
              37HR-FT                               F      LB/FT-HR          F
              4T/SEQ                     BTU/HR-SQFT-F        //////*$
               VECTOR VALUES HEAD3 = $ 120H2          TUBE NO      VAPOR TEMP
              1     LAT HEAT       T WALL OUT          DT FILM          T FILM
              2        C-K       C-DENSITY       / 120H
              3     F            BTU/LB                F                F
              4     F         BTU/HR-FT          LB/CUFT        //////*$
               VECTOR VALUES HEAD4 = $ 120H2          TUBE NO     C-VISCOSITY
              1         PHYGR         HEAT DUTY            LMTD            UO
              1          HI            H COND    / 120H                   LB/F
              3T-HR                            BTU/HR                F  BTU/HR-SQF
              4T-F   BTU/HR-SQFT-F   BTU/HR-SQFT-F           //////   *$
               VECTOR VALUES HEAD5 = $ 60H2          TUBE NO      COND CONST
              1CONST/0.725                 CN        //////   *$
               VECTOR VALUES A =  0.10124896E 01, -0.46678063E-03,
              1 0.58540867E-05, -0.32721741E-07, 0.72640616E-10, 0.0E0
               VECTOR VALUES D =  -0.21968738E01, 0.54722744E03,
              1 -0.41363282E05, 0.16141324E07, -0.24764542E08, 0.0E0
               VECTOR VALUES E = 1095.2, -0.5800, 0.0, 0.0, 0.0
               VECTOR VALUES F = 0.63130000E02, -0.11700000E-01, 0.0E0,
              1 0.0E0, 0.0E0, 0.0E0
               VECTOR VALUES G = 0.30377927E00, 0.25267360E-03,
              1 0.92050520E-05, -0.75847219E-07, 0.17507457E-09, 0.0E0
               VECTOR VALUES H = 0.30377927E00, 0.25267360E-03,
              1 0.92050520E-05, -0.75847219E-07, 0.17507457E-09, 0.0E0
               VECTOR VALUES K = 0.63130000E02, -0.11700000E-01, 0.0E0
               VECTOR VALUES L =  -0.21968738E01, 0.54722744E03,
              1 -0.41363282E05, 0.16141324E07, -0.24764542E08, 0.0E0
               TRANSFER TO START
               END OF PROGRAM
```

AFLOW	TUBESIDE FLOW AREA, SQ.FT.
AIT	TOTAL INSIDE HEAT TRANSFER AREA, SQ.FT.
AMET	TOTAL MEAN METAL AREA, SQ.FT.
AOT	TOTAL OUTSIDE HEAT TRANSFER AREA, SQ.FT.
AVGVEL	AVERAGE WATER VELOCITY, FT./SEC.
AVGVT	AVERAGE STEAM TEMPERATURE, F.
A(I)	CONSTANTS FOR HEAT CAPACITY OF WATER
CI	ASSUMED VALUE OF INSIDE HEAT TRANSFER COEFFICIENT CONSTANT
CONST	CONDENSING COEFFICIENT CONSTANT
CN	CONDENSING COEFFICIENT CORRECTION FACTOR
CPT	SPECIFIC HEAT FOR WATER, BTU/LB-F
DCOND	DENSITY OF CONDENSATE, LB/CU.FT.
DELTF	TEMPERATURE DROP ACROSS CONDENSATE FILM, F.
DELTFA	CALCULATED VALUE OF TEMPERATURE DROP ACROSS CONDENSING FILM, F.
DEN	DENSITY OF WATER, LB./CU.FT.
DM	MEAN METAL DIAMETER OF TUBE, IN. OR FT.
D(I)	CONSTANTS FOR VISCOSITY OF WATER
E(I)	CONSTANTS FOR LATENT HEAT OF STEAM
FILMT	CONDENSATE FILM TEMPERATURE, F.
F(I)	CONSTANTS FOR DENSITY OF WATER
G(I)	CONSTANTS FOR THERMAL CONDUCTIVITY OF WATER
HCOND	CONDENSING COEFFICIENT, BTU/HR.-SQ.FT.-F.
HI	INSIDE HEAT TRANSFER COEFFICIENT, BTU/HR.-SQ.FT.-F.
H(I)	CONSTANTS FOR THERMAL CONDUCTIVITY OF CONDENSATE
ID	TUBE INSIDE DIAMETER, IN. OR FT.
KCOND	THERMAL CONDUCTIVITY OF CONDENSATE FILM, BTU/HR.-SQ.FT.-F./FT.
K(I)	CONSTANTS FOR DENSITY OF CONDENSATE
KT	THERMAL CONDUCTIVITY OF WATER, BTU/HR.-SQ.FT.-F./FT.
LAT	LATENT HEAT OF STEAM, BTU/LB.
LMTD	LOGARITHMIC TEMPERATURE DIFFERENCE, F.
L(I)	CONSTANTS FOR VISCOSITY OF CONDENSATE
OD	TUBE OUTSIDE DIAMETER, IN. OR FT.
PHYGR	PHYSICAL PROPERTY GROUP
PR	PRANDTL NUMBER OF WATER
Q	HEAT DUTY, BTU/HR.
QA	CALCULATED VALUE OF HEAT DUTY, BTU/HR.
RE	REYNOLDS NUMBER
RM	METAL RESISTANCE, HR.-SQ.FT.(OUTSIDE AREA)-F./BTU
SCPT	SUM OF HEAT CAPACITY FOR WATER
SDEN	SUM OF DENSITIES OF WATER
STIN	SUM OF INLET WATER TEMPERATURES
SUMLAT	SUM OF LATENT HEATS FOR ALL RUNS
SUMVEL	SUM OF WATER VELOCITIES
SUMVT	SUM OF VAPOR TEMPERATURES
TAVG	AVERAGE TUBESIDE TEMPERATURE, F.
TK	THERMAL CONDUCTIVITY OF TUBE METAL, BTU/HR.-SQ.FT.-F./FT.
TL	TUBE LENGTH, IN. OR FT.
TTUBEI	INLET WATER TEMPERATURE, F.
TTUBEO	OUTLET WATER TEMPERATURE, F.
TUBENO	TUBE NUMBER IN A VERTICAL ROW FROM TOP
TWALLA	ESTIMATED VALUE OF INSIDE WALL TEMPERATURE, F.
TWALL	CALCULATED VALUE OF INSIDE WALL TEMPERATURE, F.
TWALLO	OUTSIDE WALL TEMPERATURE, F.
UO	OVERALL HEAT TRANSFER COEFFICIENT, BTU/HR.-SQ.FT.-F.
VAPORT	STEAM VAPOR TEMPERATURE, F.
VCOND	VISCOSITY OF CONDENSATE, LB./FT.-HR.
VEL	WATER VELOCITY, FT./SEC.
VISC	VISCOSITY OF WATER, LB./FT.-HR.
VISCW	VISCOSITY OF WATER AT WALL TEMPERATURE, LB./FT.-HR.
WTUBE	TUBESIDE FLOW RATE, LB./HR.

TABLE XVI

Typical Multiple Tube Analysis Computer Calculated Results

CALCULATED RESULTS FOR RUN NUMBER 197044C

TUBE OUTSIDE DIAMETER - INCHES	.6271
TUBE INSIDE DIAMETER - INCHES	.5581
TUBE LENGTH - INCHES	72.1560
TUBE THERMAL CONDUCTIVITY - BTU/HR-FT-F	10.0000
TUBE METAL	TITANIUM
TUBE OUTSIDE HEAT TRANSFER AREA - SQFT/FT	.9872
TUBE INSIDE HEAT TRANSFER AREA - SQFT/FT	.8786
TUBE FLOW AREA - SQFT	.0016988
METAL RESISTANCE - BTU/HR-SQFT-F	.0002875
INSIDE COEFFICIENT CONSTANT	.02468

CALCULATED RESULTS FOR RAW DATA

TUBE NO	W TUBE LB/HR	T TUBE IN F	T TUBE OUT F	T-AVG F	T-CP BTU/LB-F	T-DENSITY LB/CUFT	T-VISCOSITY LB/FT-HR
1	10112	74.990	78.100	76.545	.999	62.234	2.160
2	9048	74.990	77.520	76.255	.999	62.238	2.168
3	9390	74.990	77.450	76.220	.999	62.238	2.169
4	9591	75.000	77.330	76.165	.999	62.239	2.171
5	9328	75.020	77.390	76.205	.999	62.238	2.169
6	9555	75.040	77.320	76.180	.999	62.239	2.170
7	9050	75.060	77.340	76.200	.999	62.238	2.170
8	9550	75.070	77.270	76.170	.999	62.239	2.170
9	9690	75.070	77.260	76.165	.999	62.239	2.171

TABLE XVI (Continued)

TUBE NO	T-K BTU/HR-FT	PR	T WALL IN F	TW-VISCOSITY LB/FT-HR	T-VELOCITY FT/SEC	RE	HI BTU/HR-SQFT-F
1	.3490	6.182	85.05	1.95	26.568	128140.818	4205.14
2	.3489	6.208	83.05	2.00	23.771	114248.812	3828.78
3	.3488	6.211	82.88	2.00	24.669	118516.046	3942.28
4	.3488	6.216	82.51	2.01	25.197	120970.830	4006.00
5	.3488	6.212	82.62	2.01	24.506	117711.722	3919.41
6	.3488	6.214	82.38	2.01	25.102	120539.080	3993.44
7	.3488	6.213	82.34	2.01	23.776	114196.544	3823.78
8	.3488	6.215	82.16	2.02	25.089	120461.128	3990.05
9	.3488	6.216	82.14	2.02	25.457	122219.510	4036.58

TUBE NO	VAPOR TEMP F	LAT HEAT BTU/LB	T WALL OUT F	DT FILM F	T FILM F	C-K BTU/HR-FT	C-DENSITY LB/CUFT
1	100.960	1036.64	94.773	6.187	97.866	.3616	61.985
2	100.970	1036.64	90.129	10.841	95.550	.3604	62.012
3	100.990	1036.63	90.021	10.969	95.506	.3604	62.013
4	101.030	1036.60	89.413	11.617	95.221	.3602	62.016
5	101.060	1036.59	89.450	11.610	95.255	.3602	62.016
6	101.090	1036.57	89.114	11.976	95.102	.3601	62.017
7	101.120	1036.55	88.712	12.408	94.916	.3600	62.019
8	101.120	1036.55	88.648	12.472	94.884	.3600	62.020
9	101.120	1036.55	88.698	12.422	94.909	.3600	62.020

TABLE XVI (Continued)

TUBE NO	C-VISCOSITY LB/FT-HR	PHYGR	HEAT DUTY BTU/HR	LMTD F	UO BTU/HR-SQFT-F	HI BTU/HR-SQFT-F	H COND BTU/HR-SQFT-F
1	1.696	2.040	31413.04	24.382	1305.100	4205.136	5143.039
2	1.738	1.758	22865.86	24.693	938.013	3828.780	2136.613
3	1.739	1.753	23073.60	24.750	944.385	3942.284	2130.892
4	1.744	1.726	22322.09	24.847	910.054	4005.996	1946.410
5	1.744	1.726	22082.68	24.836	900.678	3919.414	1926.752
6	1.747	1.712	21761.08	24.893	885.549	3993.441	1840.634
7	1.750	1.696	20610.96	24.903	838.409	3823.779	1682.654
8	1.751	1.693	20986.55	24.934	852.618	3990.055	1704.543
9	1.750	1.695	21197.42	24.939	861.007	4036.578	1728.651

CALCULATED RESULTS FOR DATA ADJUSTED TO CONSTANT INLET WATER TEMPERATURE AND CONSTANT VAPOR TEMPERATURE

TUBE NO	W TUBE LB/HR	T TUBE IN F	T TUBE OUT F	T-AVG F	T-CP BTU/LB-F	T-DENSITY LB/CUFT	T-VISCOSITY LB/FT-HR
1	9479	75.026	78.287	76.656	.999	62.233	2.157
2	9479	75.026	77.470	76.248	.999	62.238	2.168
3	9479	75.026	77.470	76.248	.999	62.238	2.168
4	9479	75.026	77.377	76.201	.999	62.238	2.170
5	9479	75.026	77.364	76.195	.999	62.239	2.170
6	9479	75.026	77.318	76.172	.999	62.239	2.170
7	9480	75.026	77.219	76.122	.999	62.239	2.172
8	9480	75.026	77.236	76.131	.999	62.239	2.171
9	9479	75.026	77.252	76.139	.999	62.239	2.171

TABLE XVI (Continued)

TUBE NO	T-K BTU/HR-FT	PR	T WALL IN F	TW-VISCOSITY LB/FT-HR	T-VELOCITY FT/SEC	RE	HI BTU/HR-SQFT-F
1	.3491	6.173	85.45	1.94	24.904	120278.457	3998.34
2	.3489	6.208	82.88	2.01	24.904	119684.846	3971.71
3	.3489	6.208	82.88	2.00	24.904	119684.333	3972.83
4	.3488	6.213	82.59	2.01	24.904	119616.596	3969.41
5	.3488	6.213	82.54	2.01	24.904	119607.618	3970.02
6	.3488	6.215	82.40	2.01	24.904	119573.656	3967.99
7	.3488	6.220	82.09	2.02	24.904	119502.302	3964.27
8	.3488	6.219	82.14	2.02	24.904	119514.472	3965.66
9	.3488	6.218	82.19	2.02	24.904	119525.911	3965.73

TUBE NO	VAPOR TEMP F	LAT HEAT BTU/LB	T WALL OUT F	DT FILM F	T FILM F	C-K BTU/HR-FT	C-DENSITY LB/CUFT
1	101.051	1036.59	94.973	6.049	98.027	.3617	61.983
2	101.051	1036.59	90.024	11.016	95.543	.3604	62.012
3	101.051	1036.59	90.020	11.014	95.544	.3604	62.012
4	101.051	1036.59	89.455	11.579	95.262	.3602	62.015
5	101.051	1036.59	89.377	11.658	95.222	.3602	62.016
6	101.051	1036.59	89.095	11.940	95.081	.3601	62.018
7	101.051	1036.59	88.496	12.555	94.774	.3600	62.021
8	101.051	1036.59	88.599	12.437	94.832	.3600	62.020
9	101.051	1036.59	88.696	12.340	94.881	.3600	62.020

TABLE XVI (Continued)

TUBE NO	C-VISCOSITY LB/FT-HR	PHYGR	HEAT DUTY BTU/HR	LMTD F	UU BTU/HR-SQFT-F	HI BTU/HR-SQFT-F	H COND BTU/HR-SQFT-F
1	1.693	2.053	30878.12	24.359	1283.962	3998.338	5175.129
2	1.738	1.751	23148.49	24.783	945.706	3971.712	2128.020
3	1.738	1.751	23144.96	24.783	945.963	3972.834	2128.961
4	1.744	1.727	22264.84	24.831	908.327	3969.415	1948.293
5	1.744	1.724	22146.09	24.838	903.158	3970.018	1924.507
6	1.747	1.713	21705.49	24.862	884.423	3967.985	1841.879
7	1.753	1.690	20772.92	24.913	844.318	3964.266	1676.827
8	1.752	1.694	20934.71	24.904	851.577	3965.664	1705.412
9	1.751	1.698	21084.60	24.896	858.000	3965.727	1731.353

CALCULATED RESULTS ARE FOR AVERAGE CONDITIONS FOR TOP I TUBE

TUBE NO	W TUBE LB/HR	T TUBE IN F	T TUBE OUT F	T-AVG F	T-CP BTU/LB-F	T-DENSITY LB/CUFT	T-VISCOSITY LB/FT-HR
1	9479	75.026	78.287	76.656	.999	62.233	2.157
2	18958	75.026	77.879	76.452	.999	62.236	2.163
3	28437	75.026	77.742	76.384	.999	62.236	2.165
4	37917	75.026	77.651	76.338	.999	62.237	2.166
5	47396	75.026	77.594	76.310	.999	62.237	2.167
6	56875	75.026	77.548	76.287	.999	62.237	2.167
7	66355	75.026	77.501	76.263	.999	62.238	2.168
8	75835	75.026	77.468	76.247	.999	62.238	2.168
9	85314	75.026	77.444	76.235	.999	62.238	2.169

TABLE XVI (Continued)

TUBE NO	T-K BTU/HR-FT	PR	T WALL IN F	TW-VISCOSITY LB/FT-HR	T-VELOCITY FT/SEC	RE	HI BTU/HR-SQFT-F
1	.3491	6.173	85.45	1.94	24.904	120278.457	3997.15
2	.3490	6.208	84.18	1.97	24.904	119684.846	3980.91
3	.3489	6.208	83.74	1.98	24.904	119684.333	3978.05
4	.3489	6.213	83.46	1.99	24.904	119616.596	3975.24
5	.3489	6.213	83.27	1.99	24.904	119607.618	3973.92
6	.3489	6.215	83.13	2.00	24.904	119573.656	3972.51
7	.3489	6.220	82.98	2.00	24.904	119502.302	3970.58
8	.3489	6.219	82.88	2.00	24.904	119514.472	3970.04
9	.3488	6.218	82.80	2.00	24.904	119525.911	3969.69

TUBE NO	VAPOR TEMP F	LAT HEAT BTU/LB	T WALL OUT F	DT FILM F	T FILM F	C-K BTU/HR-FT	C-DENSITY LB/CUFT
1	101.051	1036.59	94.973	6.039	98.032	.3617	61.983
2	101.051	1036.59	90.024	8.513	96.795	.3611	61.998
3	101.051	1036.59	90.020	9.345	96.379	.3608	62.002
4	101.051	1036.59	89.455	9.902	96.100	.3607	62.006
5	101.051	1036.59	89.377	10.252	95.925	.3606	62.008
6	101.051	1036.59	89.095	10.532	95.785	.3605	62.009
7	101.051	1036.59	88.496	10.817	95.642	.3604	62.011
8	101.051	1036.59	88.599	11.020	95.541	.3604	62.012
9	101.051	1036.59	88.696	11.167	95.468	.3603	62.013

TABLE XVI (Continued)

TUBE NO	C-VISCOSITY LB/FT-HR	PHYGR	HEAT DUTY BTU/HR	LMTD F	UO BTU/HR-SQFT-F	HI BTU/HR-SQFT-F	H COND BTU/HR-SQFT-F
1	1.693	2.054	30878.12	24.359	1284.111	3997.151	5179.789
2	1.715	1.876	54026.61	24.571	1113.652	3980.910	3214.304
3	1.723	1.830	77171.56	24.642	1057.448	3978.050	2788.369
4	1.728	1.802	99436.41	24.690	1019.939	3975.242	2543.165
5	1.731	1.785	121582.50	24.719	996.478	3973.922	2402.690
6	1.734	1.772	143287.99	24.743	977.704	3972.507	2296.899
7	1.737	1.760	164060.91	24.767	958.584	3970.583	2194.747
8	1.738	1.751	184995.61	24.784	945.138	3970.044	2125.686
9	1.740	1.745	206080.21	24.797	935.408	3969.690	2077.200

TUBE NO	COND CCNST	CCNST/0.725	CN
1	1.4866	2.0504	2.0514
2	.7166	.9885	1.6571
3	.7169	.9889	1.6309
4	.6651	.9173	1.6233
5	.6582	.9078	1.6369
6	.6340	.8745	1.6497
7	.5852	.8071	1.6501
8	.5936	.8188	1.6608
9	.6013	.8294	1.6774