DEPARTMENT OF CHEMICAL AND METALLURGICAL ENGINEERING

Heat Transfer Laboratory

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THE CONDENSING OF STEAM ON HORIZONTAL CORRUGATED AND BARE TUBES

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ABSTRACT

Experimental heat transfer data are presented for steam condensing at 101°F and 212°F on the outside of horizontal copper and 90-10 Cupro-Nickel tubes in vertical rows. The performance of five-eighths and one-inch corrugated and bare tubes were investigated. An analysis of the experimental data and the resulting steam condensing coefficient correlations are presented.

OBJECTIVE

The purpose of this investigation was to establish correlations for predicting steam condensing heat transfer coefficients for multi-tube bundles of 90-10 Cupro-Nickel corrugated and bare tubes in steam condensing applications.

INTRODUCTION

This investigation was undertaken to determine experimentally the advantages of using corrugated type tubes in steam condensing applications. An earlier investigation had been undertaken to study the performance of bare titanium tubes in the condensing of low pressure steam. The results of this investigation were presented in Report 55[1]* and in a technical paper published in AIChE Journal in January, 1966[2]. A reprint of this paper appears in Appendix I.** In order to evaluate the performance of titanium tubes, experimental data was also collected on 5/8-inch O.D. copper tubes. This copper tube test data was used in this corrugated tube current investigation.

In order to utilize the earlier experimental data obtained on 5/8-inch copper tubes, 5/8-inch corrugated tubes were fabricated from copper and studied experimentally. A set of 1-inch bare tubes and a set of 1-inch corrugated tubes fabricated from 90-10 Cupro-Nickel were also studied experimentally with steam condensing at atmospheric pressure and under 28 inches of vacuum.

* Literature cited will be found on page 45.

** Appendices will be found beginning on page 86.

REVIEW OF THE LITERATURE

In 1916, Nusselt[3] 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

$$t_f = t_{sv} - \frac{3}{4} \Delta t_f \tag{2}$$

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.[3] 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.[4]

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

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.[3]

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

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[5], Short and Brown[6], and Young and Wohlenberg[7] 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[4] to give Equation (5).

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

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.[4] 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.[3] 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(8) 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 made by the British Admiralty in which condensing heat transfer data were obtained for multiple tube arrangements with film and dropwise condensation of steam.(9) 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.

DESCRIPTION OF TUBES INVESTIGATED

Two corrugated tubes, 5/8-inch O.D. and 1-inch O.D., and two corresponding bare tubes were studied in a laboratory steam condenser. Figure 1* presents a picture of the two corrugated tubes. Table 1 presents the dimensions and characteristics of the four tubes investigated. The pair of 5/8-inch tubes were fabricated from copper and the pair of 1-inch tubes were fabricated from 90-10 Cupro-Nickel.

TABLE 1

Tube Dimensions and Characteristics of Four Tubes Investigated

Tube Type	5/8-Inch Bare	5/8-Inch Corrugated	1-Inch Bare	1-Inch Corrugated
Tube outside diameter, in.	0.6252	0.6132	1.0020	0.9370
Tube inside diameter, in.	0.5550	0.5300	0.9008	0.8220
Tube wall thickness, in.	0.0351	0.0416	0.0456	0.0575
Tube length, in.	72.156	72.156	72.156	72.156
Tube material	copper	copper	90-10 Cu-Ni	90-10 Cu-Ni
Thermal conductivity, BTU/hr-ft^2-°F/ft.	196	196	26	26
Helix:				
Pitch	none	1/4"	none	1/4"
Depth	none	0.033"	none	0.031"

* Figures are presented in section beginning on page 46.

EQUIPMENT

The equipment used in the 5/8-inch bare copper tube investigation is described in the reprint presented in Appendix I. The equipment used in the 5/8-inch corrugated copper tube, the 90-10 Cupro-Nickel 1-inch corrugated tube, and the 90-10 Cupro-Nickel 1-inch bare tube investigations consisted of a condenser, inlet and outlet water pots, reboiler, make-up tank, water preheater, water cooler, line pump, surge tank, manual flowrate valve, steam jet ejector and automatic controls. Figures 2 and 3 show a front and partial rear view of the laboratory equipment. Figure 4 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 5. Steam was generated by boiling distilled water in the reboiler with 125 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 4-inch line. Distilled water was used as the coolant in a closed loop.

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 steel plate with both sides surface ground to give a flat surface. Figure 6 gives a detailed drawing of the tube sheets showing the tube layout for the 5/8-inch tubes (Tube Sheet No. 1) and the 1-inch tubes (Tube Sheet No. 2). Tube Sheet No. 1 was constructed to accommodate 25 tubes placed in three vertical rows with the tubes on a 7/8-inch equilateral triangular pitch. Tube Sheet No. 2 was constructed to accommodate nineteen tubes placed in three vertical rows with the tubes on a 1 1/4-inch equilateral triangular pitch. The 5/8-inch and 1-inch tubes were sealed in the tube sheet by expanding them with an expansion tool. 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 7. 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 4-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. One-half inch lines with accompanying valves were placed at the top of the condenser to provide a means of removing non-condensibles during atmospheric operation. These can be seen in Figure 2. The condenser was wrapped with fiberglass insulating material. Corrugated metal asbestos gaskets were used between the tube sheets and ring flanges.

The 5/8-inch corrugated tube bundle consisted of twenty-three 5/8-inch O. D. corrugated copper tubes and two 5/8-inch O. D. bare copper tubes. The two bare tubes were inserted at the top of each side vertical row in the tubesheet. The 1-inch corrugated tube bundle consisted of seventeen 1-inch O. D. corrugated 90-10 Cupro-Nickel tubes and two 1-inch O. D. bare 90-10 Cupro-Nickel tubes. Once again the two bare tubes were inserted at the top of each side vertical row in the tubesheet. The 1-inch bare tube bundle consisted of nineteen 1-inch O. D. bare 90-10 Cupro-Nickel tubes.

For the 5/8-inch tubes, the inlet and outlet water pots 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 approximately six inches into the other plates. 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. For the 1-inch tubes, the inlet and outlet water pots consisted of 15-inch lengths of 16-inch standard steel pipe with ring flanges welded to each end of the pipe. The flanges were made from 1 1/2-inch thick plate steel with a bolt circle identical to a standard 16-inch 150-pound flange. Tube sheets were constructed from 1 1/2-inch steel plate. The inlet pot was placed approximately six feet from the condenser while the outlet pot was placed approximately 25 inches from the condenser. Seventy-six-inch lengths of tubes were expanded in the condenser tube sheets such that the tubes extended beyond both ends of the condenser approximately two inches. For the 5/8-inch tube, 6-foot lengths of tubes were placed in the inlet pot (extending approximately one inch into the pot) and joined to the condenser tubes by soldering a connecting coupling between the two. For the 1-inch tubes, 5-inch sections of tube were expanded in the pot flange (extending approximately two inches on either side of the flange) and joined to 6-foot lengths of tube by a soldered coupling. The other ends of the 6-foot lengths were joined to the condenser tubes by soldering couplings between them. This 6-foot entry section of tubes, seen in Figure 3, provided a means of obtaining an established flow pattern before the coolant entered the condenser. The section was tightly wrapped with fiberglass insulation to prevent heat losses. Five-inch lengths of tube were secured in the outlet water pot by O-rings in the 5/8-inch tube experiment and by expansion in the 1-inch tube experiment. Each section was placed in such a manner that the tube extended approximately 1 1/2-inch beyond either side of the pot face. In these positions, the condenser tubes and the pot tubes were joined by placing the orifice sections between them. Each end of the orifice section was connected to the appropriate tube by using a soldered coupling. In the 1-inch tube experiment, reducing couplings were used at the condenser end of the orifice section.

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. All blind flanges were constructed of similar material. The flanges were bolted together with a corrugated metal asbestos gasket placed between the two flanges. A 6-inch section of 24-inch diameter pipe with accompanying flanges was installed at one end to serve as a steam chest. A 2-inch thick steel tube sheet was constructed and welded into place six inches within the shell. The reboiler tube sheet was made to accommodate forty-five 10-foot long, 3/4-inch O. D. U-bend tubes. Wolverine Type S/T copper Trufin* U-bend tubes were rolled into the reboiler tube sheets. Tube supports were provided within the reboiler. High pressure steam (125 psig) was used to vaporize the water in the reboiler. The condensate was returned to the high pressure boiler through a steam trap. A Jerguson 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 5. 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 makes it possible to preheat and partially de-gas the water before it was allowed to enter the reboiler.

A 30-gallon capacity surge tank was placed in the water line after the outlet water pot. A 2-inch diameter pipe with a valve connected the tank to the water line and permitted the exclusion of the tank from the system if so desired. Three pipe lines were incorporated to the top of the surge tank to permit expansion of the coolant water to the atmosphere and also to provide a means of filling the system with water.

A 13-foot long, 18-inch diameter heat exchanger was installed in the water line after the surge tank to permit cooling of the water coolant after it left the condenser. The heat exchanger had 12 baffles at 10-inch baffle spacing and 25% baffle cut. End baffle spacing was 12 inches. The bundle consisted of one hundred and seventeen 12-foot long U-bends of 5/8-inch O. D. Wolverine S/T Trufin* on 15/16-inch triangular pitch for a total outside surface of 1, 300 ft^2.

A 100 gpm, single stage, centrifugal pump driven by a 25 HP motor was installed in the water line between the cooler and the water pre-heater, which was a commercially available Bell and Gossett water heater, Type

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* Registered trademark of the Wolverine Tube.

SU, Model 83-2. The pump was used during operation to circulate the water coolant through the closed system.

A 3-inch gate-valve was installed in the water line between the preheater and the inlet water pot. This valve served as a manual control of the flowrate of water coolant through the system.

A two-stage Schutte and Koerting Model 3TC2 jet ejector with inter-stage 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 the operation of the equipment when taking data. The controllers can be seen in Figure 2. One 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. Two of the instruments were absolute pressure controllers which were used during the operation of the equipment at vacuum conditions. 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 dur to variations in the steam flow rate. The control instrument controlled a small bleed valve. By bleeding in small amounts of steam, the pressure in the ejector header could be kept relatively constant. The fourth instrument was used to control the pressure in the condenser when operating at atmospheric pressure conditions. The air lines from the vacuum pressure controller described above were simply installed into this instrument (it worked on the same principle as the vacuum instrument). The steam jet ejector and its controller were not used while the equipment was being operated at atmospheric pressure.

The water flow rates in each tube were measured by calibrated orifices placed in 9-inch orifice holders which were located at the outlet end of the test tubes between the condenser and the outlet water pot. Five-eighths-inch tube extensions were inserted at both ends of the orifice holders. The length of the orifice section was approximately 23 inches. Figure 8 shows the orifice assembly. The orifices were calibrated for each individual assembly. 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 $\pm$ 1/4 and $\pm$ 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 and null detector. The inlet water and condenser steam temperatures were also measured with calibrated thermometers. Temperatures could be measured to 0.01°F. The inlet water thermometer and inlet water thermocouple were placed in the inlet water pot. The exit water thermocouples were located in the orifice holder assemblies as shown in Figure 8. The steam temperature thermometer and thermocouple were placed in the overhead steam line between the reboiler and condenser. The stainless steel sheath extended up-stream along the tube axis for one 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.

TEST PROCEDURE

The order of testing the various tubes in this investigation was to study the 5/8-inch corrugated tube first, the 1-inch corrugated tube second, and the 1-inch bare tube last. Before the testing began, the equipment was thoroughly de-greased. To do this, a 55-gallon barrel of trichloroethylene was added to the reboiler. The cooling water system was filled with tap water from a hose connected to the overhead line of the surge tank. The line pump was then turned on with the pump by-pass valve wide open. The by-pass valve was slowly closed to prevent the tygon tubing in the test tube section from being damaged by sudden surges of water during the pump start-up. While cooling water was flowing through the tubes, the steam line to the reboiler was opened. Trichloroethylene was boiled in the reboiler, condensed on the copper tubes and returned to the reboiler. Since the trichloroethylene temperature was higher than the ambient temperature, some condensation occurred throughout the entire system. This insured a thorough cleaning throughout. The used trichloroethylene was transferred to an empty barrel and a clean barrel of trichloroethylene added for a final cleaning. The cooling water system was then drained and filled again with tap water through the surge tank. The water was once again allowed to circulate through the system for approximately 30 minutes and was then drained out of the system. This flushing process was performed three or four times before the testing of each new tube began.

During normal operation, the reboiler was 3/4 to 7/8 filled with distilled water through the make-up tank. For the vacuum runs, 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 optimal evacuation rate. The bleed valve on top of the condenser were always closed during vacuum operation. The line pump was then started with the by-pass valve wide open. After slowly closing the by-pass valve, to reach maximum flow, the manual flowrate valve was adjusted to the desired flowrate. The cooling tower water to the cooler was turned on by adjusting the manual valves in the lines. 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 operating under these conditions for approximately 20 - 30 minutes. This further assisted in de-gassing the water and evacuating the system. The inlet water temperature control was 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 steam bleed and permitted maximum removal of non-condensibles during the period when data were taken. During pressure operation, the procedure was much like that described above except for these alterations. The steam jet ejector was eliminated from the system by closing its line valve. The reboiler steam valve control lines were installed on the atmospheric pressure controller. Also, the bleed valves on top of the condenser were fully opened. The pressure in the condenser was always maintained at 2 - 3 inches of mercury above the atmospheric pressures. At this pressure, steam from the reboiler flowed freely through the bleed valves into the atmosphere and prevented any appreciable quantities of non-condensibles from entering the condenser. During pressure operation the inlet water temperature controller had to be operated manually. During vacuum and pressure operation, the saturated steam temperature was calculated and compared to the measured steam pressure. If the two temperatures agreed within 1/2°F, the system was considered ready for taking data.

Heat transfer data were taken when the automatic controllers had stabilized all the control variables at the desired set points. The tube numbering was such that the top tube in the center vertical row was Tube 1, the second tube in the center vertical row was Tube 2, etc. The top tube in each side vertical row was labeled Tube A and Tube B, respectively. The data-taking procedure required two people and was taken in this order: inlet water thermocouple, inlet water thermometer, condenser steam thermometer, exit water thermocouple for Tube 1; condenser steam thermocouple, inlet water thermocouple, inlet water thermometer, condenser steam thermometer, exit water thermocouple for Tube 2; condenser steam thermocouple, etc. 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 pressure was measured with a mercury manometer two or three times during the run. Barometer readings were made before and after the runs. All the thermocouple readings were recorded by one man while the other measured the remaining data. Usually two 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 $\pm$ 0.2°F. The data on Tube A and Tube B was taken prior to the start of each run.

Whenever the water level in the reboiler dropped below one-half 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 Wilson Plot Procedure used in obtaining the values of C_i for the tube studied can be found in Appendix II, "Modified Wilson Plot Techniques for Obtaining Heat Transfer Correlations for Shell and Tube Heat Exchangers," pages 97 through 99. The computer program and nomenclature used in analyzing the data are also given in Appendix II.

A line diagram of the equipment used in obtaining the Wilson Plot data is shown in Figure 9. The equipment was located in the Research and Development Laboratories of Wolverine Tube in Allen Park, Michigan, and consisted of a concentric shell and tube heat exchanger, two weigh tanks, two pumps, a pre-heater, and two constant head tanks. To insure minimum fouling on the inside of each tube tested, fresh water was continually used on the tube side. Recirculating water was used on the shell side to enable more precise temperature control. To minimize fouling on the outside of the tubes studied, the shell side water was periodically changed every two or three days.

For the 5/8-inch corrugated and bare tubes, the shell of the concentric shell-and-tube heat exchanger was constructed of a 13-foot length of 1-inch I.D. copper tube. A 20-foot length of test tube was inserted into the shell and secured by a threaded fitting at each end of the shell as shown in Figure 10. The test tube, in addition to being supported at each end of the shell, was supported at approximately 3-foot increments by three radially symmetrical brass pins as shown in Figure 10. For the 1-inch corrugated and bare tubes, the heat exchanger was identical to that described above with the exception that the shell was constructed of a 1.59-inch I.D. copper tube. In this position, the test tube extended two feet beyond the shell at the tube inlet end and five feet beyond the shell at the tube outlet end.

The tubeside water flow rate was maintained by a 5 HP Aurora pump, Model K-5. The shellside water was circulated by a 3 HP Aurora pump, Model K-5. Each pump was supplied with a constant head tank on the suction intake end of the pump. To prevent sudden surges of water during start-up, a by-pass line with valve was constructed around each pump. A Bell and Gossett, Type SU Preheater was installed in the shell-side water line between the shell-and-tube heat exchanger and the pump.

The tubeside and shellside water flow rates were determined using two 50-gallon weigh tanks.

An automatic controller-recorder was installed in the inlet shell-side water line to control the inlet water temperature. A mercury filled bulb installed in the water line served as the sensing element for the controller. The controller pneumatically activated a 1 1/2-inch steam valve which regulated the amount of steam entering the water preheater.

Inlet shellside water, outlet shellside water, inlet tubeside water, and outlet tubeside water temperatures were determined using four calibrated thermometers.

All of the experimental Wilson plot data was collected by Wolverine Tube personnel. The experimental procedure used in obtaining the Wilson Plot data was as follows: a set of data were obtained over a wide range of different tubeside flow rates and a constant shellside flow rate. To help insure an accurate heat balance, the temperature difference on the tubeside and the shellside were maintained at a minimum of 10°F. At equilibrium conditions, experimental data was recorded. This data consisted of tubeside and shellside flow rates, the inlet and outlet temperatures of the shellside water, and the inlet and outlet temperature of the tubeside water. A second set of data was then taken using the above procedure except this time the data were taken over a wide range of different shellside flow rates with a constant tubeside flow rate.

A program was prepared for the Wolverine Tube Honeywell 200 digital computer (as shown in Appendix II) and only the $\pm$ 2% heat balance Wilson Plot data were processed using that program. The input data to the program were the water flow rates, the inlet and outlet water temperatures, tube dimensions, thermal conductivity of the tube metal, and an initial estimate for the inside heat transfer coefficient, C_i. The necessary physical properties of water were written into the program. The program took the value of C_i, went through the process outlined in the A. I. Ch. E. preprint of 1968, in Appendix II, pages 97 to 99, and obtained the values of the three functions necessary for the modified Wilson Plot. A least square sub-routine 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 0.0005 from the calculated value, the calculated value was used and the process was repeated until the assumed and calculated values agreed within 0.0005.

Three sets of Wilson Plot data were processed: that of the 5/8-inch corrugated copper tube, the 1-inch corrugated 90-10 Cupro-Nickel tube, and the 1-inch bare 90-10 Cupro-Nickel tube. The Wilson Plot results for the 5/8-inch bare copper tube were taken from Report 55(1). Table 2 lists the computed values of the inside heat transfer coefficient constants. The Wilson Plot results for the three sets of data obtained in this investigation are presented graphically in Figures 11-13, pages 57-59.

TABLE 2

Computed Values of the
Inside Heat Transfer Coefficient Constant

Tube	C_i	Figure No. & Page No.
5/8" Bare Copper	0.02468	Report 55[1], page 28
5/8" Corrugated Copper	0.067301	Figure 11, page 57
1" Corrugated 90-10 Cupro-Nickel	0.05786	Figure 12, page 58
1" Bare 90-10 Cupro-Nickel	0.026423	Figure 13, page 59

MULTIPLE TUBE DATA PROCESSING

Three sets of heat transfer data were taken on the tubes in the center vertical row of tube bundles. Data was also taken on the top tube on each side row. The data on these two side tubes were used only as a reference and do not appear in Results section of this report. The first set of data were taken on the 5/8-inch corrugated tubes. The second set of data were taken on the 1-inch corrugated tubes. The third set of data were taken on the 1-inch bare tubes.

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 360 Model 67 digital computer to process the data. The program, along with its nomenclature and a sample printout, is presented in Appendix III. The computer program consisted of four sections. First, the input data for Tube A and Tube B, together with the tube dimensions and characteristics and the value of the inside heat transfer coefficient constant, C_i, were read into the computer and calculations were made. These operations included the calculation for Tube A and Tube B, 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 Equations 5, 6, 7, 8, and 9. 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

$$\frac{1}{h_m} = \frac{1}{U_o} - \frac{A_o}{A_i h_i} - r_m \tag{8}$$

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.

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

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. From the condensing coefficient and physical properties of the condensate film, the condensing coefficient correction factor, C_n, was calculated using Equation 5. A printout of the results completed the first section. The remaining three sections of the computer program perform the calculations for the tubes in the center vertical row.

In the second section of the program, the input data for the tubes in the center vertical row were read into the computer along with the value of the inside heat transfer coefficient, C_i, and preliminary calculations were made. These preliminary calculations 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 above, using Equations 6 through 9. 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 tubes in the center vertical row were also calculated. A printout of the results completed the second section.

In the third 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 printout of the results completed the third section.

The condensing coefficient correction factor was calculated in the fourth section of the computer program. The correction factor is by definition that factor which makes Equation 5 an equality and is calculated from Equation 10:

$$C_n = \frac{h_m}{0.725\left[\dfrac{k^3\ \rho^2\ g\ \lambda}{n\ \mu\ D\ \Delta t_f}\right]^{1/4}} \tag{10}$$

In Equation 10, 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. Equation 11 was used to calculate the temperature drop across the condensing film.

$$\Delta t_f = \frac{U_o\ \Delta t_m}{h_m} \tag{11}$$

and Equation 3 used to calculate the film temperature.

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

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 10 for the top tube.

To determine C_n for the top two tubes in the center 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 11 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 10.

The correction factors for 3, 4...7 or 9 tubes in a vertical row were calculated by adding the heat duties for the top n tubes and following the procedure previously outlined. Appendix IV contains the values of the C_n 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 steam temperature of 212°F and 101°F and various inlet water temperatures. The C_n results are also presented in Figures 14 through 37. The Results section, which follows, presents graphically the analysis of the experimental data made on the above basis.

RESULTS

As indicated in the previous section of this report, the values of U_o and of C_n as determined from Euations 6 through 9 were obtained from the digital computer output using the computer program presented in Appendix III. Samples of computer output for 5/8-inch corrugated, 1-inch bare, and 1-inch corrugated tubes are presented in Tables III-1, III-2, and III-3 in Appendix III. Approximately 400 experimental runs were made, of which 93% were useable. It was not practical to present all the computer printout for all the experimental runs used in this report. Copies of all the printout are in the research project files and copies are also in the possession of Wolverine Tube, the sponsors of the project, in Allen Park, Michigan. It should be noted that Tables III-1, III-2 and III-3 in Appendix III also present the input experimental test variables and the calculated values of heat duty, LMTD, U_o, h_i, h_{cond}, and $C_n/N^{1/4}$.

Appendix IV contains Tables IV-1 through IV-13, which present the summary of the C_n and U_o values for the 5/8-inch bare, 5/8-inch corrugated, 1-inch bare, and 1-inch corrugated tubes, respectively. Figures 14 through 37, with the exception of Figures 19 and 24, present graphical plots of the C_n data tabulated in Appendix IV.

For most of the data runs, the C_n values for the top tube in the center vertical row were found to be abnormally higher than those of the second tube. The exact reason for this situation was not clear. However, it was suspected that it might be due to the construction of the equipment. These experimental C_n values of the top tube were not used in obtaining the equations given in Figures 14 through 37.

DISCUSSION OF RESULTS

In order to ascertain the relative fraction of the overall resistance to heat transfer due to the resistance of the steam condensing film, a special computer program was prepared. A copy of this computer program is presented in Appendix V. The program calculates C_n, h_i, h_{cond}, metal resistance, U_o, and Q for various fouled and non-fouled point conditions with 5% concentrated sea water as the tubeside coolant.* The percentages due to each of the above-named resistances are also calculated. It calculates the above values for five circular bundles having various numbers of tubes in a vertical row. The five circular bundles contain from 400 to 3600 tubes. The average number of tubes in the vertical row are calculated using the following equation:

$$N_{avg} = 1/2\sqrt{N_{total}} \tag{12}$$

where

N_{total} = total number of tubes in a circular bundle

N_{avg} = average number of tubes in a vertical row. (See Table 3.)

TABLE 3

Calculated Values of N_{avg} as a Function of N_{total} Tubes in a Circular Bundle Using Equation 12

N_{total}	(No. Tubes) N_{avg}
400	10
900	15
1600	20
2500	25
3600	30

* Sea water properties were obtained from Reference 10.

Tables VI-1, 2, 3, and 4, in Appendix VI, present typical computer printout for a 1-inch O.D. bare 90-10 Cupro-Nickel tube with steam condensing at 100°F and 212°F with sea water flowing through the tube at six feet per second, with a 6°F steam to water temperature difference and with no fouling and 0.0005 fouling. These tables were used in preparing Table 4. Table 4 summarizes the percentage of the total resistances due to the condensing steam film resistance for a circular tube bundle containing 2,500 1-inch O.D. bare tubes, i.e., with an average of 25 tubes in a vertical row. The computer program in Appendix V was used for making the calculations.

TABLE 4

Summary of Calculated U_o and h_{cond} and
Corresponding Per Cent of Overall Resistances for
25 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes
in a Vertical Row With and Without Fouling
(From Appendix VI, Tables VI-1 to 4)

Condensing Temp. °F.	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	U_o	h_{cond}	% Resistance due to h_{cond}
100	0	6.0	6	712	2559	27.8
100	0.0005	6.0	6	534	2806	19.0
212	0	6.0	6	988	3232	30.6
212	0.0005	6.0	6	677	3660	18.5

An examination of Table 4 indicates that with no fouling the steam condensing film resistance amounts to approximately 30% of the overall resistance to heat transfer, whereas with 0.0005 fouling the steam condensing film resistance amounts to approximately 20% of the overall resistance. Since the steam condensing resistance amounts to only 1/5 to 1/4 of the overall resistance after fouling has occurred, there is no justification for introducing the refinements that would result from using the C_n equations that appear on Figures 14, 15, 16, and 17, which present C_n

plots with water velocity as a variable. Consequently, the C_n equation that correlates all of the data appearing in Figures 14, 15, 16 and 17, as shown in Figure 18, is recommended for design purposes, i.e., $C_n = 1.07\ (N)^{0.170}$. Further justification for this recommendation will be presented later.

It should be noted that Figures 14 through 17 present C_n plots for steam condensing at 212°F and 101°F with water flowing through 1-inch O.D. bare tubes at 3.5 feet per second, 4.7 feet per second, 5.3 feet per second, and 6.0 feet per second, respectively. Figure 19 presents the C_n lines shown in Figures 14, 15, 16, and 17 for comparison purposes. It is evident in this figure that the variations in water velocity introduce no significant effect on the values of C_n.

The legitimate question arises as to whether or not the steam condensing temperature level introduces any significant effect. Figure 18 presents all of the C_n values of Figures 14, 15, 16 and 17 for condensing at 212°F and 101°F. It should be noted that in Figure 18, the C_n values for steam condensing at 101°F lie primarily above the recommended C_n line. Further analysis is required to determine whether or not there is any significant temperature level effect. This analysis is presented later in this report.

Table 5 summarizes the percentage of the overall resistance due to steam film resistance for a circular tube bundle containing 2,500 1-inch O.D. corrugated tubes, i.e., with an average of 25 tubes in a vertical row. The computer program in Appendix V was used for making the calculations. Tables VI-5, 6, 7, and 8, in Appendix VI, contain the printout of the computer calculations which are used as the basis of Table 5. A sea water velocity of 3.5 feet per second was arbitrarily selected for corrugated tubes because of the higher tubeside pressure drop that results from a water velocity of 6.0 feet per second with such tubes. One would use such tubes in steam condensing applications with lower water velocities. Pressure drop considerations will be covered in a later section of this report along with heat transfer considerations at the same water velocities.

An examination of Table 5 indicates that with no fouling the steam condensing film resistance amounts to approximately 24% of the overall resistance to heat transfer, whereas with 0.0005 fouling the steam condensing resistance amounts to approximately 14% of the overall resistance. Since the steam condensing film resistance amounts to only 1/6 to 1/4 of the overall resistance after fouling has occurred, there is no justification for introducing the refinements that would result from using the C_n equations that appear on Figures 20, 21 and 22. Consequently, the C_n equation that correlates the 3.5, 4.0, 4.7, 5.3 and 6.0 feet per second water velocity results, as shown in Figure 23, is recommended for design purposes, i.e., $C_n = 1.45\ (N)^{0.203}$. The justification for this recommendation appears in a later section of this report.

TABLE 5

Summary of Calculated U_o and h_{cond} and Corresponding Overall Resistances for 25 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-5 to 8)

Condensing Temp.	Fouling	Water Velocity (ft./sec.)	ΔT °F	U_o	h_{cond}	% Resistance due to h_{cond}
100°F	0	3.5	6	963	4082	23.6
100°F	0.0005	3.5	6	662	4602	14.4
212°F	0	3.5	6	1308	5210	25.1
212°F	0.0005	3.5	6	808	6070	13.3

It should be noted that Figures 20, 21 and 22 present C_n plots for steam condensing at 212°F and 101°F with water flowing through 1-inch O.D. corrugated tubes at 3.5 feet per second, 4.7 feet per second, and 6.0 feet per second, respectively. Figure 24 presents the C_n lines shown in Figures 20, 21, and 22 for comparison purposes. A comparison of Figure 24 with Figure 19 indicates that the 3.5 feet per second line of Figure 24 is inconsistent with 1-inch O.D. corrugated tubes as compared with 1-inch O.D. bare tubes. It is believed that since there was no significant velocity effect with 1-inch O.D. bare tubes, there should be no significant velocity effects with 1-inch O.D. corrugated tubes, particularly since the 4.7 feet per second and 6.0 feet per second corrugated tube C_n lines compare so favorably. This effect is analyzed further in a later section of this report.

Again, the legitimate question arises as to whether or not the steam condensing temperature level introduces any significant effect. Figure 23 presents all of the C_n values of Figures 20, 21, and 22 for condensing at 212°F and 101°F. It should be noted that the C_n values for steam condensing at 212°F on bare 1-inch O.D. tubes are concentrated below the recommended C_n line. A further analysis of this situation is presented in a later section of this report.

No experimental heat transfer data were collected on 5/8-inch O.D. bare 90-10 Cupro-Nickel tubes in this investigation. Instead, the experimental data collected on 5/8-inch bare copper tubes and presented in Report 55[1] was assumed to be applicable to 5/8-inch bare 90-10 Cupro-Nickel tubes. The C_n values presented in Report 55[1] and reproduced in

Appendix IV are plotted in Figure 25 for water velocities of 6.0 feet per second, 8.9 feet per second, and 11.6 feet per second. It should also be noted that all of these experimental results are only for steam condensing at 101°F. No experimental test data was collected at 212°F in that investigation.

An examination of Figure 25 indicates that for the three velocities plotted, there is no significant velocity effect. The lack of velocity effect for the 5/8-inch O.D. bare copper tubes is in agreement with the lack of velocity effect for the 1-inch O.D. bare 90-10 Cupro-Nickel tubes.

Table 6 summarizes the percentage of overall resistance due to steam film resistance for a circular tube bundle containing 2,500 five-eighths-inch O.D. bare tubes, i.e., with an average of 25 tubes in a vertical row. Tables VI-9, 10, 11, and 12 in Appendix VI contain the printout of the computer calculations which are used as the basis of Table 6.

TABLE 6

Summary of Calculated U_o and h_{cond} and Corresponding Overall Resistances for 25 Bare 5/8-inch O.D., Schedule 20, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-9 to 12)

Condensing Temp.	Fouling	Water Velocity (ft./sec.)	ΔT °F	U_o	h_{cond}	% Resistance due to h_{cond}
100°F	0	6.0	6	731	2122	34.5
100°F	0.0005	6.0	6	548	2329	23.5
212°F	0	6.0	6	1015	2687	37.8
212°F	0.0005	6.0	6	693	3039	22.8

An examination of Table 6 indicates that with no fouling the steam condensing film resistance amounts to approximately 34% of the overall resistance to heat transfer, whereas with 0.0005 fouling, the steam condensing film resistance amounts to approximately 23%. Since the steam condensing film resistance amounts to only 1/4 to 1/3 of the overall resistance after fouling has occurred, the C_n equation that appears on

Figure 25 is recommended for design purposes, i.e., $C_n = 1.20\ (N)^{0.0557}$. It was assumed that the C_n equation obtained on bare copper tubes would apply to bare 90-10 Cupro-Nickel tubes.

Experimental data were collected on 5/8-inch corrugated copper tubes with steam condensing at 212°F and 101°F at water velocity of 4.0, 4.7, 5.5, and 6.0 feet per second. The C_n values are plotted in Figure 26.

Table 7 summarizes the percentage of overall resistance due to steam film resistance for a circular tube bundle containing 2,500 five-eighths-inch O.D. corrugated 90-10 Cupro-Nickel tubes, i.e., with an average of 25 tubes in a vertical row. Tables VI-13, 14, 15, and 16 in Appendix VI contain the printout of the computer calculations which are used as the basis of Table 7.

TABLE 7

Summary of Calculated U_o and h_{cond} and Corresponding Overall Resistances for 25 Corrugated 5/8-inch O.D., Schedule 20, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-13 to 16)

Condensing Temp.	Fouling	Water Velocity (ft./sec.)	ΔT °F	U_o	h_{cond}	% Resistance due to h_{cond}
100°F	0	3.5	6	1069	3173	33.7
100°F	0.0005	3.5	6	715	3602	19.9
212°F	0	3.5	6	1447	4051	35.7
212°F	0.0005	3.5	6	866	4765	18.2

An examination of Table 7 indicates that with no fouling the steam condensing resistance amounts to approximately 34% of the overall resistance to heat transfer, whereas with 0.0005 fouling the steam condensing resistance amounts to approximately 20% of the overall resistance. Since the steam condensing resistance amounts to only 1/5 to 1/3 of the overall resistance after fouling has occurred, there is no justification for introducing additional refinements. Therefore, the C_n equation that correlates all of the data appearing in Figure 26 is recommended for design purposes, i.e., $C_n = 1.11\ (N)^{0.200}$.

A comparison of Table 7 and Table 5, which is a comparison of 5/8-inch O.D. corrugated with 1-inch O.D. corrugated tubes, indicates that the condensing film resistance is approximately 1/3 of the overall resistance for the 5/8-inch tube, whereas it is 1/4 for the 1-inch tube. With 0.0005 fouling, the corresponding fractions are 1/5 and 1/6.

Table 8 contains a summary of the C_n equations obtained at combined vacuum and pressure steam condensing conditions for the various tubeside water velocities studied.

TABLE 8

Summary of the C_n Equations
at Combined Vacuum and Pressure Steam Condensing Conditions
for Various Tubeside Water Velocities

Figure No.		
	1-inch Bare Tubes	
14	Equation for 3.5 ft./sec. data:	$C_n = 1.10\ (N)^{0.165}$
15	Equation for 4.7 ft./sec. data:	$C_n = 1.18\ (N)^{0.146}$
16	Equation for 5.3 ft./sec. data:	$C_n = 1.10\ (N)^{0.179}$
17	Equation for 6.0 ft./sec. data:	$C_n = 1.04\ (N)^{0.182}$
18	Equation recommended for design use:	$C_n = 1.07\ (N)^{0.170}$
	1-inch Corrugated Tubes	
20	Equation for 3.5 ft./sec. data:	$C_n = 1.23\ (N)^{0.208}$
21	Equation for 4.7 ft./sec. data:	$C_n = 1.48\ (N)^{0.207}$
22	Equation for 6.0 ft./sec. data:	$C_n = 1.45\ (N)^{0.198}$
23	Equation recommended for design use:	$C_n = 1.45\ (N)^{0.203}$
	5/8-inch Bare Tubes*	
25	Equation recommended for design use:	$C_n = 1.20\ (N)^{0.0557}$
	5/8-inch Corrugated Tubes	
26	Equation for all data and the recommended equation for design use:	$C_n = 1.11\ (N)^{0.200}$

* 5/8-inch bare data are for vacuum conditions

THE EFFECTS OF STEAM CONDENSING TEMPERATURE LEVEL UPON C_n AND DESIGN CALCULATIONS

Figure 27 contains all of the C_n values calculated from the data collected on 1-inch O.D. bare tubes with steam condensing at 101°F and tubeside water velocities of 3.5, 4.7, 5.3, and 6.0 feet per second. The C_n values are tabulated in Appendix IV, Table IV-1. The same values are shown in Figures 14, 15, 16, 17, and 18. The solid line drawn on Figure 27 best fits the data and has the following equation: $C_n = 1.15\ (N)^{0.156}$. Also presented in Figure 27, as a dotted line, is the recommended equation for design purposes, $C_n = 1.07\ (N)^{0.170}$.

Figure 28 contains all of the C_n values calculated from the data collected on 1-inch O.D. bare tubes with steam condensing at 212°F and tubeside water velocities of 3.5, 4.7, 5.3, and 6.0 feet per second. The C_n values are tabulated in Appendix IV, Table IV-2. The same values are shown in Figures 14, 15, 16, 17, and 18. The solid line drawn on Figure 28 best fits the data and has the following equation: $C_n = 1.05\ (N)^{0.174}$. Also presented in Figure 28, as a dotted line, is the recommended equation for design purposes, $C_n = 1.07\ (N)^{0.170}$. The above three equations were used in the computer program, presented in Appendix V, to determine their effect on design calculations with and without fouling. The printout of the computer calculations are presented in Appendix VII, Tables VII-1 through 8. The calculated results without fouling are summarized in the first section of Table 9.

Referring to the summary of the calculations made for 1-inch bare tubes in Table 9, it should be noted that the U_o's and Q's calculated using the C_n equations on Figures 27 and 28 with no fouling differ from the results calculated using the recommended equation by approximately 1.0% and 0.3%, respectively. These variations are not considered significant and the recommended equation can be used with confidence. The above percentages are reduced to 0.6% and 0.1%, respectively, when a fouling factor of 0.0005 is introduced into the design calculations as indicated in Tables VII-2, 4, 6 and 8.

Figure 29 contains all of the C_n values calculated from the data collected on 1-inch O.D. corrugated tubes with steam condensing at 101°F and tubeside water velocities of 3.5, 4.7, and 6.0 feet per second. The C_n values are tabulated in Appendix IV, Table IV-3. The same values are shown in Figures 20, 21, 22, and 23. The solid line drawn in Figure 29 best fits the data and has the following equation: $C_n = 1.30\ (N)^{0.226}$. Also presented in Figure 29, as a dotted line, is the recommended equation for design purposes, $C_n = 1.45\ (N)^{0.203}$.

Figure 30 contains all of the C_n values calculated from the data collected on 1-inch O.D. corrugated tubes with steam condensing at 212°F and tubeside water velocities of 3.5, 4.0, 4.7, 5.3, and 6.0 feet per second.

TABLE 9

The Effect of Steam Condensing Temperature Level on C_n, h_{cond}, U_o, and Q and the Corresponding Per Cent Difference in Q for 25 Tubes in a Vertical Row Without Fouling for a Temperature Difference Between the Water and Condensing Steam of 6°F (From Appendix VII, Tables VII-1 to 24)

Condensing Temp.	Equation for C_n	C_n	h_{cond}	U_o	Q	%
	1-inch Bare 90-10 Cupro-Nickel**					
100°F	$1.15(N)^{0.156}$	1.90	2644	718	1131	1.0
100°F*	$1.07(N)^{0.170}$	1.85	2559	712	1120	
212°F	$1.05(N)^{0.174}$	1.84	3209	986	1551	0.3
212°F*	$1.07(N)^{0.170}$	1.85	3232	988	1555	
	1-inch Corrugated 90-10 Cupro-Nickel***					
100°F	$1.30(N)^{0.226}$	2.69	3910	954	1403	1.1
100°F*	$1.45(N)^{0.203}$	2.79	4082	963	1418	
212°F	$1.30(N)^{0.191}$	2.40	4353	1246	1834	5.0
212°F*	$1.45(N)^{0.203}$	2.79	5210	1308	1925	
	5/8-inch Corrugated 90-10 Cupro-Nickel***					
100°F	$1.21(N)^{0.193}$	2.25	3394	1093	1053	2.3
100°F*	$1.11(N)^{0.200}$	2.11	3161	1068	1029	
212°F	$0.99(N)^{0.220}$	2.01	3792	1413	1361	2.4
212°F*	$1.11(N)^{0.200}$	2.11	4034	1445	1392	

* Recommended C_n Equation

** Water velocity used was 6.0 feet per second

*** Water velocity used was 3.5 feet per second

The C_n values are tabulated in Appendix IV, Table IV-4. The same values are shown in Figures 20, 21, 22 and 23. The solid line drawn on Figure 30 best fits the data and has the following equation: $C_n = 1.30\ (N)^{0.191}$. Also presented in Figure 30, as a dotted line, is the recommended equation for design purposes, $C_n = 1.45\ (N)^{0.203}$. The above three equations were used in the computer program presented in Appendix V, to determine their effect on design calculations with and without fouling. The printout of the computer calculations are presented in Appendix VII, Tables VII-9 through VII-16. The calculated results without fouling are summarized in the middle section of Table 9.

Referring to the summary of the calculations made for 1-inch corrugated tubes in Table 9, it should be noted that the U_o's and Q's calculated using the C_n equations on Figures 29 and 30 differ from the results calculated using the recommended equation by approximately 1.1% and 5.0%, respectively. These percentages are reduced to 0.6% and 2.8%, respectively, when a fouling factor of 0.0005 is introduced into the design calculations, as indicated in Tables VII-10, 12, 14 and 16.

Figure 31 contains all of the C_n values calculated from the data collected on 5/8-inch O.D. corrugated tubes with steam condensing at 101°F and a tubeside water velocity of 6.0 feet per second. The C_n values are tabulated in Appendix IV, Table IV-5. The same values are shown in Figure 26. The solid line drawn in Figure 31 best fits the data and has the following equation: $C_n = 1.21\ (N)^{0.193}$. Also presented in Figure 31, as a dotted line, is the recommended equation for design purposes, $C_n = 1.11\ (N)^{0.200}$.

Figure 32 contains all of the C_n values calculated from the data collected on 5/8-inch O.D. corrugated tubes with steam condensing at 212°F and a tubeside water velocity of 6.0 feet per second. The C_n values are tabulated in Appendix IV, Table IV-6. The same values are shown in Figure 26. The solid line drawn on Figure 32 best fits the data and has the following equation: $C_n = 0.99\ (N)^{0.200}$. The above three equations were used in the computer program, presented in Appendix V, to determine their effect on design calculations with and without fouling. The printout of the computer calculations are presented in Appendix VII, Tables VII-17 through VII-24. The calculated results without fouling are summarized in the lower section of Table 9.

Referring to the summary of the calculations made for 5/8-inch corrugated tubes in Table 9, it should be noted that the U_o's and Q's calculated using the C_n equations on Figures 31 and 32 differ from the results calculated using the recommended equation by approximately 2.3% and 2.4%, respectively. These percentages are reduced to 1.6% and 1.2%, respectively, if a fouling factor of 0.0005 is introduced into the design calculations, as indicated in Tables VII-18, 20, 22 and 24.

Since steam condensing data was only collected with steam condensing at 101°F on 5/8-inch bare tubes, a similar analysis cannot be made. The above analysis clearly indicates that the three recommended equations for design purposes can be used with confidence. Table 10 contains a summary of all of the C_n equations used in the above analysis.

The above analysis indicates that there is no significant steam condensing temperature level effect on C_n.

TABLE 10

Summary of the C_n Equations
at Vacuum and Pressure Conditions for the Combined Data at
3.5 Feet Per Second, 4.7 Feet Per Second, and
6.0 Feet Per Second Water Velocities

1-inch Bare Tube	
Equation for the 100°F Data:	$C_n = 1.15\ (N)^{0.156}$
Equation for the 212°F Data:	$C_n = 1.05\ (N)^{0.174}$
Equation recommended for design use:	$C_n = 1.07\ (N)^{0.170}$
1-inch Corrugated Tube	
Equation for the 100°F Data:	$C_n = 1.30\ (N)^{0.226}$
Equation for the 212°F Data:	$C_n = 1.30\ (N)^{0.191}$
Equation recommended for design use:	$C_n = 1.45\ (N)^{0.203}$
5/8-inch Corrugated Tube*	
Equation for the 100°F Data:	$C_n = 1.21\ (N)^{0.193}$
Equation for the 212°F Data:	$C_n = 0.99\ (N)^{0.220}$
Equation recommended for design use:	$C_n = 1.11\ (N)^{0.200}$

* 5/8-inch data for only 6.0 feet per second water velocity

THE EFFECT OF LMTD ON C_n VALUES

Examination of some of the Office of Saline Water reports indicated that most of the multistage flash sea water distillation plants were being designed to operate with 5°F or 6°F LMTD's. In the early stages of this investigation, it was found that it was extremely difficult, if not impossible, to obtain accurate reproducible data with 6 to 10°F LMTD's. This was believed to be due to the short length of the test section. At low LMTD's and with 5 to 6 feet per second water velocities, small temperature rises were encountered. The accuracy of results of the analysis of the experimental test data is primarily dependent upon an accurate measurement of the heat duty, Q, which is, in turn, dependent upon the temperature rise of the water. Low LMTD's lead to low heat duties and, therefore, introduced large experimental errors. It was found experimentally that very accurate reproducible heat duties could be obtained with large LMTD's in the neighborhood of 20 to 40°F.

Figure 33 presents plots of C_n versus LMTD for 1, 3, 5, and 7 corrugated 1-inch O.D. tubes in a vertical row with steam condensing at 212°F and a tubeside water velocity of 3.5 feet per second. The numerical values of C_n are presented in Appendix IV, Table IV-4. Examination of this figure clearly indicates that there is no significant effect of LMTD on the C_n values.

Figure 34 presents a similar plot for 5/8-inch O.D. corrugated tubes with steam condensing also at 212°F but with a tubeside water velocity of 6.0 feet per second. The C_n values are presented in Appendix IV, Table IV-6. It should be noted that there is only a limited amount of data in Table IV-6. Although a slight dependency of C_n value upon LMTD is apparently indicated in Figure 34, it is not believed to be conclusive due to the small amount of experimental data.

Therefore, based on the evidence shown in Figure 33, it is believed that the C_n equations obtained from high LMTD data is applicable to condensation of steam at low LMTD's, i.e., 4° to 12°F.

THE EFFECT OF TUBESIDE WATER VELOCITY ON C_n VALUES

For the purpose of design applications, it was decided early in this investigation that it was necessary to determine the dependence of C_n upon water velocity since it would be very advantageous to the designer if one equation for C_n could be used for all water velocities for a particular tube. To determine this dependence, all the data for the 1-inch bare and corrugated tubes were taken at four different water velocities, approximately 3.5, 4.7, 5.3, and 6.0 feet per second.

The C_n values obtained on the 1-inch bare tubes at atmospheric pressure steam condensing conditions were plotted against water velocity and are shown for 1, 3, 5, and 7 tubes in a vertical row in Figure 35. This figure indicates that the difference between the values of C_n at 3.5, 4.7, 5.3, and 6.0 feet per second water velocity are not significant.

The C_n values obtained on the 1-inch corrugated tubes condensing steam at 212°F were plotted against water velocity and are shown in Figure 36. The values of C_n in this figure at the 3.5 feet per second water velocity appear to be lower than the values corresponding to the other four water velocities. To show the significance of this difference, the C_n equation for the 3.5 feet per second data (shown on Figure 20) and the recommended C_n equation (shown on Figure 23) were used to calculate point values of U_o and Q, assuming no fouling, using the computer program in Appendix V. It was found that the difference in the values of Q as predicted by the two C_n equations is approximately 5 per cent. These calculated results are found in Tables VII-25 and VII-26 in Appendix VII. It was concluded that the 3.5 feet per second water velocity data collected on 1-inch corrugated tubes is inconsistent with all the water velocity results collected on the tubes and shown in Figures 35, 36, and 37. This is the justification for the recommendation of the C_n equation shown in Figure 24 to be used for design calculations.

The study of velocity effects was undertaken with 1-inch tubes after the heat transfer data had been collected on the 5/8-inch corrugated tubes. Therefore, there are no 5/8-inch O.D. corrugated tube experimental data as a function of velocity available for making a velocity effect analysis.

An analysis was made of the experimental steam condensing data collected on 5/8-inch O.D. copper bare tubes presented in Report 55(1). Heat transfer data was collected on the copper tubes with water velocities of 5.9 to 25.5 feet per second with steam condensing at 101°F. The C_n values as a function of velocity for 1, 4, 6, and 9 tubes in a vertical row are presented in Figure 37. An examination of this figure indicates no significant effect of velocity upon C_n.

It is believed that the C_n correlations recommended in this report for design purposes are valid and do not require the inclusion of any tubeside water velocity term.

A COMPARISON OF TUBESIDE AND STEAMSIDE HEAT TRANSFER PERFORMANCES FOR CORRUGATED AND BARE TUBES

The purpose of this investigation was to study the steamside condensing heat transfer performance of corrugated tubes. The overall performance of corrugated and bare tubes is in part determined by the tubeside heat transfer performance. The tubeside heat transfer performance of the two corrugated tubes and the two bare tubes reported in this investigation are summarized in Tables 11 through 18 for point conditions involving 2,500 tubes in a circular bundle with steam condensing at 100°F and 212°F.

The computer program used for making the calculations is presented in Appendix V and the computer printout can be found in Appendix VI, Tables VI-1 through VI-16. Calculations in these tables were made for a tubeside water velocity of 3.5 feet per second in the corrugated tubes and 6.0 feet per second in the bare tubes with no fouling and 0.0005 fouling. In all the calculations a ΔT of 6°F was used.

Tables 11 through 18 report the calculated U_o's, h_i's and corresponding per cent of the overall resistance due to the tubeside resistance. An examination of these tables indicates:

a) Tubeside resistance of 5/8-inch and 1-inch O.D. bare tubes amounts to 50 to 60 per cent with no fouling and 33 to 45 per cent with fouling;

b) Tubeside resistance of 5/8-inch and 1-inch O.D. corrugated tubes amounts to 43 to 58 per cent with no fouling and 26 to 40 per cent with fouling;

c) Steam condensing side resistance of 5/8-inch and 1-inch O.D. bare tubes amounts to 28 to 38 per cent with no fouling and 18 to 24 per cent with fouling;

d) Steam condensing side resistance of 5/8-inch and 1-inch O.D. corrugated tubes amounts to 23 to 36 per cent with no fouling and 13 to 20 per cent with fouling.

Tables 15 through 18 present the exact calculated per cent distribution of the heat transfer coefficients for comparison purposes. These four tables obviously indicate that the tubeside water film resistance is the major resistance to heat transfer. Tables 11 through 14 indicate that even though the water velocity through the corrugated tubes is only 3.5 feet per second as compared with 6.0 feet per second through the bare tubes, the tubeside heat transfer coefficient for the corrugated tubes is running 45 per cent higher than those for the bare tubes. The corresponding steamside heat transfer coefficients are running 60 per cent higher for the corrugated tubes than those of the bare tubes. In spite of these differences, Tables 11 through 18 indicate that the percentage distribution of film resistances are still approximately the same.

TABLE 11

Summary of Calculated U_o and h_i and Corresponding Per Cent of Overall Resistances for 25 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-1 to 4)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	U_o	h_i	% Resistance due to h_i
100	0	6.0	6	712	1319	60.0
100	0.0005	6.0	6	534	1318	45.1
212	0	6.0	6	988	2091	52.5
212	0.0005	6.0	6	677	2089	36.1

TABLE 12

Summary of Calculated U_o and h_i and Corresponding Per Cent of Overall Resistances for 25 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-5 to 8)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	U_o	h_i	% Resistance due to h_i
100	0	3.5	6	963	1911	49.2
100	0.0005	3.5	6	662	1908	39.5
212	0	3.5	6	1308	3030	49.2
212	0.0005	3.5	6	808	3027	30.4

TABLE 13

Summary of Calculated U_o and h_i and Corresponding Per Cent of Overall Resistances for 25 Bare 5/8-inch O.D., Schedule 20, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-9 to 12)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	U_o	h_i	% Resistance due to h_i
100	0	6.0	6	731	1488	56.0
100	0.0005	6.0	6	548	1486	42.0
212	0	6.0	6	1015	2359	49.0
212	0.0005	6.0	6	693	2357	33.5

TABLE 14

Summary of Calculated U_o and h_i and Corresponding Per Cent of Overall Resistances for 25 Corrugated 5/8-inch O.D., Schedule 20, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-13 to 16)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	U_o	h_i	% Resistance due to h_i
100	0	3.5	6	1069	2426	51.0
100	0.0005	3.5	6	715	2422	34.2
212	0	3.5	6	1447	3846	43.5
212	0.0005	3.5	6	866	3843	26.1

TABLE 15

Summary of Calculated h_{cond} and h_i and
Corresponding Per Cent of Overall Resistances for
25 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes
in a Vertical Row With and Without Fouling
(From Appendix VI, Tables VI-1 to 4)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	% Resistance due to h_{cond}	% Resistance due to h_i
100	0	6.0	6	27.8	60.0
100	0.0005	6.0	6	19.0	45.1
212	0	6.0	6	30.6	52.5
212	0.0005	6.0	6	18.5	36.1

TABLE 16

Summary of Calculated h_{cond} and h_i and
Corresponding Per Cent of Overall Resistances for
25 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes
in a Vertical Row With and Without Fouling
(From Appendix VI, Tables VI-5 to 8)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	% Resistance due to h_{cond}	% Resistance due to h_i
100	0	3.5	6	23.6	57.5
100	0.0005	3.5	6	14.4	39.5
212	0	3.5	6	25.1	49.2
212	0.0005	3.5	6	13.3	30.4

TABLE 17

Summary of Calculated h_{cond} and h_i and Corresponding Per Cent of Overall Resistances for 25 Bare 5/8-inch O.D., Schedule 20, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-9 to 12)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	% Resistance due to h_{cond}	% Resistance due to h_i
100	0	6.0	6	34.5	56.0
100	0.0005	6.0	6	23.5	42.0
212	0	6.0	6	37.8	49.0
212	0.0005	6.0	6	22.8	33.5

TABLE 18

Summary of Calculated h_{cond} and h_i and Corresponding Per Cent of Overall Resistances for 25 Corrugated 5/8-inch O.D., Schedule 20, 90-10 Cupro-Nickel Tubes in a Vertical Row With and Without Fouling (From Appendix VI, Tables VI-13 to 16)

Condensing Temp. °F	Fouling Factor	Water Velocity (ft./sec.)	ΔT °F	% Resistance due to h_{cond}	% Resistance due to h_i
100	0	3.5	6	33.7	51.0
100	0.0005	3.5	6	19.9	34.2
212	0	3.5	6	35.7	43.5
212	0.0005	3.5	6	18.2	26.1

THE TUBESIDE PRESSURE DROP

The determination of the proper water velocity to be used with corrugated tubes in steam condensing applications requires an economic analysis. Such an analysis is beyond the scope of this report. Figure 38 presents a plot of the tubeside pressure drop in pounds per square inch per foot of tube length as a function of tubeside water velocity in feet per second at the temperatures indicated for the four tubes studied in this investigation. The pressure drop information appearing in Figure 38 has been converted to a Moody Friction Factor plot as shown in Figure 39.[11]

An examination of Figure 38 indicates that the water velocity flowing through the inside of a corrugated tube must be reduced considerably to give a pressure drop per foot of tube comparable to that of the corresponding bare tube. On the other hand, the heat transfer performance of the corrugated tubes with the same water velocity as flowing through the corresponding bare tubes is considerably higher. This is shown in Table 19 with no fouling and in Table 20 with a 0.0005 fouling factor. Table 19 indicates that with no fouling and a water velocity of 6.0 ft. per second the corrugated tubes produce 44.0 to 62.6% more condensate per foot of tube length and 53.5 to 72.5% more condensate with a water velocity of 3.5 feet per second. The corresponding figures with a 0.0005 fouling factor presented in Table 20 are 23.0 to 34.5% with a 6.0 feet per second water velocity and 30.0 to 43.5% with 3.5 feet per second water velocity. Consequently, adjustments must be made and the designer has considerable choices as to what these adjustments might be. One recommended possibility consists of using a larger diameter corrugated tube in place of the bare tube with a somewhat lower water velocity. Without making any detail economic analysis, an arbitrary decision was made to compare the overall heat transfer performance of the corrugated tubes at a water velocity of 3.5 feet per second with the overall heat transfer performance of the bare tubes at a water velocity of 6.0 feet per second.

TABLE 19

Relative Condensing Heat Transfer Performance of Corrugated and Bare Tubes With Water Velocities of 6.0 and 3.5 Feet Per Second With No Fouling
(T_{sv} = 212°F, ΔT = 6°F, 25 Tubes in a Vertical Row)

	h_i	h_{cond}	U_o	W lb./ft.-hr.	
Velocity = 6.0 ft./sec.; Fouling = 0					
5/8-inch Bare	2359	2687	1015	1.02	
5/8-inch Corrugated	5917	3853	1671	1.66	(+62.6%)
1-inch Bare	2091	3232	988	1.60	
1-inch Corrugated	4660	4580	1516	2.30	(+44.0%)
Velocity = 3.5 ft./sec.; Fouling = 0					
5/8-inch Bare	1534	2880	819	0.83	
5/8-inch Corrugated	3847	4051	1447	1.43	(+72.5%)
1-inch Bare	1389	3494	795	1.29	
1-inch Corrugated	3030	5210	1308	1.98	(+53.5%)

TABLE 20

Relative Condensing Heat Transfer Performance of Corrugated and Bare Tubes With Water Velocities of 6.0 and 3.5 Feet Per Second With a 0.0005 Fouling Factor
(T_{sv} = 212°F, ΔT = 6°F, 25 Tubes in a Vertical Row)

	h_i	h_{cond}	U_o	W lb./ft.-hr.	
Velocity = 6.0 ft./sec.; Fouling = 0.0005					
5/8-inch Bare	2357	3039	693	0.70	
5/8-inch Corrugated	5912	4630	945	0.94	(+34.5%)
1-inch Bare	2089	3660	677	1.10	
1-inch Corrugated	4656	5445	889	1.35	(+23.0%)
Velocity = 6.0 ft./sec.; Fouling = 0.0005					
5/8-inch Bare	1532	3194	593	0.60	
5/8-inch Corrugated	3843	4765	866	0.86	(+43.5%)
1-inch Bare	1388	3866	578	0.94	
1-inch Corrugated	3027	6070	808	1.22	(+30.0%)

CONCLUSIONS

It was concluded that corrugated 90-10 Cupro-Nickel tubes have distinct heat transfer performance advantages on both tubeside and steam condensing side over bare 90-10 Cupro-Nickel tubes in steam condensing applications. It was further concluded that the steam condensing coefficient correction factor, C_n, is not a function of steam condensing temperature level, LMTD, or tubeside water velocity.

RECOMMENDATIONS

It is recommended that the users of the tubeside heat transfer correlations, pressure drop correlations and the steamside condensing coefficient correlations presented in this report for 90-10 Cupro-Nickel tubes determine the optimum diameter of the corrugated tube and tubeside water velocity to be used in steam condensing applications from economic considerations.

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FIGURES

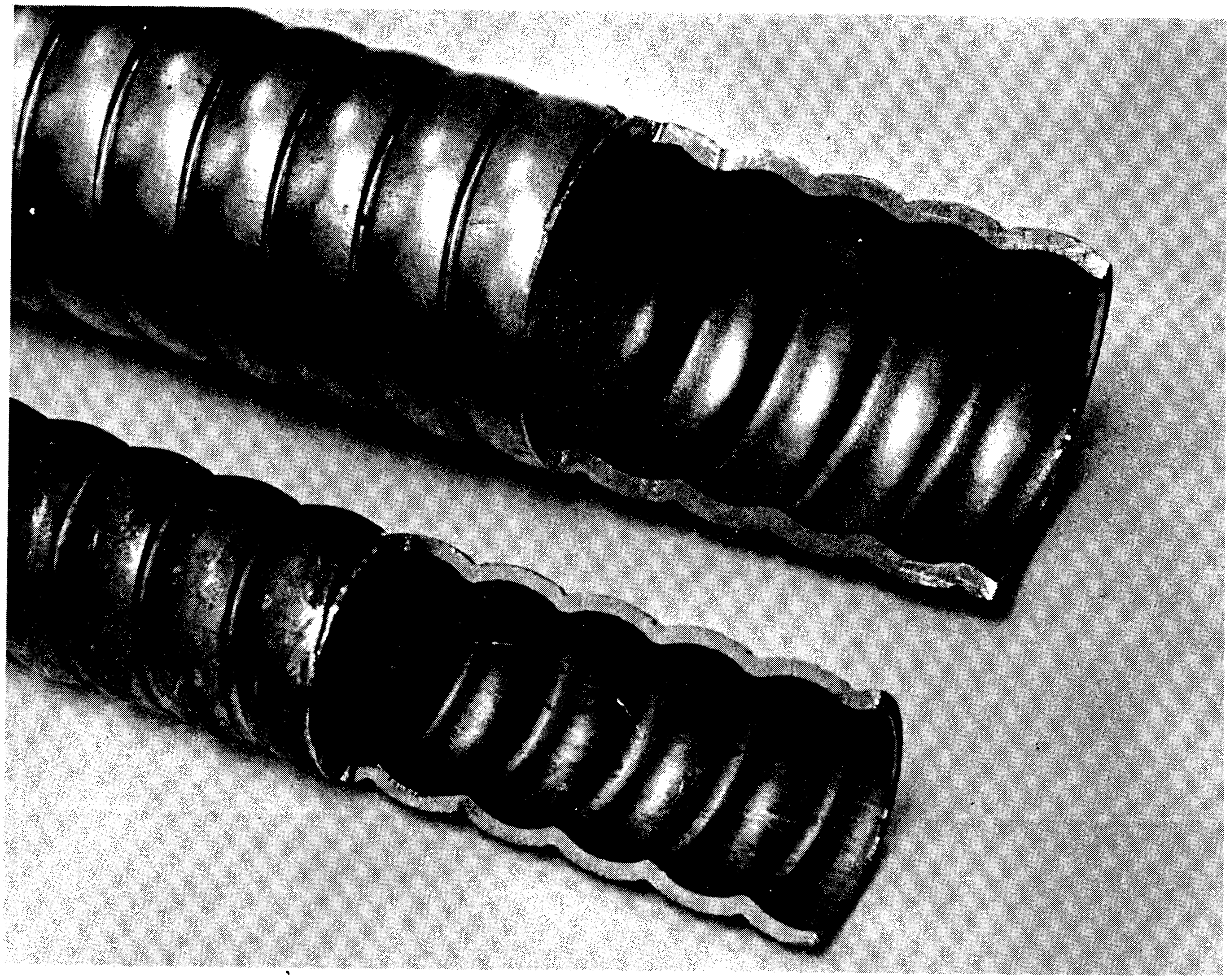


Figure 1. Sections of the 1-inch O.D., Schedule 18, Corrugated 90-10 Cupro-Nickel and 5/8-inch O.D., Schedule 20, Corrugated Copper Tubes.

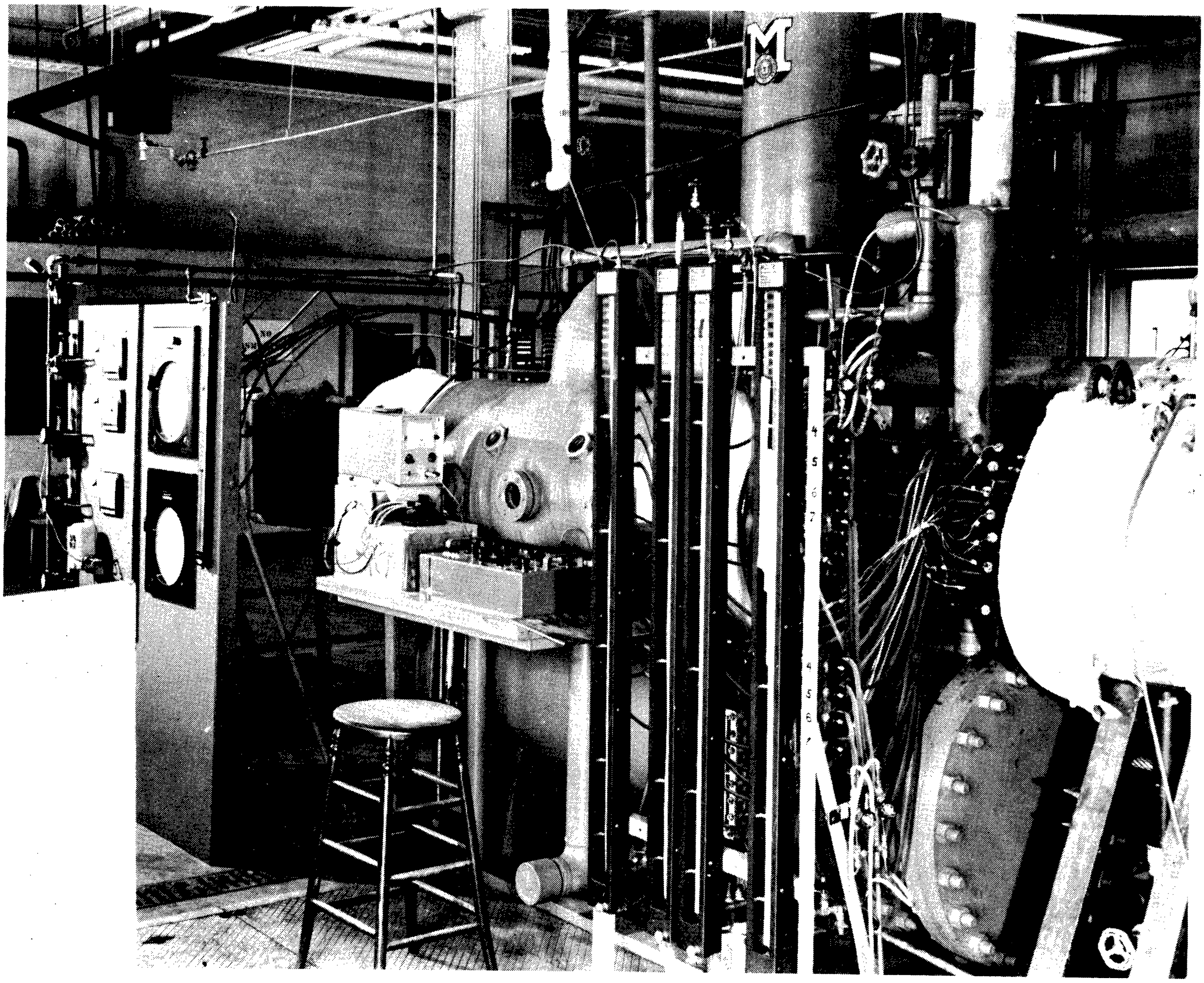


Figure 2. Overall View of Equipment Showing Test Tubes, Automatic Controls, Potentiometer Set-up, and Manometers.

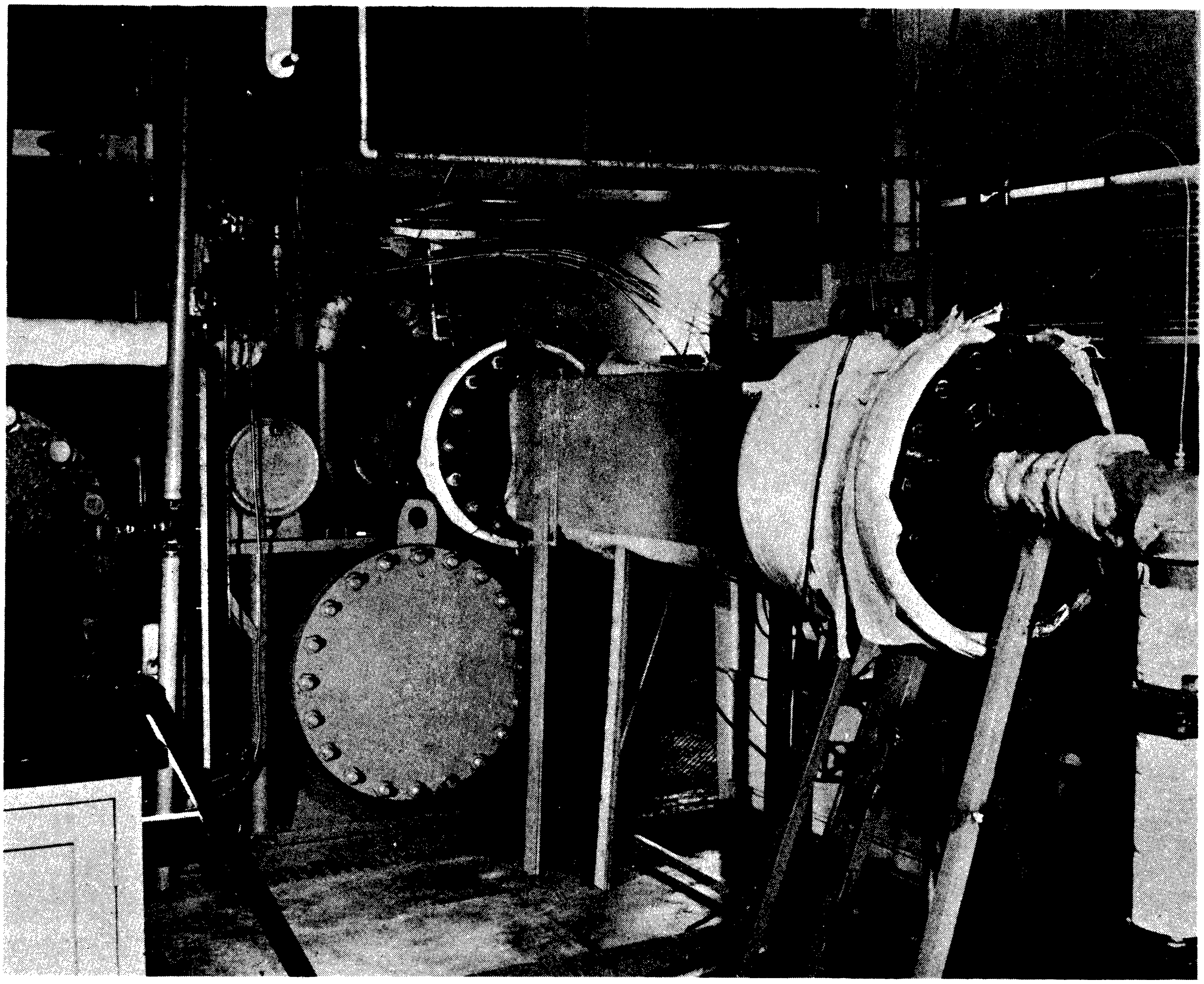


Figure 3. Partial Rear View of Equipment Showing Inlet Pot and Well Insulated Inlet Tube Section.

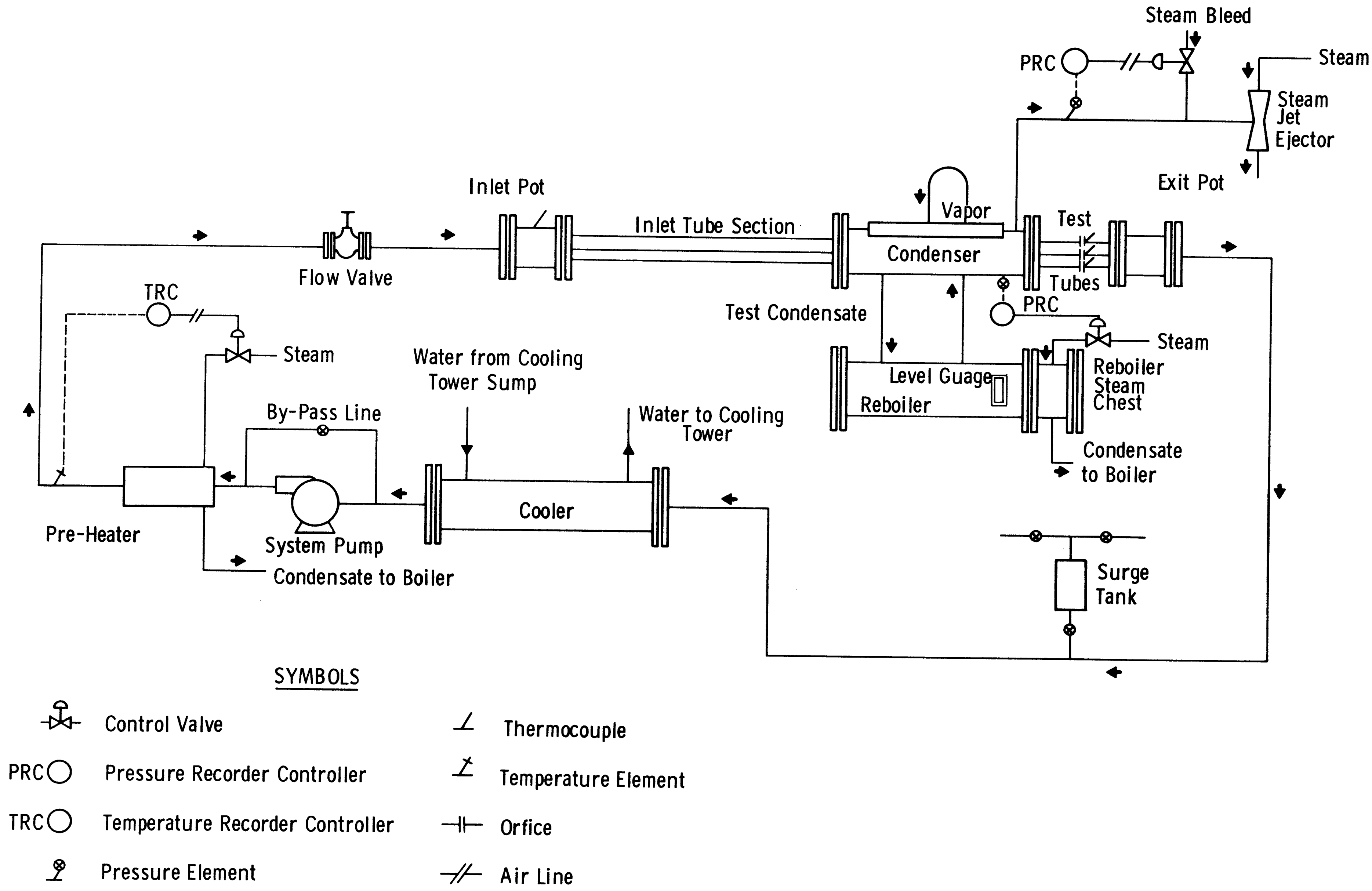


Figure 4. Line Diagram of Equipment Showing the Flow of Steam and Water.

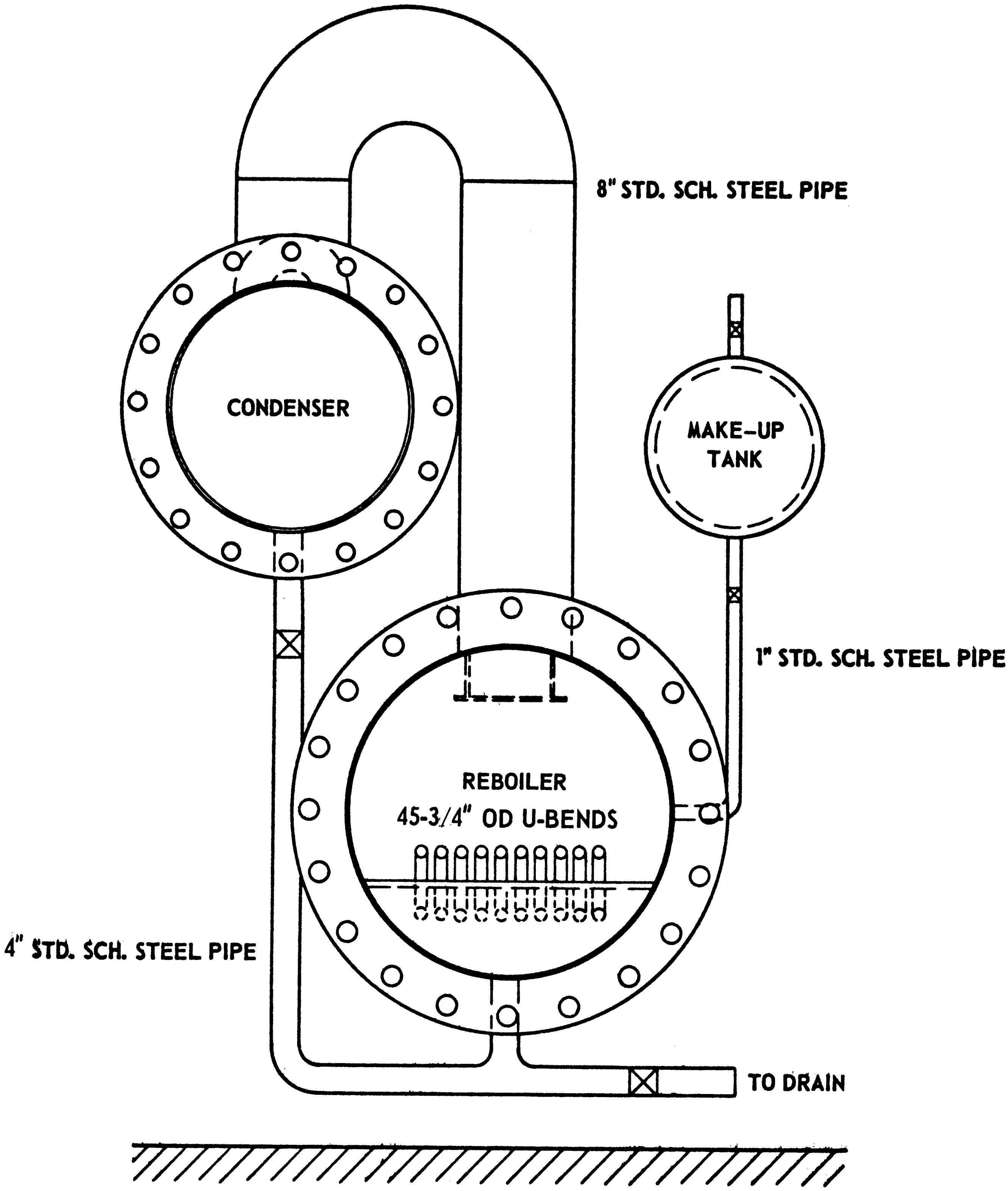


Figure 5. Elevation Drawing of Condenser, Reboiler, and Make-up Tank with the Condenser Tube Sheets and Reboiler Blind Flanges Removed.

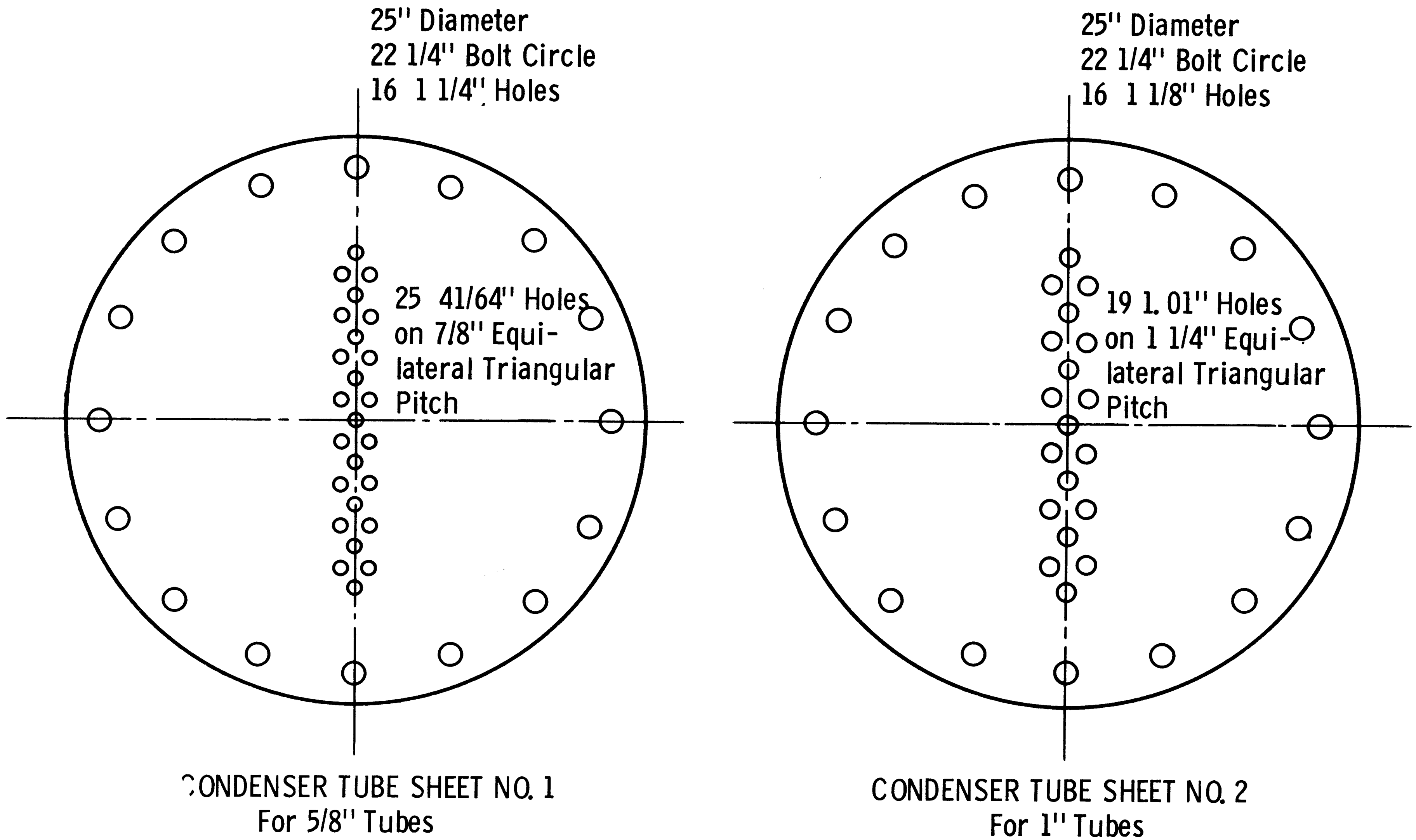


Figure 6. Detailed Drawing of Condenser Tube Sheets.

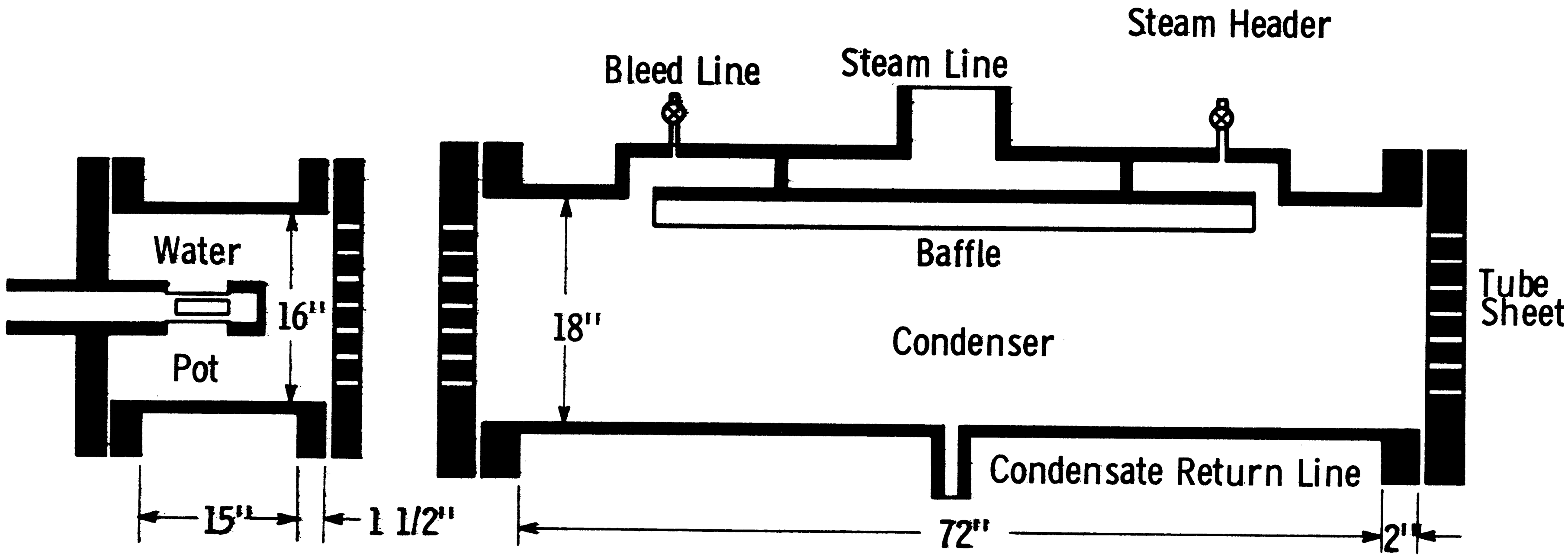


Figure 7. Cross-sectional Drawing of Condenser and Inlet Water Pot.

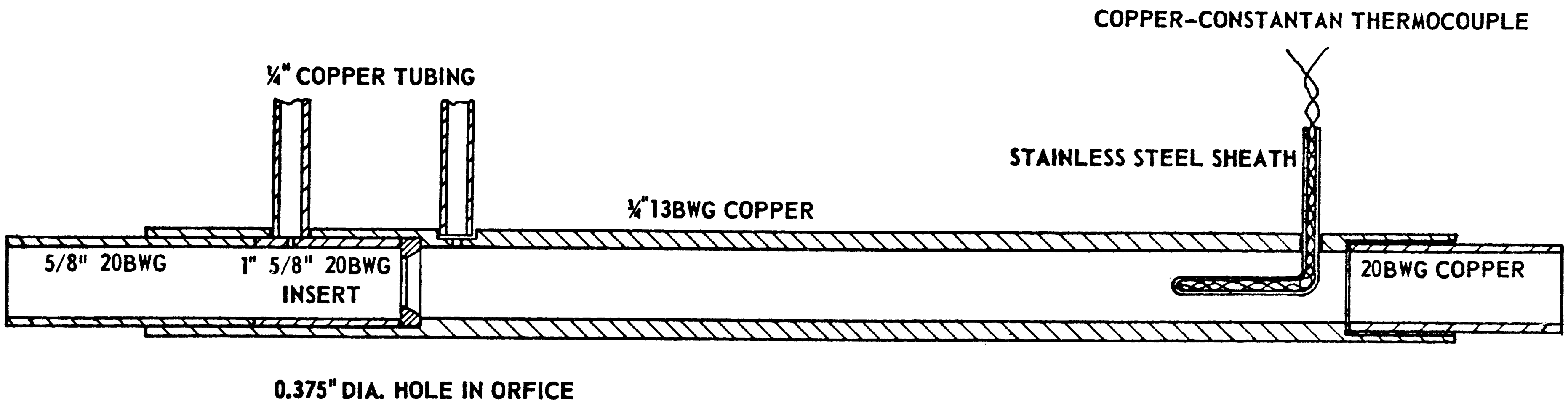
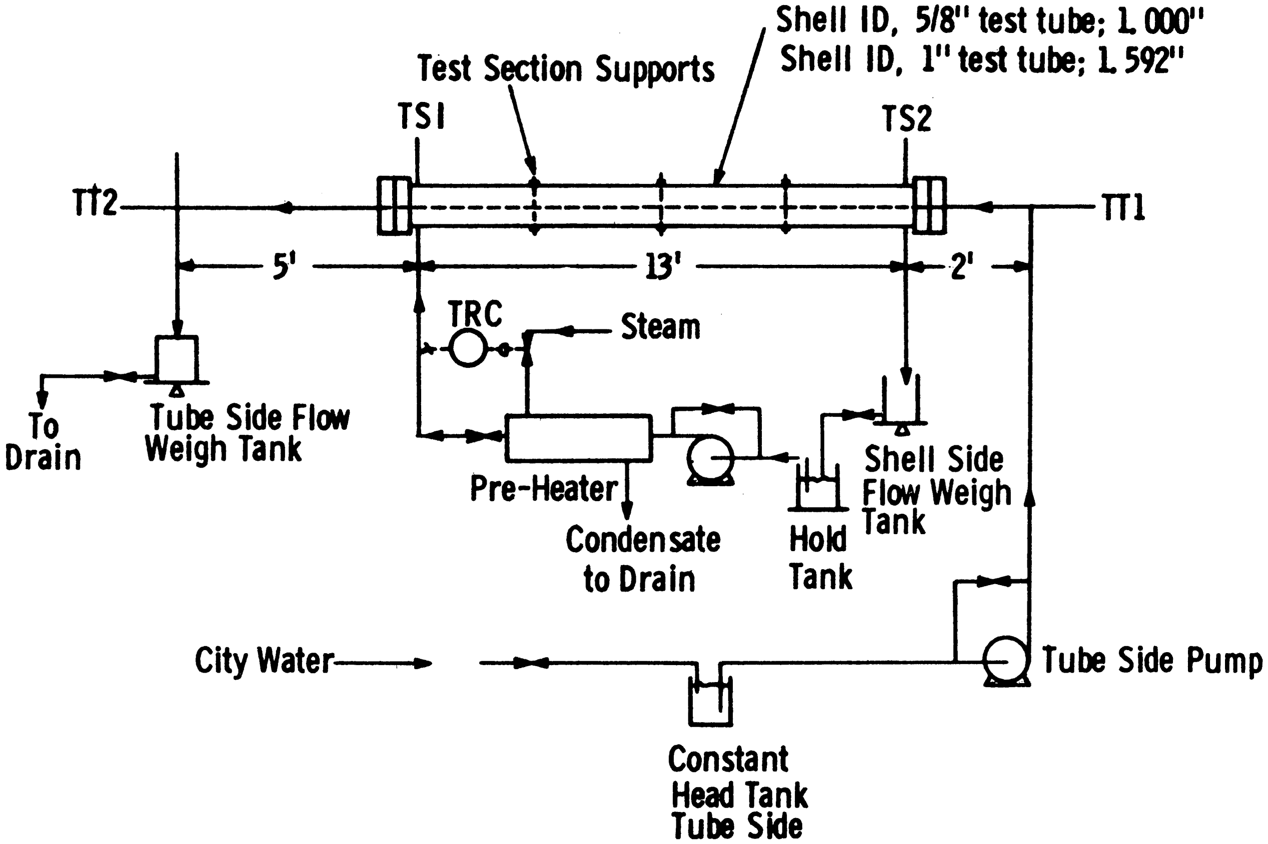


Figure 8. Cross-sectional Drawing of Orifice Holder Assembly and Extensions at Each End.



TRC Temperature Recorder Controller

FRC Flow Recorder Controller

TS1 Temperature Shell Side Water, In

TS2 Temperature Shell Side Water, Out

TT1 Temperature Tube Side Water, In

TT2 Temperature Tube Side Water, Out

Figure 9. Line Diagram of Concentric Tube and Shell Heat Exchanger for Wilson Plot Determination Showing Flow of Steam and Water.

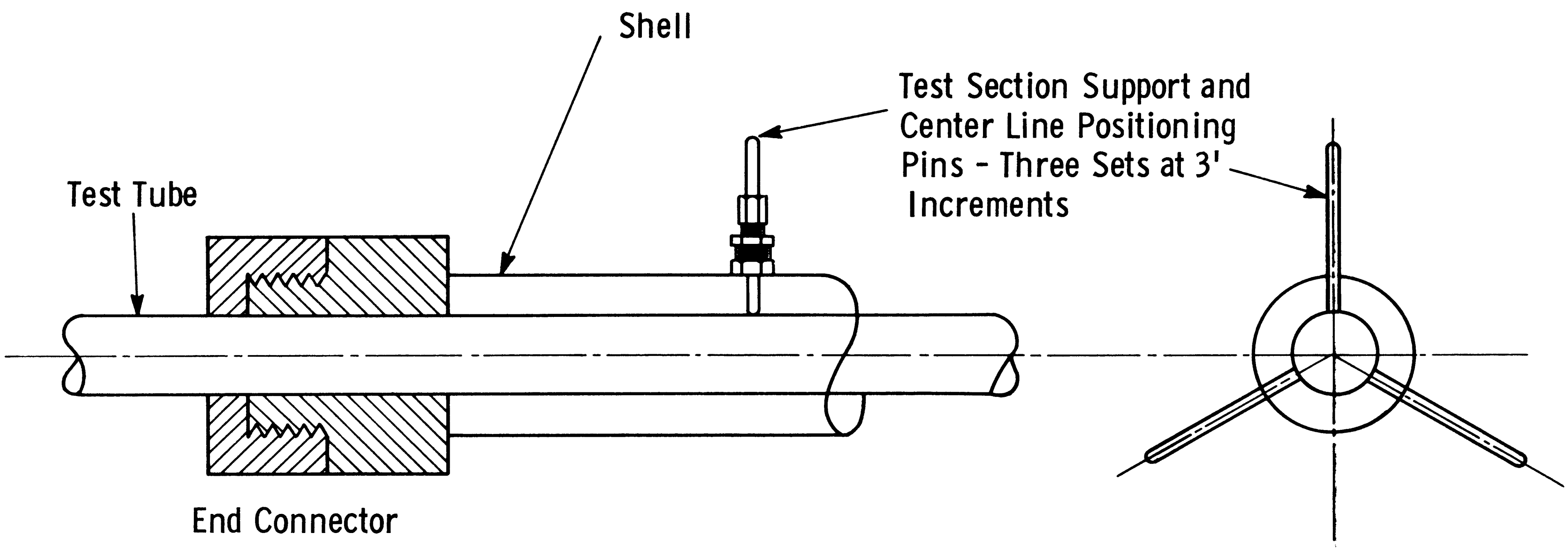


Figure 10. Cross-sectional Drawing of Concentric Tube and Shell Heat Exchanger End Fittings and Test Tube Supports.

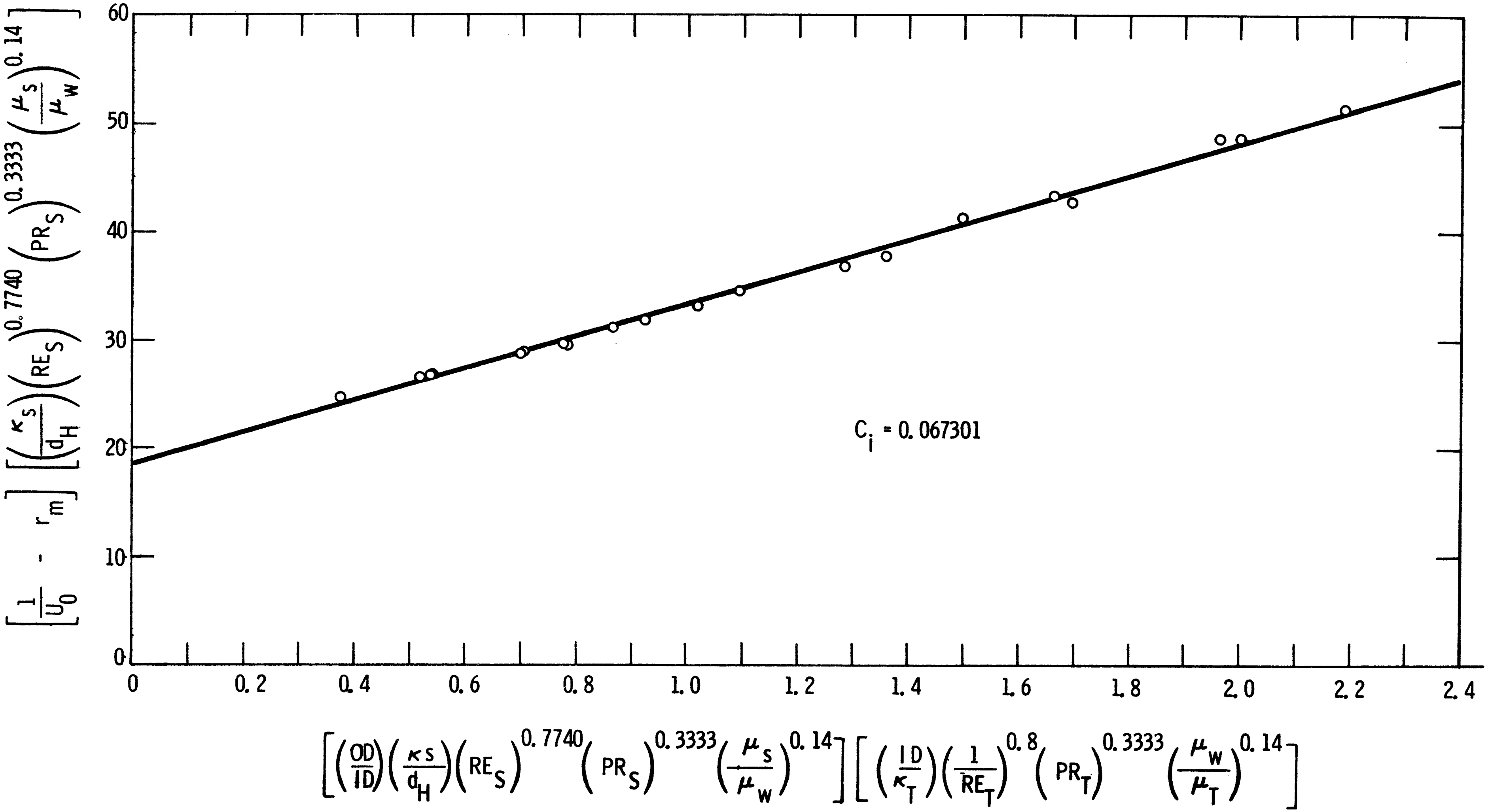


Figure 11. Modified Wilson Plot for the 5/8-inch O.D., Schedule 20, Corrugated Copper Tube.

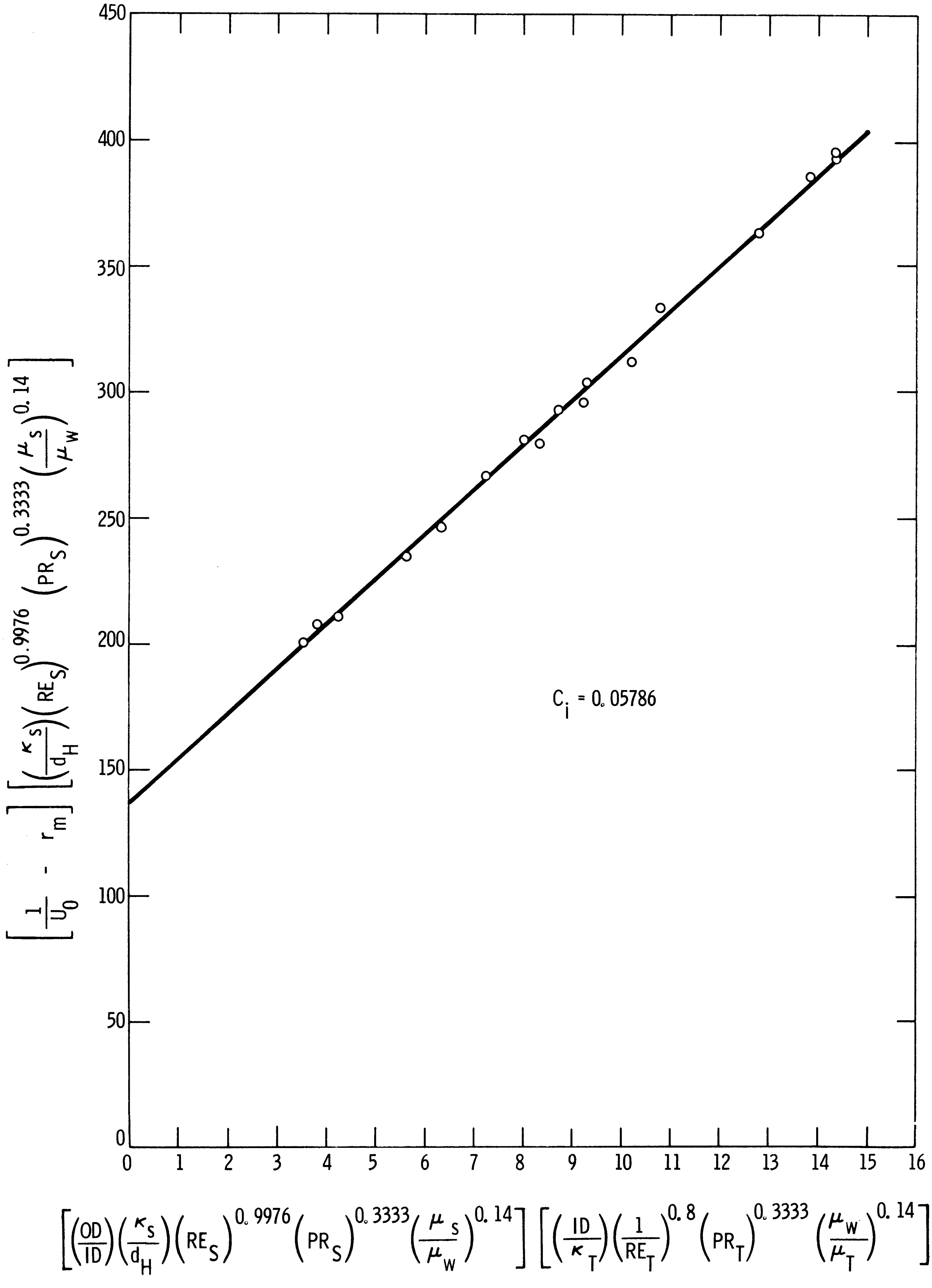


Figure 12. Modified Wilson Plot for the 1-inch O. D., Schedule 18, Corrugated 90-10 Cupro-Nickel Tube

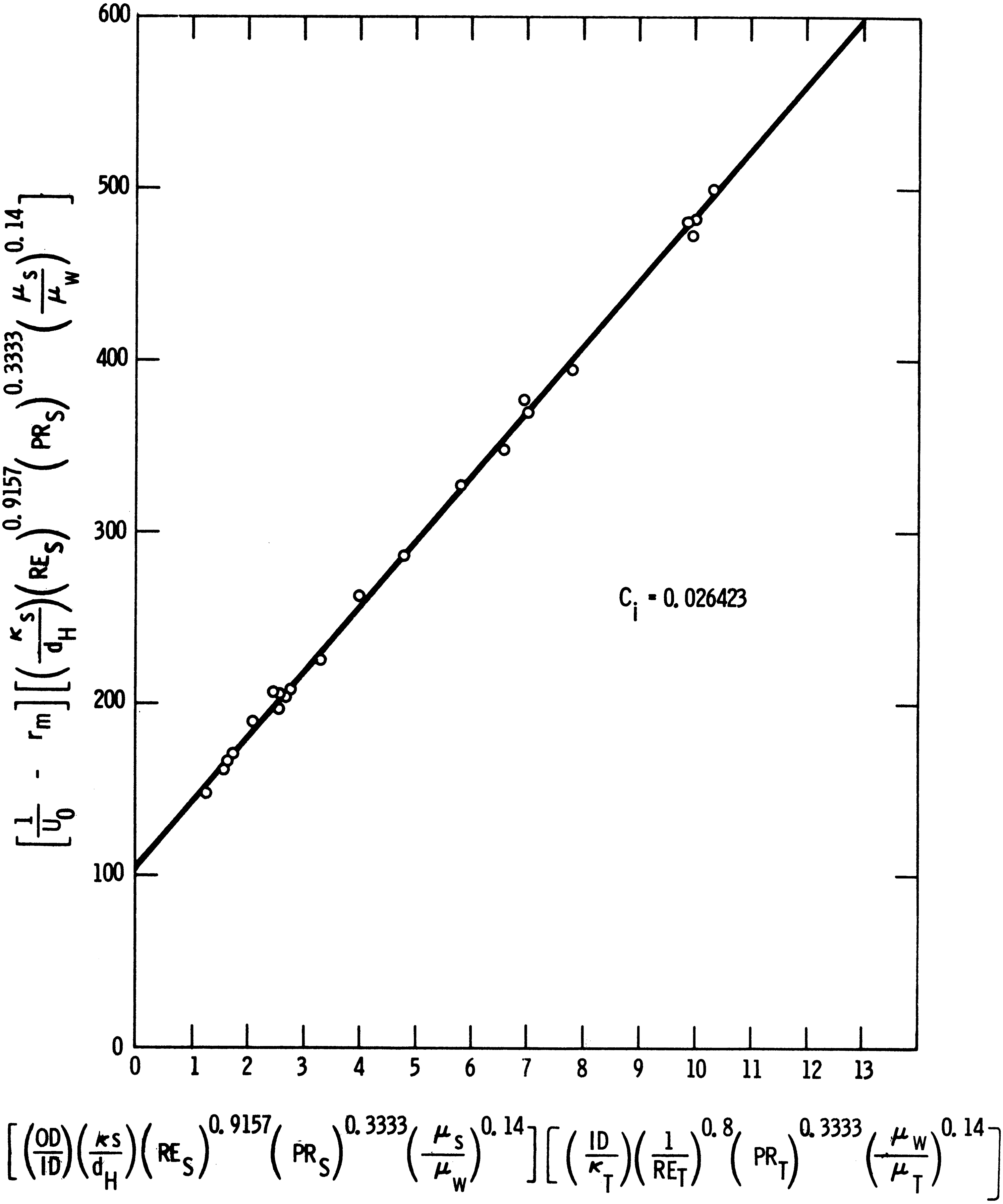


Figure 13. Modified Wilson Plot for the 1-inch O.D., Schedule 18, Bare 90-10 Cupro-Nickel Tube.

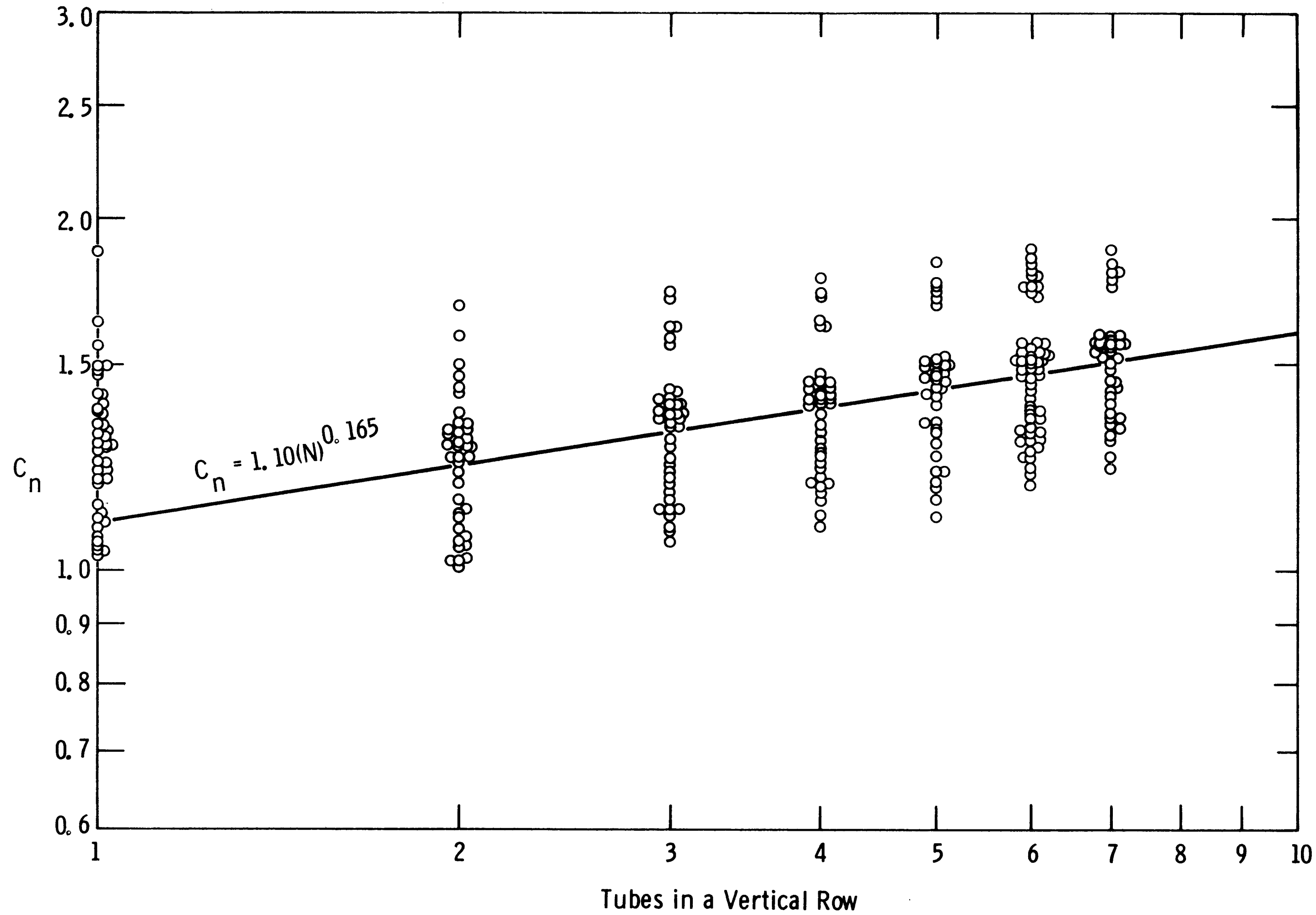


Figure 14. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

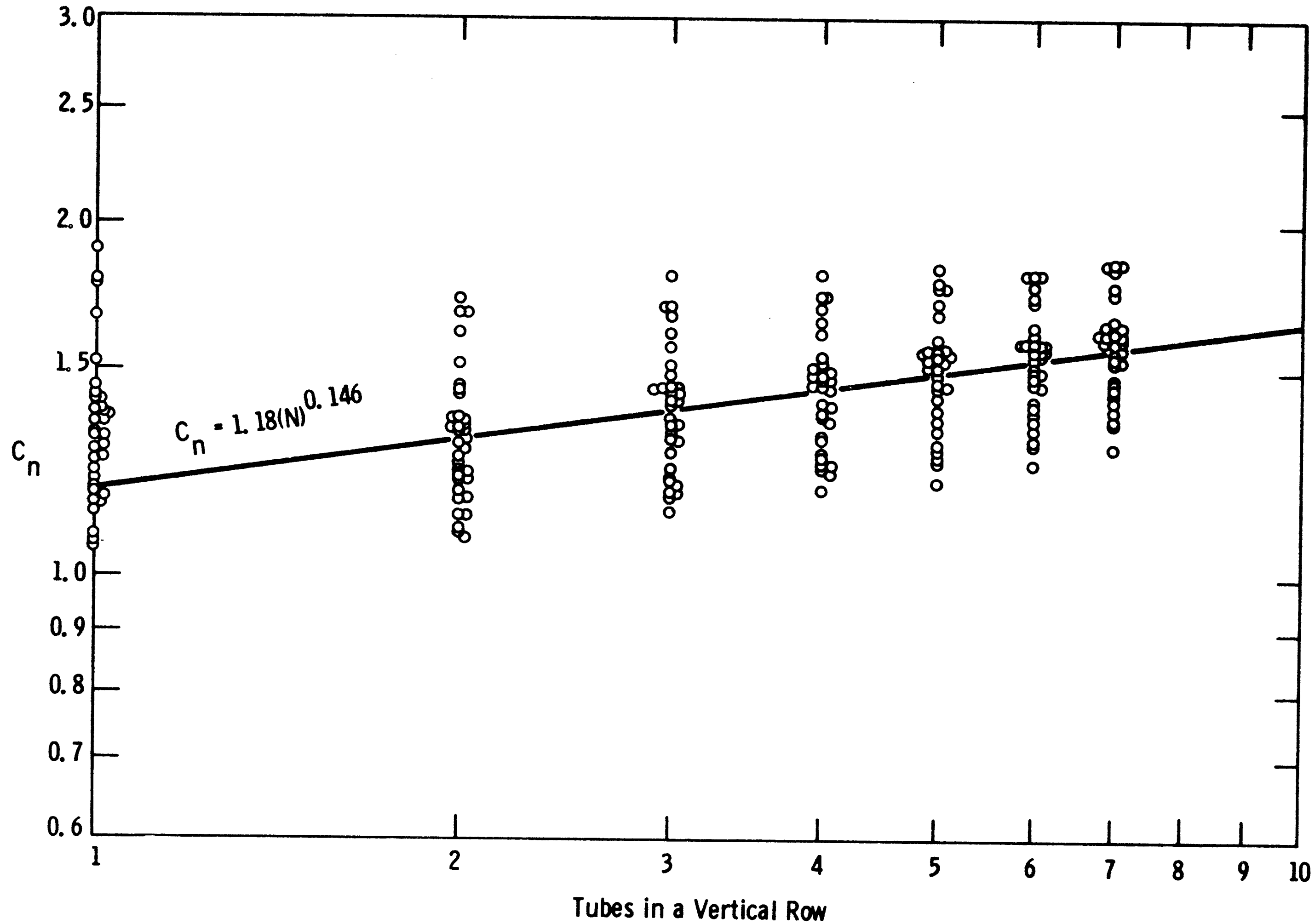


Figure 15. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 4.7 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

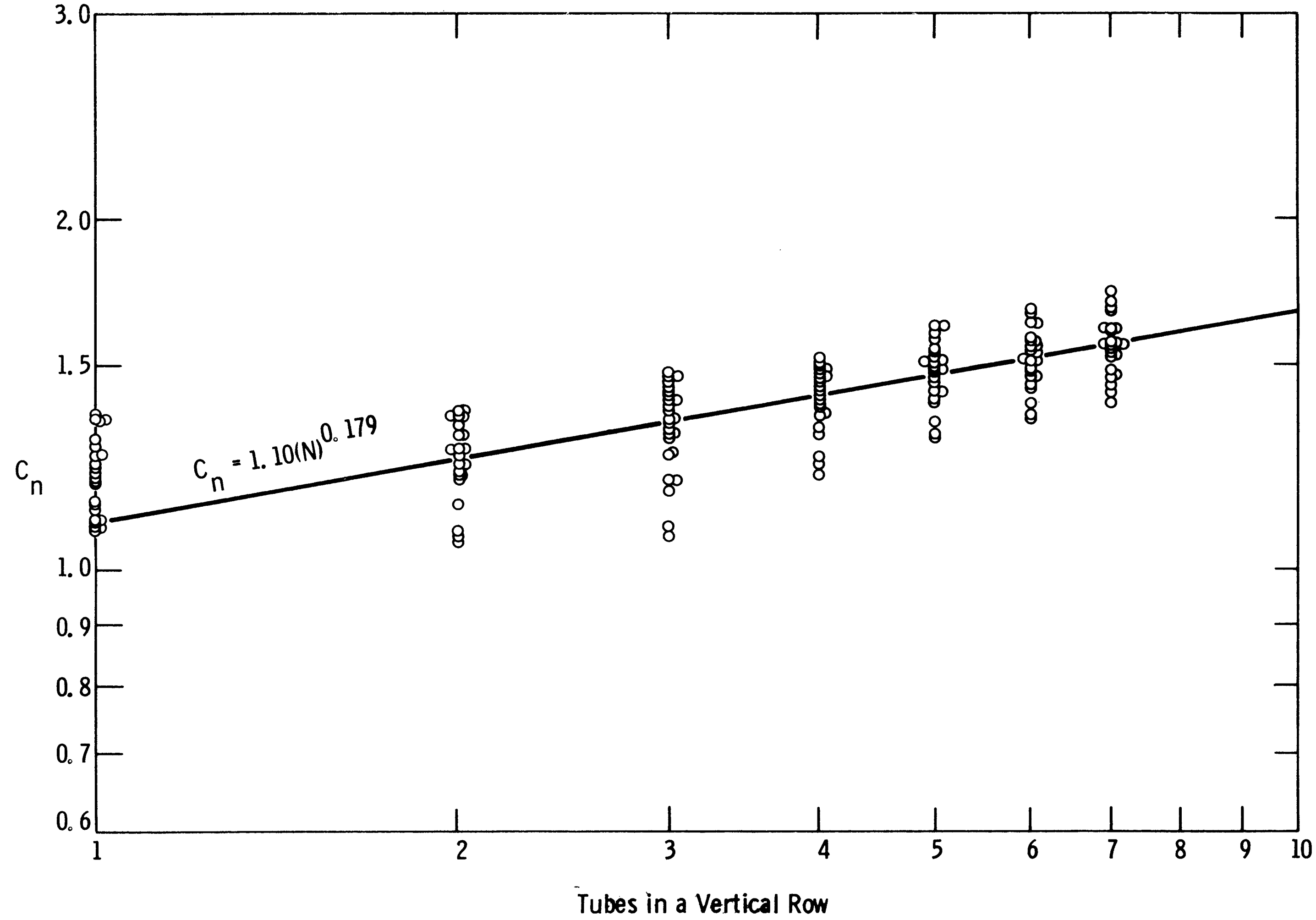


Figure 16. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 5.3 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

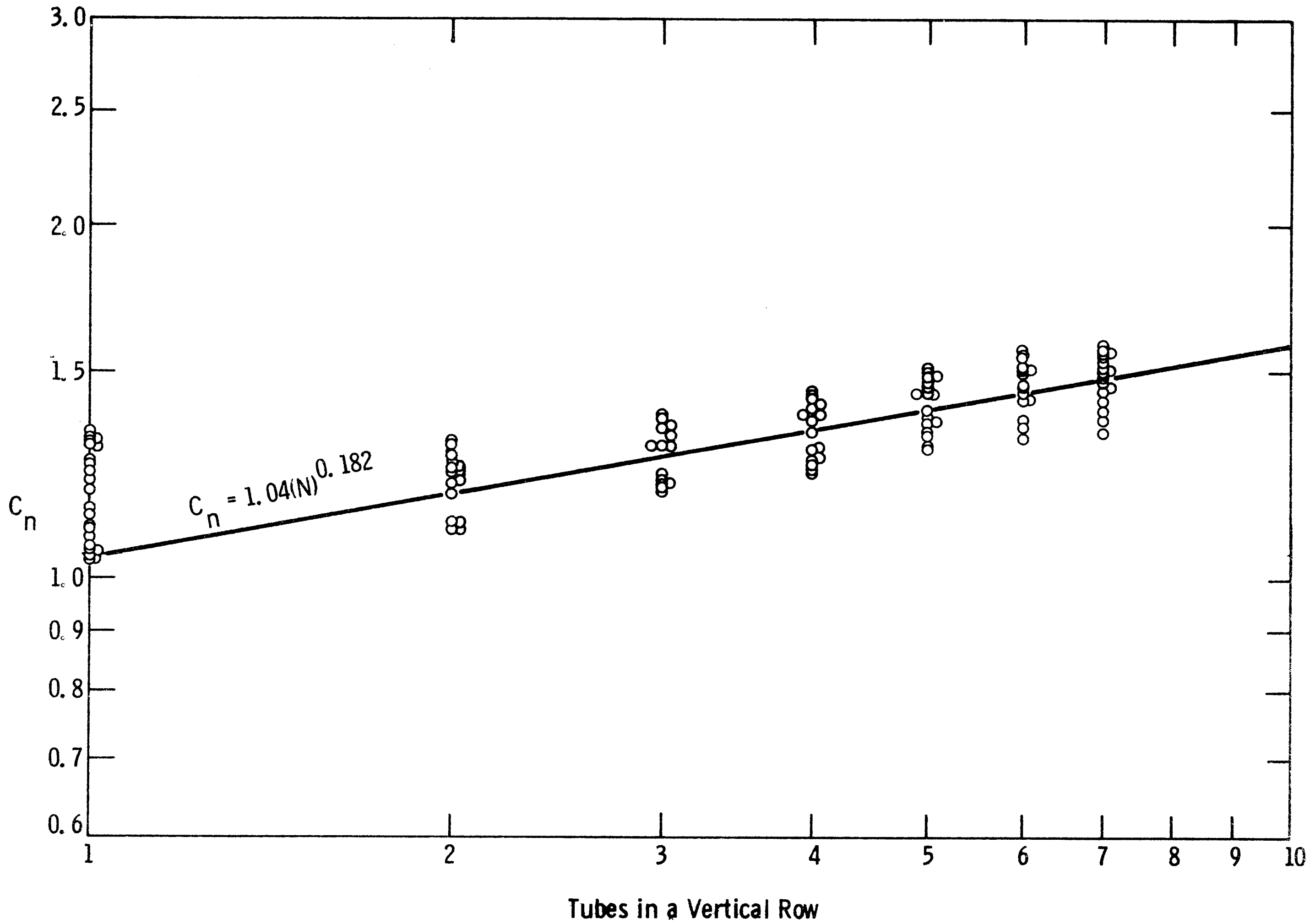


Figure 17. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

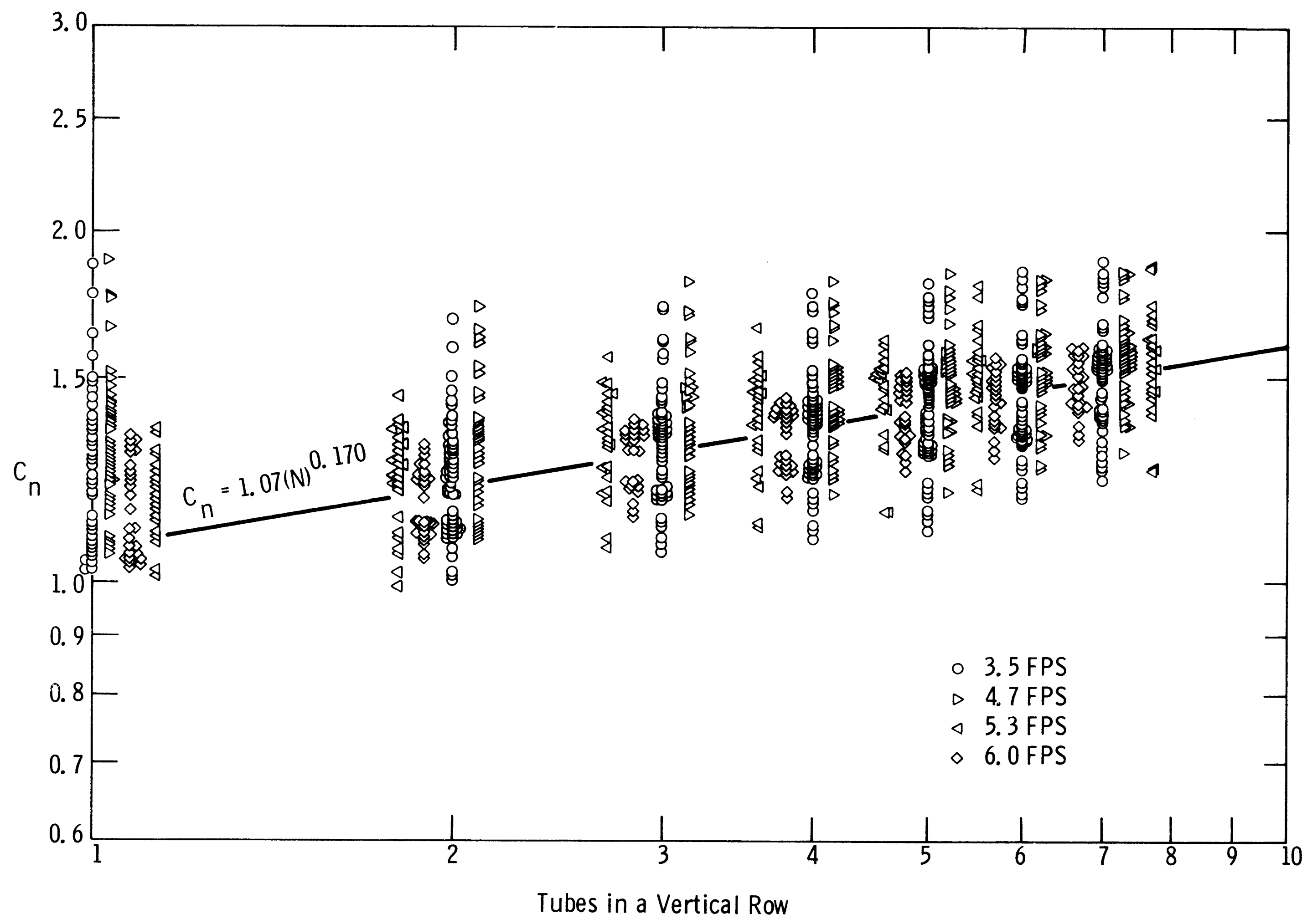


Figure 18. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

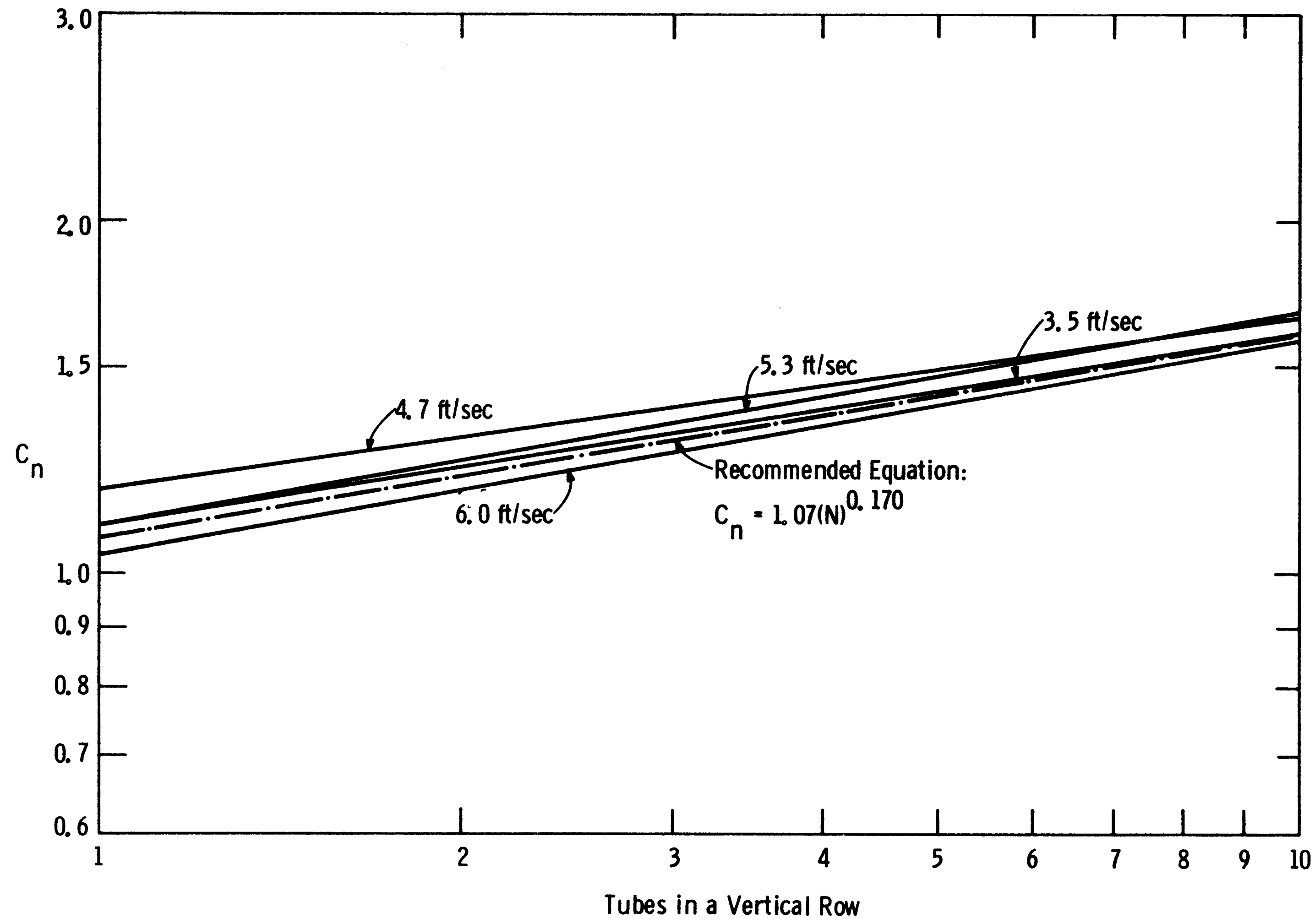


Figure 19. Comparison of the Condensing Coefficient Correction Factor Curves for Tubeside Water Velocities at 3.5, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

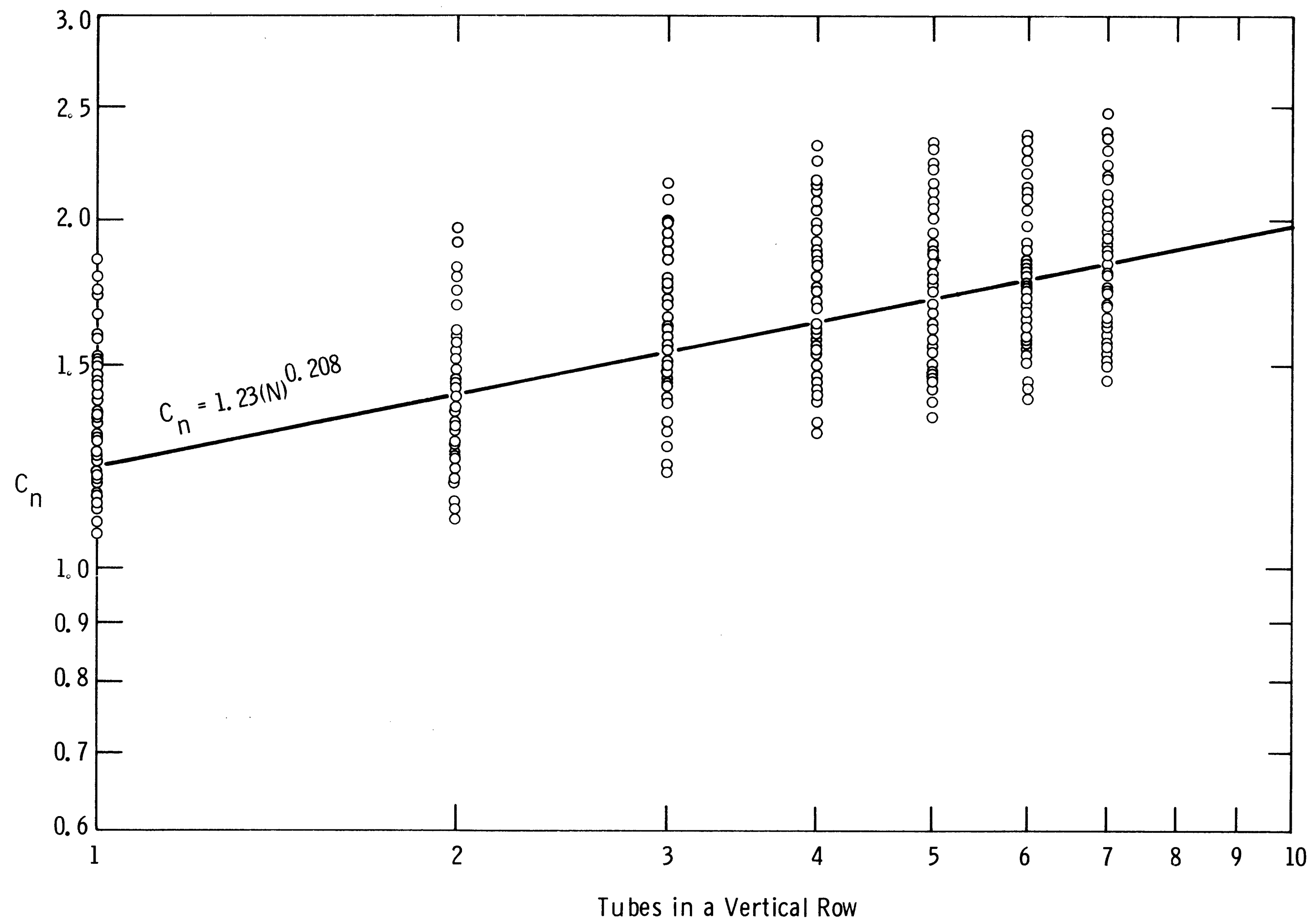


Figure 20. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

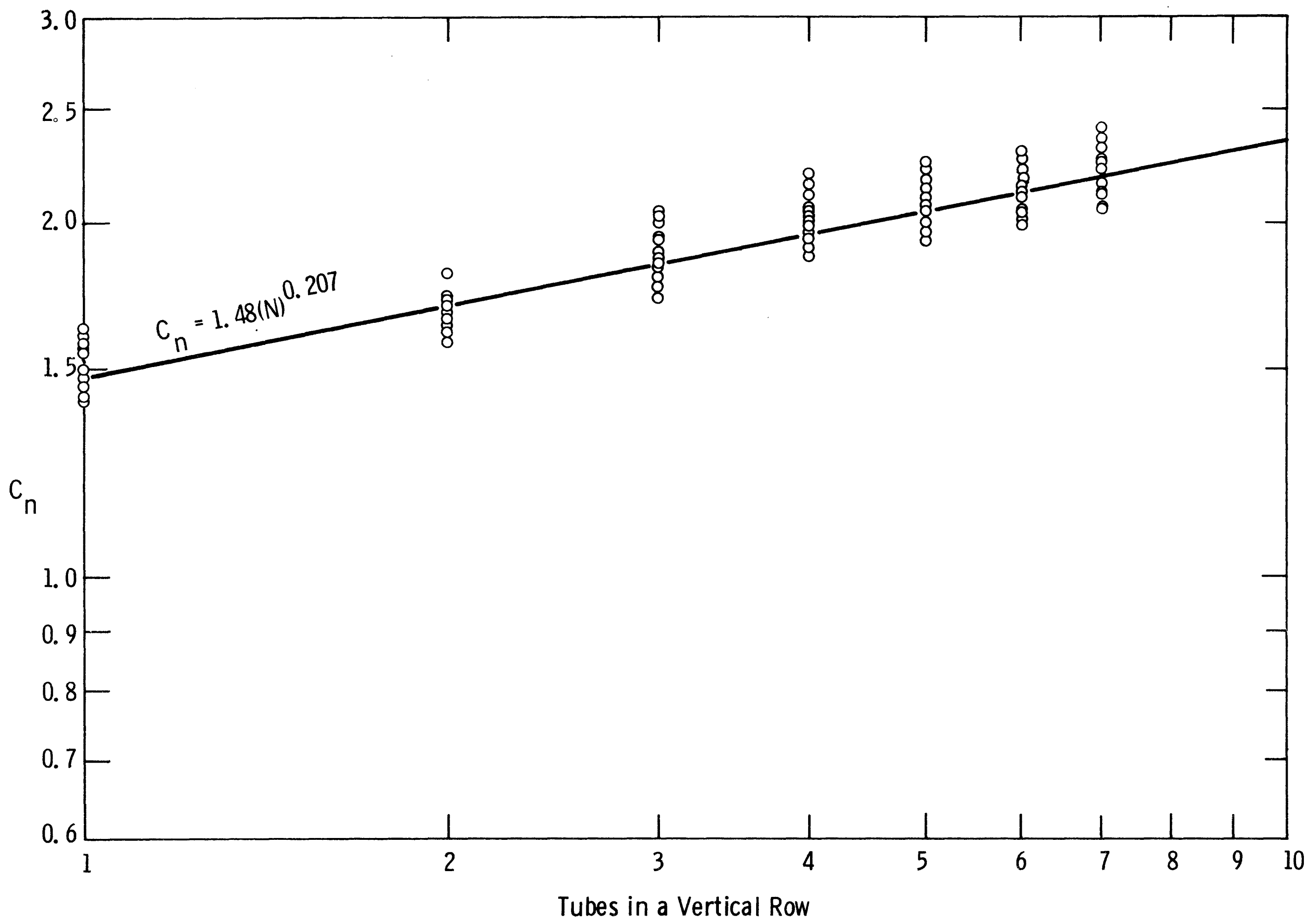


Figure 21. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 4.7 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

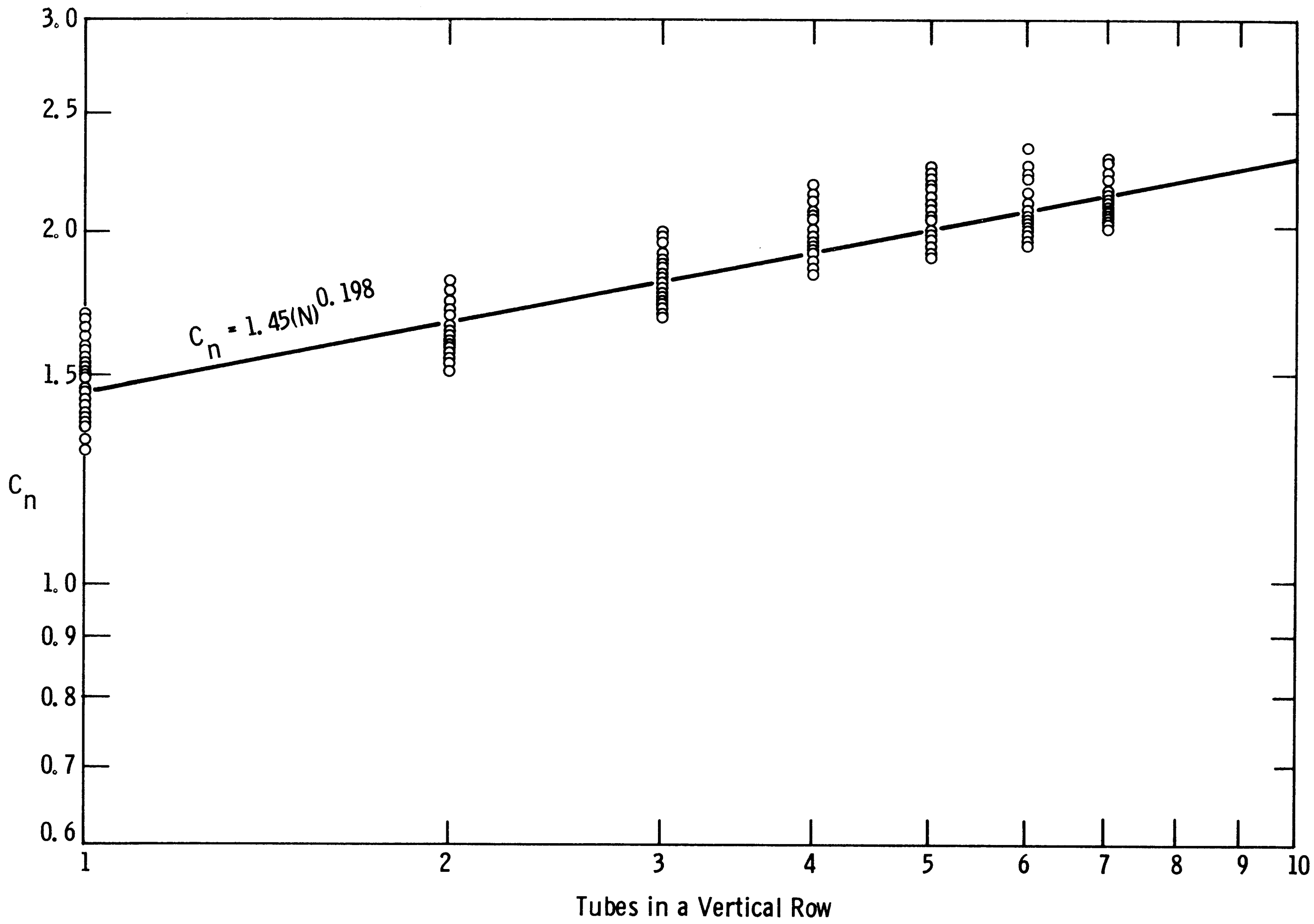


Figure 22. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

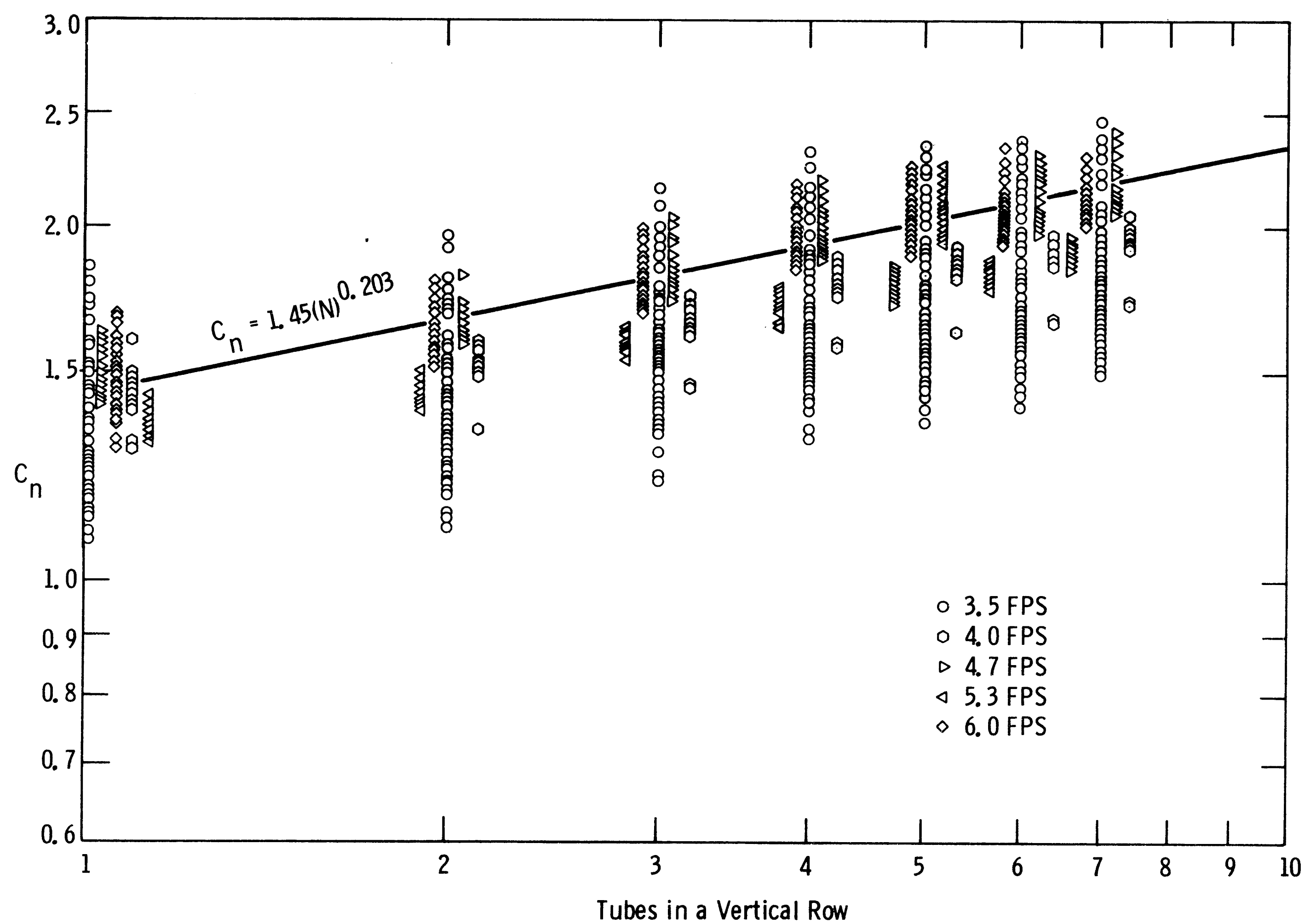


Figure 23. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.0, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

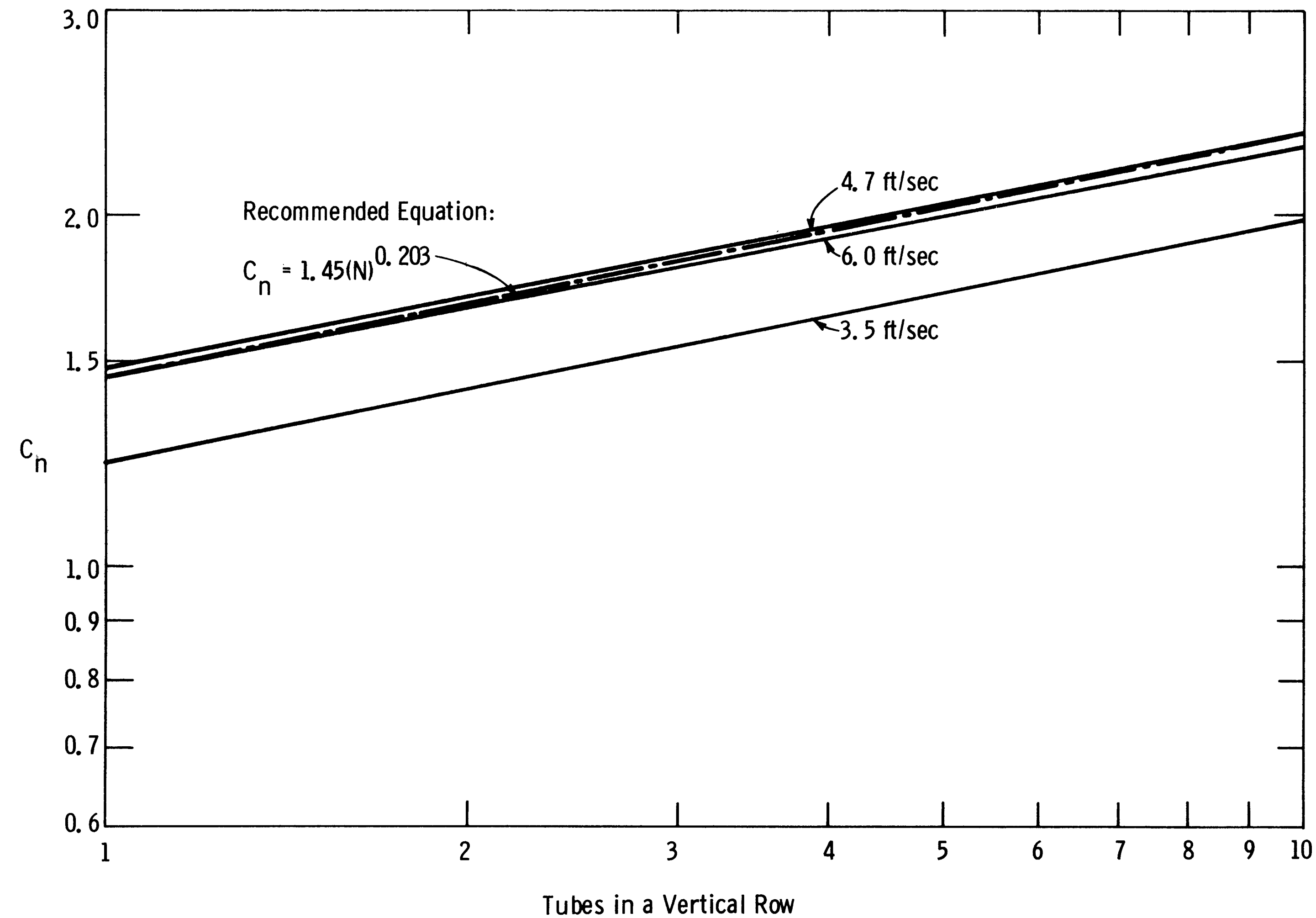


Figure 24. Comparison of the Condensing Coefficient Correction Factor Curves for Tubeside Water Velocities at 3.5, 4.7, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

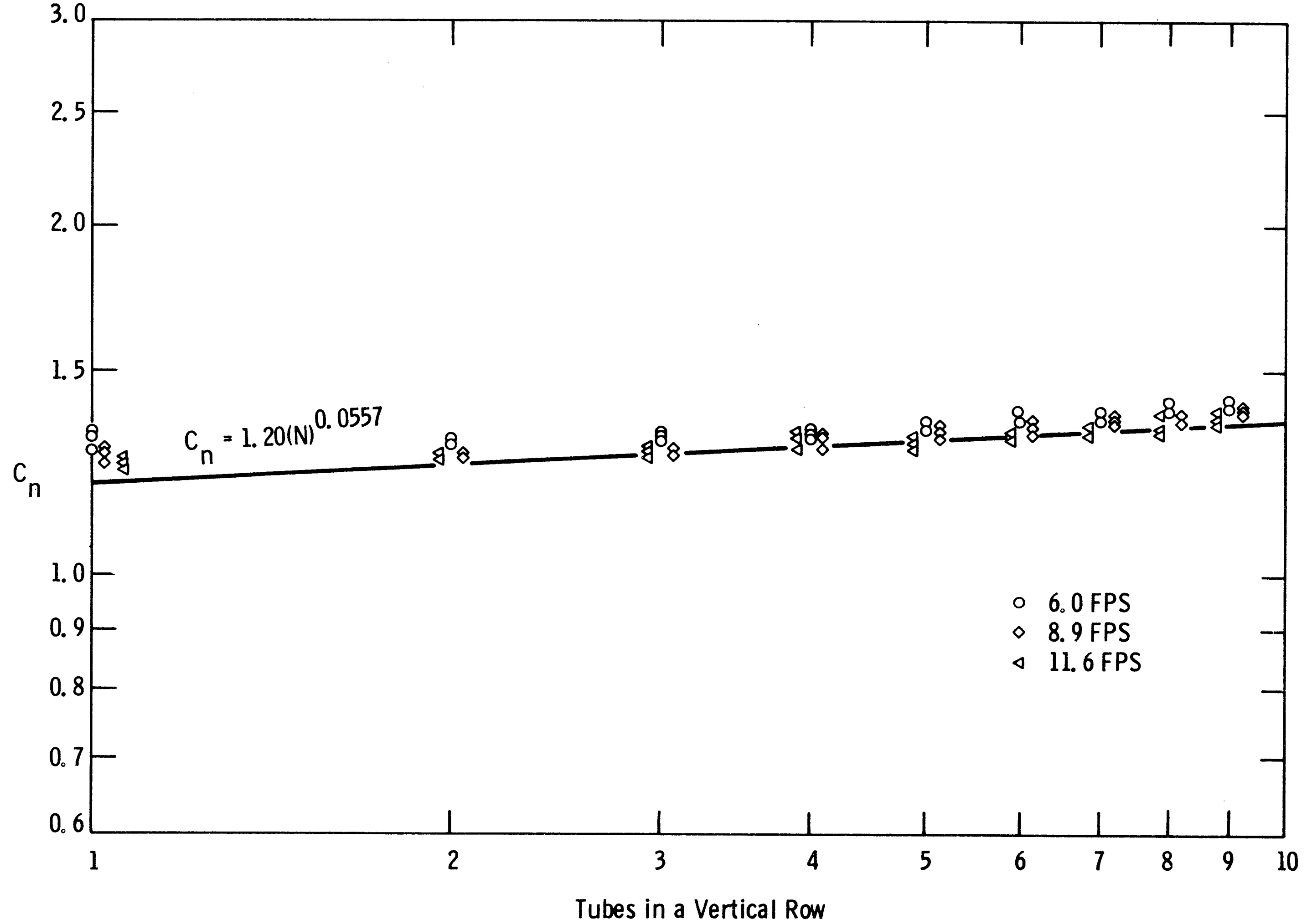


Figure 25. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 6.0, 8.9, and 11.6 feet per second and Condensation of Steam at 101°F on 1 to 9 Bare 5/8-inch O.D., Schedule 20, Copper Tubes in a Vertical Row.

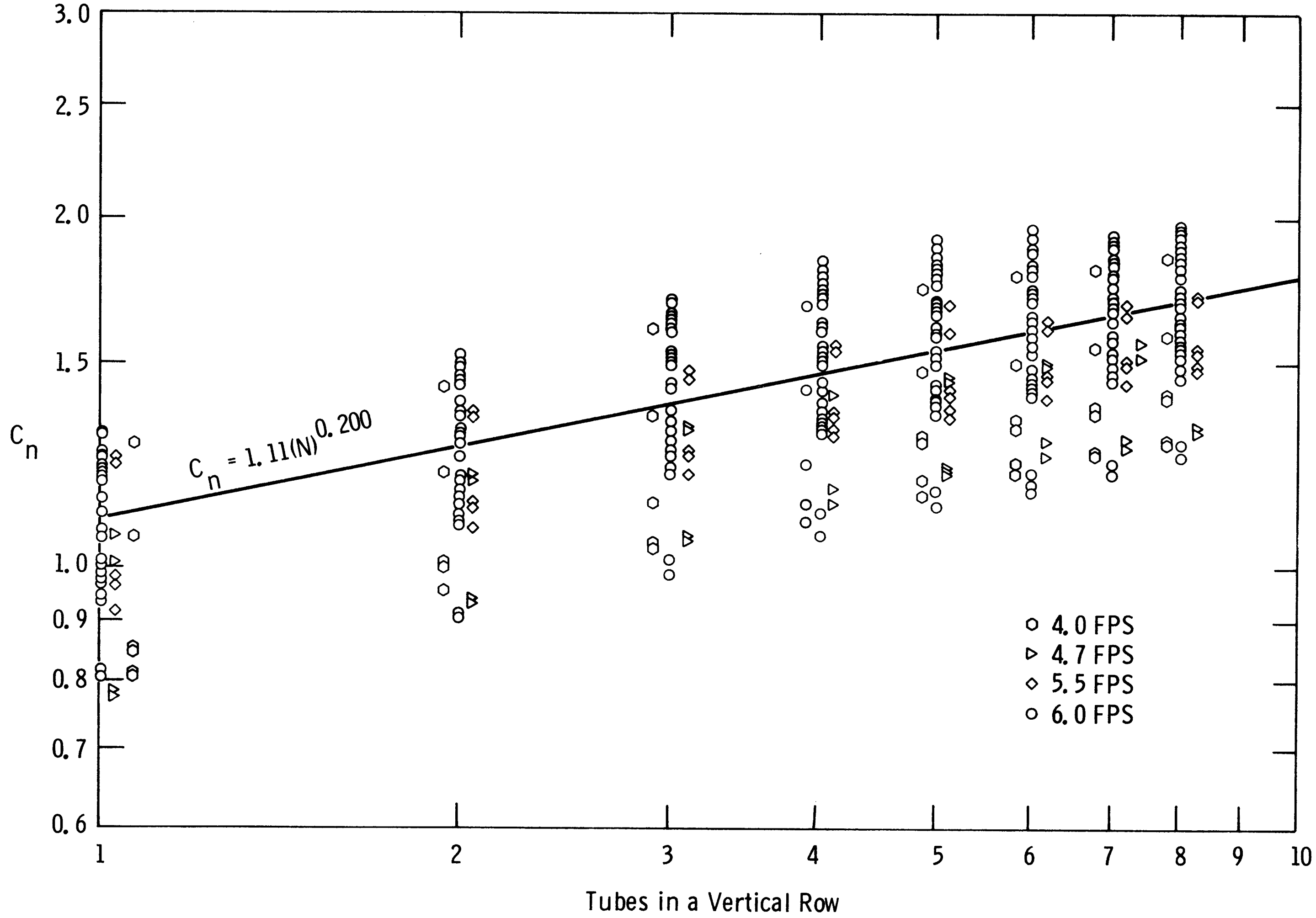


Figure 26. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 4.0, 4.7, 5.5, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 8 Corrugated 5/8-inch O.D., Schedule 20, Copper Tubes in a Vertical Row.

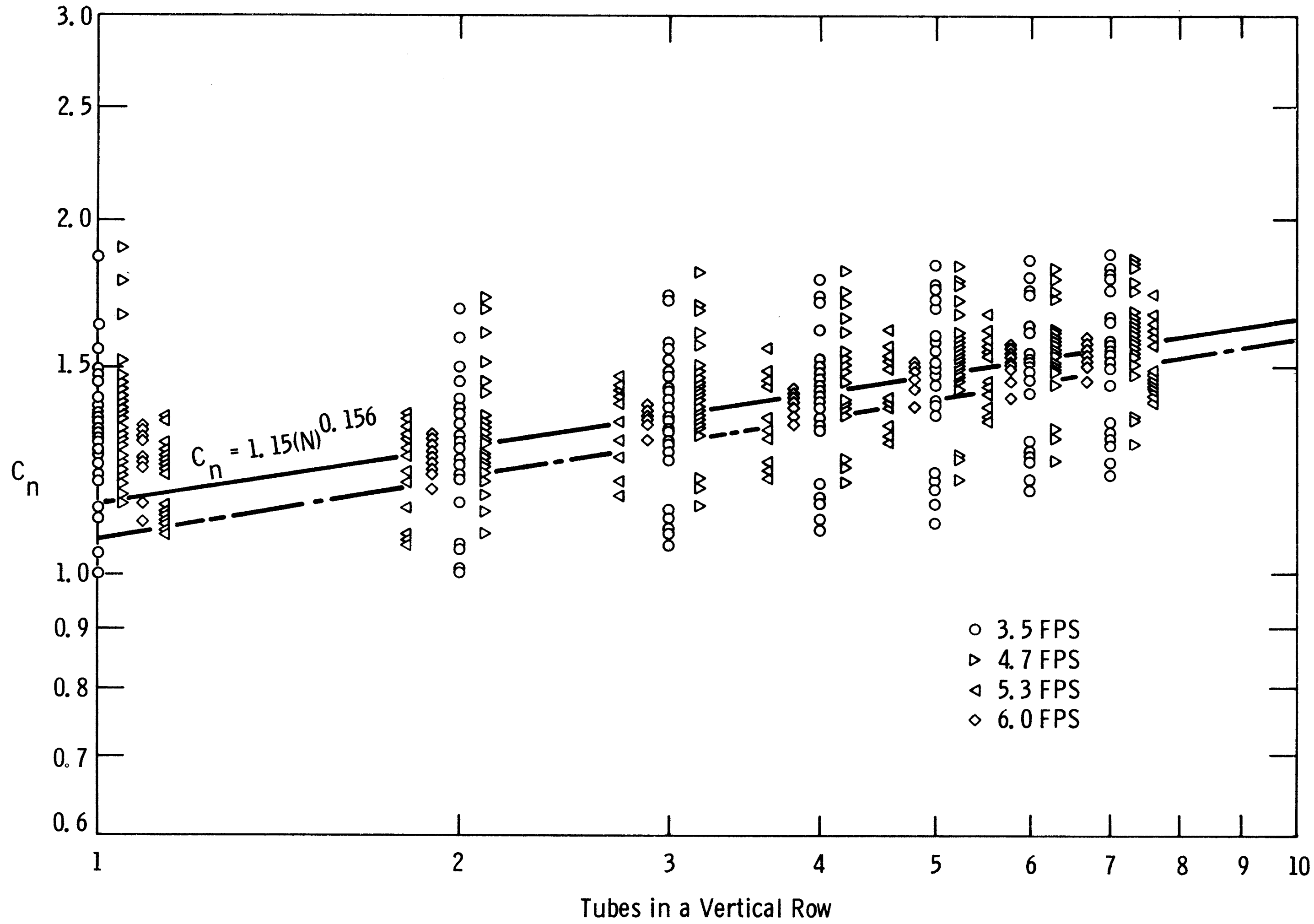


Figure 27. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101 °F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

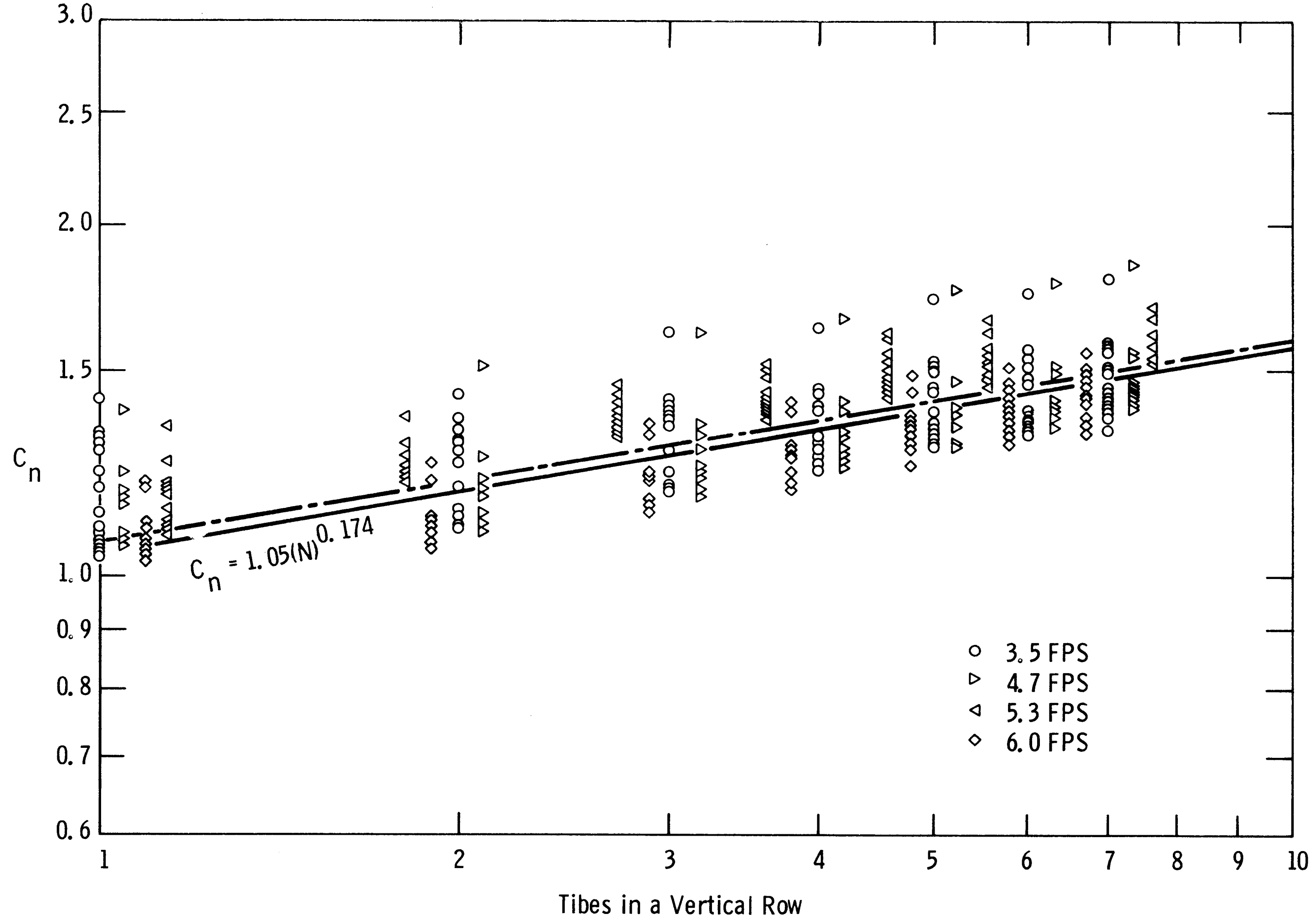


Figure 28. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

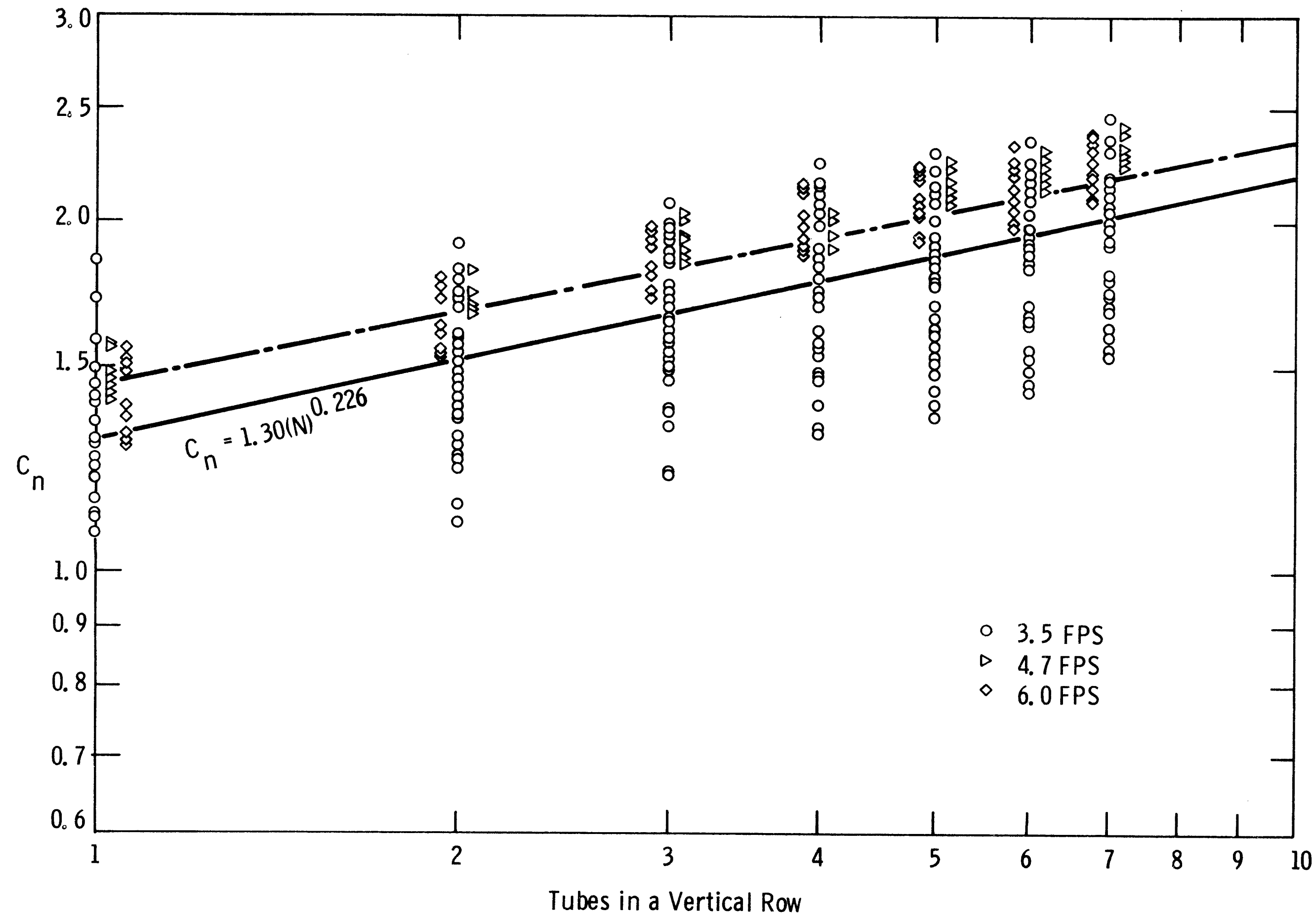


Figure 29. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.7, and 6.0 feet per second and Condensation of Steam at 101°F on 1 to 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

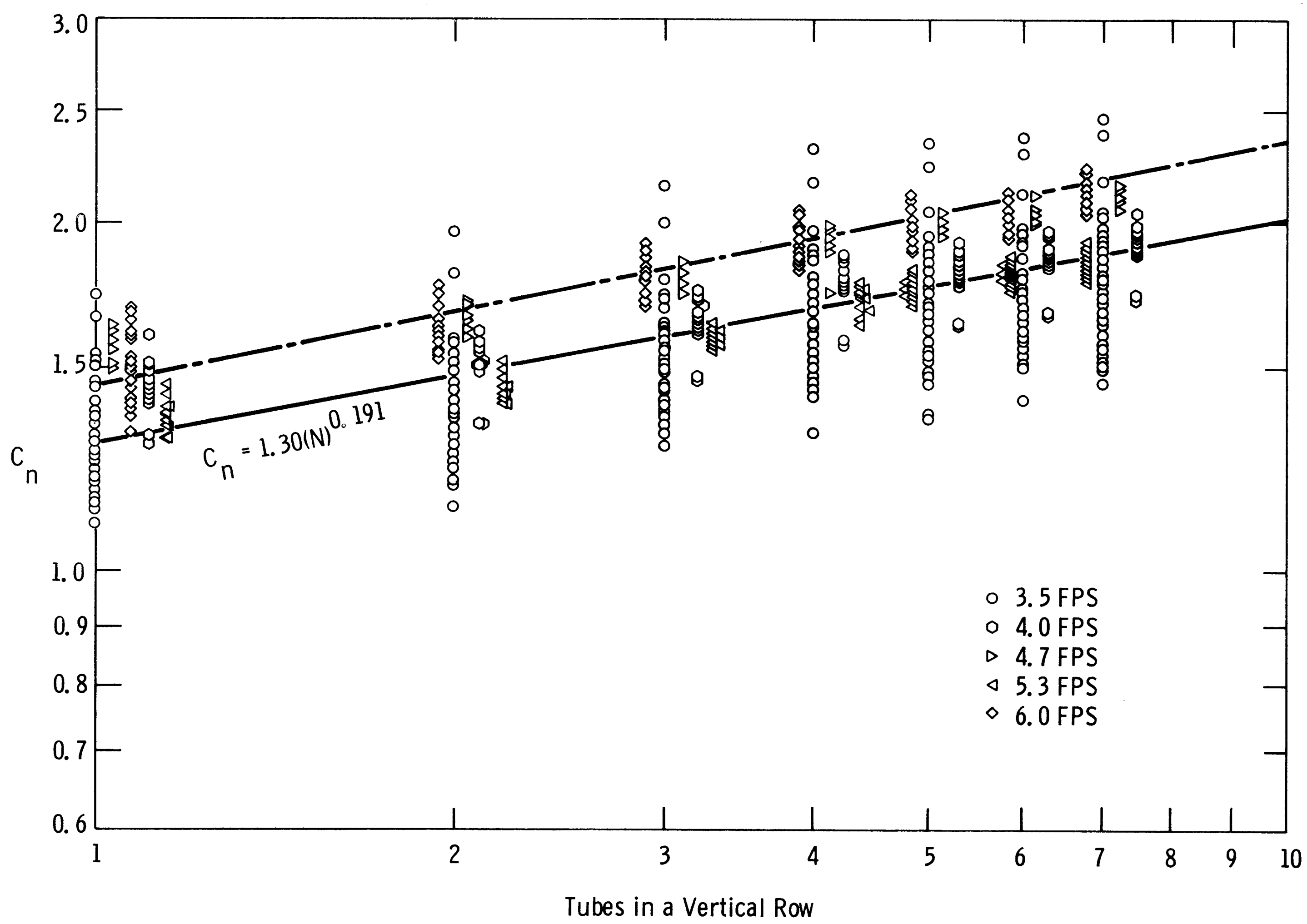


Figure 30. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.0, 4.7, 5.3 and 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

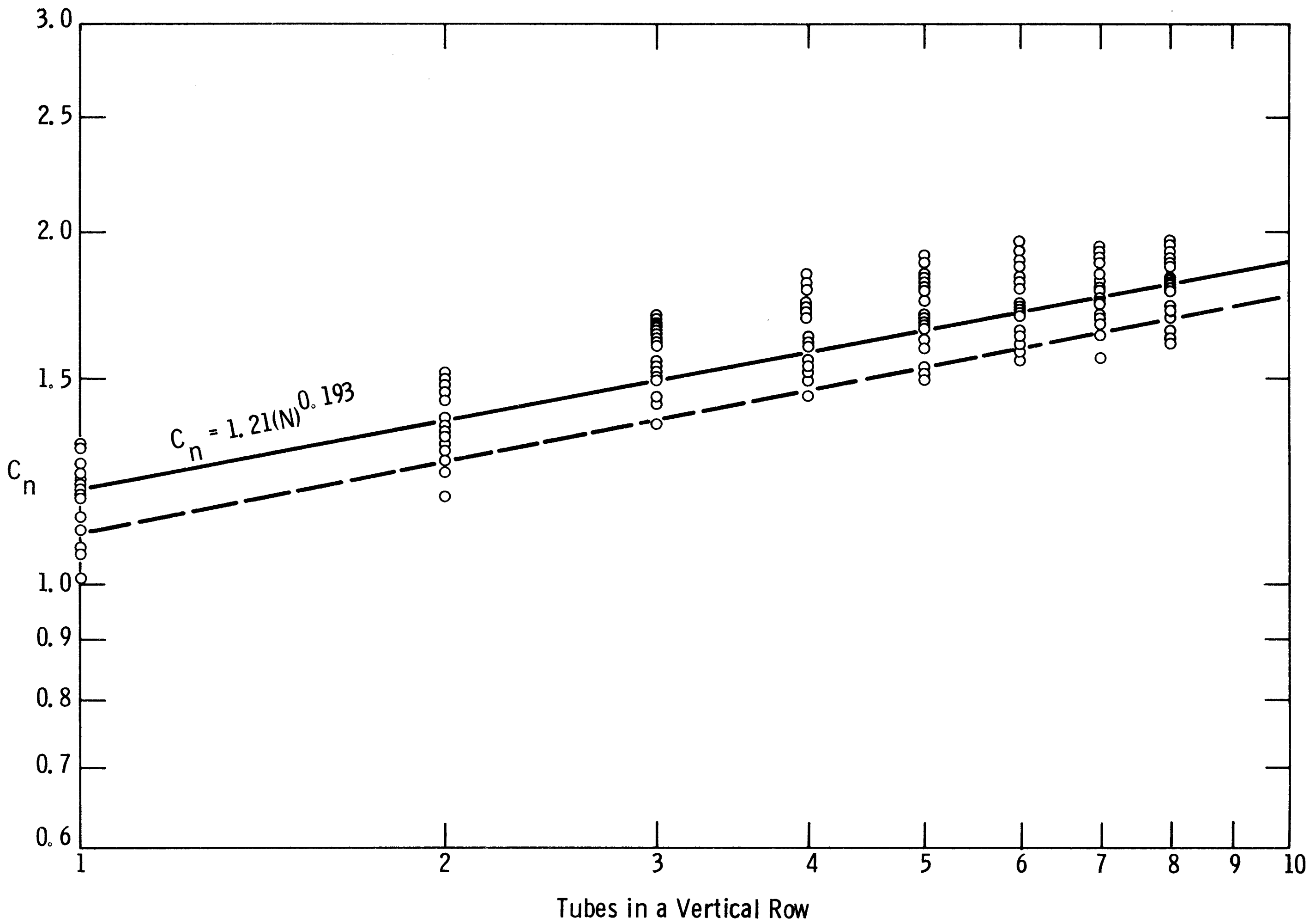


Figure 31. Summary of the Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 101°F on 1 to 8 Corrugated 5/8-inch O.D., Schedule 20, Copper Tubes in a Vertical Row.

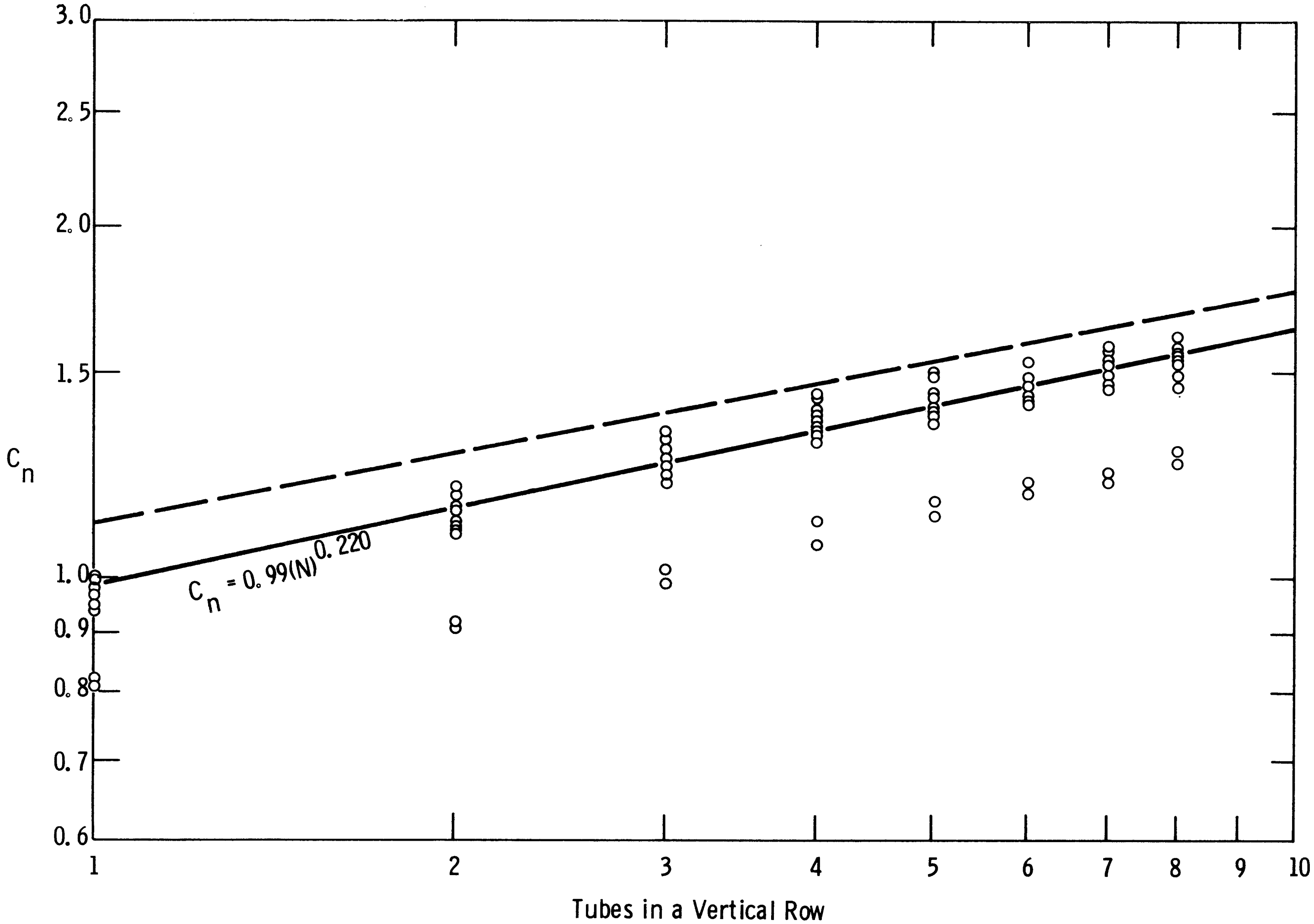


Figure 32. Summary of the Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 8 Corrugated 5/8-inch O.D., Schedule 20, Copper Tubes in a Vertical Row.

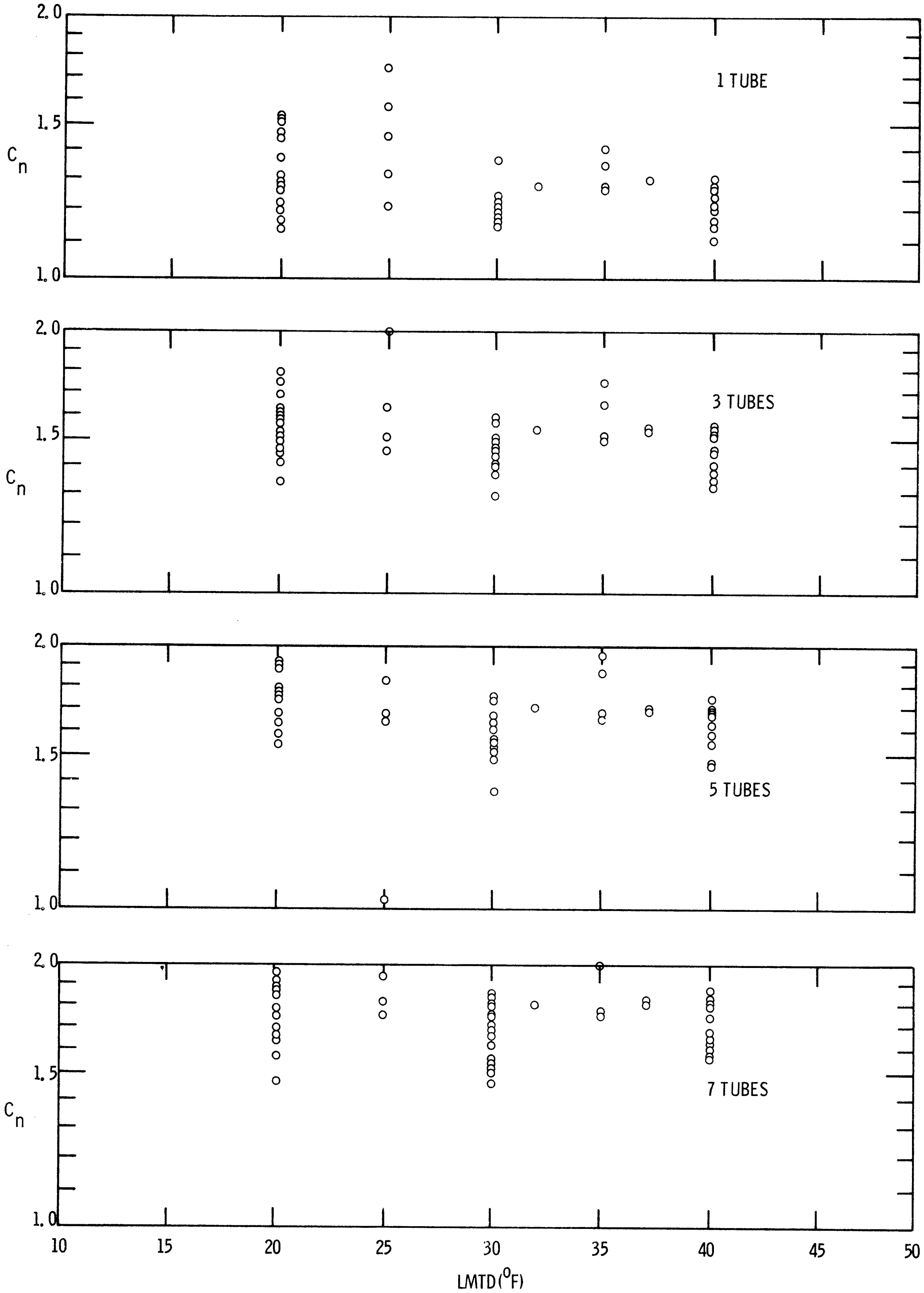


Figure 33. Summary of the Condensing Coefficient Correction Factors, C_n, for a Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1, 3, 5, and 7 Corrugated 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row, Indicating No Significant Effect of LMTD on the Values of C_n.

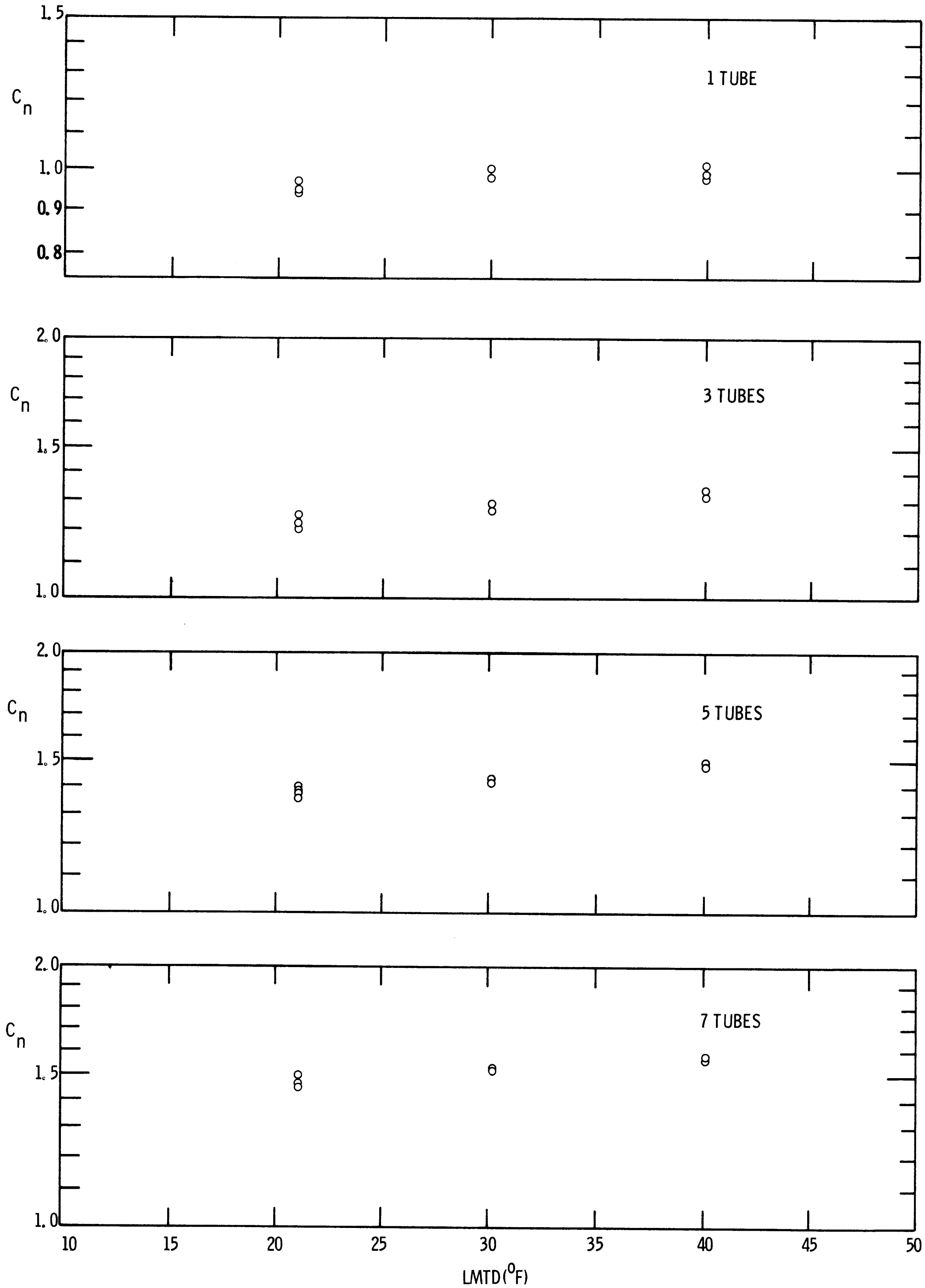


Figure 34. Summary of the Condensing Coefficient Correction Factors, C_n, for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1, 3, 5, and 7 Corrugated 5/8-inch O.D., Schedule 20, Copper Tubes in a Vertical Row, Indicating No Significant Effect of LMTD on the Values of C_n.

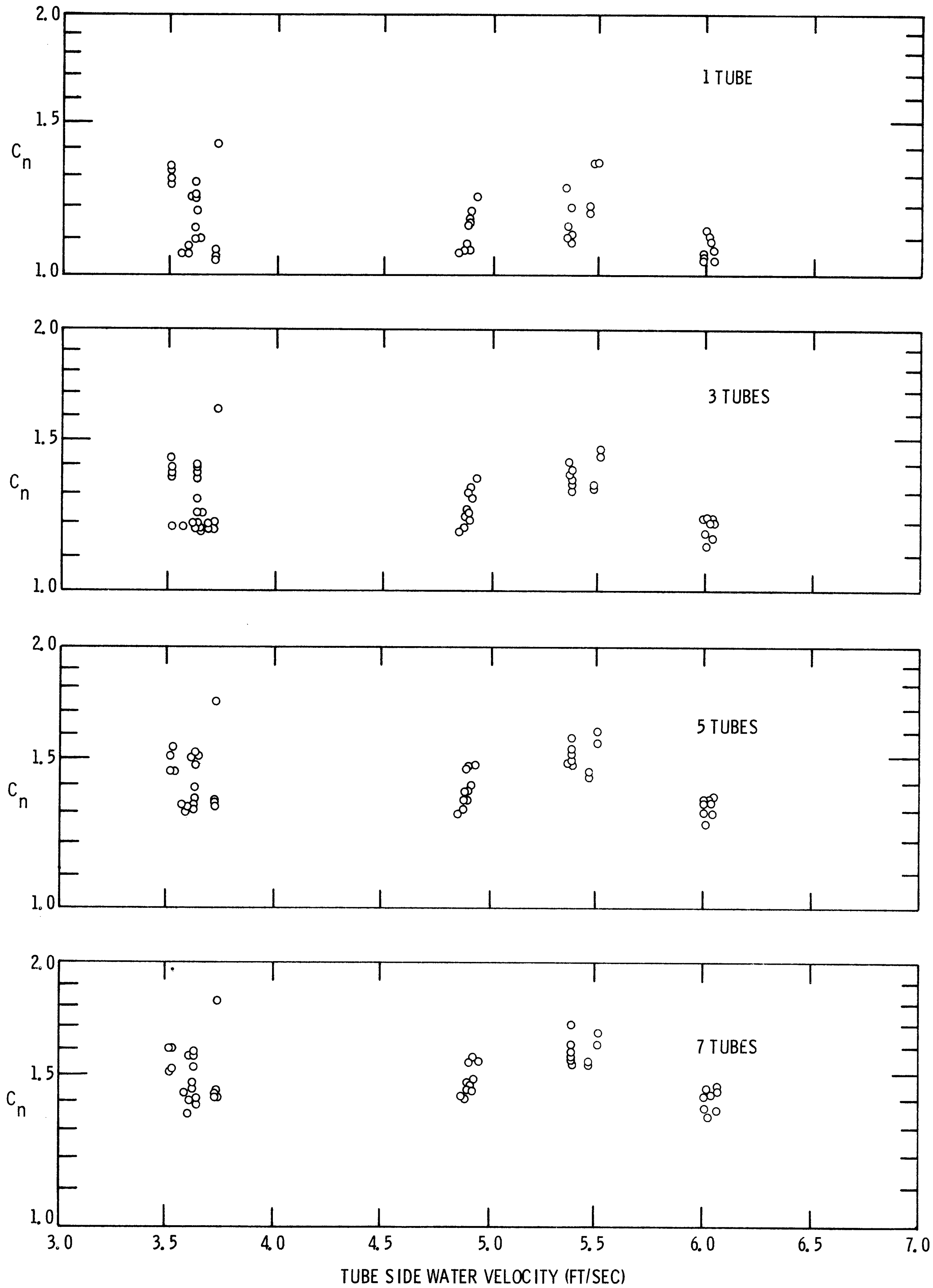


Figure 35. Summary of the Condensing Coefficient Correction Factors as a Function of Velocity for Condensation of Steam at 212°F on 1, 3, 5, and 7 Bare 1-inch O.D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

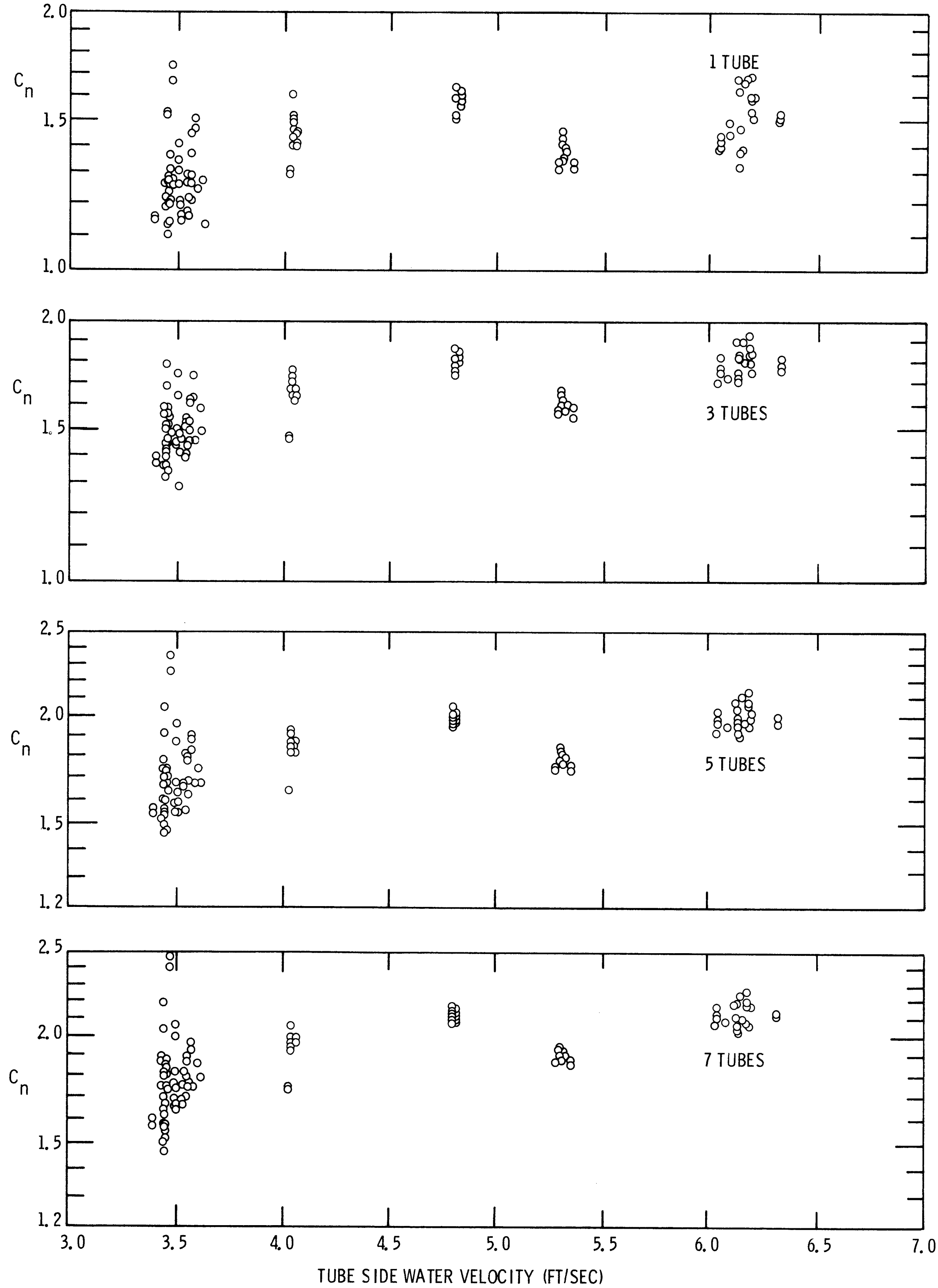


Figure 36. Summary of the Condensing Coefficient Correction Factors as a Function of Velocity for Condensation of Steam at 212°F on 1, 3, 5, and 7 Corrugated 1-inch O. D., Schedule 18, 90-10 Cupro-Nickel Tubes in a Vertical Row.

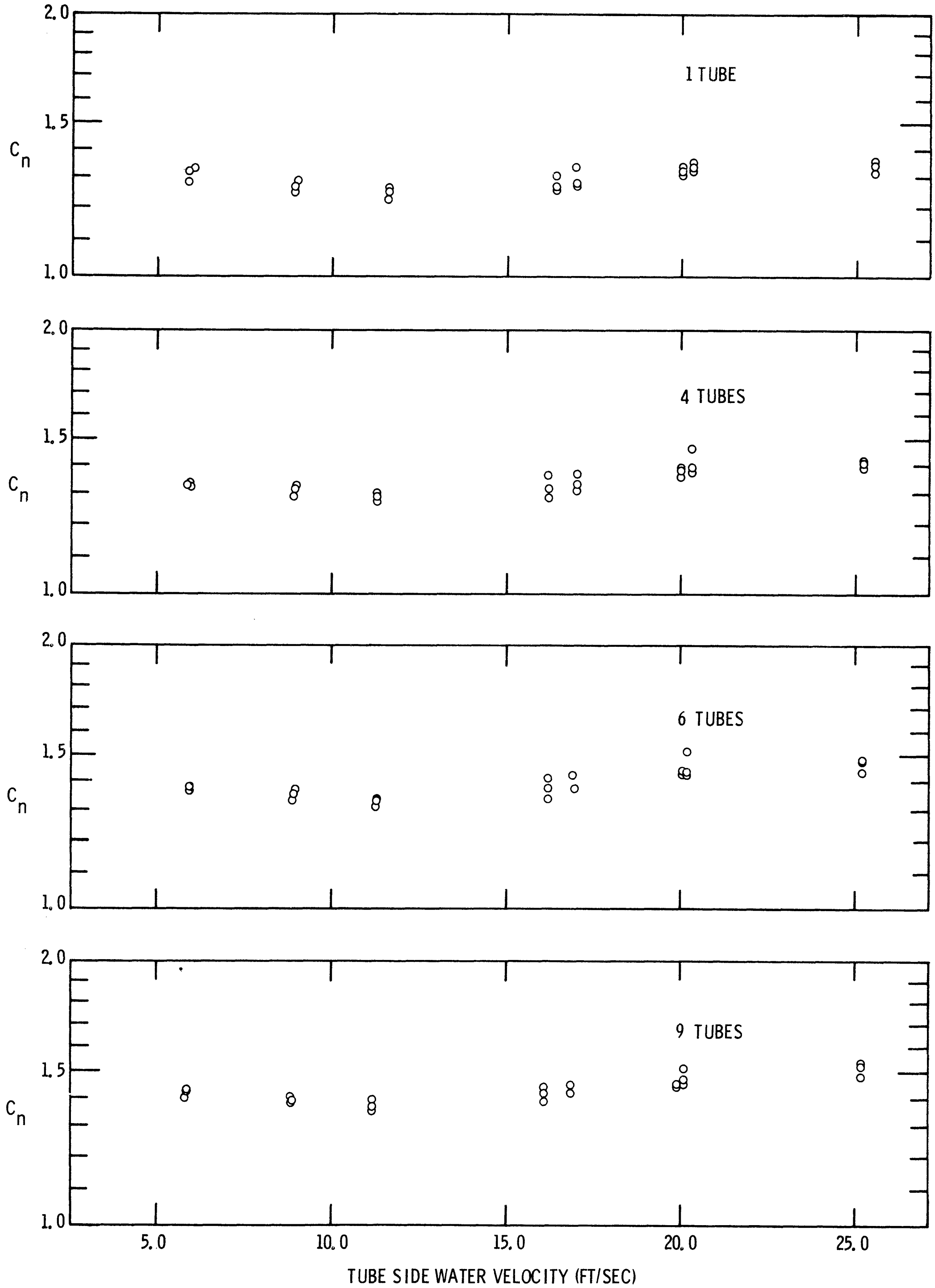


Figure 37. Summary of the Condensing Coefficient Correction Factors as a Function of Velocity for Condensation of Steam at 101°F on 1, 4, 6, and 9 Bare 5/8-inch O.D., Schedule 20, Copper Tubes in a Vertical Row.

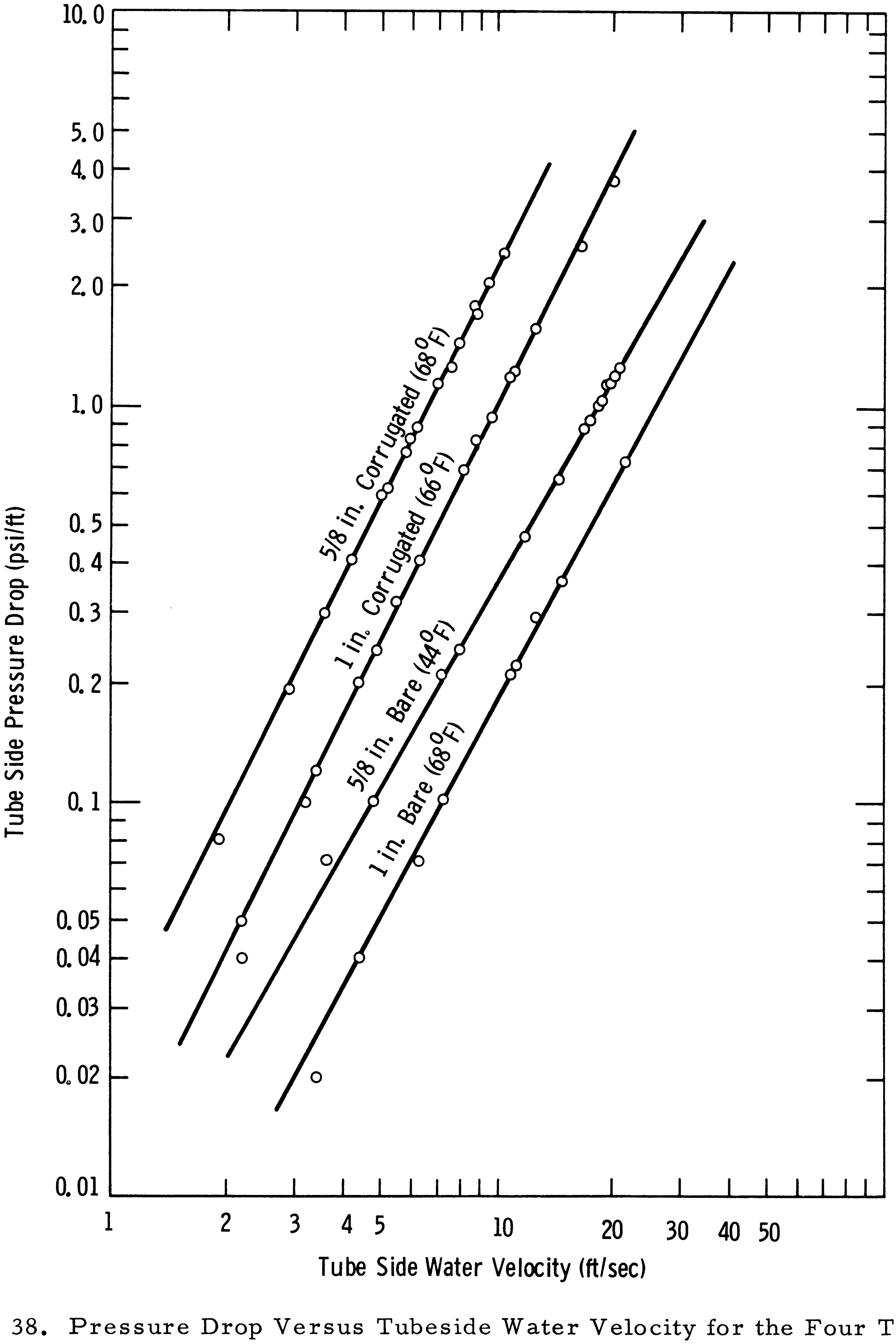


Figure 38. Pressure Drop Versus Tubeside Water Velocity for the Four Tubes Studied in This Investigation.

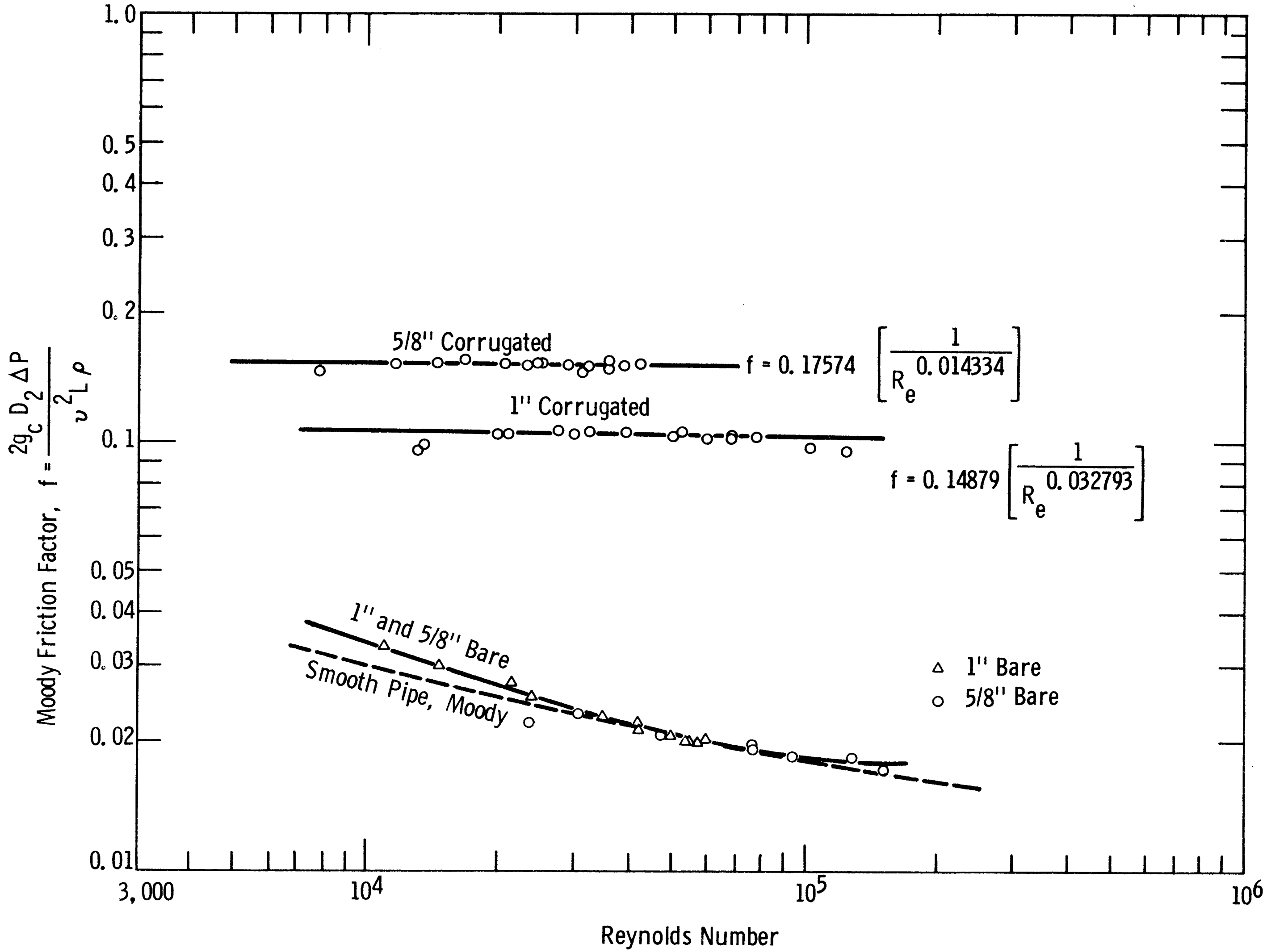


Figure 39. Moody Friction Factor Plot from the Tubeside Pressure Drop Data Appearing in Figure 38.

APPENDICES

APPENDIX I

Reprint of Paper Published in the AIChE Journal in January 1966,
"The Condensing of Low Pressure Steam on
Vertical Rows of Horizontal Copper and Titanium Tubes"

The Condensing of Low Pressure Steam on Vertical Rows of Horizontal Copper and Titanium Tubes

EDWIN H. YOUNG and DALE E. BRIGGS

University of Michigan, Ann Arbor, Michigan

Heat transfer data are presented for condensing steam at 2 in. Hg absolute pressure on the outside of nine copper and nine titanium horizontal tubes in a vertical row. The condensing coefficient correction factor was maximum for the top titanium tube and was 46% 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% higher than the correction factor for copper tubes with six to nine tubes in a vertical row.

The use of titanium tubes for steam condensation in shipboard power plants and in saline water conversion processes is currently of significant interest. The low wettability surface characteristics of titanium tubes tend to give higher condensing coefficients and the high mechanical strength permits the use of thinner tube walls when compared to conventional materials. Favorable erosion and corrosion resistance properties of titanium further add to the benefits of using titanium tubes.

REVIEW OF THE LITERATURE

In 1916, Nusselt (*1*) derived the equation governing the condensation of pure saturated vapors on the outside of a horizontal tube with a wettable surface. Equation (1) was obtained by assuming laminar flow of the condensate and no vapor velocity effects:

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

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

$$t_f = t_{sv} - \frac{3}{4} \Delta t_f \tag{2}$$

Experimental investigations of the condensation of pure saturated vapors on single horizontal tubes indicate that Equation (1) predicts values generally within ± 10% of the experimental condensing coefficients (*2*). The experimental coefficients are usually higher than the theoretical values. This is attributable to turbulence or rippling in the condensate layer. When turbulent flow of the condensate is expected, the average film temperature is often evaluated with Equation (3) (*3*).

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

When several horizontal tubes are placed in a vertical row so that condensate from the upper tubes drops on 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, Nusselt derived Equation (4) to predict the average condensing coefficient h_m for n tubes located in a vertical row (*1*).

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

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 (*4*), Short and Brown (*5*), and Young and Wohlenberg (*6*) 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 Balenkjian (*3*) to give Equation (5).

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

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 (*3*). The correction factor C_n varies with the number of tubes in a vertical row, the physical properties of the condensate, the tube surface, and the vapor velocity.

An extensive experimental program was 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 can be used 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 twenty-two 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 fourteenth or fifteenth tube.

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

The existence of any noncondensible gas in the condensing vapor significantly reduces the rate of heat transfer due to the buildup of noncondensible gas around the condensing surface. Experimental work by Othmer (8) and Hampson (9) indicates that as little as 1.5% air by volume can reduce the condensing coefficient by 50%. The greatest effect occurs when there is little motion of vapor across the tubes. Under these conditions, most of the noncondensible gases eventually migrate to the vicinity of the tube.

EQUIPMENT AND TEST PROCEDURE

The equipment in this investigation consisted of a condenser, inlet and outlet water headers, reboiler, make-up tank, water preheater, pump, two-stage steam jet ejector, and automatic controllers. Figure 1 is a line diagram showing the flow of steam and water. Steam was generated by boiling distilled water in the reboiler with 150 lb./sq. in. gauge steam. The vapor flowed to the condenser where it condensed on the test tubes. The condensate was returned to the reboiler. Water from the cooling tower system was used as the coolant.

The condenser was 6 ft. long and 18 in. in diameter. O rings were used to seal the tubes in the tube sheets to permit changing. An impingement baffle was placed over and 2 in. above the tubes in the condenser to prevent direct impingement of steam onto the tubes.

The reboiler was 6 ft. long and 24 in. in diameter. High pressure steam (150 lb./sq. in. gauge) was used to vaporize the water in the reboiler. The condensate was returned to the high pressure boiler through a steam trap.

Four automatic controllers were installed to assist in the operation of the equipment when taking data. One instrument controlled the water flow rate. A second instrument served as an inlet cooling water temperature 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

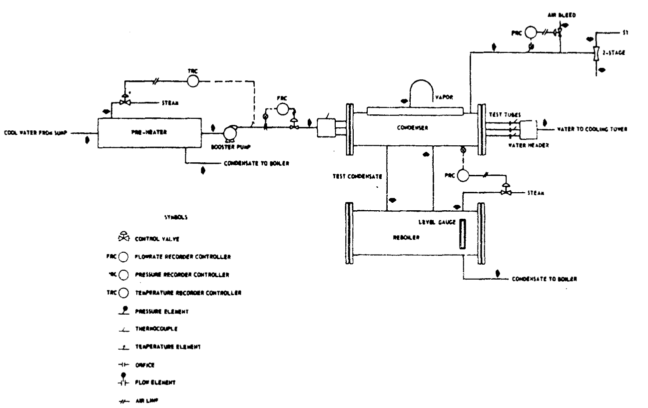


Fig. 1. Line diagram of equipment showing the flow of steam and water.

used the pressure signal to regulate the amount of steam entering the reboiler through a ¾ in. 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. The orifices were calibrated for each tube tested. The pressure drop across the orifices was measured with water over mercury manometers. Both 50- and 100-in. 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 ¼ and ½%.

Inlet water, outlet water, and condenser steam temperatures were measured with calibrated 30 gauge copper-constantan thermocouples with 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 within stainless steel sheaths extended upstream along the tube axis for 1 in. 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.

During normal operation, the reboiler was one-half to two-thirds 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 to 45 min. to evacuate thoroughly noncondensible 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 to 30 min. 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 noncondensible gases during the period when data were taken. There was a very small amount of air leakage into the system. Before data were taken, the saturated steam temperature was calculated on the basis of the absolute pressure indicated by the manometer and compared to the steam temperature measured with a thermocouple. If the two temperatures agreed within ½°F., the system was considered ready for taking data. If the temperature calculated from the absolute pressure in the condenser was greater than ½°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.

MULTIPLE TUBE DATA PROCESSING AND RESULTS

The overall heat transfer coefficient for each tube was calculated from

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

where the heat duty Q was obtained experimentally from

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

TABLE 1. TUBE DIMENSIONS AND CHARACTERISTICS

	Copper		Titanium	
	Top tube	Average for vertical row	Top tube	Average for vertical row
Tube type	plain	plain	plain	plain
Tube O. D., in.	0.6252	0.6252	0.6287	0.6271
Tube I. D., 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, B.t.u./(hr.) (sq. ft.)(°F.)/ft.	196	196	10	10

A modified Wilson plot technique (*10*) was used to obtain a realistic value of the coefficient in Equation (8) for the particular experimental equipment used in the investigation. This was done in preference to using an arbitrary value from the technical literature. The modified Wilson plot technique took into account the variation in the average temperature drop across the condensing film with changes in water velocity. It did not take into account the variation of the temperature drop across the condensing film from one end of a tube to the other end. The intent of the investigation was to look at the average condensing heat transfer coefficients with titanium and copper tubes. Wilson plot data were obtained on the top tube in the vertical row for each alloy tube. The tube dimensions are given in Table 1. With the use of the average value of C_i for the two sets of data, the inside heat transfer coefficient became

$$\frac{h_i D_i}{k_i} = 0.0248 \left[\frac{D_i G}{\mu}\right]^{0.8} \left[\frac{c_p \mu}{k}\right]^{1/3} \left[\frac{\mu_i}{\mu_w}\right]^{0.14} \tag{8}$$

The condensing coefficient and the condensing coefficient constant were calculated with Equations (9) and (10), respectively, for all the Wilson plot data.

$$\frac{1}{h_m} = \frac{1}{U_o} - \frac{A_o}{A_i h_i} - r_m \tag{9}$$

From Equation (5) with $n = 1$ for the top tube

$$C = \frac{h_m}{\left[\dfrac{k^3 \rho^2 g \lambda}{\mu D \Delta t_f}\right]^{1/4}} \tag{10}$$

Two sets of heat transfer data were taken on the nine tubes in a vertical row. The first set of data were taken on copper tubes and the second set of titanium tubes. The original data appear in reference *10*.

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 for the condensation of steam at 2 in. Hg absolute pressure. 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 constant, were read into the computer and preliminary calculations were 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 coefficient, and condensing coefficient from Equation (9). From the condensing coefficient and physical properties of the condensate film, the condensing coefficient constant was calculated from Equation (10). The average inlet water temperature, water velocity, and steam temperature for all nine tubes were also calculated. A printout 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 printout 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 (11):

$$C_n = \frac{h_m}{0.725 \left[\dfrac{k^3 \rho^2 g \lambda}{n \mu D \Delta t_f}\right]^{1/4}} \tag{11}$$

In Equation (11), 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 with 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 (9). Equation (12) was used to calculate the temperature drop across the condensing film

$$\Delta t_f = \frac{U_o \Delta t_m}{h_m} \tag{12}$$

and Equation (3) was used to calculate the film temperature. Once the film temperature was known, the quantity with $n = 1$

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

was calculated and C_n computed from Equation (11) 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 of the computer program for the top two rows were added to give the total heat transferred. With the mean values of the water density and heat capacity for the top two tubes, we calculated the average exit water temperature for the top two tubes. The logarithmic temperature difference, overall heat transfer coefficient, and inside heat transfer coefficient were calculated next and the mean condensing coefficient was calculated from Equation (9), the temperature drop across the condensing film was calculated from Equation (12), and the film temperature was 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 was calculated from Equation (11). 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 by following the procedure previously outlined.

The computer program and typical calculated results can be found in reference *10*.

DISCUSSION OF RESULTS

Tables 2* and 3 give the values of the condensing coefficient correction factors for a vertical row of one to nine copper and titanium tubes, respectively. The results were obtained from experimental data taken at a steam pressure of approximately 2 in. Hg absolute and an inlet water temperature of 75°F. Average values of C_n for each water velocity are given in Tables 4 and 5 for copper and titanium tubes, respectively. The results are also presented in Figures 2 and 3. 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 4 for copper tubes and Table 5 for titanium tubes.

As can be seen in Figures 2 and 3, the condensing coefficient correction factor C_n is 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% 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% greater with six to nine 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 2 and 3, 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 is attributable in part to the varying degrees of turbulence in the condensate film depending upon the tube condensate flow rate, as previously mentioned. The maximum deviations from the mean values in Figures 2 and 3 are 5.3 and 6.3%, 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.

* Tables 2 through 5 have been deposited as document 8560 with the American Documentation Institute, Photoduplication Service, Library of Congress, Washington 25, D. C., and may be obtained for $1.25 for photoprints or 35-mm. microfilm.

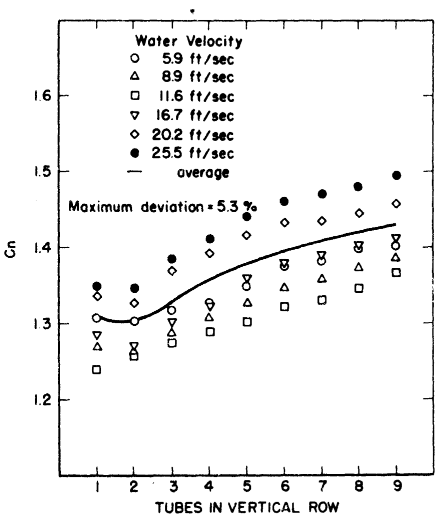


Fig. 2. Condensing coefficient correction factors for condensation of steam at 2 in. Hg absolute pressure on one to nine copper tubes in a vertical row.

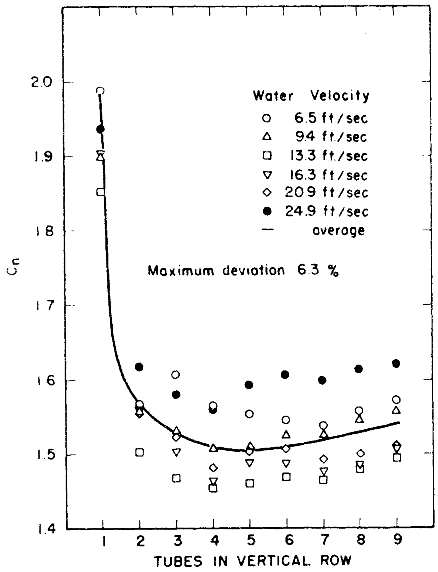


Fig. 3. Condensing coefficient correction factors for condensation of steam at 2 in. Hg absolute pressure on one to nine titanium tubes in a vertical row.

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NOTATION

A_i = total internal heat transfer surface, sq. ft.
A_o = total external heat transfer area, sq. ft.
C = condensing coefficient constant which is equivalent to 0.725 C_n, dimensionless
C_i = inside heat transfer coefficient constant, dimensionless
C_n = turbulence correction factor, dimensionless
c_p = specific heat of water, B.t.u./(lb.)(°F.)
D = outside diameter of tube, ft.
D_i = tube inside diameter, ft.
G = mass flow rate, lb./(hr.)(sq. ft.)
g = acceleration due to gravity, taken as 4.17×10^8 ft./hr.^{2}
h_i = inside heat transfer coefficient, B.t.u./(hr.)(sq. ft.)(°F.)
h_m = mean condensing coefficient, B.t.u./(hr.)(sq. ft.)(°F.)
k = thermal conductivity of condensate evaluated at film temperature, B.t.u./(hr.)(sq. ft.)(°F.)/ft.
k_i = water thermal conductivity at bulk water temperature, B.t.u./(hr.)(sq. ft.)(°F.)/ft.
n = number of tubes in a vertical row
Q = total heat transfer, B.t.u./hr.
r_m = metal resistance, hr./sq. ft. (outside area) °F./B.t.u.
t_{in} = inlet water temperature, °F.
t_f = average condensing film temperature, °F.
t_{out} = outlet water temperature, °F.
t_s = outside wall temperature of the tube, °F.
t_{sv} = temperature of the saturated vapor, °F.
U_o = overall heat transfer coefficient, B.t.u./(hr.)(sq. ft.)(°F.)
W = water flow rate, lb./hr.

Greek Letters

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

ΔT_m = logarithm temperature difference, °F.
λ = latent heat at saturation temperature, B.t.u./lb.
μ_b = water viscosity at bulk water temperature, lb./(ft.)(hr.)
μ = viscosity of condensate evaluated at film temperature, lb./(ft.)(hr.)
μ_w = water viscosity at average inside wall temperature, lb./(ft.)(hr.)
ρ = density of condensate evaluated at film temperature, lb./cu. ft.

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APPENDIX II

Copy of AIChE Preprint 5
"Modified Wilson Plot Techniques for Obtaining
Heat Transfer Correlations for Shell-and-Tube Heat Exchangers"
and
Computer Program and Nomenclature
Used by Wolverine Tube to Determine
The Seider-Tate Inside Heat Transfer Coefficient Constant in Equation 9

MODIFIED WILSON PLOT TECHNIQUES FOR OBTAINING HEAT TRANSFER CORRELATIONS FOR SHELL-AND-TUBE HEAT EXCHANGERS

AIChE
PREPRINT 5

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The University of Michigan, Ann Arbor, Michigan

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INTRODUCTION

The separation of individual heat transfer resistances from the overall heat transfer resistance of the system is extremely important in obtaining heat transfer correlations for forced convection, condensation, and boiling. To develop shell-side heat transfer correlations for concentric pipe and shell-and-tube heat exchangers, accurate shell-side heat transfer coefficients are needed. Accurate condensation and boiling heat transfer coefficients are required to obtain correlations suitable for design purposes.

Local heat transfer coefficients can be found by direct measurement of the temperature drop across a convective or condensate film by using thermocouples located in the wall of the tube and in the bulk stream. This method works well for single resistance heated tubes for which thermocouples can be attached to the tube wall without disturbing the fluid flow in the vicinity of the thermocouple. The accuracy of the process is directly related to the temperature drop across the heat transfer film.

In the design of heat transfer equipment, overall convective film, condensing, or boiling coefficients are usually preferred to local coefficients. Although local coefficients can be suitably integrated over the tube length to give the average film coefficient for the whole tube, i.e., as with a boiling refrigerant inside a tube, this cannot be conveniently done for many systems and configurations. The large number of tubes and the baffle arrangement in shell-and-tube heat exchangers makes it impossible to put a sufficient number of thermocouples inside the shell without seriously affecting the flow of the shell-side fluid.

A useful technique for determining individual resistances from an overall resistance was devised by Wilson[1] in 1915. Wilson was interested in determining the effects of water temperature and velocity on the overall coefficient for a steam condenser. Wilson's technique was used by Katz and Geist[2] in 1948 to obtain condensing coefficients for six finned

tubes in a vertical row. The technique was used by Knudsen and Katz[3] in 1950 to develop tube-side and shell-side heat transfer coefficient correlations for concentric pipe heat exchangers. In 1952, Williams and Katz[4] used the same procedure to evaluate tube-side and shell-side heat transfer coefficient correlations for shell-and-tube heat exchangers. In 1957, Young and Wall[5] modified the procedure and obtained shell-side and tube-side heat transfer correlations for concentric pipe heat exchangers.

EXISTING WILSON PLOT PROCEDURE FOR NO PHASE CHANGES

In the method used by Young and Wall[6,7] for finned tubes, the fin-resistance procedure was employed. Their modification involved the use of the Sieder and Tate equation[8] for the outside and inside heat transfer coefficients:

$$\frac{h'_o D_{eq}}{k_o} = C_o \left(\frac{D_{eq} G}{\mu}\right)_o^{0.8} \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14} \tag{1}$$

and

$$\frac{h_i D_i}{k_i} = C_i \left(\frac{D_i G}{\mu}\right)_i^{0.8} \left(\frac{c_p \mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14} \tag{2}$$

Equations (1) and (2) were solved for h'_o and h_i, respectively, and were substituted into the following overall heat transfer relationship:

$$\frac{1}{U_o} = \frac{1}{h'_o} + r_{fin} + r_m + \frac{1}{h_i}\frac{A_o}{A_i} \tag{3}$$

The substitutions give:

$$\left(\frac{1}{U_o} - r_{fin} - r_m\right) = \frac{1}{C_o \frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^{0.8} \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}} + \frac{A_o}{A_i C_i \frac{k_i}{D_i} \left(\frac{D_i G}{\mu}\right)_i^{0.8} \left(\frac{c_p \mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14}} \quad (4)$$

If the tube-side fluid flow rate varies, the viscosity ratios will vary even if the bulk fluid temperature and the shell-side flow rates are held constant. In order to make the expression for the outside heat transfer coefficient constant, it is necessary to multiply Equation (4) by the expression $\left(\frac{\mu}{\mu_w}\right)_o^{0.14}$. This substitution gives

$$\left(\frac{1}{U_o} - r_{fin} - r_m\right)\left(\frac{\mu}{\mu_w}\right)_o^{0.14} = \frac{1}{C_o \frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^{0.8} \left(\frac{c_p \mu}{k}\right)_o^{1/3}} + \frac{\frac{A_o}{A_i}\left(\frac{\mu}{\mu_w}\right)_o^{0.14}}{C_i \frac{k_i}{D_i} \left(\frac{D_i G}{\mu}\right)_i^{0.8} \left(\frac{c_p \mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14}} \quad (5)$$

In using this procedure, tube-side Wilson plot data are obtained by maintaining the shell-side bulk temperature and flow rate constant while collecting field test data at several different tube-side fluid flow rates. For these conditions, Equation (5) has the mathematical form:

$$y = mx + b \quad (6)$$

where:

$$y = \left(\frac{1}{U_o} - r_{fin} - r_m\right)\left(\frac{\mu}{\mu_w}\right)_o^{0.14} \quad (7)$$

$$m = \frac{1}{C_i} \quad (8)$$

$$x = \frac{\frac{A_o}{A_i}\left(\frac{\mu}{\mu_w}\right)_o^{0.14}}{\frac{k_i}{D_i} \left(\frac{D_i G}{\mu}\right)_i^{0.8} \left(\frac{c_p \mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14}} \quad (9)$$

and the intercept:

$$b = \frac{1}{C_o \frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^{0.8} \left(\frac{c_p \mu}{k}\right)_o^{1/3}} \quad (10)$$

Tube-side Wilson plot results are obtained by a linear regression of the function y on x. The reciprocal of the slope of the least squared deviation line through the data is equal to the inside heat transfer coefficient correlation constant, C_i. The value of the outside heat transfer coefficient correlation constant, C_o, can be calculated from Equation (10).

The above procedure of Young and Wall was applied to the test data of Williams and Katz[4,9]. In the technique, an initial estimate of the constant, C_i, for Equation (2) is made in order to determine the wall temperatures from the experimental data. The Wilson plot functions are calculated and the slope of the least squared deviation line through the data determined. The reciprocal of the slope of the line is equal to the calculated value of C_i. If the assumed and calculated values of C_i differ by more than some allowable error, a re-estimated value is taken as the assumed value and the procedure repeated. Convergence of the assumed and calculated values of C_i to within 0.05 percent is usually obtained within 4 or 5 trials. Figure 1 presents Wilson plot results typical of this method for the data. The data were processed with an IBM 7090 digital computer. The linear regression of y on x was effected with a subroutine. Calculated values of C_i for Equation (2) are given in Table I.

TABLE I

Calculated Values of the Inside Heat Transfer Correlation Constant Obtained by the Wilson Plot Method as Modified by Young and Wall for Data Taken on a 6-inch Heat Exchanger with Water on the Shell-and-Tube Sides

Runs	C_i
24A-24D	0.02665
25A-25D	0.02431
26A-26D	0.02540
27A-27D	0.02558
28A-28D	0.02508
Average	0.02540

Shell-side heat transfer correlations can be obtained in several ways. The constant, C_o, for Equation (1) can be evaluated from the value of the intercept found in the tube-side regression analysis, but there is no guarantee that the resulting correlation will be valid over a wide range of Reynolds numbers without calculating C_o from the intercept values for several sets of tube-side Wilson plot data each with a different shell-side flow rate. The values of C_o for each set of data should be averaged to give the correlation expressed by Equation (1). If the tube-side correlation is established by a Wilson plot method, a shell-side correlation can be devised by taking data at several different shell-side flow rates, evaluating the shell-side coefficient from Equation (3) and plotting the function y_{shell} versus x_{shell}:

$$y_{shell} = \ln \left[\frac{\frac{(h_o' D_{eq})}{k_o}}{\left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}} \right] \tag{11}$$

$$x_{shell} = \ln \left[\left(\frac{D_{eq} G}{\mu}\right) \right]_o \tag{12}$$

The slope, P, of the least squared deviation line through the processed data $\left[y_{shell}, x_{shell}\right]$ is equal to the exponent of the Reynolds number and the exponential of the intercept (where Re = 1) is equal to the shell-side correlation constant, C_o, in Equation (13):

$$\frac{h'_o D_{eq}}{k_o} = C_o \left(\frac{D_{eq} G}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14} \qquad (13)$$

The value of the exponent P varies from about 0.6 at low Reynolds numbers ($Re < 1000$) to approximately 0.9 at high Reynolds numbers ($Re > 10,000$). This is evident on j-factor plots covering a wide range of Reynolds numbers[10]. Shell-side correlations can also be obtained by taking heat transfer data with a constant bulk fluid temperature on the tube-side and making shell-side Wilson plot calculations. In this instance, Equation (4) is multiplied by $\left(\frac{\mu}{\mu_w}\right)_i^{0.14}$, and the procedure outlined in the tube-side Wilson plots technique is followed. The shell-side Reynolds number exponent, 0.8, in Equation (4) could be replaced, but the best value to use is seldom known <u>a priori.</u>

MODIFIED WILSON PLOT TECHNIQUE FOR NO PHASE CHANGES

There are two distinct disadvantages to the traditional Wilson plot techniques and the modified technique of Young and Wall. Firstly, the data are troublesome to obtain because of the constant flow rate and constant average bulk fluid temperature requirements. Secondly, a considerable number of data are required for accurate tube- and shell-side heat transfer correlations. It would be very desirable to have available a type of regression analysis procedure which could determine the values of the constants C_i, C_o, and P in Equation (14) in a least square deviation sense while obviating the disadvantages of the traditional Wilson plot procedures.

$$\left(\frac{1}{U_o} - r_{fin} - r_m\right) = \frac{1}{C_o \frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}} + \frac{A_o}{A_i C_i \frac{k_i}{D_i} \left(\frac{D_i G}{\mu}\right)_i^{0.8} \left(\frac{c_p \mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14}} \qquad (14)$$

Upon examination of Equation (14) it is obvious that a linear regression analysis scheme is impossible except for plain tubes under conditions where the group $(\mu/\mu_w)^{0.14}$ is essentially unity and where the value of P is known. For finned tubes, the shell-side coefficient must be known to evaluate the fin resistance. If the viscosity ratio groups and the shell-side Reynolds number exponent are to be included in addition to relaxing the flow rate and fluid temperature conditions, a non-linear regression analysis procedure must be used.

A non-linear regression analysis can be effected by using successive linear regressions in a trial and error procedure. Multiplying Equation (14) by

$$\frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}$$

gives

$$\left(\frac{1}{U_o} - r_{fin} - r_m\right)\left[\frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}\right] = \frac{1}{C_o} + \frac{\frac{A_o}{A_i}\left[\frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}\right]}{C_i \left[\frac{k_i}{D_i} \left(\frac{D_i G}{\mu}\right)_i^{0.8} \left(\frac{c_p \mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14}\right]} \qquad (15)$$

which again is of the form

$$y = mx + b \qquad (6)$$

where

$$y = \left(\frac{1}{U_o} - r_{fin} - r_m\right)\left[\frac{k_o}{D_{eq}}\left(\frac{D_{eq}G}{\mu}\right)_o^P \left(\frac{c_p\mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}\right] \tag{16}$$

$$m = \frac{1}{C_i} \tag{8}$$

$$x = \frac{\frac{A_o}{A_i}\left[\frac{k_o}{D_{eq}}\left(\frac{D_{eq}G}{\mu}\right)_o^P \left(\frac{c_p\mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}\right]}{\left[\frac{k_i}{D_i}\left(\frac{D_iG}{\mu}\right)_i^{0.8} \left(\frac{c_p\mu}{k}\right)_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_i^{0.14}\right]} \tag{17}$$

and

$$b = \frac{1}{C_o} \tag{18}$$

As indicated by Mickley, Sherwood, and Reed[11], the transformation of Equation (14) into Equation (15) is mathematically permissible and although it may appear to give an improved or inferior correlation of the data when plotted, the correlation is in fact unaltered. The advantage of such a transformation is that it puts Equation (15) into a form suitable for effecting a linear regression of y on x giving the least square values of m and b or of more importance, their reciprocals, C_i and C_o, respectively.

The evaluation of the functions y and x requires an initial estimate of P and C_i. The constant C_i is used to calculate an estimated

value of the inside heat transfer coefficient and subsequently the wall temperatures and the viscosity ratio functions. If the least squared deviation value of C_i obtained by the linear regression differs from the assumed value by more than some allowable error, C_i is re-estimated and the calculations repeated until satisfactory agreement between the assumed and calculated values is attained. The shell-side coefficient for each run is calculated using Equation (3) and the functions y_{shell} and x_{shell} calculated. A linear regression of y_{shell} on x_{shell} gives the least squared deviation values of P and C_o. If the calculated value of P differs from the assumed value of P by more than the specified maximum amount, P is re-estimated and all the calculations repeated until satisfactory agreement between the assumed and calculated values is reached. The values of C_o obtained from the two linear regression analyses should agree closely.

The non-linear regression procedure can be considered as being a further modification of the original Wilson plot procedure in which the equations are transformed into a form suitable for a linear regression analysis. Figures 2 and 3 give the linear regression analysis results for the data presented in Figure 1. Figure 2 indicates that all the experimental data in Figure 1 can be correlated together giving a greater statistical meaning to the results. Figure 3 presents the shell-side correlation obtained in the process of evaluating the inside heat transfer coefficient constant. The heat transfer correlations for the finned tube heat exchanger with water on both sides become

$$Nu_i = 0.02589\, Re_i^{0.8}\, Pr_i^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14} \tag{19}$$

and

$$Nu_o = 0.01809\, Re_o^{0.9389}\, Pr_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14} \tag{20}$$

Agreement between the assumed and calculated values of C_i and P were within 0.05 and 0.1 percent, respectively. The values of the shell-side correlation constant calculated from the intercept values of Figures 2 and 3 agreed within 0.5 percent.

Wilson plot data for oil and glycerine on the shell-side of Bundle 6 of Reference (4) were also analyzed. The results obtained by the two methods are given in Tables II and III. As the shell-side resistance is controlling with oil and glycerine on the shell-side, it is difficult to obtain good tube-side Wilson plot results with only 4 data points. By correlating all the data for a particular shell-side fluid together as shown in Figures 4 and 5 significantly better results are obtained. The calculated value of the constant, C_i, for oil on the shell-side agreed with the value obtained for water on the shell-side and the value of C_i for glycerine on the shell-side agreed within 6 percent. Figures 6 and 7 give shell-side correlations for oil and glycerine, respectively. These correlations were obtained in the process of effecting the linear regression analysis for P. As can be seen from Figures 6 and 7, there is very good agreement between the two correlations as there should be. Figure 8 presents the results given in Figures 3, 6 and 7.

Whenever heat transfer data taken over a wide range of shell-side Reynolds numbers, i.e., 10-100,000, are correlated together, Equation (13) is no longer a satisfactory correlating equation for the shell-side coefficient since the power to which the Reynolds number should be raised to represent the data changes with Reynolds numbers as is evident in Figure 8 and on most j-factor plots[10]. Equation (13) can be modified by making the Reynolds power a function of the Reynolds number as, for example, in

$$Nu_o = C_o Re_o^{(P + P1 \times \ell n\, Re_o)} Pr_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14} \qquad (21)$$

TABLE II

Calculated Values of the
Inside Heat Transfer Correlation Constant
Obtained by the Wilson Plot Technique Modified by Young and Wall
for Data Taken on a 6-Inch Diameter Heat Exchanger
with Water on the Tube-side

Shell-side Fluid	Run Numbers		C_i from Young and Wall Modification
Oil	32A-32D		0.01406
	33A-33D		0.01974
	34A-34D		0.01450
	35A-35D		0.01661
	36A-36D		0.02010
	37A-37D		0.02374
	38A-38D		0.02549
	72A-72D		0.01563
	73A-73D		0.01134
		Average	0.01801
Glycerine	81A-81D		0.02385
	87A-87D		0.01680
		Average	0.02032

TABLE III

Calculated Values of the
Inside Heat Transfer Correlation Constant
Obtained by the Wilson Plot Technique as Modified by Briggs
for Data Taken on a 6-Inch Diameter Heat Exchanger
with Water on the Tube-side

Shell-side Fluid	Run Numbers	C_i from Briggs Modification
Oil	32A-73D	0.02588
Glycerine	80, 81A-81D, 82-86, 87A-87D, 101, 103	0.02439

Equation (21) has been used to represent the shell-side heat transfer coefficient in the modified version of the Wilson plot technique with satisfactory results. The procedure parallels the method outlined. Other shell-side correlation models, such as proposed by Bell[10], can also be used with suitable adaptation.

MODIFIED WILSON PLOT TECHNIQUE FOR CONDENSATION

The Nusselt[12] expression for condensation on a single horizontal plain tube is

$$h_c = 0.725 \left[\frac{k_f^3 \rho_f^2 g\lambda}{\mu_f D \Delta t_f} \right]^{1/4} \tag{22}$$

Beatty[13] derived an expression for condensation on horizontal finned tubes using Equation (22) in which for finned tubes the diameter, D, is defined by

$$\left(\frac{1}{D} \right)^{1/4} = \frac{A_r}{A_{eq} D_r^{1/4}} + \frac{1.30\, \phi^{3/4} A_f}{A_{eq} L^{1/4}} \tag{23}$$

where

$$A_{eq} = A_r + \phi A_f \tag{24}$$

Equation (22) has been modified for multiple tube arrangements[14] and a turbulence correction factor[15], C_n, has been included to account for the system variance from Equation (22). These changes give for condensation on a multiple tube arrangement of plain or finned tubes,

$$h_o' = 0.725\, C_n \left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4} \tag{25}$$

Using Equations (2) and (25) to represent the inside and condensing heat transfer coefficients, respectively, and substituting the expressions for the coefficients into Equation (3) and rearranging gives

$$\left(\frac{1}{U_o} - r_{fin} - r_m \right) = \frac{1}{0.725\, C_n \left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4}} + \frac{A_o}{A_i C_i \frac{k_i}{D_i} \left(\frac{D_i G}{\mu} \right)_i^{0.8} \left(\frac{c_p \mu}{k} \right)_i^{1/3} \left(\frac{\mu}{\mu_w} \right)_i^{0.14}} \tag{26}$$

The condensing coefficient represented by the middle group of terms can be held constant with only the greatest of difficulty. Even if the vapor temperature and average tube-side fluid temperature are held constant, the condensing coefficient will vary with changes in the tube-side fluid velocity due to the resultant changes in the temperature drop across the condensing film.

Multiplying Equation (26) by

$$\left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4}$$

gives

$$\left(\frac{1}{U_o} - r_{fin} - r_m \right) \left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4} =$$

$$\frac{1}{0.725\, C_n} + \frac{\frac{A_o}{A_i} \left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4}}{C_i \frac{k_i}{D_i} \left(\frac{D_i G}{\mu} \right)_i^{0.8} \left(\frac{c_p \mu}{k} \right)_i^{1/3} \left(\frac{\mu}{\mu_w} \right)_i^{0.14}} \tag{27}$$

which has the required form for a linear regression

$$y = mx + b \tag{6}$$

where

$$y = \left(\frac{1}{U_o} - r_{fin} - r_m \right) \left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4} \tag{28}$$

$$m = \frac{1}{C_i} \tag{8}$$

$$x = \frac{\frac{A_o}{A_i} \left[\frac{k_f^3 \rho_f^2 g \lambda}{\mu_f N_a D \Delta t_f} \right]^{1/4}}{\frac{k_i}{D_i} \left(\frac{D_i G}{\mu} \right)_i^{0.8} \left(\frac{c_p \mu}{k} \right)_i^{1/3} \left(\frac{\mu}{\mu_w} \right)_i^{0.14}} \tag{29}$$

$$b = \frac{1}{0.725\, C_n} \tag{30}$$

A linear regression of the function y above on x gives the least squared deviation values of m and b or more important their reciprocals C_i and $0.725\ C_n$, respectively. There is, however, a trial-and-error calculation involved due to the presence of the viscosity ratio group in the equation for the inside heat transfer coefficient. As before a value of C_i is assumed and calculations made to evaluate the required functions. The calculated and assumed values of C_i are compared and the procedure repeated until satisfactory agreement is attained.

To illustrate the modified Wilson plot technique, data for condensation of refrigerant 114 on a single horizontal finned tube at two different condensing temperatures were used[15]. Figure 9 presents a traditional Wilson plot for condensation. The intercepts of the lines through the data are supposedly equal to the value of $(1/h_o') + r_m + r_{fin}$ at an infinite water velocity, but as can be seen from Equation (26), this can only be true if the change in $(1/h_o')$ with changes in $(A_o/A_i h_i)$ is constant. A modified Wilson plot is given in Figure 10. The condensing data for two different temperatures correlate well with a single straight line. The heat transfer correlations obtained by the two methods are given in Figures 9 and 10.

WILSON PLOTS FOR BOILING

The Wilson plot technique can also be used to separate coefficients in systems where boiling occurs. Heat transfer correlations for boiling refrigerants inside of horizontal tubes[16] and for forced convection on the shell-side of a heat exchanger are

$$\frac{h_b D_i}{k_L} = C_b \left[\left(\frac{D_i G}{\mu_L} \right)^2 \left(\frac{J \Delta x \lambda}{L_t} \right) \right]^{0.5} \qquad (31)$$

and Equation (13), respectively. Substituting the expressions for h_o' and h_b defined by Equations (13) and (31) into Equation (3) and rearranging gives

$$\left(\frac{1}{U_o} - r_{fin} - r_m \right) = \frac{1}{C_o \dfrac{k_o}{D_{eq}} \left(\dfrac{D_{eq} G}{\mu} \right)_o^P \left(\dfrac{c_p \mu}{k} \right)_o^{1/3} \left(\dfrac{\mu}{\mu_w} \right)_o^{0.14}} + \frac{A_o}{A_i C_b \dfrac{k_i}{D_i} \left[\left(\dfrac{D_i G}{\mu_L} \right)^2 \left(\dfrac{J \Delta x \lambda}{L_t} \right) \right]^{0.5}} \qquad (32)$$

Multiplying Equation (32) by the group of terms representing h_o' and excluding C_o gives

$$\left(\frac{1}{U_o} - r_{fin} - r_m \right) \left[\frac{k_o}{D_{eq}} \left(\frac{D_{eq} G}{\mu} \right)_o^P \left(\frac{c_p \mu}{k} \right)_o^{1/3} \left(\frac{\mu}{\mu_w} \right)_o^{0.14} \right] = \frac{1}{C_o}$$

$$+ \frac{\dfrac{A_o}{A_i} \left[\dfrac{k_o}{D_{eq}} \left(\dfrac{D_{eq} G}{\mu} \right)_o^P \left(\dfrac{c_p \mu}{k} \right)_o^{1/3} \left(\dfrac{\mu}{\mu_w} \right)_o^{0.14} \right]}{C_b \dfrac{k_L}{D_i} \left[\left(\dfrac{D_i G}{\mu_L} \right)^2 \left(\dfrac{J \Delta x \lambda}{L_t} \right) \right]^{0.5}} \qquad (33)$$

which again is of the form

$$y = mx + b$$

where

$$y = \left(\frac{1}{U_o} - r_{fin} - r_m\right) \left[\frac{k_o}{D_i} \left(\frac{D_{eq}}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}\right] \tag{34}$$

$$m = \frac{1}{C_b} \tag{35}$$

$$x = \frac{\frac{A_o}{A_i} \frac{k_o}{D_i} \left[\left(\frac{D_{eq} G}{\mu}\right)_o^P \left(\frac{c_p \mu}{k}\right)_o^{1/3} \left(\frac{\mu}{\mu_w}\right)_o^{0.14}\right]}{\frac{k_L}{D_i} \left[\left(\frac{D_i G}{\mu_L}\right)^2 \left(\frac{J \Delta x \lambda}{L_t}\right)^{0.5}\right]} \tag{36}$$

$$b = \frac{1}{C_o} \tag{37}$$

For initial values of C_b and P the trial-and-error calculations can be carried out in a manner analagous to the procedure outlined for no phase change and the constants C_b, C_o, and P evaluated.

CONCLUSIONS

Modified Wilson plot techniques have been developed and successfully used to determine individual heat transfer coefficients from overall heat transfer coefficients for many types of heat transfer processes. The approach consists of developing modified Wilson plot expressions for the individual coefficients which describe the heat transfer

mechanisms. The resulting equations are put into a linear form by suitable manipulations and the required constants are solved for in an iterative fashion using linear regression analyses. It is not the authors' intention to advocate what models should be used but rather to illustrate how given models can be used to analyze data to determine the appropriate constants for the models. There is a significant difference between the choice of models and the evaluation of constants for models. The paper was written to present examples of how one could determine constants for mathematical models from experimental test data. It does take considerable experience in the area of heat transfer to be able to develop a mathematical model to represent heat transfer data. If certain parameters are important to the representation of the data, then the correlation will be inadequate without those parameters.

The availability and use of modern digital computers have made rational, comprehensive, and exact analysis of heat transfer data possible with modified Wilson plot techniques. The resulting heat transfer correlations obtained from such techniques are invaluable to the design of heat exchangers.

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NOTATION

A_{eq}	=	equivalent outside heat transfer area of a fin tube, sq. ft.
A_f	=	fin area of a finned tube, sq. ft.
A_i	=	inside heat transfer area, sq. ft.
A_o	=	outside heat transfer area, sq. ft.
A_r	=	root area of a fin tube, sq. ft.
b	=	intercept of line with ordinate
C_b	=	constant for boiling correlation, Equation
C_i	=	constant for inside heat transfer correlation
C_n	=	turbulence correction factor for condensing coefficient correlation
C_o	=	constant for shell-side heat transfer correlation
c_p	=	heat capacity of fluid, Btu/lb. - °F
D	=	tube diameter for condensing correlation; equal to outside diameter of a plain tube and defined by Equation ( ) for a finned tube - ft.
D_{eq}	=	characteristic length for shell side correlation; root diameter for finned tube bundles - ft.
D_i	=	inside diameter of tube, ft.
d_i	=	inside diameter of tube, in.
G	=	mass flow rate, lb./hr.-sq. ft.
g	=	gravitation constant, 4.17×10^8 $lb._m$-ft./$lb._f$-$hr.^2$
h_b	=	boiling heat transfer coefficient, Btu/hr.-sq. ft.-°F
h_c	=	condensing heat transfer coefficient, Btu/hr.-sq.ft.-°F
h_i	=	inside heat transfer coefficient, Btu/hr.-sq.ft.-°F
h_o	=	outside heat transfer coefficient including fin resistance, Btu/hr.-sq.ft.-°F
h'_o	=	actual outside heat transfer coefficient, Btu/hr.-sq. ft.-°F
J	=	mechanical equivalent of heat, 778.26 ft.-lb./Btu
k	=	thermal conductivity of fluid, Btu/hr.-sq.ft.-°F
L	=	area of one side of one fin/fin diameter, ft.
L_t	=	tube length, ft.

m	=	slope of least squared deviation line
N_a	=	mean number of tubes in a vertical row for a condenser
Nu	=	Nusselt number
P	=	power to which Reynolds number is raised as in Equation (13)
Pl	=	constant determining power to which Reynolds number is to be raised, Equation (21)
Pr	=	Prandtl number
Re	=	Reynolds number
r_{fin}	=	fin resistance, hr. sq. ft.-°F/Btu
r_m	=	metal resistance, hr. sq. ft. (Outside area) -°F/Btu
t_w	=	average water temperature, °F
U_o	=	overall heat transfer coefficient, Btu/hr. sq.ft.-°F
v	=	velocity, ft./sec.
x	=	Wilson plot function
x_{shell}	=	shell-side correlation function
y	=	Wilson plot function
y_{shell}	=	shell-side correlation function
Δt_f	=	temperature drop across condensing film, °F
Δx	=	vapor quality change, fraction
λ	=	latent heat of condensing vapor, Btu./lb.
μ	=	viscosity, lb./ft.-hr.
ϕ	=	fin efficiency
ρ	=	density of fluid, lb./cu. ft.

Subscripts

f	=	film
i	=	inside
L	=	liquid
o	=	outside
w	=	wall

LIST OF CAPTIONS

Figure 1 — Wilson Plots as Modified by Young and Wall of Data Obtained with Water on the Shell-side of 6-Inch Diameter Exchanger with 5/8-Inch Finned Tubes--Bundle 6[4]

Figure 2 — Wilson Plot as Modified by Briggs of Data with Water on the Shell-side of a 6-Inch Diameter Exchanger with 5/8-Inch Finned Tubes--Bundle 6[4]

Figure 3 — Shell-side Heat Transfer Correlation for Water on the Shell-side of a 6-Inch Diameter Exchanger with 5/8-Inch Finned Tubes--Bundle 6 for Reynolds Numbers Between 8000 and 36,000

Figure 4 — Wilson Plot as Modified by Briggs of Data with Oil on the Shell-side of a 6-Inch Diameter Exchanger with 5/8-Inch Finned Tubes--Bundle 6[4]

Figure 5 — Wilson Plot as Modified by Briggs of Data with Glycerine on the Shell-side of a 6-Inch Diameter Exchanger with 5/8-Inch Finned Tubes--Bundle 6[4]

Figure 6 — Shell-side Heat Transfer Correlation for Oil on the Shell-side of a 6-Inch Diameter Exchanger with 5/8-Inch Finned Tubes--Bundle 6 for Reynolds Numbers between 20 and 600

Figure 7 — Shell-side Heat Transfer Correlation for Glycerine on the Shell-side of a 6-Inch Diameter Heat Exchanger with 5/8-Inch Finned Tubes--Bundle 6[4] for Reynolds Number Between 30-1000

Figure 8 — Shell-side Heat Transfer Correlation for Three Fluids on the Shell-side of a 6-Inch Diameter Heat Exchanger with 5/8-Inch Finned Tubes--Bundle 6[4]

Figure 9 — Wilson Plot for Condensation of Refrigerant 114 on a Single Horizontal Finned Tube

Figure 10 — Wilson Plot as Modified by Briggs for Condensation of Refrigerant 114 on a Single Horizontal Finned Tube

Figure 1

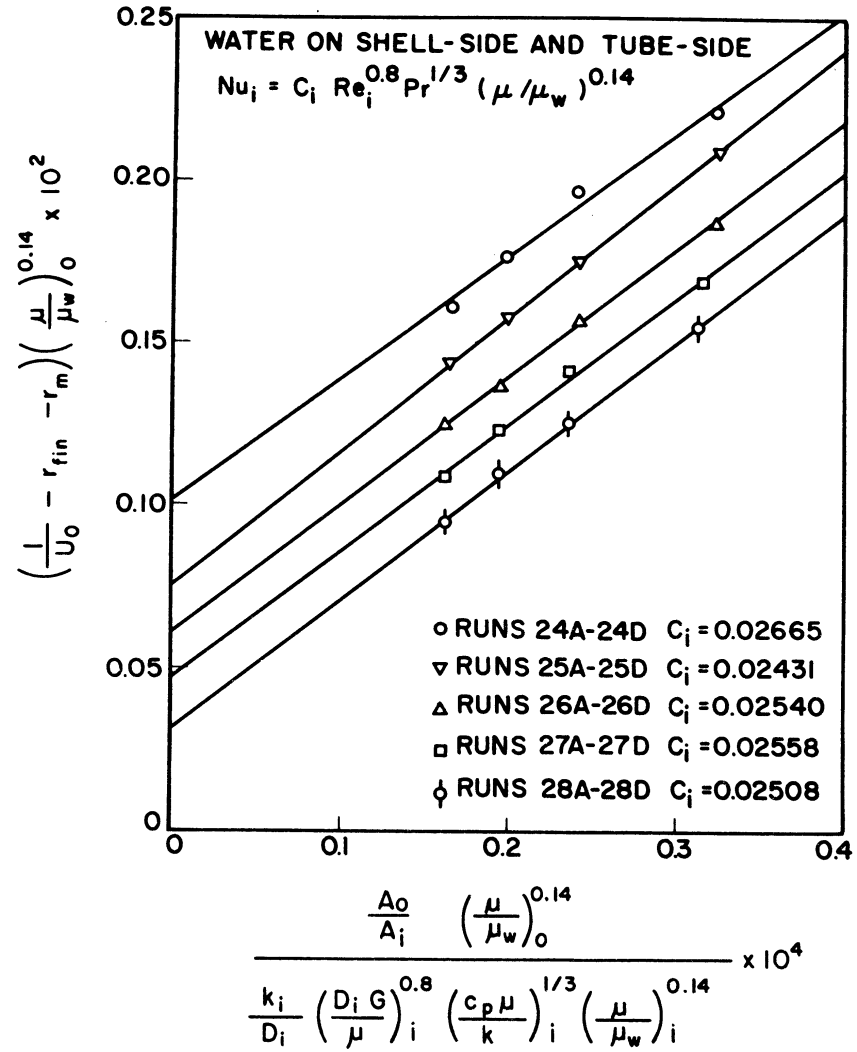
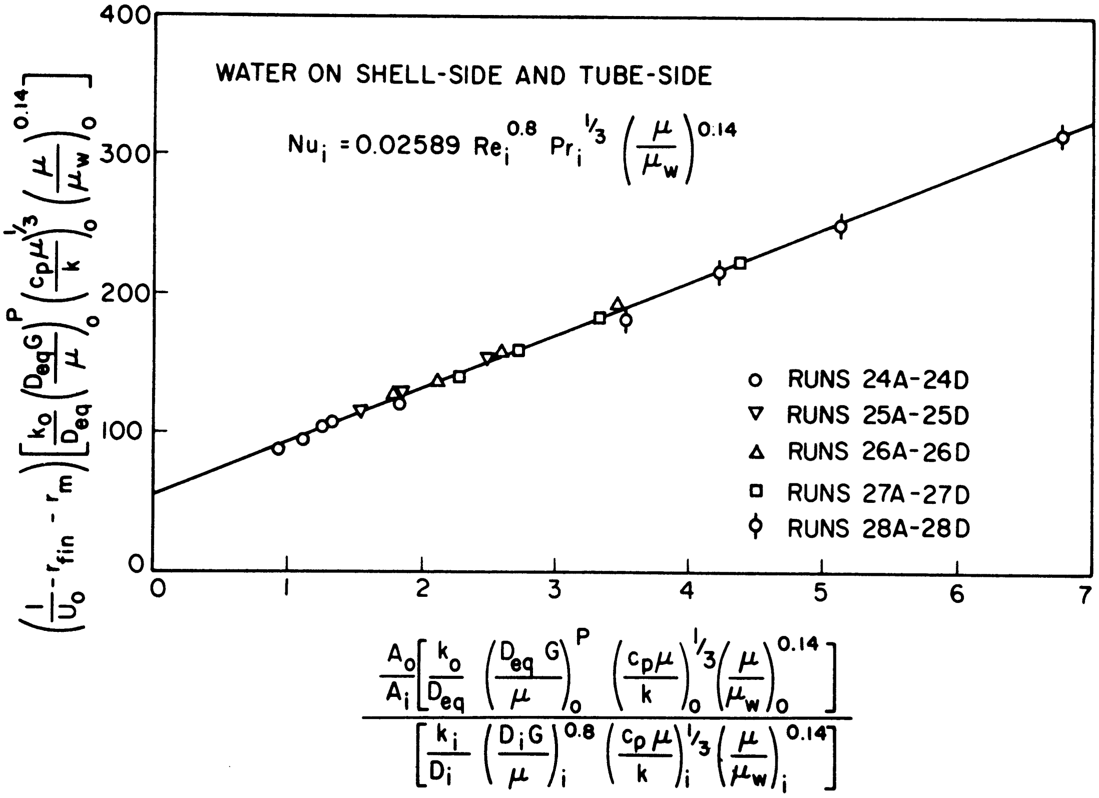


Figure 2



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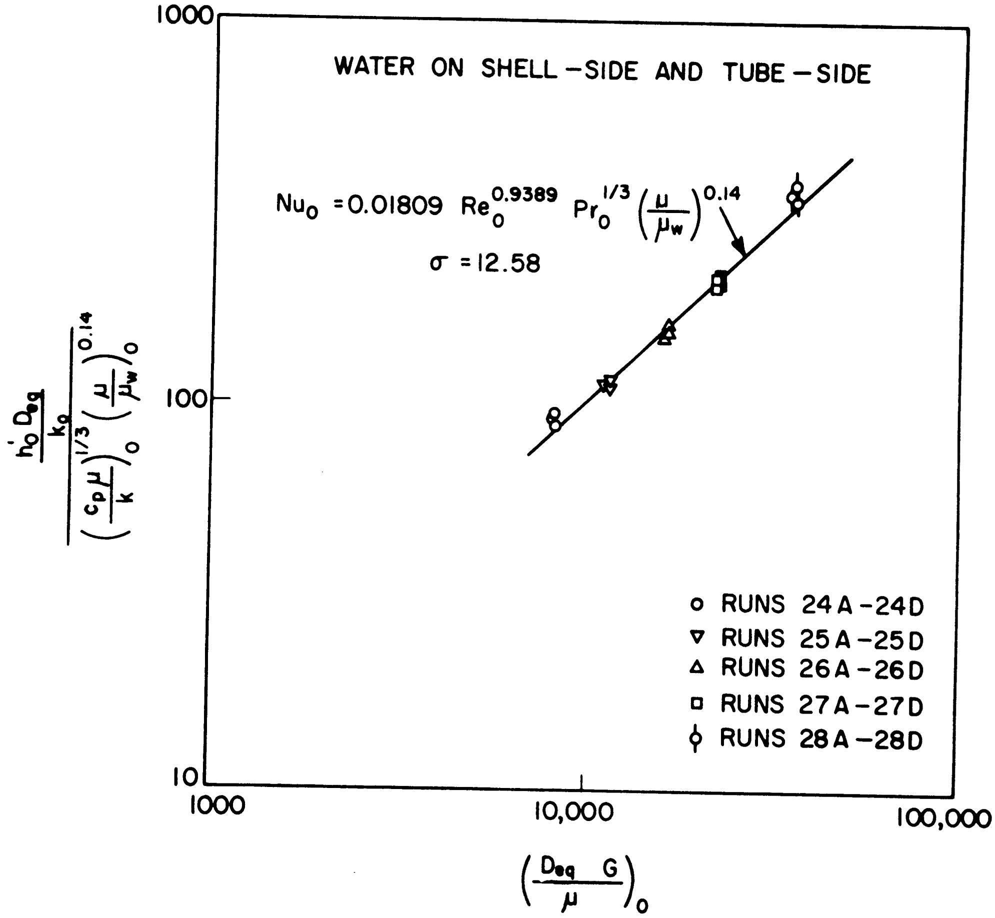


Figure 4

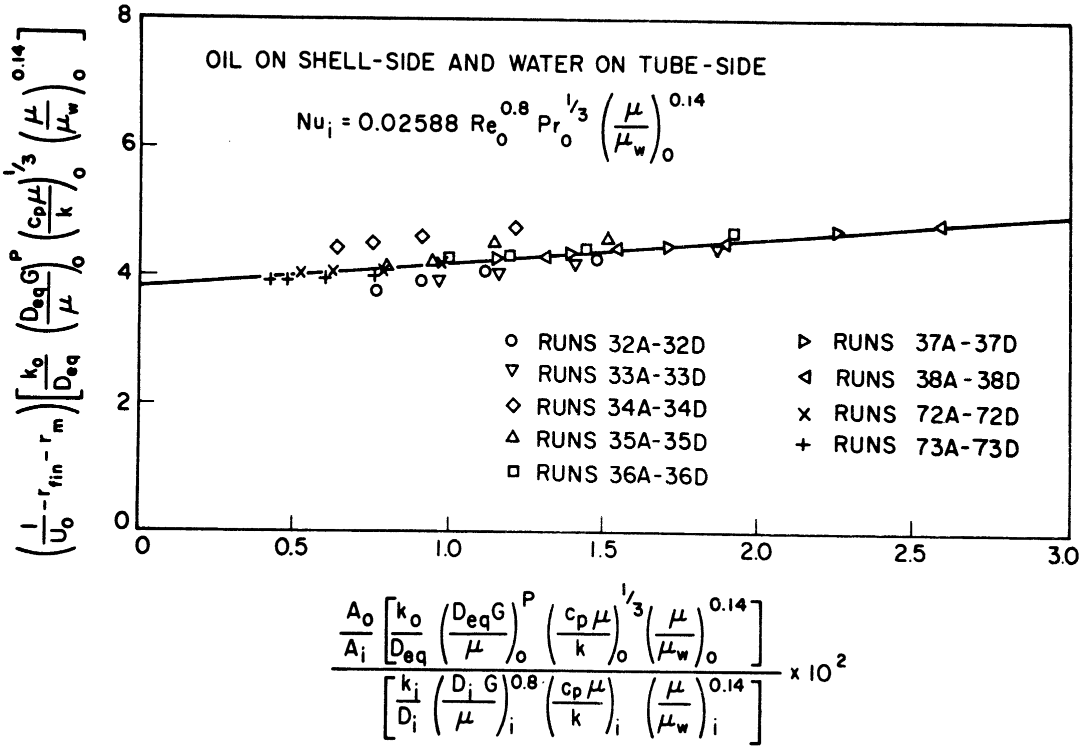


Figure 5

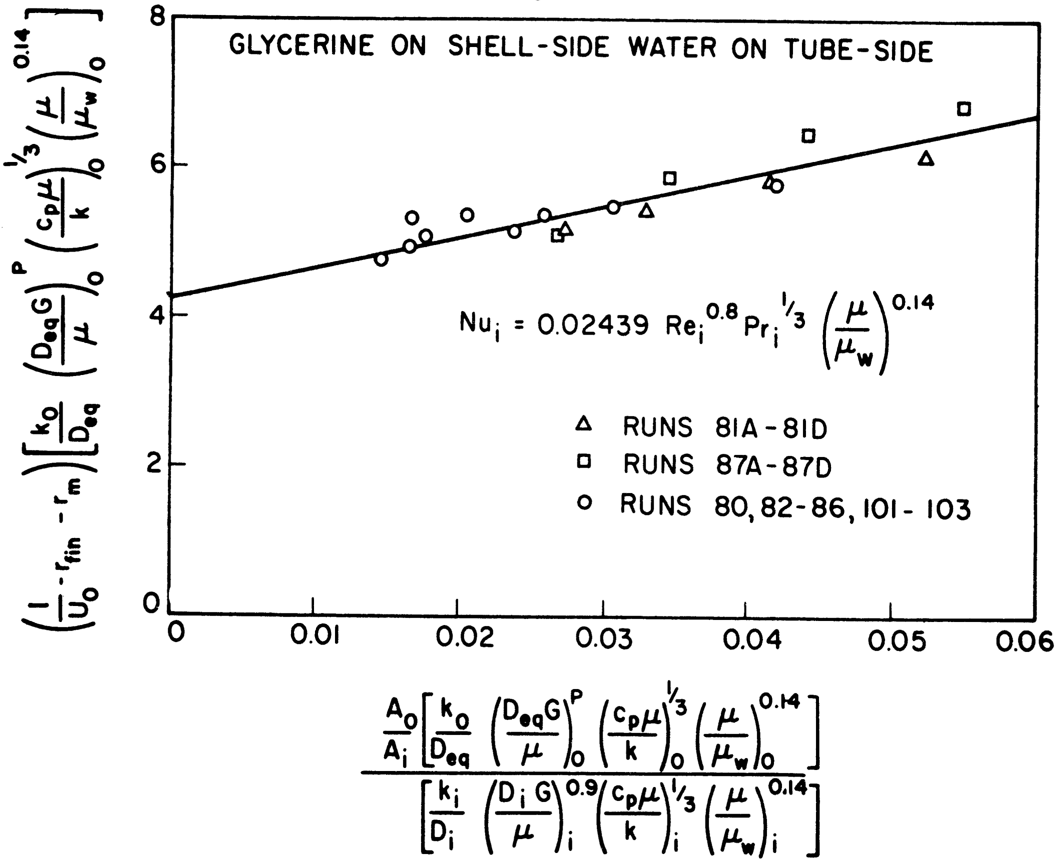
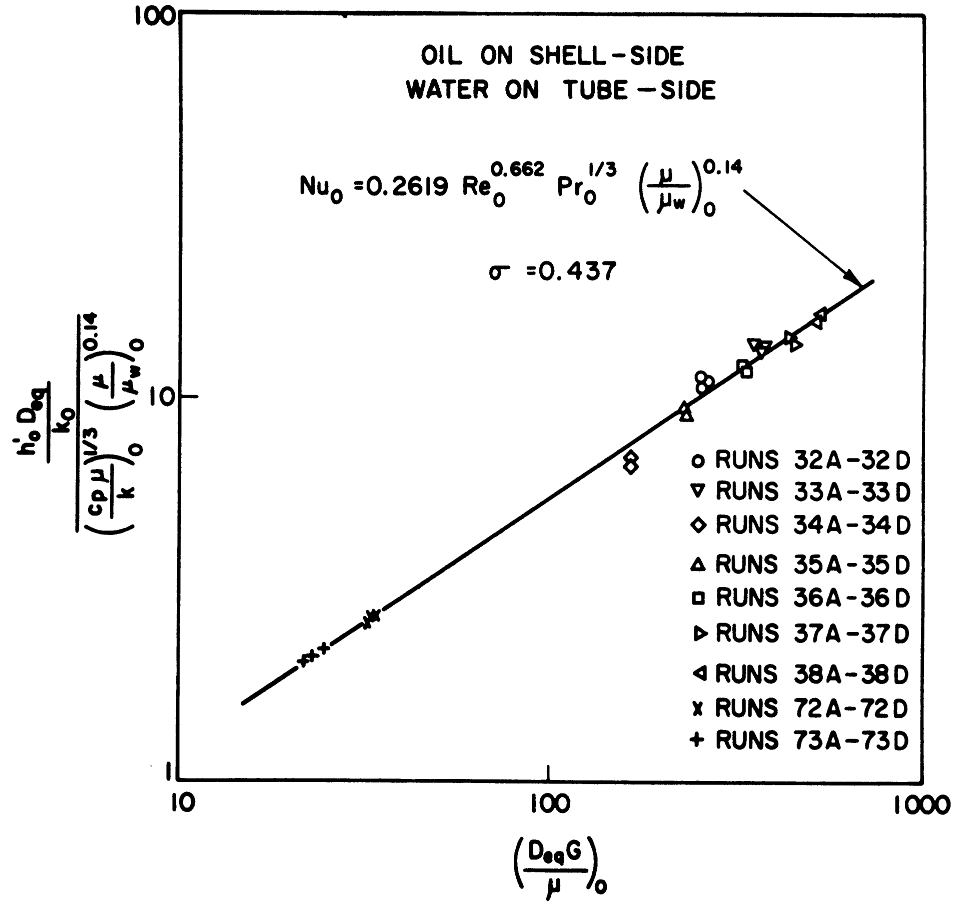


Figure 6



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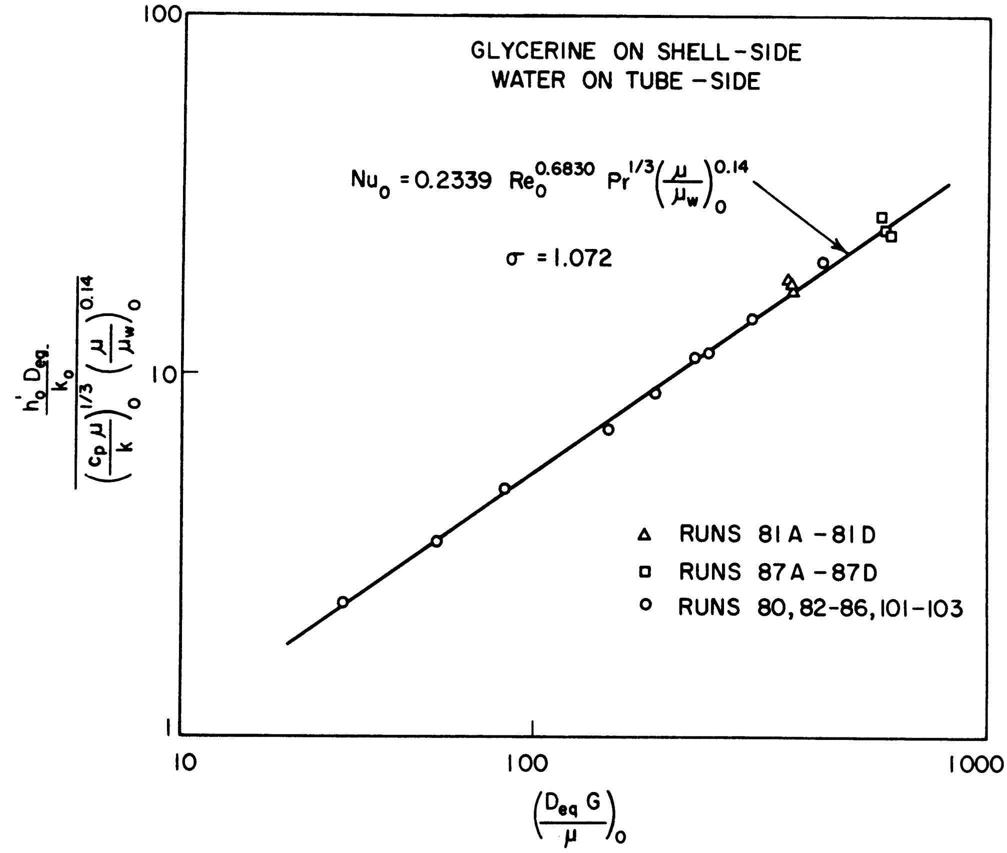


Figure 9

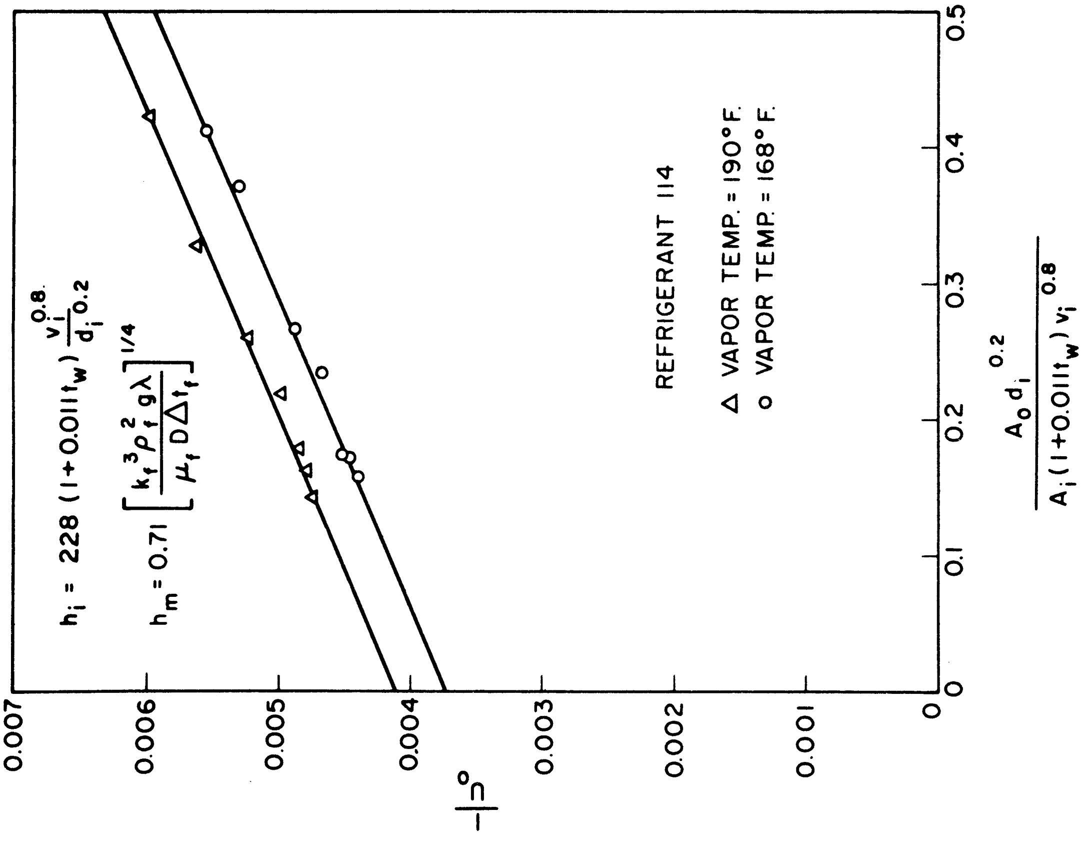


Figure 8

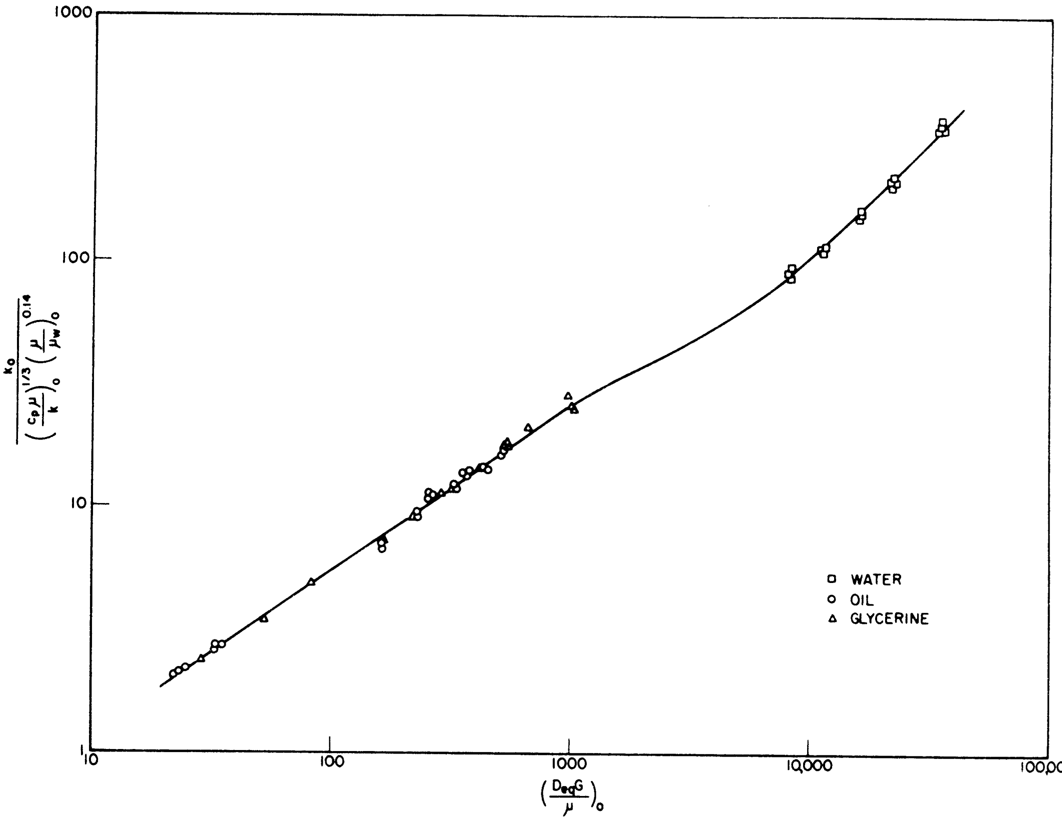
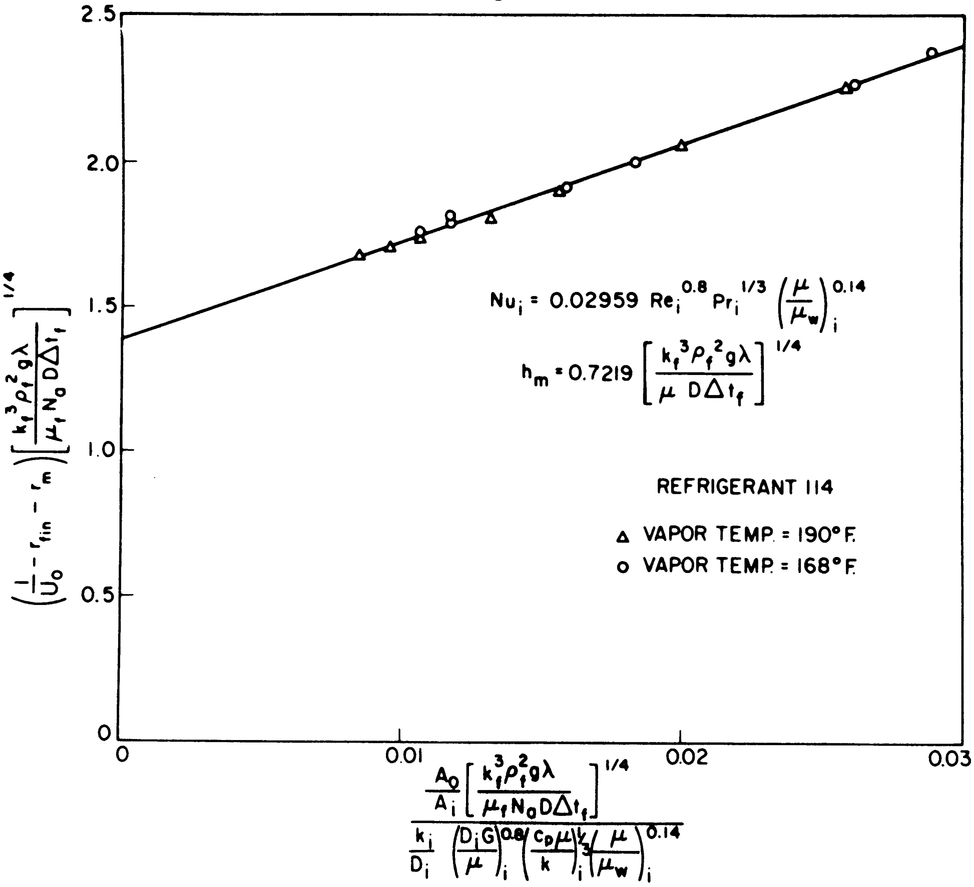


Figure 10



2.5
2.0
1.5
1.0
0.5
0
0
0.01
0.02
0.03
$\left(\frac{1}{U_o} - r_{fin} - r_\varepsilon\right)\left[\frac{k_f^3\rho_f^2 g\lambda}{\mu_f N_a D\Delta t_f}\right]^{1/4}$
$\frac{\frac{A_o}{A_i}\left[\frac{k_f^3\rho_f^2 g\lambda}{\mu_f N_a D\Delta t_f}\right]^{1/4}}{\frac{k_i}{D_i}\left(\frac{D_i G}{\mu}\right)_i^{0.8}\left(\frac{c_p\mu}{k}\right)_i^{1/3}\left(\frac{\mu}{\mu_w}\right)_i^{0.14}}$
$Nu_i = 0.02959\ Re_i^{0.8}\ Pr_i^{1/3}\left(\frac{\mu}{\mu_w}\right)_i^{0.14}$
$h_m = 0.7219\left[\frac{k_f^3\rho_f^2 g\lambda}{\mu\ D\Delta t_f}\right]^{1/4}$
REFRIGERANT 114
△ VAPOR TEMP. = 190°F.
○ VAPOR TEMP. = 168°F.

```
      TITLE1300
C         A.KARGILIS
C
C         JUNE 24, 1968
C
C         WILSON PLOT, CONCENTRIC PIPE HEAT EXCHANGER.
C         WATER TUBE AND SHELL SIDE.
C         5/8 COPPER TUBE NO. 1300
C         VALUES OF X AND Y ARE BEST FIT VIA THE METHOD OF LEAST SQUARES
          DIMENSION RES(35),PRS(35),         SSW(35), TSW(35), TS1(35),
         1TS2(35), TT1(35), TT2(35), RUN(35),VISRS(35),RET(35),PRT(35),
         2HC(35),UO(35),CWAS(35),CWAT(35),VISRT(35),HI(35),HCC(35)
          IT = 1
        1 N = 0
        3 N = N+1
          READ(6,4)SSW(N ),TSW(N ),TS1(N ),TS2(N ),TT1(N ),TT2(N ),RUN(N )
        4 FORMAT (2F6.3,4F6.2,F4.1)
          CALL FOF(K)
          GO TO (10,3),K
       10 STC=0.069315
          N=N-1
       31 RM=0.00001808
          DI=0.04417
C
C         TEST LENGTH FOR HEAT TRANSFER = 12,698 FEET
C
          AOT=2.040
          CPWAT=0.999
          DO 60 I=1,N
          Q=TSW(I)*3600.0*CPWAT*(TT2(I)-TT1(I))
          TDLM=((TS1(I)-TT2(I))-(TS2(I)-TT1(I)))/ALOG((TS1(I)-TT2(I))/(TS2(I
         1)-TT1(I)))
          UO(I)=Q/(AOT*TDLM)
          TWBT=(TT1(I)+TT2(I))/2.0
          TWBTC=5.0*(TWBT-32.0)/9.0
          VISWAT=242.0/(2.1482*((TWBTC-8.435)+SQRT(8078.4+(T BTC-8.435)**2
         1))-120.0)
          GT=TSW(I)*3600.0*1.2732/(DI*DI)
          RET(I)=DI*GT/VISWAT
          CWAT(I)=0.000299*TWBT+0.3334
          PRT(I)=CPWAT*VISWAT/CWAT(I)
          HII=CWAT(I)*STC/DI*(RET(I)**0.8)*(PRT(I)**0.3333)
          ALPHA=HII
          DO 7 J=1,20,1
          AIT=1.762
          EPS=0.001
          TWI=TWBT+Q/(AIT*ALPHA)
```

```
      TWIC=5.0*(TWI-32.0)/9.0
      VISWAW=242.0/(2.1482*((TWIC-8.435)+SQRT(8078.4+(TWIC-8.435)**2  ))
     1-120.0)
      VISRTX  =(VISWAT/VISWAW)**0.14
      HIX  =CWAT(I)*STC/DI*(RET(I)**0.8)*(PRT(I)**0.3333)*VISRTX
      IF(ABS((ALPHA-HIX  )/ALPHA).LT.EPS ) GO TO 8
    7 ALPHA=HIX
    8 HI(I)=HIX
      VISRT(I)=VISRTX
      HC(I)=1.0/(1.0/UO(I)-AOT/(AIT*HI(I))-RM)
C
C     ANU=PI/4(SHROUD ID*SHROUD ID-TEST OD*TEST OD)1/144
C
      ANU=0.00340
      TWBS=(TS1(I)+TS2(I))/2.0
      TWBSC=5.0*(TWBS-32.0)/9.0
      VISWAS=242.0/(2.1482*((TWBSC-8.435)+SQRT(8078.4+(TWBSC-8.435)**2
     1))-120.0)
      GS=SSW(I)*3600.0/ANU
C
C     DH=SHELL ID - TUBE OD
C
      DH=0.0322
      OD=0.0511
      RES(I)=DH*GS/VISWAS
      CWAS(I)=0.000299*TWBS+0.3334
      PRS(I)=CPWAT*VISWAS/CWAS(I)
      VISRS(I)=(VISWAS/VISWAW)**0.14
      XAXRE=ALOG(RES(I))
      YAXRE=ALOG((HC(I)*DH/CWAS(I))/(PRS(I)**0.333*VISRS(I)))
    5 FORMAT(5H1 RUN, 7X,1HX,12X,1HY,10X,3HRES,9X,3HRET,7X,2HHI,9X,2HHC,
     18X,5HYAXRE,7X,5HXAXRE,4X,3HHCC)
    6 FORMAT(1X,F5.1,2X,F10.5,3X,F12.5,3X,F9.1,3X,F9.1,3X,F7.1,3X,F7.1,
     13X,F8.3,2X,F8.3,1X,F7.0)
      WRITE(1) XAXRE, YAXRE
   60 CONTINUE
      END FILE 1
      REWIND 1
      ITAPE=1
      CALL LINREG (P,YAXRE,ITAPE)
      DO 16 I=1,N
      YS=(1.0/UO(I)-RM)*CWAS(I)/DH*RES(I)**P*PRS(I)**0.3333*VISRS(I)
      XS=(OD/DI*CWAS(I)/DH*RES(I)**P*PRS(I)**0.3333*VISRS(I))/(CWAT(I)/D
     1I*RET(I)**0.8*PRT(I)**0.3333*VISRT(I))
      WRITE (2) XS, YS
   16 CONTINUE
      END FILE 2
      REWIND 2
      ITAPE=2
      CALL LINREG (A,B,ITAPE)
      STCI=1.0/A
```

```
      STCO=1.0/B
      DO 99 I=1,N
      HCC(I)=CWAS(I)*STCO/DH*(RES(I)**P)*(PRS(I)**0.3333)*VISRS(I)
   99 CONTINUE
      WRITE (3,14)
      WRITE (3,15) STCO, P , STCI
   14 FORMAT (4X,4HSTCO,12X,1HP ,15X,4HSTCI)
   15 FORMAT(1X,F10.4,6X,F10.6,8X,F9.6)
      IF (ABS(STCI-STC)-0.0005) 20,20,21
   21 STC=(STCI+STC)/2.0
      GO TO 31
   20 CONTINUE
      WRITE(3,5)
      DO 32 I=1,N
      READ (1) XAXRE, YAXRE
      READ (2)  XS, YS
   32 WRITE(3,6)RUN(I),XS,YS,RES(I),RET(I),HI(I),HC(I),YAXRE,XAXRE,
     1HCC(I)
   33 PAUSE 77777
      END
```

```
FORTRAN    200        SOURCE LISTING AND DIAGNOSTICS                          PROGRAM: LINREG

         TITLELINREG
               SUBROUTINE LINREG (A,B,ITAPE)
               Z = 0.0
               SX=0.0
               SY=0.0
               SXX=0.0
               SXY=0.0
           100 READ (ITAPE) X,Y
               CALL FOF (I)
               GO TO (13,12),I
            12 Z=Z+1.0
               SX=SX+X
               SY=SY+Y
               SXX=SXX+X*X
               SXY=SXY+X*Y
               GO TO 100
            13 A=(Z*SXY-SX*SY)/(Z*SXX-SX*SX)
               B=(SY*SXX-SX*SXY)/(Z*SXX-SX*SX)
         C
         C     A IS THE SLOPE AND B IS THE Y INTERCEPT
         C
               REWIND ITAPE
               RETURN
               END
```

NOMENCLATURE

RES	Re shellside
PRS	Pr shellside
SSW	Shellside water flow, lbs./sec.
TSW	Tubeside water flow, lbs./sec.
TS1	Temperature water in, shellside, °F
TS2	Temperature water out, shellside, °F
TT1	Temperature water in, tubeside, °F
TT2	Temperature water out, tubeside, °F
VISRS	Viscosity ratio to .14 power $\left(\frac{\mu}{\mu_w}\right)^{.14}$, shellside
RET	Re tubeside
PRT	Pr tubeside
HC	Shellside film coefficient
UO	Overall coefficient
CWAS	Thermal conductivity, water, shellside, based on bulk temperature
CWAT	Thermal conductivity water, tubeside, based on bulk temperature
VISRT	Viscosity ratio to .14 power $\left(\frac{\mu}{\mu_w}\right)^{.14}$, tubeside
HI	Inside film coefficient
YS	Ordinate Wilson Plot
XS	Absicca Wilson Plot
RM	Wall resistance
DH	Hydraulic diameter
P	Re power shellside
OD	Outside diameter, test tube, ft.
DI	Inside diameter, test tube, ft.
XAXRE	Abcissa, Re shellside power plot
YAXRE	Ordinate, Re shellside power plot

APPENDIX III

Computer Program for
Analyzing Experimental Multiple Tube Steam Condensing Data,
Its Nomenclature and Sample Printout in Tables III-1, III-2, and III-3

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C         THE FOLLOWING PROGRAM IS WRITTEN FOR THE STEAM CONDENSING     C
C         ON MULTIPLE TUBES.                                            C
C         THE PROGRAM IS WRITTEN IN FORTRAN IV G-LEVEL.                 C
C         TO BE RUN ON THE IBM O/S 360 MODEL 67.                        C
C                                                                       C
C         THE ORIGINAL ARGORITHM WAS BY MR. DALE BRIGGS.                C
C                                                                       C
C         BY GEORGE T. S. CHEN IN MARCH 1968.                           C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION TTUBEI(20), WTUBE(20), TAVG(20), DEN(20), PR(20), Q(20),
     1          TTUBEO(20), VISCW(20), VISC(20), VEL(20), RE(20),
     2          VAPORT(20), TWALL(20), PVEL(20), CNN(20), QA(20),
     3          TUBENO(20), DELTF(20);           PTI(20), UO(20),
     4          CONSTA(20), PHYGR(20),           PTO(20), CN(20),
     5          TWALLA(20), CONST(20),           PTV(20), HO(20),
     6          TWALLO(20), HCOND(20),           EMF(20), PQ(20),
     7          DELTFA(20), FILMT(20),           HOA(20), HG(20),
     8                      DCOND(20),           UOA(20), HI(20),
     9                      VCOND(20),           CPT(20)
      DOUBLE PRECISION RUNNO, DAY, YEAR, METAL1, METAL2, METAL3, METAL4,
     1                METAL5, METAL6, METAL7, METAL8
      REAL  KCOND(20), LMTD(20),LAT(20),KT(20),ID
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C         STATEMENTS 101 TO 111 ARE FOR TUBES A AND B.                  C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  101 READ(5,20005)ID, OD, TL, TK, CI, N, METAL1, METAL2, METAL3, METAL4
      READ(5,20007)RUNNO, DAY, YEAR
      WRITE(6,20001)RUNNO, DAY, YEAR
      DO 102  I = 1,2
  102 READ(5,20006)TUBENO(I), HG(I), TTUBEI(I), EMF(I), VAPORT(I)
      WTUBE(1)   = EXP((ALOG(HG(1)/11.8979))/1.9866)                 NO. 12
      WTUBE(2)   = EXP((ALOG(HG(2)/12.1606))/2.0464)                 NO. 18
      DO 103  I = 1,2
      TTUBEO(I) = (0.31909129E+02)           +(0.47341237E+02)*EMF(I)
     1           -(0.24948922E+01)*EMF(I)**2 +(0.10769889E+01)*EMF(I)**3
     2           -(0.49329147E+00)*EMF(I)**4 +(0.13393543E+00)*EMF(I)**5
     3           -(0.18958908E-01)*EMF(I)**6 +(0.10851047E-02)*EMF(I)**7
      PTI(I)     = TTUBEI(I)
      PTO(I)     = TTUBEO(I)
      PTV(I)     = VAPORT(I)
      WTUBE(I)   = WTUBE(I)*3600.0
  103 CONTINUE
      WRITE(6,20028)
      WRITE(6,20008)OD, ID, TL, TK, METAL1, METAL2, METAL3, METAL4
      OD         = OD/12.0
      ID         = ID/12.0
      TL         = TL/12.0
      RM         = (OD-ID)/TK/2.0
      DM         = (OD-ID)/ALOG(OD/ID)
      AOT        = 3.1416*OD*TL
      AIT        = 3.1416*ID*TL
      AMET       = 3.1416*DM*TL
      WRITE(6,20009)AOT, AIT, AFLOW, RM, CI
      AFLOW      = 3.1416*ID*ID/4.0
      DO 105  I = 1,2
      TAVG(I)    = (TTUBEI(I) + TTUBEO(I))/2.0
      CALL WATER(TAVG(I),CPT(I),DEN(I),KT(I),VISC(I),HEAT)
```

```
      CALL WATER(VAPORT(I),CP,WATERD,WATERK,WATERV,LAT(I))
      Q(I)        = WTUBE(I)*CPT(I)*(TTUBEO(I)-TTUBEI(I))
      PQ(I)       = Q(I)
      LMTD(I)     = (TTUBEO(I)-TTUBEI(I))/ALOG((VAPORT(I)-TTUBEI(I))/
     1              (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)
      PVEL(I)     = VEL(I)
      TWALLA(I) = TAVG(I)
      CALL TRIAL(TWALLA(I),TAVG(I),CI,KT(I),RE(I),PR(I),VISC(I),
     1           VISCW(I),Q(I),AIT,HI(I),ID,TWALL(I),1)
      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
      CALL WATER( FILMT(I),CP,DCOND(I),KCOND(I),VCOND(I),HEAT)
      PHYGR(I)    = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
     1              (VCOND(I)*DELTF(I)))**0.25
      CN(I)       = HCOND(I)/(0.725*PHYGR(I)*(LAT(I)*4.17*10.0**8/OD)
     1              **0.25)
  105 CNN(I)      = CN(I)
      WRITE(6,20002)
      WRITE(6,20015)
      DO 106  I = 1,2
  106 WRITE(6,20010)TUBENO(I),WTUBE(I),TTUBEI(I),TTUBEO(I),TAVG(I),
     1                 CPT(I),DEN(I),VISC(I)
      WRITE(6,20016)
      DO 107  I = 1,2
  107 WRITE(6,20011)TUBENO(I),KT(I),PR(I),TWALL(I),VISCW(I),VEL(I),
     1                 RE(I),HI(I)
      WRITE(6,10005)
      DO 108  I = 1,2
  108 WRITE(6,10002)TUBENO(I),VAPORT(I),LAT(I),Q(I),LMTD(I),UO(I),
     1                 HI(I),HCOND(I)
      WRITE(6,10001)
      WRITE(6,20028)
      WRITE(6,10006)
      DO 109  I = 1,2
  109 WRITE(6,10003)TUBENO(I),DELTF(I),FILMT(I),KCOND(I),DCOND(I),
     1                 PHYGR(I)
      WRITE(6,10007)
      DO 111  I = 1,2
  111 WRITE(6,10004)TUBENO(I),HI(I),UO(I),HCOND(I),CN(I)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C         STATEMENTS 200 TO 227 ARE FOR TUBES 1 THROUGH 7.              C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
  200 READ (5,20005)ID,OD,TL,TK,CI,N,METAL5,METAL6,METAL7,METAL8
      WRITE(6,20001)RUNNO,DAY,YEAR
      N           = N + 2
      SUMVT       = 0.0
      SUMVEL      = 0.0
      STIN        = 0.0
      DO 201  I = 3,N
  201 READ (5,20006)TUBENO(I),HG(I),TTUBEI(I),EMF(I),VAPORT(I)
      WTUBE(3)    = EXP((ALOG(HG(3)/12.4550))/2.0518)              NO. 15
      WTUBE(4)    = EXP((ALOG(HG(4)/12.8193))/2.0380)              NO. 17
      WTUBE(5)    = EXP((ALOG(HG(5)/12.0399))/2.0213)              NO. 11
```

```
      WTUBE(6)    = EXP((ALOG(HG(6)/12.7039))/2.0251)                          NO. 16
      WTUBE(7)    = EXP((ALOG(HG(7)/12.1947))/2.0091)                          NO.  7
      WTUBE(8)    = EXP((ALOG(HG(8)/12.8830))/2.0078)                          NO. 25
      WTUBE(9)    = EXP((ALOG(HG(9)/12.6345))/2.0377)                          NO.  4
      WRITE(6,20028)
      WRITE(6,20008)OD,ID,TL,TK,METAL5,METAL6,METAL7,METAL8
      DO 202  I = 3,N
      TTUBEO(I) = (0.31909129E+02)            +(0.47341237E+02)*EMF(I)
     1           -(0.24948922E+01)*EMF(I)**2 +(0.10769889E+01)*EMF(I)**3
     2           -(0.49329147E+00)*EMF(I)**4 +(0.13393543E+00)*EMF(I)**5
     3           -(0.18958908E-01)*EMF(I)**6 +(0.10851047E-02)*EMF(I)**7
      PTI(I)      = TTUBEI(I)
      PTO(I)      = TTUBEO(I)
      PTV(I)      = VAPORT(I)
      WTUBE(I)    = WTUBE(I)*3600.0
  202 CONTINUE
      OD          = OD/12.0
      ID          = ID/12.0
      TL          = TL/12.0
      RM          = (OD-ID)/TK/2.0
      DM          = (OD-ID)/ALOG(OD/ID)
      AOT         = 3.1416*OD*TL
      AIT         = 3.1416*ID*TL
      AMET        = 3.1416*DM*TL
      AFLOW       = 3.1416*ID*ID/4.0
      WRITE(6,20009)AOT, AIT, AFLOW, RM, CI
      DO 204  I = 3,N
      TAVG(I)     = (TTUBEI(I) + TTUBEO(I))/2.0
      CALL WATER(VAPORT(I),CP,WATERD,WATERK,WATERV,LAT(I))
      CALL WATER(TAVG(I),CPT(I),DEN(I),KT(I),VISC(I),HEAT)
      Q(I)        = WTUBE(I)*CPT(I)*(TTUBEO(I)-TTUBEI(I))
      LMTD(I)     = (TTUBEO(I)-TTUBEI(I))/ALOG((VAPORT(I)-TTUBEI(I))/
     1              (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)
      PVEL(I)     = VEL(I)
      SUMVEL      = SUMVEL  + VEL(I)
      STIN        = STIN + TTUBEI(I)
      SUMVT       = SUMVT + VAPORT(I)
      TWALLA(I) = TAVG(I)
      CALL TRIAL(TWALLA(I),TAVG(I),CI,KT(I),RE(I),PR(I),VISC(I),
     1           VISCW(I),Q(I),AIT,HI(I),ID,TWALL(I),1)
      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
      CALL WATER( FILMT(I),CP,DCOND(I),KCOND(I),VCOND(I),HEAT)
      PHYGR(I)  = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
     1            (VCOND(I)*DELTF(I)))**0.25
  204 CONST(I)  = HCOND(I)*(OD/(4.17*10.0**8*LAT(I)))**0.25/PHYGR(I)
      XM          = N - 2
      ATIN        = STIN/XM
      AVGVT       = SUMVT/XM
      AVGVEL      = SUMVEL/XM
      WRITE(6,20002)
      WRITE(6,20015)
      DO 205  I = 3,N
  205 WRITE(6,20010)TUBENO(I),WTUBE(I),TTUBEI(I),TTUBEO(I),TAVG(I),
```

```
     1              CPT(I),DEN(I),VISC(I)
      WRITE(6,20016)
      DO 206  I = 3,N
  206 WRITE(6,20011)TUBENO(I),KT(I),PR(I),TWALL(I),VISCW(I),VEL(I),
     1              RE(I),HI(I)
      WRITE(6,20017)
      DO 207  I = 3,N
  207 WRITE(6,20012)TUBENO(I),VAPORT(I),LAT(I),TWALLO(I),DELTF(I),
     1              FILMT(I),KCOND(I),DCOND(I)
      WRITE(6,20018)
      DO 208  I = 3,N
  208 WRITE(6,20013)TUBENO(I),VCOND(I),PHYGR(I),Q(I),LMTD(I),UO(I),
     1              HI(I),HCOND(I)
      DO 212  I = 3,N
      TTUBEI(I) = ATIN
      VEL(I)    = AVGVEL
      VAPORT(I) = AVGVT
  209 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
      CALL WATER(TAVG(I),CPT(I),DEN(I),KT(I),VISC(I),HEAT)
      PR(I)     = CPT(I)*VISC(I)/KT(I)
      RE(I)     = ID*WTUBE(I)/(AFLOW*VISC(I))
      CALL WATER(VAPORT(I),CP,WATERD,WATERK,WATERV,LAT(I))
      LMTD(I)   = (TTUBEO(I)-TTUBEI(I))/ALOG((VAPORT(I)-TTUBEI(I))/
     1            (VAPORT(I)-TTUBEO(I)))
  210 CALL TRIAL(TWALLA(I),TAVG(I),CI,KT(I),RE(I),PR(I),VISC(I),
     1           VISCW(I),Q(I),AIT,HI(I),ID,TWALL(I),1)
      TWALLO(I) = TWALL(I) + Q(I)*RM/AMET
      DELTF(I)  = VAPORT(I) - TWALLO(I)
  211 FILMT(I)  = VAPORT(I) -DELTF(I)/2.0
      CALL WATER( FILMT(I),CP,DCOND(I),KCOND(I),VCOND(I),HEAT)
      PHYGR(I)  = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
     1            (VCOND(I)*DELTF(I)))**0.25
      HCOND(I)  = CONST(I)*PHYGR(I)*(4.17*10.0**8*LAT(I)/OD)**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)
      IF(ABS(DELTFA(I)-DELTF(I))/DELTFA(I) - 0.001) 241,241,231
  231 DELTF(I)  = DELTFA(I)
      GO TO. 211
  241 QA(I)     = UO(I)*LMTD(I)*AOT
      IF(ABS(QA(I) - Q(I))/QA(I) - 0.001)212,212,    251
  251 Q(I)      = QA(I)
      GO TO  209
  212 CONTINUE
      WRITE(6,20003)
      WRITE(6,20015)
      DO 213  I = 3,N
  213 WRITE(6,20010)TUBENO(I),WTUBE(I),TTUBEI(I),TTUBEO(I),TAVG(I),
     1              CPT(I),DEN(I),VISC(I)
      WRITE(6,20016)
      DO 214  I = 3,N
  214 WRITE(6,20011)TUBENO(I),KT(I),PR(I),TWALL(I),VISCW(I),VEL(I),
     1              RE(I),HI(I)
      WRITE(6,20017)
      DO 215  I = 3,N
  215 WRITE(6,20012)TUBENO(I),VAPORT(I),LAT(I),TWALLO(I),DELTF(I),
     1              FILMT(I),KCOND(I),DCOND(I)
      WRITE(6,20018)
      DO 216  I = 3,N
```

```
216 WRITE(6,20013)TUBENO(I),VCOND(I),PHYGR(I),Q(I),LMTD(I),UO(I),
   1               HI(I),HCOND(I)
    Q(1)        = 0.0
    Q(2)        = 0.0
    SCPT        = 0.0
    SDEN        = 0.0
    DO 218 I=3,N
    II          = I-2
    Q(I)        = Q(I-1) + Q(I)
    PQ(I)       = Q(I)
    SDEN        = SDEN + DEN(I)
    DEN(I)      = SDEN/II
    SCPT        = SCPT + CPT(I)
    CPT(I)      = SCPT/II
    WTUBE(I)    = DEN(I)*AVGVEL*3600.0*AFLOW*II
    TTUBEO(I) = TTUBEI(I) + Q(I)/(WTUBE(I)*CPT(I))
    TAVG(I)     = (TTUBEI(I)+TTUBEO(I))/2.0
    CALL WATER(VAPORT(I),CP,WATERD,WATERK,WATERV,LAT(I))
    CALL WATER(TAVG(I),CPT(I),DEN(I),KT(I),VISC(I),HEAT)
    TWALLA(I) = TWALL(I)
    CALL TRIAL(TWALLA(I),TAVG(I),CI,KT(I),RE(I),PR(I),VISC(I),
   1           VISCW(I),Q(I),AIT,HI(I),ID,TWALL(I),II)
    LMTD(I)     = (TTUBEO(I)-TTUBEI(I))/ALOG((VAPORT(I)-TTUBEI(I))/
   1              (VAPORT(I)-TTUBEO(I)))
    UO(I)       = Q(I)/(LMTD(I)*AOT*II)
    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
    CALL WATER( FILMT(I),CP,DCOND(I),KCOND(I),VCOND(I),HEAT)
    PHYGR(I)    = (KCOND(I)*KCOND(I)*KCOND(I)*DCOND(I)*DCOND(I)/
   1              (VCOND(I)*DELTF(I)))**0.25
    CN(I)       = HCOND(I)/(0.725*PHYGR(I)*(LAT(I)*4.17*10.0**8/(OD*II))
   1              **0.25)
    CNN(I)      = CN(I)/(II**0.25)
218 CONSTA(I) = CONST(I)/0.725
    WRITE(6,20004)
    WRITE(6,20015)
    DO 219  I = 3,N
219 WRITE(6,20010)TUBENO(I),WTUBE(I),TTUBEI(I),TTUBEO(I),TAVG(I),
   1               CPT(I),DEN(I),VISC(I)
    WRITE(6,20016)
    DO 220  I = 3,N
220 WRITE(6,20011)TUBENO(I),KT(I),PR(I),TWALL(I),VISCW(I),VEL(I),
   1               RE(I),HI(I)
    WRITE(6,20017)
    DO 221  I = 3,N
221 WRITE(6,20012)TUBENO(I),VAPORT(I),LAT(I),TWALLO(I),DELTF(I),
   1               FILMT(I),KCOND(I),DCOND(I)
    WRITE(6,20018)
    DO 222  I = 3,N
222 WRITE(6,20013)TUBENO(I),VCOND(I),PHYGR(I),Q(I),LMTD(I),UO(I),
   1               HI(I),HCOND(I)
    WRITE(6,20019)
    DO 223  I = 3,N
223 WRITE(6,20014)TUBENO(I),CONST(I),CONSTA(I),CN(I)
    DO 227  J = 1,2
    WRITE(6,20020)RUNNO, DAY,YEAR
    WRITE(6,20026)METAL1,METAL2,METAL3,METAL4
    WRITE(6,20027)METAL5,METAL6,METAL7,METAL8
    WRITE(6,20021)
```

```
      DO 224  I = 1,2
  224 WRITE(6,20022)TUBENO(I),HG(I),PVEL(I),PTI(I),PTO(I),EMF(I),PTV(I),
     1             PQ(I)
      WRITE(6,20025)
      DO 225  I = 3,N
  225 WRITE(6,20022)TUBENO(I),HG(I),PVEL(I),PTI(I),PTO(I),EMF(I),PTV(I),
     1             PQ(I)
      WRITE(6,20023)
      DO 226  I = 1,2
  226 WRITE(6,20024)TUBENO(I),LMTD(I),UO(I),HI(I),HCOND(I),CN(I),CNN(I)
      WRITE(6,20025)
      DO 227  I = 3,N
  227 WRITE(6,20024)TUBENO(I),LMTD(I),UO(I),HI(I),HCOND(I),CN(I),CNN(I)
      GO TO 101
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                       C
C          STATEMENTS 10001 TO 20028 ARE INPUT AND OUTPUT FORMATS.      C
C                                                                       C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
10001 FORMAT(1H1,5X, 'THE FOLLOWING RESULTS WERE CACULATED FOR THE RAW D
     1ATA ACCORDING TO THE THEORETICAL RELATIONSHIPS OF NUSSELT')
10002 FORMAT(13X,A2,7F15.4)
10003 FORMAT(13X,A2,2F15.3,2F15.5,F15.2)
10004 FORMAT(13X,A2,4X,F15.3,4X,F15.3,2X,F15.3,3X,F15.4)
10005 FORMAT('2',7X,  'TUBE NO    VAPOR TEMP        LAT HEAT        HEAT DUT
     1Y            LMTD            UO              HI              H COND'/
     225X, 'F               BTU/LB          BTU/HR              F       BTU/HR-S
     3QFT-F  BTU/HR-SQFT-F  BTU/HR-SQFT-F'/////)
10006 FORMAT(    7X,  'TUBE NO          DT FILM       FILM TEMP           C-K
     1       C-DENSITY              PHYGR'/26X, 'F                 F           BTU/
     2HR-FT            LB/CUFT'/////)
10007 FORMAT('2',7X,  'TUBE NO                 HI                      UO
     1     H COND                    CN'/23X, 'BTU/HR-SQFT-F      BTU/HR-SQFT-
     2F      BTU/HR-SQFT-F'/////)
20001 FORMAT(1H1,30X,'CALCULATED RESULTS FOR RUN NUMBER      ',3A8)
20002 FORMAT(1H1,30X,'CALCULATED RESULTS FOR RAW DATA')
20003 FORMAT(1H1,15X, 'CALCULATED RESULTS FOR DATA ADJUSTED TO CONSTANT
     1 INLET WATER TEMPERATURE AND CONSTANT VAPOR TEMPERATURES')
20004 FORMAT(1H1,38X, 'CALCULATED RESULTS ARE FOR AVERAGE CONDITIONS FOR
     1 TOP I TUBES')
20005 FORMAT(5F10.4, I2,8X,4A5)
20006 FORMAT(A2,8X,4F10.4)
20007 FORMAT(3A8)
20008 FORMAT( '  TUBE OUTSIDE DIAMETER - INCHES'31X,F10.4/ '  TUBE INSID
     1E DIAMETER - INCHES'32X,F10.4/ '  TUBE LENTH - INCHES'42X,F10.4/ '
     2  TUBE THERMAL CONDUCTIVITY - BTU/HR-FT-F'22X,F10.4/ '  TUBE METAL
     3',42X,4A5)
20009 FORMAT( '  TUBE OUTSIDE HEAT TRANSFER AREA - SQFT'23X,F10.4/ '  TU
     1BE INSIDE HEAT TRANSFER AREA - SQFT'24X,F10.4/ '  TUBE FLOW AREA -
     2 SQFT'40X,F13.7/ '  METAL RESISTANCE - BTU/HR-SQFT-F'29X,F13.7/ '
     3 INSIDE COEFFICIENT CONSTANT'35X,F10.5)
20010 FORMAT(13X,A2,F15.0,6F15.3)
20011 FORMAT(13X,A2,F15.3,2F15.2,2F15.3,2F15.2)
20012 FORMAT(13X,A2,F15.3,F15.2,3F15.3,3F15.4,F15.3)
20013 FORMAT(13X,A2,2F15.3,F15.2,4F15.3)
20014 FORMAT(13X,A2,3F15.4)
20015 FORMAT('2',7X, 'TUBE NO          W TUBE        T TUBE IN      T TUBE O
     1UT           T-AVG             T-CP         T-DENSITY      T-VISCOSITY'/
     2  24X, 'LB/HR                 F                F                F        B
     3TU/LB-F          LB-CUFT        LB/FT-HR'/////)
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20016 FORMAT( 1H1,7X,'TUBE NO',12X,'T-K',13X,'PR',6X,'T WALL IN',3X,
     1 'TW-VISCOSITY',5X,'T-VELOCITY',12X,'RE',13X,'HI'/  20X,'BTU/HR-FT
     2',  29X,'F',8X,'LB/FT-HR',9X,'FT/SEC',17X,'BTU/HR-SQFT-F'/////)
20017 FORMAT('2', '          TUBE NO     VAPOR TEMP        LAT HEAT     T
     1WALL OUT       DT-FILM        T-FILM               C-K          C-DENSIT
     2Y'/30X,'BTU/LB                  F                       F           F
     3        BTU/HR/FT        LB/CUFT'/////)
20018 FORMAT('2', '         TUBE NO     C-VISCOSITY               PHYGR      HE
     1AT DUTY            LMTD          UO                    HI          H COND
     3'/ '                       LB/FT-HT                               BTU/HR
     4                 F   BTU/HR-SQFT-F  BTU/HR-SQFT-F  BTU/HR-SQFT-F'/////)
20019 FORMAT('2', '         TUBE NO     COND CONST      CONST/0.725
     1    CN'/////)
20020 FORMAT(1H1,///// '              SUMMARY SHEET FOR RUN NO.    '3A8)
20021 FORMAT(///// '  NO   ORIFICE   VEL     T IN     T OUT     EMF     T VAP
     1OR     HEAT DUTY'/ '            IN HG    FT/SEC     F        F       M-V
     2  F          BTU/HR'///)
20022 FORMAT(2X,A2,3X,F5.2,3X,F5.2,2X,F6.2,2X,F6.2,2X,F6.4,2X,F6.2,2X,
     1F9.1)
20023 FORMAT(///// '  NO     LMTD       UO          HI          H COND       CN
     1  CN/N-QT'///)
20024 FORMAT(2X,A2,3X,F5.2,3X,F7.1,3X,F7.1,3X,F7.1,3X,F6.4,3X,F6.4)
20025 FORMAT(' **********************************************************
     1******************')
20026 FORMAT(// '                SIDE TUBES                           ',4A5)
20027 FORMAT(   '                CENTER TUBES                         ',4A5)
20028 FORMAT(////////)
      CALL SYSTEM
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C          THE FOLLOWING SUBROUTINE IS WRITTEN FOR THE TRIAL-AND-ERROR          C
C          PROCEDURES FOR FINDING OUT THE CORRECT VISCOSITY ON THE WALL         C
C          WRITTEN IN FORTRAN IV G-LEVEL, ON IBM O/S 360 MODEL 67.              C
C                                                                               C
C          BY GEORGE T. S. CHEN IN MARCH 1968.                                  C
C                                                                               C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SUBROUTINE TRIAL(TT, TA,CI,TH,RE,PR,V,VW,Q,A,HI,DI,TWALL,M)
  104 CALL WATER(TT,CP,WATERD,WATERK,VW,HEAT)
      HI        = CI*TH*RE**0.80*PR**0.33333*(V/VW)**0.14/DI
      TWALL     = TA+ Q/(A*HI*M)
      IF(ABS(TT-TWALL)-0.3)124,124,114
  114 TT        = TWALL
      GO TO 104
  124 RETURN
      END
C
C
      SUBROUTINE WATER(T, CP, WATERD, WATERK, WATERV, HEAT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C          THIS SUBROUTINE IS WRITTEN FOR THE CALCULATION OF                    C
C          THE PHYSICAL PROPERTIES OF WATER AND STEAM.                          C
C                                                                               C
C          EQUATIONS OBTAINED FROM DALE BRIGG.                                  C
C                                                                               C
C          WRITTEN BY GEOTGE T. S. CHEN IN MARCH 1968                           C
C                                                                               C
C          T          #  TEMPERATURE                                            C
C          CP         #  SPECIFIC HEAT AS FUNCTION OF TEMPERATURE               C
C          WATERD     #  DENSITY AS FUNCTION OF TEMPERATURE                     C
```

```
C           WATERK      #  THERMAL CONDUCTIVITY AS FUNCTION OF TEMPERATURE       C
C           WATERV      #  VISCOSITY AS FUNCTION OF TEMPERATURE                  C
C           HEAT        #  LATENT HEAT OF VAPORIZATION AS FUNCTION OF TEMPERATUREC
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      CP          =  (0.10124896E+01)        -(0.46678063E-03)*T
     1              +(0.58540867E-05)*T**2  -(0.32721741E-07)*T**3
     2              +(0.72640616E-10)*T**4
      WATERD      =  (0.63130000E+02)        -(0.11700000E-01)*T
      WATERK      =  (0.30377927E+00)        +(0.25267360E-03)*T
     1              +(0.92050520E-05)*T**2  -(0.75847219E-07)*T**3
     2              +(0.17507457E-09)*T**4
      DUMMY     =                            -(0.21968718E+01)
     1              +(0.54722744E+03)/T     -(0.41363282E+05)/T**2.0
     2              +(0.16141324E+07)/T**3.0-(0.24764542E+08)/T**4.0
      WATERV    = EXP(DUMMY)
      HEAT        =  (0.10952000E+04)        -(0.58000000E+00)*T
      RETURN
      END
```

NOMENCLATURE

AFLOW	Cross-sectional flow area per tube; ft.^{2}
AIT	Total inside heat transfer area per tube; ft.^{2}
AMET	Mean heat transfer area per tube; ft.^{2}
AOT	Total outside heat transfer area per tube; ft.^{2}
ATIN	Average inlet temperature of coolant for n tubes in a vertical row; °F
AVGVEL	Average coolant velocity for n tubes in a vertical row, ft./sec.
AVGVT	Average vapor temperature for n tubes in a vertical row, °F
CI	Seider-Tate constant for inside heat transfer coefficient
CN	Condensing heat transfer coefficient correction factor
CNN	$C_n/(N)^{1/4}$
CP	Dummy variable
CPT	Heat capacity of coolant at the average bulk temperature of the coolant; BTU/lb.
DAY, YEAR	Date on which run was taken for format
DCOND	Density of the condensate at the film temperature; lbs./ft.^{3}
DELTF	Temperature drop across the condensing film; °F
DEN	Density of coolant at the average bulk temperature of the coolant; lbs./ft.^{3}
DM	Mean diameter; ft.
EMF	Thermocouple reading; emf
FILMT	Temperature of the condensing film; °F
HCOND	Condensing heat transfer coefficient, BTU/hr.-ft.^{2}-°F
HEAT	Dummy variable
HG	Orifice pressure drop in inches of Hg; ins. of Hg
HI	Inside heat transfer coefficient; BTU/hr.-ft.^{2}-°F
ID	Tube inside diameter; ins.
KCOND	Thermal conductivity of the condensate at the film temperature; BTU/hr.-ft.-°F
KT	Thermal conductivity of coolant at average bulk temperature of the coolant; BTU/hr.-ft.-°F

LAT	Latent heat of vaporization at the saturated vapor temperature; BTU/lb.
LMTD	Logarithmic temperature differential; °F
METAL1	Tube description for format statement
METAL2	Tube description for format statement
METAL3	Tube description for format statement
METAL4	Tube description for format statement
N	Number of tubes in a vertical row
OD	Tube outside diameter; ins.
PHYGR	Physical property group: $\left[\dfrac{k_f^3 \ \rho_f^2}{\mu_f \ \Delta t_f}\right]^{1/4}$
PQ	Q
PR	Prandtl Number; dimensionless
PTI	TTUBEI
PTO	TTUBEO
PTV	VAPORT
PVEL	VEL
QA, Q	Heat duty; BTU/hr.
RE	Reynolds Number; dimensionless
RM	Metal resistance; hr./ft.^{2}-°F-BTU
RUNNO	Run number for output format
SCPT	Summation of the coolant heat capacities for n tubes in a vertical row; BTU/lb.
SDEN	Summation of the coolant densities for n tubes in a vertical row; lbs./ft.^{3}
STIN	Summation of the coolant inlet temperatures for n tubes in a vertical row; °F
SUMVEL	Summation of the velocities for n tubes in a vertical row; ft./sec.
SUMVT	Summation of the vapor temperatures for n tubes in a vertical row; °F

TAVG	Average bulk temperature of coolant in a tube; °F
TK	Thermal conductivity of tube metal; BTU/hr.-ft.-°F
TL	Tube length; ins.
TTUBEI	Temperature of coolant entering test tubes; °F
TTUBEO	Temperature of coolant leaving a tube; °F
TUBENO	Tube number in a vertical row
TWALLA, TWALL	Temperature of coolant at tube wall; °F
TWALLO	Temperature of condensate at the tube outside wall; °F
UO	Overall outside heat transfer coefficient, BTU/hr.-ft.^{2}-°F
VAPORT	Temperature of saturated vapor; °F
VCOND	Viscosity of the condensate at the film temperature, lbs./hr.-ft.
VEL	Tubeside coolant velocity; ft./sec.
VISC	Viscosity of coolant at average bulk temperature of the coolant; lbs./hr.-ft.
VISCW	Viscosity of coolant at the temperature of the coolant at the tube wall; lbs./hr.-ft.
WATERD	Dummy variable
WATERK	Dummy variable
WTUBE	Coolant flow rate in a tube; lbs./sec.

TABLE III-1

Sample Computer Printout for 5/8-inch Corrugated Copper Tubes

SUMMARY SHEET FOR RUN NO. 205874E SEPT.26,1967

BARE TUBES COPPER NO. 100

CORRUGATED TUBES COPPER NO. 1300

NO	ORIFICE IN HG	VEL FT/SEC	T IN F	T OUT F	EMF VOLTS	T VAP F	HEAT DUTY BTU/HR
A	11.41	3.62	80.30	88.19	1.2446	99.81	10491.0
B	9.32	3.41	81.31	88.39	1.2492	100.06	8864.0
1	25.61	5.91	80.40	90.41	1.2955	100.20	20291.8
2	26.24	5.91	80.40	89.85	1.2826	100.09	39520.0
3	26.09	6.05	80.37	89.98	1.2857	99.92	59482.6
4	26.56	5.99	80.30	89.85	1.2827	100.02	79079.1
5	25.20	5.97	80.40	89.71	1.2793	100.09	98151.7
6	26.81	6.14	80.39	89.14	1.2664	100.00	116442.7
7	29.29	6.34	80.30	88.66	1.2554	99.28	134773.5
8	28.59	6.28	80.31	89.27	1.2694	99.80	153826.9

NO	LMTD F	UO	HI	H COND	CN	CN/N-QT
A	15.22	700.2	991.7	3814.7	1.2431	1.2431
B	14.93	603.3	946.6	2289.5	.8137	.8137
1	14.13	1487.7	3752.3	2899.8	1.2028	1.2028
2	14.29	1432.2	3744.5	2701.0	1.3481	1.1336
3	14.27	1439.2	3749.9	2722.5	1.5020	1.1413
4	14.29	1433.2	3747.2	2702.9	1.6042	1.1343
5	14.33	1418.9	3745.1	2653.6	1.6703	1.1170
6	14.40	1396.2	3741.2	2577.4	1.7059	1.0900
7	14.45	1380.7	3740.8	2525.2	1.7428	1.0715
8	14.45	1378.1	3743.1	2515.6	1.7963	1.0681

TABLE III-2

Sample Computer Printout
for 1-inch Bare 90-10 Cupro-Nickel Tubes

SUMMARY SHEET FOR RUN NO. 2060708 MAY 31, 1968

SIDE TUBES 90/10 CU-NI NO. 200
CENTER TUBES 90/10 CU-NI NO. 200

NO	ORIFICE IN HG	VEL FT/SEC	T IN F	T OUT F	EMF M-V	T VAPOR F	HEAT DUTY BTU/HR
A	20.50	4.87	178.18	186.44	3.6210	211.05	39290.1
B	21.70	4.92	178.27	186.22	3.6154	211.15	38160.1
************	************	************	************	************	************	************	************
1	21.55	4.84	178.27	186.66	3.6264	211.05	40031.0
2	22.25	4.86	178.27	186.09	3.6120	211.14	77346.1
3	21.65	4.95	178.18	185.95	3.6085	211.14	114711.1
4	22.25	4.89	178.18	185.92	3.6076	211.05	151757.1
5	22.10	4.98	178.09	185.97	3.6090	211.17	189662.4
6	22.55	4.89	177.91	185.34	3.5930	211.05	224999.4
7	21.80	4.84	177.82	185.88	3.6067	211.05	263019.9

NO	LMTD	UO	HI	H COND	CN	CN/N-QT
A	28.54	872.9	1753.3	2939.4	1.0914	1.0914
B	28.72	842.2	1764.9	2589.9	0.9861	0.9861
************	************	************	************	************	************	************
1	28.59	887.6	1759.3	3092.6	1.1386	1.1386
2	28.75	852.9	1757.0	2713.9	1.2183	1.0245
3	28.80	841.8	1756.7	2605.5	1.3044	0.9912
4	28.83	834.2	1756.3	2535.3	1.3709	0.9694
5	28.83	834.0	1756.7	2532.8	1.4484	0.9686
6	28.88	823.1	1755.1	2438.0	1.4694	0.9389
7	28.87	825.0	1756.9	2450.8	1.5339	0.9430

TABLE III-3

Sample Computer Printout for 1-inch Corrugated 90-10 Cupro-Nickel Tubes

SUMMARY SHEET FOR RUN NO. 205998A FEB. 16, 1968

BARE TUBES 90/10 CU-NI NO. 200
CORRUGATED TUBES 90/10 CU-NI NO. 2000

NO	ORIFICE IN HG	VEL FT/SEC	T IN F	T OUT F	EMF VOLTS	T VAP F	HEAT DUTY BTU/HR
A	8.15	2.99	76.36	82.01	1.1033	100.74	16696.5
B	8.08	2.99	76.46	81.99	1.1030	100.69	16374.3
1	8.15	3.49	76.48	85.30	1.1783	100.59	25584.5
2	8.05	3.53	76.40	84.84	1.1680	100.54	50220.8
3	7.70	3.50	76.30	84.92	1.1698	100.51	75186.9
4	8.35	3.55	76.20	84.93	1.1700	100.64	100443.0
5	7.71	3.47	76.09	84.56	1.1615	100.54	124684.1
6	7.98	3.44	76.08	84.71	1.1649	100.64	149125.7
7	8.05	3.50	76.18	85.17	1.1755	100.64	174927.0

NO	LMTD F	UO	HI	H COND	CN	CN/N-QT
A	21.43	493.9	741.9	2820.6	1.1116	1.1116
B	21.34	486.4	742.2	2587.7	1.0377	1.0377
1	19.56	886.6	1856.8	3150.6	1.3489	1.3489
2	19.66	865.9	1853.8	2912.6	1.5062	1.2666
3	19.67	863.8	1854.8	2886.2	1.6549	1.2574
4	19.66	865.9	1855.3	2907.2	1.7888	1.2648
5	19.70	858.4	1853.8	2829.4	1.8504	1.2375
6	19.71	854.8	1853.2	2792.5	1.9164	1.2245
7	19.68	860.7	1856.1	2847.9	2.0237	1.2441

APPENDIX IV

Tables IV-1 through IV-13 Containing
the Summary of the Calculated C_n and U_o Values for
the 5/8-inch Bare, the 5/8-inch Corrugated, the 1-inch Bare, and
the 1-inch Corrugated Tubes

TABLE IV-1

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 101°F on 1 to 7 1-inch Bare 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206074A	3.51	24	1.56	1.50	1.62	1.71	1.76	1.79	1.83
206074B	3.57	24	1.63	1.59	1.73	1.78	1.84	1.85	1.88
206078A	3.62	22	1.14	1.02	1.08	1.12	1.15	1.21	1.25
206078B	3.62	22	1.24	1.07	1.13	1.17	1.19	1.25	1.29
206080B	3.66	18	1.42	1.34	1.43	1.47	1.51	1.53	1.57
206084B	3.64	12	1.87	1.68	1.71	1.73	1.75	1.73	1.75
206086A	3.62	23	1.28	1.28	1.33	1.41	1.48	1.51	1.56
206086B	3.61	24	1.39	1.22	1.25	1.33	1.41	1.48	1.54
206088A	3.61	24	1.30	1.02	1.06	1.09	1.11	1.18	1.22
206091A	3.58	24	1.04	1.01	1.09	1.15	1.18	1.26	1.31
206091B	3.58	24	1.11	1.05	1.13	1.19	1.22	1.30	1.35
206098A	3.62	24	1.50	1.42	1.56	1.62	1.69	1.73	1.79
206098B	3.62	24	1.49	1.46	1.57	1.62	1.71	1.75	1.80
206100B	3.57	24	1.22	1.25	1.35	1.39	1.45	1.49	1.52
206104A	3.60	24	1.12	1.15	1.30	1.36	1.41	1.43	1.45
206104B	3.55	24	1.04	1.02	1.12	1.19	1.22	1.27	1.32
206105A	3.71	37	1.31	1.29	1.36	1.41	1.47	1.51	1.55
206105B	3.71	37	1.34	1.31	1.39	1.45	1.52	1.55	1.58
206113A	3.61	32	1.50	1.38	1.47	1.51	1.57	1.61	1.64
206113B	3.60	32	1.47	1.39	1.48	1.52	1.60	1.63	1.66
206115A	3.64	32	1.29	1.29	1.36	1.44	1.51	1.53	1.56
206115B	3.65	32	1.20	1.25	1.34	1.41	1.49	1.51	1.55
206117A	3.61	34	1.38	1.25	1.27	1.34	1.37	1.43	1.45
206117B	3.61	34	1.37	1.21	1.29	1.36	1.40	1.47	1.51
206120A	3.65	35	1.36	1.37	1.44	1.48	1.56	1.63	1.66
206120B	3.65	35	1.26	1.25	1.35	1.42	1.47	1.51	1.54
206122A	3.65	34	1.20	1.25	1.32	1.40	1.46	1.50	1.54
206122B	3.65	34	1.28	1.24	1.35	1.42	1.49	1.53	1.56
206126A	3.60	37	1.33	1.34	1.41	1.45	1.50	1.52	1.55
206126B	3.61	37	1.33	1.28	1.36	1.41	1.49	1.53	1.57

TABLE IV-1 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206081A	4.79	17	1.78	1.68	1.70	1.74	1.77	1.81	1.85
206083A	4.76	11	1.66	1.61	1.68	1.70	1.78	1.78	1.84
206083B	4.77	11	1.90	1.72	1.81	1.81	1.84	1.81	1.85
206075A	4.76	24	1.38	1.35	1.45	1.51	1.55	1.59	1.63
206075B	4.75	24	1.45	1.43	1.51	1.54	1.60	1.64	1.66
206076A	4.75	23	1.43	1.45	1.57	1.61	1.67	1.72	1.75
206076B	4.76	23	1.52	1.52	1.61	1.65	1.71	1.74	1.77
206081A	4.79	17	1.78	1.68	1.70	1.74	1.77	1.81	1.85
206079A	4.69	22	1.38	1.17	1.20	1.25	1.27	1.32	1.37
206079B	4.71	22	1.26	1.13	1.18	1.23	1.26	1.31	1.36
206085A	4.76	22	1.37	1.33	1.44	1.48	1.54	1.57	1.60
206085B	4.75	22	1.41	1.37	1.45	1.50	1.56	1.61	1.64
206087A	4.79	24	1.36	1.34	1.44	1.49	1.55	1.59	1.61
206087B	4.79	24	1.37	1.36	1.45	1.51	1.56	1.59	1.62
206089A	4.75	24	1.15	1.08	1.14	1.19	1.21	1.25	1.29
206099A	4.74	25	1.17	1.23	1.31	1.36	1.43	1.46	1.48
206102A	4.74	24	1.41	1.37	1.45	1.52	1.57	1.59	1.62
206102B	4.74	24	1.29	1.29	1.40	1.46	1.53	1.58	1.61
206103A	4.65	24	1.21	1.21	1.35	1.40	1.46	1.50	1.54
206103B	4.63	24	1.31	1.31	1.41	1.46	1.52	1.55	1.57
206118A	4.80	34	1.35	1.44	1.49	1.49	1.51	1.56	1.59
206118B	4.81	33	1.47	1.37	1.46	1.52	1.58	1.64	1.68
206119A	4.75	36	1.19	1.21	1.34	1.40	1.47	1.52	1.56
206119B	4.75	36	1.28	1.27	1.35	1.41	1.49	1.55	1.60
206121A	4.82	35	1.26	1.20	1.32	1.39	1.46	1.49	1.53
206121B	4.82	34	1.24	1.23	1.33	1.38	1.47	1.52	1.56
206123B	4.78	33	1.28	1.27	1.33	1.40	1.45	1.50	1.53
206123A	4.79	33	1.23	1.25	1.35	1.40	1.47	1.52	1.55
206124A	4.79	33	1.32	1.30	1.37	1.41	1.47	1.51	1.56
206124B	4.79	33	1.23	1.25	1.34	1.38	1.46	1.50	1.52
206128A	4.77	37	1.26	1.31	1.41	1.49	1.57	1.62	1.66
206128B	4.77	36	1.31	1.34	1.42	1.48	1.54	1.59	1.62

TABLE IV-1 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206092A	5.18	24	1.28	1.37	1.48	1.56	1.62	1.67	1.73
206092B	5.18	25	1.24	1.33	1.42	1.49	1.57	1.62	1.67
206093A	5.16	24	1.23	1.23	1.26	1.33	1.39	1.43	1.46
206093B	5.16	24	1.15	1.20	1.30	1.36	1.42	1.46	1.48
206094A	5.18	24	1.26	1.31	1.40	1.46	1.51	1.55	1.57
206094B	5.18	24	1.35	1.36	1.45	1.49	1.54	1.58	1.60
206095A	5.23	24	1.22	1.27	1.35	1.45	1.51	1.54	1.57
206095B	5.18	24	1.30	1.31	1.40	1.45	1.51	1.54	1.57
206096A	5.24	24	1.11	1.07	1.20	1.23	1.31	1.36	1.42
206096B	5.24	24	1.09	1.08	[illegible]	1.25	1.34	1.39	1.44
206097A	5.23	24	1.08	1.06	1.17	1.21	1.30	1.35	1.39
206097B	5.23	24	1.13	1.14	1.26	1.31	1.40	1.44	1.49
206101B	5.25	24	1.36	1.36	1.48	1.46	1.50	1.57	1.61
206106A	6.00	36	1.23	1.24	1.34	1.40	1.48	1.54	1.57
206106B	6.01	36	1.25	1.27	1.37	1.42	1.50	1.54	1.58
206109B	6.00	26	1.31	1.24	1.30	1.34	1.39	1.42	1.46
206109A	6.00	26	1.30	1.22	1.30	1.38	1.44	1.47	1.50
206112A	6.00	32	1.31	1.30	1.38	1.43	1.49	1.52	1.55
206112B	6.01	32	1.26	1.24	1.34	1.41	1.47	1.51	1.53
206114A	5.95	32	1.32	1.29	1.36	1.44	1.51	1.56	1.58
206114B	5.95	32	1.34	1.31	1.34	1.37	1.46	1.50	1.52
206116A	6.02	34	1.15	1.23	1.34	1.41	1.47	1.52	1.55
206116B	6.02	34	1.11	1.18	1.30	1.37	1.44	1.49	1.53
206127B	5.93	37	1.24	1.26	1.35	1.42	1.49	1.54	1.56
206127A	5.93	37	1.30	1.26	1.37	1.4[illegible]	1.50	1.55	1.58

TABLE IV-2

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 212°F on 1 to 7 1-inch Bare 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206053A	3.55	28	1.32	1.37	1.42	1.45	1.50	1.53	1.59
206053B	3.50	29	1.30	1.33	1.39	1.45	1.53	1.56	1.59
206054A	3.49	29	1.28	1.30	1.36	1.40	1.44	1.46	1.49
206054B	3.50	28	1.33	1.28	1.37	1.40	1.44	1.47	1.50
206055A	3.73	28	1.42	1.43	1.62	1.64	1.73	1.75	1.80
206059A	3.63	29	1.23	1.28	1.37	1.43	1.50	1.51	1.56
206059B	3.62	29	1.28	1.32	1.39	1.43	1.51	1.53	1.57
206063A	3.63	29	1.10	1.13	1.23	1.28	1.34	1.37	1.43
206063B	3.61	28	1.19	1.19	1.28	1.32	1.38	1.40	1.45
206067A	3.63	28	1.24	1.25	1.35	1.39	1.46	1.47	1.51
206067B	3.62	28	1.23	1.31	1.40	1.44	1.50	1.51	1.56
206111B	3.63	44	1.04	1.10	1.18	1.24	1.31	1.34	1.39
206111A	3.65	43	1.08	1.14	1.23	1.29	1.35	1.39	1.44
206125A	3.56	44	1.06	1.11	1.20	1.25	1.32	1.36	1.41
206125B	3.56	44	1.06	1.11	1.20	1.26	1.32	1.36	1.41
206129A	3.71	44	1.07	1.11	1.19	1.25	1.31	1.35	1.39
206129B	3.71	45	1.05	1.12	1.19	1.24	1.32	1.36	1.39
206131A	3.71	44	1.07	1.11	1.20	1.26	1.32	1.36	1.41
206131B	3.71	44	1.04	1.11	1.20	1.26	1.33	1.38	1.42
206133A	3.62	44	1.13	1.11	1.19	1.24	1.30	1.33	1.37
206133B	3.59	44	1.08	1.10	1.18	1.23	1.31	1.34	1.38
206135A	3.62	44	1.10	1.12	1.19	1.25	1.32	1.34	1.38
206135B	3.50	45	1.07	1.10	1.19	1.24	1.29	1.32	1.33

TABLE IV-2 (Continued)

Run No.	Velocity ft. / sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206058A	5.50	29	1.35	1.36	1.43	1.48	1.55	1.57	1.61
206058B	5.49	29	1.35	1.37	1.46	1.52	1.60	1.62	1.66
206064A	5.43	29	1:18	1.22	1.31	1.36	1.42	1.46	1.52
206064B	5.44	28	1.20	1.23	1.32	1.39	1.44	1.47	1.53
206066A	5.36	28	1.19	1.27	1.35	1.41	1.49	1.51	1.56
206066B	5.37	28	1.26	1.30	1.38	1.44	1.53	1.55	1.61
206069A	5.40	29	1.10	1.21	1.31	1.38	1.46	1.49	1.53
206071A	5.36	29	1.14	1.21	1.33	1.40	1.48	1.51	1.55
206071B	5.36	29	1.11	1.25	1.37	1.42	1.50	1.51	1.57
206072A	5.34	29	1.09	1.27	1.41	1.50	1.62	1.66	1.70
206062A	4.88	29	1.08	1.13	1.24	1.31	1.37	1.40	1.45
206062B	4.90	28	1.07	1.13	1.21	1.27	1.34	1.37	1.42
206065A	4.87	29	1.07	1.11	1.18	1.25	1.30	1.34	1.39
206065B	4.85	29	1.06	1.09	1.17	1.24	1.29	1.34	1.40
206068A	4.91	29	1.18	1.18	1.28	1.32	1.39	1.42	1.47
206068B	4.93	29	1.23	1.27	1.35	1.41	1.47	1.49	1.54
206070A	4.90	28	1.16	1.22	1.32	1.38	1.47	1.50	1.55
206070B	4.89	28	1.14	1.22	1.30	1.37	1.45	1.47	1.53
206073B	4.78	28	1.39	1.52	1.62	1.66	1.76	1.78	1.85
206082A	4.88	28	1.08	1.13	1.22	1.28	1.34	1.39	1.43
206082B	4.89	28	1.15	1.17	1.24	1.31	1.37	1.40	1.44
206107A	6.12	29	1.19	1.21	1.32	1.38	1.44	1.46	1.51
206107B	6.12	28	1.21	1.25	1.35	1.41	1.49	1.51	1.56
206108A	6.10	43	1.04	1.10	1.21	1.27	1.36	1.44	1.48
206108B	6.11	43	1.06	1.12	1.22	1.29	1.37	1.42	1.47
206110A	6.04	45	1.07	1.11	1.20	1.26	1.33	1.37	1.42
206110B	6.04	45	1.07	1.11	1.21	1.28	1.35	1.39	1.44
206130A	5.99	48	1.06	1.12	1.21	1.28	1.34	1.38	1.43
206130B	5.99	48	1.05	1.12	1.21	1.26	1.32	1.37	1.40
206132A	6.04	47	1.04	1.06	1.15	1.20	1.28	1.31	1.35
206132B	6.00	46	1.03	1.12	1.22	1.26	1.34	1.37	1.41
206134A	5.99	47	1.04	1.08	1.17	1.23	1.29	1.32	1.36
206134B	6.00	47	1.05	1.05	1.13	1.18	1.24	1.29	1.33
206136A	6.01	46	1.11	1.12	1.21	1.27	1.34	1.38	1.42
206136B	6.02	46	1.09	1.11	1.20	1.26	1.33	1.36	1.41

TABLE IV-3

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 101°F on 1 to 7 1-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
205987A	3.50	27	1.13	1.26	1.39	1.48	1.52	1.56	1.68
205987B	3.50	27	1.12	1.29	1.39	1.49	1.53	1.56	1.69
205988A	3.50	19	1.25	1.43	1.58	1.72	1.77	1.83	1.90
205988B	3.50	19	1.30	1.47	1.63	1.75	1.80	1.85	1.93
205989A	3.52	9	1.31	1.36	1.47	1.60	1.70	1.81	1.98
205989B	3.52	10	1.85	1.70	1.77	1.91	1.92	1.97	2.05
205990A	3.52	19	1.50	1.69	1.85	1.99	2.01	2.09	2.19
205990B	3.52	19	1.42	1.57	1.72	1.87	1.91	1.98	2.11
205991A	3.51	24	1.59	1.77	1.93	2.08	2.12	2.18	2.30
205991B	3.51	24	1.49	1.71	1.89	2.04	2.08	2.13	2.23
205992A	3.37	24	1.30	1.49	1.67	1.84	1.89	1.94	2.04
205992B	3.37	24	1.29	1.49	1.65	1.80	1.86	1.92	2.01
205993A	3.50	20	1.13	1.23	1.34	1.40	1.44	1.50	1.60
205993B	3.50	20	1.13	1.25	1.38	1.47	1.49	1.53	1.63
205994A	3.53	27	1.23	1.37	1.51	1.62	1.66	1.70	1.81
205994B	3.49	27	1.21	1.36	1.50	1.58	1.61	1.65	1.75
205995A	3.50	24	1.29	1.42	1.52	1.61	1.63	1.66	1.75
205995B	3.49	24	1.16	1.32	1.47	1.57	1.60	1.64	1.74
205996A	3.49	27	1.23	1.42	1.55	1.70	1.77	1.82	1.93
205996B	3.49	27	1.30	1.44	1.59	1.73	1.78	1.82	1.93
205997A	3.50	9	1.12	1.11	1.23	1.32	1.37	1.44	1.54
205997B	3.50	10	1.08	1.15	1.22	1.34	1.40	1.46	1.56
205998A	3.50	20	1.35	1.51	1.66	1.79	1.85	1.92	2.02
205998B	3.50	19	1.40	1.59	1.75	1.88	1.93	1.98	2.08
205999A	3.49	25	1.29	1.45	1.59	1.72	1.77	1.82	1.92
205999B	3.49	25	1.30	1.47	1.61	1.73	1.77	1.81	1.91
206000A	3.50	27	1.28	1.48	1.69	1.84	1.87	1.89	1.98
206000B	3.50	27	1.31	1.54	1.71	1.85	1.87	1.89	1.99
206001A	3.49	27	1.29	1.47	1.65	1.79	1.84	1.88	1.98
206001B	3.49	27	1.31	1.52	1.69	1.83	1.87	1.91	2.01
206002A	3.51	9	1.36	1.55	1.65	1.71	1.70	1.70	1.78
206002B	3.51	9	1.30	1.38	1.53	1.54	1.58	1.65	1.72

TABLE IV-3 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206020A	3.57	24	1.45	1.74	1.95	2.13	2.16	2.20	2.30
206020B	3.58	24	1.50	1.61	1.77	1.90	1.95	2.04	2.18
206021A	3.64	26	1.58	1.79	1.98	2.17	2.22	2.26	2.36
206021B	3.64	26	1.58	1.82	2.00	2.16	2.22	2.26	2.36
206036B	3.54	24	1.72	1.92	2.09	2.25	2.30	2.35	2.47
206023A	4.76	25	1.45	1.67	1.85	2.01	2.07	2.12	2.23
206023B	4.75	25	1.42	1.67	1.86	2.03	2.10	2.14	2.25
206025A	4.75	25	1.56	1.81	2.03	2.20	2.26	2.30	2.41
206025B	4.76	25	1.57	1.81	2.00	2.16	2.22	2.27	2.37
206026A	4.74	23	1.48	1.69	1.89	2.05	2.14	2.18	2.27
206026B	4.74	23	1.41	1.68	1.89	2.06	2.13	2.17	2.27
206029A	4.75	23	1.44	1.71	1.93	2.11	2.18	2.21	2.31
206029B	4.76	23	1.46	1.73	1.94	2.11	2.18	2.22	2.31
206022A	6.04	26	1.56	1.80	1.99	2.17	2.23	2.26	2.37
206022B	6.03	26	1.51	1.76	1.96	2.15	2.22	2.34	2.38
206024A	6.08	26	1.52	1.76	1.97	2.15	2.20	2.22	2.31
206024B	6.08	26	1.49	1.72	1.93	2.12	2.18	2.21	2.33
206027A	6.11	24	1.38	1.63	1.83	1.99	2.04	2.05	2.15
206027B	6.11	24	1.36	1.60	1.80	2.00	2.06	2.09	2.19
206028A	6.19	22	1.32	1.71	1.91	2.04	2.10	2.14	2.25
206028B	6.21	22	1.32	1.56	1.80	1.95	2.02	2.08	2.20
206030A	6.18	22	1.30	1.55	1.75	1.91	1.94	1.98	2.09
206030B	6.17	22	1.29	1.54	1.73	1.88	1.95	2.00	2.10

TABLE IV-4

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 212°F on 1 to 7 1-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
205954A	3.45	19	1.52	1.59	1.68	1.86	1.91	1.97	2.03
205954B	3.45	19	1.53	1.58	1.78	1.97	2.04	2.12	2.18
205955A	3.58	20	1.50	1.54	1.73	1.86	1.88	1.92	1.92
205955B	3.58	20	1.46	1.53	1.73	1.87	1.90	1.93	1.96
205956A	3.46	20	1.25	1.32	1.52	1.65	1.69	1.71	1.74
205956B	3.45	19	1.21	1.28	1.44	1.58	1.60	1.64	1.69
205957A	3.46	21	1.20	1.14	1.33	1.47	1.54	1.58	1.47
205957B	3.47	21	1.31	1.37	1.51	1.63	1.67	1.71	1.57
205958A	3.43	30	1.18	1.23	1.36	1.46	1.51	1.57	1.50
205958B	3.45	30	1.13	1.23	1.36	1.48	1.53	1.57	1.51
205959A	3.47	30	1.23	1.29	1.42	1.53	1.56	1.60	1.54
205959B	3.47	30	1.24	1.31	1.44	1.54	1.59	1.62	1.56
205960A	3.40	39	1.16	1.24	1.37	1.49	1.54	1.59	1.57
205960B	3.40	39	1.15	1.25	1.39	1.51	1.56	1.61	1.60
205961A	3.45	40	1.23	1.31	1.44	1.56	1.60	1.65	1.63
205961B	3.45	40	1.19	1.26	1.39	1.51	1.55	1.60	1.57
205962A	3.45	39	1.29	1.38	1.50	1.63	1.67	1.72	1.79
205962B	3.45	38	1.27	1.37	1.51	1.64	1.69	1.74	1.80
205963A	3.46	29	1.36	1.43	1.57	1.70	1.73	1.78	1.83
205963B	3.46	28	1.36	1.43	1.58	1.70	1.74	1.79	1.84
205964A	3.46	20	1.27	1.37	1.48	1.59	1.63	1.67	1.74
205964B	3.47	20	1.28	1.36	1.48	1.59	1.63	1.67	1.73
205965A	3.45	28	1.21	1.29	1.41	1.52	1.56	1.60	1.66
205965B	3.45	28	1.23	1.33	1.46	1.43	1.48	1.53	1.61
205966A	3.45	38	1.22	1.32	1.44	1.56	1.59	1.63	1.69
205966B	3.45	38	1.18	1.43	1.53	1.62	1.66	1.69	1.75
205967A	3.51	21	1.16	1.36	1.46	1.54	1.58	1.61	1.66
205967B	3.51	20	1.19	1.28	1.41	1.52	1.54	1.57	1.63
205968A	3.45	40	1.10	1.20	1.33	1.42	1.46	1.50	1.56
205968B	3.46	39	1.14	1.23	1.34	1.43	1.47	1.51	1.57
205969A	3.51	29	1.14	1.18	1.28	1.32	1.37	1.41	1.47
205969B	3.51	29	1.16	1.32	1.48	1.62	1.63	1.68	1.73

TABLE IV-4 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
205970A	3.50	40	1.26	1.33	1.44	1.55	1.58	1.62	1.68
205970B	3.50	40	1.26	1.33	1.45	1.50	1.55	1.59	1.65
205974A	3.47	41	1.26	1.41	1.55	1.68	1.74	1.79	1.87
205974B	3.46	40	1.21	1.37	1.51	1.64	1.70	1.75	1.83
205975A	3.45	30	1.20	1.36	1.49	1.62	1.67	1.71	1.79
205975B	3.46	30	1.19	1.34	1.46	1.60	1.67	1.72	1.80
205976A	3.38	18	1.26	1.45	1.59	1.73	1.78	1.81	1.89
205976B	3.44	17	1.22	1.41	1.56	1.70	1.74	1.78	1.87
205977A	3.56	19	1.37	1.50	1.60	1.71	1.75	1.78	1.86
205977B	3.56	18	1.44	1.52	1.62	1.71	1.76	1.79	1.89
205978A	3.56	39	1.29	1.42	1.53	1.64	1.68	1.72	1.79
205978B	3.56	40	1.21	1.34	1.45	1.57	1.62	1.67	1.74
205979A	3.54	29	1.17	1.29	1.39	1.50	1.55	1.58	1.66
205979B	3.54	30	1.16	1.29	1.40	1.51	1.57	1.61	1.68
205980A	3.62	22	1.13	1.33	1.48	1.59	1.67	1.70	1.78
205980B	3.61	21	1.27	1.44	1.58	1.71	1.74	1.78	1.85
205982B	3.57	25	1.45	1.51	1.63	1.77	1.82	1.87	1.94
205983A	3.47	25	1.66	1.81	2.00	2.17	2.24	2.30	2.39
205983B	3.47	25	1.73	1.97	2.16	2.32	2.34	2.37	2.47
205984A	3.50	35	1.40	1.59	1.74	1.90	1.95	1.99	2.05
205984B	3.50	35	1.34	1.50	1.64	1.80	1.86	1.91	1.99
205985A	3.50	25	1.20	1.29	1.45	1.58	1.64	1.68	1.75
205985B	3.50	25	1.31	1.38	1.50	1.63	1.67	1.72	1.81
206003A	3.54	37	1.29	1.41	1.54	1.66	1.70	1.74	1.81
206003B	3.54	37	1.29	1.41	1.53	1.65	1.69	1.73	1.80
206004A	3.54	32	1.27	1.41	1.53	1.65	1.70	1.73	1.80
206005A	3.56	34	1.27	1.37	1.51	1.60	1.65	1.68	1.75
206005B	3.56	34	1.26	1.36	1.49	1.61	1.66	1.69	1.76
206006A	3.59	28	1.24	1.36	1.45	1.58	1.67	1.68	1.74
206006B	3.55	29	1.22	1.31	1.43	1.55	1.61	1.62	1.70

TABLE IV-4 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206037A	4.04	29	1.51	1.58	1.72	1.86	1.90	1.93	1.99
206037B	4.04	29	1.50	1.57	1.70	1.84	1.90	1.93	1.99
206040A	4.04	38	1.48	1.52	1.65	1.79	1.85	1.89	1.96
206040B	4.04	37	1.60	1.61	1.75	1.88	1.92	1.97	2.04
206041A	4.06	38	1.44	1.51	1.63	1.76	1.81	1.87	1.94
206041B	4.06	38	1.45	1.54	1.67	1.81	1.86	1.90	1.97
206043A	4.05	38	1.39	1.49	1.62	1.75	1.81	1.86	1.93
206043B	4.05	38	1.41	1.50	1.65	1.77	1.83	1.87	1.94
206045A	4.04	38	1.40	1.51	1.64	1.77	1.81	1.86	1.92
206045B	4.04	38	1.43	1.53	1.66	1.79	1.84	1.87	1.93
206047A	4.04	38	1.46	1.53	1.66	1.79	1.85	1.89	1.95
206047B	4.04	38	1.40	1.50	1.70	1.79	1.84	1.88	1.94
206048A	4.03	39	1.29	1.34	1.47	1.59	1.63	1.66	1.72
206048B	4.02	38	1.31	1.34	1.46	1.58	1.63	1.67	1.73
206031A	4.80	38	1.58	1.66	1.80	1.94	2.00	2.04	2.12
206031B	4.80	38	1.51	1.62	1.77	1.91	1.97	2.05	2.11
206032A	4.80	38	1.50	1.58	1.73	1.88	1.94	1.98	2.05
206032B	4.80	38	1.51	1.60	1.74	1.89	1.95	1.99	2.06
206033A	4.80	38	1.50	1.63	1.77	1.91	1.98	2.04	2.10
206033B	4.80	38	1.63	1.70	1.85	1.99	2.04	2.11	2.16
206034A	4.82	37	1.61	1.72	1.84	1.97	2.01	2.05	2.11
206034B	4.82	37	1.60	1.70	1.82	1.95	1.99	2.03	2.09
206035A	4.82	38	1.55	1.66	1.79	1.92	1.97	2.01	2.08
206035B	4.82	38	1.57	1.68	1.80	1.93	1.98	2.00	2.07
206044A	5.31	40	1.38	1.47	1.61	1.75	1.80	1.84	1.91
206044B	5.30	40	1.39	1.45	1.59	1.72	1.77	1.82	1.88
206046A	5.30	40	1.45	1.52	1.65	1.77	1.83	1.87	1.93
206046B	5.30	39	1.42	1.50	1.64	1.76	1.81	1.85	1.91
206049A	5.32	40	1.39	1.45	1.60	1.72	1.78	1.82	1.88
206049B	5.31	40	1.37	1.43	1.57	1.70	1.75	1.80	1.86
206050A	5.35	40	1.33	1.41	1.58	1.70	1.75	1.79	1.86
206050B	5.35	40	1.31	1.39	1.54	1.64	1.72	1.77	1.84
206051A	5.28	40	1.33	1.41	1.57	1.69	1.74	1.79	1.85
206051B	5.28	40	1.31	1.40	1.56	1.67	1.73	1.79	1.85
206052A	5.30	40	1.34	1.44	1.61	1.72	1.79	1.83	1.90
206052B	5.30	40	1.35	1.44	1.60	1.72	1.79	1.84	1.91

TABLE IV-4 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206011B	6.03	39	1.38	1.53	1.69	1.86	1.90	1.95	2.04
206012A	6.04	30	1.41	1.59	1.76	1.92	1.97	2.01	2.10
206012B	6.04	30	1.43	1.59	1.81	1.96	2.01	2.06	2.14
206013A	6.32	39	1.52	1.62	1.80	1.97	2.00	2.03	2.11
206013B	6.32	39	1.50	1.63	1.80	1.94	1.98	2.02	2.09
206014A	6.14	39	1.38	1.64	1.80	1.85	1.89	1.93	2.00
206014B	6.13	39	1.37	1.54	1.70	1.84	1.90	1.94	2.02
206015A	6.13	30	1.46	1.61	1.81	1.91	1.97	2.01	2.04
206015B	6.13	30	1.32	1.52	1.71	1.87	1.94	2.00	2.09
206016A	6.18	20	1.68	1.77	1.92	2.05	2.12	2.14	2.23
206016B	6.18	20	1.59	1.69	1.82	1.97	2.04	2.07	2.16
206017A	6.19	39	1.50	1.61	1.74	1.83	1.97	2.00	2.04
206017B	6.18	39	1.53	1.62	1.78	1.90	1.94	1.99	2.06
206018A	6.15	21	1.65	1.75	1.89	2.04	2.09	2.12	2.21
206018B	6.16	21	1.67	1.65	1.79	1.91	1.95	1.99	2.08
206019A	6.19	21	1.58	1.69	1.86	2.03	2.06	2.09	2.16
206019B	6.19	21	1.59	1.65	1.83	1.95	2.02	2.06	2.15
205981A	6.32	30	1.49	1.62	1.75	1.92	1.96	2.00	2.09
205981B	6.32	29	1.51	1.65	1.77	1.94	1.99	2.04	2.13
206007A	6.08	30	1.49	1.59	1.73	1.90	1.93	1.99	2.06
206008A	6.07	41	1.46	1.58	1.74	1.94	1.98	2.02	2.09
206008B	6.08	41	1.44	1.55	1.71	1.87	1.93	1.98	2.06
206009A	6.12	20	1.67	1.74	1.89	2.04	2.07	2.10	2.16
206009B	6.13	20	1.61	1.69	1.83	1.98	2.02	2.06	2.16
206011A	6.04	39	1.39	1.57	1.74	1.88	1.95	2.00	2.08

TABLE IV-5

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 101°F on 1 to 9 5/8-inch Bare Copper Tubes in a Vertical Row

		C_n for n Copper Tubes in a Vertical Row								
Run No.	Vel.	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-6

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 101°F on 1 to 8 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7	8
205889A	2.86	9	1.07	1.21	1.35	1.43	1.48	1.50	1.55	1.59
205882A	3.85	8	1.28	1.43	1.61	1.68	1.74	1.78	1.81	1.85
205879A	4.75	9	1.02	1.19	1.32	1.41	1.47	1.50	1.56	1.61
205879B	4.75	9	1.07	1.21	1.33	1.41	1.46	1.79	1.51	1.58
205878A	5.34	10	1.25	1.36	1.48	1.55	1.60	1.63	1.68	1.71
205878B	5.33	10	1.23	1.35	1.46	1.54	1.58	1.61	1.65	1.70
205862A	5.97	18	1.12	1.31	1.45	1.54	1.59	1.63	1.68	1.72
205864A	6.14	19	1.27	1.45	1.61	1.72	1.78	1.81	1.84	1.88
205865A	6.11	18	1.25	1.44	1.60	1.69	1.75	1.79	1.84	1.87
205870A	6.12	16	1.12	1.30	1.43	1.50	1.52	1.56	1.57	1.61
205870B	6.12	16	1.15	1.32	1.45	1.53	1.54	1.58	1.57	1.62
205871A	6.67	15	1.22	1.46	1.64	1.73	1.80	1.82	1.83	1.86
205873A	6.06	17	1.21	1.37	1.53	1.63	1.70	1.74	1.78	1.82
205873B	6.07	17	1.20	1.36	1.52	1.63	1.68	1.72	1.75	1.80
205873C	6.07	16	1.19	1.37	1.51	1.60	1.67	1.70	1.73	1.78
205874A	6.07	14	1.15	1.28	1.45	1.56	1.62	1.65	1.67	1.73
205874B	6.08	14	1.20	1.35	1.50	1.60	1.67	1.71	1.74	1.80
205874C	6.08	14	1.20	1.39	1.55	1.63	1.69	1.73	1.75	1.81
205875A	6.35	20	1.31	1.44	1.65	1.75	1.82	1.87	1.89	1.93
205875B	6.36	21	1.32	1.49	1.66	1.79	1.85	1.89	1.90	1.95
205876A	6.38	15	1.32	1.50	1.69	1.81	1.89	1.93	1.84	1.90
205876B	6.38	15	1.32	1.52	1.70	1.84	1.92	1.96	1.85	1.90
205880A	5.87	10	1.21	1.36	1.51	1.62	1.69	1.74	1.79	1.83
205880B	5.89	10	1.25	1.36	1.50	1.60	1.66	1.71	1.75	1.79
205888A	6.07	18	1.07	1.25	1.43	1.50	1.54	1.61	1.67	1.70
205888B	5.88	18	1.08	1.25	1.45	1.52	1.58	1.63	1.70	1.69
205888C	6.09	17	1.02	1.19	1.37	1.45	1.50	1.56	1.63	1.65
205904A	6.13	23	1.23	1.44	1.63	1.75	1.82	1.87	1.92	1.96
205904B	6.13	24	1.24	1.45	1.64	1.76	1.83	1.87	1.93	1.96

TABLE IV-7

Condensing Coefficient Correction Factors, C_n, for Condensation of Steam at 212°F on 1 to 8 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7	8
205881A	3.95	15	0.81	0.96	1.04	1.10	1.16	1.21	1.25	1.28
205881B	3.95	15	0.82	1.96	1.06	1.14	1.19	1.23	1.26	1.29
205896A	4.01	21	0.85	1.01	1.14	1.23	1.28	1.32	1.36	1.40
205896B	4.02	21	0.86	1.02	1.14	1.23	1.30	1.34	1.38	1.41
205886A	4.76	10	0.78	0.95	1.07	1.17	1.23	1.28	1.30	1.33
205886B	4.75	10	0.79	0.94	1.06	1.14	1.21	1.25	1.27	1.31
205886C	4.75	10	0.79	0.94	1.07	1.14	1.22	1.25	1.27	1.31
205900A	5.57	22	0.92	1.08	1.21	1.30	1.36	1.40	1.44	1.48
205900B	5.58	22	0.92	1.08	1.21	1.31	1.37	1.40	1.44	1.49
205902A	5.58	30	0.97	1.13	1.26	1.35	1.41	1.45	1.49	1.53
205902B	5.58	30	0.99	1.14	1.27	1.36	1.42	1.46	1.51	1.55
205891B	6.3	21	0.94	1.09	1.21	1.31	1.36	1.41	1.45	1.49
205892A	6.4	40	0.99	1.18	1.33	1.43	1.50	1.53	1.57	1.60
205892B	6.3	40	0.98	1.17	1.32	1.43	1.50	1.53	1.57	1.60
205893A	6.4	21	0.95	1.11	1.23	1.33	1.39	1.43	1.47	1.52
205893B	6.4	21	0.95	1.11	1.23	1.32	1.38	1.42	1.47	1.46
205894A	6.3	40	1.01	1.20	1.34	1.44	1.49	1.53	1.58	1.61
205894B	6.3	39	1.01	1.20	1.34	1.44	1.49	1.53	1.58	1.61
205895A	6.5	21	0.97	1.12	1.25	1.35	1.40	1.45	1.49	1.53
205895B	6.5	21	0.97	1.12	1.25	1.34	1.40	1.45	1.49	1.54
205901A	6.4	30	1.00	1.15	1.29	1.39	1.44	1.49	1.53	1.57
205901B	6.4	29	0.97	1.14	1.27	1.37	1.43	1.47	1.52	1.56
205906B	6.2	8	0.81	0.91	0.99	1.07	1.13	1.18	1.21	1.25
205906A	6.3	9	0.82	0.92	1.02	1.12	1.17	1.21	1.23	1.28

TABLE IV-8

Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 101°F on 1 to 7 1-inch Bare 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206074A	3.51	24	565	540	537	535	532	528	526
206074B	3.57	24	574	552	549	544	541	536	533
206078A	3.62	22	542	498	490	485	480	481	480
206078B	3.62	22	553	506	498	493	487	487	486
206080B	3.66	18	588	558	553	547	542	537	536
206084B	3.64	12	639	611	601	534	588	581	577
206086A	3.62	23	556	532	523	521	520	516	515
206086B	3.61	24	565	524	512	511	511	512	512
206088A	3.61	24	552	492	481	475	467	470	469
206091A	3.58	24	521	489	485	483	478	480	481
206091B	3.58	24	530	496	491	488	483	486	486
206098A	3.62	24	571	542	542	537	535	532	531
206098B	3.62	24	570	546	542	537	536	534	532
206100B	3.57	24	542	521	518	511	509	507	504
206104A	3.60	24	532	511	514	511	508	502	498
206104B	3.55	24	518	489	487	486	481	480	479
206105A	3.71	37	564	535	528	521	519	516	514
206105B	3.71	37	568	538	532	526	525	521	517
206113A	3.61	32	586	551	546	538	535	532	529
206113B	3.60	32	584	551	546	539	538	534	531
206115A	3.64	32	575	549	541	538	537	532	528
206115B	3.65	32	565	543	538	535	536	530	528
206117A	3.61	34	570	530	516	513	507	507	502
206117B	3.61	34	569	524	518	515	511	511	510
206120A	3.65	35	567	543	535	529	528	528	524
206120B	3.65	35	557	529	525	521	518	515	511
206122A	3.65	34	552	530	524	521	519	516	514
206122B	3.65	34	561	530	526	523	522	518	516
206126A	3.60	37	559	536	528	521	517	512	509
206126B	3.61	37	561	530	523	517	517	514	512

TABLE IV-8 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206081A	4.79	17	718	684	668	659	652	648	645
206083A	4.76	11	734	704	694	684	682	674	673
206083B	4.77	11	752	715	707	696	689	678	675
206075A	4.76	24	649	614	609	602	596	592	589
206075B	4.75	24	656	624	615	606	602	598	593
206076A	4.75	23	657	630	625	617	613	610	606
206076B	4.76	23	668	639	631	623	619	614	609
206081A	4.79	17	718	684	668	659	652	648	645
206079A	4.69	22	652	590	576	568	560	559	559
206079B	4.71	22	639	584	573	567	559	559	559
206085A	4.76	22	662	625	620	612	608	604	600
206085B	4.75	22	664	628	621	614	609	607	602
206087A	4.79	24	655	620	614	607	604	599	594
206087B	4.79	24	655	622	616	610	605	600	595
206089A	4.75	24	617	569	559	553	545	542	540
206099A	4.74	25	618	594	587	580	578	574	568
206102A	4.74	24	645	610	602	597	593	586	582
206102B	4.74	24	629	598	594	589	587	584	580
206103A	4.65	24	622	590	592	583	581	578	575
206103B	4.63	24	635	604	598	592	588	583	579
206118A	4.80	34	659	637	624	608	600	597	591
206118B	4.81	33	675	626	620	613	610	607	604
206119A	4.75	36	623	590	589	584	583	580	577
206119B	4.75	36	637	599	591	585	586	585	582
206121A	4.82	35	642	595	595	591	588	583	581
206121B	4.82	34	640	601	596	589	590	587	585
206123B	4.78	33	650	613	602	596	592	590	586
206123A	4.79	33	643	609	605	597	595	594	588
206124A	4.79	33	657	618	609	599	596	593	591
206124B	4.79	33	643	610	604	595	595	592	585
206128A	4.77	37	635	607	602	598	598	595	592
206128B	4.77	36	642	613	604	597	594	590	587

TABLE IV-8 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206092A	5.18	24	662	642	636	632	629	626	624
206092B	5.18	25	656	635	628	623	622	618	617
206093A	5.16	24	658	621	605	600	598	593	589
206093B	5.16	24	645	617	611	605	602	598	593
206094A	5.18	24	660	633	626	619	615	610	605
206094B	5.18	24	673	641	633	624	618	614	608
206095A	5.23	24	659	630	622	622	618	613	608
206095B	5.18	24	668	634	627	620	616	610	606
206096A	5.24	24	639	593	595	584	587	584	585
206096B	5.24	24	636	594	596	588	592	589	589
206097A	5.23	24	633	590	588	580	584	582	580
206097B	5.23	24	642	606	606	598	602	598	596
206101B	5.25	24	680	646	641	624	617	618	613
206106A	6.00	36	703	658	652	646	646	643	639
206106B	6.01	36	706	666	659	650	649	645	640
206109B	6.00	26	755	696	683	670	666	659	655
206109A	6.00	26	753	692	682	679	675	668	663
206112A	6.00	32	731	684	673	663	660	654	648
206112B	6.01	32	721	673	667	661	658	652	645
206114A	5.95	32	731	681	668	665	662	658	651
206114B	5.95	32	734	684	665	652	653	647	641
206116A	6.02	34	693	665	661	654	651	647	642
206116B	6.02	34	683	655	652	646	646	643	639
206127B	5.93	37	696	656	648	642	640	636	630
206127A	5.93	37	708	656	651	641	644	638	633

Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 212°F on 1 to 7 1-inch Bare 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206053A	3.55	28	804	774	758	746	741	734	734
206053B	3.50	29	795	762	748	740	741	733	729
206054A	3.49	29	790	754	742	730	723	716	711
206054B	3.50	28	800	752	744	732	725	719	714
206055A	3.73	28	839	802	807	793	792	784	782
206059A	3.63	29	800	768	758	751	750	740	737
206059B	3.62	29	809	775	763	752	752	742	740
206063A	3.63	29	772	735	730	723	720	713	713
206063B	3.61	28	790	747	739	729	725	718	717
206067A	3.63	28	800	761	754	744	742	732	728
206067B	3.62	28	798	770	762	751	748	738	736
206111B	3.63	44	711	680	673	666	666	661	660
206111A	3.65	43	723	694	687	679	677	673	671
206125A	3.56	44	710	678	671	663	662	658	658
206125B	3.56	44	710	677	671	665	663	659	657
206129A	3.71	44	724	688	680	672	672	666	663
206129B	3.71	45	718	689	680	671	672	667	664
206131A	3.71	44	726	690	683	676	673	670	668
206131B	3.71	44	717	689	682	676	676	673	670
206133A	3.62	44	732	684	675	666	664	657	655
206133B	3.59	44	719	679	671	663	664	658	655
206135A	3.62	44	724	684	674	667	667	660	658
206135B	3.50	45	714	678	670	662	659	652	644
206062A	4.88	29	868	824	822	816	813	805	803
206062B	4.90	28	867	828	815	808	806	798	798
206065A	4.87	29	865	816	805	799	793	787	787
206065B	4.85	29	859	812	802	795	791	786	790
206068A	4.91	29	898	839	832	819	818	809	809
206068B	4.93	29	913	867	854	843	839	827	824
206070A	4.90	28	895	852	845	837	840	831	829
206070B	4.89	28	888	853	842	834	834	823	825
206073B	4.78	28	940	914	904	889	889	879	879
206082A	4.88	28	872	830	821	811	809	804	800
206082B	4.89	28	891	839	826	820	817	807	804

TABLE IV-9 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206058A	5.50	29	986	930	913	897	895	882	878
206058B	5.49	29	986	930	917	906	904	894	888
206064A	5.43	29	935	886	874	862	858	850	850
206064B	5.44	28	945	891	881	871	863	855	855
206066A	5.36	28	937	900	885	874	874	863	860
206066B	5.37	28	956	907	894	883	885	873	872
206069A	5.40	29	909	882	872	864	865	855	852
206071A	5.36	29	918	878	875	868	870	858	855
206071B	5.36	29	911	893	887	875	875	859	860
206072A	5.34	29	900	894	893	865	877	872	871
206107A	6.12	29	982	920	915	903	900	887	884
206107B	6.12	28	992	936	926	915	915	902	900
206108A	6.10	43	868	824	821	811	816	821	816
206108B	6.11	43	878	831	825	817	820	816	813
206110A	6.04	45	871	816	807	798	798	792	789
206110B	6.04	45	870	814	811	804	804	798	795
206130A	5.99	48	855	811	802	792	791	784	782
206130B	5.99	48	852	810	799	786	785	779	775
206132A	6.04	47	859	796	788	778	779	770	767
206132B	6.00	46	857	819	813	799	800	790	786
206134A	5.99	47	856	802	793	784	781	773	769
206134B	6.00	47	861	791	779	769	767	762	760
206136A	6.01	46	884	819	809	798	798	791	787
206136B	6.02	46	875	814	806	797	795	787	786

TABLE IV-10

Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 101°F on 1 to 7 1-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
205987A	3.50	27	784	762	762	758	748	741	754
205987B	3.50	27	782	770	762	760	750	742	757
205988A	3.50	19	863	849	850	855	844	840	842
205988B	3.50	19	876	859	859	860	850	844	845
205989A	3.52	9	960	917	909	914	914	921	938
205989B	3.52	10	1054	982	964	965	950	943	943
205990A	3.52	19	922	904	901	902	886	886	887
205990B	3.52	19	905	882	879	882	871	867	876
205991A	3.51	24	907	886	884	883	872	866	872
205991B	3.51	24	888	877	876	878	867	859	863
205992A	3.37	24	832	819	824	832	822	817	820
205992B	3.37	24	830	820	821	826	819	813	816
205993A	3.50	20	828	799	792	783	774	770	780
205993B	3.50	20	827	801	802	797	782	776	785
205994A	3.53	27	815	792	792	790	779	772	780
205994B	3.49	27	806	789	786	780	766	760	768
205995A	3.50	24	842	815	806	800	784	776	782
205995B	3.49	24	807	791	793	793	779	771	778
205996A	3.49	27	814	803	799	807	800	795	802
205996B	3.49	27	832	809	808	812	802	796	802
205997A	3.50	9	910	845	846	848	841	841	851
205997B	3.50	10	894	856	840	846	842	842	852
205998A	3.50	20	887	866	864	866	858	855	861
205998B	3.50	19	898	885	883	883	873	866	870
205999A	3.49	25	840	821	819	822	812	806	811
205999B	3.49	25	843	827	823	824	811	804	809
206000A	3.50	27	825	816	826	830	816	805	809
206000B	3.50	27	832	828	830	832	817	805	811
206001A	3.49	27	826	812	817	821	811	803	809
206001B	3.49	27	832	823	825	828	817	808	813
206002A	3.51	9	972	958	945	933	912	899	900
206002B	3.51	9	956	920	920	899	889	887	889
206020A	3.57	24	883	886	890	895	882	872	875
206020B	3.58	24	893	861	858	859	849	848	858
206021A	3.64	26	912	897	898	904	892	883	886
206021B	3.64	26	914	903	901	904	894	885	887
206036B	3.54	24	931	913	909	909	898	891	895

TABLE IV-10 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	U_o 2	U_o 3	U_o 4	U_o 5	U_o 6	U_o 7
206023A	4.76	25	979	966	967	972	962	953	959
206023B	4.75	25	972	966	970	978	967	957	963
206025A	4.75	25	1012	1002	1008	1011	998	987	992
206025B	4.75	25	1013	1002	1002	1003	993	983	986
206026A	4.74	23	997	981	985	989	984	972	974
206026B	4.74	23	978	980	986	992	981	970	973
206029A	4.75	23	992	992	1000	1006	996	984	986
206029B	4.76	23	997	996	1001	1007	996	986	987
206022A	6.04	26	1086	1074	1073	1079	1066	1052	1055
206022B	6.03	26	1073	1064	1067	1076	1064	1068	1057
206024A	6.08	26	1079	1067	1073	1080	1064	1047	1048
206024B	6.08	26	1069	1054	1062	1072	1058	1044	1050
206027A	6.11	24	1049	1047	1054	1059	1044	1025	1030
206027B	6.11	24	1043	1039	1046	1063	1048	1033	1038
206028A	6.19	22	1044	1085	1091	1086	1073	1060	1066
206028B	6.21	22	1044	1042	1061	1065	1055	1048	1055
206030A	6.18	22	1039	1041	1050	1057	1039	1025	1033
206030B	6.17	22	1039	1040	1046	1054	1042	1032	1038

TABLE IV-11

Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 212°F on 1 to 7 1-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
205954A	3.45	19	1276	1219	1196	1212	1196	1190	1187
205954B	3.45	19	1280	1218	1226	1240	1229	1225	1222
205955A	3.58	20	1280	1210	1219	1219	1196	1185	1163
205955B	3.58	20	1268	1210	1218	1222	1201	1188	1176
205956A	3.46	20	1185	1129	1148	1154	1136	1121	1109
205956B	3.45	19	1173	1118	1123	1134	1115	1104	1097
205957A	3.46	21	1162	1046	1076	1090	1083	1073	1014
205957B	3.47	21	1205	1142	1141	1141	1126	1116	1050
205958A	3.43	30	1092	1028	1025	1028	1016	1011	969
205958B	3.45	30	1077	1032	1032	1037	1025	1015	974
205959A	3.47	30	1116	1054	1051	1052	1034	1024	984
205959B	3.47	30	1124	1065	1060	1060	1046	1034	993
205960A	3.40	39	1038	982	983	989	977	969	944
205960B	3.40	39	1029	987	990	996	982	974	951
205961A	3.45	40	1068	1015	1012	1016	1000	993	967
205961B	3.45	40	1050	994	991	999	982	974	947
205962A	3.45	39	1091	1039	1032	1037	1022	1014	1014
205962B	3.45	38	1087	1036	1035	1041	1028	1019	1017
205963A	3.46	29	1166	1109	1103	1107	1090	1080	1075
205963B	3.46	28	1167	1108	1107	1108	1093	1082	1078
205964A	3.46	20	1192	1142	1132	1130	1116	1105	1106
205964B	3.47	20	1193	1141	1134	1134	1116	1106	1105
205965A	3.45	28	1113	1059	1053	1054	1036	1027	1027
205965B	3.45	28	1112	1066	1062	1016	1004	1000	1006
205966A	3.45	38	1070	1020	1015	1018	999	990	990
205966B	3.45	38	1050	1060	1043	1038	1020	1006	1004
205967A	3.51	21	1148	1141	1125	1115	1101	1087	1082
205967B	3.51	20	1166	1117	1112	1115	1094	1080	1078
205968A	3.45	40	1012	971	969	968	953	945	943
205968B	3.46	39	1035	982	974	974	958	949	949
205969A	3.51	29	1091	1021	1012	989	978	972	971
205969B	3.51	29	1096	1075	1082	1091	1067	1057	1054
205970A	3.50	40	1084	1023	1014	1013	995	984	983
205970B	3.50	40	1086	1027	1018	997	985	977	977

TABLE IV-11 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
205974A	3.47	41	1079	1049	1045	1050	1040	1030	1033
205974B	3.46	40	1060	1034	1034	1040	1029	1020	1023
205975A	3.45	30	1108	1081	1078	1083	1071	1060	1064
205975B	3.46	30	1096	1069	1062	1073	1064	1056	1061
205976A	3.38	18	1201	1186	1181	1186	1172	1159	1162
205976B	3.44	17	1197	1181	1180	1187	1170	1161	1166
205977A	3.56	19	1247	1207	1192	1188	1171	1158	1161
205977B	3.56	18	1278	1221	1201	1194	1179	1166	1175
205978A	3.56	39	1101	1062	1050	1051	1034	1021	1023
205978B	3.56	40	1067	1030	1021	1024	1011	1002	1006
205979A	3.54	29	1103	1066	1052	1054	1040	1028	1033
205979B	3.54	30	1096	1062	1051	1053	1042	1033	1037
205980A	3.62	22	1143	1134	1139	1140	1134	1122	1124
205980B	3.61	21	1202	1177	1173	1178	1158	1146	1148
205982B	3.57	25	1236	1171	1160	1165	1150	1140	1141
205983A	3.47	25	1281	1243	1242	1246	1235	1226	1227
205983B	3.47	25	1302	1281	1278	1278	1256	1242	1243
205984A	3.50	35	1154	1130	1126	1134	1118	1106	1104
205984B	3.50	35	1134	1104	1100	1109	1097	1087	1089
205985A	3.50	25	1133	1082	1091	1099	1090	1078	1081
205985B	3.50	25	1176	1113	1106	1112	1097	1089	1094
206003A	3.54	37	1106	1064	1058	1062	1045	1034	1035
206003B	3.54	37	1108	1065	1056	1059	1042	1032	1033
206004A	3.54	32	1124	1089	1082	1084	1069	1056	1056
206005A	3.56	34	1116	1068	1064	1059	1047	1030	1033
206005B	3.56	34	1114	1066	1059	1062	1048	1034	1036
206006A	3.59	28	1137	1096	1079	1087	1084	1064	1062
206006B	3.55	29	1125	1075	1068	1073	1061	1043	1049
206031A	4.80	38	1318	1247	1236	1237	1221	1205	1207
206031B	4.80	38	1293	1234	1226	1230	1214	1211	1206
206032A	4.80	38	1290	1218	1212	1218	1203	1190	1187
206032B	4.80	38	1291	1224	1215	1222	1205	1192	1189
206033A	4.80	38	1286	1234	1222	1226	1214	1204	1201

TABLE IV-11 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206033B	4.80	38	1334	1261	1250	1251	1233	1225	1217
206034A	4.82	37	1333	1272	1252	1249	1229	1212	1207
206034B	4.82	37	1330	1265	1246	1244	1223	1206	1202
206035A	4.82	38	1310	1250	1235	1234	1216	1201	1198
206035B	4.82	38	1316	1256	1238	1237	1217	1198	1194
206037A	4.04	29	1282	1215	1208	1211	1192	1175	1170
206037B	4.04	29	1277	1211	1200	1204	1189	1176	1171
206040A	4.04	38	1223	1145	1135	1141	1126	1114	1114
206040B	4.04	37	1263	1176	1166	1167	1148	1138	1135
206041A	4.06	38	1209	1142	1130	1133	1119	1110	1109
206041B	4.06	38	1216	1154	1143	1150	1133	1121	1119
206043A	4.05	38	1189	1132	1126	1129	1116	1105	1105
206043B	4.05	38	1199	1139	1133	1136	1121	1109	1108
206045A	4.04	38	1192	1140	1132	1133	1116	1104	1102
206045B	4.04	38	1204	1148	1138	1139	1123	1109	1105
206047A	4.04	38	1214	1146	1135	1140	1126	1112	1110
206047B	4.04	38	1192	1138	1151	1137	1122	1110	1106
206048A	4.03	39	1147	1074	1071	1072	1055	1042	1042
206048B	4.02	38	1155	1075	1067	1069	1055	1044	1044
206044A	5.31	40	1268	1199	1194	1198	1181	1168	1166
206044B	5.30	40	1270	1190	1185	1189	1172	1159	1155
206046A	5.30	40	1295	1220	1208	1207	1190	1175	1173
206046B	5.30	39	1283	1211	1206	1205	1187	1171	1168
206049A	5.32	40	1272	1191	1188	1189	1174	1159	1157
206049B	5.31	40	1260	1182	1177	1179	1164	1152	1151
206050A	5.35	40	1246	1175	1181	1184	1167	1153	1152
206050B	5.35	40	1235	1164	1168	1158	1154	1143	1144
206051A	5.28	40	1245	1174	1176	1175	1162	1148	1147
206051B	5.28	40	1234	1165	1170	1169	1157	1148	1146
206052A	5.30	40	1245	1184	1190	1188	1176	1162	1161
206052B	5.30	40	1250	1184	1187	1188	1177	1164	1163

TABLE IV-11 (Continued)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
205981A	6.32	30	1432	1372	1355	1369	1346	1330	1332
205981B	6.32	29	1443	1383	1365	1378	1357	1341	1344
206007A	6.08	30	1415	1345	1331	1346	1321	1308	1308
206008A	6.07	41	1342	1278	1276	1301	1278	1261	1258
206008B	6.08	41	1333	1266	1264	1274	1258	1245	1248
206009A	6.12	20	1572	1487	1474	1478	1450	1427	1422
206009B	6.13	20	1548	1467	1455	1458	1435	1414	1422
206011A	6.04	39	1315	1280	1280	1285	1271	1258	1258
206011B	6.03	39	1308	1259	1260	1274	1253	1240	1244
206012A	6.04	30	1375	1339	1342	1350	1332	1315	1316
206012B	6.04	30	1389	1343	1362	1368	1348	1333	1332
206013A	6.32	39	1385	1312	1316	1326	1298	1279	1279
206013B	6.32	39	1377	1316	1315	1318	1293	1278	1274
206014A	6.14	39	1310	1311	1304	1275	1252	1237	1235
206014B	6.13	39	1305	1267	1266	1271	1255	1240	1239
206015A	6.13	30	1408	1358	1367	1356	1338	1321	1307
206015B	6.13	30	1337	1318	1330	1340	1328	1317	1321
206016A	6.18	20	1575	1498	1486	1481	1466	1444	1446
206016B	6.18	20	1540	1466	1448	1452	1437	1416	1419
206017A	6.19	39	1370	1301	1285	1273	1285	1263	1251
206017B	6.18	39	1383	1306	1300	1297	1273	1259	1257
206018A	6.15	21	1560	1484	1470	1472	1450	1431	1431
206018B	6.16	21	1562	1443	1428	1423	1401	1381	1385
206019A	6.19	21	1531	1463	1456	1468	1440	1419	1418
206019B	6.19	21	1534	1444	1448	1444	1427	1411	1413

TABLE IV-12

Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 101°F on 1 to 8 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7	8
205889A	2.86	9	1139	1112	1117	1108	1097	1062	1079	1073
205882A	3.85	8	1406	1368	1379	1360	1346	1331	1314	1306
205879A	4.75	9	1356	1334	1341	1337	1322	1303	1304	1304
205879B	4.75	9	1394	1350	1348	1336	1316	1296	1280	1288
205878A	5.34	10	1560	1481	1468	1444	1420	1396	1390	1378
205878B	5.33	10	1548	1473	1458	1442	1412	1390	1380	1373
205862A	5.97	18	1366	1350	1352	1343	1321	1299	1296	1287
205864A	6.14	19	1481	1441	1445	1441	1420	1392	1376	1362
205865A	6.11	18	1463	1435	1441	1426	1403	1381	1371	1359
205870A	6.12	16	1396	1377	1374	1351	1313	1292	1263	1258
205870B	6.12	16	1425	1391	1386	1368	1327	1305	1270	1265
205871A	6.67	15	1535	1543	1554	1539	1518	1488	1454	1435
205873A	6.06	17	1446	1402	1415	1406	1394	1370	1355	1349
205873B	6.07	17	1443	1403	1411	1411	1387	1363	1347	1343
205873C	6.07	16	1450	1416	1414	1405	1390	1367	1348	1342
205874A	6.07	14	1444	1390	1408	1411	1394	1370	1344	1344
205874B	6.08	14	1488	1432	1439	1433	1419	1396	1381	1378
205874C	6.08	14	1490	1462	1469	1452	1434	1410	1387	1385
205875A	6.35	20	1506	1435	1466	1452	1434	1417	1394	1380
205875B	6.36	21	1510	1456	1464	1469	1446	1425	1390	1384
205876A	6.38	15	1596	1550	1568	1563	1551	1528	1441	1441
205876B	6.38	15	1604	1570	1583	1590	1575	1552	1455	1455
205880A	5.87	10	1582	1527	1536	1532	1517	1501	1494	1485
205880B	5.89	10	1615	1534	1531	1523	1503	1487	1475	1466
205888A	6.07	18	1334	1319	1349	1325	1302	1296	1300	1281
205888B	5.88	18	1332	1312	1356	1331	1314	1304	1305	1268
205888C	6.09	17	1301	1280	1316	1306	1286	1279	1286	1263
205904A	6.13	23	1408	1396	1416	1416	1400	1380	1372	1357
205904B	6.13	24	1414	1403	1422	1422	1402	1384	1375	1360

TABLE IV-13

Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 212°F on 1 to 8 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes in a Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7	8
205881A	3.95	15	1446	1446	1425	1409	1406	1398	1394	1383
205881B	3.95	15	1466	1443	1450	1444	1433	1422	1406	1394
205896A	4.01	21	1403	1402	1418	1422	1411	1394	1383	1381
205896B	4.02	21	1418	1408	1424	1428	1421	1405	1395	1388
205886A	4.76	10	1583	1609	1638	1657	1650	1636	1610	1601
205886B	4.75	10	1610	1604	1633	1631	1638	1623	1596	1591
205886C	4.75	10	1615	1614	1648	1637	1645	1626	1595	1592
205900A	5.57	22	1576	1557	1576	1577	1562	1544	1533	1527
205900B	5.58	22	1581	1565	1578	1582	1569	1546	1534	1535
205902A	5.58	30	1543	1517	1526	1522	1506	1486	1474	1464
205902B	5.58	30	1567	1525	1533	1533	1516	1495	1485	1476
205891B	6.3	21	1654	1631	1635	1639	1619	1602	1592	1584
205892A	6.4	40	1484	1489	1513	1517	1503	1471	1457	1441
205892B	6.3	40	1476	1481	1507	1512	1502	1475	1460	1441
205893A	6.4	21	1678	1660	1665	1667	1652	1633	1621	1615
205893B	6.4	21	1677	1654	1661	1655	1642	1625	1615	1570
205894A	6.3	40	1520	1517	1523	1523	1503	1479	1466	1451
205894B	6.3	39	1519	1518	1523	1526	1503	1481	1470	1455
205895A	6.5	21	1709	1670	1680	1680	1663	1644	1630	1624
205895B	6.5	21	1706	1665	1677	1678	1663	1643	1635	1628
205901A	6.4	30	1619	1583	1597	1596	1578	1557	1546	1536
205901B	6.4	29	1593	1580	1584	1587	1572	1554	1543	1532
205906B	6.2	8	1819	1740	1717	1726	1729	1724	1700	1705
205906A	6.3	9	1803	1719	1727	1759	1742	1723	1698	1700

APPENDIX V

Computer Program with Nomenclature for Calculating Point Values of C_n, h_i, h_{cond}, Metal Resistance, U_o and Q With and Without Fouling

```
      CCCCCCCCCCC                                                 CCCCCCCCCCC
      C                                                                     C
      C       THE FOLLOWING PROGRAM IS WRITTEN TO CALCULATE THE OVERALL     C
      C       HEAT TRANSFER COEFFICIENT FROM THE GIVEN CORELATIONS OF       C
      C       INDIVIDUAL TRANSFER COEFFICIENTS, AT CERTAIN VAPOR TEMPERATURE C
      C       AND CERTAIN WATER TEMPERATURE IN THE TUBE SIDE.               C
      C                                                                     C
      C       BY GEORGE T. S. CHEN IN MAY 1968.                             C
      C                                                                     C
      CCCCCCCCCCC                                                 CCCCCCCCCCC
            DIMENSION M(10)
            REAL ID,KT,LAT,KCOND,IDIN
            DOUBLE PRECISION METAL1,METAL2,METAL3,METAL4
            READ (5,1000) IDIN,ODIN,FF,TK,CI,METAL1,METAL2,METAL3,METAL4
            ID         = IDIN/12.0
            OD         = ODIN/12.0
            RM         = (OD -ID)/(2.0*TK)
            AIT        = 3.1416*ID
            AOT        = 3.1416*OD
            AFLOW      = 3.1416*ID*ID/4.0
            AMET       = 3.1416*(OD-ID)/ALOG(OD/ID)
            READ (5,1002) (M(I), I=1,5)
         20 READ (5,1003) A, B, VEL, VAPORT, TW
            IF(A)99,99,17
         17 WRITE(6,1001)ODIN,IDIN,TK,METAL1,METAL2,METAL3,METAL4,AOT,AIT,
           1           AFLOW, RM,CI,FF
            CALL BRINE(TW,CPT,DEN,KT, VISC,HEAT)
            W          = VEL*AFLOW*DEN*3600.0
            RE         = ID*DEN*VEL*3600.0/VISC
            PR         = CPT*VISC/KT
            WRITE(6,1004)VAPORT,VEL,W,TW,RE,PR,A,B
            WRITE(6,1005)
            CALL WATER(VAPORT,CP,WATERD,WATERK,WATERV,LAT)
            DO 10 I=1,5
            XN         = M(I)
            CN         = A*XN**B
            DT         = VAPORT - TW
            T1         = VAPORT - DT/3.0
         11 DELTF      = VAPORT - T1
            FILMT      = VAPORT - DELTF/2.0
            CALL WATER(FILMT,CP,DCOND,KCOND,VCOND,HEAT)
            HCOND      = 0.725*CN*(KCOND*KCOND*KCOND*DCOND*DCOND*LAT*4.17*10.0
           1           **8/(XN*VCOND*OD*DELTF))**0.25
            T3         = T1 - RM*AOT*HCOND*DELTF/AMET
            T2         = T3 - FF*HCOND*DELTF
            CALL BRINE(T2,CP,BRINED,BRINEK,VISCW,HEAT)
            HI         = CI*RE**0.8*PR**0.33333*(VISC/VISCW)**0.14*KT/ID
            UO         = 1.0/(1.0/HCOND + AOT/(AIT*HI) + AOT*RM/AMET + FF)
            T1C        = (HCOND*VAPORT- UO*DT)/HCOND
            IF(ABS(T1C - T1) - 0.03)12,12,13
         13 T1         = T1C
            GO TO 11
         12 Q          = AOT*UO*DT
            RO         = 1.0/(UO*AOT)
            ET         = RM/AMET
```

```
0044              RI         = 1.0/(HI*AIT)
0045              RC         = 1.0/(HCOND*AOT)
0046              PHCOND     = RC/RO*100.0
0047              PHI        = RI/RO*100.0
0048              PMET       = RMET/RO*100.0
0049              PF         = FF/(RO*AOT)*100.0
0050              DU         = Q/LAT
0051              WRITE(6,1006)M(I),CN,UO,HCOND,PHCOND,HI,PHI,PMET,PF,Q,DU
0052           10 CONTINUE
0053              GO TO 20
0054         1000 FORMAT(5F10.4,4A5)
0055         1001 FORMAT(1H1,///'  CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.
             1  '//
             2      '  TUBE OUTSIDE DIAMETER (INCHES)                        ',F10.5/
             3      '  TUBE INSIDE  DIAMETER (INCHES)                        ',F10.5/
             4      '  TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)               ',F10.5/
             5      '  TUBE METAL                                            ',4A5/
             1      '  OUTSIDE HEAT TRANSFER AREA (SQFT/FT)                  ',F10.5/
             1      '  INSIDE  HEAT TRANSFER AREA (SQFT/FT)                  ',F10.5/
             2      '  FLOW AREA (SQFT)                                      ',F12.7/
             3      '  METAL RESISTANCE (HR/SQFT-F-BTU)                      ',F12.7/
             5      '  INSIDE SIEDER-TATE CONSTANT                           ',F10.5/
             6      '  FOULING FACTOR (HR-SQFT-F/BTU)                        ',F10.5)
0056         1002 FORMAT(5(8X,I2))
0057         1003 FORMAT(5F10.4)
0058         1004 FORMAT( 10X,'VAPOR TEMPERATURE (DEG. F)                 ',F10.2/
             1           10X,'LINEAR VELOCITY OF BRINE(FT/SEC)           ',F10.2/
             2           10X,'MASS VELOCITY OF BRINE (LBS/HR)            ',F10.2/
             1           10X,'BRINE TEMPERATURE (DEG. F)                 ',F10.2/
             3           10X,'REYNOLDS NUMBER                            ',F10.2/
             4           10X,'PRANDTLS NUMBER                            ',F10.2/
             6           10X,'CONSTANT FOR CN:  A                        ',F8.4/
             7           10X,'POWER OF CN:  B                            ',F8.4/  )
0059         1005 FORMAT(///'  NO    CN    UO     HCOND   HCOND   HI      HI    MET. FOULI
             1NG    Q     Q/LAT'/' TUBES                    %                  %  RES
             2.%    %     BTU/HR  LB/HR'//)
0060         1006 FORMAT(/2X,I2,2X,F4.2,1X,F6.1,1X,F6.1,1X,F4.1,'%',1X,F6.1,
             1     1X,F4.1,'%',1X,F4.1,'%',2X,F4.1,'%',2X,F6.1,3X,F4.2)
0061           99 CALL SYSTEM
0062              END
```

```
0001          SUBROUTINE  BRINE(T, CP, BRINED, BRINEK, BRINEV, HEAT)
          C          PHYSICAL PROPERTIES OF 5% BRINE.                                      C
0002          CP        =  0.93578076E+00           + 0.21301210E-04*T
             1            +0.40057057E-06*T**2      - 0.23777602E-09*T**3
0003          BRINED    =  0.64729111E+02           +0.23612976E-02*T
             1            -0.96149743E-04*T**2      +0.12916280E-06*T**3
             2            -0.90608410E-10*T**4
0004          BRINEK    =  0.27882683E+00           + 0.13049617E-02*T
             1            -0.81092730E-05*T**2      + 0.38319286E-07*T**3
             2            -0.10878543E-09*T**4      + 0.12212887E-12*T**5
0005          X         = 1.0/T
0006          BRINEV    = -0.12931222E+00           + 0.15922876E+03*X
             1            +0.68623125E+04*X**2      - 0.86924000E+05*X**3
             1            -0.40719760E+08*X**4      + 0.15597084E+10*X**5
0007          HEAT       =  (0.10952000E+04)          -(0.58000000E+00)*T
0008          RETURN
0009          END
```

```
0001          SUBROUTINE  WATER(T, CP,WATERD, WATERK, WATERV, HEAT)
       C            PHYSICAL PROPERTIES OF WATER.                                      C
0002          CP        =  0.10065384E+01           - 0.15302375E-03*T
             1            +0.80402242E-06*T**2      - 0.34208369E-09*T**3
0003          WATERD    =  0.63277298E+02           -0.22062302E-01*T
             1            +0.17648935E-03*T**2      -0.12005765E-05*T**3
             2            +0.28273348E-08*T**4      -0.22901681E-11*T**5
0004          WATERK    =  0.26081796E+00           + 0.21708496E-02*T
             1            -0.19852305E-04*T**2      + 0.11187643E-06*T**3
             2            -0.32420733E-09*T**4      + 0.36065335E-12*T**5
0005          X         = 1.0/T
0006          WATERV    = -0.44590950E-01           + 0.11010742E+03*X
             1            +0.10510937E+05*X**2      - 0.11860300E+06*X**3
             2            -0.49631344E+08*X**4      + 0.18674199E+10*X**5
0007          HEAT       =  (0.10952000E+04)         -(0.58000000E+00)*T
0008          RETURN
0009          END
```

NOMENCLATURE

A	Constant in the equation to calculate C_n
AFLOW	Cross-sectional area of flow; ft.^{2}
AIT	Inside heat transfer areas; ft.^{2}
AMET	Mean heat transfer area; ft.^{2}
AOT	Outside heat transfer area; ft.^{2}
B	Power in the equation to calculate C_n
CI	C_i in the Sieder-Tate equation
CN	Condensing coefficient correction factor
CPT	Heat capacity of water at TW; BTU/lb.
DCOND	Density of condensate at FILMT; lbs./ft.^{3}
DELTF	Temperature difference across the film; °F
DEN	Density of water at TW; lbs./ft.^{3}
DT	VAPORT - TW; °F
FF	Fouling factor on the inside
FILMT	Mean temperature of film; °F
HCOND	Condensing heat transfer coefficient; BTU/hr.-ft.^{2}-°F
HI	Inside heat transfer coefficient; BTU/hr.-ft.^{2}-°F
ID	Inside diameter; ft.
KCOND	Thermal conductivity of condensate at FILMT; BTU/hr.-ft.-°F
KT	Thermal conductivity of water at TW; BTU/hr.-ft.-°F
LAT	Latent heat of vaporization at VAPORT; BTU/lb.
N	Number of tubes in a vertical row
OD	Outside diameter; ft.
PR	Prandtl number
Q	Heat duty; BTU/hr.
RE	Reynolds number
RM	Metal resistance; hr./ft.^{2}-°F-BTU
T1	Temperature at the outside of tube; °F
T2	Temperature at the inside of tube with fouling; °F

NOMENCLATURE (continued)

T2C	T2 calculated
T3	The temperature at the inside wall; °F
TK	Thermal conductivity of metal; BTU/hr.-ft.-°F
TW	Water temperature; °F
UO	Overall outside heat transfer coefficient; BTU/hr.-ft.^{2}-°F
VAPORT	Steam temperature; °F
VCOND	Viscosity of condensate at FILMT; lbs./hr.-ft.
VEL	Linear velocity of water; ft./sec.
VISC	Viscosity of water at TW; lbs./hr.-ft.
VISCW	Viscosity of water at T2; lbs./hr.-ft.

APPENDIX VI

Computer Output from the Program in Appendix V Which Calculates Point Values of U_o, h_{cond}, h_i, and Q Using the Recommended C_n Equations

Note: The C_n equations are in the following form:

$$C_n = A\,(N)^B$$

where A and B are as indicated and N is the number of tubes in a vertical row.

TABLE VI-1

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes With Steam Condensing at 100°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	6137.40
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	54005.56
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	729.2	2797.5	26.1%	1319.6	61.5%	12.5%	0.0%	1147.7	1.11
15	1.70	721.6	2689.1	26.8%	1319.5	60.8%	12.3%	0.0%	1135.7	1.09
20	1.78	716.1	2614.8	27.4%	1319.4	60.4%	12.2%	0.0%	1127.1	1.09
25	1.85	711.8	2558.6	27.8%	1319.4	60.0%	12.2%	0.0%	1120.3	1.08
30	1.91	708.3	2513.7	28.2%	1319.4	59.7%	12.1%	0.0%	1114.8	1.07

TABLE VI-2

Calculated Point Values for
1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	6137.40
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	54005.56
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	543.4	3074.6	17.7%	1317.7	45.9%	9.3%	27.2%	855.2	0.82
15	1.70	539.4	2952.7	18.3%	1317.6	45.5%	9.2%	27.0%	849.0	0.82
20	1.78	536.6	2869.2	18.7%	1317.6	45.3%	9.2%	26.8%	844.5	0.81
25	1.85	534.3	2806.2	19.0%	1317.6	45.1%	9.1%	26.7%	841.0	0.81
30	1.91	532.5	2755.8	19.3%	1317.6	45.0%	9.1%	26.6%	838.1	0.81

TABLE VI-3

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes With Steam Condensing at 212°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	5936.61
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	129592.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	1015.1	3542.0	28.7%	2091.5	54.0%	17.4%	0.0%	1597.7	1.64
15	1.70	1003.6	3405.8	29.5%	2091.4	53.4%	17.2%	0.0%	1579.5	1.62
20	1.78	994.1	3300.0	30.1%	2091.3	52.9%	17.0%	0.0%	1564.7	1.61
25	1.85	987.8	3231.5	30.6%	2091.3	52.5%	16.9%	0.0%	1554.8	1.60
30	1.91	982.6	3176.7	30.9%	2091.2	52.3%	16.8%	0.0%	1546.6	1.59

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TABLE VI-4

Calculated Point Values for
1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	5936.61
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	129592.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	688.4	4009.8	17.2%	2089.5	36.6%	11.8%	34.4%	1083.4	1.11
15	1.70	683.5	3850.7	17.8%	2089.4	36.4%	11.7%	34.2%	1075.8	1.11
20	1.78	680.0	3741.9	18.2%	2089.4	36.2%	11.6%	34.0%	1070.3	1.10
25	1.85	677.2	3659.7	18.5%	2089.4	36.1%	11.6%	33.9%	1065.9	1.10
30	1.91	674.9	3593.9	18.8%	2089.4	35.9%	11.5%	33.7%	1062.3	1.09

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TABLE VI-5

Calculated Point Values for
1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F, Without Fouling

CALCULATIONS OF THE POINT. VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2981.18
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	28747.43
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	975.3	4304.0	22.7%	1911.5	58.2%	19.2%	0.0%	1435.5	1.38
15	2.51	970.1	4204.3	23.1%	1911.5	57.9%	19.1%	0.0%	1427.8	1.38
20	2.66	966.3	4134.9	23.4%	1911.4	57.6%	19.0%	0.0%	1422.3	1.37
25	2.79	963.4	4082.0	23.6%	1911.4	57.5%	18.9%	0.0%	1418.0	1.37
30	2.89	961.0	4039.2	23.8%	1911.4	57.3%	18.9%	0.0%	1414.4	1.36

TABLE VI-6

Calculated Point Values for
1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2981.18
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	28747.43
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	666.7	4858.6	13.7%	1908.2	39.8%	13.1%	33.3%	981.3	0.95
15	2.51	664.5	4743.2	14.0%	1908.2	39.7%	13.1%	33.2%	978.1	0.94
20	2.66	662.9	4663.1	14.2%	1908.2	39.6%	13.0%	33.1%	975.7	0.94
25	2.79	661.7	4601.9	14.4%	1908.2	39.5%	13.0%	33.1%	973.9	0.94
30	2.89	660.6	4552.5	14.5%	1908.2	39.5%	13.0%	33.0%	972.4	0.94

TABLE VI-7

Calculated Point Values for
1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	1324.6	5491.8	24.1%	3029.9	49.8%	26.0%	0.0%	1949.6	2.01
15	2.51	1317.1	5365.3	24.5%	3029.9	49.6%	25.9%	0.0%	1938.6	1.99
20	2.66	1311.7	5277.1	24.9%	3029.9	49.4%	25.8%	0.0%	1930.7	1.99
25	2.79	1307.6	5210.1	25.1%	3029.8	49.2%	25.7%	0.0%	1924.5	1.98
30	2.89	1304.1	5155.7	25.3%	3029.8	49.1%	25.6%	0.0%	1919.4	1.97

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TABLE VI-8

Calculated Point Values for
1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	813.5	6409.1	12.7%	3026.6	30.6%	16.0%	40.7%	1197.3	1.23
15	2.51	811.0	6256.7	13.0%	3026.6	30.5%	15.9%	40.5%	1193.6	1.23
20	2.66	809.2	6151.0	13.2%	3026.6	30.5%	15.9%	40.5%	1191.0	1.22
25	2.79	807.8	6070.1	13.3%	3026.6	30.4%	15.9%	40.4%	1188.9	1.22
30	2.89	806.6	6004.9	13.4%	3026.6	30.4%	15.9%	40.3%	1187.2	1.22

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TABLE VI-9

Calculated Point Values for 5/8-inch Bare Cupro-Nickel Tubes With Steam Condensing at 100°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.62520
TUBE INSIDE DIAMETER (INCHES)	0.54880
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16368
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.14368
FLOW AREA (SQFT)	0.0016427
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001224
INSIDE SIEDER-TATE CONSTANT	0.02700
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	2278.01
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	32902.18
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.2000
POWER OF CN: B	0.0557

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.36	782.2	2614.0	29.9%	1488.6	59.9%	10.2%	0.0%	768.2	0.74
15	1.40	760.1	2383.0	31.9%	1488.4	58.2%	9.9%	0.0%	746.5	0.72
20	1.42	744.0	2232.1	33.3%	1488.3	57.0%	9.7%	0.0%	730.7	0.70
25	1.44	731.3	2121.9	34.5%	1488.2	56.0%	9.6%	0.0%	718.2	0.69
30	1.45	720.8	2036.0	35.4%	1488.1	55.2%	9.4%	0.0%	707.9	0.68

TABLE VI-10

Calculated Point Values for
5/8-inch Bare Cupro-Nickel Tubes
With Steam Condensing at 100°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.62520
TUBE INSIDE DIAMETER (INCHES)	0.54880
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16368
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.14368
FLOW AREA (SQFT)	0.0016427
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001224
INSIDE SIEDER-TATE CONSTANT	0.02700
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	2278.01
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	32902.18
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.2000
POWER OF CN: B	0.0557

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.36	574.2	2901.4	19.8%	1486.5	44.0%	7.5%	28.7%	563.9	0.54
15	1.40	562.7	2631.6	21.4%	1486.4	43.1%	7.3%	28.1%	552.7	0.53
20	1.42	554.3	2456.3	22.6%	1486.3	42.5%	7.2%	27.7%	544.3	0.52
25	1.44	547.5	2328.6	23.5%	1486.3	42.0%	7.1%	27.4%	537.7	0.52
30	1.45	541.8	2229.5	24.3%	1486.2	41.5%	7.1%	27.1%	532.1	0.51

TABLE VI-11

Calculated Point Values for 5/8-inch Bare Cupro-Nickel Tubes With Steam Condensing at 212°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.62520
TUBE INSIDE DIAMETER (INCHES)	0.54880
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16368
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.14368
FLOW AREA (SQFT)	0.0016427
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001224
INSIDE SIEDER-TATE CONSTANT	0.02700
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	2203.49
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	78952.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.2000
POWER OF CN: B	0.0557

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.36	1092.4	3310.5	33.0%	2359.6	52.7%	14.3%	0.0%	1072.8	1.10
15	1.40	1059.7	3027.5	35.0%	2359.5	51.2%	13.8%	0.0%	1040.6	1.07
20	1.42	1035.3	2837.0	36.5%	2359.4	50.0%	13.5%	0.0%	1016.7	1.05
25	1.44	1014.5	2686.7	37.8%	2359.2	49.0%	13.2%	0.0%	996.3	1.02
30	1.45	998.4	2576.7	38.7%	2359.1	48.2%	13.0%	0.0%	980.5	1.01

TABLE VI-12

Calculated Point Values for 5/8-inch Bare Cupro-Nickel Tubes With Steam Condensing at 212°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.62520
TUBE INSIDE DIAMETER (INCHES)	0.54880
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16368
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.14368
FLOW AREA (SQFT)	0.0016427
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001224
INSIDE SIEDER-TATE CONSTANT	0.02700
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	2203.49
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	78952.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.2000
POWER OF CN: B	0.0557

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.36	725.8	3787.4	19.2%	2357.4	35.1%	9.5%	36.3%	712.7	0.73
15	1.40	711.8	3435.0	20.7%	2357.3	34.4%	9.3%	35.6%	699.0	0.72
20	1.42	701.4	3205.9	21.9%	2357.3	33.9%	9.2%	35.1%	688.8	0.71
25	1.44	693.0	3039.3	22.8%	2357.2	33.5%	9.1%	34.7%	680.6	0.70
30	1.45	686.1	2909.8	23.6%	2357.2	33.2%	9.0%	34.3%	673.8	0.69

TABLE VI-13

Calculated Point Values for 5/8-inch Corrugated Cupro-Nickel Tubes With Steam Condensing at 100°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1239.36
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	18535.45
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.1140
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.77	1087.2	3338.0	32.6%	2426.1	51.8%	15.6%	0.0%	1047.2	1.01
15	1.91	1078.2	3254.7	33.1%	2425.9	51.4%	15.4%	0.0%	1038.6	1.00
20	2.03	1073.1	3208.2	33.4%	2426.0	51.2%	15.4%	0.0%	1033.6	1.00
25	2.12	1069.1	3172.6	33.7%	2426.0	51.0%	15.3%	0.0%	1029.7	0.99
30	2.20	1064.2	3130.3	34.0%	2425.9	50.8%	15.2%	0.0%	1025.1	0.99

TABLE VI-14

Calculated Point Values for 5/8-inch Corrugated Cupro-Nickel Tubes With Steam Condensing at 100°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1239.36
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	18535.45
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.1140
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.77	722.9	3812.4	19.0%	2422.2	34.5%	10.4%	36.1%	696.3	0.67
15	1.91	719.4	3717.5	19.4%	2422.2	34.4%	10.3%	36.0%	693.0	0.67
20	2.03	716.9	3651.7	19.6%	2422.1	34.2%	10.3%	35.8%	690.6	0.67
25	2.12	715.0	3601.5	19.9%	2422.1	34.2%	10.2%	35.7%	688.7	0.66
30	2.20	713.4	3561.0	20.0%	2422.1	34.1%	10.2%	35.7%	687.1	0.66

TABLE VI-15

Calculated Point Values for
5/8-inch Corrugated Cupro-Nickel Tubes
With Steam Condensing at 212°F, Without Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"KORD CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1198.81
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	44477.86
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.1140
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.77	1474.7	4273.0	34.5%	3846.7	44.4%	21.1%	0.0%	1420.5	1.46
15	1.91	1462.7	4173.3	35.0%	3846.6	44.0%	21.0%	0.0%	1408.9	1.45
20	2.03	1454.0	4104.0	35.4%	3846.6	43.7%	20.8%	0.0%	1400.6	1.44
25	2.12	1447.3	4051.1	35.7%	3846.5	43.5%	20.7%	0.0%	1394.1	1.43
30	2.20	1441.9	4008.4	36.0%	3846.5	43.4%	20.7%	0.0%	1388.8	1.43

TABLE VI-16

Calculated Point Values for
5/8-inch Corrugated Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8"KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1198.81
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	44477.86
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.1140
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.77	875.2	5044.7	17.3%	3842.7	26.4%	12.5%	43.8%	843.0	0.87
15	1.91	871.3	4918.7	17.7%	3842.7	26.2%	12.5%	43.6%	839.3	0.86
20	2.03	868.5	4831.3	18.0%	3842.7	26.2%	12.4%	43.4%	836.6	0.86
25	2.12	866.4	4764.7	18.2%	3842.7	26.1%	12.4%	43.3%	834.5	0.86
30	2.20	864.6	4710.9	18.4%	3842.6	26.0%	12.4%	43.2%	832.8	0.86

APPENDIX VII

Computer Output from the Program in Appendix V
Which Calculates Point Values of U_o, h_{cond}, h_i, and Q
Using the C_n Equations for Steam Condensing at 100°F and 212°F
and the Recommended C_n Equations

Note: The C_n equations are in the following form:

$$C_n = A\,(N)^B$$

where A and B are as indicated and N is the number of tubes in a vertical row.

TABLE VII-1

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
Without Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	6137.40
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	54005.56
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.1500
POWER OF CN: B	0.1560

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.65	738.4	2937.2	25.1%	1319.6	62.2%	12.6%	0.0%	1162.1	1.12
15	1.75	729.6	2803.5	26.0%	1319.6	61.5%	12.5%	0.0%	1148.3	1.11
20	1.84	723.3	2712.6	26.7%	1319.5	61.0%	12.4%	0.0%	1138.4	1.10
25	1.90	718.3	2644.1	27.2%	1319.5	60.6%	12.3%	0.0%	1130.5	1.09
30	1.95	714.2	2589.6	27.6%	1319.4	60.2%	12.2%	0.0%	1124.1	1.08

TABLE VII-2

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
With 0.0005 Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	6137.40
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	54005.56
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.1500
POWER OF CN: B	0.1560

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.65	548.1	3231.6	17.0%	1317.7	46.3%	9.4%	27.4%	862.6	0.83
15	1.75	543.6	3081.3	17.6%	1317.7	45.9%	9.3%	27.2%	855.5	0.82
20	1.84	540.3	2979.1	18.1%	1317.6	45.6%	9.2%	27.0%	850.4	0.82
25	1.90	537.7	2902.2	18.5%	1317.6	45.4%	9.2%	26.9%	846.3	0.82
30	1.95	535.6	2841.0	18.9%	1317.6	45.2%	9.2%	26.8%	843.0	0.81

TABLE VII-3

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
Without Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	6137.40
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	54005.56
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	729.2	2797.5	26.1%	1319.6	61.5%	12.5%	0.0%	1147.7	1.11
15	1.70	721.6	2689.1	26.8%	1319.5	60.8%	12.3%	0.0%	1135.7	1.09
20	1.78	716.1	2614.8	27.4%	1319.4	60.4%	12.2%	0.0%	1127.1	1.09
25	1.85	711.8	2558.6	27.8%	1319.4	60.0%	12.2%	0.0%	1120.3	1.08
30	1.91	708.3	2513.7	28.2%	1319.4	59.7%	12.1%	0.0%	1114.8	1.07

TABLE VII-4

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
With 0.0005 Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	6137.40
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	54005.56
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	543.4	3074.6	17.7%	1317.7	45.9%	9.3%	27.2%	855.2	0.82
15	1.70	539.4	2952.7	18.3%	1317.6	45.5%	9.2%	27.0%	849.0	0.82
20	1.78	536.6	2869.2	18.7%	1317.6	45.3%	9.2%	26.8%	844.5	0.81
25	1.85	534.3	2806.2	19.0%	1317.6	45.1%	9.1%	26.7%	841.0	0.81
30	1.91	532.5	2755.8	19.3%	1317.6	45.0%	9.1%	26.6%	838.1	0.81

TABLE VII-5

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	5936.61
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	129592.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.0500
POWER OF CN: B	0.1740

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.57	1011.7	3500.9	28.9%	2091.5	53.8%	17.3%	0.0%	1592.3	1.64
15	1.68	1000.7	3372.9	29.7%	2091.4	53.2%	17.1%	0.0%	1575.0	1.62
20	1.77	991.7	3273.4	30.3%	2091.3	52.7%	17.0%	0.0%	1560.9	1.61
25	1.84	985.7	3208.9	30.7%	2091.3	52.4%	16.9%	0.0%	1551.4	1.60
30	1.90	980.8	3157.1	31.1%	2091.2	52.2%	16.8%	0.0%	1543.7	1.59

TABLE VII-6

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
With 0.0005 Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	5936.61
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	129592.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.0500
POWER OF CN: B	0.1740

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.57	686.9	3961.7	17.3%	2089.5	36.6%	11.7%	34.3%	1081.2	1.11
15	1.68	682.3	3812.4	17.9%	2089.4	36.3%	11.7%	34.1%	1073.9	1.10
20	1.77	678.9	3709.9	18.3%	2089.4	36.1%	11.6%	33.9%	1068.6	1.10
25	1.84	676.3	3632.5	18.6%	2089.4	36.0%	11.6%	33.8%	1064.5	1.09
30	1.90	674.1	3570.5	18.9%	2089.4	35.9%	11.5%	33.7%	1061.0	1.09

TABLE VII-7

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	5936.61
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	129592.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	1015.1	3542.0	28.7%	2091.5	54.0%	17.4%	0.0%	1597.7	1.64
15	1.70	1003.6	3405.8	29.5%	2091.4	53.4%	17.2%	0.0%	1579.5	1.62
20	1.78	994.1	3300.0	30.1%	2091.3	52.9%	17.0%	0.0%	1564.7	1.61
25	1.85	987.8	3231.5	30.6%	2091.3	52.5%	16.9%	0.0%	1554.8	1.60
30	1.91	982.6	3176.7	30.9%	2091.3	52.3%	16.8%	0.0%	1546.6	1.59

EXECUTION TERMINATED

TABLE VII-8

Calculated Point Values for 1-inch Bare 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
With 0.0005 Fouling at Tubeside Velocity of 6.0 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" BARE CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.26232
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23583
FLOW AREA (SQFT)	0.0044257
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001622
INSIDE SIEDER-TATE CONSTANT	0.02642
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	6.00
MASS VELOCITY OF BRINE (LBS/HR)	5936.61
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	129592.31
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.0700
POWER OF CN: B	0.1700

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.58	688.4	4009.8	17.2%	2089.5	36.6%	11.8%	34.4%	1083.4	1.11
15	1.70	683.5	3850.7	17.8%	2089.4	36.4%	11.7%	34.2%	1075.8	1.11
20	1.78	680.0	3741.9	18.2%	2089.4	36.2%	11.6%	34.0%	1070.3	1.10
25	1.85	677.2	3659.7	18.5%	2089.4	36.1%	11.6%	33.9%	1065.9	1.10
30	1.91	674.9	3593.9	18.8%	2089.4	35.9%	11.5%	33.7%	1062.3	1.09

EXECUTION TERMINATED

TABLE VII-9

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2981.18
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	28747.43
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.3000
POWER OF CN: B	0.2260

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.19	959.7	4016.4	23.9%	1911.4	57.2%	18.9%	0.0%	1412.5	1.36
15	2.40	957.0	3968.8	24.1%	1911.3	57.1%	18.8%	0.0%	1408.5	1.36
20	2.56	955.0	3935.3	24.3%	1911.3	57.0%	18.8%	0.0%	1405.6	1.36
25	2.69	953.5	3909.5	24.4%	1911.3	56.9%	18.7%	0.0%	1403.3	1.35
30	2.80	952.2	3888.6	24.5%	1911.3	56.8%	18.7%	0.0%	1401.5	1.35

TABLE VII-10

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2981.18
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	28747.43
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.3000
POWER OF CN: B	0.2260

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.19	660.1	4526.2	14.6%	1908.2	39.4%	13.0%	33.0%	971.5	0.94
15	2.40	658.9	4471.1	14.7%	1908.2	39.4%	13.0%	32.9%	969.8	0.94
20	2.56	658.1	4432.4	14.8%	1908.1	39.3%	12.9%	32.9%	968.6	0.93
25	2.69	657.4	4402.7	14.9%	1908.1	39.3%	12.9%	32.9%	967.6	0.93
30	2.80	656.9	4378.5	15.0%	1908.1	39.2%	12.9%	32.8%	966.8	0.93

TABLE VII-11

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2981.18
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	28747.43
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	975.3	4304.0	22.7%	1911.5	58.2%	19.2%	0.0%	1435.5	1.38
15	2.51	970.1	4204.3	23.1%	1911.5	57.9%	19.1%	0.0%	1427.8	1.38
20	2.66	966.3	4134.9	23.4%	1911.4	57.6%	19.0%	0.0%	1422.3	1.37
25	2.79	963.4	4082.0	23.6%	1911.4	57.5%	18.9%	0.0%	1418.0	1.37
30	2.89	961.0	4039.2	23.8%	1911.4	57.3%	18.9%	0.0%	1414.4	1.36

TABLE VII-12

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2981.18
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	28747.43
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	666.7	4858.6	13.7%	1908.2	39.8%	13.1%	33.3%	981.3	0.95
15	2.51	664.5	4743.2	14.0%	1908.2	39.7%	13.1%	33.2%	978.1	0.94
20	2.66	662.9	4663.1	14.2%	1908.2	39.6%	13.0%	33.1%	975.7	0.94
25	2.79	661.7	4601.9	14.4%	1908.2	39.5%	13.0%	33.1%	973.9	0.94
30	2.89	660.6	4552.5	14.5%	1908.2	39.5%	13.0%	33.0%	972.4	0.94

TABLE VII-13

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes With Steam Condensing at 212°F Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.3000
POWER OF CN: B	0.1910

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.02	1269.0	4647.5	27.3%	3029.6	47.7%	25.0%	0.0%	1867.7	1.92
15	2.18	1258.8	4514.5	27.9%	3029.6	47.4%	24.8%	0.0%	1852.8	1.91
20	2.30	1251.6	4422.5	28.3%	3029.5	47.1%	24.6%	0.0%	1842.1	1.89
25	2.40	1245.9	4352.5	28.6%	3029.5	46.9%	24.5%	0.0%	1833.7	1.89
30	2.49	1241.2	4296.2	28.9%	3029.5	46.7%	24.4%	0.0%	1826.9	1.88

TABLE VII-14

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KURO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.3000
POWER OF CN: B	0.1910

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.02	794.5	5393.7	14.7%	3026.6	29.9%	15.6%	39.7%	1169.4	1.20
15	2.18	790.9	5234.2	15.1%	3026.5	29.8%	15.6%	39.5%	1164.1	1.20
20	2.30	788.4	5124.2	15.4%	3026.5	29.7%	15.5%	39.4%	1160.4	1.19
25	2.40	786.4	5040.3	15.6%	3026.5	29.6%	15.5%	39.3%	1157.4	1.19
30	2.49	784.7	4972.7	15.8%	3026.5	29.6%	15.4%	39.2%	1155.0	1.19

TABLE VII-15

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	1324.6	5491.8	24.1%	3029.9	49.8%	26.0%	0.0%	1949.6	2.01
15	2.51	1317.1	5365.3	24.5%	3029.9	49.6%	25.9%	0.0%	1938.6	1.99
20	2.66	1311.7	5277.1	24.9%	3029.9	49.4%	25.8%	0.0%	1930.7	1.99
25	2.79	1307.6	5210.1	25.1%	3029.8	49.2%	25.7%	0.0%	1924.5	1.98
30	2.89	1304.1	5155.7	25.3%	3029.8	49.1%	25.6%	0.0%	1919.4	1.97

EXECUTION TERMINATED

TABLE VII-16

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	813.5	6409.1	12.7%	3026.6	30.6%	16.0%	40.7%	1197.3	1.23
15	2.51	811.0	6256.7	13.0%	3026.6	30.5%	15.9%	40.5%	1193.6	1.23
20	2.66	809.2	6151.0	13.2%	3026.6	30.5%	15.9%	40.5%	1191.0	1.22
25	2.79	807.8	6070.1	13.3%	3026.6	30.4%	15.9%	40.4%	1188.9	1.22
30	2.89	806.6	6004.9	13.4%	3026.6	30.4%	15.9%	40.3%	1187.2	1.22

EXECUTION TERMINATED

TABLE VII-17

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1239.36
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	18535.45
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.2100
POWER OF CN: B	0.1930

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.89	1114.5	3608.9	30.9%	2426.3	53.1%	16.0%	0.0%	1073.5	1.04
15	2.04	1105.1	3512.3	31.5%	2426.2	52.7%	15.8%	0.0%	1064.5	1.03
20	2.16	1098.4	3445.4	31.9%	2426.2	52.4%	15.7%	0.0%	1058.0	1.02
25	2.25	1093.2	3394.4	32.2%	2426.2	52.1%	15.7%	0.0%	1053.0	1.02
30	2.33	1088.9	3353.4	32.5%	2426.1	51.9%	15.6%	0.0%	1048.8	1.01

TABLE VII-18

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1239.36
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	18535.45
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.2100
POWER OF CN: B	0.1930

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.89	734.0	4142.0	17.7%	2422.3	35.1%	10.5%	36.7%	707.0	0.68
15	2.04	730.2	4024.3	18.1%	2422.3	34.9%	10.5%	36.5%	703.4	0.68
20	2.16	727.5	3942.9	18.5%	2422.2	34.7%	10.4%	36.4%	700.7	0.68
25	2.25	725.4	3880.9	18.7%	2422.2	34.6%	10.4%	36.3%	698.7	0.67
30	2.33	723.6	3831.1	18.9%	2422.2	34.6%	10.4%	36.2%	697.0	0.67

TABLE VII-19

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1239.36
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	18535.45
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.1100
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.76	1085.7	3324.0	32.7%	2426.1	51.8%	15.6%	0.0%	1045.8	1.01
15	1.91	1076.9	3243.0	33.2%	2426.0	51.4%	15.4%	0.0%	1037.3	1.00
20	2.02	1071.8	3196.7	33.5%	2426.0	51.1%	15.4%	0.0%	1032.4	1.00
25	2.11	1067.8	3161.2	33.8%	2426.1	50.9%	15.3%	0.0%	1028.5	0.99
30	2.19	1062.7	3117.2	34.1%	2425.9	50.7%	15.2%	0.0%	1023.6	0.99

TABLE VII-20

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 100°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	100.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1239.36
BRINE TEMPERATURE (DEG. F)	94.00
REYNOLDS NUMBER	18535.45
PRANDTLS NUMBER	5.12
CONSTANT FOR CN: A	1.1100
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.76	722.3	3795.4	19.0%	2422.2	34.5%	10.4%	36.1%	695.8	0.67
15	1.91	718.8	3700.9	19.4%	2422.2	34.3%	10.3%	35.9%	692.4	0.67
20	2.02	716.3	3635.4	19.7%	2422.2	34.2%	10.3%	35.8%	690.0	0.67
25	2.11	714.4	3585.4	19.9%	2422.2	34.1%	10.2%	35.7%	688.1	0.66
30	2.19	712.7	3545.1	20.1%	2422.1	34.0%	10.2%	35.6%	686.5	0.66

TABLE VII-21

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1198.81
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	44477.86
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	0.9900
POWER OF CN: B	0.2200

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.64	1431.6	3929.9	36.4%	3846.5	43.1%	20.5%	0.0%	1378.9	1.42
15	1.80	1424.2	3874.8	36.8%	3846.5	42.8%	20.4%	0.0%	1371.8	1.41
20	1.91	1417.0	3822.5	37.1%	3846.3	42.6%	20.3%	0.0%	1364.9	1.40
25	2.01	1412.9	3792.3	37.3%	3846.3	42.5%	20.2%	0.0%	1360.9	1.40
30	2.09	1409.5	3767.9	37.4%	3846.3	42.4%	20.2%	0.0%	1357.6	1.40

TABLE VII-22

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1198.81
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	44477.86
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	0.9900
POWER OF CN: B	0.2200

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.64	861.2	4612.2	18.7%	3842.7	25.9%	12.3%	43.1%	829.5	0.85
15	1.80	858.7	4543.0	18.9%	3842.7	25.9%	12.3%	42.9%	827.2	0.85
20	1.91	857.0	4494.5	19.1%	3842.7	25.8%	12.3%	42.8%	825.5	0.85
25	2.01	855.6	4457.3	19.2%	3842.7	25.8%	12.3%	42.8%	824.2	0.85
30	2.09	854.5	4427.1	19.3%	3842.7	25.7%	12.2%	42.7%	823.1	0.85

TABLE VII-23

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1198.91
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	44477.86
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.1100
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.76	1472.6	4255.1	34.6%	3846.7	44.3%	21.1%	0.0%	1418.4	1.46
15	1.91	1460.5	4155.9	35.1%	3846.6	43.9%	20.9%	0.0%	1406.8	1.45
20	2.02	1451.9	4086.9	35.5%	3846.6	43.7%	20.8%	0.0%	1398.5	1.44
25	2.11	1445.2	4034.2	35.8%	3846.6	43.5%	20.7%	0.0%	1392.0	1.43
30	2.19	1439.7	3991.7	36.1%	3846.6	43.3%	20.6%	0.0%	1386.7	1.43

EXECUTION TERMINATED

TABLE VII-24

Calculated Point Values for 5/8-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
With 0.0005 Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.61320
TUBE INSIDE DIAMETER (INCHES)	0.53000
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	5/8" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.16054
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.13875
FLOW AREA (SQFT)	0.0015321
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001333
INSIDE SIEDER-TATE CONSTANT	0.06730
FOULING FACTOR (HR-SQFT-F/BTU)	0.00050
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	1198.81
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	44477.86
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.1100
POWER OF CN: B	0.2000

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.76	874.5	5022.1	17.4%	3842.7	26.3%	12.5%	43.7%	842.3	0.87
15	1.91	870.6	4896.7	17.8%	3842.7	26.2%	12.5%	43.5%	838.6	0.86
20	2.02	867.8	4809.7	18.0%	3842.7	26.1%	12.4%	43.4%	835.9	0.86
25	2.11	865.7	4743.4	18.2%	3842.7	26.1%	12.4%	43.3%	833.8	0.86
30	2.19	863.9	4689.9	18.4%	3842.7	26.0%	12.4%	43.2%	832.1	0.86

EXECUTION TERMINATED

TABLE VII-25

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.63
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.2300
POWER OF CN: B	0.2080

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.99	1262.1	4556.9	27.7%	3029.6	47.5%	24.8%	0.0%	1857.6	1.91
15	2.16	1254.8	4463.8	28.1%	3029.6	47.2%	24.7%	0.0%	1846.9	1.90
20	2.29	1249.7	4398.9	28.4%	3029.5	47.0%	24.6%	0.0%	1839.3	1.89
25	2.40	1245.6	4349.2	28.6%	3029.5	46.9%	24.5%	0.0%	1833.3	1.89
30	2.50	1242.3	4309.1	28.8%	3029.5	46.7%	24.4%	0.0%	1828.5	1.88

EXECUTION TERMINATED

TABLE VII-26

Calculated Point Values for 1-inch Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F
Without Fouling at Tubeside Velocity of 3.5 ft./sec.

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
TUBE METAL	1" KORO CU-NI
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLOW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05786
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELOCITY OF BRINE(FT/SEC)	3.50
MASS VELOCITY OF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.62
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4500
POWER OF CN: B	0.2030

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.31	1324.6	5491.8	24.1%	3029.9	49.8%	26.0%	0.0%	1949.6	2.01
15	2.51	1317.1	5365.3	24.5%	3029.9	49.6%	25.9%	0.0%	1938.6	1.99
20	2.66	1311.7	5277.1	24.9%	3029.9	49.4%	25.8%	0.0%	1930.7	1.99
25	2.79	1307.6	5210.1	25.1%	3029.8	49.2%	25.7%	0.0%	1924.5	1.98
30	2.89	1304.1	5155.7	25.3%	3029.8	49.1%	25.6%	0.0%	1919.4	1.97