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THE CONDENSING OF STEAM ON HORIZONTAL SINGLE-START AND TRIPLE-START CORRUGATED TUBES

Report No. 61

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ABSTRACT

Experimental heat transfer data are presented for steam condensing at 212°F on the outside of horizontal 1-inch, 90-10 Cupro-Nickel triple-start corrugated tubes with two tube-support plates. The differences between the performance of a single vertical row of tubes and of the center row of three vertical rows of horizontal tubes in the test condenser are presented. The experimental results are compared with the results presented in the previous publication covering earlier research work. Data obtained on a single vertical row of horizontal bare Cupro-Nickel tubes without tube-support plates are also reported.

INTRODUCTION

This investigation is an extension of the work published under the title "The Condensing of Steam on Horizontal Corrugated and Bare Tubes," Report No. 60, September 1968, which was limited to single-start corrugated tubes and bare tubes. The investigation was extended to include the heat transfer performance of 1-inch, 90-10 Cupro-Nickel triple-start corrugated tubes with two tube-support plates with steam condensing at 212°F.

PREVIOUS WORK

In the earlier investigation, Young, McParland, Chen and Young[(1)*] established that in the modified Nusselt equation for steam condensing

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

The correction factor C_n is a function of the number of tubes in a vertical row. The experimental data indicated that C_n has the following form:

$$C_n = A\,(N)^B \quad (2)$$

where N is the number of tubes in a vertical row. The constants A and B have to be determined experimentally for the particular type of tubes of interest. The results of that investigation are summarized in Figure 1[**] for 1-inch bare tubes; Figure 2 for 1-inch single-start corrugated tubes; Figure 3 for 5/8-inch bare tubes; and Figure 4 for 5/8-inch single-start corrugated tubes. The C_n equations recommended by the authors of Report No. 60 for design use for these tubes are:

1-inch bare tubes: $$C_n = 1.07\,(N)^{0.170} \quad (3)$$

1-inch single-start corrugated tubes: $$C_n = 1.45\,(N)^{0.203} \quad (4)$$

5/8-inch bare tubes: $$C_n = 1.20\,(N)^{0.0557} \quad (5)$$

* Literature cited will be found on page 21.

** Figures are presented in section beginning on page 23.

5/8-inch single-start corrugated tubes: $$C_n = 1.11\,(N)^{0.200} \qquad (6)$$

In Report No. 60, the Sieder-Tate equation, with appropriate constant, was used as the basis for correlating the tube-side heat transfer performance of the above bare and corrugated tubes from experimental heat transfer data obtained on a concentric pipe heat exchanger. The Sieder-Tate constants for the above four tubes are summarized in the following table:

TABLE 1

Values of the Sieder-Tate Constant, C_i, for Predicting the Inside Heat Transfer Coefficient for the Four Tubes of Report No. 60

Tube	C_i
5/8-inch Bare Copper	0.02468
5/8-inch Single-Start Corrugated Copper	0.06730
1-inch Single-Start Corrugated 90-10 Cupro-Nickel	0.05786
1-inch Bare 90-10 Cupro-Nickel	0.02642

The calculated values of C_n were made using the steam condensing experimental data collected on seven to nine tubes in a vertical row. The resulting C_n values always appeared to be a linear function of N when plotted on the log-log scale. The extrapolation of C_n up to N = 25 tubes in a vertical row is believed to be valid for design purposes.

Eissenberg[2] also studied the steam condensing heat transfer performance of similar type corrugated tubes. Since the operating condition and the equipment configuration of their work are different from that of this investigation, no attempt was made to compare their results with that of this investigation.

Since the publication of Report No. 60, a question has been raised concerning the vertical alignment of the tubes investigated in that report and concerning the straightness of the individual tubes. These points are discussed in a later section of this current report.

EQUIPMENT AND TEST PROCEDURE

The basic equipment and test procedure used in this investigation are the same as described in Report No. 60[1]. The reader is referred to that report for complete details. The dimensions and characteristics of the triple-start corrugated tubes studied in this investigation along with the single-start corrugated tubes of Report No. 60 are given in Table 2. Figure 5 presents sections of the single-start and triple-start corrugated tubes.

TABLE 2

Tube Dimensions and Characteristics of
The Triple-Start and Single-Start Corrugated Tubes Investigated

	Triple-Start	Single-Start
Tube outside diameter, in.	0.9900	0.9370
Tube inside diameter, in.	0.9132	0.8220
Tube wall thickness, in.	0.0384	0.0575
Tube length, in.	71.375	72.156
Tube material	90-10 Cupro-Nickel	
Thermal conductivity, BTU/hr-ft-°F	26.0	26.0
Helix		
Pitch	0.375"	0.250"
Depth	0.030"	0.031"
Start	Three	One

Initially, further test data was collected on the existing bundle of bare tubes left in the steam condenser at the completion of the previous investigation. Later two equally spaced support plates were installed to hold the tubes in place in the condenser. The support baffles were made of 1/8-inch thick steel plate with holes properly drilled to support the tubes and were spaced 24 inches apart. The edges of the baffles were partially cut out to allow the steam to pass through the baffles.

RESULTS

Before the tube-support baffles were installed, the two side vertical rows of the three vertical rows of horizontal bare 1-inch O.D. tubes still remaining in the steam condensing test section from the previous investigation were removed and further test data collected with steam condensing at 212°F with a tube-side water velocity of 6 feet per second. Tables I-1, I-2 and I-3 in Appendix I* contain C_n, U_o for each individual tube, and U_o cumulative, respectively.

Figure 6 presents a plot of the C_n values tabulated in Table I-1; Figure 7 presents a plot of the individual U_o values tabulated in Table I-2; and Figure 8 presents a plot of the cumulative U_o values tabulated in Table I-3.

After the 1-inch O.D. bare tubes were removed, the tube-support baffles were installed in the condenser test section. A single vertical row of 1-inch triple-start corrugated tubes was installed in the steam condenser test section. Data were collected with steam condensing at 212°F with tube-side water velocities of 3-1/2 and 6 feet per second. Tables II-1, II-2, and II-3 in Appendix II contain C_n, U_o for each individual tube and U_o cumulative, respectively. Figures 9, 10 and 11 present plots of C_n; Figures 12 and 13 present plots of U_o individual; and Figures 14 and 15 present plots of U_o cumulative using the values tabulated in Tables II-1, II-2, and II-3, respectively.

After collecting the experimental test data on the single vertical row of horizontal triple-start corrugated tubes, two side rows of triple-start corrugated tubes were added with one row on each side of the existing row. Test data were collected on the center row with steam condensing at 212°F on all three rows with tube-side water velocities of 3-1/2 and 6 feet per second. Tables III-1, III-2 and III-3 in Appendix III contain C_n, U_o individual and U_o cumulative, respectively. Figures 16, 17 and 18 present plots of C_n; Figures 19 and 20 present plots of U_o individual; and Figures 21 and 22 present plots of U_o cumulative using the values tabulated in Tables III-1, III-2 and III-3, respectively.

The determination of the Sieder-Tate constant and tube-side pressure drop curve for the 1-inch triple-start corrugated tubes used in this investigation was made by the UOP Wolverine Tube Division in their Engineering and Development Laboratories in Allen Park, Michigan. Figure 23 presents the modified Wilson plot curve that establishes the Sieder-Tate constant for the inside of the triple-start corrugated tube as 0.05058.

Figure 24 presents the tube-side pressure drop data for the triple-start corrugated tube superimposed on Figure 38, page 84, of Report No. 60. Figure 25 gives the corresponding Moody friction factor for the triple-start corrugated tube superimposed on Figure 39, page 85, of Report No. 60.

* Appendices will be found beginning on page 51.

DISCUSSION OF RESULTS

In the earlier section of this report entitled "Previous Work" on page 3, reference was made to the fact that a question has been raised concerning the vertical alignment and straightness of the tubes investigated and reported in Report No. 60. Figure 1 presents all of the data collected with 3.5, 4.7, 5.3 and 6.0 feet per second water velocities through the center row of the three vertical rows of 1-inch bare, 18 gage, 90-10 Cupro-Nickel tubes with steam condensing at 101°F and 212°F. Equation 3, page 3, is the equation of the recommended line for C_n under these conditions. Figure 7 and Figure 8 present plots of individual U_o and cumulative U_o values, respectively, obtained with a water velocity of 6.0 feet per second and steam condensing at 212°F on the center vertical row of tubes after removing the two side rows of tubes. Figures 26 and 27 present plots of individual U_o and cumulative U_o values respectively, obtained with a water velocity of 6.0 feet per second and steam condensing at 212°F before removing the two side rows of tubes. The data used for the preparation of Figures 26 and 27 appeared in Table IV-9, page 152, of Report No. 60. This data was abstracted and is presented as Tables I-4 and I-5 of Appendix I of this report. The dotted curves appearing in Figures 26 and 27 are the solid lines appearing in Figures 7 and 8, respectively, for comparison purposes.

A comparison of the single row data in Figure 7 with the data with two side rows shown in Figure 26 indicates that the presence of the two side rows of tubes had a marked effect on the overall heat transfer coefficients with log-mean temperature differences of approximately 43°F to 47°F. A comparison of the performance of corresponding tubes in Figures 7 and 26 indicates Tube No. 2 and No. 6 are in marked disagreement; No. 7 is in partial disagreement, while the rest of the individual tubes are within experimental agreement. The only explanation that can be offered at this time is that there must have been some interference between the center row and the side rows of tubes. A similar comparison can be made on the cumulative U_o basis by comparing Figure 8 with Figure 27, and another by comparing Figure 8 with Figure 7, and Figure 27 with Figure 26. A comparison of Figure 7 with Figure 8, and Figure 26 with Figure 27, indicates that the performance of an individual tube is submerged in the cumulative performance of the tube row to such an extent that C_n plot given in Figure 1 gives no clear indication of the performance of the individual tubes. The question as to the degree of vertical alignment of the rows and the straightness of the tubes and subsequently their effect on the heat transfer performance cannot be fully answered on the basis of the data collected to date. In order to answer these questions, it would be necessary to re-tube the steam condenser with three rows of bare tubes with the two tube-support baffles in place and collect more experimental data. In the meantime, it is recommended that Equation 3 be used for design purposes. A study of the effect of using the equation for a single row in comparison with using Equation 3 was made. Figure 6 presents the C_n plot for the data collected on the single row. This C_n equation is presented in Table 3 as Equation 7.

TABLE 3

Summary of the C_n Equations

1-inch Bare Tube, Single Row			
Equation for 6.0 ft/sec data	(Fig. 6)	$C_n = 1.22\,(N)^{0.0895}$	(7)
1-inch Triple-Start Corrugated Tube, Single Row			
Equation for 3.5 ft/sec data	(Fig. 9)	$C_n = 1.40\,(N)^{0.0620}$	(8)
Equation for 6.0 ft/sec data	(Fig. 10)	$C_n = 1.48\,(N)^{0.0795}$	(9)
Equation for Combined Data	(Fig. 11)	$C_n = 1.43\,(N)^{0.0708}$	(10)
1-inch Triple-Start Corrugated Tube, Three Rows			
Equation for 3.5 ft/sec data	(Fig. 16)	$C_n = 1.47\,(N)^{0.0968}$	(11)
Equation for 6.0 ft/sec data	(Fig. 17)	$C_n = 1.52\,(N)^{0.1097}$	(12)
Equation Recommended for Design Use	(Fig. 18)	$C_n = 1.48\,(N)^{0.1050}$	(13)

The C_n equation for the single row of tubes and Equation 3 for three rows were used in the design computer program given in Appendix V of Report No. 60, pages 161-167. Appendix IV of this report presents the calculated results for non-fouling and a 0.0005 fouling factor for steam condensing at 212°F with a water velocity of 6.0 feet per second. A comparison of the results for Equation 3 without fouling given in Table IV-1 with corresponding C_n equation for a single row of tubes given in Table IV-2 indicates that the use of Equation 3 results in 4.5 percent more steam being condensed. On the other hand, a comparison of Table IV-3 with Table IV-4 with 0.0005 fouling indicates 3.5 percent more steam being condensed. Thus, the use of Equation 3 results in a prediction of approximately 4 percent more steam condensed.

A similar study of the performance of a single vertical row of triple-start corrugated tubes versus the performance of the middle vertical row of three rows with two tube-support plates was also made. Figures 9, 10, and 11 present C_n plots for the single row using the data in Table II-1. The resulting C_n equations are summarized in the middle of Table 3. Figures 12 through 15 present plots of the individual and cumulative U_o values from Tables II-2 and II-3. A comparison of Figures 12 and 13 with Figure 7 indicates that the use of two tube-support plates resulted in a more consistent pattern of performance. A comparison of Figures 14 and 15 with Figure 8 supports this conclusion.

Figures 16, 17 and 18 present C_n plots for the center row of a three-row bundle of triple-start corrugated tubes using the data in Table III-1. The resulting C_n equation is summarized at the bottom of Table 3. Figures 19 through 22 present plots of the individual and cumulative U_o values from Tables III-2 and III-3. A comparison of Figures 19 and 20 for triple-start corrugated tubes with Figure 26 for one-inch bare tubes further indicates that the use of the two tube-support plates resulted in a more consistant pattern of performance. A similar comparison of Figures 21 and 22 with Figure 27 also supports this conclusion.

Further comparisons must be made between the single row and multiple row results for the triple-start corrugated tubes. The individual tube performances given in Figures 12 and 13 for a single row must be compared with those given in Figures 19 and 20 for the center row of three rows, respectively. Likewise, the cumulative performances given in Figures 14 and 15 for a single row must be compared with those given in Figures 21 and 22 for the center row, respectively. If such a comparison is made, it will be noted that in all cases, without exception, the center row in a three row bundle always gives slightly higher overall heat transfer coefficients than the single row. Since the tubes studied were identical in both instances and the operating conditions were the same, the differences in overall heat transfer performance must be due to the steam-side condensing behavior. Furthermore, it is believed that the performance of the center vertical row of tubes in a three row bundle is physically more representative of the performance of a row of tubes in an actual steam condensing bundle. It is recommended that the C_n equation obtained from the center row of a simulated bundle be used for design purposes. This logic is the basis for justifying the recommendation of Equation 3 for bare tubes.

The triple-start corrugated tube studied in this investigation had a 50 percent thicker wall than the single-start tube studied and reported in Report No. 60. A direct comparison between these two tubes is not strictly valid. A direct comparison should be made on tubes having similar inside diameter, outside diameter and wall thickness. A hypothetical single-start tube having the same inside diameter, outside diameter, and wall thickness as the triple-start corrugated tube was assumed and comparison performance calculations made. The results are reported in Appendix V. Table 4 presents the characteristics of the hypothetical single-start corrugated tube. This hypothetical tube differs from the triple-start tube in Table 2 only in the number of corrugation starts. The C_i value and C_n equations for this tube were obtained by interpolating the values presented in Report No. 60 and in this report.

TABLE 4

Characteristics of the Hypothetical Single-Start Corrugated Tube

Outside Diameter, inches	0.9900
Inside Diameter, inches	0.9132
Average Tube Wall, inches	0.0384
Tube Material	90-10 CuNi
Thermal Conductivity, Btu/ft-hr-°F	26.0
Helix	
Pitch, inches	0.375
Depth, inches	0.030
Start	One
Sieder-Tate Constant	0.0550
C_n Equation	$C_n = 1.505(N)^{0.204}$

Appendix V contains design calculations for the hypothetical 1-inch single-start and the triple-start 90-10 Cupro-Nickel corrugated tubes for 10, 15, 20, 25 and 30 tubes in a vertical row with steam condensing at 212°F with a tube-side water velocity of 3.5 feet per second with and without fouling. An examination of these tables indicates that without fouling the single-start tubes will condense approximately 18 percent more steam than the triple-start tubes with 25 tubes in a vertical row under the same condition. For the same condition and arrangement but with a 0.0005 fouling factor on the tubeside, the triple-start tubes condense approximately 10 percent more steam than the single-start tubes.

Another interesting hypothetical comparison can be made if one assumes that a triple-start corrugated tube could be made that had the identical outside diameter, identical inside diameter and correspondingly identical wall thickness as the single-start corrugated tube. If it is further assumed that (a) the Sieder-Tate constant has the same value as reported herein, and (b) the C_n equation is the same as that reported herein, then corresponding computer design calculations can be made. Such calculations were made and are presented in Table VI-1 and Table VI-2 for no fouling and Tables VI-3 and VI-4 for a fouling factor of 0.0005. A comparison of Table VI-1 with Table VI-2 and Table VI-3 with Table VI-4 indicates that the single-start corrugated tube would condense approximately 17 percent more steam at 212°F than the hypothetical triple-start corrugated tube without fouling and would condense approximately 10 percent more steam at 212°F with a 0.0005 fouling factor with tubeside water velocities of 3.5 feet per second.

PRESSURE DROP CONSIDERATIONS

The previous section indicated that hypothetical 1-inch single-start corrugated tubes would condense 18 percent more steam with no fouling and 10 percent more steam with a 0.0005 fouling factor if pressure drop considerations were ignored. The pressure drop of the single-start corrugated tube, from Figure 24, is approximately 44 percent higher per unit length than the triple-start tube with a 3.5 feet-per-second water velocity. A more useful comparison can be made for equal pressure drop conditions for a stage of an MSF (multi-stage flash) distillation plant. A computer design program prepared by UOP Wolverine Tube Division was used for making the design calculations. The computer program is listed in Appendix VII. The characteristics of the tubes studied in the design comparison are presented in Table 5 along with the MSF recovery stage design conditions.

The Sieder-Tate constant for the 3/4-inch bare tube of Table 5 was obtained by interpolating the constant for the 5/8-inch bare tube in Report No. 55[3] and for the 1-inch bare tube in Report No. 60. The C_n equation for this tube was also obtained in a similar manner. The friction factor equation for this tube was obtained by fitting an equation to the bottom curve of Figure 25, page 48 of this report. The hypothetical 1-inch single-start corrugated tube of Table 5 is the same tube presented in Table 4 with additional information concerning the tube-side friction factor. This friction factor was obtained by cross-plotting the relative roughness (ε /D) of Moody[4] for the 5/8-inch and 1-inch single-start corrugated tubes of Report No. 60 and extrapolating to the inside diameter indicated in Table 4. All of the information given in Table 5 for the 1-inch triple-start corrugated tube was reported earlier in this report.

The performance of 3/4-inch outside diameter bare tubes in the steam condensing application is used as a basis of comparison. Table VIII-1 of Appendix VIII summarizes the calculations for the 3/4-inch bare tube; Table VII-2 summarizes the calculations for the 1-inch outside diameter hypothetical single-start corrugated tubes; and Table VIII-3 summarizes the calculations for the 1-inch outside diameter triple-start corrugated tubes. It should be noted that a 0.0003 fouling factor was used for the MSF stage calculations. For comparison purposes, Table 6, page 15, summarizes the calculation results for the 3/4-inch bare tubes, the 1-inch single-start and 1-inch triple-start corrugated tubes.

An examination of Table 6 indicates that approximately 24 percent less weight of tubing is required for the hypothetical 1-inch single-start corrugated tube and approximately 17 percent less for the 1-inch triple-start corrugated tubing as compared with 3/4-inch bare tubing. Table 6 further indicates that the stage length required for the hypothetical single-start corrugated tube stage length is 37 percent shorter than for the 3/4-inch bare tube and the triple-start corrugated tube stage length is 20 percent shorter.

TABLE 5

Dimensions and Characteristics of the Three Tubes and the MSF Stage Conditions Used in the Stage Calculations by the Computer Program in Appendix VII

Condenser Duty, Btu/hr	29,950,000	Brine Concentration, Wt. % Solid	5.0
Condensing Temperature, °F	212.70	Total Tubeside Brine Flow Rate, lbs/hr	8,191,000
Tubeside Brine Inlet Temperature, °F	201.42	Tubefield Layout	Triangular
Tubeside Brine Outlet Temperature, °F	205.25	Tube Pitch, inches	1.25 (nom. O.D.)
Log Mean Temperature Difference	9.23	Tubefield Shape	Circular

Tube Designation	3/4" Bare	Hypothetical 1" Corrugated (single-start)	1" Corrugated (triple-start)
Tube, O.D., inches	0.750	0.990	0.990
Average tube wall, inches	0.0384	0.0384	0.0384
Tube material	90-10 CuNi	90-10 CuNi	90-10 CuNi
Tubeside Fouling Resistance, hr-ft^2-°F/Btu	0.0003	0.0003	0.0003
Sieder-Tate Constant	0.0251	0.0550	0.0505
C_n Equation	$C_n = 1.158\ (N)^{0.093}$	$C_n = 1.505\ (N)^{0.204}$	$C_n = 1.48\ (N)^{0.105}$
Friction Factor Equation	$f = 0.316 \left[\frac{1}{(Re)^{0.25}}\right]$	$f = 0.10$	$f = 0.386 \left[\frac{1}{(Re)^{0.16}}\right]$

TABLE 6

Results of an MSF Stage Design Using Three Different Tubes

Tube Designation	3/4" Bare	Hypothetical 1" Corrugated (single-start)	1" Corrugated (triple-start)
Tubeside Pressure Drop per Stage, psi	0.70	0.70	0.70
Tubeside Velocity, ft/sec	6.0	3.7	4.3
Tube Length per Stage, ft	9.0	5.7	7.2
Total No. of Tubes per Stage	2,456	2,162	1,880
Total Tube Length per Stage, ft	21,998	12,390	13,503
Overall Heat Transfer Coefficient, U_o	751	1,010	927
Tubeside Heat Transfer Coefficient, h_i	2,099	2,941	3,019
Condensing Heat Transfer Coefficient, h_o	2,695	5,171	3,427
Tube Weight per Stage, lbs	7,332	5,583	6,085
Percent of Tube Weight	100	76	83

SUMMARY OF RESULTS

The previous two sections of this report indicated that pressure drop consideration must be taken into account when evaluating single-start and triple-start corrugated tubes in desalination applications in comparison with bare tubes. With the same water velocity of 3.5 feet per second, the single-start corrugated tubes would condense approximately 18 percent more steam at 212°F than the triple-start corrugated tubes without fouling, or approximately 10 percent more with a fouling factor of 0.0005, but with a 44 percent higher pressure drop. On the other hand, if one considers an actual desalination design application and introduces an equal pressure drop constraint and equal LMTD constraint for an MSF stage with steam condensing at 212°F, the tube-side water velocity would then be different for the single-start corrugated tubes and the triple-start corrugated tubes, i.e., 3.7 feet per second for the single-start corrugated tubes and 4.3 feet per second for the triple-start corrugated tubes, respectively. At these water velocities, the single-start corrugated tubes would condense approximately 8 percent more steam per unit length than the triple-start corrugated tubes with a fouling factor of 0.0003 as would be used in the heat recovery section of an MSF desalination plant. Under these operating conditions, the length of tubes required per stage would be 5.7 feet and 7.2 feet, respectively, and the corresponding total number of tubes per stage, as indicated in Table 6, would be 2,162 and 1,880. The use of 1-inch single-start corrugated tubes would amount to approximately 9 percent saving in tube weight over the use of triple-start corrugated tubes in this design application with the two indicated constraints.

The corresponding comparison of both single-start and triple-start corrugated tubes with the use of 3/4-inch bare tubes was made by referring to Table 6 and presented on page 15.

CONCLUSIONS

The single-start and triple-start corrugated tubes are both significantly better for condensing steam than corresponding bare tubes. The increased pressure drop resulting from the internal corrugation requires that a larger diameter corrugated tube be used in place of the normally used bare tubes and that lower water velocities be used with the corrugated tubes. Consequently, the use of corrugated tubes for desalination applications requires that great care be taken in the design of MSF plants with such tubes. Complete economic studies must be made of plant designs for specific applications in order to determine the relative economic merits of corrugated tubes over bare tubes.

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FIGURES

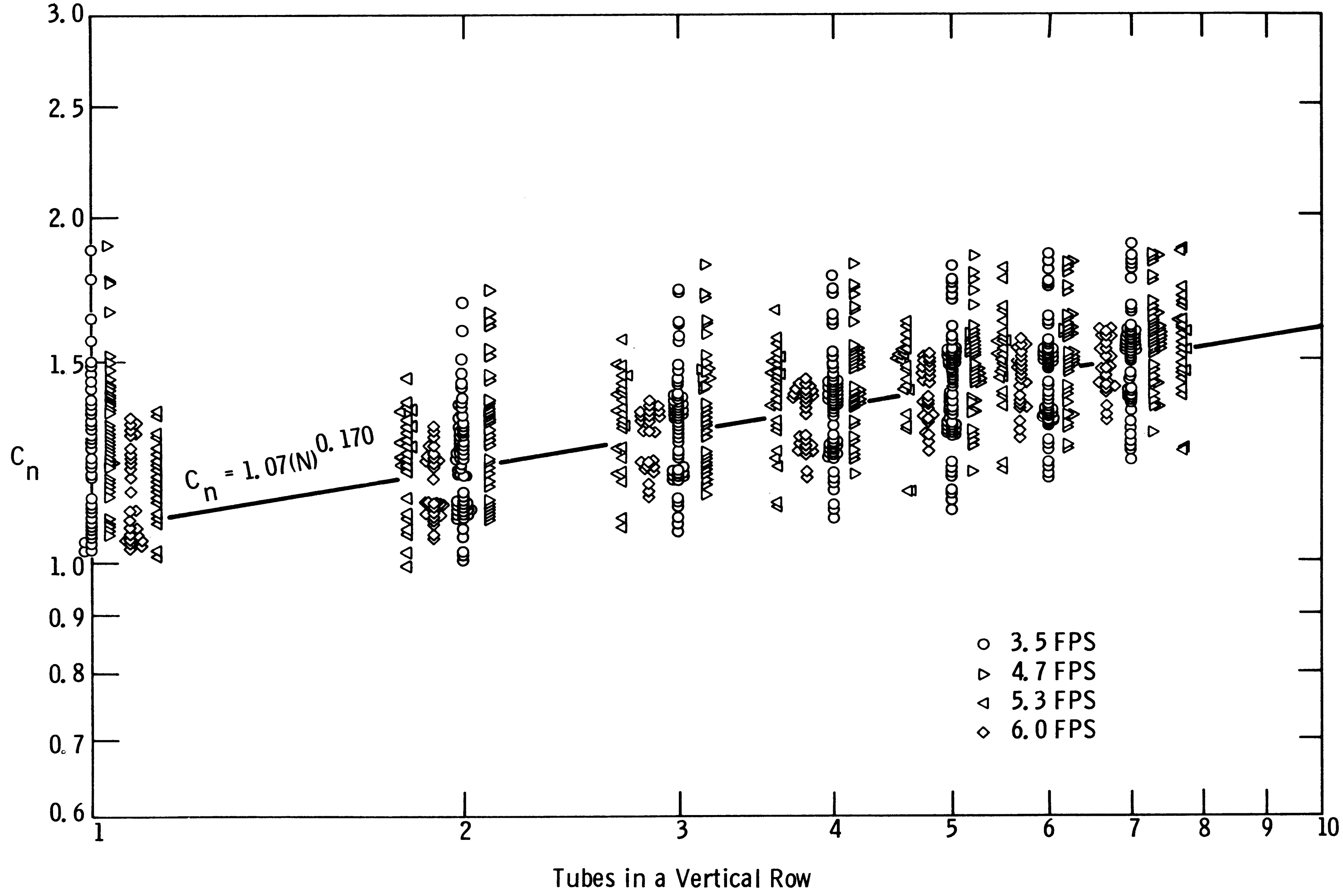

Figure 1. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Bare 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes in a Vertical Row. (Fig. 18, page 64, of Report 60)

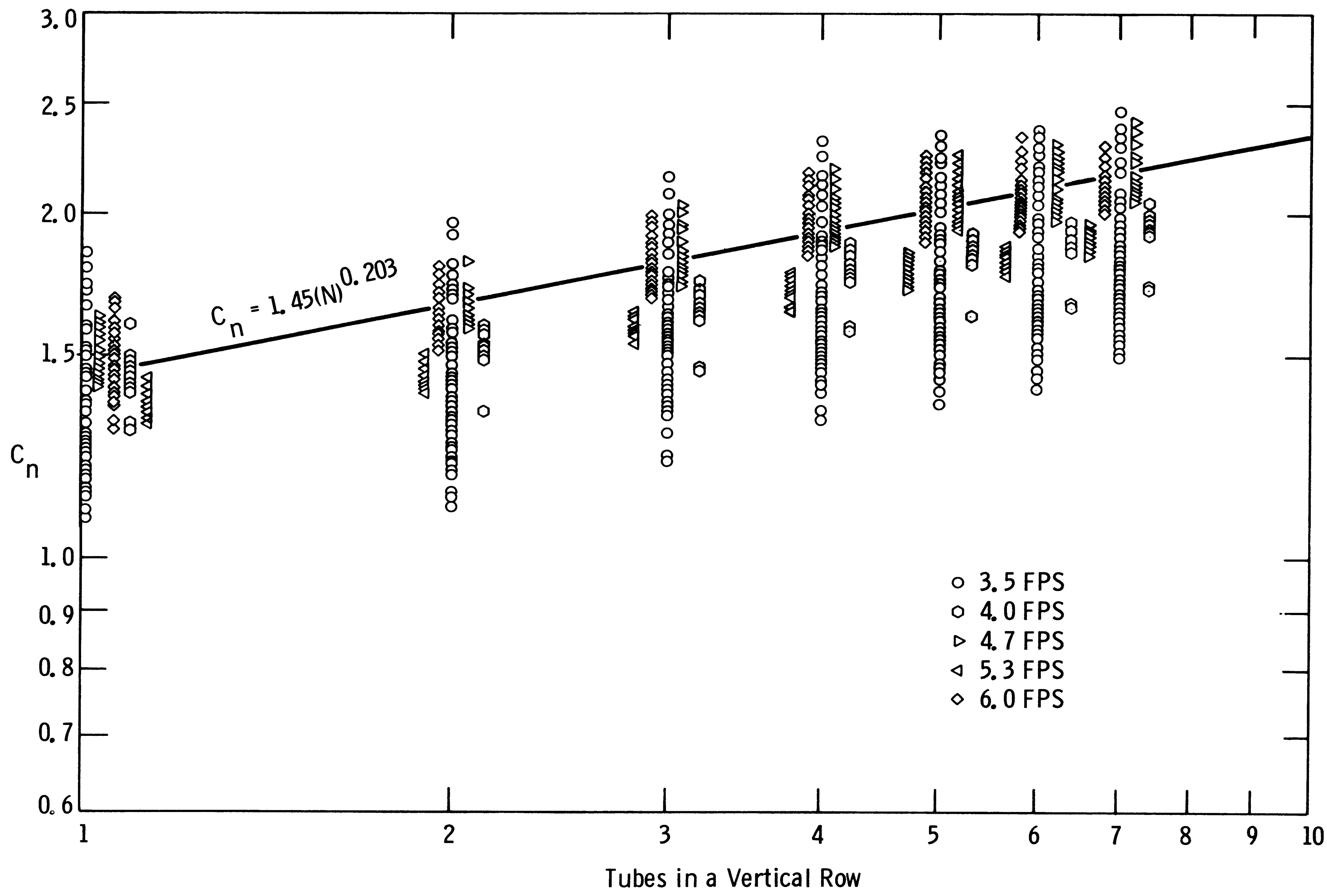

Figure 2. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 3.5, 4.0, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 7 Single-Start Corrugated 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes in a Vertical Row. (Fig. 23, page 69, of Report 60)

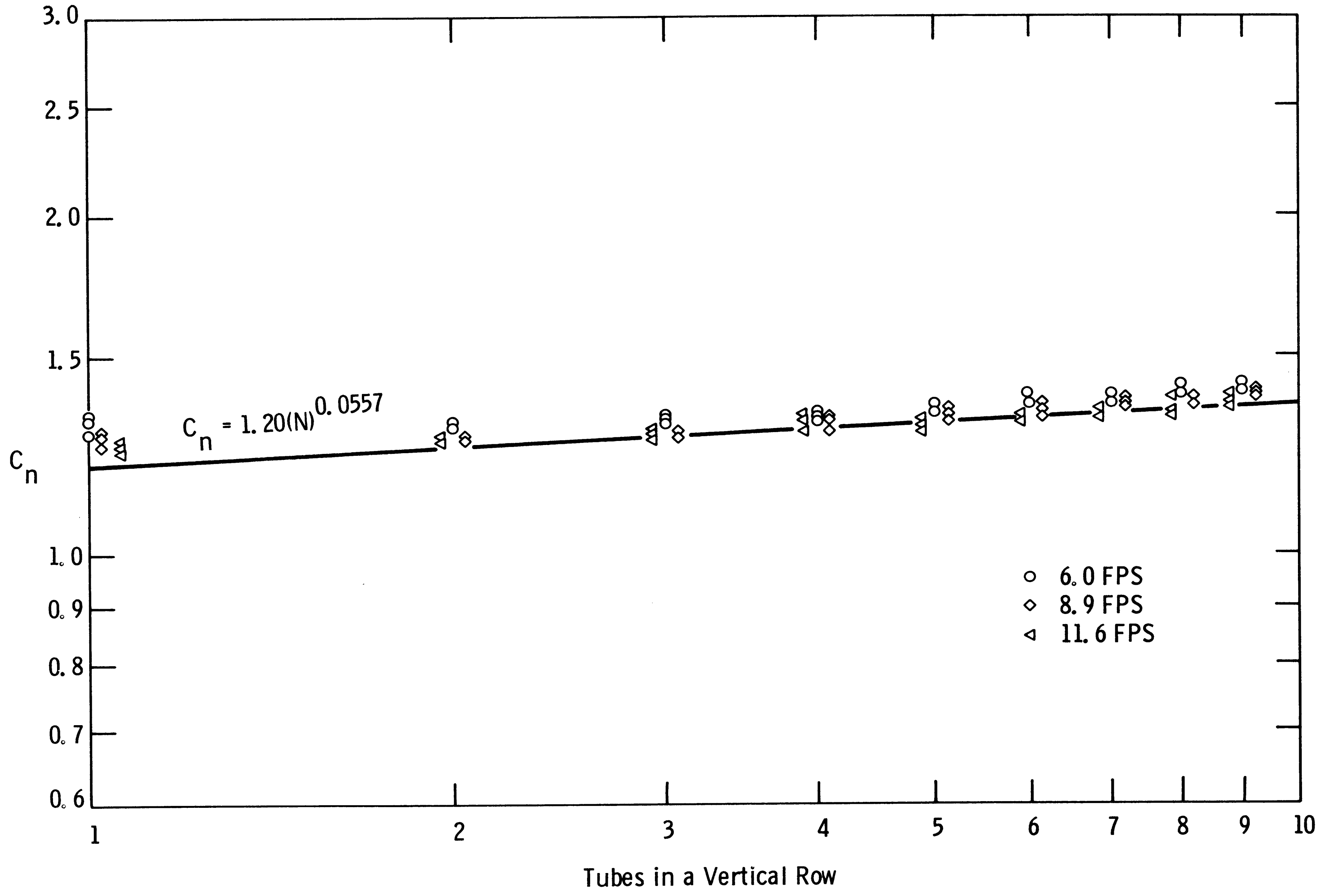

Figure 3. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 6.0, 8.9, and 11.6 feet per second and Condensation of Steam at 101°F on 1 to 9 Bare 5/8-inch O.D., 20 Gage, Copper Tubes in a Vertical Row. (Fig. 25, page 71, of Report 60)

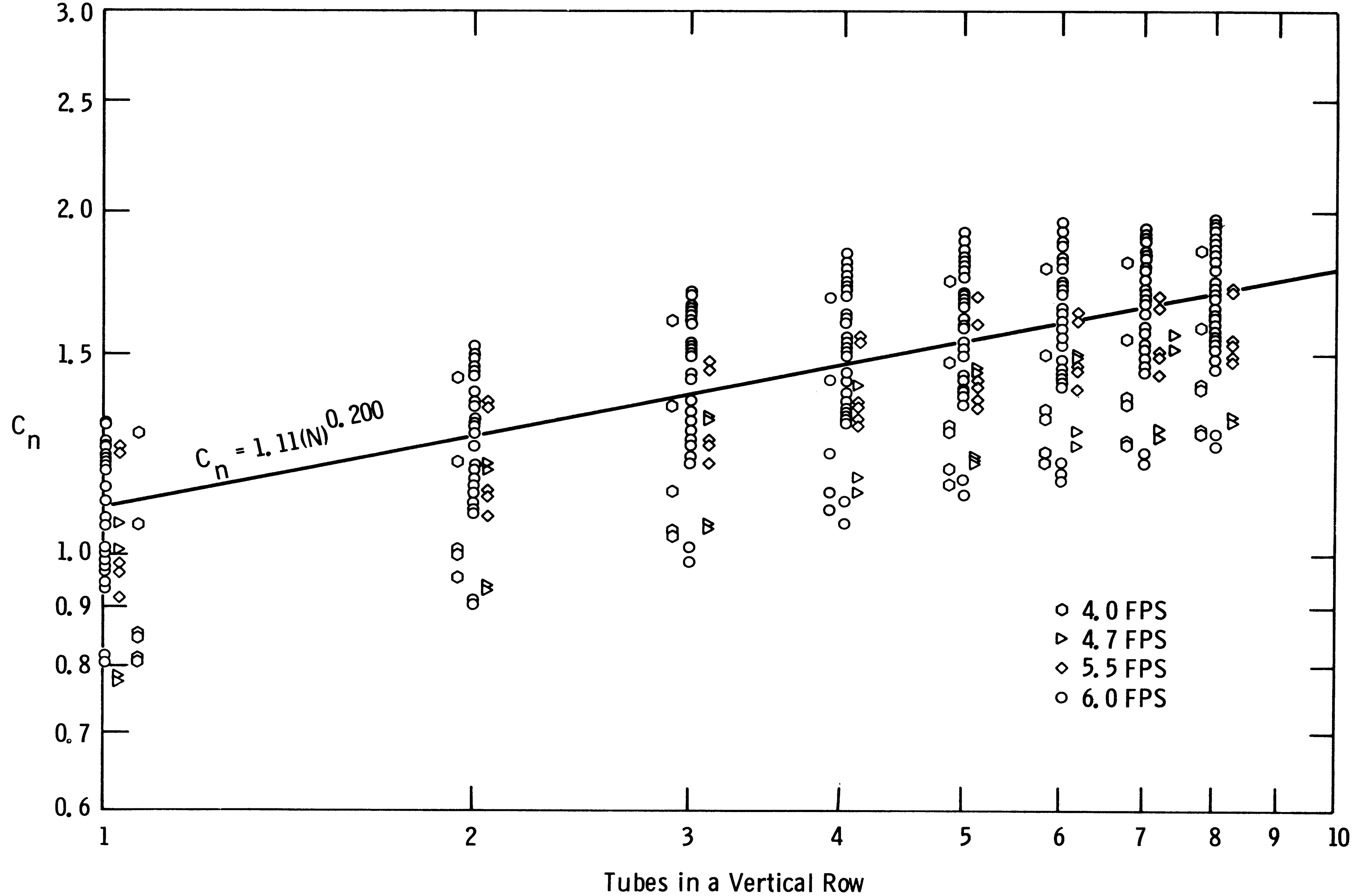

Figure 4. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocities of 4.0, 4.7, 5.3, and 6.0 feet per second and Condensation of Steam at 101°F and 212°F on 1 to 8 Single-Start Corrugated 5/8-inch O.D., 20 Gage, Copper Tubes in a Vertical Row. (Fig. 26, page 72, of Report 60)

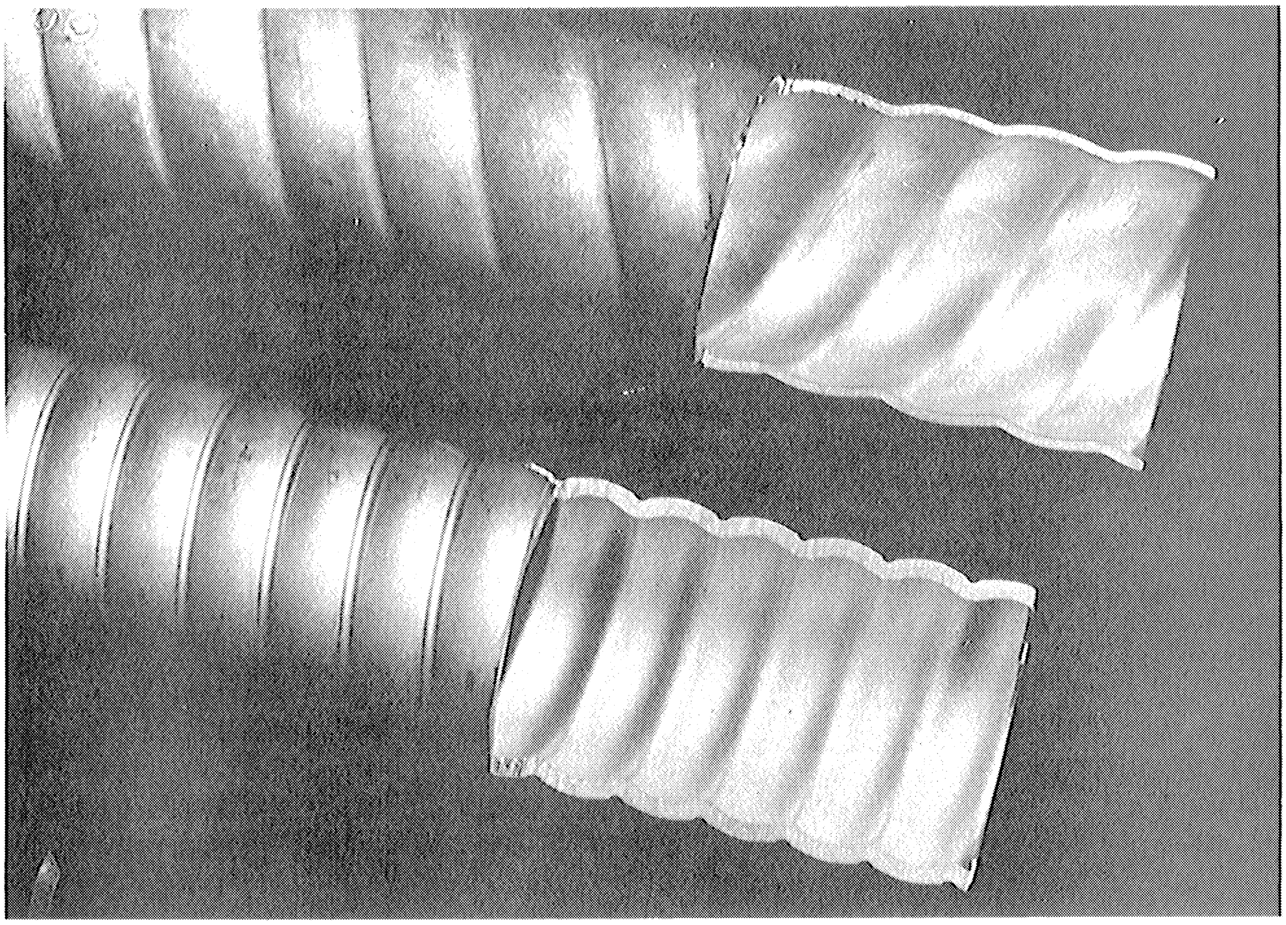

Figure 5. Sections of the 1-inch Single-Start and Triple-Start Corrugated 90-10 Cupro-Nickel Tubes. Triple-Start, Upper Specimen; Single-Start, Lower Specimen.

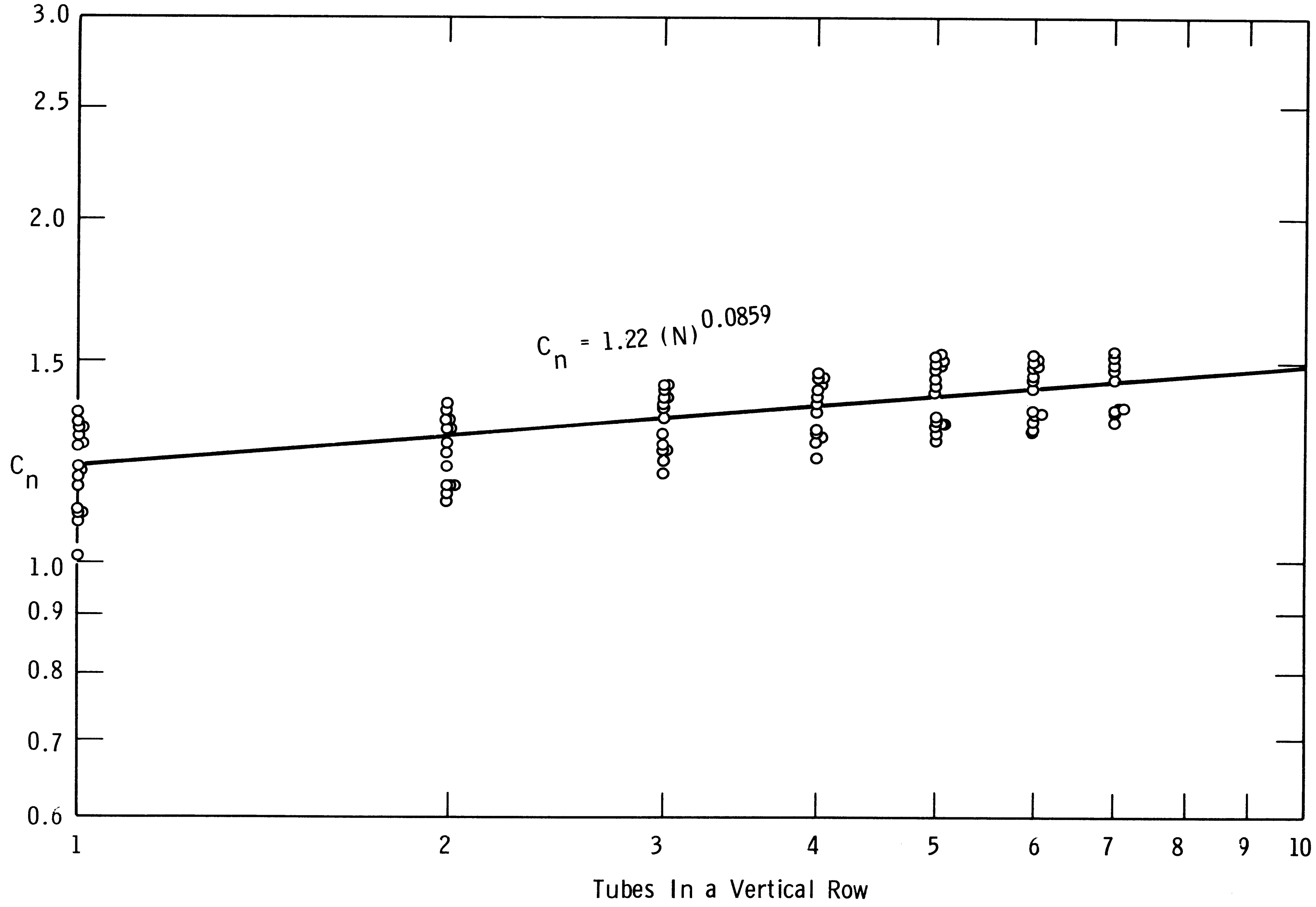

Figure 6. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Bare 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

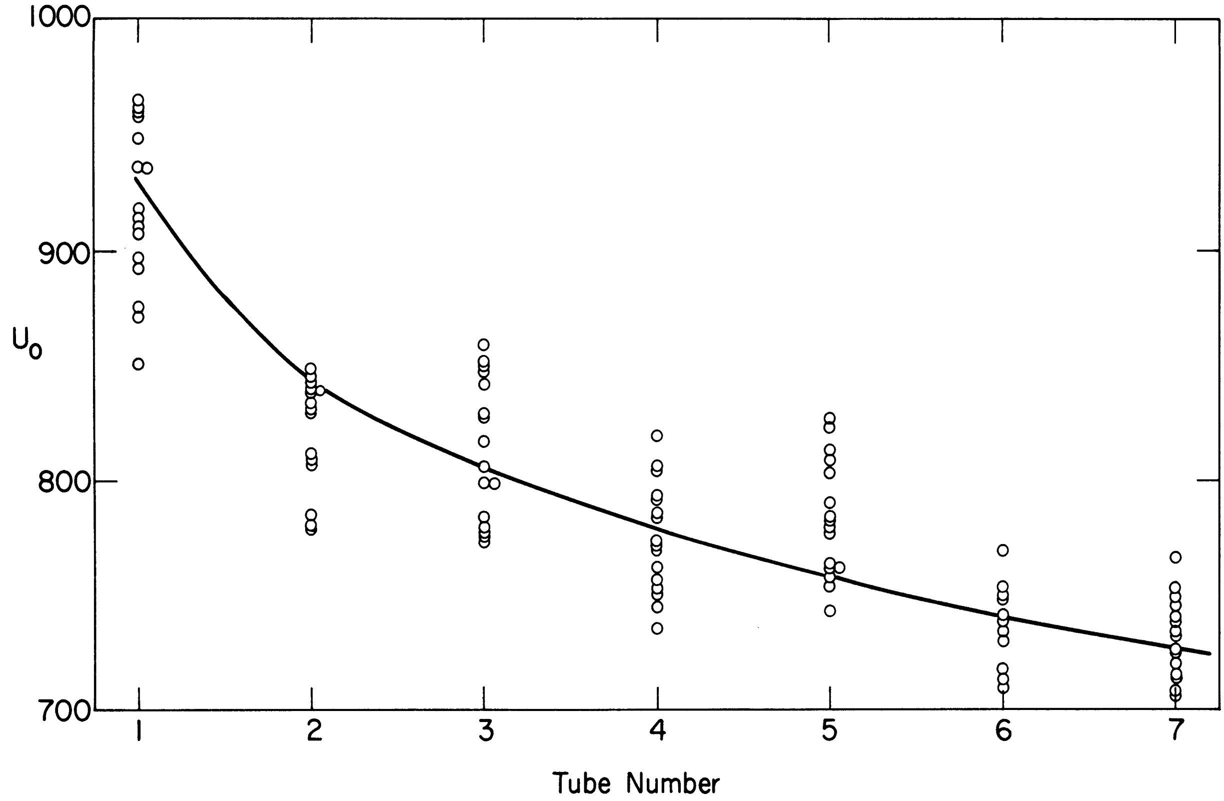

Figure 7. Individual Tube Overall Heat Transfer Coefficients for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Bare 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

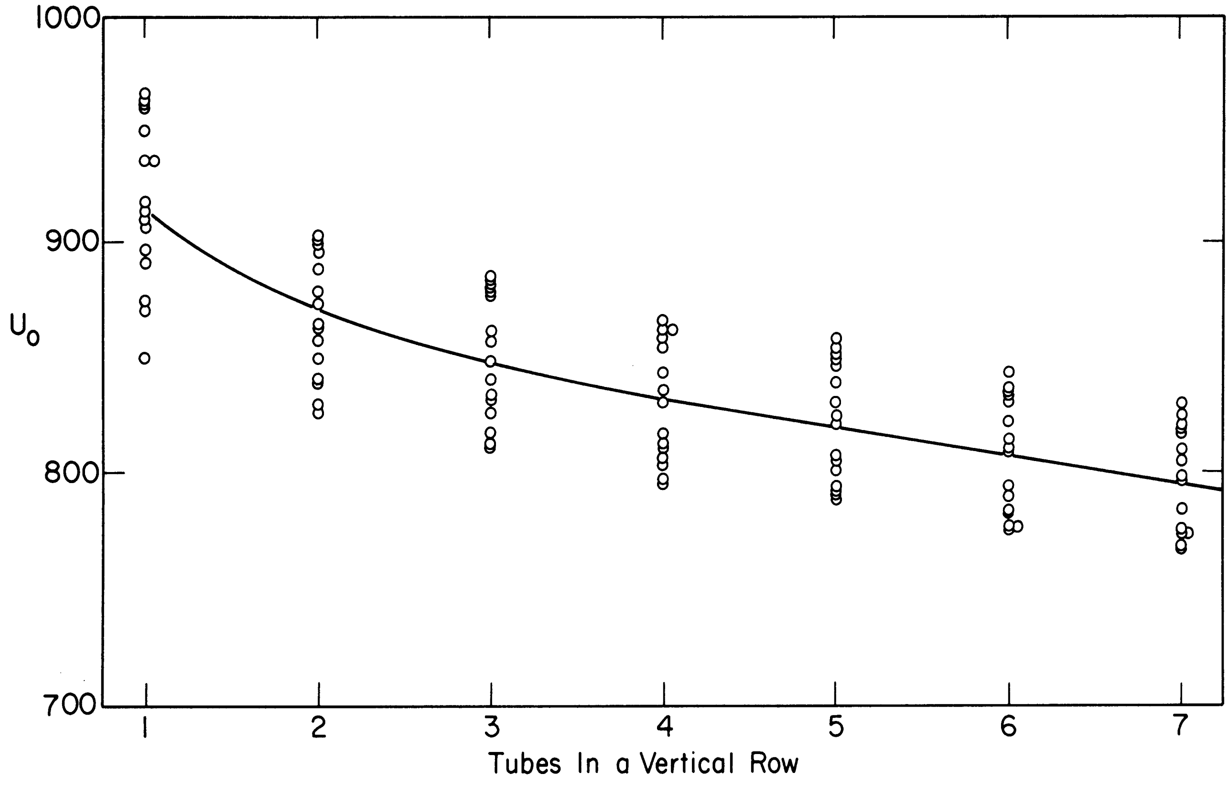

Figure 8. Cumulative Overall Heat Transfer Coefficients for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Bare 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

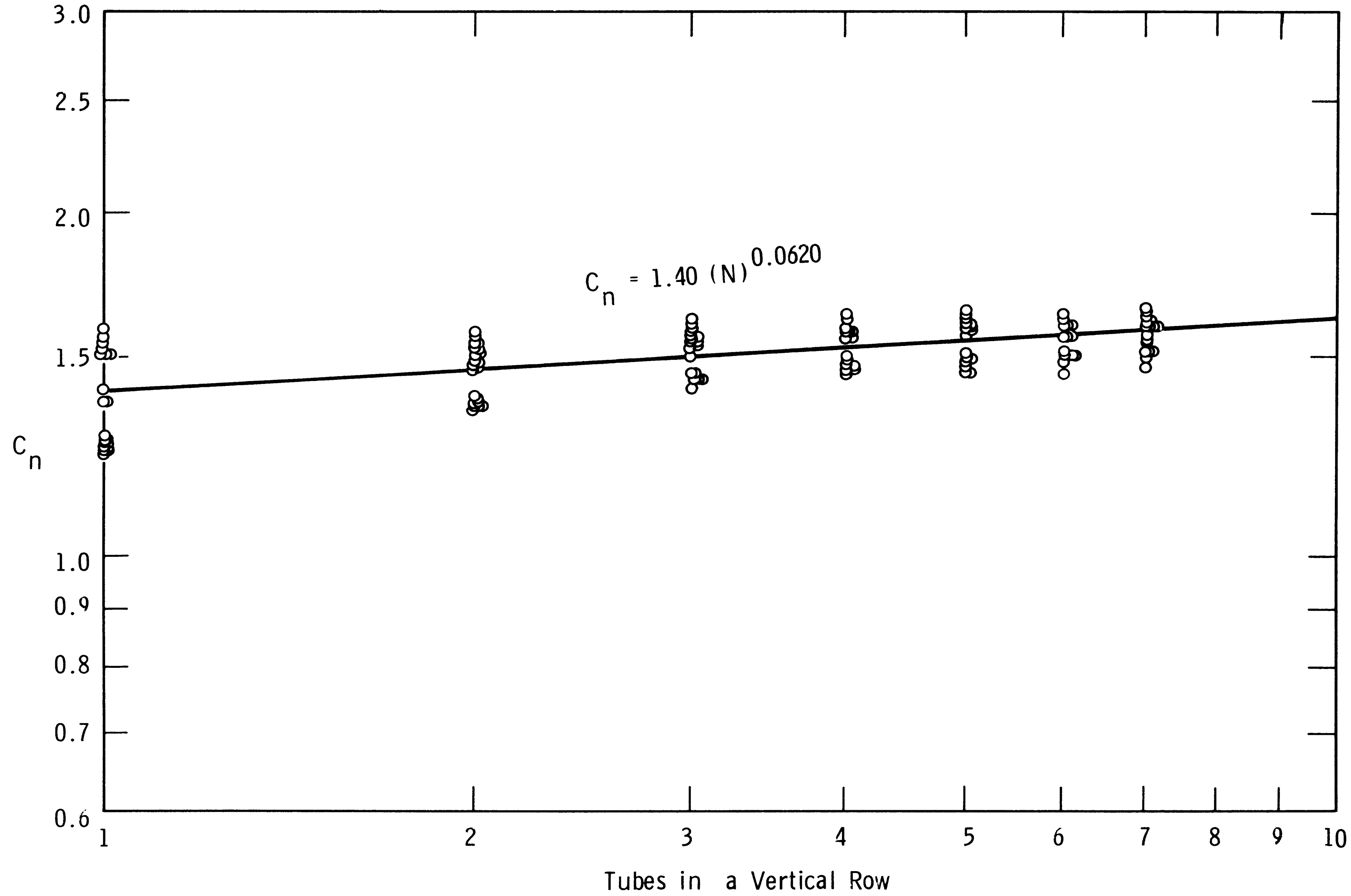

Figure 9. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

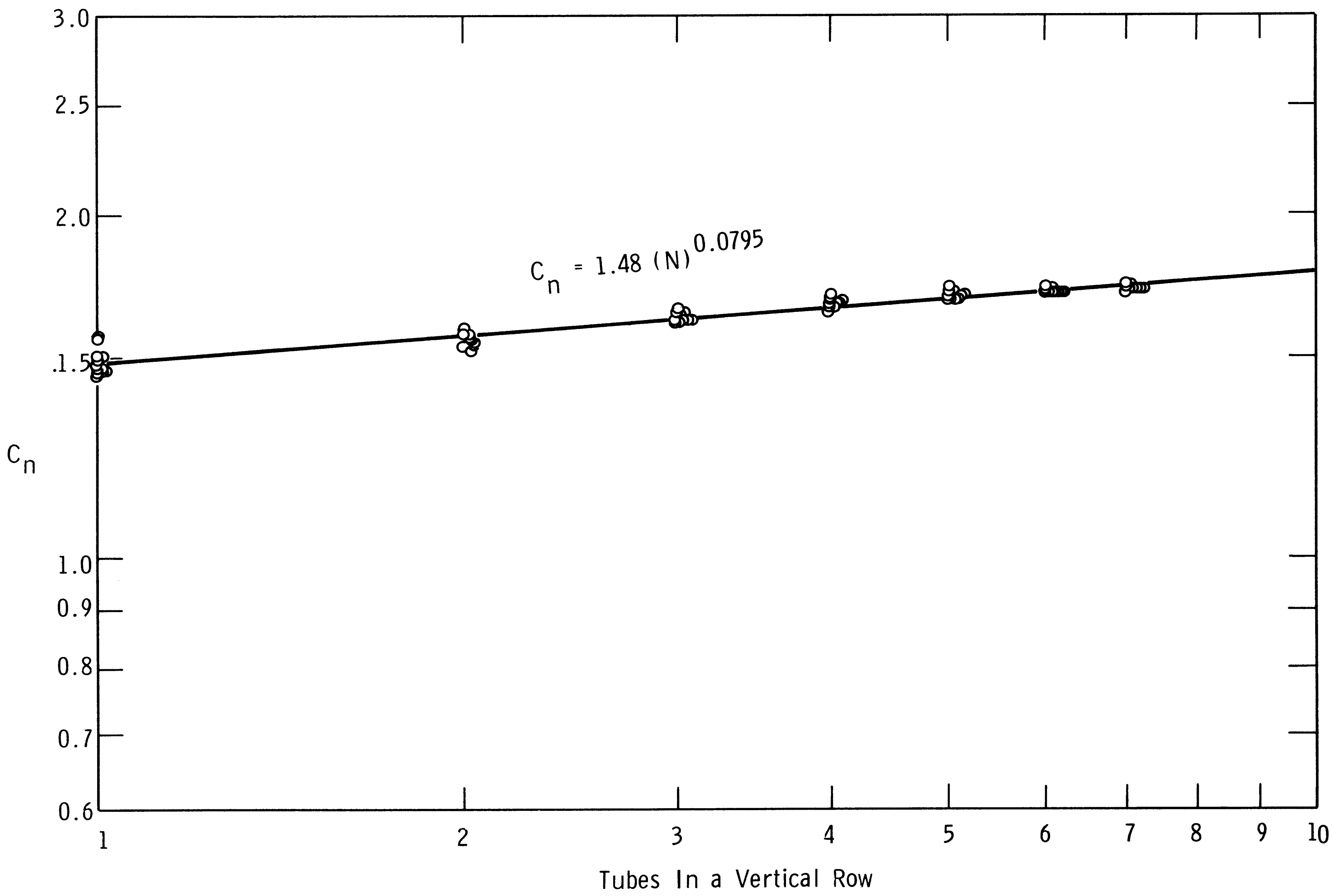

Figure 10. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

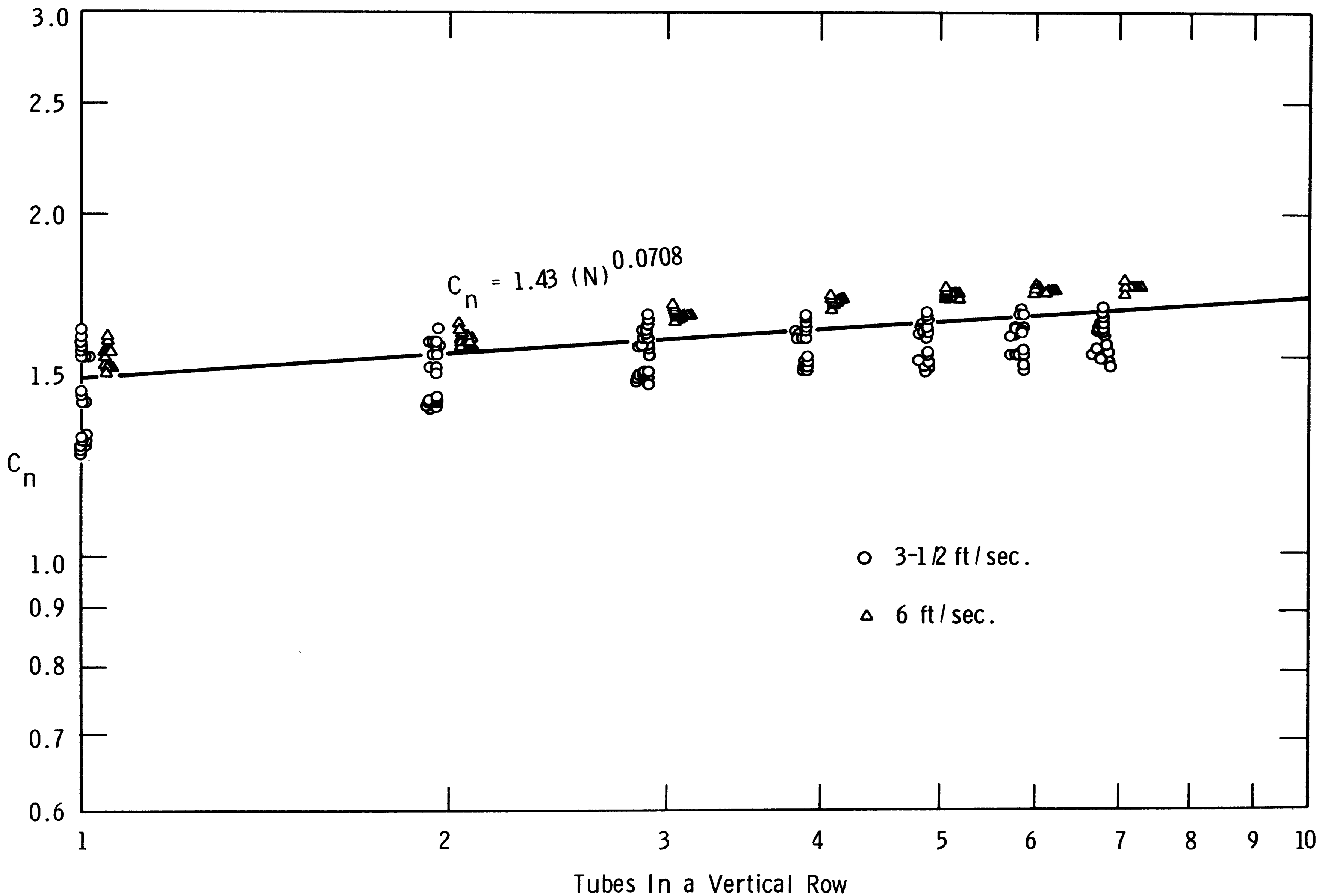

Figure 11. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocity of 3.5 and 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

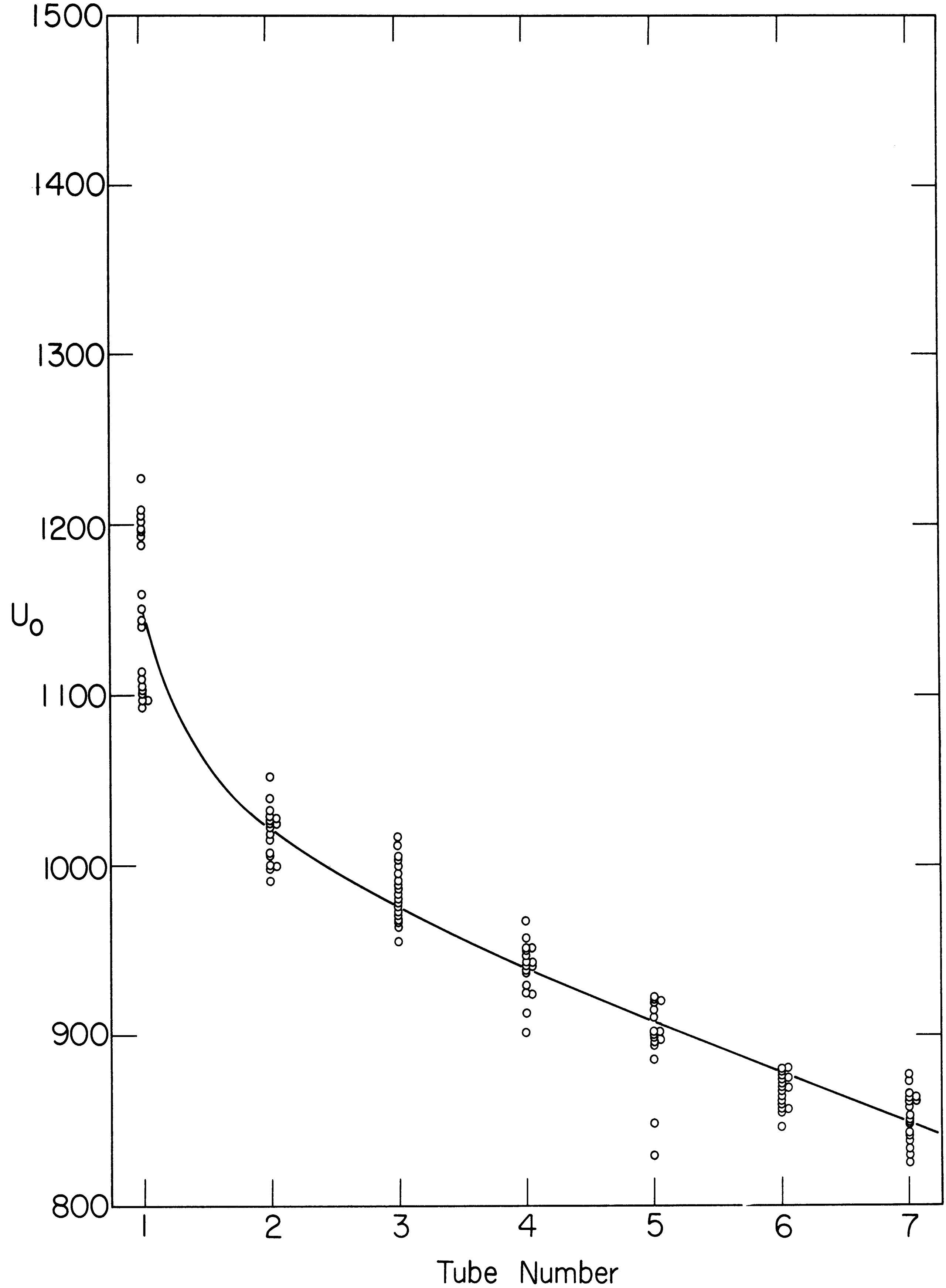

Figure 12. Individual Tube Overall Heat Transfer Coefficients for a Tube-side Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

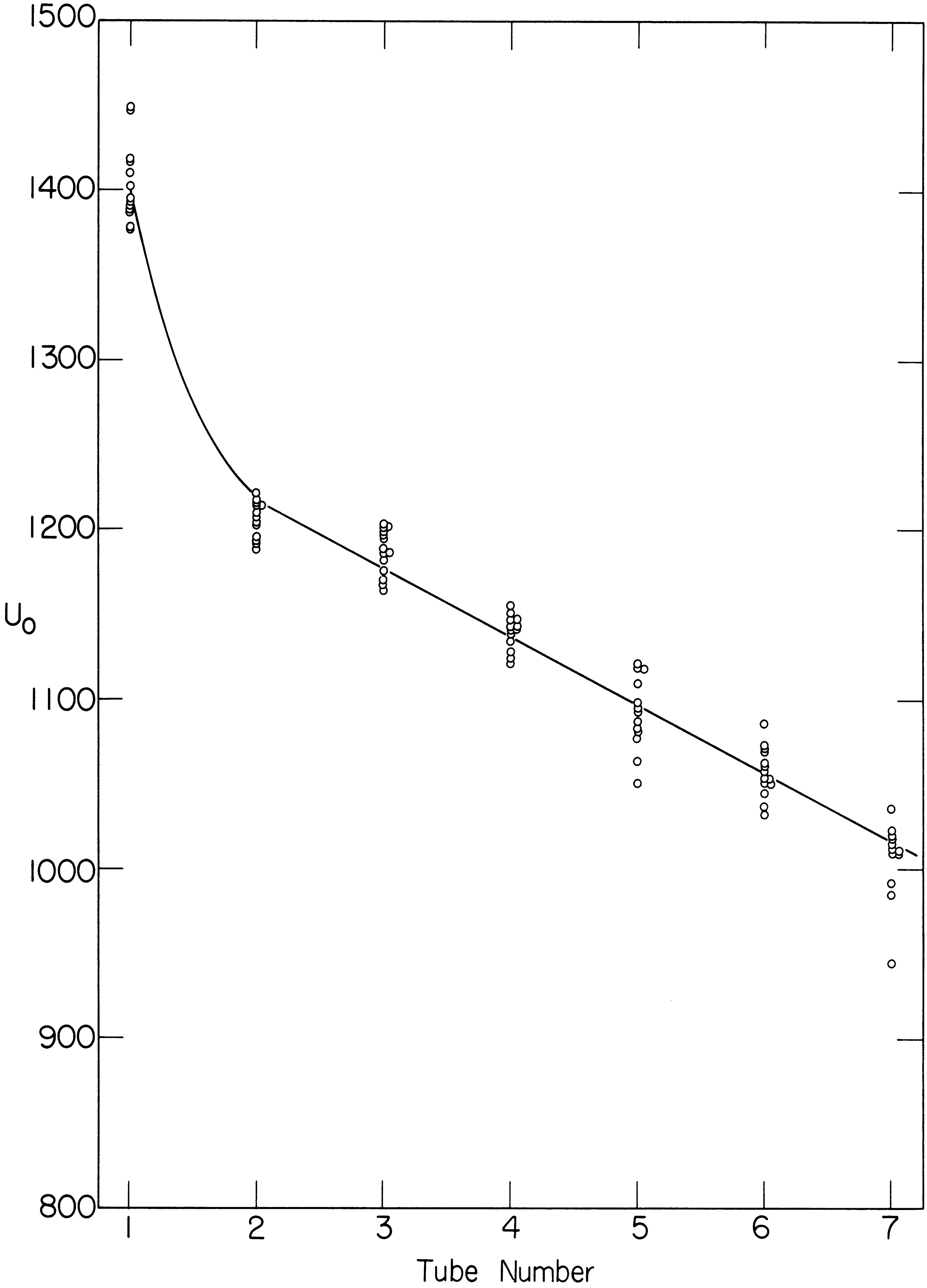

Figure 13. Individual Tube Overall Heat Transfer Coefficients for a Tube-side Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

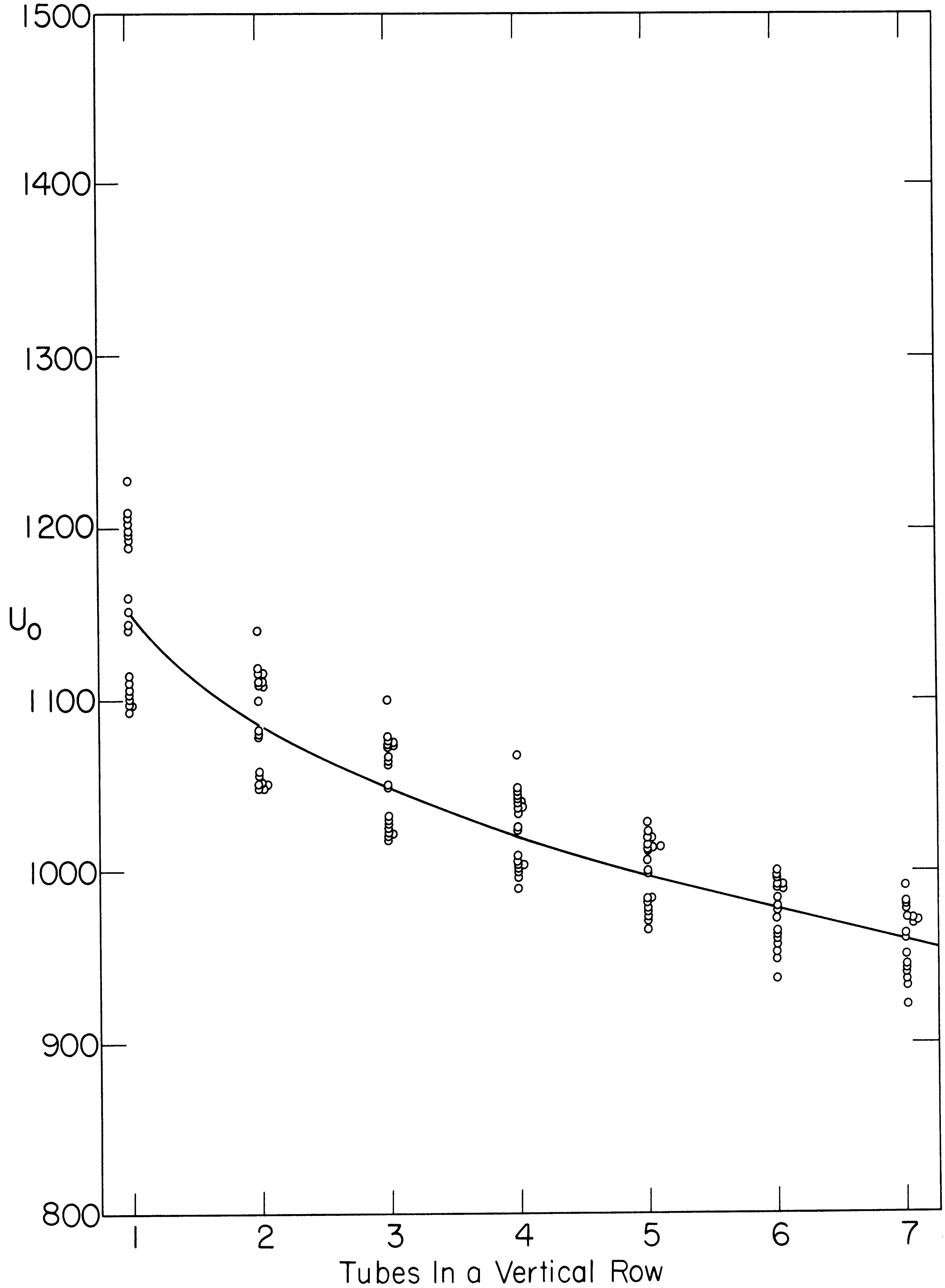

Figure 14. Cumulative Overall Heat Transfer Coefficients for a Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

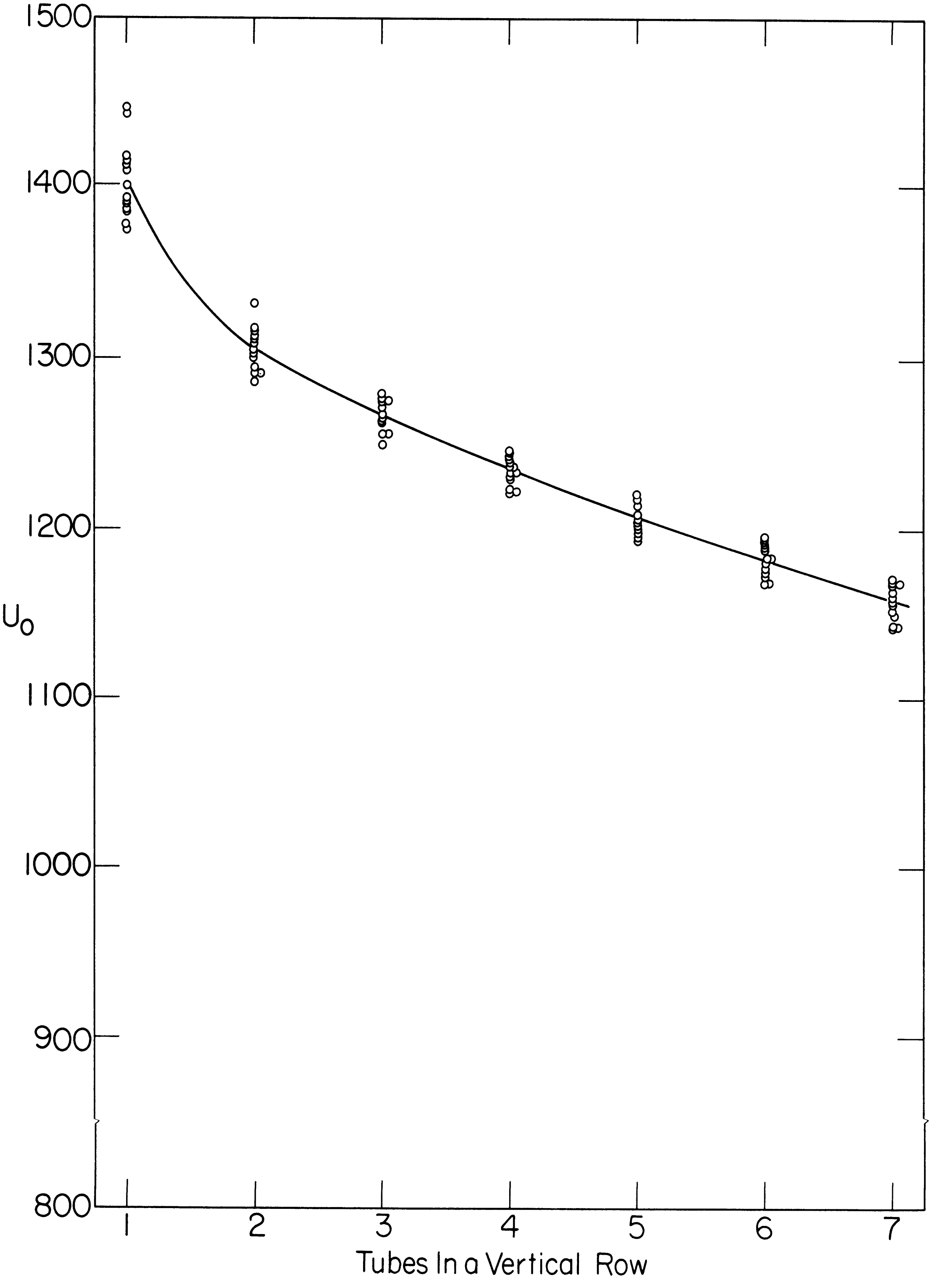

Figure 15. Cumulative Overall Heat Transfer Coefficients for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes in a Single Vertical Row.

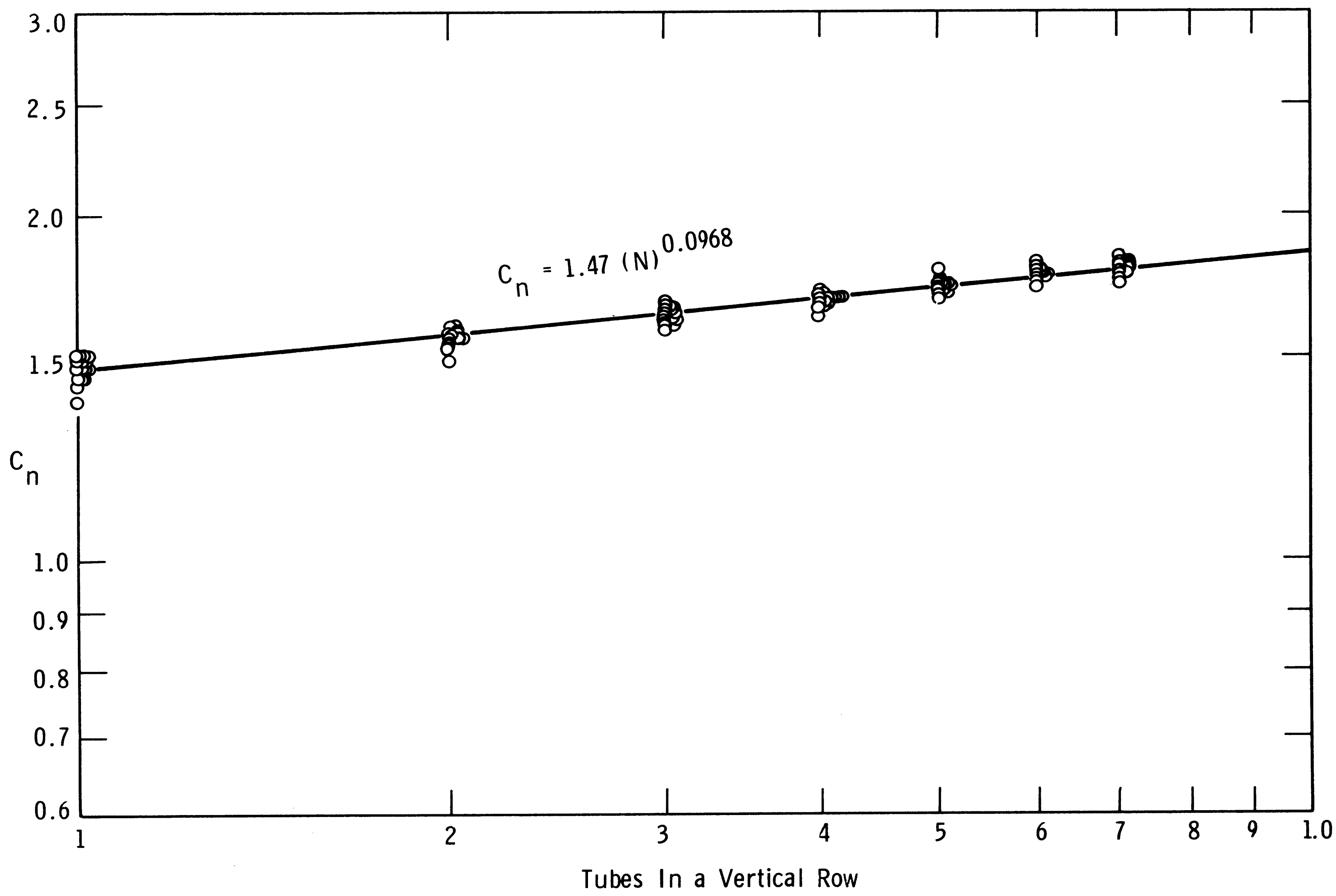

Figure 16. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

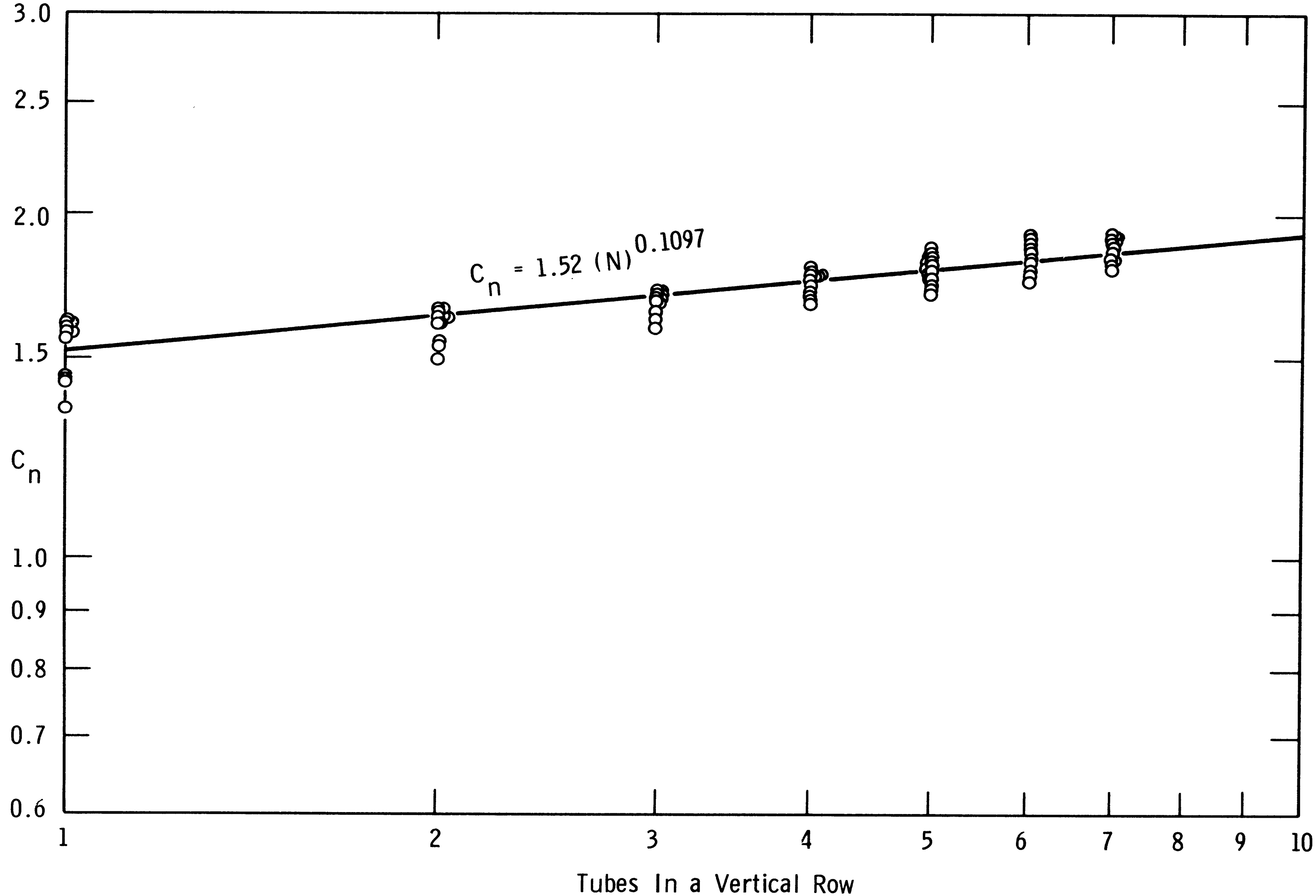

Figure 17. Condensing Coefficient Correction Factors for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

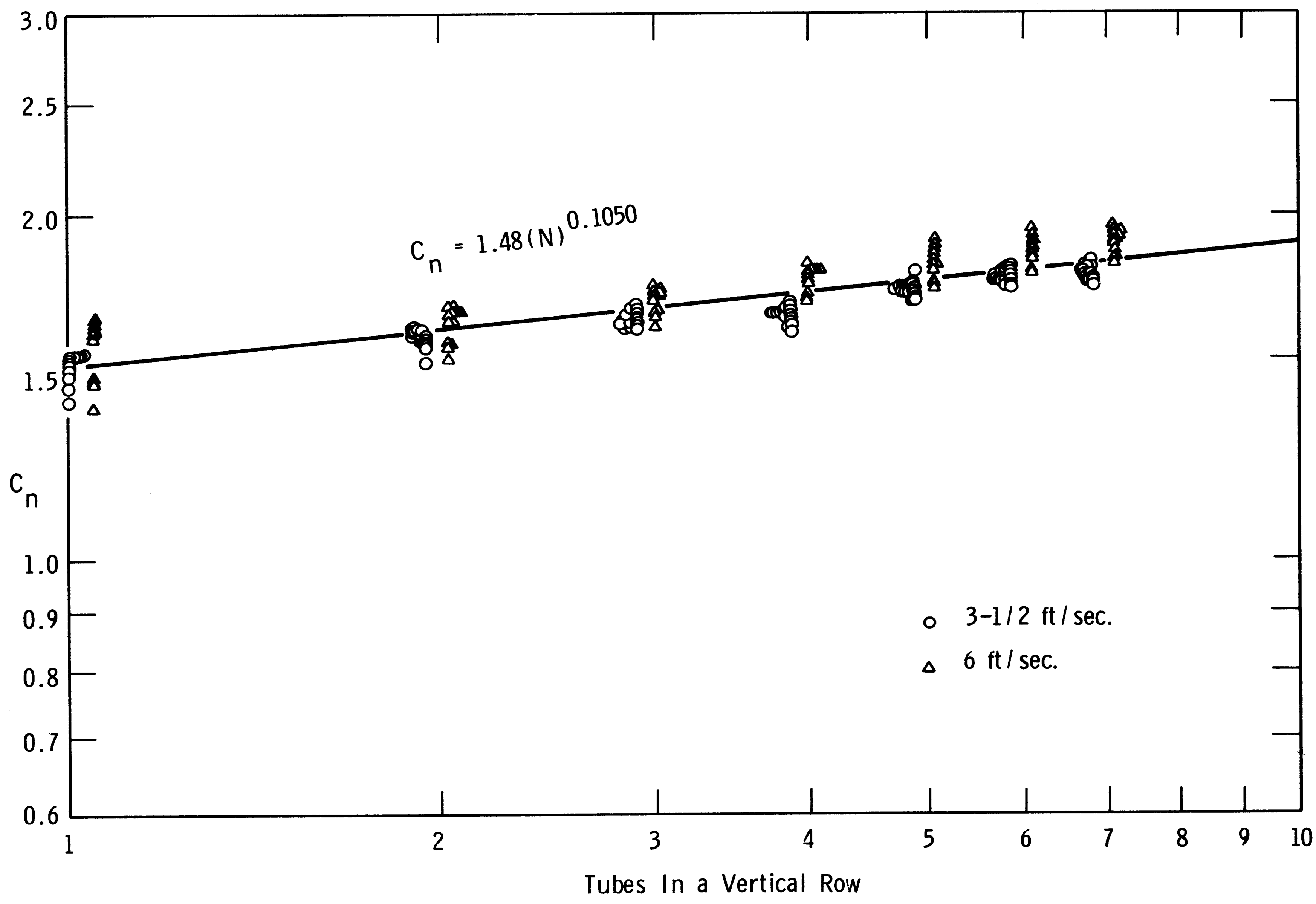

Figure 18. Summary of the Condensing Coefficient Correction Factors for Tubeside Water Velocity of 3.5 and 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

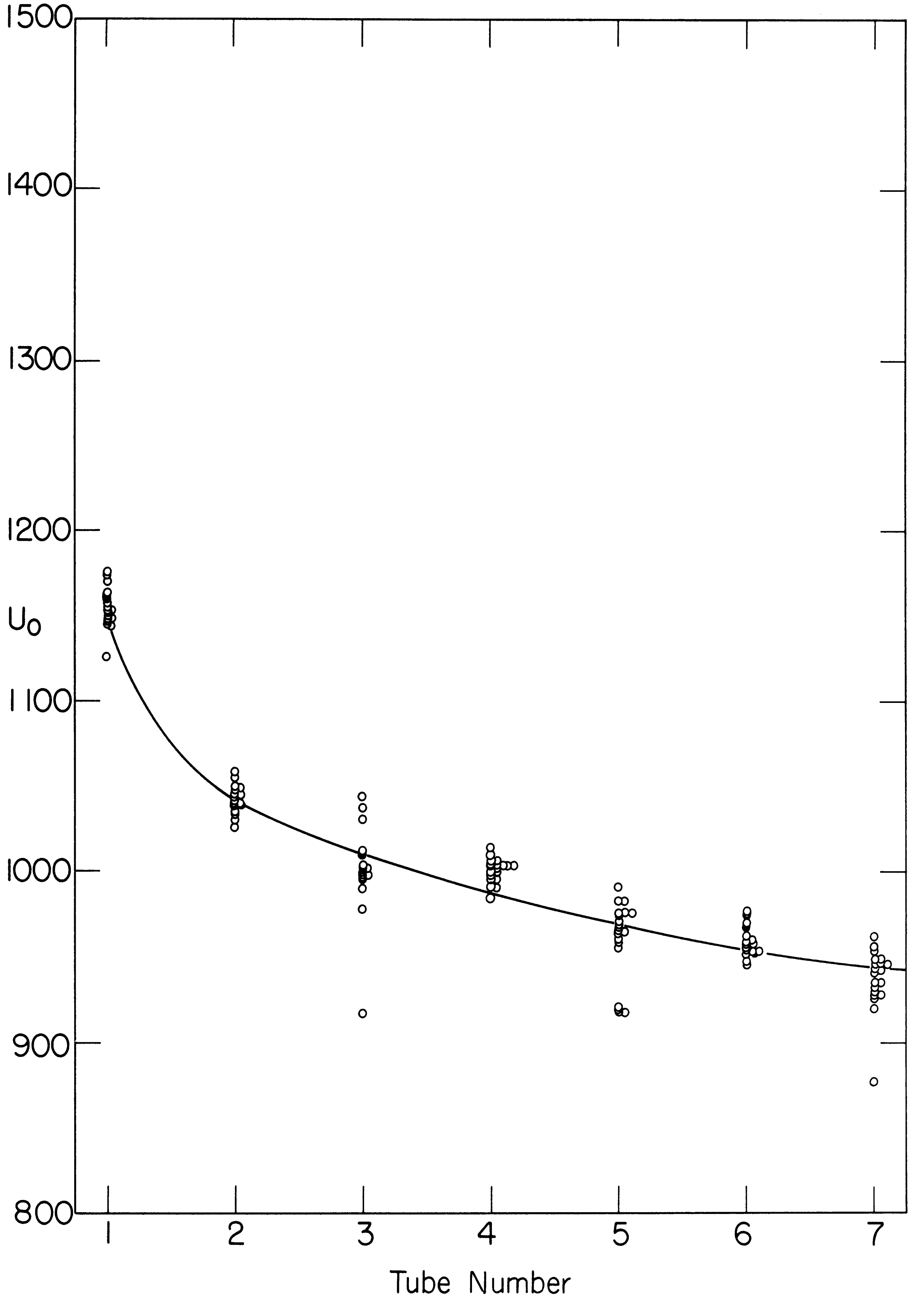

Figure 19. Individual Tube Overall Heat Transfer Coefficients for Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

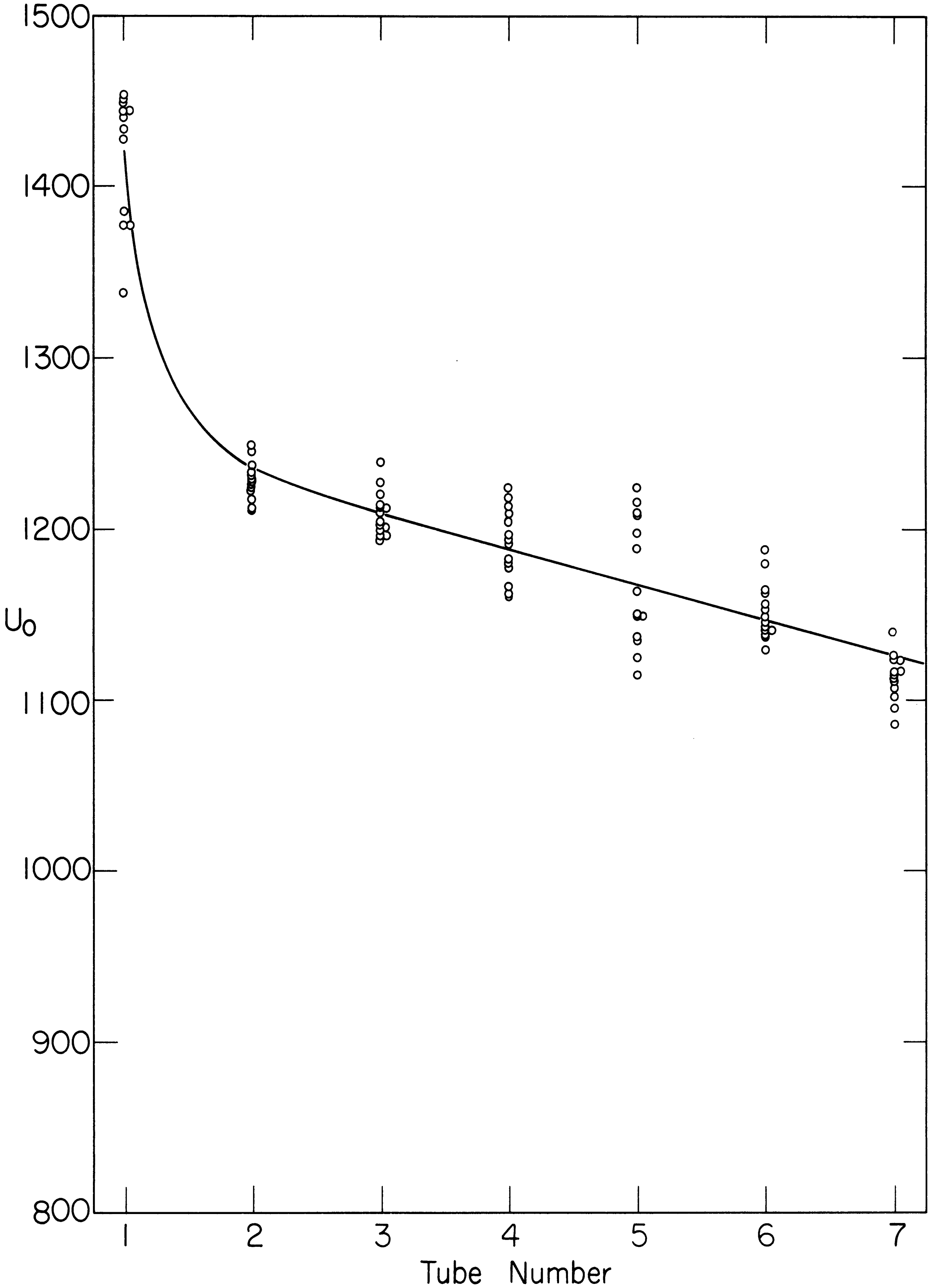

Figure 20. Individual Tube Overall Heat Transfer Coefficients for Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

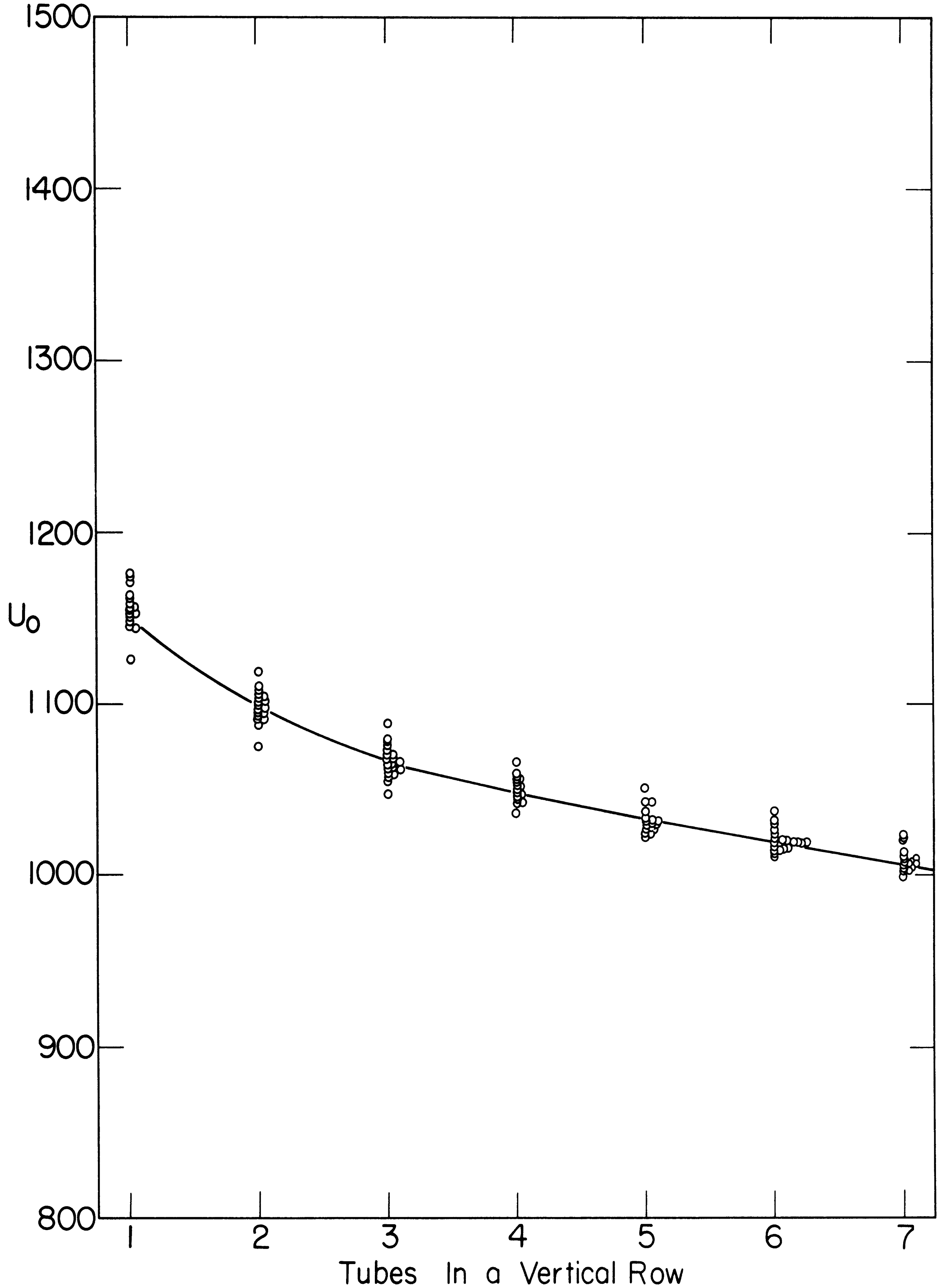

Figure 21. Cumulative Overall Heat Transfer Coefficients for Tubeside Water Velocity of 3.5 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

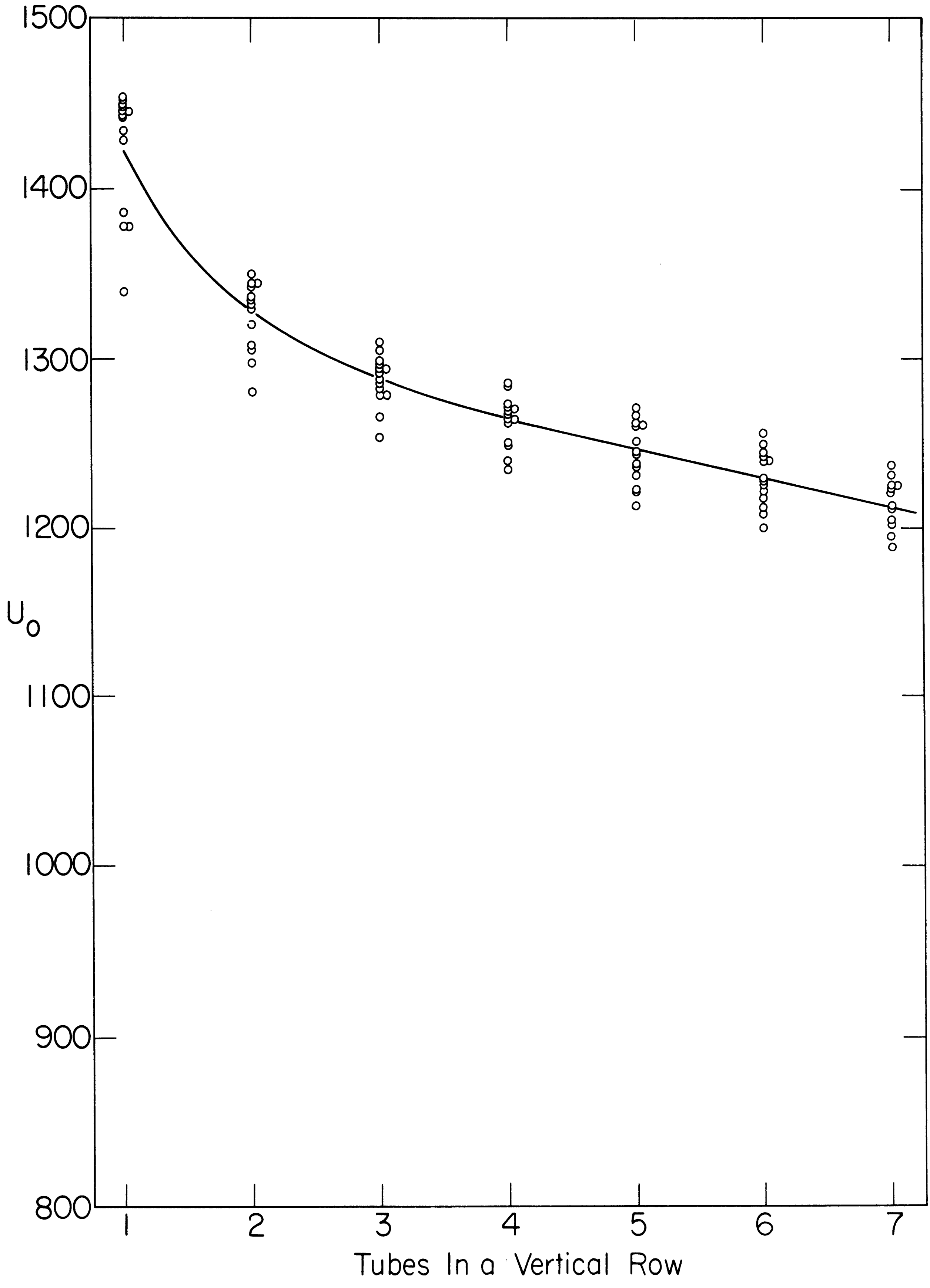

Figure 22. Cumulative Overall Heat Transfer Coefficients for Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

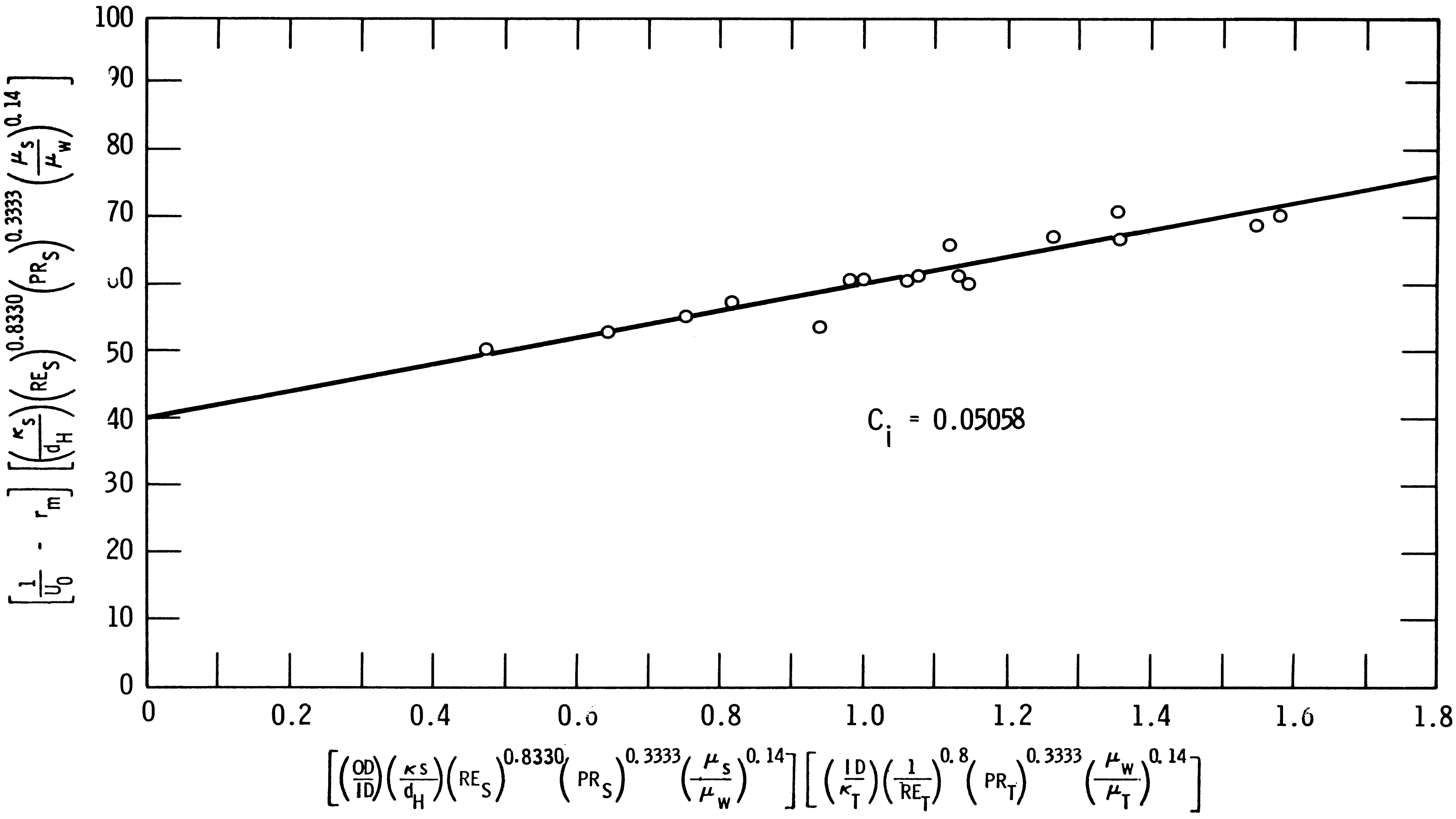

Figure 23. Modified Wilson Plot for Triple-Start Corrugated 1-inch O.D., 20 Gage, 90-10 Cupro-Nickel Tubes.

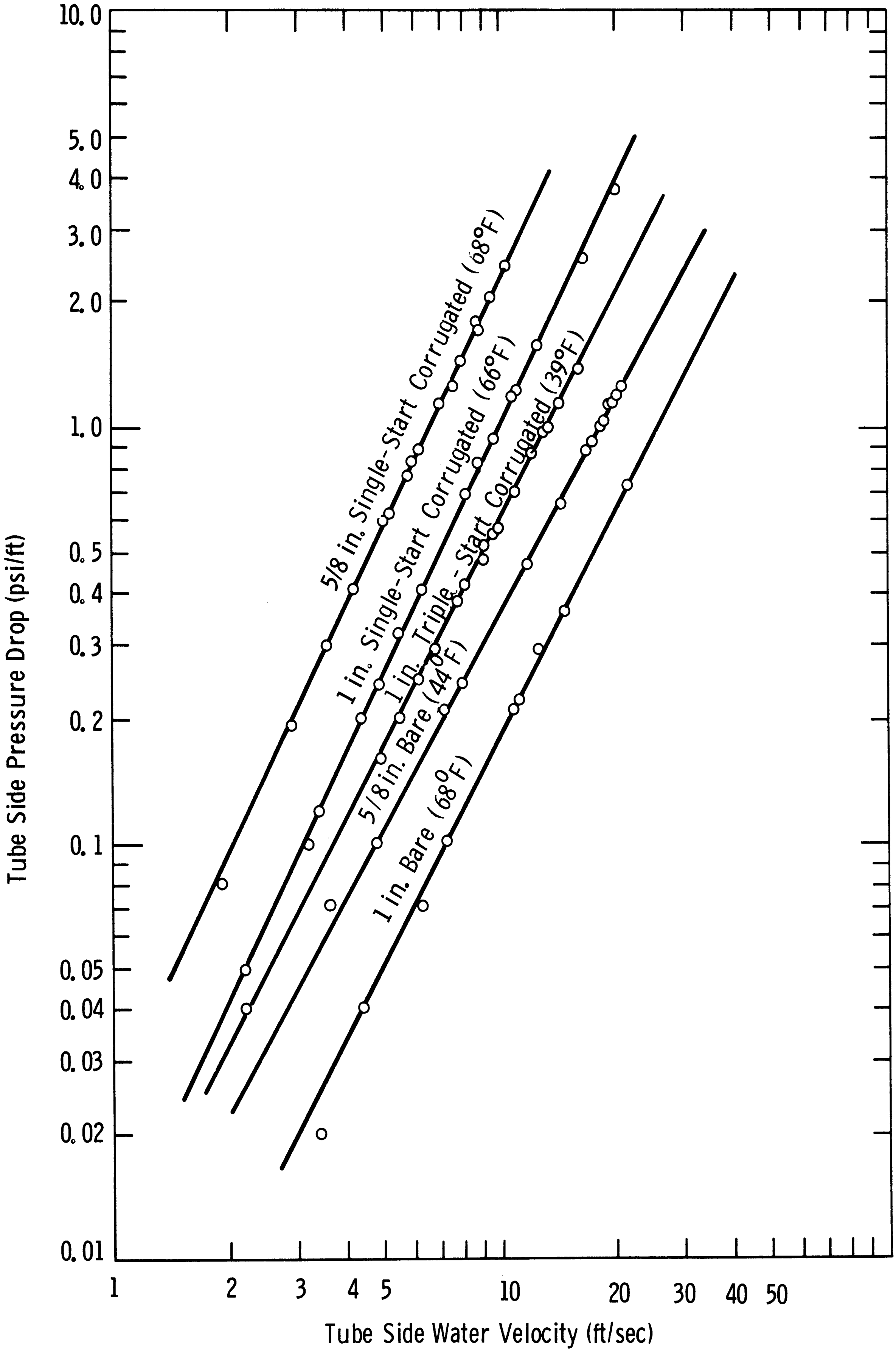

Figure 24. Pressure Drop Data Versus Tubeside Water Velocity for the 1-inch Triple-Start Corrugated Tubes Studied in This Report and Four Other Types of Tubes Studied in Previous Report.

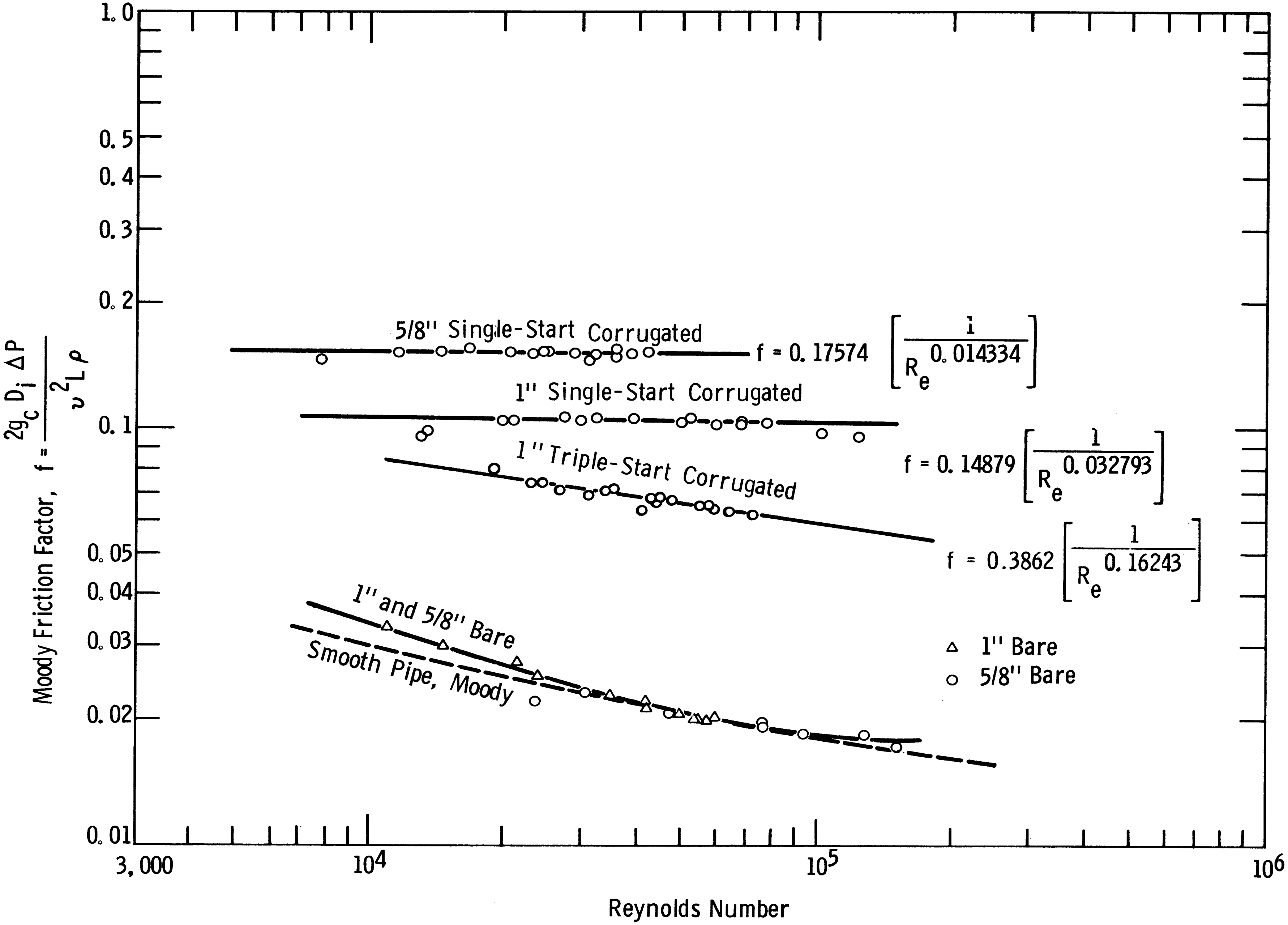

Figure 25. Moody Friction Factor Plot from the Tubeside Pressure Drop Data Appearing in Figure 24.

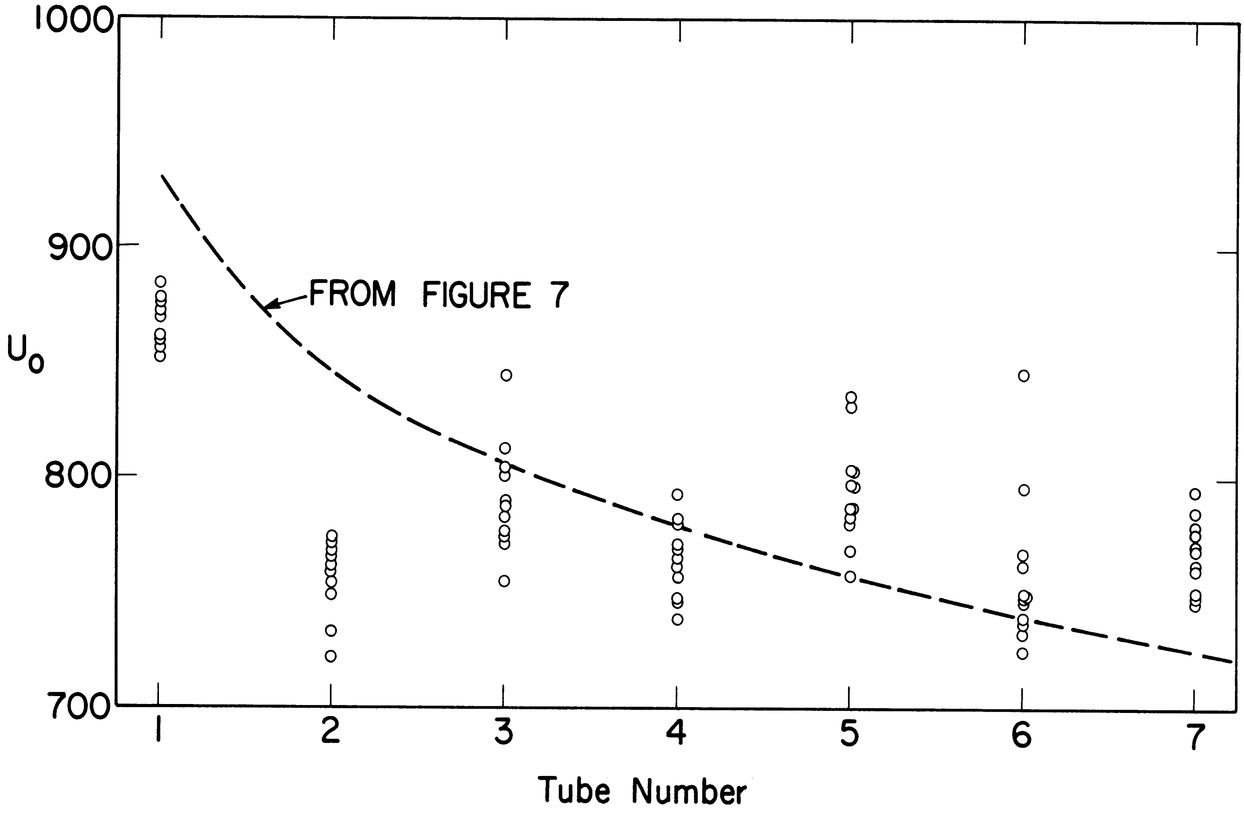

Figure 26. Individual Tube Overall Heat Transfer Coefficients for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Bare 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

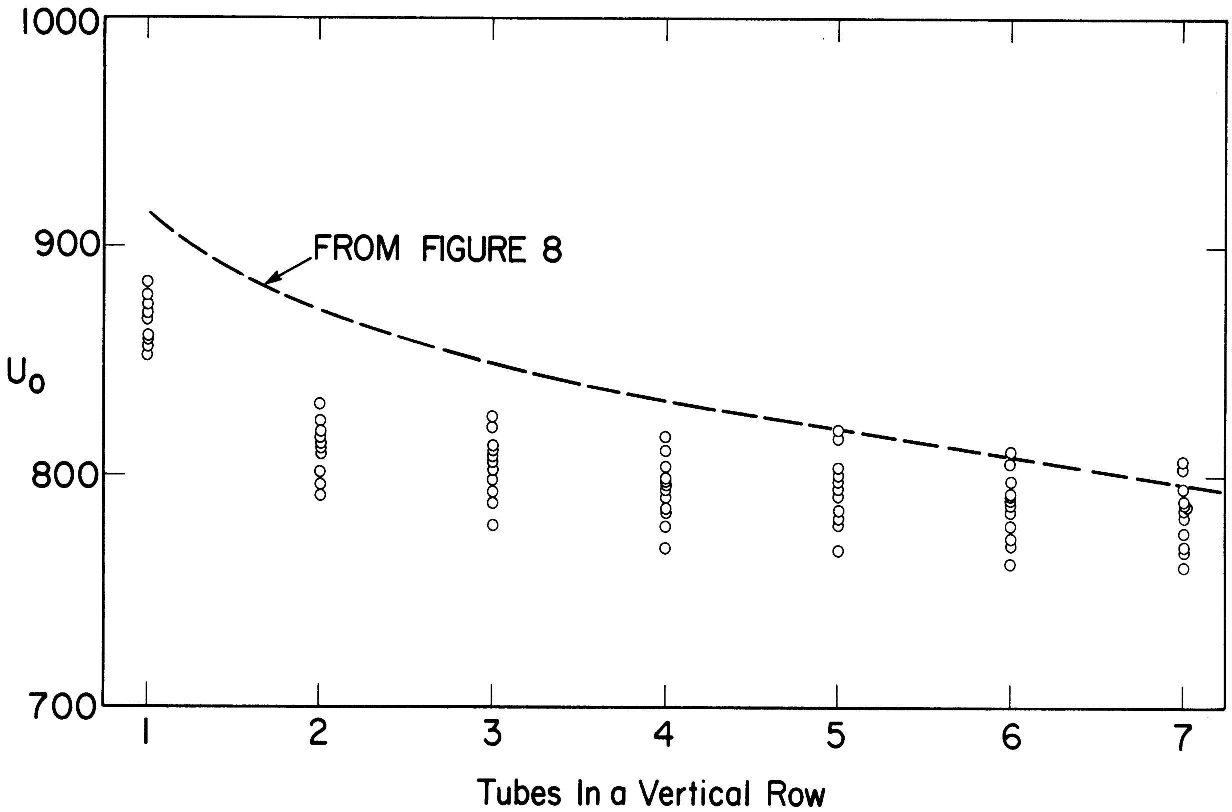

Figure 27. Cumulative Overall Heat Transfer Coefficients for a Tubeside Water Velocity of 6.0 feet per second and Condensation of Steam at 212°F on 1 to 7 Bare 1-inch O.D., 18 Gage, 90-10 Cupro-Nickel Tubes, Center Row of the Three Vertical Rows.

APPENDICES

APPENDIX I

Summary of the Calculated C_n, Individual U_o, and Cumulative U_o Values for the 1-inch Bare 90-10 Cupro-Nickel Tubes in a Single Vertical Row and in the Center Row of Three Vertical Rows

TABLE I-1

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

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206153A	6.16	43	1.30	1.32	1.40	1.45	1.50	1.51	1.53
206153B	6.12	46	1.01	1.17	1.25	1.30	1.34	1.34	1.36
206155A	6.05	49	1.10	1.17	1.24	1.28	1.33	1.35	1.37
206155B	6.05	49	1.09	1.16	1.24	1.28	1.33	1.35	1.37
206156A	6.03	46	1.19	1.30	1.38	1.42	1.45	1.46	1.48
206156B	6.03	46	1.27	1.34	1.44	1.46	1.48	1.49	1.50
206157A	6.03	46	1.22	1.26	1.34	1.37	1.42	1.44	1.46
206157B	6.03	46	1.27	1.32	1.37	1.40	1.43	1.45	1.46
206158A	6.09	46	1.19	1.28	1.30	1.31	1.35	1.36	1.37
206158A	6.10	46	1.17	1.22	1.27	1.28	1.31	1.32	1.33
206159A	6.15	44	1.10	1.17	1.25	1.28	1.33	1.35	1.37
206159B	6.15	44	1.11	1.14	1.20	1.24	1.28	1.31	1.33
206164A	6.08	46	1.31	1.36	1.44	1.46	1.50	1.51	1.52
206164B	6.08	46	1.36	1.38	1.43	1.47	1.52	1.52	1.54
206165A	6.14	43	1.31	1.34	1.42	1.44	1.49	1.49	1.51
206165B	6.14	43	1.33	1.33	1.40	1.44	1.49	1.49	1.49

TABLE I-2

Individual Tube 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 Single Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206153A	6.16	43	959	839	851	819	824	769	753
206153B	6.12	46	851	831	799	771	758	688	720
206155A	6.05	49	875	785	779	753	763	713	708
206155B	6.05	49	872	780	784	752	762	718	715
206156A	6.03	46	910	848	828	786	783	741	746
206156B	6.03	46	936	842	859	783	780	738	739
206157A	6.03	46	918	812	817	773	790	750	726
206157B	6.03	46	936	832	806	774	777	741	734
206158A	6.09	46	914	834	775	745	762	710	692
206158B	6.10	46	907	809	780	736	743	687	707
206159A	6.15	44	892	808	799	757	784	730	725
206159B	6.15	44	897	781	776	762	754	734	714
206164A	6.08	46	949	843	848	792	803	751	740
206164B	6.08	46	962	840	829	805	809	753	749
206165A	6.14	43	961	845	852	794	813	751	766
206165B	6.14	43	965	839	842	806	823	847	732

TABLE I-3

Cumulative 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 Single Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206153A	6.16	43	959	899	883	867	859	844	831
206153B	6.12	46	851	841	827	813	802	783	774
206155A	6.05	49	875	830	813	798	791	778	768
206155B	6.05	49	872	826	812	797	790	778	769
206156A	6.03	46	910	879	862	844	831	816	806
206156B	6.03	46	936	889	879	855	840	823	811
206157A	6.03	46	918	865	849	830	822	810	798
206157B	6.03	46	936	864	858	837	825	811	800
206158A	6.09	46	914	784	841	817	806	790	776
206158B	6.10	46	907	858	832	808	795	777	767
206159A	6.15	44	892	850	833	814	808	795	785
206159B	6.15	44	897	839	818	804	794	784	774
206164A	6.08	46	949	896	880	858	847	831	818
206164B	6.08	46	962	901	877	859	849	833	821
206165A	6.14	43	961	903	886	863	853	836	826
206165B	6.14	43	965	902	882	863	855	837	822

TABLE I-4

Individual Tube Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 212°F with a Water Velocity of 6.0 ft/sec on 1 to 7 1-inch Single-Start Corrugated 90-10 Cupro-Nickel Tubes in Three Vertical Rows (Abstracted from Report No. 60)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206108A	6.10	43	868	780	845	781	836	846	786
206108B	6.11	63	878	784	813	793	832	796	795
206110A	6.04	45	871	761	789	771	798	762	771
206110B	6.04	45	870	758	805	783	804	768	777
206130A	5.99	48	855	767	784	762	787	769	770
206130B	5.99	48	852	768	777	747	781	769	751
206132A	6.04	47	859	733	772	748	783	725	749
206132B	6.00	46	857	781	801	757	804	740	762
206134A	5.99	47	856	748	775	757	769	733	745
206134B	6.00	47	861	721	775	739	759	737	748
206136A	6.01	46	884	754	789	765	798	750	763
206136B	6.02	46	875	753	790	770	787	747	780

TABLE I-5

Cumulative Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 212°F with a Water Velocity of 6.0 ft/sec on 1 to 7 1-inch Single-Start Corrugated 90-10 Cupro-Nickel Tubes in Three Vertical Rows (Abstracted from Report No. 60)

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
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

APPENDIX II

Summary of the Calculated C_n, Individual U_o, and Cumulative U_o Values for the 1-inch Triple-Start 90-10 Cupro-Nickel Corrugated Tubes in a Single Vertical Row

TABLE II-1

Condensing Coefficient Correction Factor, C_n, for Condensation of Steam at 212°F on 1 to 7 1-inch Triple-Start Corrugated Tubes in a Single Vertical Row

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206177A	3.55	42	1.38	1.45	1.52	1.55	1.57	1.57	1.58
206177B	3.55	42	1.37	1.46	1.51	1.55	1.56	1.57	1.58
206178A	3.56	39	1.58	1.58	1.62	1.63	1.63	1.63	1.63
206178B	3.56	39	1.50	1.51	1.55	1.57	1.58	1.58	1.59
206179A	3.56	41	1.54	1.53	1.57	1.59	1.59	1.59	1.60
206179B	3.57	41	1.55	1.54	1.57	1.58	1.59	1.59	1.60
206180A	3.54	39	1.50	1.50	1.53	1.55	1.57	1.58	1.58
206180B	3.54	39	1.50	1.50	1.55	1.57	1.58	1.58	1.58
206181A	3.53	41	1.51	1.54	1.60	1.62	1.64	1.64	1.65
206181B	3.53	41	1.52	1.54	1.59	1.61	1.62	1.63	1.64
206182A	3.56	41	1.37	1.46	1.53	1.56	1.57	1.57	1.57
206182B	3.56	41	1.40	1.48	1.53	1.57	1.58	1.59	1.60
206183A	3.56	42	1.28	1.36	1.43	1.50	1.51	1.52	1.54
206183B	3.56	41	1.25	1.35	1.42	1.47	1.49	1.50	1.52
206184A	3.58	41	1.27	1.36	1.43	1.46	1.48	1.49	1.51
206184B	3.58	41	1.25	1.36	1.43	1.47	1.49	1.50	1.51
206185A	3.56	42	1.26	1.38	1.45	1.49	1.49	1.50	1.51
206185B	3.56	42	1.24	1.36	1.43	1.46	1.45	1.48	1.49
206186A	3.58	43	1.27	1.37	1.45	1.48	1.45	1.46	1.47
206186B	3.58	43	1.26	1.37	1.43	1.45	1.48	1.50	1.51
206168A	6.01	41	1.51	1.56	1.64	1.68	1.70	1.71	1.72
206168B	6.01	41	1.51	1.54	1.63	1.67	1.69	1.71	1.73
206169A	6.01	42	1.49	1.56	1.62	1.67	1.69	1.71	1.70
206169B	6.01	42	1.47	1.54	1.62	1.67	1.70	1.71	1.72
206170A	6.02	44	1.46	1.54	1.61	1.67	1.70	1.71	1.72
206170B	6.02	44	1.50	1.58	1.65	1.69	1.70	1.71	1.72
206172A	6.01	43	1.48	1.53	1.62	1.66	1.69	1.71	1.72
206172B	6.01	43	1.45	1.53	1.62	1.66	1.69	1.71	1.72
206173A	6.00	39	1.47	1.53	1.61	1.66	1.69	1.71	1.72
206173B	6.00	39	1.48	1.54	1.62	1.66	1.70	1.72	1.72
206175A	6.01	42	1.46	1.54	1.63	1.68	1.72	1.73	1.74
206175B	6.01	42	1.46	1.53	1.62	1.67	1.70	1.72	1.73
206176A	5.99	40	1.56	1.56	1.61	1.65	1.70	1.72	1.73
206176B	5.99	40	1.57	1.59	1.64	1.67	1.71	1.73	1.74

TABLE II-2

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

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206177A	3.55	42	1144	1018	988	946	899	867	851
206177B	3.55	42	1140	1024	983	941	902	860	849
206178A	3.56	39	1228	1052	1017	967	921	875	863
206178B	3.56	39	1202	1028	995	951	914	874	861
206179A	3.56	41	1206	1024	989	949	897	863	862
206179B	3.57	41	1209	1027	986	939	900	874	863
206180A	3.54	39	1197	1021	980	942	920	868	862
206180B	3.54	39	1198	1022	999	941	910	870	857
206181A	3.53	41	1188	1032	1011	957	922	878	872
206181B	3.53	41	1193	1025	1004	950	918	880	876
206182A	3.56	41	1151	1027	1005	945	897	873	829
206182B	3.56	41	1159	1039	991	951	920	880	850
206183A	3.56	42	1109	991	966	942	902	868	865
206183B	3.56	41	1097	999	967	937	885	857	852
206184A	3.58	41	1114	1000	970	924	892	854	847
206184B	3.58	41	1106	1006	975	929	894	856	842
206185A	3.56	42	1101	1015	977	939	848	856	837
206185B	3.56	42	1093	1007	963	913	829	871	841
206186A	3.58	43	1103	997	972	924	784	846	824
206186B	3.58	43	1097	999	955	901	893	861	832
206168A	6.01	41	1418	1210	1197	1151	1064	1058	1015
206168B	6.01	41	1416	1194	1203	1127	1095	1063	1036
206169A	6.01	42	1402	1214	1170	1138	1081	1045	944
206169B	6.01	42	1393	1207	1189	1143	1083	1053	1010
206170A	6.02	44	1376	1196	1175	1141	1077	1037	992
206170B	6.02	44	1395	1215	1182	1128	1050	1032	985
206172A	6.01	43	1390	1192	1186	1120	1087	1051	1010
206172B	6.01	43	1378	1204	1186	1124	1093	1053	1012
206173A	6.00	39	1410	1214	1201	1147	1118	1074	1019
206173B	6.00	39	1415	1221	1201	1147	1118	1070	1020
206175A	6.01	42	1389	1217	1195	1155	1109	1051	1011
206175B	6.01	42	1387	1203	1199	1143	1098	1062	1014
206176A	5.99	40	1447	1187	1164	1142	1120	1086	1023
206176B	5.99	40	1448	1216	1167	1133	1121	1073	1011

TABLE II-3

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

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206187A	3.35	41	1126	1076	1063	1048	1022	1012	1003
206187B	3.35	41	1162	1104	1073	1056	1029	1019	1007
206188A	3.32	39	1145	1100	1070	1055	1028	1019	1007
206188B	3.33	39	1155	1097	1066	1053	1026	1016	1003
206189A	3.34	40	1171	1110	1088	1066	1051	1037	1024
206189B	3.34	40	1164	1105	1080	1056	1038	1025	1013
206190A	3.31	38	1177	1118	1079	1060	1043	1030	1019
206190B	3.31	38	1176	1108	1076	1058	1043	1032	1022
206191A	3.31	41	1158	1104	1070	1050	1032	1020	1009
206191B	3.32	41	1158	1101	1067	1049	1038	1020	1009
206192A	3.21	38	1152	1096	1063	1047	1032	1019	1006
206192B	3.21	38	1163	1101	1066	1051	1036	1023	1012
206193A	3.21	39	1157	1096	1063	1046	1031	1017	997
206193B	3.21	40	1154	1098	1066	1051	1032	1019	1006
206194A	3.18	38	1144	1087	1056	1043	1031	1019	1009
206194B	3.21	38	1144	1091	1060	1045	1031	1019	1010
206195A	3.23	40	1148	1092	1058	1043	1026	1014	1002
206195B	3.23	40	1147	1091	1059	1045	1029	1016	1006
206196A	3.21	39	1155	1102	1047	1036	1024	1011	998
206196B	3.21	39	1153	1098	1058	1041	1028	1016	1004
206199A	6.13	42	1386	1309	1282	1264	1251	1239	1225
206199B	6.14	42	1378	1308	1279	1251	1231	1217	1204
206200A	6.14	43	1339	1281	1254	1235	1213	1201	1189
206200B	6.12	43	1378	1298	1266	1240	1222	1208	1195
206201A	6.15	46	1428	1320	1279	1250	1223	1212	1194
206201B	6.16	46	1434	1331	1288	1261	1236	1221	1203
206202A	6.15	45	1442	1334	1291	1264	1238	1226	1209
206202B	6.15	45	1445	1337	1296	1270	1246	1230	1213
206203A	6.16	46	1448	1336	1294	1275	1262	1244	1225
200203B	6.16	46	1445	1329	1285	1265	1245	1228	1210
206204A	6.15	45	1449	1345	1298	1272	1261	1241	1223
206204B	6.15	45	1454	1344	1294	1270	1261	1239	1221
206205A	6.12	42	1451	1350	1305	1285	1266	1249	1231
206205B	6.12	42	1444	1345	1310	1286	1271	1256	1237

APPENDIX III

Summary of the Calculated C_n, Individual U_o, and Cumulative U_o Values for the Center Row of 1-inch Triple-Start 90-10 Cupro-Nickel Corrugated Tubes in Three Vertical Rows

TABLE III-1

Condensing Coefficient Correction Factor, C_n, for Condensation of Steam at 212°F on 1 to 7 1-inch Triple-Start Corrugated Tubes in Multiple Vertical Rows

Run No.	Velocity ft./sec.	LMTD °F	C_n 1	2	3	4	5	6	7
206187A	3.35	41	1.38	1.49	1.61	1.67	1.68	1.73	1.76
206187B	3.35	41	1.49	1.58	1.64	1.70	1.71	1.75	1.78
206188A	3.32	39	1.42	1.55	1.61	1.68	1.69	1.73	1.76
206188B	3.33	39	1.45	1.54	1.60	1.67	1.68	1.72	1.74
206189A	3.34	40	1.51	1.59	1.68	1.73	1.78	1.81	1.83
206189B	3.34	40	1.49	1.58	1.66	1.70	1.73	1.77	1.80
206190A	3.31	38	1.51	1.59	1.63	1.68	1.72	1.76	1.79
216190B	3.31	38	1.51	1.56	1.62	1.68	1.72	1.76	1.80
206191A	3.31	41	1.48	1.57	1.63	1.68	1.72	1.75	1.78
206191B	3.32	41	1.48	1.57	1.62	1.68	1.72	1.76	1.79
206192A	3.21	38	1.47	1.56	1.61	1.68	1.72	1.75	1.78
206192B	3.21	38	1.51	1.57	1.62	1.69	1.73	1.77	1.80
206193A	3.21	39	1.51	1.57	1.63	1.69	1.74	1.77	1.76
206193B	3.21	40	1.50	1.59	1.65	1.71	1.74	1.78	1.80
206194A	3.18	38	1.45	1.53	1.59	1.66	1.71	1.75	1.78
206194B	3.21	38	1.45	1.54	1.60	1.67	1.71	1.75	1.79
206195A	3.23	40	1.47	1.56	1.61	1.68	1.71	1.75	1.77
206195B	3.23	40	1.47	1.55	1.61	1.68	1.72	1.76	1.79
206196A	3.21	39	1.48	1.58	1.66	1.64	1.69	1.73	1.75
206196B	3.21	39	1.47	1.56	1.60	1.66	1.71	1.74	1.77
206199A	6.13	42	1.45	1.55	1.65	1.73	1.80	1.85	1.89
206199B	6.14	42	1.43	1.55	1.65	1.70	1.75	1.80	1.83
206200A	6.14	43	1.36	1.50	1.60	1.68	1.72	1.77	1.81
206200B	6.12	43	1.44	1.54	1.63	1.69	1.74	1.79	1.83
206201A	6.15	46	1.60	1.64	1.72	1.78	1.82	1.86	1.89
206201B	6.16	46	1.58	1.62	1.69	1.75	1.78	1.84	1.86
206202A	6.15	45	1.59	1.64	1.71	1.77	1.80	1.86	1.88
206202B	6.15	45	1.60	1.64	1.72	1.78	1.82	1.87	1.90
206203A	6.16	46	1.62	1.65	1.73	1.81	1.88	1.92	1.94
206203B	6.16	46	1.61	1.64	1.70	1.78	1.83	1.87	1.90
206204A	6.15	45	1.61	1.66	1.72	1.79	1.86	1.90	1.92
206204B	6.15	45	1.62	1.66	1.71	1.78	1.86	1.89	1.92
206205A	6.12	42	1.56	1.62	1.71	1.78	1.85	1.89	1.92
206205B	6.12	42	1.58	1.64	1.70	1.78	1.84	1.88	1.90

TABLE III-2

Individual Tube Overall Heat Transfer Coefficients, U_o, for Condensation of Steam at 212°F on 1 to 7 1-inch Triple-Start Corrugated 90-10 Cupro-Nickel Tubes in Multiple Vertical Rows

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206187A	3.35	41	1126	1026	1037	1003	918	962	949
206187B	3.35	41	1162	1046	1011	1005	921	969	935
206188A	3.32	39	1145	1055	1010	1010	920	974	935
206188B	3.33	39	1155	1039	1004	1014	918	966	925
206189A	3.34	40	1171	1049	1044	1000	991	967	946
206189B	3.34	40	1164	1046	1030	984	966	960	941
206190A	3.31	38	1177	1059	1001	1003	965	975	953
206190B	3.31	38	1176	1040	1012	1004	983	977	962
206191A	3.31	41	1158	1050	1002	990	960	960	943
206191B	3.32	41	1158	1044	999	995	969	955	943
206192A	3.21	38	1152	1040	997	1003	968	954	928
206192B	3.21	38	1163	1039	996	1006	976	958	946
206193A	3.21	39	1157	1035	997	995	971	947	877
206193B	3.21	40	1154	1042	1002	1006	956	954	928
206194A	3.18	38	1144	1030	994	1004	983	959	949
206194B	3.21	38	1144	1038	998	1000	975	959	956
206195A	3.23	40	1148	1036	990	998	958	954	930
206195B	3.23	40	1147	1045	995	1003	965	951	946
206196A	3.21	39	1155	1049	937	1003	976	946	920
206196B	3.21	39	1153	1043	978	990	976	956	932
206199A	6.13	42	1386	1232	1228	1210	1199	1189	1141
206199B	6.14	42	1378	1238	1221	1167	1151	1147	1126
206200A	6.14	43	1339	1223	1200	1178	1125	1141	1117
206200B	6.12	43	1378	1218	1202	1162	1150	1138	1117
206201A	6.15	46	1428	1212	1197	1163	1115	1157	1086
206201B	6.16	46	1434	1228	1202	1180	1136	1146	1095
206202A	6.15	45	1442	1226	1205	1183	1134	1166	1107
206202B	6.15	45	1445	1229	1214	1192	1150	1150	1111
206203A	6.16	46	1448	1224	1210	1219	1210	1154	1114
206203B	6.16	46	1445	1213	1197	1205	1165	1143	1102
206204A	6.15	45	1449	1231	1214	1194	1217	1141	1115
206204B	6.15	45	1454	1234	1194	1198	1225	1129	1113
206205A	6.12	42	1451	1249	1215	1225	1190	1164	1123
206205B	6.12	42	1444	1246	1240	1214	1211	1181	1123

TABLE III-3

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

Run No.	Velocity ft./sec.	LMTD °F	U_o 1	2	3	4	5	6	7
206177A	3.55	42	1144	1081	1050	1024	999	977	959
206177B	3.55	42	1140	1082	1049	1022	998	975	957
206178A	3.56	39	1228	1140	1099	1066	1037	1010	989
206178B	3.56	39	1202	1115	1075	1044	1018	994	975
206179A	3.56	41	1206	1115	1073	1042	1013	988	970
206179B	3.57	41	1209	1118	1074	1040	1012	989	971
206180A	3.54	39	1197	1109	1066	1035	1012	988	970
206180B	3.54	39	1198	1110	1073	1040	1014	990	971
206181A	3.53	41	1188	1110	1077	1047	1022	998	980
206181B	3.53	41	1193	1109	1074	1043	1018	995	978
206182A	3.56	41	1151	1089	1061	1032	1005	983	961
206182B	3.56	41	1159	1099	1063	1035	1012	990	970
206183A	3.56	42	1109	1050	1022	1002	982	963	949
206183B	3.56	41	1097	1048	1021	1000	977	957	942
206184A	3.58	41	1114	1057	1028	1002	980	959	943
206184B	3.58	41	1106	1056	1029	1004	982	961	944
206185A	3.56	42	1101	1058	1031	1008	976	956	939
206185B	3.56	42	1093	1050	1021	994	961	946	931
206186A	3.58	43	1103	1050	1024	999	954	936	920
206186B	3.58	43	1097	1048	1017	988	969	951	934
206168A	6.01	41	1418	1314	1275	1244	1208	1183	1159
206168B	6.01	41	1416	1305	1271	1235	1207	1183	1162
206169A	6.01	42	1402	1308	1262	1231	1201	1175	1142
206169B	6.01	42	1393	1300	1263	1233	1203	1178	1154
206170A	6.02	44	1376	1286	1249	1222	1193	1167	1142
206170B	6.02	44	1395	1305	1264	1230	1194	1167	1141
206172A	6.01	43	1390	1291	1256	1222	1195	1171	1148
206172B	6.01	43	1378	1291	1256	1223	1197	1173	1150
206173A	6.00	39	1410	1312	1275	1243	1218	1194	1169
206173B	6.00	39	1415	1318	1279	1246	1220	1195	1170
206175A	6.01	42	1389	1303	1267	1239	1213	1186	1161
206175B	6.01	42	1387	1295	1263	1233	1206	1182	1158
206176A	5.99	40	1444	1317	1266	1235	1212	1191	1167
206176B	5.99	40	1448	1332	1277	1241	1217	1193	1167

APPENDIX IV

Computer Output from the Program in Appendix V,
Pages 162-167, of Report No. 60,
Which Calculates the Point Values of U_o, h_{cond}, h_i and Q,
Using the Equations Presented in Table 3
For Steam Condensing at 212°F on 1-inch Bare Tubes

TABLE IV-1

Calculated Point Values for
1-inch Bare 90-10 Cupro-Nickel Tubes
With Steaming Condensing at 212°F, Without Fouling,
Using Equation (3)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" BARE
TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
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	1015.0	3542.1	28.7%	2091.2	54.0%	17.4%	0.0%	1597.6	1.64
15	1.70	1003.5	3405.8	29.5%	2091.2	53.4%	17.2%	0.0%	1579.5	1.62
20	1.78	994.1	3300.0	30.1%	2091.1	52.9%	17.0%	0.0%	1564.6	1.61
25	1.85	987.8	3231.6	30.6%	2091.0	52.5%	16.9%	0.0%	1554.7	1.60
30	1.91	982.6	3176.7	30.9%	2091.0	52.3%	16.8%	0.0%	1546.5	1.59

TABLE IV-2

Calculated Point Values for
1-inch Bare 90-10 Cupro-Nickel Tubes
With Steaming Condensing at 212°F, Without Fouling,
Using Equation (7)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" BARE
TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
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	1.2200
POWER OF CN: B	0.0895

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.50	994.5	3305.0	30.1%	2091.1	52.9%	17.0%	0.0%	1565.3	1.61
15	1.55	971.3	3062.1	31.7%	2091.0	51.7%	16.6%	0.0%	1528.8	1.57
20	1.60	953.6	2893.0	33.0%	2090.8	50.7%	16.3%	0.0%	1500.9	1.54
25	1.63	942.3	2791.2	33.8%	2090.9	50.1%	16.1%	0.0%	1483.1	1.53
30	1.65	930.3	2688.9	34.6%	2090.8	49.5%	15.9%	0.0%	1464.3	1.51

TABLE IV-3

Calculated Point Values for
1-inch Bare 90-10 Cupro-Nickel Tubes
With Steaming Condensing at 212°F, With 0.0005 Fouling,
Using Equation (3)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" BARE
TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
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	688.3	4009.8	17.2%	2089.2	36.6%	11.8%	34.4%	1083.4	1.11
15	1.70	683.5	3850.8	17.7%	2089.2	36.4%	11.7%	34.2%	1075.8	1.11
20	1.78	680.0	3741.9	18.2%	2089.2	36.2%	11.6%	34.0%	1070.2	1.10
25	1.85	677.2	3659.7	18.5%	2089.2	36.1%	11.6%	33.9%	1065.9	1.10
30	1.91	674.9	3593.9	18.8%	2089.2	35.9%	11.5%	33.7%	1062.3	1.09

TABLE IV-4

Calculated Point Values for
1-inch Bare 90-10 Cupro-Nickel Tubes
With Steaming Condensing at 212°F, With 0.0005 Fouling,
Using Equation (7)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" BARE
TUBE OUTSIDE DIAMETER (INCHES)	1.00200
TUBE INSIDE DIAMETER (INCHES)	0.90080
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
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	1.2200
POWER OF CN: B	0.0895

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.50	680.2	3747.9	18.1%	2089.2	36.2%	11.6%	34.0%	1070.6	1.10
15	1.55	669.9	3456.6	19.4%	2089.1	35.7%	11.5%	33.5%	1054.4	1.08
20	1.60	662.4	3264.3	20.3%	2089.1	35.3%	11.3%	33.1%	1042.5	1.07
25	1.63	656.3	3122.9	21.0%	2089.1	34.9%	11.2%	32.8%	1033.0	1.06
30	1.65	651.3	3012.1	21.6%	2089.1	34.7%	11.1%	32.6%	1025.1	1.05

APPENDIX V

Computer Output from the Program in Appendix V,
Pages 162-167, of Report No. 60,
Which Calculates the Point Values of U_o, h_{cond}, h_i and Q,
For Steam Condensing at 212°F on Hypothetical 1-inch Single-Start and on
The Triple-Start Corrugated 90-10 Cupro-Nickel Tubes

TABLE V-1

Calculated Point Values for
The Hypothetical 1-inch Single-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, Without Fouling
Using Table 4

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	HYPO 1" 1-START KORO
TUBE OUTSIDE DIAMETER (INCHES)	0.99000
TUBE INSIDE DIAMETER (INCHES)	0.91320
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.25918
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23908
FLOW AREA (SQFT)	0.0045484
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001231
INSIDE SIEDER-TATE CONSTANT	0.05500
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)	3559.02
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	76636.13
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.5050
POWER OF CN: B	0.2040

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.41	1442.4	5528.9	26.1%	2821.0	55.4%	18.5%	0.0%	2243.1	2.31
15	2.61	1433.8	5404.8	26.5%	2821.0	55.1%	18.4%	0.0%	2229.7	2.29
20	2.77	1427.7	5318.4	26.8%	2821.0	54.9%	18.3%	0.0%	2220.2	2.28
25	2.90	1422.9	5252.4	27.1%	2820.9	54.7%	18.2%	0.0%	2212.7	2.28
30	3.01	1418.9	5199.1	27.3%	2820.9	54.5%	18.2%	0.0%	2206.6	2.27

TABLE V-2

Calculated Point Values for
The 1-inch Triple-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, Without Fouling
Using Table 2 and Equation (13)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" 3-START KORO
TUBE OUTSIDE DIAMETER (INCHES)	0.99000
TUBE INSIDE DIAMETER (INCHES)	0.91320
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.25918
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23908
FLOW AREA (SQFT)	0.0045484
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001231
INSIDE SIEDER-TATE CONSTANT	0.05058
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)	3559.02
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	76636.13
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4800
POWER OF CN: B	0.1050

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.88	1270.9	4152.6	30.6%	2594.0	53.1%	16.3%	0.0%	1976.3	2.03
15	1.97	1243.7	3876.1	32.1%	2593.9	52.0%	15.9%	0.0%	1934.1	1.99
20	2.03	1223.6	3687.4	33.2%	2593.8	51.1%	15.7%	0.0%	1902.8	1.96
25	2.08	1208.6	3554.7	34.0%	2593.7	50.5%	15.5%	0.0%	1879.5	1.93
30	2.12	1195.9	3446.9	34.7%	2593.7	50.0%	15.3%	0.0%	1859.7	1.91

TABLE V-3

Calculated Point Values for
The Hypothetical 1-inch Single-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling
Using Table 4

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	HYPO 1" 1-START KORO
TUBE OUTSIDE DIAMETER (INCHES)	0.99000
TUBE INSIDE DIAMETER (INCHES)	0.91320
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.25918
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23908
FLOW AREA (SQFT)	0.0045484
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001231
INSIDE SIEDER-TATE CONSTANT	0.05500
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)	3559.02
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	76636.13
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.5050
POWER OF CN: B	0.2040

NO TUBES	CN	UO	HCOND	HCOND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	2.41	857.5	6521.5	13.1%	2817.5	33.0%	11.0%	42.9%	1333.4	1.37
15	2.61	854.8	6369.6	13.4%	2817.5	32.9%	11.0%	42.7%	1329.3	1.37
20	2.77	852.9	6264.3	13.6%	2817.5	32.8%	10.9%	42.6%	1326.3	1.36
25	2.90	851.4	6184.0	13.8%	2817.4	32.8%	10.9%	42.6%	1323.9	1.36
30	3.01	850.1	6118.7	13.9%	2817.4	32.7%	10.9%	42.5%	1322.0	1.36

TABLE V-4

Calculated Point Values for
The 1-inch Triple-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling
Using Table 2 and Equation (13)

CALCULATICNS CF THE POINT VALUES CF UC ANC HCCND.

TUBE DESIGNATION	1" 3-START KORC
TUBE OUTSIDE DIAMETER (INCHES)	0.99000
TUBE INSIDE DIAMETER (INCHES)	0.91320
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.25918
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.23908
FLOW AREA (SQFT)	0.0045484
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001231
INSIDE SIEDER-TATE CONSTANT	0.05058
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)	3559.02
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	76636.13
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4800
POWER OF CN: B	0.1050

NO TUBES	CN	UC	HCCND	HCCND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.88	797.9	4835.4	16.5%	2591.2	33.4%	10.2%	39.9%	1240.8	1.28
15	1.97	788.0	4493.1	17.5%	2591.2	33.0%	10.1%	39.4%	1225.4	1.26
20	2.03	780.7	4265.5	18.3%	2591.1	32.7%	10.0%	39.0%	1214.0	1.25
25	2.08	774.9	4097.2	18.9%	2591.1	32.4%	9.9%	38.7%	1205.0	1.24
30	2.12	770.0	3964.9	19.4%	2591.1	32.2%	9.9%	38.5%	1197.4	1.23

APPENDIX VI

Computer Output from the Program in Appendix V,
Pages 162-167, of Report No. 60,
Which Calculates the Point Values of U_o, h_{cond}, h_i and Q,
For a Hypothetical 1-inch Triple-Start Corrugated Tube
Having the Same O. D. and I. D. as
The Single-Start Corrugated Tubes of Report No. 60

TABLE VI-1

Calculated Point Values for
The 1-inch Single-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, Without Fouling
Using Equation (4)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" 1-START KORO
TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
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	1.4500
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

TABLE VI-2

Calculated Point Values for
The Hypothetical 1-inch Triple-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, Without Fouling
Using Equation (13)

CALCULATICNS OF THE POINT VALUES CF UC AND HCCND.

TUBE DESIGNATION	HYPO 1" 3-START KCRC
TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
OUTSIDE HEAT TRANSFER AREA (SQFT/FT)	0.24531
INSIDE HEAT TRANSFER AREA (SQFT/FT)	0.21520
FLCW AREA (SQFT)	0.0036853
METAL RESISTANCE (HR/SQFT-F-BTU)	0.0001843
INSIDE SIEDER-TATE CONSTANT	0.05058
FOULING FACTOR (HR-SQFT-F/BTU)	0.0
VAPOR TEMPERATURE (DEG. F)	212.00
LINEAR VELCCITY CF BRINE(FT/SEC)	3.50
MASS VELOCITY CF BRINE (LBS/HR)	2883.65
BRINE TEMPERATURE (DEG. F)	206.00
REYNOLDS NUMBER	68982.63
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4800
PCWER CF CN: B	0.1050

NO TUBES	CN	UC	HCCND	HCCND %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.88	1167.9	4361.1	26.8%	2648.8	50.3%	23.0%	0.0%	1718.9	1.77
15	1.97	1145.1	4060.5	28.2%	2648.7	49.3%	22.5%	0.0%	1685.4	1.73
20	2.03	1128.6	3860.6	29.2%	2648.6	48.6%	22.2%	0.0%	1661.2	1.71
25	2.08	1114.3	3698.7	30.1%	2648.4	48.0%	21.9%	0.0%	1640.1	1.69
30	2.12	1103.8	3585.6	30.8%	2648.4	47.5%	21.7%	0.0%	1624.7	1.67

TABLE VI-3

Calculated Point Values for
The 1-inch Single-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling
Using Equation (4)

CALCULATIONS OF THE POINT VALUES OF UO AND HCOND.

TUBE DESIGNATION	1" 1-START KORO
TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONDUCTIVITY (BTU/HR-FT-F)	26.00000
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	68982.63
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

TABLE VI-4

Calculated Point Values for
The Hypothetical 1-inch Triple-Start Corrugated 90-10 Cupro-Nickel Tubes
With Steam Condensing at 212°F, With 0.0005 Fouling
Using Equation (13)

CALCULATICNS OF THE POINT VALUES CF UC ANC HCONC.

TUBE DESIGNATION	HYPO 1" 3-START KCRC
TUBE OUTSIDE DIAMETER (INCHES)	0.93700
TUBE INSIDE DIAMETER (INCHES)	0.82200
TUBE THERMAL CONCUCTIVITY (BTU/HR-FT-F)	26.00000
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	0.05058
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	68982.63
PRANDTLS NUMBER	1.91
CONSTANT FOR CN: A	1.4800
POWER OF CN: B	0.1050

NO TUBES	CN	UO	HCONC	HCONC %	HI	HI %	MET. RES.%	FOULING %	Q BTU/HR	Q/LAT LB/HR
10	1.88	753.6	5013.3	15.0%	2646.1	32.5%	14.8%	37.7%	1109.3	1.14
15	1.97	745.1	4656.9	16.0%	2646.1	32.1%	14.6%	37.3%	1096.6	1.13
20	2.03	738.7	4420.0	16.7%	2646.1	31.8%	14.5%	36.9%	1087.3	1.12
25	2.08	733.7	4244.9	17.3%	2646.1	31.6%	14.4%	36.7%	1079.9	1.11
30	2.12	729.5	4107.2	17.8%	2646.0	31.4%	14.3%	36.5%	1073.6	1.10

APPENDIX VII

Computer Program for Condenser Stage Design Calculations

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CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C                                                                              C
C           STEAM CONDENSER DESIGN PROGRAM                                     C
C                                                                              C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C      A SUBROUTINE TO TEST THE DIFFERENCE BETWEEN VARIABLES IN
C .         SUCCESSIVE TRIALS.
C
      LOGICAL TEST
      TEST(ARG1, ARG2) = ABS((ARG1-ARG2)/ARG1) .LT. .00025
C
  100 READ(2,22)TUNO,TUBTYP,ALLOY,
     1            STC,DI,AI,XN,XNT,FR,WF,DO,
     1            T,AO,PW,Z,TW1,TW2,DPT,BPT,
     1            A,B,RUN,WR,BETA,VN,Q
      XRUN=15.0
      WRITE (3,41)
      WRITE (3,71)
      WRITE (3,72)
      WRITE (3,74)
      WRITE(3,42)TUNO,STC,TUBTYP,A,ALLOY,B,DO,VN,DI,XN,AI,XNT,AO,Z,
     1            WF,PW,T,FR,WR,TW1
      WRITE(3,73)TW2,DPT,BPT,Q
      WRITE (3,77)
      WRITE(3,75)
      DIM = 1.273238/(DI*DI)
  131 XMR=(((DO-DI)/2.0)*DO)/(T*(DO+DI)/2.0)
      AIXNT = AI * XNT
      AOXNT = AO * XNT
      TWA=(TW1+TW2)/2.0
      X=1.0/TWA
      DEN=64.7291+0.2361E-2*TWA-0.9615E-4*TWA*TWA+0.1292E-6*TWA**3.0
     1-0.9061E-10*TWA**4.0
      SRHO=1.0/DEN
      CPWAT=0.9358+0.2130E-4*TWA+0.4006E-6*TWA*TWA-0.2378E-9*TWA**3.0
      CWAT=0.2788+0.1305E-2*TWA-0.8109E-5*TWA*TWA+0.3832E-7*TWA**3.0
     1-0.1088E-9*TWA**4.0+0.1221E-12*TWA**5.0
      VISWAT=-0.1293+0.1592E3*X+0.6862E4*X*X-0.8692E5*X**3.0-0.4072E8
     1*X**4.0+0.1559E10*X**5.0
      RFI=0.0
      S = DPT - TW2
      E = BPT-TW1
      TDLM = (E-S)/ALOG(E/S)
      WT = Q*XN/((TW2-TW1)*XNT*CPWAT)
      TWT=(WT/1000.0)*(XNT/XN)
      G = WT * DIM
      RE = DI * G / VISWAT
      PR = CPWAT*VISWAT/CWAT
      HII = CWAT * STC / DI*(RE**0.8)*(PR**0.3333)
      ALPHA = HII
      VEL=(G*SRHO)/3600.0
      DO 7 J=1, 200
   38 AOTI= BETA*AOXNT
      UOI=Q/(AOTI*TDLM)
      AIT = BETA * AIXNT
      DO 3 I=1, 90
      VISWAW = VISANY(TWA + Q/(AIT*ALPHA))
      HI1 = HII*((VISWAT/VISWAW)**0.14)
      IF (TEST(ALPHA, HI1)) GO TO 4
    3 ALPHA = HI1
```

```
      GO TO 12
    4 CONTINUE
      W = AO/AI
      HI=HI1
      GAMMA = 1.0/(1.0/UOI - FR - W/HI -XMR)
      IF (GAMMA.LT.0.0) GO TO 36
      GO TO 37
   36  BETA = BETA + 1.0
      GO TO 38
   37 DELTF = (UOI*TDLM)/GAMMA
      TF=ABS((DPT-0.50*DELTF))
      VAPOH=1095.2-0.58*TF
      PHP=(TF**0.360452)*0.620385
      CN = A*VN**B
      HC1=0.725*CN*PHP*((VAPOH/(DO*DELTF*VN ))**0.25)*142.92
      UO   = 1.0/(XMR + W/HI + 1.0/HC1 + FR)
      UOI=UO
      AOT = Q/(UO*TDLM)
      TL1 = AOT/AOXNT
      UOAO=UO*AO
      IF (TEST(BETA, TL1)) GO TO 9
    7 BETA = TL1
   12 WRITE (3, 31) RE,VEL,RUN
      GOTO100
    9 FF = Z/RE**PW
      PT=FF*VEL*VEL*TL1/(9273.6*DI*SRHO)
      PF=PT/(TL1*XN)
      TLT=TL1*XNT
      TTWT=TLT*WF
      WRITE (3,79)
      WRITE (3, 10)
      WRITE (3,121)RE,HI1,UO,TDLM,HC1,AOT,TL1,VEL,UOAO,RUN
      WRITE (3,50)
      WRITE (3,51) WT,CWAT,VISWAT,PR,SRHO,DELTF,TF,PHP,CN,XMR
      WRITE(3,52)
      WRITE(3,53)PT,PF,TLT,TTWT,TWT
      IF(  RUN.LT.XRUN)GOTO100
C
C            INPUT AND OUTPUT FORMATS
C
   22 FORMAT(I10,6X,A4,6X,A4/8F10.5/8F10.5/6F10.5,F10.1)
   41 FORMAT(1H1,25X,'VAPOR CONDENSING PROGRAM------TUBE LENGTH IS A VAR
     1IABLE')
   71 FORMAT(1H ,25X,'BASIS------SIEDER-TATE EQUATION FOR TUBESIDE TRANS
     1FER COEFFICIENT')
   72 FORMAT(1H0,'FLUID...SHELL SIDE--CONDENSING STEAM'/
     1          'FLUID...TUBE  SIDE--5% BRINE')
   74 FORMAT (1H0,83HTUBE CHARACTERISTICS
     1          INPUT DATA AND CONSTANTS)
   42 FORMAT(1H0,'TUNO   , TUBE DESIGNATION NO.          =',I10,12X,
     1          'STC    , SIEDER-TATE CONSTANT           =',F10.5/
     1          'TUBTYP, TUBE TYPE                       =',6X,A4,12X,
     1          'A      , CONSTANT IN CN EQUATION        =',F10.5/
     1          'ALLOY  , ALLOY DESIGNATION              =',6X,A4,12X,
     1          'B      , POWER IN CN EQUATION           =',F10.5/
     1          'DO     , OUTSIDE DIAMETER, FT.          =',F10.5,12X,
     1          'VN     , NO. OF TUBES IN VERTICAL ROW=',F10.5/
     1          'DI     , INSIDE DIAMETER, FT.           =',F10.5,12X
     1          'XN     , NO. OF PASSES                  =',F10.5/
     1          'AI     , INSIDE SURFACE AREA, SQFT/FT=',F10.5,12X,
```

```
    1              'XNT    , TOTAL NO. OF TUBES              =',F10.5/
    1              'AO     , OUTSIDE SURFACE AREA SQFT/FT=',F10.5,12X,
    1              'Z      , FRICTION FACTOR EQUA. CONST.=',F10.5/
    1              'WF     , WEIGHT OF TUBE PER FT. LB/FT=',F10.5,12X,
    1              'PW     , FRICTION FACTOR EQUA.POWER  =',F10.5/
    1              'T      , THERMAL COND.BTU/SQFT-HR-F  =',F10.5,12X,
    1              'FR     , FOULING RESISTANCE          =',F10.5/
    1              'WR     , WALL THICKNESS, FT          =',F10.5,12X,
    1              'TW1    , TUBE INLET TEMP. F          =',F10.5)
 73 FORMAT(60X,'TW2    , TUBE OUTLET TEMP. F         =',F10.5/
    1 60X,         'DPT    , DEW POINT, F                =',F10.5/
    1 60X,         'BPT    , BOILING POINT, F            =',F10.5/
    1 60X,         'Q      , HEAT DUTY,     BTU/HR       =',F10.1//)
 77 FORMAT(1H0,40X,'OUTPUT NOMENCLATURE'///
    1              'RE     , REYNOLDS NO.                 ',3X,
    1              'HI1    , TUBESIDE TRANSFER COEFF.     '3X,
    1              'UO     , OVERALL TRANSFER COEFFICIENT'/
    1              'TDLM   , LOG MEAN TEMP. DIFF.  F      ',3X,
    1              'HC1    , CONDENSING COEFFICIENT       ',3X,
    1              'AOT    , TOTAL TRANSFER AREA  SQFT    '/
    1              'VEL    , TUBESIDE VELOCITY  FT/SEC    ',3X
    1              'UOAO   , PRODUCT OF UO BY AOT         ',3X,
    1              'RUN    , RUN NUMBER                   '/
    1              'WT     , FLOW PER TUBE    LB/HR       ',3X
    1              'CWAT   , THERMAL COND. OF FLUID       ',3X,
    1              'VISWAT, VISCOSITY OF FLUID            '/
    1              'PR     , PRANDTL NUMBER               ',3X,
    1              'SRHO   , SPECIFIC VOLUME              ',3X,
    1              'DELTF  , TEMP. DIFF. ACCROSS FILM     '/
    1              'TF     , TEMP. OF CONDENSATE FILM     ',3X,
    1              'PHP    , PHYSICAL GROUP               ',3X,
    1              'CN     , CORRECTION FACTOR            ')
 75 FORMAT(        'XMR    , WALL RESISTANCE              ',3X,
    1              'PT     , TOTAL PRESSURE DROP  PSI     ',3X,
    1              'PF     , PRESSURE DROP PER FT         '/
    1              'TLT    , TOTAL LENGTH OF TUBE  FT     ',3X,
    1              'TTWT   , TOTAL WEIGHT OF TUBE  LB     ',3X,
    1              'TWT    , TOTAL TUBESIDE FLOW,KLB/HR   '//)
 31 FORMAT (1H , 1X,F9.1,10X,16HDID NOT CONVERGE,54X,F5.1, 5X,F4.1)
 79 FORMAT (1H0,42X,6HOUTPUT)
 10 FORMAT (1H0,4X,2HRE,7X,3HHI1,7X,2HUO,7X,4HTDLM,7X,3HHC1,7X,3HAOT,7
    1X,3HTL1,7X,3HVEL,6X,4HUOAO,7X,3HRUN)
121 FORMAT(1X,F8.0,1X,F7.0,3X,F7.1,3X,F8.2,2X,F8.1,2X,F7.1,4X,F7.1,3X,
    1F6.2,3X,F7.1,3X,F6.1)
 50 FORMAT (1H0,4X,2HWT,7X,4HCWAT,6X,6HVISWAT,5X,2HPR,6X,4HSPHO,5X,5HD
    1ELTF,7X,2HTF,8X,3HPHP,6X,2HCN,9X,3HXMR)
 51 FORMAT (1X,F6.0,4X,F7.4,4X,F7.4,3X,F7.4,3X,F6.4,2X,F7.4,4X,F7.2,3X
    1,F7.4,2X,F7.4,4X,F8.6)
 52 FORMAT (1H0,4X,2HPT,7X,2HPF,8X,3HTLT,6X,4HTTWT,6X,3HTWT)
 53 FORMAT (2X,F7.4,3X,F7.4,2X,F7.0,3X,F7.1,2X,F7.1)
    CALL SYSTEM
    END
    REAL FUNCTION VAPANY(ARG)
    A SUBROUTINE FOR CALCULATING HEAT OF VAPORIZATION
    VAPANY=85.32-0.0935*ARG
    RETURN
    END
    REAL FUNCTION PHPANY(ARG)
    A SUBROUTINE FOR PHYSICAL PROPERTY GROUP
    PHPANY=1.117-0.0004667*(ARG)
```

```
      RETURN
      END
      REAL FUNCTION VISANY(ARG)
C
C     A SUBROUTINE FOR CALCULATING VISCOSITY.
C
      A=1.0/ARG
      VISANY=-0.1293+159.2*A+6862.3*A*A-86924.0*A*A*A-40719760.0*A*A*A*A
     1+1559708400.0*A*A*A*A*A
      RETURN
      END
```

NOMENCLATURE

A	Constant in C_n equation
AI	Inside surface area per foot of tube, ft^2/ft
ALLOY	Alloy identification number
AO	Outside surface area per foot of tube, ft^2/ft
AOT	Total outside heat transfer area, ft^2
B	Power in C_n equation
BETA	Initial estimation of tube length
BPT	Bubble point temperature, °F
CN	C_n, the Nusselt equation correction factor
CPWAT	Specific heat of fluid at average fluid temperature, BTU/lb-°F
CWAT	Thermal conductivity of fluid at average fluid temperature, BTU/ft-hr-°F
DELTF	Temperature difference across condensate film, °F
DEN	Density of fluid at average fluid temperature, lb/ft^3
DI	Inside diameter, ft
DO	Outside diameter, ft
DPT	Dew point temperature, °F
FR	Inside fouling resistance, ft^2-hr-°F/BTU
HC1	Condensing heat transfer coefficient, BTU/ft^2-hr-°F
HI1	Tubeside heat transfer coefficient, BTU/ft^2-hr-°F
PF	Pressure drop per foot of tube, psi/ft
PHP	Physical group of fluid at film temperature
PR	Prandtl number
PT	Total pressure drop across the stage, psi

PW	Friction factor equation power
Q	Heat duty, BTU/hr
RE	Reynolds number
RUN	Run number
SRHO	Specific volume of fluid, ft^3/lb
STC	Sieder-Tate constant
T	Tube thermal conductivity, BTU/ft-hr-°F
TDLM	Log mean temperature difference, °F
TF	Condensate film temperature, °F
TL1	Tube length per stage, ft
TLT	Total length of tube required, ft
TTWT	Total weight of tube required, lb
TUBTYP	Tube type number
TUNO	Tube designation number
TWA	Average fluid temperature, °F
TW1	Tube inlet temperature, °F
TW2	Tube outlet temperature, °F
TWT	Total tubeside fluid flow, Klb/hr
UO	Overall heat transfer coefficient, BTU/ft^2-hr-°F
UOAO	U_oA_o
VAPOH	Latent heat of vaporization at film temperature, BTU/lb
VEL	Tubeside fluid velocity, ft/sec
VISWAT	Viscosity of fluid at average fluid temperature, lb/ft-hr

VISWAW	Viscosity of fluid at wall temperature, lb/ft-hr
VN	Number of tubes in a vertical row
WF	Weight per foot of tube, lb
WR	Wall thickness, ft
WT	Fluid flow per tube, lb/hr
XMR	Wall resistance to heat transfer, ft^2-hr-°F/BTU
XN	Number of passes
XNT	Total number of tubes
XRUN	Run counter
Z	Friction factor equation constant

APPENDIX VIII

Steam Condensing Design Calculations for A Hypothetical Stage in a Desalination Plant

TABLE VIII-1

Design Calculations for a 3/4-inch Bare Tube for an MSF Desalination Plant Stage

VAPOR CONDENSING PROGRAM------TUBE LENGTH IS A VARIABLE
BASIS------SIEDER-TATE EQUATION FOR TUBESIDE TRANSFER COEFFICIENT

FLUID...SHELL SIDE--CONDENSING STEAM
FLUID...TUBE SIDE--5% BRINE

TUBE CHARACTERISTICS			INPUT DATA AND CONSTANTS		
TUNO	, TUBE DESIGNATION NO.	= 750	STC	, SIEDER-TATE CONSTANT	= 0.02510
TUBTYP	, TUBE TYPE	= BARE	A	, CONSTANT IN CN EQUATION	= 1.15800
ALLOY	, ALLOY DESIGNATION	= CUNI	B	, POWER IN CN EQUATION	= 0.09300
DO	, OUTSIDE DIAMETER, FT.	= 0.06250	VN	, NO. OF TUBES IN VERTICAL ROW	= 27.00000
DI	, INSIDE DIAMETER, FT.	= 0.05610	XN	, NO. OF PASSES	= 1.00000
AI	, INSIDE SURFACE AREA, SQFT/FT	= 0.17620	XNT	, TOTAL NO. OF TUBES	=2456.00000
AO	, OUTSIDE SURFACE AREA SQFT/FT	= 0.19640	Z	, FRICTION FACTOR EQUA. CONST.	= 0.31640
WF	, WEIGHT OF TUBE PER FT. LB/FT	= 0.33330	PW	, FRICTION FACTOR EQUA.POWER	= 0.25000
T	, THERMAL COND.BTU/SQFT-HR-F	= 26.00000	FR	, FOULING RESISTANCE	= 0.00030
WR	, WALL THICKNESS, FT	= 0.00321	TW1	, TUBE INLET TEMP. F	= 201.42000
			TW2	, TUBE OUTLET TEMP. F	= 205.25000
			DPT	, DEW POINT, F	= 212.70000
			BPT	, BOILING POINT, F	= 212.70000
			Q	, HEAT DUTY, BTU/HR	=29950000.0

OUTPUT NOMENCLATURE

RE	, REYNOLDS NO.	HI1	, TUBESIDE TRANSFER COEFF.	UO	, OVERALL TRANSFER COEFFICIENT
TDLM	, LOG MEAN TEMP. DIFF. F	HC1	, CONDENSING COEFFICIENT	AOT	, TOTAL TRANSFER AREA SQFT
VEL	, TUBESIDE VELOCITY FT/SEC	UOAO	, PRODUCT OF UO BY AOT	RUN	, RUN NUMBER
WT	, FLOW PER TUBE LB/HR	CWAT	, THERMAL COND. OF FLUID	VISWAT	, VISCOSITY OF FLUID
PR	, PRANDTL NUMBER	SRHO	, SPECIFIC VOLUME	DELTF	, TEMP. DIFF. ACCROSS FILM
TF	, TEMP. OF CONDENSATE FILM	PHP	, PHYSICAL GROUP	CN	, CORRECTION FACTOR
XMR	, WALL RESISTANCE	PT	, TOTAL PRESSURE DROP PSI	PF	, PRESSURE DROP PER FT
TLT	, TOTAL LENGTH OF TUBE FT	TTWT	, TOTAL WEIGHT OF TUBE LB	TWT	, TOTAL TUBESIDE FLOW,KLB/HR

OUTPUT

RE	HI1	UO	TDLM	HC1	AOT	TL1	VEL	UOAO	RUN
95821.	2099.	750.8	9.23	2695.1	4320.4	9.0	6.03	147.5	1.0

WT	CWAT	VISWAT	PR	SPHO	DELTF	TF	PHP	CN	XMR
3335.	0.3875	0.7899	1.9462	0.0161	2.5730	211.41	4.2733	1.5733	0.000130

PT	PF	TLT	TTWT	TWT
0.6996	0.0781	21998.	7332.0	8190.9

TABLE VIII-2

Design Calculations for a Hypothetical 1-inch Single-Start Corrugated Tube for an MSF Desalination Plant Stage

VAPOR CONDENSING PROGRAM------TUBE LENGTH IS A VARIABLE
BASIS------SIEDER-TATE EQUATION FOR TUBESIDE TRANSFER COEFFICIENT

FLUID...SHELL SIDE--CONDENSING STEAM
FLUID...TUBE SIDE--5% BRINE

TUBE CHARACTERISTICS				INPUT DATA AND CONSTANTS			
TUNO	, TUBE DESIGNATION NO.	=	2001	STC	, SIEDER-TATE CONSTANT	=	0.05500
TUBTYP	, TUBE TYPE	=	KORO	A	, CONSTANT IN CN EQUATION	=	1.50500
ALLOY	, ALLOY DESIGNATION	=	CUNI	B	, POWER IN CN EQUATION	=	0.20400
DO	, OUTSIDE DIAMETER, FT.	=	0.08250	VN	, NO. OF TUBES IN VERTICAL ROW	=	25.00000
DI	, INSIDE DIAMETER, FT.	=	0.07610	XN	, NO. OF PASSES	=	1.00000
AI	, INSIDE SURFACE AREA, SQFT/FT	=	0.23910	XNT	, TOTAL NO. OF TUBES	=	2162.00000
AO	, OUTSIDE SURFACE AREA SQFT/FT	=	0.25920	Z	, FRICTION FACTOR EQUA. CONST.	=	0.10000
WF	, WEIGHT OF TUBE PER FT. LB/FT	=	0.45060	PW	, FRICTION FACTOR EQUA.POWER	=	0.0
T	, THERMAL COND.BTU/SQFT-HR-F	=	26.00000	FR	, FOULING RESISTANCE	=	0.00030
WR	, WALL THICKNESS, FT	=	0.00321	TW1	, TUBE INLET TEMP. F	=	201.42000
				TW2	, TUBE OUTLET TEMP. F	=	205.25000
				DPT	, DEW POINT, F	=	212.70000
				BPT	, BOILING POINT, F	=	212.70000
				Q	, HEAT DUTY, BTU/HR	=	29950000.0

OUTPUT NOMENCLATURE

RE	, REYNOLDS NO.	HI1	, TUBESIDE TRANSFER COEFF.	UO	, OVERALL TRANSFER COEFFICIENT
TDLM	, LOG MEAN TEMP. DIFF. F	HC1	, CONDENSING COEFFICIENT	AOT	, TOTAL TRANSFER AREA SQFT
VEL	, TUBESIDE VELOCITY FT/SEC	UOAO	, PRODUCT OF UO BY AOT	RUN	, RUN NUMBER
WT	, FLOW PER TUBE LB/HR	CWAT	, THERMAL COND. OF FLUID	VISWAT	, VISCOSITY OF FLUID
PR	, PRANDTL NUMBER	SRHO	, SPECIFIC VOLUME	DELTF	, TEMP. DIFF. ACCROSS FILM
TF	, TEMP. OF CONDENSATE FILM	PHP	, PHYSICAL GROUP	CN	, CORRECTION FACTOR
XMR	, WALL RESISTANCE	PT	, TOTAL PRESSURE DROP PSI	PF	, PRESSURE DROP PER FT
TLT	, TOTAL LENGTH OF TUBE FT	TTWT	, TOTAL WEIGHT OF TUBE LB	TWT	, TOTAL TUBESIDE FLOW,KLB/HR

OUTPUT

RE	HI1	UO	TDLM	HC1	AOT	TL1	VEL	UOAO	RUN
80244.	2941.	1010.0	9.23	5170.6	3211.6	5.7	3.72	261.8	3.0

WT	CWAT	VISWAT	PR	SPHO	DELTF	TF	PHP	CN	XMR
3789.	0.3875	0.7899	1.9462	0.0161	1.8031	211.80	4.2761	2.9021	0.000128

PT	PF	TLT	TTWT	TWT
0.6993	0.1220	12390.	5583.1	8190.9

TABLE VIII-3

Design Calculations for a
1-inch Triple-Start Corrugated Tube for an
MSF Desalination Plant Stage

VAPOR CONDENSING PROGRAM------TUBE LENGTH IS A VARIABLE
BASIS------SIEDER-TATE EQUATION FOR TUBESIDE TRANSFER COEFFICIENT

FLUID...SHELL SIDE--CONDENSING STEAM
FLUID...TUBE SIDE--5% BRINE

TUBE CHARACTERISTICS			INPUT DATA AND CONSTANTS		
TUNO	, TUBE DESIGNATION NO. =	3000	STC	, SIEDER-TATE CONSTANT =	0.05050
TUBTYP.	TUBE TYPE =	KORO	A	, CONSTANT IN CN EQUATION =	1.48000
ALLOY	, ALLOY DESIGNATION =	CUNI	B	, POWER IN CN EQUATION =	0.10500
DO	, OUTSIDE DIAMETER, FT. =	0.08250	VN	, NO. OF TUBES IN VERTICAL ROW=	24.00000
DI	, INSIDE DIAMETER, FT. =	0.C7610	XN	, NO. OF PASSES =	1.00000
AI	, INSIDE SURFACE AREA, SQFT/FT=	0.23910	XNT	, TOTAL NO. OF TUBES =	1880.00000
AO	, OUTSIDE SURFACE AREA SQFT/FT=	0.25920	Z	, FRICTION FACTOR EQUA. CONST.=	0.38620
WF	, WEIGHT OF TUBE PER FT. LB/FT=	0.45C60	PW	, FRICTION FACTOR EQUA.POWER =	0.16240
T	, THERMAL COND.BTU/SQFT-HR-F =	26.00000	FR	, FOULING RESISTANCE =	0.00030
WR	, WALL THICKNESS, FT =	0.C0321	TW1	, TUBE INLET TEMP. F =	201.42000
			TW2	, TUBE OUTLET TEMP. F =	205.25000
			DPT	, DEW POINT, F =	212.70000
			BPT	, BOILING POINT, F =	212.70000
			Q	, HEAT DUTY, BTU/HR =	29950000.0

OUTPUT NOMENCLATURE

RE	, REYNOLDS NO.	HI1	, TUBESIDE TRANSFER COEFF.	UO	, OVERALL TRANSFER COEFFICIENT
TDLM	, LOG MEAN TEMP. DIFF. F	HC1	, CONDENSING COEFFICIENT	AOT	, TOTAL TRANSFER AREA SQFT
VEL	, TUBESIDE VELOCITY FT/SEC	UOAO	, PRODUCT OF UO BY AOT	RUN	, RUN NUMBER
WT	, FLOW PER TUBE LB/HR	CWAT	, THERMAL COND. OF FLUID	VISWAT	, VISCOSITY OF FLUID
PR	, PRANDTL NUMBER	SRHO	, SPECIFIC VOLUME	DELTF	, TEMP. DIFF. ACCROSS FILM
TF	, TEMP. OF CONDENSATE FILM	PHP	, PHYSICAL GROUP	CN	, CORRECTION FACTOR
XMR	, WALL RESISTANCE	PT	, TOTAL PRESSURE DROP PSI	PF	, PRESSURE DROP PER FT
TLT	, TOTAL LENGTH OF TUBE FT	TTWT	, TOTAL WEIGHT OF TUBE LB	TWT	, TOTAL TUBESIDE FLOW,KLB/HR

OUTPUT

RE	HI1	UO	TDLM	HC1	ACT	TL1	VEL	UOAO	RUN
92280.	3019.	926.8	9.23	3426.9	3500.0	7.2	4.28	240.2	2.0

WT	CWAT	VISWAT	PR	SPHC	DELTF	TF	PHP	CN	XMR
4357.	0.3875	0.7899	1.9462	0.0161	2.4961	211.45	4.2735	2.0663	0.000128

PT	PF	TLT	TTWT	TWT
0.6992	0.0973	13503.	6084.5	8190.9