THESIS

FILMWISE CONDENSATION OF STEAM
ON HORIZONTAL WIRED-WRAPPED SMOOTH
AND ROPED TITANIUM TUBES

by

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September 1992

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Results obtained for the wire-wrapped smooth titanium tubes showed a maximum enhancement of 30% as compared to a smooth titanium tube. This was for a tube using a 0.5 mm wire diameter (PD = 7.92), corresponding to a fraction of the tube covered by the wire of 12%. The LPD KORODENSE titanium tube showed an enhancement of 20% compared to a smooth titanium tube for both atmospheric and vacuum pressures. The addition of wrapping a wire in the grooves of the LPD tube showed no further significant enhancement for the three wire diameters tested.
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Filmwise Condensation of Steam on Horizontal Wire-Wrapped Smooth and Roped Titanium Tubes

by

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ABSTRACT

Filmwise condensation heat-transfer measurements were performed on horizontal smooth and roped titanium tubes using steam. The roped tubes were a commercially available tube (KORODENSE) with a nominal pitch of 7 mm. To further enhance the outside heat-transfer coefficient of both the smooth and roped tubes a wire was tightly wrapped around the tubes. To see the effect that the wire diameter and wire pitch had on the enhancement, 3 different wire diameters were used (nominal diameters of 0.5, 1.0, 1.6 mm) giving a range of wire pitch to wire diameter ratio of between 2 and 9. Tests were conducted under vacuum and atmospheric pressure conditions. The data reduction technique used the modified Wilson plot.

Results obtained for the wire-wrapped smooth titanium tubes showed a maximum enhancement of 30% as compared to a smooth titanium tube. This was for a tube using a 0.5 mm wire diameter \((P/D_w = 7.92)\), corresponding to a fraction of the tube covered by the wire of 12%. The LPD KORODENSE titanium tube showed an enhancement of 20% as compared to a smooth titanium tube for both atmospheric and vacuum pressures. The addition of wrapping a wire in the grooves of the LPD tube showed no further significant enhancement for the three wire diameters tested.
TABLE OF CONTENTS

I. INTRODUCTION ............................................. 1
   A. BACKGROUND ............................................. 1
   B. CONDENSATION .......................................... 2
   C. CONDENSATION RESEARCH AT THE NAVAL POSTGRADUATE
      SCHOOL ................................................... 5
         1. Condensation Research Using Roped and Wire-
             Wrapped Tubes ........................................ 6
   D. OBJECTIVES ............................................... 7

II. LITERATURE SURVEY ........................................ 8
   A. INTRODUCTION ........................................... 8
   B. FILM CONDENSATION OF STEAM ON A SMOOTH TUBE .... 8
   C. FILM CONDENSATION ON WIRE WRAPPED TUBES ........ 10
      1. Summary of Wire-Wrap Tube Research .............. 11
   D. FILM CONDENSATION ON ROPED TUBES ................. 14
      1. Summary of Roped Tube Condensation Data .......... 14

III. APPARATUS AND SYSTEM INSTRUMENTATION ................. 18
   A. SYSTEM OVERVIEW ...................................... 18
   B. SYSTEM INSTRUMENTATION ................................ 20
   C. TUBES TESTED ........................................... 24
LIST OF TABLES

Table I. LISTING OF THE TUBES TESTED .......................... 25
Table II. SMOOTH TITANIUM TUBE WITH A HEATEX INSERT
(PRESENT WORK) .................................................. 59
Table III. SMOOTH TITANIUM TUBE WITH NO INSERT (PRESENT
WORK) ............................................................... 60
Table IV. SMOOTH COPPER TUBE WITH A HEATEX INSERT .... 61
Table V. SMOOTH COPPER TUBE WITH A WIRE WRAP INSERT 62
Table VI. SMOOTH COPPER TUBE WITH NO INSERT ............. 63
Table VII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH A
HEATEX INSERT .................................................... 66
Table VIII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH NO
INSERT .............................................................. 67
Table IX. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A HEATEX
INSERT .............................................................. 68
Table X. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A WIRE
WRAP INSERT ......................................................... 69
Table XI. LPD KORODENSE TUBES WITH A HEATEX INSERT ... 79
Table XII. LPD KORODENSE TUBES WITH NO INSERT .......... 80
Table A.1 FRICTION TEMPERATURE RISE EQUATIONS .......... 89
<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Idealized Condensate Film Profile on a Wire-Wrapped Tube</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>Profile of a Roped Tube</td>
<td>15</td>
</tr>
<tr>
<td>3</td>
<td>Schematic of the Single Tube Test Apparatus</td>
<td>19</td>
</tr>
<tr>
<td>4</td>
<td>Schematic of the Test Section Insert</td>
<td>21</td>
</tr>
<tr>
<td>5</td>
<td>Schematic of Purging System and Cooling Water Sump</td>
<td>22</td>
</tr>
<tr>
<td>6</td>
<td>Comparison of Results for the Outside Heat Transfer Coefficient at Atmospheric Pressure Using the Swensen Correlations</td>
<td>41</td>
</tr>
<tr>
<td>7</td>
<td>Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure using the Swensen Correlations</td>
<td>42</td>
</tr>
<tr>
<td>8</td>
<td>Comparison of the Outside Heat Transfer Coefficients at Atmospheric Pressure using the Petukhov-Popov Correlation</td>
<td>45</td>
</tr>
<tr>
<td>9</td>
<td>Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure Using the Petukhov-Popov Correlation</td>
<td>46</td>
</tr>
<tr>
<td>10</td>
<td>Comparison if the Inside Heat Transfer Coefficients using the Petukhov-Popov and Sleicher-Rouse Correlations</td>
<td>47</td>
</tr>
</tbody>
</table>
Figure 11. Comparison of the Outside Heat Transfer Coefficients for Atmospheric Pressure Using the Petukhov-Popov and Sieder-Tate (Re"\textsuperscript{0.8}) Correlations

Figure 12. \(U_{\text{o}}\) vs. \(V_{\text{o}}\) for a Smooth Tube at Atmospheric Pressure with a HEATEX Insert

Figure 13. \(U_{\text{o}}\) vs. \(V_{\text{o}}\) for a Smooth at Atmospheric Pressure with No Insert

Figure 14. \(U_{\text{o}}\) vs. \(V_{\text{o}}\) for a Smooth Tube at Vacuum Pressure with a HEATEX Insert

Figure 15. \(U_{\text{o}}\) vs. \(V_{\text{o}}\) for a Smooth Tube at Vacuum Pressure with No Insert

Figure 16. Effect of Vapor Velocity on Smooth Titanium Tubes Average \(U_{\text{o}}\) Values

Figure 17. \(h_{\text{o}}\) vs. \(\Delta T_{\text{r}}\) for Smooth Tubes at Atmospheric Pressure

Figure 18. \(h_{\text{o}}\) vs. \(\Delta T_{\text{r}}\) for a Smooth Tube at Vacuum Pressure

Figure 19. \(U_{\text{o}}\) vs \(V_{\text{o}}\) for Wire-Wrapped Tubes at Atmospheric Pressure with a Heatex Insert

Figure 20. Comparison of the Outside Heat Transfer Coefficients of Tubes 6 and 7 with a Smooth Titanium Tube

Figure 21. Comparison of the Outside Heat Transfer Coefficients of Tubes 1, 2, and 3 to a Smooth Titanium Tube
Figure 22. Comparison of the Outside Heat Transfer Coefficients for tubes 4 and 5 to a Smooth Titanium Tube

Figure 23. Comparison of the Outside Heat Transfer Coefficients between the Titanium and Copper Tubes

Figure 24. Comparison of the Enhancement vs. P/D, Ratio of the Data from Mitrou, O'Keefe, and Sethumadhavan & Rao

Figure 25. Comparison of the Enhancement vs. F for the data of Mitrou, O'Keefe, and Sethumadhavan & Rao

Figure 26. Comparison of the Outside Heat Transfer Coefficients for the plain LPD KORODENSE Tube and the Smooth Titanium Tube

Figure 27. Comparison of the Outside Heat Transfer Coefficient for the Wire-Wrapped LPD KORODENSE Titanium Tubes and the Smooth Titanium Tube

Figure 28. Comparison of $h_s/h_m$ vs. P/D, Ratio for the Wire-Wrapped LPD KORODENSE Tubes

Figure 29. Comparison of $h_s/h_{LPD}$ vs. F for the Wire-Wrapped LPD KORODENSE tubes

Figure A.1 Frictional Temperature Rise Curves for the Smooth Titanium Tube with a HEATEX Insert and No Insert

Figure A.2 Frictional Temperature Rise Curves for the LPD KORODENSE Titanium Tube with a HEATEX Insert and No Insert
NOMENCLATURE

a as defined in equation (4.23)
A_i effective inside surface area, m^2
A_o effective outside surface area, m^2
b as defined in equation (4.22)
c as defined in equation (4.15)
C_l leading coefficient for the inside heat transfer correlation used
C_p specific heat at a constant pressure, J/kgK
d as defined in equation (4.15)
D_i tube inside diameter, m
D_o tube outside diameter, m
E_e enhancement ratio based on ΔT
F fraction of the tube covered by wire
F' as defined in equation (2.3)
g gravitational constant, 9.81 m/s
h_{fg} specific enthalpy of vaporization, J/kg
h_i inside heat transfer coefficient, W/m^2K
h_o outside heat transfer coefficient, W/m^2K
k_c thermal conductivity of the coolant film, W/mK
k_z thermal conductivity of the condensate film, W/mK
k_a thermal conductivity of the tube material, W/mK
K_1 as defined in equation (4.16)
K_2 as defined in equation (4.16)
L  active length of tube exposed to steam, m
L_1  length of inlet portion of tube, m
L_2  length of outlet portion of tube, m
LMTD log mean temperature difference, K
\( \Phi \) mass flow rate of the coolant, kg/s
Nu Nusselt number
P_\text{sat} saturation pressure, Pa
Pr Prandtl number
Pr_w Prandtl number at the wall temperature
Q heat transfer rate, W
q heat flux, W/m²
Re Reynolds number
Re_r Reynolds number for the condensate film
Re_{pq} two phase Reynolds number
R_1 inside thermal resistance, m²K/W
R_o outside thermal resistance, m²K/W
R_{total} total thermal resistance, m²K/W
R_w wall thermal resistance, m²K/W
T_{cr} temperature difference across the condensate film, K
\Delta T_f temperature difference across the film, K
T_{sat} vapor saturation temperature, K
T_1 cooling water inlet temperature, K
T_2 cooling water outlet temperature, K
U_o overall heat transfer coefficient, W/m²K
U_v vapor velocity, m/s
V_v velocity of the coolant, m/s
X as defined in equation (4.19)

Y as defined in equation (4.18)

Z as defined in equation (4.12)

Greek Symbols

\( \alpha \)  dimensionless coefficient

\( \varepsilon \)  as defined in equation (4.16)

\( \mu_c \)  dynamic viscosity of the coolant, kg/m s

\( \mu_f \)  dynamic viscosity of the condensate film, kg/m s

\( \mu_w \)  dynamic viscosity of the condensate at the wall, kg/ms

\( \rho_f \)  density of the condensate film, kg/m³

\( \rho_v \)  density of the vapor, kg/m³

\( \eta \)  surface efficiency

\( \Omega \)  as defined in equation (4.13)
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I. INTRODUCTION

A. BACKGROUND

Since the Cold War has ended, the money allocated for new weapon platforms in the Navy has been greatly reduced. There is therefore an increased emphasis on making ships as cost efficient as possible. Technology has progressed to the point where the heat removal requirements of modern weapons systems have increased. Future classes of attack submarines are expected to be smaller in size and just as capable as the existing 688 class. This will require the main and auxiliary propulsion systems to be designed for maximum power with the smallest, lightest, and most cost efficient components. One method to reduce the main propulsion system size and weight is to use enhanced tubing in the main condenser. In addition, submarine and surface ship refrigeration systems can have larger capacities, and maintain the same approximate size and weight if enhanced tubing is used in the refrigeration condenser. The Naval Postgraduate School, with support from the David Taylor Research Center, has been conducting research on various types of condenser tubing with the object of designing smaller, lighter, and more efficient condensers.

The DDG-51 class of destroyers was originally designed to have enhanced titanium tubes used for the refrigeration
condenser to give significant weight reduction to the refrigeration plant. In submarines, the use of enhanced titanium tubes in the main and auxiliary condensers would lead to a major reduction in weight of the steam propulsion plant. Titanium has the advantage over copper-nickel, which is presently used in condensers, of a higher strength to weight ratio, as well as excellent corrosion and erosion resistance. This allows for thinner tube walls and higher coolant flow rates to be used, so the same overall amount of heat can be transferred [Ref. 1]. The improved performance of enhanced tubes allows the same amount of power to be produced at a lower turbine backpressure, allowing for the design of smaller, more efficient propulsion plants. Alternatively, a larger power output can be achieved at the same backpressure for a plant of the same size. Some of the disadvantages of titanium are that it has a much smaller thermal conductivity and it is very expensive compared to copper-nickel.

B. CONDENSATION

Condensation occurs when a vapor is cooled below its saturation temperature, or when a vapor/gas mixture is cooled below its dew point. Condensation also occurs when a vapor comes into contact with a subcooled liquid. This is known as direct contact condensation. The most common type of condensation involved with heat exchangers is surface condensation. This occurs when the vapor contacts a surface
that is maintained below the saturation temperature of the vapor. Two types of surface condensation can take place. The first is filmwise condensation, so called because the condensate "wets" the surface with a continuous film. The second is dropwise condensation, so called because the condensate does not "wet" the surface, but instead forms distinct droplets of various sizes. Microscopic droplets coalesce to form large drops, which are then removed from the surface by gravity and/or vapor shear forces. Dropwise condensation results in much higher heat transfer coefficients (typically by an order of magnitude) than with filmwise condensation due to the fact that a certain portion of the cooled metal surface is exposed to the vapor. However, dropwise condensation is difficult to maintain over the life of a typical condenser. Many attempts have been made to promote dropwise condensation by using special surface coatings, but these tend to get 'washed' off in the little long term, reverting back to filmwise condensation. Therefore, condensers are normally designed to operate assuming filmwise condensation takes place, Thus providing for a conservative design [Ref. 2].

The heat transfer rate across a condenser tube is controlled by the tube wall, fouling, coolant side, and vapor side thermal resistances. For most laboratory experimental work, the tubes are thoroughly cleaned before testing, so the fouling thermal resistance is negligible. The other thermal
resistances vary depending on the condensing and coolant fluids used, tube geometry and material, and the flow conditions of the coolant and vapor. During condensation of steam, the coolant side thermal resistance is usually the dominant controlling resistance.

Methods of lowering the coolant side resistance include the use of inserts and roped tubes. However, any increase in heat transfer is offset by an increase in the pressure drop along the tube. Although inserts provide the best enhancement, the large pressure drop involved generally restricts their use to laminar flows and other specialist applications. Roped tubes, which tend to incur a much lower pressure drop, have been used successfully in a large scale condenser at the Gallatin Unit 1 300-MW power plant for the Tennessee Valley Authority. Low pressure drop (LPD) KORODENSE 90-10 Cu-Ni tubes were used to retube the condenser in August 1980 (LPD KORODENSE is a particular type of roped tube made by the Wolverine Tube Co.). Although it cost about $65,000 more to retube using the roped tubes, a projected savings of $908,000 is expected over the remaining life of the plant based on actual performance [Ref. 3]. The wall resistance is controlled by the type of material used and the thickness of the tube wall.

The vapor side thermal resistance is lowered essentially by thinning the condensate film. One way of thinning the condensate film can be achieved by changing the geometry of
the outside surface of the tube to utilize the surface tension effects of the fluid. Thinning the condensate film can significantly increase the heat transfer, especially for fluids like water where the surface tension is high. The use of fins, wire-wrap, and roped tubes have all been used to lower the vapor side resistance by causing an uneven pressure distribution through the condensate film on the surface of the tube.

C. CONDENSATION RESEARCH AT THE NAVAL POSTGRADUATE SCHOOL

The Naval Postgraduate School (NPS) has been conducting condensation research on enhanced tubes since 1982. Van Petten [Ref. 4] provides a summary of the research efforts on single horizontal tube condensation at NPS from 1982 to 1988. In particular, the research has looked at many aspects of enhancing tubes with low integral fins. Previous researchers have varied the fin spacing, fin shape, fin material, and tube diameter to determine how the performance of the tube is affected. Work has been done on single tubes and tube bundles at various pressures. Several different types of working fluids have also been used: steam, R-113, and ethylene glycol. All of this has been done to determine if the performance of an enhanced tube can be predicted, and under what condition the maximum enhancement will be realized.

Previously, the modified Wilson plot technique has been used to find the outside heat-transfer coefficient. However,
without an accurate inside heat transfer correlation, past researchers have had trouble reducing their data to provide an accurate value of the outside heat-transfer coefficient. Swensen [Ref. 5] used an instrumented tube to find the values of the tube wall temperatures. With a mean wall temperature of the tube, the inside and outside heat-transfer coefficients could be calculated directly. He then developed several inside heat transfer correlations using his data, based on the form of the Sieder-Tate [Ref. 6] correlation. His research noted that the outside heat transfer correlations were very sensitive to the Reynolds number exponent.

1. Condensation Research Using Roped and Wire-Wrapped Tubes

Most of the single tube condensation research done previously at NPS has involved the use of smooth and low integral fin copper tubes. Only a few researchers at NPS have studied the effects of wire-wrapping smooth tubes in a condensation application. The first was Kanakis [Ref. 7] in 1983. He tested titanium smooth and roped tubes, both with and without wire wrapping, while condensing steam in a vertical in-line tube bundle; up to 30 tubes were simulated by using inundation tubes. Brower [Ref. 8] used the same apparatus as Kanakis to try and determine the effects of wire diameter and pitch on the steam side heat transfer coefficient and to compare the effect of condensate inundation on smooth
and wire-wrapped tubes. Kanakis and Brower showed that the wire-wrapped tubes were not significantly affected by inundation (i.e. the wire provided better drainage down the bundle) in a steam condenser bundle. In a different apparatus, Mitrou [Ref. 9] conducted research on single tubes, both finned and wire-wrapped. He studied the relationship between the wire pitch and wire diameter for several wire-wrapped smooth copper tubes. Mitrou's results showed that the enhancement of a wire-wrapped tube compared to a smooth tube could be as much as 80% for the same temperature drop across the condensate film. The largest enhancements corresponded to a $P/D_0$ ratio of between 5 and 7.

D. OBJECTIVES

The main objectives of this thesis were:

1. To find an accurate inside heat-transfer correlation, which is not sensitive to the Reynolds number exponent, for use in the data reduction technique.

2. To manufacture and collect condensation data on a series of titanium wire-wrapped smooth and roped tubes.

3. To check the repeatability of results of past researchers on the enhancement in the outside heat transfer coefficient due to wire-wrapping a copper tube.

4. To determine any effect of wire pitch and wire diameter on the enhancement in the outside heat transfer coefficient as compared to a smooth tube.
II. LITERATURE SURVEY

A. INTRODUCTION

When filmwise condensation occurs on a smooth horizontal tube, a thin condensate film forms around the tube. This condensate film provides a resistance to the heat transfer across the tube, so if the thickness of the film can be reduced, then the heat transfer rate will increase. To reduce the thickness of the film, several different methods have been used including low integral fins, wire-wrapped, and roped tubes. In the past, it was thought that enhancing a tube in this way for steam condensation would be impractical because the high surface tension would cause condensate to be retained between the surface enhancement on the tube, degrading performance.

The Naval Postgraduate School has conducted extensive research in enhancing the heat transfer performance of condenser tubes. The direction of the experimental research recently has been to find the optimum tube for condensation using the various enhancement methods.

B. FILM CONDENSATION OF STEAM ON A SMOOTH TUBE

In 1916, Nusselt [Ref. 10] showed that for a quiescent vapor condensing on a horizontal tube, the thickness of the condensate film varied around the tube. This variation led to
a variation in the local heat transfer coefficient, being a maximum at the top of the tube where the film is the thinnest. Nusselt's theoretical result for the mean heat transfer coefficient of a pure saturated vapor on a horizontal cylinder was:

$$h_o = 0.728 \left[ \frac{k_f^3 \rho_f (\rho_f - \rho_v) g h_{fg}}{\mu_f D_o \Delta T_f} \right]^{1/4} \tag{2.1}$$

Nusselt's equation has been verified experimentally for a stationary vapor surrounding the tube. However, in most steam surface condensers, the vapor is moving with some velocity. The velocity of the vapor affects the thickness of the condensate film due to the drag imparted on it by the vapor. Shekriladze and Gomelauri (1966) [Ref. 11] took this surface shear into account and derived the following theoretical equation for the mean Nusselt number (dimensionless mean heat transfer coefficient):

$$\frac{\text{Nu}}{Re_2^1/2} = 0.64 \left(1 + (1 + 1.69 F^*)^{1/2}\right)^{1/2} \tag{2.2}$$

where:

$$F^* = \frac{Pr}{Fr Ph} = \frac{g D_o \mu_f h_{fg}}{U_f^2 k_f \Delta T_f} \tag{2.3}$$

$$Re_2^1 = \frac{\rho_f U_o D_o}{\mu_f} = \text{two phase Reynolds number}$$
F' is a dimensionless parameter which relates the gravity force to the shear force. At high values of F', where gravitational forces dominate, equation (2.2) reduces to the Nusselt equation shown in equation (2.1). A low values of F', equation (2.2) predicts significantly higher values of \( h \) than equation (2.1) due to the action of the vapor shear forces thinning the condensate film.

Fujii et al [Ref. 12], in 1979, formed an empirical correlation for the vapor side Nusselt number from forced convection steam condensation data:

\[
\frac{Nu}{Re_{26}^{1/2}} = 0.96 F'^{1/5}
\]  

(2.4)

Again, at high values of F', equation (2.4) gives the same result as equation (2.1).

In a situation where surface shear forces are significant for steam condensation, equation (2.4) seems to be the most accurate. The reader is referred to Rose [Ref. 13] for further reading on the topic of filmwise condensation on a smooth horizontal cylinder.

C. FILM CONDENSATION ON WIRE WRAPPED TUBES

The technique of wrapping a wire around a smooth tube to enhance performance was first introduced by Thomas [Ref. 14] in 1967 for vertical tubes. He judged that the wire, creates a low pressure region at the base of the wire due to the small
radius of curvature. This low pressure region draws in condensate from between the wires (where the pressure is greater), thinning the condensate film and improving the outside heat transfer coefficient.

The same explanation can be used to explain why enhancement occurs for a horizontal wire-wrapped horizontal tube. Figure 1 is an idealized profile of a wire wrapped tube. The low pressure region forms at the base of the wire with the higher pressure region forms between the wires. The amount of heat transferred through the wire is usually negligible compared to the rest of the surface. This is not only because of the high thermal contact resistance between the tube and the wire but also because the thicker condensate layer that is formed at the base of the wire tends to inhibit heat transfer in this region.

1. Summary of Wire-Wrap Tube Research

Previous researchers have found that wire-wrapped smooth tubes can lead to significant enhancement over plain smooth tubes. Sethumadhavan and Rao [Ref. 15] used single wire-wrapped horizontal tubes in a steam condenser with negligible vapor shear and showed that the tubes had an outside heat transfer coefficient enhancement of between 10% and 45% over plain smooth tubes; unfortunately, the material of the tube was not specified. They used three different wire diameters, 0.71 mm, 1.5 mm, and 3.0 mm. The maximum
enhancement of 45% was obtained for the 3.0 mm wire at a pitch of 15 mm, giving a \( P/D_w = 5 \). The fractional coverage by the wire of the tube, \( F \), in this case corresponded to 21%. They were trying to determine if there was a relationship between either \( F \) or \( P/D_w \) and the heat transfer enhancement such that the performance of wire-wrapped smooth tubes could be predicted.

The same year Fujii et al. [Ref. 16] presented data condensing R-11 and ethanol on a single wire-wrapped smooth tube. Wire diameters of 0.1 mm, 0.2 mm, and 0.3 mm were used on copper tubes. They showed an increase in the outside heat transfer coefficient of 2 to 3 times that predicted by the
Nusselt equation for a smooth tube. This maximum enhancement of the outside heat transfer coefficient occurred at P/D_w of 2. They also modeled the relationship between P/D_w and the outside heat transfer coefficient enhancement and found reasonable agreement with their data.

Marto et al. [Ref. 17] showed enhancements in the outside heat transfer coefficient of up to 80% for a single wire-wrapped smooth copper tube over a plain smooth copper tube condensing steam (i.e. significantly lower than that found by Fujii [Ref. 16] for R-11). Their results showed an optimum P/D_w between 5 and 7. Titanium wire diameters of 0.5 mm, 1.0 mm, and 1.6 mm were used, the difference in the results for R-11 and steam is the condensate retention between the wires for the case of steam. They then improved the model of Fujii et al. [Ref. 16] to account for the condensate retention and obtained reasonable agreement with their data.

Marto and Wanniarachchi [Ref. 19] tested smooth and roped titanium tubes, both with and without wire-wrap using steam in a tube bundle that could simulate up to 30 tubes in a vertical column. For the wire-wrapped tubes, a wire diameter of 1.6 mm was used. They reported that the mean bundle outside heat transfer coefficient could be significantly increased by using wire-wrapped tubes. Due to the fact that they are much less susceptible to the effects of condensate inundation.
D. FILM CONDENSATION ON ROPED TUBES

Roped tubes lower the overall thermal resistance in several ways; first by promoting turbulent flow on the coolant side disrupting the laminar sublayer. Secondly, the rounded geometry and grooves on the outside surface of the tube set up low pressure regions which thin the condensate film over much of the tube's outer surface area (Figure 2). The grooves in the roped tube also make it easier for the condensate to drain off the tube. By thinning the film over most of the tube surface, the outside heat-transfer is enhanced.

The disadvantage of roped tubes is that the tubeside pressure drop is increased, so more pumping capacity is needed to provide the same coolant flow rate as with a smooth tube. The magnitude of this increased pressure drop is related to the groove depth and pitch. There is therefore always a trade-off between the increased heat transfer and the increased pressure drop, which can only be sorted out from an economic standpoint.

1. Summary of Roped Tube Condensation Data

In 1971, Withers and Young [Ref. 19] evaluated the use of roped tubes in a distillation plant condenser. They obtained enhancements of up to 50% in the overall heat transfer coefficient using the roped tubes with an equal pressure drop across the coolant side of the condenser. Catchpole and Drew [Ref. 20] tested various single roped
tubes. They varied the pitch and groove depth in the tubes and also obtained overall heat transfer improvements of up to 50%. There was always an enhancement with the roped tubes; the optimum tube for use, based on single tube data only, depended on a balance between space and weight requirements and higher operating cost due to the increased pumping power required.

Mehta and Rao [Ref. 21] tested roped aluminum tubes and were able to show that the outside heat transfer coefficient was enhanced between 16% and 38%, as compared to Nusselt theory for a smooth aluminum tube. Marto, Reilly, and Fenner [Ref. 22] tested eleven different roped tube configurations
(i.e. varying the groove pitch and depth) made of various materials. The tube was set up in a bundle arrangement to simulate a portion of a steam condenser. They found that the outside heat transfer coefficients, when compared to a smooth tube, were enhanced from 0.85 to 1.34 for the various tubes. The tubes with the highest performance had the deeper grooves and, as a consequence, larger coolantside pressure drops. They also noted that if the high performance tubes were not supported properly, there could be problems with tube vibration.

Cunningham et al. [Ref. 23, 24] studied the use of roped tube bundles in a steam condenser. They looked at two roped tubes with the same groove depth and pitch except one tube had six helical starts and the other tube had two helical starts. Their results showed that the roped tubes increased the overall heat transfer coefficient by 20% for the six start tube and up to 50% for the two start tube. The two start tubes showed higher performance for the top tube in the bundle, but lower tubes had problems with inundation. For the six start tubes, inundation did not have as large an effect as with the two start tubes, probably due to the better drainage. The six start tubes would therefore give the best overall performance when operating in a bundle.

In 1980, the Tennessee Valley authority retubed their Gallatin Steam plant Unit I condenser with 90-10 Cu-Ni LPD roped tubes and obtained an increase between 38% and 43% in
the overall bundle heat transfer coefficient, as compared to the original smooth tube bundle. However, the overall bundle heat transfer coefficient dropped as the tubes became fouled over a 2 to 4 month period. The fouling was removed by driving a stiff bristle brush through the tubes with high pressure air and water. After the fouling was removed, a 47% increase in the overall bundle heat transfer coefficient. (as compared to a smooth tube bundle) was observed [Ref. 3]. Mussalli and Gordon [Ref. 25] give a good review of the use of roped tubes in power plant condenser operations. Their paper points out that studies have shown the biofouling rate in smooth and roped tubes is approximately the same for the same water velocity. They also say that the tube enhancement may inhibit fouling buildup beyond a certain thickness due to the increased turbulence of the flow at the wall surface and that the use of chlorination treatment was effective at controlling biofouling in titanium tubes.

In summary, previous research conducted using wire-wrapped smooth and roped tubes in bundles have shown that the effects of condensate inundation can be significantly reduced. This thesis research has been conducted with a view to analyzing the enhancements in the outside heat transfer coefficient of wire-wrapped smooth and roped tubes and to determine if there is a relationship (with an optimum) between P/D, or F to the heat transfer enhancement.
A. SYSTEM OVERVIEW

The apparatus used is the same as that used by Swensen [Ref. 5]. A schematic of the overall system is shown in Figure 3. Steam is generated from distilled water using ten 4 kW, 440 Volt Watlow immersion heaters in a 0.30m diameter Pyrex boiler. The steam passes from the boiler section up through a 2.13m (ID of 0.15m) straight length of Pyrex glass piping. It is then redirected 180 degrees by two 90 degree Pyrex glass elbows, and flows 1.52m down a straight length of Pyrex tubing into the stainless steel test section. The stainless steel test section contains the horizontally mounted condenser tube as shown in Figures 3 and 4. A circular viewing port in the test section allows the condensation process to be observed during testing. Any excess steam passes through the test section and into the auxiliary condenser unit. The auxiliary condenser is constructed of a single copper coil mounted to a stainless steel base at the bottom of a Pyrex glass condenser section. The condensed water is then returned to the boiler section by a gravity drain in the baseplate of the auxiliary condenser.

The auxiliary condenser is cooled by a continuous supply of tap water controlled by a throttle valve and flow meter.
Figure 3. Schematic of the Single Tube Test Apparatus
Cooling water for the single horizontal tube is provided by a coolant system. This closed loop system consisted of a water sump tank, two centrifugal pumps in series, a flow control valve, and a calibrated flow meter as shown in Figure 3. Figure 4 shows the details of the test section and the arrangement of all the temperature measuring devices used to measure the temperature rise across the tube. The nylon mixing chamber mixes the flow at the outlet to ensure the average temperature of the flow is measured. The coolant flow rate through the horizontal tube can be varied to adjust the rate of condensation on the single test tube.

The system used to remove non-condensible gases is shown in Figure 5. The suction point is at the base of the auxiliary condenser where non-condensible gases are most likely to accumulate. The vacuum pump draws the air/steam mixture through an external condensing coil, which is located in the coolant sump tank, to condense any steam in the line. The condensed steam collects in a plexiglas container and is drained later. The air and other non-condensible gases are expelled to the atmosphere.

B. SYSTEM INSTRUMENTATION

The electrical power input to the 440 V ac immersion heaters was controlled by a panel mounted potentiometer. The power calculation for the data acquisition system is described in detail by Poole [Ref. 26]. System pressure was monitored by
Figure 4. Schematic of the Test Section Insert
Figure 5. Schematic of Purging System and Cooling Water Sump
three different methods:

1. Setra model 204 pressure transducer.
2. System saturation temperature converted into pressure.
3. Heise solid front pressure gage (visual reading only).

The calibration for the pressure transducer and temperature instruments is given in Swensen [Ref. 5].

The system vapor temperature was measured by both a Teflon coated and a metal sheathed type-T copper/constantan thermocouple located just upstream of the test tube. The condensate return and ambient surrounding temperatures were measured with Teflon coated type-T copper/constantan thermocouples. The temperature rise of the coolant in the tube being tested was measured by three separate methods:

1. A single Teflon coated type-T copper/constantan thermocouple.
2. A ten-junction Teflon coated type-T copper/constantan thermopile.
3. An HP 2804A quartz crystal thermometer.

The relative positions of each of these three temperature measuring methods are shown in Figure 4. At the outlet of the tube, the coolant temperature is always measured after a coolant mixing chamber to ensure a well averaged temperature measurement.

All the data from the system instrumentation were processed using an HP-3497A data acquisition system controlled
by an HP-9826A computer. The raw data were processed and stored on computer disks. The data could then be reprocessed using a modified Wilson plot technique to obtain an outside heat-transfer coefficient (see section IV.C for details).

C. TUBES TESTED

There were twelve tubes fabricated for this thesis. Some of the wire-wrapped smooth tubes were the same as used by Brower [Ref. 8], except they were altered to fit into the single tube apparatus used during this thesis. Listed in Table I are all the tubes that were tested and their associated dimensions. The tubes consisted of one smooth tube and seven wire-wrapped smooth tubes, all made of titanium. Three different wire diameters were used at various spacings on the tube, providing a range of wire pitch to wire diameter between 2 and 10. These are also listed in Table I. Commercially available titanium roped tubes (Wolverine KORODENSE LPD) were also tested, both with and without the three different wire diameters. The wires were placed in the corrugated grooves, giving the wires a fixed pitch. In addition, a smooth copper tube and two of the wire-wrapped copper tubes tested by Mitrou [Ref. 9] were tested (see Table I).
<table>
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<th>Tube Type</th>
<th>Wire Diameter (mm)</th>
<th>Wire Spacing (mm)</th>
<th>Wire Pitch (mm)</th>
<th>F/D Ratio</th>
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<th>Outside Diameter (mm)</th>
<th>Inside Diameter (mm)</th>
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IV. EXPERIMENTAL PROCEDURES AND DATA REDUCTION

A. EXPERIMENTAL PROCEDURES AND OBSERVATIONS

Titanium and copper both have different wetting characteristics with respect to water. However, to ensure filmwise condensation, both types of tubes have been successfully treated with a sodium hydroxide and ethyl alcohol solution. This treatment has been used by several researchers in the past at NPS. Each tube was prepared in the following manner:

1. Both the inside and outside surfaces of the tube are cleaned using a mild soap and soft bristle brush. The tube is then rinsed first with distilled water, then with acetone, and again with distilled water to ensure there are no impurities on the surface of the tube. The second rinse should wet the entire surface of the tube with no breaks in the film. **NOTE:** the active surface area of the tube should not be handled during this procedure.

2. The tube is then placed over a steam bath.

3. Equal amounts of a 50% by weight sodium hydroxide solution and ethyl alcohol are mixed and kept warm to ensure a watery consistency is maintained.

4. The solution is then applied to the entire surface of the tube with a small brush every 10 minutes for one hour. If the tube has not been previously treated, apply the solution every 5 minutes for 20 minutes. A black oxide layer will form on the copper tubes. A layer forms on the titanium tubes, but they are not discolored.

5. The tube is then removed from the steam bath and rinsed with distilled water to remove the excess alcohol/sodium hydroxide solution. The tube should be held over the steam bath again to ensure that the entire tube surface wets easily as the steam condenses on it. The tube
should then be installed into the test section immediately afterward. Care should be taken when installing the tube into the test apparatus so the active surface of the tube is not disturbed.

The oxide layer that forms on the tube causes very good wetting characteristics on the surface of the tube. The oxide layer is very thin so it is assumed that it is negligible to the overall thermal resistance of the tube.

When the tube has been installed, the system is started up in accordance with the procedures given in Appendix B. Tests on the tubes were performed with either a HEATEX insert or no insert at all. The system is heated up to the desired operating condition, at either vacuum or atmospheric pressure, as outlined in the start-up procedure. The system needs to be maintained at equilibrium for at least thirty minutes prior to taking any data measurements. This is to ensure that the entire apparatus is warmed up. Data were taken at coolant flow rates (in %) of 80, 70, 60, 50, 40, 30, and 20, and then in steps of 10% back to 80%. Therefore, each point is checked twice at different times in the run to ensure repeatability. Several sample sets of data were evaluated to ensure the temperature difference across the tube, the saturation temperature, and the overall heat transferred were in equilibrium for each particular flow rate before the final data point was recorded. One data set took anywhere from ten to twenty minutes before the system was in equilibrium so a data set could be recorded.
Swensen [Ref. 5] describes how difficult it is to initiate filmwise condensation on a copper tube under vacuum pressure. To establish good filmwise condensation for a vacuum run, the following should be done:

1. Ensure coolant flow to the tube is secured. Then allow the apparatus vapor temperature (channel 40) to reach 3600-3800 microvolts.

2. Raise the auxiliary condenser flow rate to 50-60%, to cool the vapor temperature to ~3200 microvolts.

3. Secure the flow to the auxiliary condenser, and allow the vapor temperature to rise to 3700 - 3800 microvolts. This forms a steam blanket around the tube.

4. Initiate cooling water flow to the single tube being tested at a flow rate of at least 80%.

5. Restore flow to the auxiliary condenser to control vapor temperature and pressure. Observe the single tube through the viewing window to ensure good filmwise condensation has been established.

6. If some dropwise condensation persists, the steps above can be repeated. If dropwise condensation still continues, the tube should be removed and retreated with the ethyl alcohol and sodium hydroxide solution.

The wettability of titanium and copper are different. It was much easier to obtain filmwise condensation on the titanium tubes than the copper tubes. Also, it appeared as if it was easier to initiate filmwise condensation on the enhanced tubes than the smooth tubes. Under vacuum conditions (pressures ≈12 kPa) at low cooling water flow rates, small patches of dropwise condensation could be seen on the bottom of the titanium tube at fairly regular intervals. These "dryout" patches appear to be the same as those described by
Swensen [Ref. 5] for the copper tube, and are believed to be caused by vortex shedding of the vapor around the tube. When the coolant flow rate was increased above 40%, there was enough condensate to spread out and cover the tube surface and the "dryout" patches did not occur.

B. DATA REDUCTION PROCEDURES

The overall thermal resistance is represented by the sum of the coolant side resistance \(R_i\), the wall resistance \(R_w\), the fouling resistance \(R_f\), and the vapor side resistance \(R_o\). Since only clean tubes are used, the fouling resistance is negligible, \(R_f = 0\). Therefore,

\[
R_{\text{total}} = R_i + R_w + R_o
\] (4.1)

The coolant and vapor side resistances are convective in nature, so they need to be related to the areas:

\[
R_i = \frac{1}{h_i A_i}
\] (4.2)

\[
R_o = \frac{1}{h_o A_o}
\] (4.3)

where:

- \(R_i\) = inside resistance to heat transfer (K/W)
- \(h_i\) = inside heat transfer coefficient (W/m²K)
- \(A_i\) = effective inside heat transfer area (m²)
- \(R_o\) = outside resistance to heat transfer (K/W)
- \(h_o\) = outside heat transfer coefficient (W/m²K)
\( A_o = \text{effective outside heat transfer area (m}^2\) \\

The effective area for the inside of the tube is represented by the entire length of the tube. The portions of the tube that are not exposed to steam act as fins, which will remove heat in the axial direction. The extended fin assumption and the associated fin efficiencies are used to account for the inlet and outlet portions of the tube. So, the effective inside area of the tube can be represented as:

\[
A_i = \pi D_i (L + L_1 \eta_1 + L_2 \eta_2)
\]  

(4.4)

where:

- \( D_i \) = inside diameter of the tube (m)
- \( L \) = length of tube exposed to steam, active working length (m)
- \( L_1 \) = length of the inlet portion of the tube (m)
- \( L_2 \) = length of the outlet portion of the tube (m)
- \( \eta_1 \) = fin efficiency of the inlet portion of the tube
- \( \eta_2 \) = fin efficiency of the outlet portion of the tube

The effective outside surface area is dependent on the length of the tube exposed to steam, the active condensation length. The effective outside area is represented as:

\[
A_o = \pi D_o L
\]  

(4.5)

The wall resistance assumes uniform radial conduction and is represented by the following equation:
\[ R_w = \frac{\ln \left( \frac{D_o}{D_i} \right)}{2\pi L k_m} \]  

where:

- \( R_w \) = tube wall resistance (K/W)
- \( D_o \) = outside diameter of the tube (m)
- \( D_i \) = inside diameter of the tube (m)
- \( k_m \) = thermal conductivity of the wall material (W/mK)

The overall thermal resistance can be related to the overall heat transfer coefficient \( (U_o) \) and the effective outside area \( (A_o) \) by:

\[ R_{\text{total}} = \frac{1}{U_o A_o} \]  

where:

- \( U_o \) = overall heat transfer coefficient (W/m²K)

Substituting equations (4.2), (4.3), and (4.7) into (4.1) gives:

\[ \frac{1}{U_o A_o} = \frac{1}{h_i A_i} + R_w + \frac{1}{h_o A_o} \]  

The total heat transfer rate to the single tube can be calculated from an energy balance by using the temperature difference of the cooling water across the tube and the mass flow rate of the coolant through the tube:
\[ Q = \dot{m}C_p(T_2 - T_1) \]  

(4.9)

The overall heat transfer coefficient can then be calculated from:

\[ Q = U_0A_0(LMTD) \]  

(4.10)

where:

\[ LMTD = \frac{(T_2 - T_1)}{\ln\left[\frac{T_{sat} - T_1}{T_{sat} - T_2}\right]} \]  

(4.11)

where:

- \( Q \) = total heat transfer rate (W)
- \( m \) = mass flow rate of the coolant (kg/s)
- \( C_p \) = Specific heat of coolant at constant pressure (J/kgK)
- \( LMTD \) = log mean temperature difference
- \( T_1 \) = inlet coolant temperature (K)
- \( T_2 \) = outlet coolant temperature (K)
- \( T_{sat} \) = vapor saturation temperature (K)

The inlet and outlet cooling water temperatures were measured with a quartz thermometer and the saturation temperature was measured using the vapor thermocouple (channel 40). In addition, a correction factor was used to account for the viscous heating of the coolant through the tube; these correction equations are shown in Appendix A.
Once the total heat transfer rate has been calculated, the overall heat transfer coefficient can be calculated by using equation (4.10). Now only two unknowns remain, the inside heat transfer coefficient, $h_i$, and the outside heat transfer coefficient, $h_o$. These are computed using the modified Wilson plot technique.

C. MODIFIED WILSON PLOT TECHNIQUE

The most accurate way to obtain inside and outside heat transfer coefficients is to measure the vapor temperature, mean wall temperature, and the coolant temperature directly. The coolant and vapor temperatures can be easily measured. However, to measure the tube wall temperature $a$, instrumented tube (with thermocouples embedded in the wall) must be used. With the instrumented tube, the inside and outside heat transfer coefficients can be calculated directly. Unfortunately, the manufacturing of instrumented tubes is costly and time consuming. Also, instrumented tubes would be impractical if a large number of tubes are to be tested.

An alternative to using an instrumented tube is to solve for both the outside and inside heat transfer coefficients simultaneously using the modified Wilson plot technique. A detailed outline of the technique is given by Marto [Ref. 27].

The modified Wilson plot technique relies on the fact that the overall heat transfer coefficient can be reliably measured from experimental data. Two forms of equations need to be
selected for the inside and outside heat transfer coefficients. In this thesis, the outside heat transfer coefficient is represented by the equation of Nusselt [Ref. 10] based on $\Delta T$:

$$h_o = \alpha \left[ \frac{k_f \rho_f g h_{fg}}{\mu_f D_f \Delta T_f} \right]^{1/4} = \alpha Z$$  \hspace{1cm} (4.12)

where:

- $\alpha$ = dimensionless Nusselt coefficient
- $k_f$ = thermal conductivity of the condensate film (W/mK)
- $\rho_f$ = density of the condensate film (kg/m$^3$)
- $\mu_f$ = dynamic viscosity of the condensate film (kg/ms)
- $h_{fg}$ = specific enthalpy of vaporization (J/kg)
- $\Delta T_f$ = temperature difference across the condensate film (K)
- $g$ = gravitational constant (9.81 m/s$^2$)

We also had the option of using Fujii's [Ref. 12] correlation, equation (2.4), for the outside heat transfer coefficient in the program used to evaluate the data. The inside heat transfer coefficient can be represented by one of several correlations. The general form for the inside heat transfer coefficient is:

$$h_i = C_i \Omega$$ \hspace{1cm} (4.13)

where $\Omega$ varies with the particular correlation used.

Using the Sieder-Tate correlation [Ref. 6]:

34
where \( x \), the exponent to the Reynolds number, can be varied in the program evaluating the data.

Using the Sleicher-Rouse correlation [Ref. 28]:

\[
\Omega = \frac{k_c}{D_i} \left( \frac{\nu_c}{\nu_w} \right)^{0.14} Re^x Pr^{1/3} \tag{4.14}
\]

\[
\Omega = \frac{k_c}{D_i} \left( 5 + 0.015 Re f^c Pr_w^d \right) \tag{4.15}
\]

where:

\[
c = 0.88 - \frac{0.24}{4 + Pr_w}
\]

\[
d = \frac{1}{3} + 0.5 e^{-0.6 Pr_w}
\]

Using the Petukhov-Popov correlation [Ref. 29]:

\[
\Omega = \frac{k_c}{D_i} \left[ \frac{\nu_c}{Re Pr} \frac{\nu}{8} \right] \left[ \frac{K_1 + K_2 \left( \frac{\nu}{8} \right)^{1/2}}{\nu} \right] \tag{4.16}
\]

where:
\[
e = [1.82 \log(Re) - 1.64]^2
\]

\[
K_1 = 1 + 3.4e
\]

\[
K_2 = 11.7 + 1.8Pr^{-\frac{1}{3}}
\]

Substituting equations (4.12) and (4.13) into equation (4.8) gives the following:

\[
\left[ \frac{1}{U_o} - R \nu A_o \right] Z = \frac{A_o Z}{C_i \Omega A_i} + \frac{1}{a}
\]

Letting:

\[
Y = \left[ \frac{1}{U_o} - R \nu A_o \right] Z \tag{4.17}
\]

and

\[
X = \frac{A_o Z}{A_i \Omega} \tag{4.19}
\]

a simplified linear equation results:

\[
Y = mX + b \tag{4.20}
\]

where

\[
m = \frac{1}{C_i} \tag{4.21}
\]

and
the parameters Ω and Z are temperature dependent, so an iterative procedure must be used to solve the equation. A least squares fit of equation (4.17) is used to determine $C_i$ and $\alpha$. The inside heat transfer coefficient can then be determined using equation (4.13). Since $h_i$ and $U_o$ are both known, the outside heat transfer coefficient can be solved using equation (4.8).

It should be noted that the accuracy of the modified Wilson plot technique is dependent on the number of data points evaluated, as well as the range of flow rates used. The current computer system does not allow different run files to be combined to evaluate a tube. Each file has to be processed separately. This leads to scatter between the data runs for the values of $\alpha$ and $C_i$ between runs for the same types of tube.

D. ENHANCEMENT RATIO

From Nusselt theory, it can be shown that:

$$q = a \Delta T_i^p$$  \hspace{1cm} (4.23)

where:

$$a = a \left[ \frac{k_f \rho_f^2 g h_{fg}}{\mu_f D_o} \right]^{1/4}$$

$q = \text{the heat flux based on the outside area (W/m}^2\text{)}$
\( \Delta T_f = \) the temperature drop across the condensate film (K)

We also know that the heat flux can be represented by:

\[
q = h_o \Delta T_f
\] (4.24)

So, the outside heat transfer coefficient can be represented by:

\[
h_o = a \Delta T_f^{n-1}
\] (4.25)

From Nusselt theory, \( n = 0.75 \), so the enhancement ratio, based on a constant temperature drop across the condensate film, can be expressed as:

\[
E_T = \frac{h_{oe}}{h_{os}} = \frac{a_e}{a_s} = \frac{a_s}{a_s}
\] (4.26)

where the subscripts of e and s refer to enhanced and smooth tubes respectively.
V. RESULTS AND DISCUSSION

A. INSIDE HEAT TRANSFER CORRELATION

Previous to this thesis, Swensen [Ref. 5] gave a discussion of how the inside heat transfer coefficient has been found at NPS. He used an instrumented tube to collect data at atmospheric pressure and empirically derived two variants of the Sieder-Tate correlation to express the inside heat transfer coefficient for a medium size copper tube ($D_i = 12.7$ mm). These correlations were represented as:

Using a HEATEX insert:

\[
Nu = 0.22 \, Re^{0.69} \, Pr^{1/3}\left(\frac{\mu_c}{\mu_w}\right)^{0.14} \quad (5.1)
\]

Using No insert:

\[
Nu = 0.013 \, Re^{0.89} \, Pr^{1/3}\left(\frac{\mu_c}{\mu_w}\right)^{0.14} \quad (5.2)
\]

Swensen developed the new correlations because it was thought that the inlet arrangement (a 90 degree bend just prior to the inlet of the tube) was affecting the correlation used to solve for the outside heat transfer coefficient. Almost all of Swensen's data were taken at atmospheric pressure using a HEATEX insert. When this thesis effort started, equations (5.1) and (5.2) were used to evaluate the inside heat transfer...
These two new correlations should provide comparable results for the outside heat transfer coefficient to those obtained by Swensen [Ref. 5]. The tubes studied in this thesis have a different inside diameter (13.86 mm) and are made from titanium and not copper.

Figures 6 and 7 show the values of the outside heat transfer coefficient for both the titanium and copper tubes at atmospheric and vacuum pressures using equations (5.1) and (5.2) in the data reduction scheme. At atmospheric pressure, Figure 6 shows Swensen's equations work well for the copper tubes; however, the results for the titanium tubes do not agree with Swensen's data well at all. In fact, a reduction of the outside heat transfer coefficient is shown for the HEATEX insert data as the temperature difference across the condensate film decreases, which is contrary to what was expected. At vacuum pressure, Swensen's equations show that the outside heat transfer coefficient curve is flatter than what is given by the instrumented copper tube data; also, the data shows much more scatter. There are several reasons this may have occurred. The first is that the leading coefficients for both correlations are fixed, so a change in the geometry (diameter) may have affected the results using these correlations. Consequently, the leading coefficient was left to 'float' to try and account for these differences. When the data were then reprocessed, the coefficient dropped by 30% for the HEATEX insert data. This drop in the leading coefficient
Figure 6. Comparison of Results for the Outside Heat Transfer Coefficient at Atmospheric Pressure Using the Swensen Correlations
Figure 7. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure using the Swensen Correlations
was much larger than expected, bringing into question the
validity of Swensen's correlations for the titanium tube data.
The other significant difference between the titanium tube
data and the copper tube data is the range of AT, which is
much lower for the titanium tube. The copper tube with the
HEATEX insert had higher AT, values for similar coolant flow
rates. Swensen produced his correlations for the range of AT,
covered by his data. They do not seem to perform well outside
this range as seen in Figures 6 and 7. Therefore, it appears
as if the data reduction scheme recommended by Swensen should
not be used for the titanium tubes.

In an effort to correct the problem, other inside heat
transfer correlations were considered. The Argonne National
Laboratory (ANL) [Ref. 31] conducted a thorough assessment of
several different inside heat transfer correlations for low
temperature turbulent water flows to determine which
correlation was the most accurate. The conclusions of the ANL
study were that the Petukhov-Popov [Ref. 30] and Sleicher-
Rouse [Ref. 29] correlations were the most accurate (± 5%) in
predicting the inside heat transfer coefficient, over a range
of Pr=6.0 to 11.6. Both the Petukhov-Popov and Sleicher-Rouse
correlations are given in Chapter IV.C and are based on having
a long straight inlet section prior to the test section.
Swensen identified these correlations as the most accurate but
he felt that he could not use them because of the sharp bend
in the inlet flow arrangement for the test apparatus as previously mentioned.

Both Petukhov-Popov and Sleicher-Rouse correlations were then used except that a floating leading coefficient was inserted to account for the different inlet to the test section, as shown in equations (4.13), (4.15), and (4.16). Figure 8 presents the same data shown in Figure 6 for atmospheric pressure, except they have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. It can be seen that the agreement between the titanium and copper tubes is much better in this case. Furthermore, the agreement with the instrumented tube data is much better, consistently within ± 7%. Uncertainty bands are shown on this figure, and the scatter is well within the predicted uncertainty. In the same way, Figure 9 shows the same data as in Figure 7 at vacuum pressure, except the data have been reprocessed using the Petukhov-Popov correlation for the inside heat transfer coefficient. Again the results show that the titanium and copper tube data compare much better with the instrumented tube data. Again the scatter is within the uncertainty of the data. Figure 10 compares the use of the Petukhov-Popov and Sleicher-Rouse correlations and it shows similar results are obtained when the Sleicher-Rouse correlation is used in evaluating the inside heat transfer coefficient. The ANL [Ref. 31] paper said:
$h_o$ vs. $T_{cf}$

Atmospheric Pressure using the Petukhov-Popov Correlation

Figure 8: Comparison of the Outside Heat Transfer Coefficients at Atmospheric Pressure using the Petukhov-Popov Correlation

$\theta_o$ (kW/m² K) vs. $T_{cf}$ (C)

- $\times$ Swenson (Cu)
- $\nabla$ O'Keefe (Tl)
- $\triangle$ O'Keefe (Cu)
- $\bullet$ Instr.
Figure 9. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure Using the Petukhov-Popov Correlation
Figure 10. Comparison of the Inside Heat Transfer Coefficients using the Petukhov-Popov and Sleicher-Rouse Correlations
It is tempting to follow the "old technology" and utilize \( n = 0.80 \) as the Reynolds number exponent, in accordance with the popular Dittus-Boelter and Sieder-Tate correlations. However, more recent correlations, such as Petukhov-Popov and Sleicher-Rouse, have been shown to exhibit much better agreement with the most carefully obtained experimental data ... In the Pr and Re ranges of interest ... these correlations yield "effective" Reynolds number exponents in the neighborhood of \( n = 0.85 \). Thus it was decided to employ \( n = 0.85 \) in the Wilson plot procedure to generate nominal values of \( h_i \).

With this information, the Sieder-Tate equation was then evaluated using an exponent of 0.85 for the Reynolds number and again floating the leading coefficient. Figure 11 shows the results for the outside heat transfer coefficient when using the Sieder-Tate correlation (with \( Re^{0.85} \)) and the Petukhov-Popov correlation for determining the inside heat transfer coefficient. The results show that there is very little difference between using these two quite different correlations for the inside heat transfer coefficient, giving confidence in the data reduction technique for the titanium tubes.

B. ANALYSIS OF THE SMOOTH TUBE RESULTS

A series of runs were made using a smooth titanium tube to get some baseline data for comparison with the enhanced wire-wrapped titanium tubes. A smooth medium sized copper tube was also tested to compare with the results of previous researchers at NPS. A HEATEX insert was used to boost the values of the inside heat transfer coefficient and thereby improve the measured accuracy of the outside heat transfer.
Figure 11. Comparison of the Outside Heat Transfer Coefficients for Atmospheric Pressure Using the Petukhov-Popov and Sieder Tate (Re^0.5) Correlations

$h_o$ vs. $T_{cf}$

Atmospheric Pressure Comparison of Petukhov-Popov and Sieder Tate (Re^0.5)
1. Overall Heat Transfer Coefficient

Figures 12 through 15 show the overall heat transfer coefficient values for each atmospheric and vacuum pressure run done on the smooth titanium and copper tube. The shape of the curve is related to the coolant flow rate through the tube; as the flow rate increases the overall heat transfer coefficient increases due to improved coolant mixing. It is obvious that in every case, the overall heat transfer coefficient is higher for the copper tube (≈18% for the HEATEX insert data and ≈14% for the no insert data at a coolant flow rate of 2.5 m/s). Most of this increase in the overall heat transfer coefficient is due to the much smaller wall resistance (approximately a factor of 6) associated with the copper tube. Figures 12 through 15 also show excellent repeatability of the data. The effect of using a Heatex insert can be seen in Figure 16, which shows values of $U_o$ averaged for all the data taken. The HEATEX insert gives a significant enhancement in the overall heat transfer coefficient of around 20% for a coolant flow rate of 2.25 m/s. The vapor shear forces also effect the overall heat transfer coefficient ($U_o$). It can be seen that $U_o$ is higher for the vacuum runs ($U_o \approx 2$ m/s) than the atmospheric runs ($U_o \approx 1$ m/s) because of the higher vapor shear effect. However, this vapor shear effect is small ($\leq 5\%$) when compared to the effect that
**$U_o$ vs. $V_w$**

Smooth Tube at Atmospheric Pressure with a HEATEX Insert

---

**Figure 12.** $U_o$ vs. $V_w$ for a Smooth Tube at Atmospheric Pressure with a HEATEX Insert

**Graph:**
- $U_o$ (kW/m$^2$ K) on the y-axis ranging from 2 to 8
- $V_w$ (m/s) on the x-axis ranging from 0.5 to 5

Legend:
- FONMAHT1, FONMAHT2, FONMAHT3, FONMAHT4
- FONMAHT5, FONMAHT6, FONMAHT7, FONMAHCl
Figure 13. $U_0$ vs. $V_w$ for a Smooth at Atmospheric Pressure with No Insert
Figure 14. $U_0$ vs. $V_w$ for a Smooth Tube at Vacuum Pressure with a HEATEX Insert
Figure 15. $U_o$ vs. $V_w$ for a Smooth Tube at Vacuum Pressure with No Insert
Figure 16. Effect of Vapor Velocity on Smooth Titanium Tubes Average $U_o$ Values
the insert has at the same coolant velocity.

2. Outside Heat Transfer Coefficient

The outside heat transfer coefficient is determined using the Nusselt [Ref. 10] equation based on ΔT_r, equation (4.12). Figures 17 and 18 show the outside heat transfer coefficient versus the temperature difference across the condensate film for all the smooth titanium tube data. Several previous researcher’s smooth copper tube data have also been reprocessed using the Petukhov-Popov correlation and plotted in the figures. For atmospheric pressure, there is good agreement for all the copper tube data between all the researchers. The titanium tube data, however, tends to fall below the copper tube data, agreeing more closely with Nusselt theory. The reason for the two Nusselt theory lines in each figure is due to the different diameters for the copper and titanium tubes. The vacuum data (Figure 17) shows the same lower values for the titanium tube. The reason for the large scatter is probably due to the much smaller coolant temperature rise in the case of the titanium tube, making the data less accurate.

In order to compare the outside heat transfer coefficient of the smooth tube to each of the enhanced tubes, the Nusselt coefficient, α, needs to be determined under similar conditions for each tube. A summary of the results for the data reduction analysis for the leading coefficients (C_i)
Figure 17. $h_o$ vs. $\Delta T_e$ for Smooth Tubes at Atmospheric Pressure
Figure 18. $h_o$ vs. $\Delta T_e$ for a Smooth Tube at Vacuum Pressure
### Table II. SMOOTH TITANIUM TUBE WITH A HEATEX INSERT (PRESENT WORK)

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Petukhov-Popov</th>
<th>Sieder-Tate (Re&lt;sup&gt;-85&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_i$</td>
<td>$\alpha$</td>
</tr>
<tr>
<td>FONMAHT1</td>
<td>2.372</td>
<td>0.780</td>
</tr>
<tr>
<td>FONMAHT2</td>
<td>2.383</td>
<td>0.774</td>
</tr>
<tr>
<td>FONMAHT3</td>
<td>2.392</td>
<td>0.755</td>
</tr>
<tr>
<td>FONMAHT4</td>
<td>2.410</td>
<td>0.748</td>
</tr>
<tr>
<td>FONMAHT5</td>
<td>2.201</td>
<td>0.770</td>
</tr>
<tr>
<td>FONMAHT6</td>
<td>2.541</td>
<td>0.776</td>
</tr>
<tr>
<td>FONMAHT7</td>
<td>2.511</td>
<td>0.793</td>
</tr>
<tr>
<td><strong>Atm. Avg.</strong></td>
<td><strong>2.401</strong></td>
<td><strong>0.776</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Run</th>
<th>Petukhov-Popov</th>
<th>Sieder-Tate (Re&lt;sup&gt;-85&lt;/sup&gt;)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_i$</td>
<td>$\alpha$</td>
</tr>
<tr>
<td><strong>Vac. Avg.</strong></td>
<td><strong>2.416</strong></td>
<td><strong>0.767</strong></td>
</tr>
<tr>
<td><strong>Total Avgs.</strong></td>
<td><strong>2.406</strong></td>
<td><strong>0.770</strong></td>
</tr>
</tbody>
</table>

Using the Petukhov-Popov and Sieder-Tate (Re<sup>-85</sup>) correlations, and the Nusselt coefficients ($\alpha$) for the smooth titanium and copper tubes are presented in Tables II through VI. The printouts for all the data runs are given in Appendix D. The researcher initials are as follows: (G)=Guttendorf [Ref. 32], (M)=Mitrou [Ref. 9], (O)=O'Keefe, (S)=Swensen [Ref. 5], and (V)=Van Petten [Ref. 4].

When using the modified Wilson plot technique to reprocess the data, the leading coefficient for the inside heat transfer...
Table III. SMOOTH TITANIUM TUBE WITH NO INSERT (PRESENT WORK)

<table>
<thead>
<tr>
<th></th>
<th>Petukhov-Popov</th>
<th>Sieder-Tate (Re.(^{0.5}))</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atmospheric Pressure No Insert</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Data Run</td>
<td>(C_1)</td>
<td>(\alpha)</td>
</tr>
<tr>
<td>FONMANT1</td>
<td>1.211</td>
<td>0.750</td>
</tr>
<tr>
<td>FONMANT2</td>
<td>1.185</td>
<td>0.760</td>
</tr>
<tr>
<td>FONMANT3</td>
<td>1.169</td>
<td>0.765</td>
</tr>
<tr>
<td>FONMANT4</td>
<td>1.181</td>
<td>0.765</td>
</tr>
<tr>
<td>FONMANT5</td>
<td>1.237</td>
<td>0.786</td>
</tr>
<tr>
<td><strong>Avgs.</strong></td>
<td><strong>1.197</strong></td>
<td><strong>0.765</strong></td>
</tr>
<tr>
<td><strong>Vacuum Pressure No Insert</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FONMVNT2</td>
<td>1.092</td>
<td>0.822</td>
</tr>
<tr>
<td>FONMVNT3</td>
<td>1.078</td>
<td>0.788</td>
</tr>
<tr>
<td>FONMVNT4</td>
<td>1.075</td>
<td>0.846</td>
</tr>
<tr>
<td>FONMVNT5</td>
<td>1.113</td>
<td>0.827</td>
</tr>
<tr>
<td><strong>NI Avgs.</strong></td>
<td><strong>1.089</strong></td>
<td><strong>0.821</strong></td>
</tr>
<tr>
<td><strong>Total Avgs.</strong></td>
<td><strong>1.149</strong></td>
<td><strong>0.790</strong></td>
</tr>
</tbody>
</table>

correlation can either be set with a user supplied value or left to "float", allowing the program to solve for the 'best' value of the coefficient itself as described in Chapter 4. Theoretically, if the leading coefficient is allowed to float, the coefficient should be about the same for all tubes with the same inner diameter. The tables show that the HEATEX inert enhances the inside heat transfer coefficient by a factor of around 2.5. Swensen [Ref. 5] and Micheal et al. [Ref. 33], show that as the vapor velocity across the tube
increases, the value of $\alpha$ increases because of the thinning of the film caused by the vapor shear. In Tables II through VI there is a general trend that the value of $\alpha$ increases between atmospheric ($U_\infty \approx 1.0 \text{ m/s}$) and vacuum ($U_\infty \approx 2.0 \text{ m/s}$) runs.

**Table IV. SMOOTH COPPER TUBE WITH A HEATEX INSERT**

<table>
<thead>
<tr>
<th>Data Run/Researcher</th>
<th>Petukhov-Popov $C_1$</th>
<th>Sieder-Tate (Re$^{1/2}$) $C_1$</th>
<th>Petukhov-Popov $\alpha$</th>
<th>Sieder-Tate (Re$^{1/2}$) $\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMAHC1 (O)</td>
<td>2.809</td>
<td>0.044</td>
<td>0.832</td>
<td>0.835</td>
</tr>
<tr>
<td>FNMAVSH4 (S)</td>
<td>3.187</td>
<td>0.051</td>
<td>0.819</td>
<td>0.823</td>
</tr>
<tr>
<td>FNMAVSH8 (S)</td>
<td>3.083</td>
<td>0.049</td>
<td>0.824</td>
<td>0.830</td>
</tr>
<tr>
<td>FSOMASH3 (S)</td>
<td>3.031</td>
<td>0.048</td>
<td>0.818</td>
<td>0.826</td>
</tr>
<tr>
<td><strong>Atm. Avgs.</strong></td>
<td>3.028</td>
<td>0.048</td>
<td>0.823</td>
<td>0.828</td>
</tr>
</tbody>
</table>

**Vacuum Pressure HEATEX Insert**

<table>
<thead>
<tr>
<th>Data Run/Researcher</th>
<th>Petukhov-Popov $C_1$</th>
<th>Sieder-Tate (Re$^{1/2}$) $C_1$</th>
<th>Petukhov-Popov $\alpha$</th>
<th>Sieder-Tate (Re$^{1/2}$) $\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVHC1 (O)</td>
<td>2.482</td>
<td>0.042</td>
<td>0.838</td>
<td>0.838</td>
</tr>
<tr>
<td><strong>Total Avgs.</strong></td>
<td>2.918</td>
<td>0.047</td>
<td>0.826</td>
<td>0.830</td>
</tr>
</tbody>
</table>

When the titanium tube is compared to the copper tube, the value of $\alpha$ for the titanium tube is significantly less than the $\alpha$ for the copper tube at the same vapor velocity. The value of $\alpha$ could be affected (between titanium and copper) by the difference in temperature profiles at the surface of the tube caused by the different material thermal conductivities. The copper tube will exhibit a much more uniform temperature profile around the tube than the titanium tube. This will affect the properties of the condensate film covering the
tube, which in turn affect the values of $\alpha$. Another reason could be the fact that it was much easier to get filmwise condensation on the titanium than on the copper tube, presumably because of the different surface wettablity characteristics of titanium and copper with water. This could lead to differences in the condensate film and even some dropwise condensation in the case of the copper tube.
Table VI. SMOOTH COPPER TUBE WITH NO INSERT

<table>
<thead>
<tr>
<th>Data Run/Researcher</th>
<th>Petukhov-Popov</th>
<th>Sieder-Tate (Re^45)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( C_1 )</td>
<td>( \alpha )</td>
</tr>
<tr>
<td>FONMANC1 (O)</td>
<td>1.265</td>
<td>0.816</td>
</tr>
<tr>
<td>FSONMASN1 (S)</td>
<td>1.355</td>
<td>0.833</td>
</tr>
<tr>
<td>S001S0A2 (G)</td>
<td>1.347</td>
<td>0.858</td>
</tr>
<tr>
<td><strong>Atm. Avgs.</strong></td>
<td><strong>1.322</strong></td>
<td><strong>0.836</strong></td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVNC1 (O)</td>
<td>1.085</td>
<td>0.866</td>
<td>0.018</td>
<td>0.867</td>
</tr>
<tr>
<td>S001S0V2 (G)</td>
<td>1.056</td>
<td>0.904</td>
<td>0.017</td>
<td>0.909</td>
</tr>
<tr>
<td>S001S0V3 (G)</td>
<td>1.147</td>
<td>0.872</td>
<td>0.019</td>
<td>0.876</td>
</tr>
<tr>
<td>S50V177 (M)</td>
<td>0.970</td>
<td>0.774</td>
<td>0.016</td>
<td>0.858</td>
</tr>
<tr>
<td><strong>Vac. Avgs.</strong></td>
<td><strong>1.064</strong></td>
<td><strong>0.854</strong></td>
<td><strong>0.018</strong></td>
<td><strong>0.857</strong></td>
</tr>
<tr>
<td><strong>Total Avgs.</strong></td>
<td><strong>1.175</strong></td>
<td><strong>0.846</strong></td>
<td><strong>0.019</strong></td>
<td><strong>0.841</strong></td>
</tr>
</tbody>
</table>

C. ANALYSIS OF THE WIRE-WRAPPED SMOOTH TUBES

The seven wire-wrapped titanium smooth tubes fabricated for this thesis and two of the wire-wrapped copper tubes used by Mitrou [Ref. 9] were tested under vacuum and atmospheric conditions to find the enhancement compared to a smooth tube for a constant temperature drop across the condensate film. Previous research done in this area has tried to find the optimum relationship between this enhancement and the wire pitch, wire diameter, and the fraction of tube covered by wire.

The overall heat transfer coefficients are similar to the smooth tube curves except that any enhancement due to the wire...
can be seen directly on this curve. The same effects caused by the insert and vapor shear (as mentioned previously) also apply to the wire-wrapped tubes. Figure 19 shows the overall heat transfer coefficient for tubes 4-7 at atmospheric pressure with a HEATEX insert. All other Uo data for the rest of the runs are listed in Appendix D.

Figure 20 shows how the outside heat transfer coefficients for tubes 6 and 7 compare with the smooth titanium tube at atmospheric pressure. Tubes 6 and 7 were the only wire-wrapped titanium tubes to show significant enhancement. Both of these tubes were wrapped with a 0.5 mm diameter wire with pitches of 4 mm (P/Dw = 7.92) and 2 mm (P/Dw = 4.02) respectively. Tube 6 showed enhancements between 23% and 30% for vacuum and atmospheric pressure respectively. Figures 21 and 22 show the outside heat transfer coefficient data for tubes 1 through 5. Tube 3 was the only tube to show a degradation in performance as compared to the smooth titanium tube. It had a 1.6 mm wire with a pitch of 3.40 mm (P/Dw = 2.13); the poor performance of this tube is attributed to the effects of condensate retention between the wires on the tube, which were clearly seen. The performance of tubes 1 and 2 were similar to the plain smooth tube. Tubes 4 and 5 showed an enhancement of about 10% over the smooth titanium tube. Tables VII through XI show the results from the data reduction scheme for C and a for each data run. The leading coefficients in front of the inside heat transfer correlation
Figure 19. $U_0$ vs $V_w$ for Wire-Wrapped Tubes at Atmospheric Pressure with a Heatex Insert
Table VII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH A HEATEX INSERT

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>$C_1$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMAH1T1 (1)</td>
<td>2.023</td>
<td>0.798</td>
<td>1.035</td>
</tr>
<tr>
<td>FONMAH2T3 (2)</td>
<td>2.448</td>
<td>0.806</td>
<td>1.046</td>
</tr>
<tr>
<td>FONMAH3T1 (3)</td>
<td>2.138</td>
<td>0.724</td>
<td>0.902</td>
</tr>
<tr>
<td>FONMAH4T1 (4)</td>
<td>2.379</td>
<td>0.853</td>
<td>1.106</td>
</tr>
<tr>
<td>FONMAH5T1 (5)</td>
<td>2.251</td>
<td>0.869</td>
<td>1.127</td>
</tr>
<tr>
<td>FONMAH6T2 (6)</td>
<td>2.389</td>
<td>0.993</td>
<td>1.289</td>
</tr>
<tr>
<td>FONMAH6T3 (6)</td>
<td>2.362</td>
<td>1.005</td>
<td>1.304</td>
</tr>
<tr>
<td>FONMAH7T1 (7)</td>
<td>2.237</td>
<td>0.925</td>
<td>1.200</td>
</tr>
<tr>
<td><strong>Atm. Avg.</strong></td>
<td>2.301</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>$C_1$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVH1T1 (1)</td>
<td>1.892</td>
<td>0.802</td>
<td>1.045</td>
</tr>
<tr>
<td>FONMVH2T1 (2)</td>
<td>2.005</td>
<td>0.797</td>
<td>1.038</td>
</tr>
<tr>
<td>FONMVH2T2 (2)</td>
<td>1.948</td>
<td>0.787</td>
<td>1.026</td>
</tr>
<tr>
<td>FONMVH2T3 (2)</td>
<td>2.240</td>
<td>0.766</td>
<td>0.999</td>
</tr>
<tr>
<td>FONMVH3T2 (3)</td>
<td>1.866</td>
<td>0.618</td>
<td>0.714</td>
</tr>
<tr>
<td>FONMVH4T1 (4)</td>
<td>2.081</td>
<td>0.821</td>
<td>1.071</td>
</tr>
<tr>
<td>FONMVH5T1 (5)</td>
<td>2.014</td>
<td>0.842</td>
<td>1.097</td>
</tr>
<tr>
<td>FONMVH6T1 (6)</td>
<td>2.160</td>
<td>0.950</td>
<td>1.238</td>
</tr>
<tr>
<td>FONMVH6T2 (6)</td>
<td>2.214</td>
<td>0.946</td>
<td>1.233</td>
</tr>
<tr>
<td>FONMVH7T2 (7)</td>
<td>1.956</td>
<td>0.855</td>
<td>1.115</td>
</tr>
<tr>
<td><strong>Vac. Avg.</strong></td>
<td>1.967</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Avg.</strong></td>
<td>2.115</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

are consistent with the smooth tube data, as expected.

The copper tubes used by Mitrou [Ref. 9], tubes 68 and 71, were tested to check the repeatability of Mitrou's data. As
Table VIII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH NO INSERT

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>$C_i$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMAN1T1 (1)</td>
<td>1.131</td>
<td>0.783</td>
<td>1.022</td>
</tr>
<tr>
<td>FONMAN2T1 (2)</td>
<td>1.095</td>
<td>0.801</td>
<td>1.047</td>
</tr>
<tr>
<td>FONMAN3T1 (3)</td>
<td>1.034</td>
<td>0.698</td>
<td>0.888</td>
</tr>
<tr>
<td>FONMAN4T1 (4)</td>
<td>1.377</td>
<td>0.791</td>
<td>1.034</td>
</tr>
<tr>
<td>FONMAN5T1 (5)</td>
<td>1.099</td>
<td>0.837</td>
<td>1.093</td>
</tr>
<tr>
<td>FONMAN6T1 (6)</td>
<td>1.120</td>
<td>1.019</td>
<td>1.331</td>
</tr>
<tr>
<td>FONMAN7T1 (7)</td>
<td>1.191</td>
<td>0.866</td>
<td>1.131</td>
</tr>
<tr>
<td><strong>Atm. Avg.</strong></td>
<td>1.150</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>$C_i$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVN1T1 (1)</td>
<td>1.024</td>
<td>0.838</td>
<td>1.021</td>
</tr>
<tr>
<td>FONMVN2T1 (2)</td>
<td>0.998</td>
<td>0.818</td>
<td>0.997</td>
</tr>
<tr>
<td>FONMVN3T1 (3)</td>
<td>0.911</td>
<td>0.636</td>
<td>0.702</td>
</tr>
<tr>
<td>FONMAN4T1 (4)</td>
<td>1.139</td>
<td>0.825</td>
<td>1.005</td>
</tr>
<tr>
<td>FONMAN5T1 (5)</td>
<td>0.978</td>
<td>0.843</td>
<td>1.027</td>
</tr>
<tr>
<td>FONMAN6T1 (6)</td>
<td>1.043</td>
<td>1.013</td>
<td>1.235</td>
</tr>
<tr>
<td>FONMVN7T1 (7)</td>
<td>0.978</td>
<td>0.870</td>
<td>1.060</td>
</tr>
<tr>
<td><strong>Vac. Avg.</strong></td>
<td>1.010</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Avg.</strong></td>
<td>1.080</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

discussed earlier, it was difficult to get good filmwise condensation over the entire tube. The enhancements found were higher than those given by Mitrou’s data (reprocessed using the Petukhov-Popov correlation) for tubes 68 and 71; for tube 68, differences of 10% and 17% and for tube 71, differences of 45% and 6% for atmospheric and vacuum pressures.
Table IX. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A HEATEX INSERT

<table>
<thead>
<tr>
<th>Data Run</th>
<th>$C_i$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMAH68C1</td>
<td>2.807</td>
<td>1.316</td>
<td>1.719</td>
</tr>
<tr>
<td>FONMAH71C1</td>
<td>3.069</td>
<td>1.722</td>
<td>2.192</td>
</tr>
<tr>
<td><strong>Atm. Avg.</strong></td>
<td><strong>2.938</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Run</th>
<th>$C_i$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVH68C1</td>
<td>2.549</td>
<td>1.289</td>
<td>1.570</td>
</tr>
<tr>
<td>FONMVH71C2</td>
<td>2.765</td>
<td>1.414</td>
<td>1.560</td>
</tr>
<tr>
<td><strong>Vac. Avg.</strong></td>
<td><strong>2.657</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Avg.</strong></td>
<td><strong>2.797</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

respectively. This increase in enhancement could have been due to small patches of dropwise condensation on the surface of the tubes, although it was difficult to see during the experiments due to condensate on the window. Figure 23 shows the comparison of tubes 6 and 71 to a smooth titanium tube. Tubes 6 and 71 have similar pitches and the same wire diameter and should, in theory, give similar values for the outside heat transfer coefficient. However, the enhancement given by the wire-wrapped copper tube (tube 71) is significantly higher ($\approx 35\%$) than the enhancement given by the wire-wrapped titanium tube (tube 6). This trend tends to reiterate the idea that tube surface wettablity characteristics or tube thermal conductivity may affect the outside heat transfer coefficient.
Table X. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A WIRE WRAP INSERT

<table>
<thead>
<tr>
<th>Data Run/Researcher</th>
<th>$C_i$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>S68A311 (M)</td>
<td>2.686</td>
<td>1.360</td>
<td>1.616</td>
</tr>
<tr>
<td>S71A305 (M)</td>
<td>2.685</td>
<td>1.489</td>
<td>1.769</td>
</tr>
<tr>
<td>S71A314 (M)</td>
<td>2.692</td>
<td>1.473</td>
<td>1.749</td>
</tr>
<tr>
<td>Atm. Avg.</td>
<td>2.688</td>
<td></td>
<td></td>
</tr>
<tr>
<td>S68V283 (M)</td>
<td>2.452</td>
<td>1.182</td>
<td>1.401</td>
</tr>
<tr>
<td>S68V293 (M)</td>
<td>2.485</td>
<td>1.166</td>
<td>1.382</td>
</tr>
<tr>
<td>S71V296 (M)</td>
<td>2.503</td>
<td>1.267</td>
<td>1.501</td>
</tr>
<tr>
<td>Vac. Avg.</td>
<td>2.480</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Avg.</td>
<td>2.584</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In order to see the relationship between the wire pitch, wire diameter and the enhancement, the values of enhancement versus the wire pitch to wire diameter ratio are plotted in Figure 24. Also shown are the newly reprocessed data (using the Petukhov-Popov correlation) from Mitrou [Ref. 9], and the data presented by Sethumadhavan and Rao [Ref. 15]. Even though the experiments were conducted very carefully, the titanium tube data tends to show the most scatter. The data of Sethumadhavan and Rao [Ref. 15] and Mitrou [Ref. 9] demonstrate a maximum enhancement at a $P/D_\alpha$ of about 5. The present data do not show such a clear maximum and tube 6 ($P/D_\alpha = 7.96$) does not appear to be in line with the data of Sethumadhavan and Rao or Mitrou. Extra experiments were done
Figure 20: Comparison of the Outside Heat Transfer Coefficients of Tubes 6 and 7 with a Smooth Titanium Tube

$h_o$ vs. $T_{cf}$
Atmospheric Pressure using the Petukhov-Popov Correlation

$h_o (\text{kW/m}^2 \text{K})$

$T_{cf} (\text{C})$
Figure 21. Comparison of the Outside Heat Transfer Coefficients of Tubes 1, 2, and 3 to a Smooth Titanium Tube
Figure 22. Comparison of the Outside Heat Transfer Coefficients for tubes 4 and 5 to a Smooth Titanium Tube
**Figure 23.** Comparison of the outside Heat Transfer Coefficients between the Titanium and Copper Tubes

**h_o vs. T_{cf}**

Atmospheric Pressure using the Petukhov-Popov Correlation

![Graph showing h_o vs. T_{cf}](image)
Figure 24. Comparison of the Enhancement vs. $P/D_*$ Ratio of the Data from Mitrou, O'Keefe, and Sethumadhavan & Rao
on tube 6 to check the repeatability with essentially the same results. It would appear that P/Dₜ is not such a good correlating parameter.

Instead of looking at the P/Dₜ ratio, the enhancement can also be compared to the percentage of the tube surface that is covered by the wire, F. In the research done by Sethumadhavan and Rao [Ref. 15], the optimal coverage of a tube was found to be 21%. The fractional wire coverage values were determined for the present titanium and copper wire-wrapped tubes. Figure 25 shows the enhancement versus the fraction of the tube covered by wire. The value of 21% for the optimal value of F does not seem to hold for the data in this thesis or for the data of Mitrou. However, this does seem to be a better correlating parameter than P/Dₜ, and the maximum value of the fractional tube coverage seems to lie somewhere between 10% and 30%. The optimal value of F for the copper tube used by Mitrou and the titanium tube appear to be different and there is a definite increase in F as the tube material thermal conductivity increases. Unfortunately, the material of the tube used by Sethumadhavan and Rao [Ref. 15] is not given, although the data would suggest some intermediate conductivity material such as aluminum. Indeed, in another paper by Mehta and Rao [Ref. 22] aluminum tubes were used.
Figure 25. Comparison of the Enhancement vs. F for the data of Mitrou, O’Keefe, and Sethumadhavan & Rao
D. ANALYSIS OF THE ROPED AND WIRE-WRAPPED ROPED TITANIUM TUBES

Four different roped tubes were tested. One tube was a plain LPD KORODENSE titanium tube that was used to get baseline data for comparing to the plain smooth titanium tube and to the wire-wrapped LPD KORODENSE titanium tubes. The values of the overall heat transfer coefficient are much higher (≈20%) for the LPD KORODENSE tubes when compared to the plain smooth titanium tube. The reason for the increase in the overall heat transfer coefficient is mainly because of the corrugation of the LPD tube on the inside which increases the turbulence of the coolant flow, thereby reducing the inside thermal resistance.

Tables 12 and 13 give the results of the data reduction procedure of all the roped tubes in comparison with the smooth titanium tube. The plain LPD tube consistently gave enhancements of about 20% in the outside heat transfer coefficient, as seen in Figure 26. The wire-wrap was put on the roped tube to try and get an additional enhancement on the outside of the tube. By looking at Tables 12 and 13, the only wire-wrapped LPD tube that showed any enhancement over the plain LPD tube was tube L3 (Dc = 0.5 mm). Figure 27 shows the outside heat transfer coefficients for the three wire-wrapped LPD tubes. The wire-wrapped LPD tubes were also checked to see if there was any relation between P/Dc or F and the enhancement over a plain LPD tube (h_e/h_{LPD}). Figures 28 and 29
Figure 26. Comparison of the Outside Heat Transfer Coefficients for the plain LPD KORODENSE Tube and the Smooth Titanium Tube
Table XI. LPD KORODENSE TUBES WITH A HEATEX INSERT

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>$C_1$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMAHLT2 (L)</td>
<td>2.903</td>
<td>0.903</td>
<td>1.171</td>
</tr>
<tr>
<td>FONMAHLT3 (L)</td>
<td>2.892</td>
<td>0.916</td>
<td>1.188</td>
</tr>
<tr>
<td>FONMAHL1T1 (L1)</td>
<td>2.667</td>
<td>0.890</td>
<td>1.154</td>
</tr>
<tr>
<td>FONMAHL2T1 (L2)</td>
<td>2.639</td>
<td>0.909</td>
<td>1.179</td>
</tr>
<tr>
<td>FONMAHL3T1 (L3)</td>
<td>2.835</td>
<td>0.968</td>
<td>1.256</td>
</tr>
<tr>
<td><strong>Atm. Avg.</strong></td>
<td></td>
<td></td>
<td><strong>2.787</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>$C_1$</th>
<th>$\alpha$</th>
<th>$E_r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVHLT1 (L)</td>
<td>2.717</td>
<td>0.945</td>
<td>1.232</td>
</tr>
<tr>
<td>FONMVHLT2 (L)</td>
<td>2.669</td>
<td>0.950</td>
<td>1.238</td>
</tr>
<tr>
<td>FONMVHL1T2 (L1)</td>
<td>2.317</td>
<td>0.880</td>
<td>1.147</td>
</tr>
<tr>
<td>FONMVHL2T3 (L2)</td>
<td>2.426</td>
<td>0.890</td>
<td>1.161</td>
</tr>
<tr>
<td>FONMVHL3T2 (L3)</td>
<td>2.609</td>
<td>0.995</td>
<td>1.297</td>
</tr>
<tr>
<td><strong>Vac. Avg.</strong></td>
<td></td>
<td></td>
<td><strong>2.548</strong></td>
</tr>
<tr>
<td><strong>Total Avg.</strong></td>
<td></td>
<td></td>
<td><strong>2.667</strong></td>
</tr>
</tbody>
</table>

show respectively the relationship between $P/D_w$ and $F$ to the enhancement over the plain LPD tube. Since the pitch here is fixed, Figure 28 indicates that there may be further enhancement possible if a smaller diameter wire is used. Figure 29 suggests there may be an optimal fractional coverage of the tube between 0 and 0.07. Based on the results from the wire-wrapped smooth titanium tubes, the maximum enhancement seen was about 30%; for the plain LPD tube over the plain smooth titanium tube the enhancement was about 20%.
Table XII. LPD KORODENSE TUBES WITH NO INSERT

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>( C_1 )</th>
<th>( \alpha )</th>
<th>( E_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMANLT2 (L)</td>
<td>2.056</td>
<td>0.919</td>
<td>1.201</td>
</tr>
<tr>
<td>FONMANLT3 (L)</td>
<td>1.993</td>
<td>0.941</td>
<td>1.230</td>
</tr>
<tr>
<td>FONMANL1T1 (L1)</td>
<td>2.036</td>
<td>0.869</td>
<td>1.135</td>
</tr>
<tr>
<td>FONMANL2T1 (L2)</td>
<td>2.057</td>
<td>0.890</td>
<td>1.163</td>
</tr>
<tr>
<td>FONMANL3T1 (L3)</td>
<td>2.202</td>
<td>0.933</td>
<td>1.219</td>
</tr>
<tr>
<td><strong>Atm. Avg.</strong></td>
<td></td>
<td></td>
<td><strong>2.069</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data Run / Tube</th>
<th>( C_1 )</th>
<th>( \alpha )</th>
<th>( E_r )</th>
</tr>
</thead>
<tbody>
<tr>
<td>FONMVNL2T2 (L)</td>
<td>1.869</td>
<td>0.953</td>
<td>1.161</td>
</tr>
<tr>
<td>FONMVNL3T3 (L)</td>
<td>1.862</td>
<td>0.956</td>
<td>1.165</td>
</tr>
<tr>
<td>FONMVNL1T2 (L1)</td>
<td>1.784</td>
<td>0.855</td>
<td>1.041</td>
</tr>
<tr>
<td>FONMVNL2T3 (L2)</td>
<td>1.839</td>
<td>0.869</td>
<td>1.059</td>
</tr>
<tr>
<td>FONMVNL3T2 (L3)</td>
<td>2.041</td>
<td>0.942</td>
<td>1.148</td>
</tr>
<tr>
<td><strong>Vac. Avg.</strong></td>
<td></td>
<td></td>
<td><strong>1.879</strong></td>
</tr>
<tr>
<td><strong>Total Avg.</strong></td>
<td></td>
<td></td>
<td><strong>1.974</strong></td>
</tr>
</tbody>
</table>

Therefore, the maximum additional enhancement expected from wire-wrapping the LPD tube with a smaller diameter wire would be about 10%.

One reason the larger diameter wires did not improve the outside enhancement of the LPD tubes is that there was more condensate retained between the wires than with the plain LPD tube. This additional condensate causes a thicker condensate film across the lower portion of the tube, resulting in less overall heat transfer. The smallest wire (0.5 mm) fitted into
Figure 27: Comparison of the Outside Heat Transfer Coefficient for the Wire-Wrapped LPD XORDENSE Titanium Tubes and the Smooth Titanium Tube.

$h_o$ vs. $T_{cf}$

Atmospheric Pressure using the Petukhov-Popov Correlation

$h_o$ (kW/m² K)

$T_{cf}$ (°C)

- Smooth Ti Tube
- Tube #1.1
- Tube #1.2
- Tube #1.3
- Tube #1. (Plain LPD)
- Nusselt
Figure 28. Comparison of $h_e/h_LPD$ vs. $P/D_w$ Ratio for the Wire-Wrapped LPD KORODENSE Tubes at Atmospheric Pressure.
Figure 29. Comparison of \( h_e/h_{LPD} \) vs. \( F \) for the Wire-Wrapped LPD KORODENSE Titanium Tubes

- **\( h_e/h_{LPD} \)**
- **\( F \)**
- **Tube L1 (1.6mm wire)**
- **Triangle Tube L2 (1.0mm wire)**
- **N выпущенный Tube L3 (0.5mm wire)**
the groove of the roped tube more closely, so that the amount of condensate retained was about the same as for a plain LPD tube. Since there was no additional condensate retention, the wire was better able to draw the condensate film to the groove. The larger pressure differential leads to greater thinning of the condensate film and thus a reduction in the vapor side thermal resistance.

In summary, the maximum enhancement in the outside heat transfer coefficient realized for a wire-wrapped smooth titanium tube was ≈30% with a $P/D_w = 7.96$. A plain LPD KORODENSE tube showed consistent enhancements of ≈20% in the outside heat transfer coefficient when compared to a smooth tube. There only seems to be a minimal gain in wire-wrapping an LPD tube to further improve the outside heat transfer coefficient. However, one benefit to wire-wrapping an LPD tube would be to reduce the effects of condensate inundation in a bundle arrangement.
CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The Petukhov-Popov inside heat transfer coefficient correlation can be used to give accurate results in this test apparatus.

2. Enhancements in the outside heat transfer coefficient of up to 30\% were obtained using a wire-wrapped titanium tube, when compared to the smooth titanium tube. \((P/D_o = 7.92)\)

3. An optimal value of the fractional wire coverage of the tube of between 10\% and 30\% was found.

4. For an LPD KORODENSE titanium roped tube, an enhancement in the outside heat transfer coefficient of up to 20\% over the smooth titanium tube was obtained. Using a wire-wrap on the LPD KORODENSE tube showed little further enhancement.

5. The surface wettability characteristics and perhaps the thermal conductivity of the tube material seems to have an influence on the outside heat transfer coefficient and possibly the optimal fractional wire coverage.

B. RECOMMENDATIONS

1. A set of tubes should be fabricated of different materials with fractional wire coverage of the tube in the range of 0.1 to 0.3, using different wire diameters and pitches.

2. Determine the effect of vapor velocity and inundation effects on the titanium wire-wrapped tubes. Use the Fujii [Ref. 12\] correlation for the outside heat transfer coefficient when reprocessing the data.

3. Fabricate several more wire-wrapped LPD KORODENSE tubes using thinner wire diameters (0.1 mm, 0.2 mm, and 0.3 mm). To determine if there is a significant increase in
the enhancement of the outside heat transfer coefficient and an optimal value for the fractional wire coverage of the tube.

4. Reprocess the data sets using all the data for a given configuration (i.e. pressure, insert used, etc...) to determine more accurate values of $C_i$ and $\alpha$.

5. Conduct bundle tests to see if condensate inundation is reduced with wire-wrapped smooth and roped tubes.
APPENDIX A. SYSTEM CORRECTIONS

A. FRICTIONAL TEMPERATURE CORRECTIONS

When the coolant flows through the tube there is a temperature rise in the bulk fluid due to frictional heating. The amount of heating is dependent on the fluid velocity and the inside geometry of the tube. The actual temperature is small, but it can have a significant effect on the calculation for the overall heat transfer coefficient. The titanium tubes had a smaller temperature rise across the tube than the copper tubes, so the effect of the frictional heating is much greater. Measurements were made for the smooth titanium tube on August 7, 1992 and August 14, 1992 for the LPD KORODENSE titanium tube. The data is plotted in Figures A.1 and A.2. Runs were conducted with and without the HEATEX insert. The data was curve fitted to a third order polynomial as shown in Table A.1.
### Table A.1  FRICTION TEMPERATURE RISE EQUATIONS

<table>
<thead>
<tr>
<th>Tube/Insert Type</th>
<th>Polynomial Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smooth/None</td>
<td>$T_{\text{rise}} = -8.843 \times 10^{-5} V^3 + 1.799 \times 10^{-3} V^2 - 7.526 \times 10^{-4} V - 4.617 \times 10^{-5}$</td>
</tr>
<tr>
<td>Smooth/HEATEX</td>
<td>$T_{\text{rise}} = -3.305 \times 10^{-5} V^3 + 2.122 \times 10^{-3} V^2 + 9.737 \times 10^{-4} V + 2.091 \times 10^{-4}$</td>
</tr>
<tr>
<td>LPD/None</td>
<td>$T_{\text{rise}} = 4.133 \times 10^{-5} V^3 + 6.013 \times 10^{-4} V^2 + 1.880 \times 10^{-3} V - 3.386 \times 10^{-4}$</td>
</tr>
<tr>
<td>LPD/HEATEX</td>
<td>$T_{\text{rise}} = -2.781 \times 10^{-5} V^3 + 1.893 \times 10^{-3} V^2 + 9.202 \times 10^{-4} V + 2.089 \times 10^{-4}$</td>
</tr>
</tbody>
</table>

where: $T_{\text{rise}} = \text{temperature rise (°K)}$

$V = \text{fluid velocity (m/s)}$
Figure A.1 Frictional Temperature Rise Curves for the Smooth Titanium Tube with a HEATEX Insert and No Insert.
Figure A.2 Frictional Temperature Rise Curves for the LPD KORODENSE Titanium Tube with a HEATEX Insert and No Insert
APPENDIX B. SYSTEM STARTUP AND SHUTDOWN PROCEDURES

A. SYSTEM STARTUP PROCEDURE

When preparing the system for taking data the following should be done:

1. Ensure the boiler section of the system is filled with distilled water, approximately 4 to 6 inches above the heaters. To fill the boiler a hose is attached between the distilled water tank and the boiler fill/drain valve. Ensure the vent valve by the auxiliary condenser is open prior to gravity filling the boiler. The boiler can be drained by ensuring the hose is removed from the boiler fill/drain valve. Then open the fill/drain valve and let the water drain to the bilge area below the boiler.

2. If the boiler has the appropriate water level then ensure the vent valve and fill/drain valve are shut.

3. Energize the data acquisition system, computer, and printer. Load the software program DRPOK and check for proper operation. Before starting any heaters check all thermocouples to ensure they are reading ambient temperature.

4. Open the fill valve to the coolant sump tank and set the flow rate such that the drain box does not overflow. (the valve is located to the left of the boiler heater control panel.)

5. Turn on the cooling water supply pumps and set the flow rate between 40% to 60% and check for leaks in the test section. Secure the flow and coolant supply pumps.

6. Open the valve supplying water to the auxiliary condenser unit and adjust the flow rate to at least 30% and check for leaks in the system. When the leak check is complete reset the flow rate as desired but at least greater than 10%.

7. CAUTION: prior to energizing any heaters ensure that the system is under a vacuum. To draw a vacuum on the system, ensure the drain valve on the plexiglas container
is shut. Check that there is flow to the sump tank, then energize the vacuum pump and open the suction valve located on the side of the auxiliary condenser. Allow the vacuum pump to run until the system pressure is below 3 psia, then shut the suction valve and secure the vacuum pump.

8. The heaters may be energized if the system is confirmed to be under vacuum conditions. To energize the heaters three switches must be placed in the "ON" position. The first switch is located on power panel P5, switch #3, in the main hallway adjacent to H-106. The second switch, the heater load bank circuit breaker, is located on the left side of the boiler heater control panel. The final switch, the condensing rig boiler power switch, is located on the front of the boiler heater control panel. When the heaters are energized, the power level should be set at 50 volts (40 volts if the system is below 2 psia to limit the vibrational shock to the system from vapor bubble formation). As the system warms up, the power can be increased at 10 volt increments until the desired setting is reached.

9. As the system warms up and the system pressure rises above 4 psia, then the non-condensible gases need to be flushed out of the system by drawing a vacuum on the system following step 7. To ensure the non-condensible gases collect at the base of the auxiliary condenser, coolant flow should remain secured and the flow rate to the auxiliary condenser adjusted until all the gases have been purged from the system. When the auxiliary condenser is warm to the touch everywhere, this is an indication that steam is filling the entire condenser and little or no non-condensible gases remain. To initially purge the system of non-condensible gases may take between 15 and 30 minutes. The process should be done every few hours if extended operation of the system is required.

10. To ensure that filmwise condensation is established on the tube being tested, the following should be done:

a. Allow the apparatus to warm up to a vapor temperature of at least 3800 microvolts.

b. Raise the auxiliary coolant flow rate to 50\% or 60\% to cool the vapor temperature to approximately 3200 microvolts.
c. Secure coolant flow to the auxiliary condenser and allow the vapor temperature to rise to about 3700 microvolts. This forms a steam blanket over the tube.

d. Initiate coolant flow of 80% in the auxiliary condenser.

e. Adjust the coolant flowrate in the auxiliary condenser to maintain the desired temperature and pressure for the system.

11. Run the software program DRPOK by pressing the "run" key on the keyboard. The program will prompt you with questions for the necessary information it needs as follows:

- Select option ... Enter 0 for taking new data
- Select fluid ... Enter 0 for water
- Enter input mode ... Enter 0 for new data
- Enter month, date, time ... when finished press enter
- Select C, ... 0 to find C, and 1 to use the program value
- Give a name for the raw data set ... enter the name
- Enter the geometry code ... select plain or finned
- Enter the insert type used... select the appropriate value
- Enter the tube type ... select the appropriate value
- Select the tube enhancement used ... select the appropriate value
- Select the tube material ... enter 0 for copper
- Select the tube diameter ... enter 1 for medium
- Enter the pressure condition ... 0 vacuum, 1 atmospheric
- Select the inside correlation ... 0 Sieder-Tate, 2 Petukhov-Popov
- Select the outside theory for analysis ... 0 Nusselt or 1 Fujii
* Select the measurement device ... 1 Quartz thermometer
* Select the output ... 0 short, 1 long
* Like to check NG concentration ... 1 yes, 2 no
* Enter flowmeter reading (%) ... enter a 2 digit number
* Connect voltage line ... flip up voltage line toggle switch on and press enter
* Disconnect voltage line ... flip voltage line toggle off and press enter
* Enter pressure gage reading ... input reading from Heise gage and press enter
* Change TCool rise? ... 1 yes, 2 no
* OK to store this point? ... 1 yes, 2 no
* Will there be another run? ... 1 yes, 0 no; if yes it returns to the step Like to check NG concentration for following runs

12. Prior to continuing past the question "Enter the flowmeter reading" ensure the system has been operating at steady-state conditions for at least 30 minutes.

13. **WARNING:** carefully monitor vapor pressure during warmup, especially around atmospheric pressure, to ensure an overpressure condition does not occur.

14. Vacuum runs are conducted at a heater setting of 90 volts and 1980 ± 10 microvolts on channel 40. This corresponds to \( T_{sat} \approx 48^\circ C \), and a vapor velocity of \( \approx 2 \) m/s.

15. Atmospheric runs are performed at a heater setting of 175 volts and 4280 ± 10 microvolts on channel 40. This corresponds to \( T_{sat} \approx 100^\circ C \), and a vapor velocity of \( \approx 1 \) m/s.

16. The viewing window can be cleared of condensation by using heated air from a blow dryer on the glass. **CAUTION:** be careful not to overheat and crack the glass.
17. When taking readings always double check the flowmeter reading prior to accepting any data point. Also, always conduct vacuum runs prior to atmospheric runs because it takes too long for the system to cool down to the vacuum operating temperatures. When trying to conduct both atmospheric and vacuum runs in the same day.

B. SYSTEM SHUTDOWN PROCEDURES

When completed taking data, the system should be secured with the following procedure:

1. Secure power to the heating elements. Turn off the switches on the boiler heater control panel.

2. Secure coolant flow in the auxiliary condenser. If the system is to remain at vacuum pressure until the next data run, then the auxiliary condenser can be used in assisting to cool the system down.

3. Secure the coolant water through the tube by securing the coolant pumps.

4. Secure the water flow to the coolant sump tank.

5. To return the system to atmospheric temperature, slowly open the vent valve on the auxiliary condenser. Ensure no foreign material is in the vicinity of the vent valve so the system does not get contaminated.

6. If an emergency should arise, such as an overpressurization or breakage, ensure the heater power is secured first! Let the system cool down prior to checking for damage.
APPENDIX C. UNCERTAINTY ANALYSIS

Uncertainties are always associated with any experimentally determined results. These uncertainties are a result of many different factors including the accuracy of measuring devices, calibration of a device, and operator experience. Although the uncertainty of a single measurement may be small, when combined with other measurements that have small uncertainties into a data reduction scheme, the effect may be to generate a large uncertainty in the final result.

The uncertainties can be estimated by using a propagation of error technique derived by Kline and McClintock [Ref. 33]. The uncertainty in a quantity, \( R \), is a function of those variables that are used to determine that quantity. So the uncertainty of \( R \) can be represented as follows:

\[
W_R = \left( \frac{\partial R}{\partial x_1} W_1 \right)^2 + \left( \frac{\partial R}{\partial x_2} W_2 \right)^2 + \ldots + \left( \frac{\partial R}{\partial x_n} W_n \right)^2
\]  
(C.1)

where:

- \( W_1, W_2, \ldots, W_n \) = the uncertainties of the measured variables
- \( x_1, x_2, \ldots, x_n \) = the measured independent variables
- \( W, W_1, W_2, \ldots, W_n \) = the uncertainty of the desired dependent variable

A complete description for the uncertainty analysis is given in Georgiadis [Ref. 34]. A program, originally designed
by Mitrou [Ref. 9], was used to calculate the uncertainties for this experiment. Sample outputs of the uncertainty evaluations are enclosed.
DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMUNC1
Pressure Condition: Vacuum
Vapor Temperature = 48.626 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 4.32 (m/s)
Heat Flux = 1.461E+05 (W/m²)
Tube-metal thermal conduc. = 365.0 (W/m.K)
Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE PERCENT UNCERTAINTY
Mass Flow Rate, Md 0.81
Reynolds Number, Re 1.14
Heat Flux, q 1.66
Log-Mean-Tem Diff, LMTD 1.38
Wall Resistance, Rw 2.67
Overall H.T.C., Uo 2.16
Water-Side H.T.C., Hi 11.22
Vapor-Side H.T.C., Ho 11.87

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMUNC1
Pressure Condition: Vacuum
Vapor Temperature = 48.619 (Deg C)
Water Flow Rate (%) = 20.00
Water Velocity = 1.16 (m/s)
Heat Flux = 8.492E+04 (W/m²)
Tube-metal thermal conduc. = 385.0 (W/m.K)
Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE PERCENT UNCERTAINTY
Mass Flow Rate, Md 3.01
Reynolds Number, Re 3.12
Heat Flux, q 3.11
Log-Mean-Tem Diff, LMTD .64
Wall Resistance, Rw 2.67
Overall H.T.C., Uo 3.18
Water-Side H.T.C., Hi 11.45
Vapor-Side H.T.C., Ho 43.62
DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHCI
Pressure Condition: Vacuum
Vapor Temperature = 48.745 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 4.32 (m/s)
Heat Flux = 1.840E+06 (W/m^2)
Tube-metal thermal conduc. = 365.0 (W/m.K)
Sieder-Tate constant = 0.0415

UNCERTAINTY ANALYSIS:

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Pressure Condition: Vacuum
Vapor Temperature = 48.733 (Deg C)
Water Flow Rate (%) = 20.00
Water Velocity = 1.16 (m/s)
Heat Flux = 1.251E+05 (W/m^2)
Tube-metal thermal conduc. = 365.0 (W/m.K)
Sieder-Tate constant = 0.0415

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### DATA FOR THE UNCERTAINTY ANALYSIS:

**File Name:** FONMANC1  
**Pressure Condition:** Atmospheric (101 kPa)  
**Vapor Temperature** = 99.919 (Deg C)  
**Water Flow Rate (%)** = 80.00  
**Water Velocity** = 4.31 (m/s)  
**Heat Flux** = 4.227E+05 (W/m²)  
**Tube-metal thermal conduc.** = 385.0 (W/m.K)  
**Sieder-Tate constant** = 0.0193

### UNCERTAINTY ANALYSIS:

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**Pressure Condition:** Atmospheric (101 kPa)  
**Vapor Temperature** = 100.024 (Deg C)  
**Water Flow Rate (%)** = 20.00  
**Water Velocity** = 1.16 (m/s)  
**Heat Flux** = 2.757E+05 (W/m²)  
**Tube-metal thermal conduc.** = 385.0 (W/m.K)  
**Sieder-Tate constant** = 0.0193

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100
DATA FOR THE UNCERTAINTY ANALYSIS:

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Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature = 99.887 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 4.31 (m/s)
Heat Flux = 4.952E+05 (W/m^2)
Tube-metal thermal conduc. = 385.0 (W/m.K)
Sieder-Tate constant = 0.0442

UNCERTAINTY ANALYSIS:

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Pressure Condition: Atmospheric (101 kPa)
Vapor Temperature = 99.879 (Deg C)
Water Flow Rate (%) = 20.00
Water Velocity = 1.15 (m/s)
Heat Flux = 3.805E+05 (W/m^2)
Tube-metal thermal conduc. = 385.0 (W/m.K)
Sieder-Tate constant = 0.0442

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### Heat Flux

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### UNCERTAINTY ANALYSIS:

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<tr>
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DATA FOR THE UNCERTAINTY ANALYSIS:

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DATA FOR THE UNCERTAINTY ANALYSIS:

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<td>Vapor-Side H.T.C., Ho</td>
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DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHTG
Pressure Condition: Atmospheric (101.3 Pa)
Vapor Temperature = 100.020 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 3.62 (m/s)
Heat Flux = 4.049E+05 (W/m²)
Tube-metal thermal conduc. = 21.0 (W/m.K)
Sieder-Tate constant = 0.0403

UNCERTAINTY ANALYSIS:

VARIABLE PERCENT UNCERTAINTY

Mass Flow Rate, Md 0.81
Reynolds Number, Re 1.15
Heat Flux, q 1.10
Log-Mean-Tem Diff, LMTD .60
Wall Resistance, Rw 5.03
Overall H.T.C., Uo 1.25
Water-Side H.T.C., H1 7.51
Vapor-Side H.T.C., Ho 4.13

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
Pressure Condition: Atmospheric (101.3 Pa)
Vapor Temperature = 99.222 (Deg C)
Water Flow Rate (%) = 20.00
Water Velocity = 0.97 (m/s)
Heat Flux = 3.120E+05 (W/m²)
Tube-metal thermal conduc. = 21.0 (W/m.K)
Sieder-Tate constant = 0.0403

UNCERTAINTY ANALYSIS:

VARIABLE PERCENT UNCERTAINTY

Mass Flow Rate, Md 3.03
Reynolds Number, Re 3.15
Heat Flux, q 3.07
Log-Mean-Tem Diff, LMTD .21
Wall Resistance, Rw 5.69
Overall H.T.C., Uo 3.88
Water-Side H.T.C., H1 7.87
Vapor-Side H.T.C., Ho 11.47

105
APPENDIX D. DATA RUNS

The names of the data files are listed in Tables 2 through 13 in Chapter 5. The data files presented in this appendix have been reprocessed using the Petukhov-Popov [Ref. 29] form of the inside heat transfer correlation. The data have been printed out in the short form format.
NOTE: Program name : ORPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.56 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.2715
Alpha (based on Nusselt (Tdel)) = 0.7601
Enhancement (q) = .963
Enhancement (Del-T) = .972

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<th>Ho</th>
<th>Qp</th>
<th>Tcf</th>
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Least-Squares Line for Ho vs q curve:
Slope = -2.043E-01
Intercept = 7.798E+05

Least-squares line for q = a*Del-t+q
a = 2.517E+04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT1
NOTE: 13 <- pairs were stored in data file
NOTE: Program name: DRPOK

Data taken by: O'KEEFE

This analysis done on file: FONMAHT2

This analysis includes end-fin effect

Thermal conductivity: \( 21.0 \text{ (W/m.K)} \)

Inside diameter, \( D_i \): \( 13.86 \text{ (mm)} \)

Outside diameter, \( D_o \): \( 15.65 \text{ (mm)} \)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient: \( 1.0000 \)

Using HEATEX insert inside tube

Tube Enhancement: SMOOTH TUBE

Tube material: TITANIUM

Pressure condition: ATMOSPHERIC

Nusselt theory is used for \( H_o \)

\( C_1 \) (based on Petukhov-Popov) = 2.3233

\( \alpha \) (based on Nusselt (Tdel)) = 0.7740

Enhancement (q) = 0.953

Enhancement (Del-T) = 0.955

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<th>( \Delta t ) (W/m²-K)</th>
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Least-Squares Line for \( H_o \) vs \( q \) curve:

Slope: \(-3.1753 \times 10^{-1}\)

Intercept: \(-7.3198 \times 10^{-2}\)

Least-squares line for \( q = a + \Delta t \times b \)

\( a = 2.4399 \times 10^{-6} \)

\( b = 7.5000 \times 10^{-3} \)

NOTE: 13 data points were stored in file FONMAHT2

NOTE: 13 \( \Delta t \) pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAHT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, \( D_i \) = 13.36 (mm)
Outside diameter, \( D_o \) = 15.65 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for \( \text{Nu} \)

\( C_1 \) (based on Petukhov-Popov) = 2.3923
\( \text{Alpha} \) (based on Nusselt \( \text{Tdel} \)) = 0.7551
Enhancement (q) = 0.915
Enhancement (\( \text{Del-T} \)) = 0.941

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Least-Squares Line for \( \text{Ho} \) vs q curve:
Slope = -3.1923E-01
Intercept = 7.7848E+05

Least-squares line for q = a + delta-T * b
\( a = 2.4500E-04 \)
\( b = 7.5300E-01 \)

NOTE: 88 data points were stored in file FONMAHT3

NOTE: 88 X-Y pairs were stored in data file
NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHT4
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D: = 13.86 (mm)
Outside diameter, Dc = 15.95 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.4099
Alpha (based on Nusselt (Tdei)) = 0.7484
Enhancement (q) = 0.911
Enhancement (Del-T) = 0.933

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Least-Squares Line for Ho vs q curve:
Slope = -3.1639E-01
Intercept = 7.7829E+05

Least-squares line for q = a+delta-T*b
a = 2.4322E+04
b = 7.5000E-01

NOTE: 17 data points were stored in file FONMAHT4
NOTE: 17 /-/ pairs were stored in data file

110
NOTE: Program name: ORPOK
Data taken by: Z'KEFE
This analysis done on file: FONMAHTS
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.36 (mm)
Outside diameter, Do = 15.35 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho
C1 (based on Petukhov-Popov) = 2.2011
Alpha (based on Nusselt (Tdel)) = 0.7700
Enhancement (q) = 0.947
Enhancement ( Del-T ) = 0.960

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Least-Squares Line for Ho vs q curve:
Slope = -3.139E+01
Intercept = 7.7964E+05

Least-squares line for q = a-delta-T*b
a = 2.4990E+04
b = 7.5000E+01

NOTE: 14 data points were stored in file FONMAHTS

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOIK
Data taken by: O'KEEFE
This analysis done on file: FONMAHT6
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.96 (mm)
Outside diameter, Do = 15.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.5406
Alpha (based on Nusselt (Tdeb)) = 0.7752
Enhancement (q) = 0.966
Enhancement (Del-T) = 0.967

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Least-Squares Line for Ho vs q curve:
Slope = 3.0334E-01
Intercept = 7.7703E-05

Least-squares line for q = a+delta-T*b
a = 2.5173E+04
b = 7.5009E-01

NOTE: 13 data points were stored in file FONMAHT6
NOTE: 13 X-Y pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAHT7
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.65 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.5109
Alpha (based on Nusselt (Tdel)) = 0.7924
Enhancement (q) = .983
Enhancement (Del-T) = .987

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Least-Squares Line for Ho vs q curve:
Slope = -3.1502E-01
Intercept = 7.8438E+05

Least-squares line for q = a+delta-T b
a = 2.5569E+04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT7

NOTE: 10 x-y pairs were stored in data file
NOTE: Program name : ORPOK
This analysis done on file : FONMANT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.66 (mm)
Outside diameter, Do = 15.65 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Patukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Patukhov-Popov) = 1.2114
Alpha (based on Nusselt (Tdel)) = 0.7504
Enhancement (q) = 0.941
Enhancement (Del-T) = 0.955

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Least-Squares Line for Ho vs q curve:
Slope = -2.5039E-01
Intercept = 7.5039E-05

Least-squares line for q = a*delta-° b
a = 2.4694E-04
b = 7.5000E-01

NOTE: 13 data points were stored in file FONMANT1:
NOTE: 13 x-y pairs were stored in data file

---

114
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMANT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.65 (mm)
Outside diameter, Do = 15.65 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petuhkov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petuhkov-Popov) = 1.1849
Alpha (based on Nusselt (Tdei)) = 0.7603
Enhancement (q) = .957
Enhancement (Dt-T) = .968

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Least-Squares Line for Ho vs q curve:
Slope = -2.5E-01
Intercept = 7.6E+05

Least-squares line for q = a*delta-T*b
a = 2.5129E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMANT2

NOTE: 15 X-Y pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMANT3
This analysis includes end-fin effect.
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, O₁ = 13.85 (mm)
Outside diameter, O₂ = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings.
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube.
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.1536
Alpha (based on Nusselt (T₁-T₂)) = 0.7650
Enhancement (q) = 0.965
Enhancement (Δ-T) = 0.974

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Least-Squares Line for Ho vs q curve:
Slope = -2.473E-01
Intercept = 7.583E-05

Least-squares line for q = a + bΔ-T
a = 2.525E-04
b = 7.5000E-01

NOTE: 12 data points were stored in file FONMANT3

NOTE: 12 x-y pairs were stored in data file.
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMANT4
This analysis includes end-fin effect
Thermal conductivity: 21.0 (W/m.K)
Inside diameter, \(D_i\): 13.96 (mm)
Outside diameter, \(D_o\): 15.35 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient: 1.0000
Using no insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for \(Ho\)

\[ C_l \text{ (based on Petukhov-Popov) } = 1.1911 \]
\[ \text{Alpha (based on Nusselt (Tdel)) } = 0.7643 \]
\[ \text{Enhancement (q) } = 0.965 \]
\[ \text{Enhancement (Del-T) } = 0.974 \]

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Least-Squares Line for \(Ho\) vs \(q\) curve:
- Slope = -2.573E01
- Intercept = 7.6093E05

Least-squares line for \(q = a + b * \text{delta } T\):
- \(a = 2.5144E+04\)
- \(b = 7.5000E-01\)

NOTE: 14 data points were stored in file FONMANT4

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMANTS
This analysis includes end-fan effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov): = 1.2370
Alpha (based on Nusselt (Tdel)): = 0.7633
Enhancement (q) = 1.00!
Enhancement (Del-T) = 1.00!

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Least-squares Line for Ho vs q curve:
Slope = -2.5021E-01
Intercept = 7.5397E+05

Least-squares line for q = a*delta-T^b
a = 2.5924E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMANTS

NOTE: 16 X-Y pairs were stored in data file
NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVHT3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.95 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement : SMOOTH TUBE

Tube material : TITANIUM

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.5472

Alpha (based on Nusselt (Tdel)) = 0.7483

Enhancement (q) = .324

Enhancement (Del-T) = .565

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Least-Squares Line for Ho vs q curve:

Slope = -3.115E-01
Intercept = 5.8173E+05

Least-squares line for q = a*delta-T^-b
a = 2.0703E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHT3

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVHT4
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.95 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2780
Alpha (based on Nusselt (Tdel)) = 0.7800
Enhancement (q) = 0.985
Enhancement (Qdel-T) = 0.913

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<th>Op</th>
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Least-Squares Line for Ho vs q curve:
Slope = -3.2707E-01
Intercept = 5.3931E+05

Least-squares line for q = a*delta-T^b
a = 2.1743E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHT4
NOTE: 16 X-Y pairs were stored in data file
NOTE: Program name : ORPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVHTS
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D_i = 13.86 (mm)
Outside diameter, D_o = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.4221
Alpha (based on Nusselt (Tdel)) = 0.7627
Enhancement (q) = 0.845
Enhancement (Del-T) = 0.881

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Least-Squares Line for Ho vs q curve:
Slope = -3.1155E-01
Intercept = 5.8244E+05

Least-squares line for q = a*delta-T^b
a = 2.0955E+04
b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVHTS
NOTE: 15 x-y pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVNT2
This analysis includes end-fin effect
Thermal conductivity: 21.0 (W/m·K)
Inside diameter, Di: 13.86 (mm)
Outside diameter, Do: 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient: 1.0000
Using no insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0922
Alpha (based on Nusselt (Tdel)) = 0.8215
Enhancement (q) = 0.379
Enhancement (Del-T) = 0.907

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Least-Squares Line for Ho vs q curve:
Slope = -2.5423E-01
Intercept = 5.7915E+05

Least-squares line for q = a*delta-T^b
a = 2.2580E+04
b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVNT2

NOTE: 12 X-Y pairs were stored in data file
NOTE: Program name: ORPOK

Data taken by: O'KEEFE

This analysis done on file: FONMUNT3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement: SMOOTH TUBE

Tube material: TITANIUM

Pressure condition: VACUUM

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0775

Alpha (based on Nusselt (Tdel)) = 0.7876

Enhancement (q) = .630

Enhancement (Del-T) = .869

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Least-Squares Line for Ho vs q curve:
Slope = -2.8853E-01
Intercept = 5.8155E+05

Least-squares line for q = a*delta-T*b
a = 2.1947E+04
b = 7.5000E-01

NOTE: 20 data points were stored in file FONMUNT3

NOTE: 20 X-Y pairs were stored in data file
NOTE: Program name : DPPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNT4
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.56 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement = SMOOTH TUBE
Tube material = TITANIUM
Pressure condition = VACUUM
Nusselt theory is used for Ho

\[ C_i (based \ on \ Petukhov-Popov) = 1.0742 \]
\[ \alpha (based \ on \ Nusselt \ (T_{del})) = 0.0455 \]
Enhancement (q) = 0.912
Enhancement (Del-T) = 0.933

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Least-Squares Line for Ho vs q curve:
Slope = -2.9438E-01
Intercept = 5.3472E+05

Least-squares line for \( q = a \cdot \delta_{T} \cdot b \)
\[ a = 2.4011E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 14 data points were stored in file FONMVNT4
NOTE: 14 X-Y pairs were stored in data file

124
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVNTS
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.66 (mm)
Outside diameter, Do = 15.65 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.1127
Alpha (based on Nusselt (Tdel)) = 0.3274
Enhancement (q) = 0.836
Enhancement (Del-T) = 0.913

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Least-Squares Line for Ho vs q curve:
Slope = -3.0256E-01
Intercept = 5.8489E+05

Least-squares line for q = a*delta-T+b
a = 2.3349E+04
b = 7.5000E-01

NOTE: 17 data points were stored in file FONMVNTS

NOTE: 17 X-Y pairs were stored in data file
NOTE: Program name: ORPOK

Data taken by: O'KEEFE
This analysis done on file: FONMAHITI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0225
Alpha (based on Nusselt (Tdel)) = 0.7981
Enhancement (q) = 1.047
Enhancement (Del-T) = 1.035

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Least-Squares Line for Ho vs q curve:
Slope = -2.821E-01
Intercept = 7.7250E+05

Least-squares line for q = a+delta-T*b
a = 2.605E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHITI

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O’KEEFE
This analysis done on file: FONMANITI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.85 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.1307
Alpha (based on Nusselt (Tdel)) = 0.7825
Enhancement (q) = 1.030
Enhancement (Del-T) = 1.022

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Least-Squares Line for Ho vs q curve:
Slope = -2.4825E-01
Intercept = 7.5014E+05

Least-squares line for q = a*delta-T + b
a = 2.5879E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANITI

NOTE: 14 K-ß pairs were stored in data file

127
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVH11
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.8918
Alpha (based on Nusselt (Tdel)) = 0.8018
Enhancement (q) = 1.061
Enhancement (Del-T) = 1.045

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Least-Squares Line for Ho vs q curve:
Slope = -3.0415E-01
Intercept = 5.8381E+05

Least-squares line for q = a*delta-T*b
a = 2.2233E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH11

NOTE: 14 X-Y pairs were stored in data file

128
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVNIT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

\[ C_1 \text{ (based on Petukhov-Popov)} = 1.0235 \]
\[ \text{Alpha (based on Nusselt (Tdel))} = 0.8381 \]
Enhancement (q) = 1.029
Enhancement (Del-T) = 1.021

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Least-Squares Line for Ho vs q curve:
Slope = -2.5701E-01
Intercept = 5.3022E+05

Least-squares line for q = a*delta-T^b
a = 2.3428E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNIT1
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAH2T3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for \( \text{Ho} \)

\[ C_1 \text{(based on Petukhov-Popov)} = 2.4479 \]
\[ \alpha \text{(based on Nusselt (Tdel))} = 0.8064 \]
Enhancement (q) = 1.062
Enhancement (Tdel-T) = 1.046

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Least-Squares Line for \( \text{Ho} \) vs \( q \) curve:
Slope = -2.8502E-01
Intercept = 7.7502E+05

Least-squares line for \( q = \alpha \cdot \text{del} \cdot T - b \)
\( a = 2.6233E+04 \)
\( b = 7.5000E-01 \)

NOTE: 14 data points were stored in file FONMAH2T3

NOTE: 14 x-y pairs were stored in data file
NOTE: Program name : ORPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.0949
Alpha (based on Nusselt (Tdel)) = 0.3014
Enhancement (q) = 1.063
Enhancement (Del-T) = 1.047

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Least-Squares Line for Ho vs q curve:
Slope = -2.3508E-01
Intercept = 7.5845E-05

Least-squares line for q = a*delta-T + b
a = 2.6571E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN2T1
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'Keeffe
This analysis done on file: FONMUV2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.08 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

\[ C_1 \text{ (based on Petukhov-Popov)} = 2.0049 \]
\[ \alpha \text{ (based on Nusselt } (T_{del}) = 0.7965 \]
Enhancement \( q \) = 1.052
Enhancement \( \alpha \text{ (Del-T)} = 1.038 \]

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Least-Squares Line for \( Ho \) vs \( q \) curve:
\[ \text{Slope} = -2.9344E-01 \]
\[ \text{Intercept} = 5.8163E+05 \]

Least-squares line for \( q = a \cdot \delta T - b \)
\[ a = 2.1707E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 13 data points were stored in file FONMUV2T1
NOTE: 13 X-Y pairs were stored in data file

132
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVH2T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPEO SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.9482
Alpha (based on Nusselt (Tdel)) = 0.7873
Enhancement (q) = 1.035
Enhancement (delta-T) = 1.026

Data

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Least-Squares Line for Ho vs q curve:
Slope = -3.2945E-01
Intercept = 5.8591E+05

Least-squares line for q = a*delta-T*b
a = 2.1568E+04
b = 7.50000E-01

NOTE: 13 data points were stored in file FONMVH2T2

NOTE: 13 X-Y pairs were stored in data file

133
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVH2T3
This analysis includes end-fin effect
Thermal conductivity \( \lambda \) = 21.0 (W/m.K)
Inside diameter, \( D_1 \) = 13.86 (mm)
Outside diameter, \( D_0 \) = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient \( = 1.0000 \)
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for \( \text{Ho} \)

\[ C_1 \text{ (based on Petukhov-Popov) } = 2.2400 \]
\[ \text{Alpha (based on Nusselt (Tdel)) } = 0.7652 \]

Enhancement \( q \) = .999
Enhancement \( \text{Del-T} \) = .999

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Least-Squares Line for \( \text{Ho} \) vs \( q \) curve:
Slope = -3.3576E-01
Intercept = 5.9581E+05

Least-squares line for \( q = a + \delta-T \times b \)
\[ a = 2.1177E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 14 data points were stored in file FONMVH2T3

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVN2T1
This analysis includes end-fins effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 0.9979
Alpha (based on Nusselt (Tdel)) = 0.8181
Enhancement (q) = .996
Enhancement (Del-T) = .997

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Least-Squares Line for Ho vs q curve:
Slope = -2.6538E-01
Intercept = 5.8038E+05

Least-squares line for q = a*delta-T^b
a = 2.2839E+04
b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVN2T1
NOTE: 15 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVN3TI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m·K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9111
Alpha (based on Nusselt (Tdel)) = 0.6359
Enhancement (q) = 0.624
Enhancement (Del-T) = 0.702

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Least-Squares Line for Ho vs q curve:
Slope = -3.4927E-01
Intercept = 5.9044E+05

Least-squares line for q = a*delta-T*b
a = 1.7709E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN3TI

NOTE: 14 X-Y pairs were stored in data file
**NOTE:** Program name: DRPK

Data taken by: O'KEEFE

This analysis done on file: FONMAH3TI

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, D1 = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC

Nusselt theory is used for Ho

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<th>Tcf</th>
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Least-Squares Line for Ho vs q curve:
Slope = -3.3392E-01
Intercept = 7.7974E+05

Least-squares line for q = a*delta-T*b
a = 2.344E+04
b = 7.5000E-01

**NOTE:** 14 data points were stored in file FONMAH3TI

**NOTE:** 14 X-Y pairs were stored in data file
NOTE: Program name : ORPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN3T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

\( C_i \) (based on Petukhov-Popov) = 1.0337
Alpha (based on Nusselt \((T_{del})\)) = 0.6976
Enhancement \((q)\) = .854
Enhancement \((\Delta T)\) = .888

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<th>( H_o ) (W/m².K)</th>
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Least-Squares Line for Ho vs q curve:
Slope = -2.872E-01
Intercept = 7.6233E+05

Least-squares line for \( q = a \Delta T + b \)
\( a = 2.2978E+04 \)
\( b = 7.5000E-01 \)

NOTE: 14 data points were stored in file FONMAN3T1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK

Data taken by: O'KEEFE

This analysis done on file: FONMVH3T2

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.86 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE

Tube material: TITANIUM

Pressure condition: VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.8658

Alpha (based on Nusselt (Tdel)) = 0.6182

Enhancement (q) = 0.638

Enhancement (Del-T) = 0.714

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Least-Squares Line for Ho vs q curve:

Slope = -4.1572E-01

Intercept = 5.8640E+05

Least-squares line for q = a*delta-T^b

\[ a = 1.7233E+04 \]

\[ b = 7.50000E-01 \]

NOTE: 14 data points were stored in file FONMVH3T2

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAH4TI
This analysis includes end-fin effect
Thermal conductivity: 21.0 (W/m.K)
Inside diameter, D1: 13.86 (mm)
Outside diameter, D0: 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient: 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3785
Alpha (based on Nusselt (Tdel)) = 0.8529
Enhancement (q) = 1.144
Enhancement (Del-T) = 1.106

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Least-Squares Line for Ho vs q curve:
Slope = -2.6757E-01
Intercept = 7.7418E+05

Least-squares line for q = a*delta-T*b
a = 2.7891E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH4TI
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAN4TI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

\[ C_1 \text{ (based on Petukhov-Popov) } = 1.3768 \]
\[ \text{Alpha (based on Nusselt } (T_{del}) \text{) } = 0.7312 \]
\[ \text{Enhancement (q) } = 1.045 \]
\[ \text{Enhancement (Del-T) } = 1.034 \]

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Least-Squares Line for \( H_o \) vs q curve:
\[ \text{Slope } = -2.4793E-01 \]
\[ \text{Intercept } = 7.6832E+05 \]

Least-squares line for \( q = a \cdot \delta T^b \):
\[ a = 2.5008E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 14 data points were stored in file FONMAN4TI

NOTE: 14 \( X-Y \) pairs were stored in data file

141
NOTE: Program name: DRPOK

Data taken by: O'KEEFE
This analysis done on file: FONMVH4T1
This analysis includes end-fin effect.
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0810
Alpha (based on Nusselt (Tdel)) = 0.8211
Enhancement (q) = 1.095
Enhancement (Del-T) = 1.071

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Least-Squares Line for Ho vs q curve:
Slope = -3.1730E-01
Intercept = 5.8664E+05

Least-squares line for q = a*delta-T^b
a = 2.2845E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH4T1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name : ORPOK
Data taken by : O'KEEFE
This analysis done on file : FONMUN4T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.1394
Alpha (based on Nusselt (Tdel)) = 0.8245
Enhancement (q) = 1.007
Enhancement (Del-T) = 1.005

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Least-Squares Line for Ho vs q curve:
Slope = -2.6143E-01
Intercept = 5.7985E+05

Least-squares line for q = a*delta-T*b
a = 2.2773E+04
b = 7.5000E-01

NOTE: 17 data points were stored in file FONMUN4T1
NOTE: 17 X-Y pairs were stored in data file

143
NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAHST1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m·K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2507
Alpha (based on Nusselt (Tdel)) = 0.8691
Enhancement (q) = 1.173
Enhancement (q) = 1.127

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Least-Squares Line for Ho vs q curve:
Slope = -2.4930E-01
Intercept = 7.5900E+05

Least-squares line for q = a+delta-T·b
a = 2.8492E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMAHST1
NOTE: 16 X-Y pairs were stored in data file
NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMANSTI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0988
Alpha (based on Nusselt (Tdel)) = 0.8367
Enhancement (q) = 1.126
Enhancement (Del-T) = 1.093

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Least-Squares Line for Ho vs q curve:
Slope = -2.1506E-01
Intercept = 7.5527E+05

Least-squares line for q = a*delta-T^b
a = 2.7811E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANSTI
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRPOK

Data taken by: O'KEEFE

This analysis done on file: FONMVHST1

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.96 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE

Tube material: TITANIUM

Pressure condition: VACUUM

Nusselt theory is used for Ho

\[ C_1 (\text{based on Petukhov-Popov}) = 2.0139 \]

\[ \text{Alpha (based on Nusselt (Tdel))} = 0.0415 \]

Enhancement (q) = 1.132

Enhancement (Del-T) = 1.097

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Least-Squares Line for Ho vs q curve:
Slope = -2.374E-01
Intercept = 5.8357E-05

Least-squares line for \( q = a + \text{delta-T} \cdot b \)

\[ a = 2.3375E+04 \]
\[ b = 7.500E-01 \]

NOTE: 16 data points were stored in file FONMVHST1

NOTE: 16 X-Y pairs were stored in data file

146
NOTE: Program name : ORPOK
Data taken by : O'KEEFE
This analysis done on file : FONMVNSTI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Do = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9775
Alpha (based on Nusselt (Tdel)) = 0.8425
Enhancement (q) = 1.036
Enhancement (Del-T) = 1.027

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Least-Squares Line for Ho vs q curve:
Slope = -2.4722E-01
Intercept = 5.7933E+05

Least-squares line for q = a*delta-T*b
a = 2.3546E+04
b = 7.5000E+01

NOTE: 16 data points were stored in file FONMVNSTI
NOTE: 16 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAHST2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.3893
Alpha (based on Nusselt (Tdel)) = 0.9933
Enhancement (q) = 1.402
Enhancement (Del-T) = 1.299

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Least-Squares Line for Ho vs q curve:
Slope = -2.1689E-01
Intercept = 7.6861E+05

Least-squares line for q = a+delta-T‘b
a = 3.2516E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHST2
NOTE: 14 <Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAH6T3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for ho

Cl (based on Petukhov-Popov) = 2.3616
Alpha (based on Nusselt (Tdel)) = 1.0051
Enhancement (q) = 1.425
Enhancement (Del-T) = 1.304

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Least-Squares Line for Ho vs q curve:
Slope = -2.1554E-01
Intercept = 7.6915E+05

Least-squares line for \( q = a * \Delta T * b \)
\( a = 3.3011E+04 \)
\( b = 7.5000E+01 \)

NOTE: 10 data points were stored in file FONMAH6T3

NOTE: 10 X-Y pairs were stored in data file
NOTE: Program name: ORPOK

Data taken by: O'KEEFE

This analysis done on file: FONMANBT1
This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC

Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.1204
Alpha (based on Nusselt (Tdel)) = 1.0190

Enhancement (q) = 1.465
Enhancement (Qel-T) = 1.331

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Least-Squares Line for Ho vs q curve:

Slope = -1.7415E-01
Intercept = 7.5468E+05

Least-squares line for q = a*delta-T*b

a = 3.4038E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANBT1

NOTE: 14 X-r pairs were stored in data file
Program name: ORPOK

Data taken by: O'KEEFE

This analysis done on file: FONMVH6T1

This analysis includes end-fin effect

Thermal conductivity $= 21.0\, (W/m\cdot K)$

Inside diameter, $D_i = 13.96\, (mm)$

Outside diameter, $D_o = 15.85\, (mm)$

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient $= 1.0000$

Using HEATEX insert inside tube

Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE

Tube material: TITANIUM

Pressure condition: VACUUM

Nusselt theory is used for $H_o$

$Cl$ (based on Petukhov-Popov) $= 2.1502$

Alpha (based on Nusselt ($T_{del}$)) $= 0.9498$

Enhancement ($q$) $= 1.330$

Enhancement ($\Delta T$) $= 1.238$

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<th>$H_o$ ($W/m^2-K$)</th>
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Least-Squares Line for $H_o$ vs $q$ curve:

Slope $= -2.4792E-01$

Intercept $= 5.8256E+05$

Least-squares line for $q = a*\Delta T + b$

$a = 2.6385E+04$

$b = 7.5000E-01$

NOTE: 10 data points were stored in file FONMVH6T1

NOTE: 10 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVH6T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.85 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2144
Alpha (based on Nusselt (Tdel)) = 0.9460
Enhancement (q) = 1.323
Enhancement (Del-T) = 1.233

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Least-Squares Line for Ho vs q curve:
Slope = -2.4920E-01
Intercept = 5.8254E+05

Least-squares line for q = a*delta-T*b
a = 2.6267E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH6T2

NOTE: 14 X-Y pairs were stored in data file

152
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FOMMTVT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

\[ C_l \text{ (based on Petukhov-Popov)} = 1.0427 \]
\[ \text{Alpha (based on Nusselt (Tdel))} = 1.0131 \]
Enhancement (q) = 1.325
Enhancement (\(\Delta T\)) = 1.235

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Least-Squares Line for Ho vs q curve:
Slope = -2.0780E-01
Intercept = 5.7958E+05

Least-squares line for q = a*delta-T^b
a = 2.9413E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FOMMVT1
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAH7TI
This analysis includes end-fin effect
Thermal conductivity: 21.0 (W/m.K)
Inside diameter, D1: 13.86 (mm)
Outside diameter, D0: 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient: 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2365
Alpha (based on Nusselt (Tdel)) = 0.9248
Enhancement (q) = 1.275
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Least-Squares Line for Ho vs q curve:
Slope = -2.2891E-01
Intercept = 7.6695E+05

Least-squares line for q = a*delta-T^b
a = 3.0311E+04
b = 7.5000E-01

NOTE: 20 data points were stored in file FONMAH7TI
NOTE: 20 X-Y pairs were stored in data file
NOTE: Program name: DR49ST
Data taken by: O'KEEFE
This analysis done on file: FONMAN7T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.35 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.1913
Alpha (based on Nusselt (Tdel)) = 0.8660
Enhancement (q) = 1.179
Enhancement (Del-T) = 1.131

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Least-Squares Line for Ho vs q curve:
Slope = -2.1515E-01
Intercept = 7.5742E+05

Least-squares line for q = a*delta-T*b
a = 2.8701E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN7T1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: OOT
Data taken by: O'KEEFE
This analysis done on file: FONMVH7T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.86 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

\[ C_i \text{ (based on Petukhov-Popov)} = 1.9559 \]

\[ \text{Alpha (based on Nusselt (Tdel))} = 0.8552 \]

\[ \text{Enhancement (q)} = 1.156 \]

\[ \text{Enhancement (Del-T)} = 1.115 \]

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Least-Squares Line for Ho vs q curve:
Slope  = -2.8347E-01
Intercept = 5.8361E+05

Least-squares line for q = a*delta-T^b
a = 2.3773E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH7T2

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRFort
Data taken by: O'KEEFE
This analysis done on file: FONMUN7T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.86 (mm)
Outside diameter, D0 = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 0.9775
Alpha (based on Nusselt (Tdel)) = 0.8700
Enhancement (q) = 1.081
Enhancement (Del-T) = 1.060

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Least-Squares Line for Ho vs q curve:
Slope = -2.4125E-01
Intercept = 5.79563E+05

Least-squares line for q = a*delta-T^b
a = 2.4307E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUN7T1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRRST
Data taken by: O'KEEFE
This analysis done on file: FONMAHLT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: LPD KORODENSE TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.9032
Alpha (based on Nusselt (Tdel)) = 0.9039
Enhancement (q) = 1.535
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Least-Squares Line for Ho vs q curve:
Slope = -2.4801E-01
Intercept = 7.7225E+05

Least-squares line for q = a+delta-T^b
a = 2.9563E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHLT2
NOTE: 14 X-Y pairs were stored in data file

158
NOTE: Program name : DRPOW
Data taken by : O'KEEFE
This analysis done on file : FONMAHLT3
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.8921
Alpha (based on Nusselt (Tdel)) = 0.9159
Enhancement (q) = 1.259
Enhancement (Del-T) = 1.188

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Least-Squares Line for Ho vs q curve:
Slope = -2.4475E-01
Intercept = 7.7234E+05

Least-squares line for q = a*delta-T^b
a = 2.9951E+04
b = 7.5000E-01

NOTE: 11 data points were stored in file FONMAHLT3
NOTE: 11 X-Y pairs were stored in data file
NOTE: Program name : DP6
Data taken by : O'KEEFE
This analysis done on file : FONMANLT2
This analysis includes end-fim effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0556
Alpha (based on Nusselt (Toel)) = 0.9191
Enhancement (q) = 1.276
Enhancement (Oel-T) = 1.201

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Least-Squares Line for Ho vs q curve:
Slope = -2.2363E-01
Intercept = 7.6548E+05

Least-squares line for q = a-delta-T' b
a = 3.0263E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANLT2
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name : OKEEF
   Data taken by : O'KEEFE
   This analysis done on file : FONMANLT3
   This analysis includes end-fin effect
   Thermal conductivity = 21.0 (W/m.K)
   Inside diameter, D1 = 13.47 (mm)
   Outside diameter, Do = 15.85 (mm)
   This analysis uses the QUARTZ THERMOMETER readings
   Modified Petukhov-Popov coefficient = 1.0000
   Using no insert inside tube
   Tube Enhancement : LPD KORODENSE TUBE
   Tube material : TITANIUM
   Pressure condition : ATMOSPHERIC
   Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.9930
Alpha (based on Nusselt (Tdel)) = 0.9411
Enhancement (q) = 1.317
Enhancement (Del-T) = 1.230

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Least-Squares Line for Ho vs q curve:
Slope = -2.3725E-01
Intercept = 7.5793E+05

Least-squares line for q = a*delta-T"b
a = 3.1076E+04
b = 7.5000E-01

NOTE: 11 data points were stored in file FONMANLT3

NOTE: 11 X-Y pairs were stored in data file
NOTE: Program name: ORCJ
Data taken by: O'KEEFE
This analysis done on file: FONMVHLT1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: LPD KORODENSE TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.7173
Alpha (based on Nusselt (Tdel)) = 0.9449
Enhancement (q) = 1.321
Enhancement (Del-T) = 1.232

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Least-Squares Line for Ho vs q curve:
Slope = -2.6049E-01
Intercept = 5.8423E+05

Least-squares line for q = a*delta-T^b
a = 2.6230E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHLT1
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name : DREVT
Data taken by : O'KEEFE
This analysis done on file : FONMVHLT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, \(D_i\) = 13.47 (mm)
Outside diameter, \(D_o\) = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for \(h_o\)

\[ C_i (\text{based on Petukhov-Popov}) = 2.6688 \]
\[ \text{Alpha (based on Nusselt (Tdel))} = 0.949F \]
Enhancement (q) = 1.729
Enhancement (\(\Delta T\)) = 1.238

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Least-Squares Line for \(h_o\) vs \(q\) curve:
\[ \text{Slope} = -2.5633E-01 \]
\[ \text{Intercept} = 5.8376E+05 \]

Least-squares line for \(q = a \times \Delta T \times b\)
\[ a = 2.6375E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 12 data points were stored in file FUNMVHLT2

NOTE: 12 X-Y pairs were stored in data file
NOTE: Program name : DR911
Data taken by : O'KEEFE
This analysis done on file : FONVMNLT2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Oi = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ct (based on Petukhov-Popov) = 1.8686
Alpha (based on Nusselt (Tdel)) = 0.9525
Enhancement (q) = 1.220
Enhancement (Del-T) = 1.161

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Least-Squares Line for Ho vs q curve:
Slope = -2.5018E-01
Intercept = 5.8313E+05

Least-squares line for q = a+delta-T*b
a = 2.6547E-04
b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVNL2

NOTE: 12 X-Y pairs were stored in data file
NOTE: Program name: ORE2ST

Data taken by: O'KEEFE

This analysis done on file: FONMVNL3

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement: LPD KORODENSE TUBE

Tube material: TITANIUM

Pressure condition: VACUUM

Nusselt theory is used for H0

C1 (based on Petukhov-Popov) = 1.865

Alpha (based on Nusselt (Tdel)) = 0.9863

Enhancement (q) = 1.226

Enhancement (Oel-T) = 1.165

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Least-Squares Line for Ho vs q curve:

Slope = -2.4579E-01

Intercept = 5.9355E+05

Least-squares line for q = a*delta-T^b

a = 2.6648E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVNL3

NOTE: 14 x-y pairs were stored in data file
NOTE: Program name: DRF

Data taken by: O'KEEFE

This analysis done on file: FONMAHLITI

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.47 (mm)

Outside diameter, Do = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE

Tube material: TITANIUM

Pressure condition: ATMOSPHERIC

Nusselt theory is used for H0

C1 (based on Petukhov-Popov) = 2.5673

Alpha (based on Nusselt (Tdel)) = 0.8097

Enhancement (q) = 1.211

Enhancement (DEL-T) = 1.154

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Least-Squares Line for H0 vs q curve:

Slope = -2.4945E-01

Intercept = 7.7129E-05

Least-squares line for q = a*delta-T\'b

a = 2.9093E+04

b = 7.5000E-01

NOTE: 15 data points were stored in file FONMAHLITI

NOTE: 15 X-Y pairs were stored in data file
NOTE: Program name: DRPFT

Data taken by: O'KEEFE

This analysis done on file: FONMANLIT

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, D1 = 13.47 (mm)

Outside diameter, Do = 15.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using no insert inside tube

Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE

Tube material: TITANIUM

Pressure condition: ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.0362

Alpha (based on Nusselt (Tdel)) = 0.8688

Enhancement (q) = 1.184

Enhancement (Del-T) = 1.135

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Least-Squares Line for Ho vs q curve:
Slope = -2.5035E-01
Intercept = 7.6937E+05

Least-squares line for q = a*delta-T*b
a = 2.8535E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANLIT

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name : DRWE
Data taken by : O'KEEFE
This analysis done on file : FONMVHLITI
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3166
Alpha (based on Nusselt (Tdel)) = 0.8799
Enhancement (q) = 1.201
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Least-Squares Line for Ho vs q curve:
Slope = -2.7629E-01
Intercept = 5.83568E+05

Least-squares line for q = a*delta-T^b
a = 2.4437E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHLITI
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRtg
Data taken by: O'KEEFE
This analysis done on file: FONMVNLIT1
This analysis includes end-fin effect.
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED LBD KORODENSE TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.7837
Alpha (based on Nusselt (Tdel)) = 0.8545
Enhancement (q) = 1.056
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Least-Squares Line for Ho vs q curve:
Slope = -2.9007E-01
Intercept = 5.8324E+05

Least-squares line for q = a*delta-T^b
a = 2.3759E+04
b = 7.5000E-01

NOTE: 15 data points were stored in file FONMVNLIT1

NOTE: 15 x-y pairs were stored in data file
NOTE: Program name: DPG
Data taken by: O'KEEFE
This analysis done on file: FONMAHL2T1
This analysis includes end-fins effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.6388
Alpha (based on Nusselt (Tdel)) = 0.9089
Enhancement (q) = 1.246
Enhancement (Del-T) = 1.179

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Least-Squares Line for Ho vs q curve:
Slope = -2.4705E-01
Intercept = 7.7249E+05

Least-squares line for q = a+delta-T*b
a = 2.9774E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL2T1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRPaT
Data taken by: O'KEEFE
This analysis done on file: FONMANL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE
Tube material: TITANIUM
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

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Least-Squares Line for Ho vs q curve:
Slope = -2.4184E-01
Intercept = 7.657E+05

Least-squares line for q = a*delta-T^b
a = 2.9268E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL2T1

NOTE: 14 X-Y pairs were stored in data file
Data taken by O'KEEFE
This analysis done on file FONMVHL2T1
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4258
Alpha (based on Nusselt (Tdel)) = 0.6901
Enhancement (q) = 1.220
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Least-Squares Line for Ho vs q curve:
Slope = -2.8095E-01
Intercept = 5.8479E+05

Least-squares line for q = a*delta-T*b
a = 2.4863E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL2T1
NOTE: 14 X-Y pairs were stored in data file
Data taken by: O'KEEFE
This analysis done on file: FONMVLINT
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, Di = 13.47 (mm)
Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE
Tube material: TITANIUM
Pressure condition: VACUUM
Nusselt theory is used for Ho

\[ C_i \text{ (based on Petukhov-Popov)} = 1.9387 \]
\[ \alpha \text{ (based on Nusselt (Tdel))} = 0.8688 \]
Enhancement (q) = 1.079
Enhancement (Tdel-T) = 1.059

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Least-Squares Line for Ho vs q curve:
Slope = -2.7734E-01
Intercept = 5.8353E+05

Least-squares line for \( q = a + \delta T b \)
\[ a = 2.4150E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 14 data points were stored in file FONMVLINT

NOTE: 14 X-Y pairs were stored in data file

173
NOTE: Program name: O'R Through
Data taken by: O'KEEFE
This analysis done on file: FONMAHL3T2
This analysis includes end-fin effect
Thermal conductivity = 21.0 (W/m.K)
Inside diameter, D1 = 13.47 (mm)
Outside diameter, D0 = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement : WIRE-WRAPPED LFD KORODENSE TUBE
Tube material : TITANIUM
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.8352
Alpha (based on Nusselt (Tdel)) = 0.9632
Enhancement (q) = 1.355
Enhancement (Del-T) = 1.256

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Least-Squares Line for Ho vs q curve:
Slope = 2.5038E-01
Intercept = 7.6980E+05

Least-squares line for q = a*delta-T^b
a = 3.1776E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHL3T2

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name : CRJ3T

Data taken by : O'KEEFE

This analysis done on file : FONMANL3T!

This analysis includes end-fin effect

Thermal conductivity  = 21.0 (W/m.K)

Inside diameter, D_i = 13.47 (mm)

Outside diameter, D_o = 15.85 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient  = 1.0000

Using no insert inside tube

Tube Enhancement : WIRE-WRAPPED LPD KORODENSE TUBE

Tube material : TITANIUM

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C_l (based on Petukhov-Popov)  = 2.2023

Alpha (based on Nusselt (T_delt)) = 0.9330

Enhancement (q)  = 1.102

Enhancement (Delt-T)  = 1.218

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Least-Squares Line for Ho vs q curve:

Slope  = -2.2935E-01

Intercept  = 7.5779E+05

Least-squares line for q = a*delta-T^b

a  = 3.0712E+04

b  = 7.5000E-01

NOTE: 14 data points were stored in file FONMANL3T!

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORP0K
Data taken by: O'KEEFE
This analysis done on file: FONMVHL3T!
This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.47 (mm)
 Outside diameter, Do = 15.85 (mm)
This analysis uses the QUARTZ THERMOMETER readings
 Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
 Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE
 Tube material: TITANIUM
 Pressure condition: VACUUM
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.6094
Alpha (based on Nusselt (Tdelta)) = 0.9949
Enhancement (q) = 1.415
Enhancement (Tdelta) = 1.297

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Least-Squares Line for Ho vs q curve:
Slope = -2.3649E-01
Intercept = 5.8263E+05

Least-squares line for q = a*delta-T^b
a = 2.7690E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL3T!
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK  
Data taken by: O'KEEFE  
This analysis done on file: FOMUNL3T1  
This analysis includes end-fin effect  
Thermal conductivity = 21.0 (W/m.K)  
Inside diameter, Di = 13.47 (mm)  
Outside diameter, Do = 15.85 (mm)  
This analysis uses the QUARTZ THERMOMETER readings  
Modified Petukhov-Popov coefficient = 1.0000  
Using no insert inside tube  
Tube Enhancement: WIRE-WRAPPED LPD KORODENSE TUBE  
Tube material: TITANIUM  
Pressure condition: VACUUM  
Nusselt theory is used for Ho  

\[ C_i \text{ (based on Petukhov-Popov)} = 2.0410 \]  
\[ \alpha \text{ (based on Nusselt (Tdel))} = 0.9419 \]  
Enhancement (q) = 1.202  
Enhancement (Delta-T) = 1.148  

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Least-Squares Line for Ho vs q curve:  
Slope = -2.5211E-01  
Intercept = 5.8301E+05  

Least-squares line for q = a*Delta-T-b  
a = 2.5202E+04  
b = 7.5000E-01  

NOTE: 14 data points were stored in file FOMUNL3T1  
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DRFKIT
Data taken by: O'KEEFE
This analysis done on file: FONMAHC1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: COPPER
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

\[ C_1 \text{ (based on Petukhov-Popov)} = 2.8056 \]
\[ \text{Alpha} \text{ (based on Nusselt (}} \Delta \text{T)} = 0.8318 \]
\[ \text{Enhancement (}} q \text{) = 1.049 \]
\[ \text{Enhancement (}} \Delta \text{T} \text{) = 1.037 \]

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Least-Squares Line for Ho vs q curve:
\[ \text{Slope} = -3.4908E-01 \]
\[ \text{Intercept} = 7.55668E-05 \]

Least-squares line for \( q = a \cdot \Delta T + b \)
\[ a = 2.5131E+04 \]
\[ b = 7.5000E-01 \]

NOTE: 17 data points were stored in file FONMAHC1.

NOTE: 17 X-Y pairs were stored in data file
NOTE: Program name : O8QQK
Data taken by : O'KEEFE
This analysis done on file : FONMANS1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.2653
Alpha (based on Nusselt (Tdel)) = 0.8159
Enhancement (q) = 1.052
Enhancement (Del-T) = 1.039

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Least-Squares Line for Ho vs q curve:
Slope = -2.3166E-01
Intercept = 7.2933E+05

Least-squares line for q = a+delta-T\'b
\(a = 2.5317E+04\)
\(b = 7.5000E-01\)

NOTE: 14 data points were stored in file FONMANS1
NOTE: 14 x-y pairs were stored in data file
NOTE: Program name: DRFMT
Data taken by: O'KEEFE
This analysis done on file: FONMVHC1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: SMOOTH TUBE
Tube material: COPPER
Pressure condition: VACUUM
Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.4815
Alpha (based on Nusselt (Tdel)) = 0.3376
Enhancement (q) = 0.958
Enhancement (Dei-T) = 0.963

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Least-Squares Line for Ho vs q curve:
Slope = -3.193E-01
Intercept = 5.544E+05

Least-squares line for q = a·delta-T·b
a = 2.1921E+04
b = 7.5000E-01

NOTE: 07 data points were stored in file FONMVHC1

NOTE: 07 X-Y pairs were stored in data file
NOTE: Program name: DRIT

Data taken by: O'KEEFE

This analysis done on file: FONMVC1

This analysis includes end-fin effect

Thermal conductivity: 385.0 (W/m.K)

Inside diameter, Di: 12.70 (mm)

Outside diameter, Do: 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient: 1.0000

Using no insert inside tube

Tube Enhancement: SMOOTH TUBE

Tube material: COPPER

Pressure condition: VACUUM

Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 1.0647

Alpha (based on Nusselt (Tdel)) = 0.8663

Enhancement (q) = 0.942

Enhancement (Del-T) = 0.956

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Least-Squares Line for Ho vs q curve:
Slope = -2.7240E-01
Intercept = 5.4543E+05

Least-squares line for q = a*Delta-T+b
a = 2.3994E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVC1

NOTE: 14 <q> pairs were stored in data file
NOTE: Program name: DRPOK
Data taken by: O'KEEFE
This analysis done on file: FONMAH68C1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, D0 = 15.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: COPPER
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.8055
Alpha (based on Nusselt (Tdel)) = 1.2643
Enhancement (q) = 1.934
Enhancement (Del-T) = 1.640

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Least-Squares Line for Ho vs q curve:
Slope = -1.9114E-01
Intercept = 7.3487E+05

Least-squares line for q = a*delta-T*b
a = 3.9079E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH68C1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name : DRPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAN68C1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, Di = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement : WIRE-WRAPPE SMOOTH TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

\[
C_i (based \ on \ Petukhov-Popov) = 1.2431 \\
\alpha (based \ on \ Nusselt (T_{del})) = 1.3153 \\
Enhancement (q) = 2.053 \\
Enhancement (\Delta T) = 1.719
\]

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Least-Squares Line for Ho vs q curve:
Slope = -1.3433E-01
Intercept = 7.1006E+05

Least-squares line for q = a*delta-T^b
\[
a = 4.1757E+04 \\
b = 7.5000E-01
\]

NOTE: 14 data points were stored in file FONMAN68C1

NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: DPPOK
Data taken by: O'KEEFE
This analysis done on file: FONMVH68C1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.000
Using HEATEX insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: COPPER
Pressure condition: VACUUM
Nusselt theory is used for Ho

Cl (based on Petukhov-Popov) = 2.5490
Alpha (based on Nusselt (Tdel)) = 1.1854
Enhancement (q) = 1.787
Enhancement (Del-T) = 1.546

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Least-Squares Line for Ho vs q curve:
Slope = -2.0791E-01
Intercept = 5.4980E+05

Least-squares line for q = a*delta-T^b
a = 3.1238E+04
b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVH68C1
NOTE: 14 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMV6BC1
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, Do = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: COPPER
Pressure condition: VACUUM
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0379
Alpha (based on Nusselt (Tdel)) = 1.2885
Enhancement (q) = 1.825
Enhancement (Del-T) = 1.570

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2 | 3.79 | 7.037E+03 | 1.934E+04 | 1.644E+05 | 8.24 | 48.70
3 | 3.26 | 6.671E+03 | 2.102E+04 | 1.549E+05 | 7.37 | 48.66
4 | 2.74 | 6.177E+03 | 2.189E+04 | 1.432E+05 | 6.54 | 48.63
5 | 2.21 | 5.557E+03 | 2.262E+04 | 1.288E+05 | 5.69 | 48.61
6 | 1.68 | 4.800E+03 | 2.340E+04 | 1.111E+05 | 4.75 | 48.60
7 | 1.16 | 3.982E+03 | 2.496E+04 | 9.997E+04 | 3.90 | 48.71
8 | 1.68 | 4.755E+03 | 2.277E+04 | 1.127E+05 | 4.95 | 48.81
9 | 1.16 | 3.877E+03 | 2.492E+04 | 9.988E+04 | 3.51 | 43.53
10 | 2.21 | 5.557E+03 | 2.308E+04 | 1.316E+05 | 5.70 | 48.57
11 | 2.74 | 6.155E+03 | 2.177E+04 | 1.446E+05 | 6.64 | 48.55
12 | 3.27 | 6.643E+03 | 2.086E+04 | 1.567E+05 | 7.51 | 48.66
13 | 3.79 | 7.016E+03 | 1.981E+04 | 1.647E+05 | 8.31 | 48.67
14 | 4.32 | 7.407E+03 | 1.954E+04 | 1.746E+05 | 8.94 | 48.85
15 | 2.74 | 6.165E+03 | 2.172E+04 | 1.423E+05 | 6.55 | 48.58
16 | 1.16 | 3.996E+03 | 2.523E+04 | 9.882E+04 | 3.52 | 48.70

Least-Squares Line for Ho vs q curve:
Slope = -1.6323E-01
Intercept = 5.4549E+05

Least-squares line for q = a*delta-T^b
a = 3.4454E+04
b = 7.5000E-01

NOTE: 16 data points were stored in file FONMV6BC1

NOTE: 16 X-Y pairs were stored in data file

185
NOTE: Program name : DPPOK
Data taken by : O'KEEFE
This analysis done on file : FONMAH71CI
This analysis includes end-fin effect
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, D0 = 19.05 (mm)
This analysis uses the QUARTZ THERMOMETER readings.
Modified Petukhov-Popov coefficient = 1.0030
Using HEATEX insert inside tube
Tube Enhancement : SMOOTH TUBE
Tube material : COPPER
Pressure condition : ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 3.0634
Alpha (based on Nusselt (Tdel)) = 1.5049
Enhancement (q) = 2.313
Enhancement (Del-T) = 1.875

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</tbody>
</table>

Least-squares Line for Ho vs q curve:
Slope = -1.473E-01
Intercept = 7.2837E+05

Least-squares line for q = a+delta-T*b
a = 4.5855E+04
b = 7.5000E-01

NOTE: 12 data points were stored in file FONMAH71CI

NOTE: 12 X-Y pairs were stored in data file
NOTE: Program name: ORPOK
Data taken by: O'KEEFE
This analysis done on file: FONMANTIC
This analysis includes end-fins effect.
Thermal conductivity = 385.0 (W/m.K)
Inside diameter, D1 = 12.70 (mm)
Outside diameter, D0 = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings
Modified Petukhov-Popov coefficient = 1.0000
Using no insert inside tube
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE
Tube material: COPPER
Pressure condition: ATMOSPHERIC
Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.25E3
Alpha (based on Nusselt (Tdel)) = 1.72E5
Enhancement (q) = 2.547
Enhancement (Del-T) = 2.132

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<tr>
<th>#</th>
<th>Vw</th>
<th>Uo</th>
<th>Ho</th>
<th>Qp</th>
<th>Tcf</th>
<th>Ts</th>
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<td>5.75E+03</td>
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Least-Squares Line for Ho vs q curve:
Slope = -3.652E-02
Intercept = 7.004E-05

Least-squares line for q = a*delta-T+b:
a = 5.5135E-04
b = 7.5000E-03

NOTE: 14 data points were stored in file FONMANTIC.

NOTE: 14 x-y pairs were stored in data file.
NOTE: Program name: DRPOK  
Data taken by: O'KEEFE  
This analysis done on file: FOMUNTIC1  
This analysis includes end-fin effect  
Thermal conductivity = 365.0 (W/m.K)  
Inside diameter, \(D_i\) = 12.70 (mm)  
Outside diameter, \(D_o\) = 19.05 (mm)  
This analysis uses the QUARTZ THERMOMETER readings.  
Modified Petukhov-Popov coefficient = 1.0000  
Using no insert inside tube  
Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE  
Tube material: COPPER  
Pressure condition: VACUUM  
Nusselt theory is used for \(\text{Nu}\).  

\(\text{Ci} \) (based on Petukhov-Popov) \(= 1.0583\)  
\(\text{Alpha} \) (based on Nusselt \((T_{de})\)) \(= 1.4135\)  
Enhancement \((q)\) \(= 1.809\)  
Enhancement \((\text{Del}-T)\) \(= 1.560\)

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<th>Data</th>
<th>(V_w) (m/s)</th>
<th>(U_o) (W/m²-K)</th>
<th>(T_{cf}) (C)</th>
<th>(T_s) (C)</th>
<th>(\text{Op}) (W/m²-K)</th>
<th>(\text{Ho}) (W/m²-K)</th>
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</table>

Least-Squares Line for \(\text{Ho} vs q\) curve:  
Slope \(= -1.4852E-01\)  
Intercept \(= 5.4553E+05\)

Least-squares line for \(q = a+b \text{e}^{-b}\):  
\(a = 3.7311E-04\)  
\(b = 7.5000E-01\)

NOTE: 14 data points were stored in file FOMUNTIC1  
NOTE: 14 \(\times\) \(y\) pairs were stored in data file.
NOTE: Program name: DRFOK

Data taken by: O'KEEFE

This analysis done on file: FONMVHTIC2

This analysis includes end-fin effect

Thermal conductivity = 385.0 (W/m.K)

Inside diameter, Di = 12.70 (mm)

Outside diameter, Do = 19.05 (mm)

This analysis uses the QUARTZ THERMOMETER readings

Modified Petukhov-Popov coefficient = 1.0000

Using HEATEX insert inside tube

Tube Enhancement: WIRE-WRAPPED SMOOTH TUBE

Tube material: COPPER

Pressure condition: VACUUM

Nusselt theory is used for Ho

\( \text{Ci} \) (based on Petukhov-Popov) = 2.7647

\( \text{Alpha} \) (based on Nusselt \( (T_{del}) \)) = 1.2803

Enhancement (q) = 1.686

Enhancement (Del-T) = 1.479

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<th>( v_w )</th>
<th>( u_o )</th>
<th>Ho</th>
<th>Qp</th>
<th>Tcf</th>
<th>Ts</th>
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<td>48.57</td>
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</table>

Least-Squares Line for Ho vs q curve:

Slope = -1.3477E-01
Intercept = 5.5020E+05

Least-squares line for \( q = a - \text{delta-T} \cdot b \)

\( a = 3.3756E+04 \)
\( b = 7.5000E+01 \)

NOTE: 10 data points were stored in file FONMVHTIC2

NOTE: 10 X-Y pairs were stored in data file
APPENDIX E. DRPOK PROGRAM LISTING

The program DRPOK, which was used to collect and reprocess all of the data, is listed in this appendix.
TO BE USED WITH NON-INSTRUMENTED TUBES ONLY
TAKES DATA IN THE FORMAT OF SWENSEN/O'KEEFE
CAN REPROCESS ANY NON-INSTRUMENTED DATA
THIS PROGRAM WAS USED TO COLLECT ALL THE NON-INSTRUMENTED DATA TAKEN BY O'KEEFE (APR-SEP 1992) FOR TITANIUM TUBES
MEANING OF ALL FLAGS IN PROGRAM

IFT: FLUID TYPE
ISO: OPTION WITHIN PROGRAM
IM: INPUT MODE
IWIL: VALUE OF C1 USED
IFG: FINNED OR SMOOTH
INN: INSERT TYPE
IWT: LOOP NO. WITHIN PROGRAM
IWITH: ALTERNATIVE CONDENSER TUBES
IMC: TUBE MATERIAL
ITDS: TUBE DIAMETER
IPC: PRESSURE CONDITION
INF: DIMENSIONLESS FILE REQUIRED
IPF: PLOT FILE REQUIRED
IOV: OUTPUT REQUIRED
IH: INSIDE HTC CORRELATION
IOC: OUTSIDE HTC THEORY/CORRELATION

DATA

READ C(*)
READ T55(*)
READ T56(*)
READ T57(*)
READ T58(*)
READ T59(*)
READ T56(*)
READ T57(*)
READ T58(*)
READ T59(*)

191
1054 READ T57(*)
1056 READ T58(*)
1057 Dr=.015875  ! Outside diameter of the outlet end
1058 Dssp=.1524  ! Inside diameter of stainless steel test section
1059 A=PI*Dssp^2/4
1060 Alp2=0.
1061 L=.13335   ! Condensing length
1062 L1=.060325 ! Inlet end "fin length"
1063 L2=.034925 ! Outlet end "fin length"
1064 PRINT 1
1065 BEEP
1066 PRINT USING "4X,""Select option:"
1067 PRINT USING "EX,"" 0 Take data or re-process previous data"
1068 PRINT USING "EX,"" 1 Print raw data"
1069 PRINT USING "EX,"" 2 WILSON Analysis"
1070 PRINT USING "EX,"" 3 MODIFY"
1071 PRINT USING "EX,"" 4 PURGE"
1072 PRINT USING "EX,"" 5 RENAME"
1073 INPUT Iso
1074 Iso=Iso+1
1075 IF Iso>1 THEN 3094
1076 BEEP
1077 INPUT "SELECT FLUID (0=WATER, 1=R-113, 2=EG)",Ift
1078 Ifto=Ift
1079 BEEP
1080 Ijob=0
1081 INPUT "ENTER INPUT MODE (0=3054A, 1=FILE)",Im
1082 Im=Im+1
1083 BEEP
1084 IF Im=1 THEN
1085 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1086 OUTPUT 709;"TD";Date$
1087 OUTPUT 709;"TD"
1088 ENTER 709;Date$
1089 END IF
1090 IF Ijob=1 THEN
1091 BEEP
1092 INPUT "SKIP PAGE AND HIT ENTER",Ol
1093 END IF
1094 PRINT "Month, date and time :";Date$
1095 END IF
1096 PRINT
PRINT USING "10X,""NOTE: Program name : DRPOK""

IF Ijob=1 THEN 1189
BEEP
INPUT "SELECT (Ci:O=FINNED,1=STORED Ci)" ,Iwl
IF Iwl=1 THEN
BEEP
INPUT "GIVE A NAME FOR THE RAW DATA FILE" ,D_file$
PRINT USING "16X,""File name : "" ,14A" ;D_file$
CREATE BDAT D_file$;30
ASSIGN @File TO D_file$
BEEP
INPUT "ENTER GEOMETRY CODE (I=FINNED,O=PLAIN)" ,Ifg
Inn=0
PRINTER IS 1
BEEP
PRINT " ENTER INSERT TYPE:"
PRINT " 0=None (DEFAULT)"
PRINT " 1=TWISTED TAPE"
PRINT " 2=WIRE WRAP"
PRINT " 3=HEATEX"
INPUT Inn
OUTPUT @File;Iwl,Ifg,Inn
Iwt=0 ! FOR UNINSTRUMENTED TUBE
Fh=0
Fp=0
Fw=0
Istu=0
IF Ifg=0 THEN 1241
INPUT "FIN PITCH, HEIGHT AND WIDTH, Fp,Fh,Fw" ,Fp,Fh,Fw
OUTPUT @File;Iwt,Fp,Fw,Fh
ELSE
BEEP
PRINTER IS 1
PRINT " STUDENT'S DATA TO BE REPROCESSED:" 
PRINT " @SWENSEN/O'KEEFE (DEFAULT)"
PRINT " I=VAN PETTEN/MITROU/COUMES/GUTTENDORF"
INPUT Istu
BEEP
PRINT " STUDENT NAME:"
PRINT " 0=VAN PETTEN"
PRINT " 1=MITROU"
PRINT " 2=COUMES"
PRINT " 3=GUTTENDORF"
ELSE
PRINT "4=SWENSEN"
PRINT "5=O'KEEFE"
END IF
INPUT Inam
BEEP
INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
PRINTER IS 701
IF Inam=0 THEN PRINT USING "16X,""Data taken by : VAN PETTEN"
IF Inam=1 THEN PRINT USING "16X,""Data taken by : MITROU"
IF Inam=2 THEN PRINT USING "16X,""Data taken by : COUMES"
IF Inam=3 THEN PRINT USING "16X,""Data taken by : GUTTENDOFF"
IF Inam=4 THEN PRINT USING "16X,""Data taken by : SWENSEN"
IF Inam=5 THEN PRINT USING "16X,""Data taken by : O'KEEFE"
PRINT USING "16X,""This analysis done on file : ",10A:D_file$
PRINTER IS 1
BEEP
INPUT "ENTER NUMBER OF DATA SETS STORED",Nrun
ASSIGN @File TO D_file$
ENTER @File;Ifg,Inn
IF Istu=0 THEN
ENTER @File;lwt,Fp,Fw,Fh
ELSE
IF Ifg=0 THEN ENTER @File;lwt
IF Ifg=1 THEN ENTER @File:Fp,Fw,Fh
END IF
IF Ijob=1 THEN 1537
IF If 0 THEN 1345
BEEP
PRINT IS 1
PRINT USING "4X,""Select tube type:"
PRINT USING "8X,""0 Thick wall Copper"
PRINT USING "8X,""1 Wolverine Korodense LPD Titanium Tube"
PRINT USING "8X,""2 Smooth Titanium Tube"
PRINT USING "8X,""3 LPO Korodense Tube"
PRINT USING "8X,""4 Wire-Wrapped LPO Korodense Tube"
INPUT ityp
BEEP
PRINT USING "4X,""Select tube Enhancement used:"
PRINT USING "8X,""0 SMOOTH TUBE"
PRINT USING "8X,""1 FINNED TUBE"
PRINT USING "8X,""2 WIRE-WRAPPED SMOOTH TUBE"
PRINT USING "8X,""3 LPO KORODENSE TUBE"
PRINT USING "8X,""4 WIRE-WRAPPED LPD KORODENSE TUBE"
INPUT Ityp
PRINTER IS 701
1332 BEEP
1333 PRINTER IS 1
1334 PRINT USING "4X","Select Material Code:"
1335 PRINT USING "6X","0 Copper   1 Stainless steel"
1336 PRINT USING "6X","2 Aluminum 3 90:10 Cu-Ni"
1337 PRINT USING "6X","4 Titanium 
1338 INPUT Imc
1339 PRINTER IS 1
1340 BEEP
1341 Itds=1
1342 IF Iwth=0 THEN
1343 PRINT USING "4X","SELECT TUBE DIA TYPE:
1344 PRINT USING "6X","0 SMALL"
1345 PRINT USING "6X","1 MEDIUM (DEFAULT)
1346 INPUT Itds
1347 END IF
1348 PRINTER IS 701
1349 IF Iwth=0 THEN
1350 Di=.0127  ! ID OF MEDIUM AND LARGE TUBES
1351 Do=.01905  ! OD OF MEDIUM TUBE
1352 END IF
1353 IF Iwth=1 THEN
1354 Di=.01347
1355 Do=.01585
1356 END IF
1357 IF Iwth=2 THEN
1358 Di=.01386
1359 Do=.01587
1360 END IF
1361 IF Iwths=0 THEN
1362 Do=.0127
1363 Di=.009525
1364 END IF
1365 IF Iwths=2 THEN Do=.025
1366 IF Iwths=1 THEN Di=.01585
1367 IF Iwths=1 THEN Do=.01585
1368 IF Iwths=2 THEN Di=.01587
1369 IF Iwths=2 THEN Do=.01587
1370 IF Imc=0 THEN Kcu=385
1371 IF Imc=1 THEN Kcu=16
1372 IF Imc=2 THEN Kcu=167
1373 IF Imc=3 THEN Kcu=45
1374 IF Imc=4 THEN Kcu=20.1

195
1498 \( R_m = \frac{D_o \cdot \log(D_o / D_i)}{(2 \cdot K_{cu})} \) Wall resistance based on outside area
1501 BEEP
1504 INPUT "ENTER PRESSURE CONDITION (0=V, 1=A)", lpc
1507 Ipc = lpc
1508 Inf = 0
1510 BEEP
1511 Ife = 1
1536 PRINTER IS 701
1543 PRINT USING "16X," "This analysis includes end-fin effect"
1546 PRINT USING "16X," "Thermal conductivity = " , D.D , " (W/m.K)" ; "kcu
1549 PRINT USING "16X," "Inside diameter, D_i = " , D.D.DD , " (mm)" ; "Di = 1000
1552 PRINT USING "16X," "Outside diameter, D_o = " , D.D.DD , " (mm)" ; "D_o = 1000
1555 BEEP
1556 Ih1 = 0
1557 PRINTER IS 1
1558 PRINT " SELECT INSIDE CORRELATION:" 
1559 PRINT " 0=SIEDER-TATE (DEFAULT)"
1560 PRINT " 1=SLEICHER-ROUSE"
1561 PRINT " 2=PETUKHOV-POPOV"
1562 INPUT Ih1
1563 IF Ih1 = 0 THEN
1564 BEEP
1565 INPUT " SELECT REYNOLDS EXPONENT", Re, p
1567 END IF
1568 Ioc = 0
1569 BEEP
1570 PRINT
1571 PRINT " SELECT OUTSIDE THEORY/CORRELATION FOR WILSON ANALYSIS:" 
1572 PRINT " 0=NUSSELT THEORY (DEFAULT)"
1573 PRINT " 1=FUJII (1979) CORRELATION"
1574 INPUT Ioc
1575 BEEP
1576 Itm = 1
1577 PRINT
1578 PRINT " SELECT COOLANT TEMPERATURE RISE MEASUREMENT:" 
1579 IF Istu = 0 THEN PRINT " 0=SINGLE TEFLOn T/C"
1580 PRINT " 1=QUARTZ THERMOMETER (DEFAULT)"
1581 PRINT " 2=10-JUNCTION THERMOPILE"
1582 INPUT Itm
1583 PRINTER IS 701
1584 IF Itm = 0 THEN PRINT USING "16X," "This analysis uses the SINGLE TEFLOn T/C readings"
1585 IF Itm = 1 THEN PRINT USING "16X," "This analysis uses the QUARTZ THERMOMETER readings"
1586 IF Itm = 2 THEN PRINT USING "16X," "This analysis uses the 10-JUNCTION THERMOPILE readings"
1587 Ic = 1 FOR MODIFIED WILSON
1588 IF Ih1 = 0 THEN C1 = .027
1589 IF Ih1 = 2 AND D1 = .003525 THEN C1 = .051 TO BE MODIFIED
1590 IF Ih1 = 2 AND D1 = .0127 THEN C1 = .052
1591 IF Ih1 = 3 THEN C1 = .22
1589:1 IF Inn=0 THEN C1=.012
1589:2 IF Ift=2 THEN C1=.035
1589:3 END IF
1589:4 IF Ihi=1 THEN C1=1.
1589:5 IF Ihi=2 THEN C1=1.
1589:6 IF Iwil=1 THEN
1589:7 BEEP
1589:8 INPUT "ENTER C1 IF DIFFERENT FROM STORED VALUE",C1
1589:9 END IF
1589:10 PRINT USING "16, Modified Sieder-Tate coefficient = ".4D";C1
1589:11 IF Ihi=0 THEN PRINT USING "16X," "Chosen Reynolds No. exponent = ".D";Rexp
1589:12 IF Ihi=1 THEN PRINT USING "16X," "Modified Sleicher-Rouse coefficient = ".24D";C1
1589:13 END IF
1589:14 IF Ihi=1 THEN PRINT USING "16X, "Modified Petukhov-Popov coefficient = ".24D";C1
1589:15 IF Inn=0 THEN PRINT USING "16X, "Using no insert inside tube"
1589:16 IF Inn=3 THEN PRINT USING "16X, "Using HEATEX insert inside tube"
1589:17 IF Istu=0 THEN
1589:18 IF Inn=1 THEN PRINT USING "15X, "Using twisted tape insert inside tube"
1589:19 ELSE
1589:20 IF Inn=2 THEN PRINT USING "15X, "Using wire wrap insert inside tube"
1589:21 END IF
1589:22 IF Iic=0 AND Ife=1 THEN Ac=26.4
1589:23 IF Iic=1 THEN Ac=0.
1589:24 BEEP
1589:25 IF Ijob=1 THEN 1648
1589:26 PRINTER IS 1
1589:27 INPUT "NAME FOR A TEMPORARY PLOT FILE (TO BE PURGED)",P_file$
1589:28 P_file$="DUMMY"
1589:29 BEEP
1589:30 CREATE BDAT P_file$,10
1589:31 ASSIGN @Filep TO P_file$
1589:32 IF Ijob=1 THEN
1589:33 Iov=1
1589:34 GOTO 1689
1589:35 END IF
1589:36 BEEP
1589:37 INPUT "SELECT OUTPUT (=SHORT, 1=LONG)",Iov
1589:38 Iov=Iov+1
1589:39 PRINTER IS 701
1589:40 IF Ityp=0 THEN PRINT USING "16Y," "Tube Enhancement : SMOOTH TUBE"
1589:41 IF Ityp=1 THEN PRINT USING "16Y," "Tube Enhancement : FINNED TUBE"

197
1674 IF Ityp=2 THEN PRINT USING "16Y,""Tube Enhancement : WIRE-WRAPPED SMOOTH TUBE""*
1675 IF Ityp=3 THEN PRINT USING "16X,""Tube Enhancement : LPC KOPODENSE TUBE**
1676 IF Ityp=4 THEN PRINT USING "16X,""Tube Enhancement : WIRE-WRAPPED LPC 1.0 KOPODENSE TUBE***
1679 BEEP
1681 IF Imc=0 THEN PRINT USING "15X,""Tube material : COFFEE""****
1682 IF Imc=1 THEN PRINT USING "15X,"" Tube material : STAINLESS-STEEL""*****
1683 IF Imc=2 THEN PRINT USING "15X,"" Tube material : ALUMINUM""******
1684 IF Imc=3 THEN PRINT USING "15X,"" Tube material : 90/10 Cu/NI""*******
1685 IF Imc=4 THEN PRINT USING "15X,"" Tube material : TITANIUM""********
1686 IF Ip=0 THEN PRINT USING "16X,""Pressure condition : VACUUM""*********
1687 IF Ip=1 THEN PRINT USING "16X,""Pressure condition : ATMOSPHERIC""**********
1688 PRINT USING "16X,""Fin pitch, width, and height (mm): "",DD.DD,2y,Z.DD,2y,,Z.DD,2y,
2.00:"Fp,Fw,Fh
1689 IF (Iw1=0 OR Iw1=2) AND Im=2 THEN
1690 Jjob=1
1691 lwd=1
1696 CALL Wilson(C1)
1699 END IF
1702 J=0
1712 IF Iov=1 THEN
1722 PRINT
1724 PRINT USING "10X,""Data Vw Uo Ho Qp Tcf Ts Fp""***
1725 PRINT USING "10X,"" # (m/s) (W/m^2-K) (W/m^2-K) (W/m^2) (C) (C)
(S-R)""****
1726 ELSE
1728 PRINT USING "10X,""Data Vw Uo Ho Qp Tcf Ts f Ts""****
1729 PRINT USING "10X,"" # (m/s) (W/m^2-K) (W/m^2-K) (W/m^2) (C)
(C)"
1730 END IF
1740 END IF
1747 Z.=0
1750 Z.=0
1753 Z.=0
1756 Z.=0
1759 S.=0
1762 S.=0
1765 S.=0
1768 S.=0
1771 Go_on=1
1774 Repeat:**
1777  J=J+1
1780  IF I=m=1 THEN
1783  BEEP
1786  INPUT "LIKE TO CHECK NG CONCENTRATION (1=Y,0=N)?",Ng
1789  IF J=1 THEN
1792  OUTPUT 709;"AR AF40 AL41 VRS"
1795  OUTPUT 709;"AS SA"
1798  END IF
1801  BEEP
1804  INPUT "ENTER FLOWMETER READING",Fm
1807  OUTPUT 709;"AR AF60 AL62 VRS"
1810  OUTPUT 709;"AS SA"
1813  ENTER 709;Etp
1816  OUTPUT 709;"AS SA"
1819  BEEP
1822  INPUT "CONNECT VOLTAGE LINE",Ok
1825  ENTER 709;Bvol
1828  BEEP
1831  INPUT "DISCONNECT VOLTAGE LINE",Ot
1834  IF Bvol<.1 THEN
1837  BEEP
1840  BEEP
1843  INPUT "INVALID VOLTAGE - TRY AGAIN!",Ot
1846  GOTO 1819
1849  END IF
1852  OUTPUT 709;"AS SA"
1855  ENTER 709;Bamp
1858  Etp=Etp*1.E+6
1861  OUTPUT 709;"AR AF40 AL47 VRS"
1864  Nn=7
1867  FOR I=0 TO Nn
1869  OUTPUT 709;"AS SA"
1872  Se=0
1875  FOR K=1 TO 10
1878  ENTER 709;E
1881  Se=Se+E
1884  NEXT K
1887  Emf(I)=ABS(Se/10)
1890  Emf(I)=Emf(I)*1.E+6
1893  NEXT I
1896  OUTPUT 709;"AS SA"
1899  OUTPUT 713;"T1R2E"
1902  WAIT 2
1905  ENTER 713;T11
1908  OUTPUT 713;"T2P2E"
1911  WAIT 2

199
1939 ENTER 713;T2  
1942 OUTPUT 713;"T1R2E"  
1945 WAIT 2  
1946 ENTER 713;T12  
1951 T1=(T11+T12)*.5  
1954 OUTPUT 713;"T3R2E"  
1960 BEEP  
1970 INPUT "ENTER PRESSURE GAGE READING (Pga)",Pga  
1971 Pvapl=Pga*6894.7 ! PSI TO Pa  
1972 OUTPUT 709;"AR AF64 AL64 VRS"  
1973 OUTPUT 709;"AS SA" ! PRESSURE TRANSDUCER  
1974 SS=0  
1975 FOR K=1 TO 20  
1976 ENTER 709;Etran  
1977 SS=SS+Etran  
1978 NEXT K  
1979 Ptran=ABS(SS/20)  
1980 BEEP  
1981 ! PRESSURE IN Pa FROM TRANSDUCER  
1982 Pvap2=(-2.93604*Ptran+14.7827)*.894.7  
1985 ELSE  
1986 IF Istu=0 THEN  
1989 ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvapl,Pvap2,Emf(*)  
1990 ELSE  
1992 ENTER @File;Bvol,Bamp,Varan,Etp,Emf:0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,T2,Phg,Pwater  
1994 END IF  
1996 IF J=1 OR J=20 OR J=Nrun THEN  
1997 Ng=1  
1998 ELSE  
1999 Ng=0  
2000 END IF  
2002 END IF  
2003 IF Istu=0 THEN  
2005 Tstream=FNTvsl(Emf(0))  
2009 Tstream=Tstream1-273.15  
2010 Tstream=FNTvsl(Emf(1))  
2011 Tstream=Tstream2-273.15  
2012 Tstream=Tstream1  
2015 Troom=FNTvsl(Emf(2))  
2023 Troom=Troom-273.15  
2025 Tcon=FNTvssl(Emf(7))  
2039 Tcon=Tcon-273.15  
2042 ELSE  
2043 Tstream=FNTvsl(Emf(0))  
2044 Troom=FNTvsl(Emf(3))
2045 Tcon=FNIVsp(Emf(4))
2046 ENI IF
2048 Psat=FNv.st(Steam)
2050 Rohg=1329-122*(Troom-26.85)/50
2053 Rowater=FNhow(Steam)
2054 IF Istu=0 THEN
2051 Ptest1=Pvap1
2052 Ptest2=Pvap2
2053 ELSE
2054 Ptest2=(Phg*Rohg*Rowater)*9.81/1000
2055 END IF
2057 Pls=Psat*1.E-3
2058 Plp=Ptest2*1.E-3
2059 Plt=Pls
2092 Tsat=FNIVsp(Psat)
2098 Vst=FNIVst(Tsteam)
2104 Fpng=(Ptest2-Psat)/Ptest2
2111 Pps=1-Fpng
2112 Mwv=18.016
2121 IF If1=1 THEN Mwv=137  !TO BE CORRECTED
2124 IF If1=2 THEN Mwv=62
2126 Mfng=1/(1+(1/Vfng-1)*Mwv/28.97)
2128 Vfng=Vfng+100
2131 BEEP
2134 IF Icv=2 THEN
2137 PRINT
2139 PRINT USING "RECORD TIME OF TAKING DATA"
2140 IF Im=1 THEN
2141 OUTPUT 709;"TD"
2142 ENTER 709;Told$ END IF
2144 PRINT USING "10X," "Data set number " = ",DD,4X,14A:";J,Told$
2145 OUTPUT 709;"AP AF40 AL40 VFE"
2146 OUTPUT 709;"AS 5A"
2149 END IF
2152 IF Icv=2 AND Ng=1 THEN
2155 PRINT USING "10X," "Psat Ftran Tmeas Tsat Ng %"
2158 PRINT USING "10X," "(IFa) (IFa) (C) (C) Molal %"
2161 PRINT USING "11X,1(3D,00,2X),1(3D,00,2X),2(3D,00,2X),2X,1:MZC,D,2X,1:Ft,2P
1p,Tsteam,Tsat,Mfng
2164 PRINT
2167 END IF
2170 IF Mfng .S THEN
2173 BEEP
2176  IF Iu=1 AND Ng=1 THEN
2178  BEEP
2180  PRINT
2182  PRINT USING "10x","Energi the vaccum system"
2184  BEEP
2186  INPUT "Gt TO ACCEPT THIS RUN (1=ACCEPT,0=DELETE)"; Gt
2188  IF Gt=0 THEN
2190  BEEP
2192  DISP "NOTE: THIS DATA SET WILL BE DISCARDED"
2194  WAIT 5
2196  GOTO 1780
2198  END IF
2200  END IF
2202  END IF
2204  IF Gt=1 THEN
2206  IF Fm 10 OR Fm 100 THEN
2208  IFm=0
2210  BEEP
2212  INPUT INCORRECT FM (1=ACCEPT,0=DELETE) ;Ifm
2214  IF Ifm=0 THEN 1904
2216  END IF
2218  END IF
2220  ANALYSIS BEGINS
2222  IF lstu=0 THEN
2224  T1=FNT.s.55;Emf(3)
2226  T1=FNT.s.55;Emf(5)
2228  T0=FNT.s.55;Emf(4)
2230  To=FNT.s.55;Emf(6)
2232  T1=T1-273.15
2234  T2=T1-273.15
2236  To=To-273.15
2238  Td1=T1-T1
2240  Td2=T2-T2
2242  Td3=T3-T2
2244  Et1=Emf(3)+Emf(2)
2246  Dte=2.4891E-02-1.5246E-06*Et1^-1.31701E-10*Et1+2.5.1164E-15*Et1 3+3.10^19+Et1 4
2248  T1s=Dte*Et1;10.
2250  T2=11+T1s
2252  IF l0=2 THEN
2254  PRINT USING "1x","TIME TIME TIME TIME TIME DELTA DELTA DELTA DELTA DELTA DELTA"
2256  PRINT USING "1x","TEFLON" QUARTZ"
2258  PRINT USING "1x","10.30.3x";T11,T11,T12,Td1,Td1,Td2,T1s
2260  END IF
Er1 = \text{ABS}(T1 - T1) \\
Er2 = \text{ABS}(T12 - T1) \\
\text{PRINT} \text{ER} \text{IF} \text{T1} \text{DIFFER BY MORE THAN 5}^\text{a} \text{AND T-PILE DIFFER BY MORE THAN 5}^\text{a} \text{AND \text{Im}=1} \text{THEN} \\
\text{IF} \text{Er2} \text{.05 AND \text{Im}=1} \text{THEN} \\
\text{END IF} \\
\text{PRINT IS \text{701}} \\
\text{ELSE} \\
T1 = \text{FNTrsv(Emf(2))} \\
\text{Grad} = \text{FNGrad}((T1 + T2) * .5) \\
T0 = T1 + \text{ABS}(Et + (10 * \text{Grad} + 1.1 * E E) \\
T1 = T1 + Tc \\
T2 = Tc \\
\text{END IF} \\
\text{IF} \text{Isu}=0 \text{AND Itm}=0 \text{THEN} \\
T1 = T1 \\
T2 = Tc \\
\text{END IF} \\
\text{IF} \text{Itm}=1 \text{THEN} \\
T1 = T1 \\
T2 = Tc \\
\text{END IF} \\
\text{ENDIF} \\
Tavg = (T1 + T2c) * .5 \\
\text{IF} \text{It}=0 \\
Cpu = \text{FNCPw(Tavg)} \\
\text{PHw} = \text{FNPHw(Tavg)} \\
\text{IF} \text{Isu}=0 \text{THEN} \\
Md = 5.7409 * Fm + 12.057 * 1000 \\
M = Md * 0.0356 = 1.96644E-3 * T1 + 5.252E-6 * T1 + 5.1 * 0.0037 \\
\text{ELSE} \\
M = 1.04505E-2 + 6.6085E-3 * Fm \\
M = Md * 1.03456E-3 * T1 + 5.252E-6 * T1 + 5.1 * 995434 \\
\text{ENDIF} \\
M = Md / PHw \\
\text{IF} \text{It}=0 \\
Vw = M / (d + 0.27E-2) \\
\text{IF} \text{Isu}=0 \text{AND Jwth}=0 \text{THEN} \text{SWESEN FPIC, SMOOTH COPPER TUBE}
IF \( \text{Inn} = 0 \) AND \( V_w < 0.5 \) THEN \( T_2 = T_2 - (-2.73E-4 + 1.73E-4 * V_w + 9.3E-4 * V_w^2 - 1.96E-5 * V_w^3) \)

IF \( \text{Inn} = 1 \) THEN \( T_2 = T_2 - (-5.44E-5 + 1.71E-3 * V_w + 4.4E-4 * V_w^2 + 4.07E-5 * V_w^3) \)

IF \( \text{Inn} = 2 \) THEN \( T_2 = T_2 - (-3.99E-4 + 2.75E-3 * V_w + 1.45E-3 * V_w^2 + 8.16E-5 * V_w^3) \)

IF \( \text{Inn} = 3 \) THEN \( T_2 = T_2 - (8.57E-5 + 1.23E-3 * V_w + 1.08E-3 * V_w^2 + 8.16E-5 * V_w^3) \)

END IF

IF \( \text{Ist} = 0 \) AND \( \text{Iwth} = 2 \) THEN FRIC FACTOR SMOOTH TITANIUM TUBE

IF \( \text{Inn} = 0 \) AND \( V_w < 0.5 \) THEN \( T_2 = T_2 - (-4.62E-5 - 7.53E-4 * V_w + 1.6E-3 * V_w^2 - 8.24E-5 * V_w^3) \)

IF \( \text{Inn} = 3 \) THEN \( T_2 = T_2 - (2.09E-4 + 9.29E-5 * V_w + 2.3E-3 * V_w^2 + 6.16E-5 * V_w^3) \)

END IF

IF \( \text{Ist} = 0 \) AND \( \text{Iwth} = 1 \) THEN FRICCTION FACTORS FOR KORODENSE

IF \( \text{Inn} = 0 \) AND \( V_w < 0.5 \) THEN \( T_2 = T_2 - (-3.38E-4 + 1.88E-3 * V_w + 5.01E-4 * V_w^2 + 4.13E-5 * V_w^3) \)

IF \( \text{Ist} = 0 \) AND \( \text{Iwth} = 1 \) THEN FRICCTION FACTORS FOR KORODENSE

IF \( \text{Inn} = 3 \) THEN \( T_2 = T_2 - (2.09E-4 + 9.29E-5 * V_w + 2.3E-3 * V_w^2 + 6.16E-5 * V_w^3) \)

END IF

\( Q = \text{Md} * C_p \omega (T_2 - T_1) \)

\( Q_p = \frac{Q}{\pi * D_c * L} \)

IF \( I_h = 0 \) THEN

\( \text{Pr}_w = \text{FN}_{Pr}(T_{\text{avg}}) \)

\( \text{Re}_w = \text{Rh}_{w} * V_{w} * D / \mu_w \) ASUMED SAME FOR KORODENSE

\( \text{Pr}_{w} = \text{FN}_{Pr}(T_{\text{avg}}) \)

\( \text{Fe}_w = 0. \)

\( \text{Fe}_2 = 0. \)

\( \text{Cf} = 1. \)

\( \text{Pr}_{w} = \text{Pr}_w \)

\( \text{Re}_w = \text{Re}_w \)

\( \text{Re}_w = \text{Re}_w \)

IF \( I_h = 0 \) THEN

\( \text{Om}_e = \text{Re}_w * \text{Re}_w * \text{Pr}_w * 0.332 + \text{Cf} \)

END IF

IF \( I_h = 1 \) THEN

\( \text{Pr}_w = \frac{\text{FN}_{Pr}(T_{\text{avg}})}{\text{Re}_w} \)

\( \text{Sra} = 0.8 * (1 + 0.15 + \text{Re}_w) \)

\( \text{Srb} = 0.33333 + 0.5 * \text{Exp}(-0.5 * \text{Pr}_w) \)

\( \text{Om}_e = (0.7 * 0.15 * \text{Re}_w * \text{Pr}_w * \text{Sra}) \)

END IF

IF \( I_h = 2 \) THEN

\( \text{Eps}_1 = (1.82 * \text{LT} + 0.64) \)

\( \text{Pp}_1 = 1.34 \)

\( \text{Pp}_2 = 1.17 + 1.8 * \text{Pr}_w \)

\( \text{Pp}_2 = (\text{Eps}_1 / 8) * \text{Re}_w * \text{Pr}_w \)

204
\[ Pp_2 = (Pp_1 + Pp_2 \cdot (Eps_1/8)^{0.5} \cdot (Prw^{-0.666}-1)) \]

\[ Ome = Pp_1 / Pp_2 \]

END IF

\[ H_i = Kw / D_1 \cdot C_1 \cdot Ome \]

IF Ife = 0 THEN GOTO 2491

\[ P_1 = P_1 \cdot (D_0 + D_1) \]

\[ A_1 = (D_0 - D_1) \cdot P_1 \cdot (D_0 + D_1) \cdot 0.5 \]

\[ M_1 = (H_i \cdot P_1 / (Kcu \cdot A_1))^{0.5} \]

\[ P_2 = P_1 \cdot (D_1 + D_2) \]

\[ A_2 = (D_0 - D_1) \cdot P_1 \cdot (D_1 + D_2) \cdot 0.5 \]

\[ M_2 = (H_i \cdot P_2 / (Kcu \cdot A_2))^{0.5} \]

\[ F_{11} = FN\tanh(M_1 \cdot L_1) / (M_1 \cdot L_1) \]

\[ F_{22} = FN\tanh(M_2 \cdot L_2) / (M_2 \cdot L_2) \]

\[ D_t = Q / (P_1 \cdot D_1 \cdot (L + L_1 \cdot F_{11} + L_2 \cdot F_{22}) \cdot H_1) \]

IF \( H_i = 0 \) THEN

\[ C_{fc} = \frac{(Muw / FNMuw(Tavg + Dt))^{0.14}}{} \]

IF \( \text{ABS}((C_{fc} - C_f) / C_{fc}) < 0.001 \) THEN

\[ C_f = (C_f + C_{fc}) / 2 \]

GOTO 2461

END IF

IF \( H_i = 1 \) THEN

\[ Prw_{fc} = FNPrw(Tavg + Dt) \]

\[ Re_{11} = Vw \cdot D_0 \cdot FN\tanh(Tavg + Dt) / (Kcu \cdot D_0) \]

IF \( \text{ABS}((Prw_{fc} - Prw_f) / Prw_f) < 0.001 \) THEN

\[ Prw_f = (Prw_{fc} + Prw_f) / 2 \]

\[ Re_f = (Re_{11} + Re_{1f}) / 2 \]

GOTO 2461

END IF

END IF

Lmtd = (T_2o - T_11) / (Tsteam - T_11) / (Tsteam - T_2o)

Uo = Q / (Lmtd \cdot Pi \cdot Do \cdot L)

Ho = 1 / (1 / Uo - Do \cdot L / (D_0 \cdot (L + L_1 \cdot F_{11} + L_2 \cdot F_{22}) \cdot H_1) - R_m)

Tcf = Qp / Ho

Cpsc = FNCpw(Tc_1n + Tsteam) / 0.5

Hfg = FNHfg(Tsteam)

Two = Tsteam - Qp / Ho

Tfilm = Tsteam / 3 + Two \cdot 2 / 3

// Tfilm

Kf = FNKw(Tfilm)

Rho = FNRow(Tfilm)

Muf = FNMuw(Tfilm)

Hpg = 6.5 \cdot Kf \cdot Rhof^2 \cdot 9.81 \cdot Hfg / (Muf \cdot Do \cdot Qp) / 3

Hnuss = 0.728 \cdot (Kf \cdot 3 \cdot 9.81 \cdot Hfg \cdot Rhof^2 / (Muf \cdot Do \cdot Tcf)) / 0.25

Asl = 0.728 \cdot Ho / Hnuss

Tfilm(J-1) = Tfilm

Qpa(J-1) = Qp
2554 \( Y = Hpq \cdot Qp \cdot 3333 \)
2557 \( X = Qp \)
2560 \( S = S + x \)
2563 \( S_y = S_y + Y \)
2566 \( S_z = S_z + x \cdot 2 \)
2569 \( S_y = S_y + x \cdot Y \)
2572 \( Q1 = 500 \)
2575 \( Qloss = Q1 / (100 - 25) \cdot (T_{steam} - T_{room}) \) TO BE MODIFIED
2578 \( Hfc = FNHf(T_{con}) \)
2581 \( Mdv = 0 \)
2584 \( Bp = (Bvol \cdot 100)^2 / 5.76 \)
2587 \( Hsc = Cpsc \cdot (T_{steam} - T_{con}) \)
2590 \( Mdvc = ((Bp - Qloss) - Mdv \cdot Hsc) / Hfg \)
2593 IF \( ABS((Mdvc - Mdvc) / Mdvc) < .01 \) THEN
2596 \( Mdvc = (Mdvc + Mdvc) \cdot 5 \)
2599 GOTO 2593
2602 END IF
2605 Mdvc = (Mdvc + Mdvc) \cdot 5
2608 \( Vg = FNvst(T_{steam}) \)
2611 \( Vv = Mdvc \cdot Vg/A_\lambda \)
2614 \( F = (9.81 \cdot Do \cdot Mu_f \cdot Hfg) / (Vv \cdot 2 \cdot K_f \cdot (T_{steam} \cdot T_{con})) \)
2617 \( Nu = Ho \cdot Do / K_f \)
2620 \( Ret = Vv \cdot Rhof \cdot Do / Mu_f \)
2623 \( Nr = Nu \cdot Ret \cdot 5 \)
2626 Hfuj = .96 \cdot (9.81 \cdot Hfg / Tcf) \cdot 2 \cdot K_f \cdot 8 \cdot Vv \cdot 1 \cdot Rhof \cdot .5 / (Do \cdot Mu_f) \cdot .3 \)
2629 IF Io = 2 THEN
2632 PRINT
2635 PRINT USING "5X," "Vw Re1 H1 Uo Hfuj(DT) Hnu(Q)""
2638 PRINT USING "5X," "Vv Ho q Tcf NuRe F Hnu(DT)""
2641 PRINT USING "5X," "Vw Ho q Tcf NuRe F Hnu(DT)""
2644 PRINT
2647 PRINT USING "5X," "Vv Ho q Tcf NuRe F Hnu(DT)""
2650 PRINT USING "5X," "Vw Re1 H1 Uo Hfuj(DT) Hnu(Q)""
2653 PRINT USING "5X," "Vv Ho q Tcf NuRe F Hnu(DT)""
2656 PRINT
2659 END IF
2662 IF Io = 1 THEN
2665 PRINT USING "11X, DD, 2X, 1X, 3(MD, 3DE, 1X), 3X, 2(MZ, 3DE, 1X)" "Vw, Ho, Go, Tcf, Tsteam, Sri";
2668 PRINT
2669 END IF
2672 ELSE
2675 PRINT USING "11X, DD, 4X, 2X, 2(MD, 3DE, 2X), 2(MZ, 3DE, 2X), SD, 2X, 30, 00" "Vw, Ho, Go, Tcf, Tsteam, Sri";
2678 END IF
2674 END IF
2675 IF Im=2 THEN
2676 IF (Iwil=0 AND Ijob=1) OR Iwil=0 THEN OUTPUT @Filep;Op,Ho
2677 END IF
2678 BEEP
2679 IF Im=1 THEN
2680 IF (Iwil=0 AND Ijob=1) OR Iwil=1 THEN OUTPUT @Filep;Op,Ho
2681 INPUT "CHANGE TCOOL RISE? 1=Y, 2=N",Itr
2682 IF Itr=1 THEN GOTO 2384
2683 INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Oks
2684 IF Oks=1 THEN
2685 OUTPUT @File:Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
2686 Alp2=Alp1+Alp2
2687 ELSE
2688 J=J-1
2689 END IF
2690 BEEP
2691 INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
2692 Nrun=J
2693 IF Go_on<>0 THEN Repeat
2694 ELSE
2695 IF J<Nrun THEN Repeat
2696 END IF
2697 IF Ijob=1 THEN
2698 IF Iwil=0 THEN
2699 ASSIGN @File TO *
2700 Ijob=1
2701 Iwd=1
2702 CALL Wilson(C1)
2703 Im=2
2704 ASSIGN @File TO D_file$
2705 GOTO 1136
2706 END IF
2707 IF Ifg=0 THEN
2708 PRINT
2709 Sl=(Nrun*Sxy-Sy*Sx)/(Nrun*S*s-S^2)
2710 Ac=(Sy-Sl-S*s)/Nrun
2711 PRINT USING "10X","Least-Squares Line for Ho vs q curve:");""
2712 PRINT USING "10X"," Slope = ",MD.4DE;Sl
2713 PRINT USING "10X"," Intercept = ",MD.4DE;Ac
2714 END IF
2715 BEEP
2716 INPUT "ENTER SAME TEMPORARY PLOT FILE NAME",Fplot$
2717 ASSIGN @Filep TO P_file$
2718 FOR I=1 TO Nrun
2719 ENTER @Filep;Op,Ho

207
2873 ENTER @Filep:Qp,Ho
2874 Xc=LOG(Qp/Ho)
2875 Ye=LOG(Qp)
2876 Zx=Zx+Xc
2877 Yx=Zx+Yc+Ye
2878 Zy=Zy+Ye
2879 NEXT I
2880 Bb=.75
2881 Aa=EXP((Zy-Bb*Zy)/Nrun)
2882 PRINT
2883 PRINT USING "10X,""Least-squares line for q = a*delta-T*b"
2884 PRINT USING "12X,""a = ",MZ.4DE";Aa
2885 PRINT USING "12X,""b = ",MZ.4DE";Bb
2886 IF Ift=0 THEN
2887 IF Ipc=0 THEN
2888 Qps=2.5E+5
2889 IF Iic=0 THEN Hop=9326
2890 IF Iic=1 THEN Hop=10165*(.01905/Do)^.33333
2891 END IF
2892 IF Ipc=1 THEN
2893 Qps=7.5E+5
2894 IF Iic=0 THEN Hop=7176
2895 IF Iic=1 THEN Hop=7569*(.01905/Do)^.33333
2896 END IF
2897 Hos=Aa*(1/Bb)*Qps*((Bb-1)/Eb)
2898 IF Ipc=0 THEN Aas=2.32E+4
2899 IF Ipc=1 THEN Aas=2.59E+4
2900 Alp=8.761 SWENSEN DATA
2901 IF Iw1=0 THEN GOTO 2959
2902 Enr=Alp2/Alp
2903 Enr=Hos/Hop
2904 Enr=Aa/Aas
2905 PRINT
2906 PRINT USING "10X,""Values computed at q = ",Z.DD," (MW/m^2):"";Qps.1.E+6
2907 PRINT USING "12X,""Heat-transfer coefficient = ",DD.DDD," (W/m^2.K)";Hos/1000
2908 PRINT USING "12X,""Enhancement ratio (Del-T) = ",DD.3D";Enrat
2909 PRINT USING "10X,""Enhancement ratio at constant Delta-T = "",DD.DD";Enr
2910 PRINT USING "10X,""Enhancement ratio at constant q = "",DD.DD";Enr
2911 ELSE
2912 PRINT
2913 Aas=2687.2 ZEBROWSKI (U = 0.4 m/s)
2914 Aas=2557.0*(.01905/Do)^.33333 VAN PETTEN (U = 0.25 m/s)
Aas=2557.0*(.01905/Do)^.33333  \* VAN PETTEN (V = 0.25 m/s)

IF Ift=2 THEN Aas=9269.7*(.01905/Do)^.33333

Edt=Aa/Aas

Eq=Edt''(4/3)

PRINT USING "10X,""Enhancement (q) = "",DD.3D";Eq

PRINT USING "10X,""Enhancement (Del-T) = "",DD.3D";Edt

END IF

IF Ift=1 THEN

BEEP

PRINT USING "10X,""NOTE: "",ZZ,"" data points were stored in file "",10A": J,D_file$

END IF

BEEP

PRINT USING "10X,""NOTE: "",ZZ,"" X-Y pairs were stored in data file "",10 A": J,Plot$

BEEP

ASSIGN @File TO *.

ASSIGN @Filep TO *

PURGE "DUMMY"

IF Iso=2 THEN CALL Raw

IF Iso=3 THEN CALL Wilson(Ci)

IF Iso=4 THEN CALL Modify

IF Iso=5 THEN CALL Purge

IF Iso=6 THEN CALL Renam

END

DEF FNPvst(Tc)

COM /Fld/ Ift,Istu

DIM K(8)

IF Ift=0 THEN

DATA -7.691234564,-26.08023696,-168.1706546,64.23285504,-118.9646225

DATA 4.16711732,20.9750676,1.E9,6

READ K(*)

T=(Tc+273.15)/647.3

Sum=0

FOR N=0 TO 4

Sum=Sum+K(N)*((1-T)^(N+1))

NEXT N

Br=Sum/(T*(1+K(5)*(1-T)+K(6)*(1-T)^2)-(1-T)/(K(7)*(1-T)^2+K(8)))

Pr=EXP(Br)

P=22120000*Pr

END IF

IF Ift=1 THEN

Tf=Tc*1.8+32+459.6

P=22120000*Pr

END IF

P=10*(33.0655-4330.98/Tf-9.2635*LGT(Tf)+2.0539E-3*Tf)
3175 \[ P = P \times 10^{1325} / 14.696 \]
3178 END IF
3161 IF Ift=2 THEN
3164 \[ A = 9.39468 \times 10^{-3} \times 10^{-(Tc+273.15)} \]
3167 \[ P = 133.32 \times 10^{-A} \]
3190 END IF
3193 RETURN P
3196 FNEND
3199 DEF FNHfg(T)
3202 COM /Fld/ Ift, Istu
3205 IF Ift=0 THEN
3208 \[ Hfg = 2477200 - 2450 \times (T-10) \]
3211 END IF
3214 IF Ift=1 THEN
3217 \[ T_f = T \times 1.8 + 32 \]
3220 \[ Hfg = 7.05595 \times 10^{-1 - T_f \times (4.838052E-2 + 1.2619048E-4 \times T_f)} \]
3223 END IF
3226 IF Ift=2 THEN
3229 \[ T_f = T + 273.15 \]
3232 \[ Hfg = 1.3 \times 10^{-2} \times 6.38253E+2 + T_k \times .747462 \]
3238 END IF
3241 RETURN Hfg
3244 FNEND
3247 DEF FNMu(T)
3250 COM /Fld/ Ift, Istu
3253 IF Ift=0 THEN
3256 \[ \mu = \frac{247.8}{T + 33.15} \]
3259 \[ \mu = 24E-5 \times 10^{-A} \]
3262 END IF
3265 IF Ift=1 THEN
3268 \[ \mu = 8.9E29819E-4 \times (1.1094609E-5 \times T \times 5.666829E-8) \]
3271 END IF
3274 IF Ift=2 THEN
3277 \[ T_k = 1 \times (T + 273.15) \]
3280 \[ \mu = \exp(-11.0179 + T_k \times (1.744E+3 - T_k \times (2.80335E+2 - T_k \times 1.12661E+8))) \]
3283 END IF
3286 RETURN \mu
3289 FNEND
3292 DEF FNVvst(Tt)
3295 COM /Fld/ Ift, Istu
3298 IF Ift=0 THEN
3301 \[ P = FNVvst(Tt) \]
3304 \[ T = T + 273.15 \]
3307 \[ X = 15000 \]
3310 \[ F_1 = 1 \times (1 + T \times 1.0 - 4) \]

210
F2=(1-EXP(-X))^-2.5*EXP(X)/X^-0.5
B=.0015+F1-.000942*F2-.0004882*X
K=2*P/(461.52*T)
V=(1+(1+2*B*K)^-0.5)*K

IF Ift=1 THEN
   Tf=Tt*1.8+32
   U=13.955357-Tf*(.16127262-Tf*1.726190E-4)
   V=U/16.018
   END IF

IF Ift=2 THEN
   Tk=Tt+273.15
   P=FNP(vst(Tt))
   V=33.955357*TK/P
   END IF

RETURN V

FNEND

DEF FNCpw(T)
   COM /Fld/ Ift, Istd
   IF Ift=0 THEN
      Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
   END IF

   IF Ift=1 THEN
      Cpw=9.2507275E-1+T*(9.3400433E-4+1.7207792E-6*T)
   END IF

   IF Ift=2 THEN
      T00=T+273.15
      Cpw=4.1868*(1.6884E-2+Tk*(3.35083E-3-Tk*(7.224E-6-Tk*7.61748E-9)))
   END IF

RETURN Cpw*1000
FNEND

DEF FNRow(T)
   COM /Fld/ Ift, Istd
   IF Ift=0 THEN
      Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
   END IF

   IF Ift=1 THEN
      Ro=1.6207479E+3-T*(2.2186346*T*2.3578291E-3)
   END IF

   IF Ift=2 THEN
      Ti=T+273.15-338.15
      Vf=9.24848E-4+Ti*(6.2796E-7+Ti*(9.2444E-10+Ti*3.057E-12))
      Ro=1/Vf
   END IF

RETURN Ro
FNEND
3451 DEF FNPrw(T)
3454 Prw=FNCPw(T)*FNMuw(T)/FNKw(T)
3457 RETURN Prw
3460 FNEND
3462 DEF FNKw(T)
3466 COM /Fl0/ Ift, Istu
3469 IF Ift=0 THEN
3472 X=(T+273.15)/273.15
3475 Kw=0.92247*X*(2.8395-X*(1.8007-X*(.52577-.07344*X)))
3478 END IF
3481 IF Ift=1 THEN
3484 Kw=8.2095238E-2-T*(2.2214286E-4+T*2.3609524E-8)
3487 END IF
3490 IF Ift=2 THEN
3493 Tk=T+273.15
3496 Kw=4.1868E-4*(519.442+.320920*Tk)
3499 END IF
3502 RETURN Kw
3505 FNEND
3508 DEF FNTanh(X)
3511 P=EXP(X)
3514 Q=EXP(-X)
3517 Tanh=(P-Q)/(P+Q)
3520 RETURN Tanh
3523 FNEND
3526 DEF FNTvsv(V)
3529 COM /Cc/ C(7)
3532 T=C(0)
3535 FOR I=1 TO 7
3538 T=T+C(I)*V^I
3541 NEXT I
3544 T=T+4.73386E-3+T*(7.692834E-3-T*8.07927E-5)
3547 RETURN T
3550 FNEND
3553 DEF FNHf(T)
3556 COM /Fl0/ Ift, Istu
3559 IF Ift=0 THEN
3562 Hf=T*(4.203849-T*(5.88132E-4-T*4.55160317E-6))
3565 END IF
3568 IF Ift=1 THEN
3571 Tf=T*1.8+32
3574 Hf=8.2076571*Tf*(.19467857*Tf*1.3214286E-4)
3577 Hf=Hf*2.326
3580 END IF
3583 IF Ift=2 THEN
3586 Hf=250 ' TO BE VERIFIED

212
DEF FNGrad(T)
Grad = 37.9853 + 0.104388*T
RETURN Grad
FNEND

DEF FqTvsp(P)
Tu = 190
T1 = 10
Ta = (Tu + T1) * 0.5
Pc = FNpVst(Ta)
IF ABS((P-Pc)/P) < 0.0001 THEN
  IF Pc < P THEN T1 = Ta
  IF Pc > P THEN Tu = Ta
GOTO 3619
END IF
RETURN Ta
FNEND

DEF FNSigma(T)
X = 647.3 - T - 273.15
S = 1.16093607/((1 + 0.83*X) + 1.12140468E-3 - 5.7280518E-6 * X + 1.28627465E-8 * X^2 - 1.14971929E-11 * X^3)
RETURN S * 0.001 * X^2
FNEND

SUB Raw
COM /Fld/ Ift, Istu
DIM X(28)
INPUT "ENTER TUBE NUMBER", Itn
INPUT "ENTER FILE NAME", File$
ASSIGN @File TO Files
INPUT "STUDENT (0=Swensen), Istu"
INPUT "SMOOTH OR FINNED (0=SMOOTH, 1=FINNED)", Ifg
INPUT "ENTER TUBE SIZE (0=S, 1=M, 2=L, 3=QMC)", Itds
INPUT "ENTER PRESSURE CONDITION (0=V, 1=A)", Ipc
IF Ipc = 0 AND Ifg = 0 THEN Vs = 2
IF Ipc = 0 AND Ifg = 2 THEN Vs = 10
IF Ipc = 1 AND Ifg = 0 THEN Vs = 1
IF Ipc = 1 AND Ifg = 1 THEN Vs = 25
IF Istu = 1 THEN Vs = 2
Nrun = 18
INPUT "ENTER NUMBER OF RUNS", Nrun
PRINT IS 701
PRINT
PRINT
IF Istu = 0 THEN PRINT USING "10X," "Data of Swensen"
"
IF Ift=0 THEN PRINT USING "10X,""Vapor is steam"
IF Ift=1 THEN PRINT USING "10X,""Vapor is R-113"
IF Ift=2 THEN PRINT USING "10X,""Vapor is ethylene glycol"

IF ltds=0 THEN PRINT USING "10X,""Tube diameter: Small"
IF ltds=1 THEN PRINT USING "10X,""Tube diameter: Medium"
IF ltds=2 THEN PRINT USING "10X,""Tube diameter: Large"
IF ltds=3 THEN PRINT USING "10X,""Tube diameter: QMC"

PRINT
PRINT USING "10X,""Tube Number: ",Ittn
PRINT USING "10X,""File Name: ",14A;File$
IF Ifg=0 THEN PRINT USING "10X,""Tube Type: Smooth"
IF Ifg=1 THEN PRINT USING "10X,""Tube Type: Finned"
IF ifc=0 THEN
PRINT USING "10X,""Pressure Condition: Vacuum"
ELSE
PRINT USING "10X,""Pressure Condition: Atmospheric"
END IF
PRINT USING "10X,""Vapor Velocity: ",DD.DD," (m/s)";Vs
ENTER @File;Ifg,Inn
IF ltds=1 OR ltds=2 THEN D1=.0127
IF ltds=0 OR ltds=3 THEN D1=.009525
ENTER @File;Iwt,Fp,Fw,Fh
IF Istu=0 AND Ifg=1 THEN
Fp=Fp-1
PRINT USING "10X,""Fin spacing, width and height (mm): ",DD.DD,2X,Z.D,2X,Z.00;Fp,Fw,Fh
END IF
PRINT
PRINT USING "10X,""Data Vw Tin Tout Ts"
PRINT USING "10X,""= (m/s) (C) (C) (C)"
FOR I=1 TO Nrun
ENTER @File;X(*)
Ts=FNTvs(S7((X(8)+X(9))/2.)
Ts=Ts-273.15
Fm=X(3)
Ti=X(4)
T2=X(5)
Tavg=(T1+T2)/2
IF inn=0 THEN T2=T2-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-5*Vw^3)
Rhou=FNRhou(Tavg)
Md=(6.7409*Fm+13.027)/1000.
Md=Md*(1.0365-1.96644E-3*T1+S.252E-6*T1^2-1/1.0037)
Mf=Md/Rhou
Vw=Mf/(Fl*D1^2/4)
IF inn=0 AND Vw .5 THEN T2=T2-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-5*Vw^3)

214
IF Inn=1 THEN \[ T2 = T2 - (-6.44E-5 + 1.71E-3 \cdot VW + 4.45E-4 \cdot YW^2 + 4.07E-5 \cdot VWZ) \]

IF Inn=2 THEN \[ T2 = T2 - (-3.99E-4 - 2.76E-3 \cdot VW + 1.45E-3 \cdot YW^2 + 8.16E-5 \cdot VWZ) \]

IF Inn=3 THEN \[ T2 = T2 - (8.57E-5 + 1.23E-3 \cdot VW + 1.08E-3 \cdot YW^2 + 8.16E-5 \cdot VWZ) \]

PRINT USING "10X,DD,5X,0.DD,2X,DD,DD,3X,0.DD,2D.DD,3X,0.DD"; I, VW, T1, T2, Ts

NEXT I

ASSIGN @File TO •

SUBEND

SUB Wilson(Ci)

COM /Wil/ Mrun, Itm, Iwth, Imc, Ife, Ijob, Iwd, Ifg, Ipco, Ifte, Iw1, In1, Ioc, Ins, cu, R.exp, Rm

COM /Fid/ Ifl, Istu

COM /Geom/ D1, D2, D3, Do, L1, L2

DIM Emf(20), Ero(25), Bam(25), Ema(25), Ear(25), Tna(25), Tnae(25)

IF loc=0 THEN

PRINT USING "16X,"; "Nusselt theory is used for Ho"

ELSE

PRINT USING "16X,"; "Fujii correlaion used for Ho"

END IF

BEEP

INPUT "RE-ENTER DATA FILE BEING PROCESSED", D_file$

BEEP

INPUT "GIVE A NAME FOR XY PLOT-DATA FILE", Plot$

CREATE BDAT Plot$ .10

ASSIGN @Io_path TO Plot$

Jj=0

ASSIGN @File TO D_file$

ENTER @File; Ifg, Inn

IF Istu=0 THEN

ENTER @File; Ddd, Ddd, Ddd

ELSE

END IF

IF Ifg=0 THEN ENTER @File; Iwt

IF Ifg=1 THEN ENTER @File; Flp, Fw, Fh

END IF

IF Jj=0 THEN

IF Ih1=0 THEN C1=.027

IF Ih1=1 THEN C1=1.00

IF Ih1=2 THEN C1=1.00

IF Ifg=0 THEN Alp=1.2

IF Ifg=1 THEN Alp=2.6

IF Ifg=2 AND Ifg=1 THEN Alp=5.0

END IF

J=0

S.x=0

S.y=0

S.s=0

S.ym=0
READ DATA FROM A USER-SPECIFIED FILE IF INPUT MODE (IM) = 2

IF J=0 THEN
IF Istu=0 THEN
ENTER @File:Evol,Bamp,Etp,Fm,T1,T2,Odd,Odd,Emf(*)
ELSE
ENTER @File:Evol,Bamp,Upm,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,T2,Odd,Odd,Emf(*)
2,Phg,Fuster
END IF

Evol(J)=Evol
Bam(J)=Bamp
Data(J)=Etp
Ear(J,0)=Emf(0)
Ear(J,1)=Emf(1)
Ear(J,2)=Emf(2)
Ear(J,3)=Emf(3)
Ear(J,4)=Emf(4)
ELSE
IF Istu=1 THEN GOTO 6961

IF Istu=1 THEN GOTO 6961

Emf(0)=Ear(J,0)
Emf(1)=Ear(J,1)
Emf(2)=Ear(J,2)
Emf(3)=Ear(J,3)
Emf(4)=Ear(J,4)
ELSE
IF Istu=1 THEN GOTO 6961

Emf(5)=Ear(J,5)
Emf(6)=Ear(J,6)
Emf(7)=Ear(J,7)

Fm=Fma(J)
T1=Tla(J)
T2=T2a(J)

END IF

IF Istu=0 THEN
Tsat=FntVs57(Emf(0)+Emf(1))/2)
Tsat=Tsat-273.15
T1=FntVs58(Emf(3))
T01=FntVs58(Emf(4))
T1=T1-273.15
7013 Tol=Tol-273.15
7016 DtdE=2.5931E-3-1.50464E-6*Ep1+1.21701E-10*Ep1 2-5.1164E-15*Ep1 3-3.220
E-19*Ep1 4
7017 Tris=DtdE*Ep1/10.
7018 Tc=T1+Tris
7019 ELSE
7020 Tsat=FNTsv(Emf(0))
7021 T1=FNTsv(Emf(2))
7022 Grad=FNGrad((T1+T2) / 2)
7023 To=T1+ABS(Etp1)/(10*Grad) * 1.0
7024 END IF
7025 CALCULATE THE LOG-MEAN-TEMPERATURE DIFFERENCE
7026 IF Istu=0 AND Itm=0 THEN
7027 Tf=T1
7028 T1=Tol
7029 END IF
7030 IF Itm=1 THEN
7031 Tf=T1
7032 T1=T2
7033 END IF
7034 IF Itm=2 THEN
7035 Tf=T1
7036 T1=To
7037 END IF
7038 Tavg=(Tf+T1) / 2
7040 Trise=T1-Tf
7041 Lmt=Lrise/LOG((TsT-Tf)/(TsT-T1))
7042 IfT=0
7043 Cp=FNcpw(Tavg)
7044 Rho=FNrho(Tavg)
7045 Kw=FNk(Tavg)
7046 Muw=FMmu(Tavg)
7051 Prw=FNPrw(Tavg)
7054 Ift=IfTo
7055 IF Istu=0 THEN
7057 Mt=6.7409*Fm+13.027/1000.
7058 Mt=Mt+(1.0365-Tf*(1.96844E-3-Tf+5.252E-6))/1.0037
7059 ELSE
7062 Mt=1.04305E-2+6.80932E-3*Fm
7063 Mt=Mt+(1.0365-Tf*(1.96844E-3-Tf+5.252E-6))/1.99543
7065 END IF
7066 Uf=Mt/Rho
7067 Vw=Uf / (PI*D1 / 2.4)
7068 Vw=Uw / (D1/1.27E-2 / 2)
7070 IF Istu=0 AND Iuth=0 THEN 'SWENSEN FRICTION FAC. FOR COPPER TUBE
IF Inn=0 AND Vw < 0.5 THEN 
Trise = Tri5e - (-2.73E-4 + 1.75E-4 * Vw + 9.35E-4 * Vw^2 - 1.9E-5 * Vw^3)

IF Inn=1 THEN 
Trise = Tri5e - (-6.44E-5 + 1.71E-3 * Vw + 4.45E-4 * Vw^2 + 4.07E-5 * Vw^3)

IF Inn=2 THEN 
Trise = Tri5e - (-3.98E-4 + 2.75E-3 * Vw + 1.45E-3 * Vw^2 + 8.16E-5 * Vw^3)

IF Inn=3 THEN 
Trise = Tri5e - (-6.57E-5 + 1.23E-3 * Vw + 1.08E-3 * Vw^2 + 8.16E-5 * Vw^3)

END IF

IF Istu=0 AND Iwth=2 THEN KEEFE FRICTION FACTORS FOR SMOOTH TITANIUM TUBE.

IF Inn=0 AND Vw < 0.5 THEN 
Trise = Tri5e - (-4.62E-5 - 7.53E-4 * Vw + 1.80E-3 * Vw^2 - 5.84E-5 * Vw^3)

IF Inn=1 THEN 
Trise = Tri5e - (-2.0E-4 + 9.74E-4 * Vw + 2.12E-3 * Vw^2 - 3.31E-5 * Vw^3)

END IF

IF Istu=0 AND Iwth=1 THEN FRICTION FACTORS FOR KORODENSE

IF Inn=0 AND Vw < 0.5 THEN 
Trise = Tri5e - (-3.386E-4 + 1.88E-3 * Vw + 6.013E-4 * Vw^2 + 4.133E-5 * Vw^3)

END IF

IF Inn=3 THEN 
Trise = Tri5e - (-2.069E-4 + 9.202E-4 * Vw + 1.893E-3 * Vw^2 - 2.761E-5 * Vw^3)

END IF

IF Istu=1 THEN

IF Inn=0 THEN 
Trise = Tri5e - (0.0130 + 0.001 * Vw^2)

IF Inn=1 THEN 
Trise = Tri5e - 0.004 * Vw^2

IF Inn=2 THEN 
Trise = Tri5e - 0.004 * Vw^2

END IF

Q = Md * Cp0 * Tri5e

Up = Op / Lmtd

Re = Rh0w * Vw * Di / Muwa

Fe = 0

Fc = 0

Cf = 1.

Prwf = Prw

Reif = Re

If t = 0

Two = Tsat - 5

Tfilm = Tset / 3 + Two * 2 / 3

Kf = FNfw / Tfilm

Rhof = FNfw / (Muf * Do * Qp)

Muf = FMuw / Tfilm

Hfgp = FNHfgp * (Tsat + 0.68 * FNCp0 * Tfilm) * (Tsat - Two)

New(kf * (Rhof)^2 * 9.81 * Hfgp / (Muf * Do * Qp)) = 3333

New(kf)^2 * 9.81 * Hfgp * Rhof^2 / (Muf * Do * (Tsat - Two)) = 0.25

IF loc = 1 THEN

New(kf)^2 * 9.81 * Hfgp / (Qp)^2 * (Muf / Do)^2 = (Rhof / 0.625)^3 * Vw / 0.125

New(kf)^2 * 9.81 * Hfgp / (Tsat - Two) * 2 * kf * 0.1 * Rhof / (Do * Muf)^2 = 0.2

END IF

Hc = Alp * New

Two = Tsat - Op / Hc

218
7165 IF ABS((Twoc-Two)/Twoc)>0.001 THEN
7166 Two=Twoc
7171 GOTO 7132
7174 END IF
7175 Rexp1=Rexp
7184 IF Ih=0 THEN
7186 Omega=Re"Rexp1*Prw".3333*Cf
7187 END IF
7188 IF Ih=1 THEN
7189 Sra=.88-(.24/(4.+Prw))
7190 Srb=.33333*.5*EXP(-6*Prw)
7191 Omega=(5.+0.15*Re*"Sra*Prw"*Srb)
7192 END IF
7193 IF Ih=2 THEN
7194 Eps1=(1.82*LGT(Re)-1.64)^(-2)
7195 Ppl1=1.34*Eps1
7196 Ppl2=11.7+1.8*Prw^(-1/3)
7197 Ppl=(Eps1/8)*Re*Prw
7198 Pp2=(Ppl1+Ppl2*(Eps1/8)^.5*(Prw^-6666-1))
7199 Omega=Pp1/Pp2
7200 END IF
7202 Hl=Kw/D1*C1*Omega
7203 IF Ife=0 THEN 7216
7204 P1=PI*(D1+D1)
7205 P2=PI*(D1+D2)
7206 A1=(D1-D1)*PI*(D1+D1)*.5
7207 A2=(D2-D1)*PI*(D1+D2)*.5
7208 M1=(H1*PI/(Kcu*A1))^*.5
7209 M2=(H1*P2/(Kcu*A2))^*.5
7210 Fe1=FNTanh(M1*L1)/(M1*L1)
7213 Fe2=FNTanh(M2*L2)/(M2*L2)
7216 Dt=G/(PI*D1*(L1*L1*Fe1+L2*Fe2)*H1)
7217 IF Ih=0 THEN
7219 Muw1=FNMuw(Tavg+Dt)
7222 Cfc=(Muwa/Muw1)^*.14
7225 IF ABS((Cfc-Cf)/Cfc)>0.001 THEN
7226 Cf=(Cf+Cfc)*.5
7231 GOTO 7184
7232 END IF
7234 END IF
7235 IF Ih=1 THEN
7236 Prwfc=FNPuw(Tavg+Dt)
7237 Re1fc=Uw*D1*FNRhow(Tavg+Dt)/FNMuw(Tavg+Dt)
7239 IF ABS((Prwfc-Prw)/Prwfc)>0.001 OR ABS((Re1fc-Re1f)/Re1f)>0.001 THEN
7240 Prw=Prwfc+Prw/2.
7241 Re1f=(Re1fc+Re1f)/2.
GOTO 7184
END IF
Ift=Ifto
x=Do*New*L/(Omega*kw*(L+L1*Fe1+L2*Fe2))
Y=New*(1/U0-Rm)
COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT STRAIGHT LINE
IF Jp=1 THEN OUTPUT @io_path;x,Y
Sx=Sx+X
Sy=Sy+Y
Sxx=Sxx+X*X
Sxy=Sxy+X*Y
IF Im=l AND J3=0 THEN OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*
J=J+1
IF J<Nrun THEN 6925
S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sx5-Sx'r2)
IF Inn=l AND Di=.009525 THEN S1=1/.051 !TO BE MODIFIED
IF Inn=0 THEN S1=1/.012
IF Inn=3 THEN S1=1/.22
IF Inn=1 AND Di=.0127 THEN S1=1/.052
IF Ift=2 THEN S1=1/.035
IF Ih1=0 THEN S1=1/.027
IF Ih1=1 THEN S1=1/1.00
IF Ih1=2 THEN S1=1/1.00
END IF
Ac=(Sy-S1*Sx)/Nrun
Cic=1/S1
Alpc=1/Ac
Jj=Jj+l
IF Jp=1 THEN Jp=2
Cerr=ABS((Cic-C1)/Cic)
Aerr=ABS((Alpc-Alp)/Alpc)
IF Cerr>.001 OR Aerr>.001 THEN
Ci=(Cic+Ci)*.5
Alp=(Alpc+Alp)*.5
BEEP
IF Ijob=1 THEN 6907
ELSE
IF Jp=0 THEN Jp=1
END IF
IF Jp=1 THEN 6674
Ci=(Ci+Cic)*.5
PRINT
IF Ih1=0 THEN
IF Ih1=1 THEN
    PRINT USING "10X","C1 (based on Sieder-Tate) = "",2.4D";C1
    IF Ioc=0 THEN
        IF Ipco=0 AND Inn=0 THEN Alp5M=.8218  !NO INSERT,VACUUM,S-T
        IF Ipco=1 AND Inn=0 THEN Alp5M=.7793  !NO INSERT,ATMOSPHERIC,S-T
        IF Ipco=0 AND Inn=3 THEN Alp5M=.7854  !HEATEX,VACUUM,S-T
        IF Ipco=1 AND Inn=3 THEN Alp5M=.7769  !HEATEX,ATMOSPHERIC,S-T
    END IF
    IF Ih1=1 THEN
        IF Ioc=0 AND Inn=0 THEN Alp5M=.8613  !NO INSERT,VACUUM,S-R
        IF Ipco=1 AND Inn=0 THEN Alp5M=.8218  !NO INSERT,ATMOSPHERIC,S-R
        IF Ipco=0 AND Inn=3 THEN Alp5M=.7791  !HEATEX,VACUUM,S-R
        IF Ipco=1 AND Inn=3 THEN Alp5M=.7929  !HEATEX,ATMOSPHERIC,S-R
    END IF
    IF Ih1=2 THEN
        IF Ioc=0 AND Inn=0 THEN Alp5M=.8205  !NO INSERT,VACUUM,P-P
        IF Ipco=1 AND Inn=0 THEN Alp5M=.7654  !NO INSERT,ATMOSPHERIC,P-P
        IF Ipco=0 AND Inn=3 THEN Alp5M=.7670  !HEATEX,VACUUM,P-P
        IF Ipco=1 AND Inn=3 THEN Alp5M=.7708  !HEATEX,ATMOSPHERIC,P-P
    END IF
    IF Inam=4 THEN
        IF Ipco=1 THEN Alp5M=.676  !SWENSEN DATA BASED ON DEL-T
    END IF
    IF Inam=0 OR Inam=3 THEN
        IF Ipco=0 THEN Alp5M=.83  !UP MISTU103
        IF Ipco=1 THEN Alp5M=.86  !UP SMTHSTAGS
        IF Ift=1 THEN Alp5M=.733  !ZEBROWSKI (V = 0.45 m/s)
        IF Ift=1 THEN Alp5M=.677  !ZEBROWSKI (V = 0.25 m/s)
        IF Ift=2 THEN Alp5M=1.262
    END IF
    IF Inam=1 THEN  !MITROU ALPHA FOR P-P FROM REPROCESSING
7402 IF Ipco=0 THEN Alpsm=.8437
7403 IF Ipco=1 THEN Alpsm=.8418
7404 END IF
7405 Et=Alp/Alpsm
7406 Eq=Et"1.333333
7407 PRINT USING "10X","Enhancement (q) = ",DD.3D;Eq
7408 PRINT USING "10X","Enhancement (Del-T) = ",DD.3D;Et
7409 ASSIGN @File TO *
7410 SUBEND
7419 SUB Modify
7520 COM /Flf/ Ift,Istu
7522 DIM Emf(20)
7525 BEEP
7528 INPUT "ENTER NAME OF FILE TO BE MODIFIED",Fileo$
7531 ASSIGN @Fileo TO Fileo$
7534 CREATE BDAT "TEST",30
7537 ASSIGN @Filed TO "TEST"
7540 ENTER @Fileo;Ifg,Inn
7543 OUTPUT @Filed;Ifg,Inn
7544 IF Istu=0 THEN
7546 ENTER @Fileo;Iwt,Fp,Fw,Fh
7547 OUTPUT @Filed;Iwt,Fp,Fw,Fh
7548 ELSE
7549 IF Ifg=0 THEN
7551 ENTER @Fileo;Iwt
7552 OUTPUT @Filed;Iwt
7553 END IF
7554 IF Ifg=1 THEN
7555 ENTER @Fileo;Fp,Fw,Fh
7556 OUTPUT @Filed;Fp,Fw,Fh
7557 END IF
7558 END IF
7560 BEEP
7561 INPUT "ENTER NUMBER OF DATA SETS STORED",N
7562 FOR I=1 TO N
7563 IF Istu=0 THEN
7565 ENTER @Fileo;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
7566 ELSE
7567 ENTER @Fileo;Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1, T2,Pvap,Pwater
7568 END IF
7570 PRINT USING "2X","DO YOU WISH TO DELETE POINT"
7571 PRINT USING "0=YES, 1=NO",Idel
7572 IF Idel=0 THEN 7580
7576 IF Istu=0 THEN
7577 OUTPUT @Fileo:Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
7578 ELSE
7579 OUTPUT @Fileo:Bvol,Bamp,Vtran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,
   T2,Phg,Pwater
7580 END IF
7581 NEXT I
7582 ASSIGN @Fileo TO *
7583 ASSIGN @Fileo TO *
7584 SUBEND
7585 SUB Purg
7586 BEEP
INPUT "ENTER FILE NAME TO BE DELETED",File$
7594 PURGE File$
7597 GOTO 7588
7600 SUBEND
7590 SUB Renam
7593 BEEP
INPUT "ENTER FILE NAME TO BE RENAMED",File1$
7599 BEEP
INPUT "ENTER NEW NAME FOR FILE",File2$
7702 RENAME File1$ TO File2$
7705 GOTO 7708
7711 SUBEND
7719 DEF FNTvsvS(V)
7721 COM /Cc55/ T55(5)
7731 T=T55(0)
7741 FOR I=1 TO 5
7751 T=T+T55(I)*V^I
7761 NEXT I
7771 RETURN T
7781 FNEND
7801 DEF FNTvsvS(V)
7811 COM /Cc56/ T56(5)
7821 T=T56(0)
7831 FOR I=1 TO 5
7841 T=T+T56(I)*V^I
7851 NEXT I
7861 RETURN T
7871 FNEND
7881 DEF FNTvsvS(V)
7891 COM /Cc57/ T57(5)
7901 T=T57(0)
7911 FOR I=1 TO 5
7921 T=T+T57(I)*V^I
7931 NEXT I
7941 RETURN T
7951 FNEND
7961 DEF FNTvsvS(V)
7971 COM /Cc58/ T58(5)
7981 T=T58(0)
7991 FOR I=1 TO 5
8001  T = T + T59(I) * V"I
8011  NEXT I
8021  RETURN T
8031  FNEND
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