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THESIS

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

by

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September 1992

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Filmwise Condensation of Steam on Horizontal
Wire-Wrapped Smooth and Roped Titanium Tubes

by

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Lieutenant, United States Navy
B.S., United States Naval Academy, 1986

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

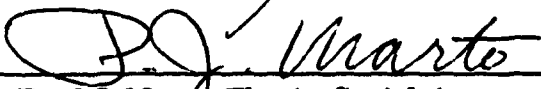
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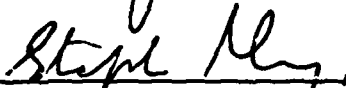
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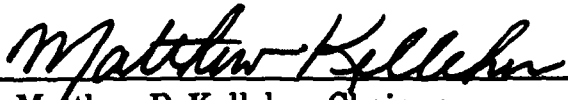
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ABSTRACT

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.

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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 define in equation (4.15)
C_i	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_r	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
$h_{r,q}$	specific enthalpy of vaporization, J/kg
h_i	inside heat transfer coefficient, W/m ² K
h_o	outside heat transfer coefficient, W/m ² K
k_c	thermal conductivity of the coolant film, W/mK
k_r	thermal conductivity of the condensate film, W/mK
k_m	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
$\dot{m}$	mass flow rate of the coolant, kg/s
Nu	Nusselt number
P_{sat}	saturation pressure, Pa
Pr	Prandtl number
Pr_w	Prandtl number at the wall temperature
Q	heat transfer rate, W
q	heat flux, W/m ²
Re	Reynolds number
Re_f	Reynolds number for the condensate film
$Re_{2\phi}$	two phase Reynolds number
R_i	inside thermal resistance, m ² K/W
R_o	outside thermal resistance, m ² K/W
R_{total}	total thermal resistance, m ² K/W
R_w	wall thermal resistance, m ² K/W
T_{cf}	temperature difference across the condensate film, K
ΔT_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/m ² K
U_v	vapor velocity, m/s
V_c	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

α	dimensionless coefficient
ϵ	as defined in equation (4.16)
μ_c	dynamic viscosity of the coolant, kg/m s
μ_f	dynamic viscosity of the condensate film, kg/m s
μ_w	dynamic viscosity of the condensate at the wall, kg/ms
ρ_f	density of the condensate film, kg/m ³
ρ_v	density of the vapor, kg/m ³
η	surface efficiency
Ω	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 determined 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_w 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:

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

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 Gomelaui (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):

$$\frac{Nu}{Re_{2\phi}^{1/2}} = 0.64 (1 + (1 + 1.69 F^*)^{1/2})^{1/2} \quad (2.2)$$

where:

$$F^* = \frac{Pr}{Fr Ph} = \frac{g D_o \mu_f h_{fg}}{U_v^2 k_f \Delta T_f} \quad (2.3)$$

$$Re_{2\phi} = \frac{\rho_f U_v D_o}{\mu_f} = \text{two phase Reynolds number}$$

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). At low values of F^* , equation (2.2) predicts significantly higher values of h_o 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:

$$\frac{Nu}{Re_{20}^{1/2}} = 0.96 F^{*1/5} \quad (2.4)$$

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

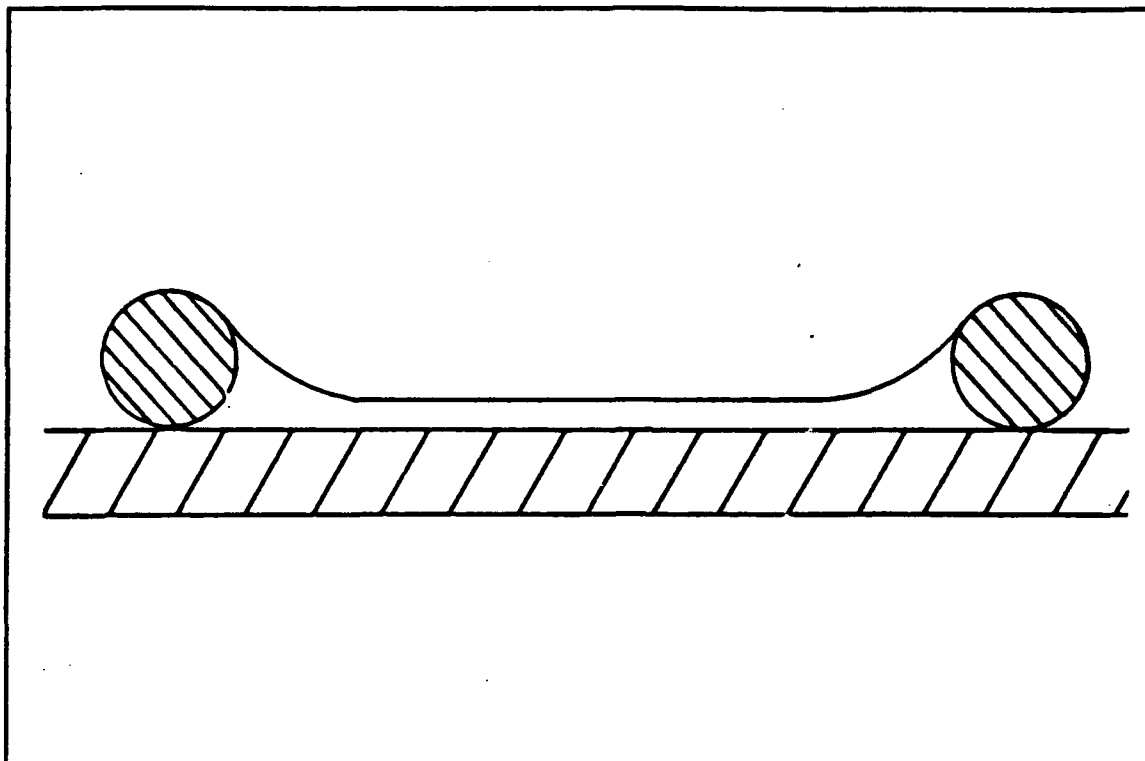


Figure 1. Idealized Condensate Film Profile on a Wire-Wrapped Tube

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 there 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

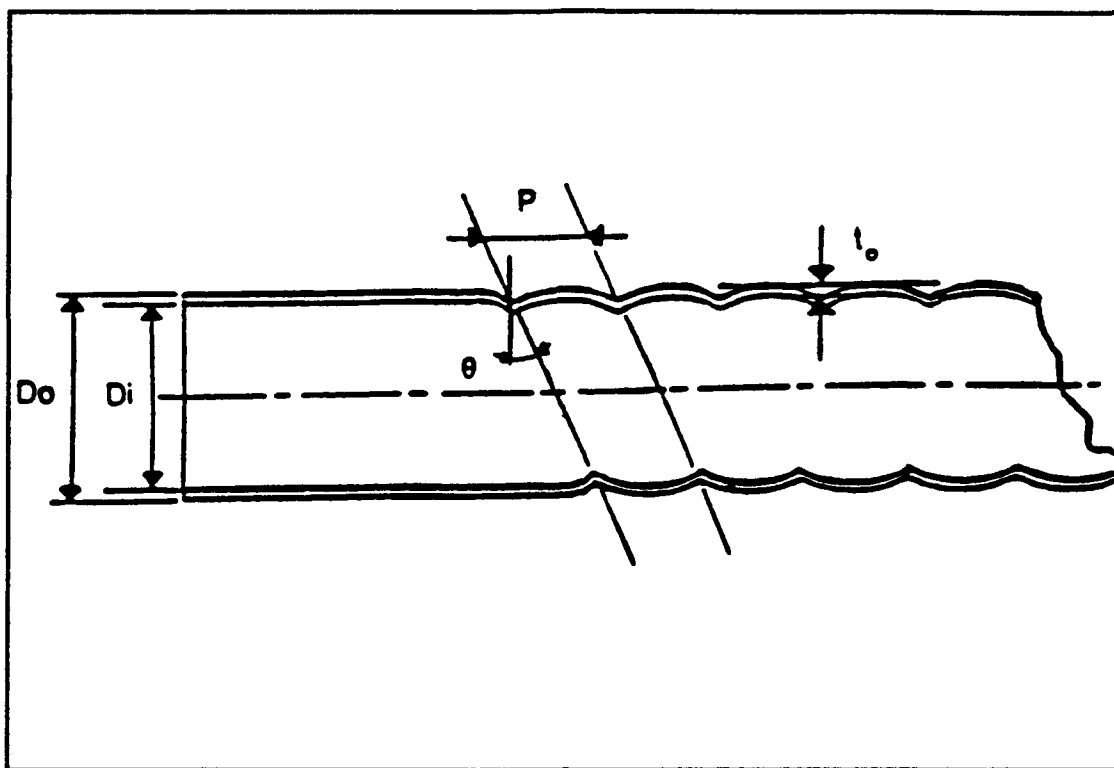


Figure 2. Profile of a Roped Tube

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_w or F to the heat transfer enhancement.

III. APPARATUS AND SYSTEM INSTRUMENTATION

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.

M MIXING CHAMBER
 QC QUARTZ CRYSTAL
 THERMOMETER PROBE
 TP THERMOPILE PROBE

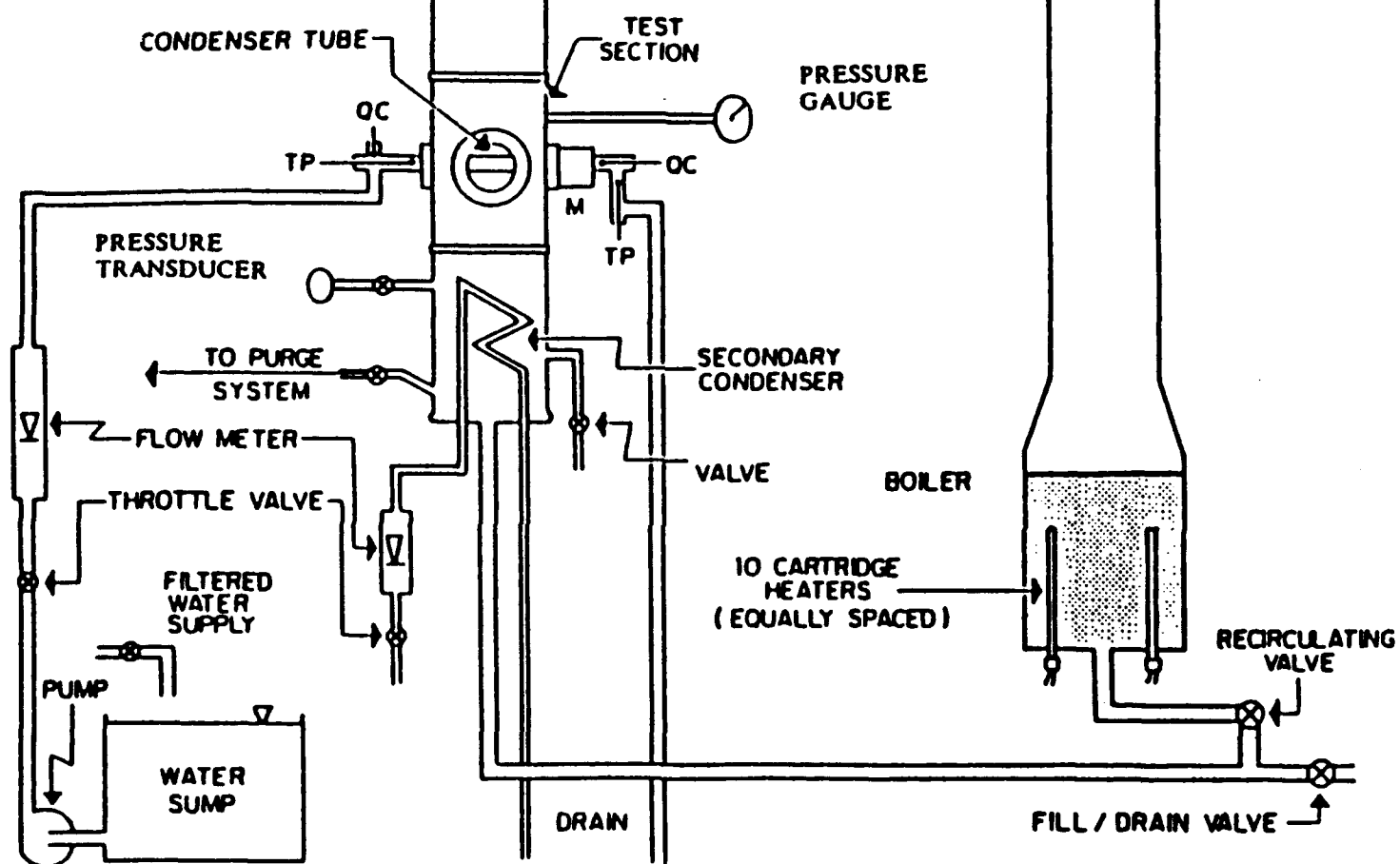


Figure 3. Schematic of the Single Tube Test Apparatus

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-condensable gases is shown in Figure 5. The suction point is at the base of the auxiliary condenser where non-condensable 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-condensable 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

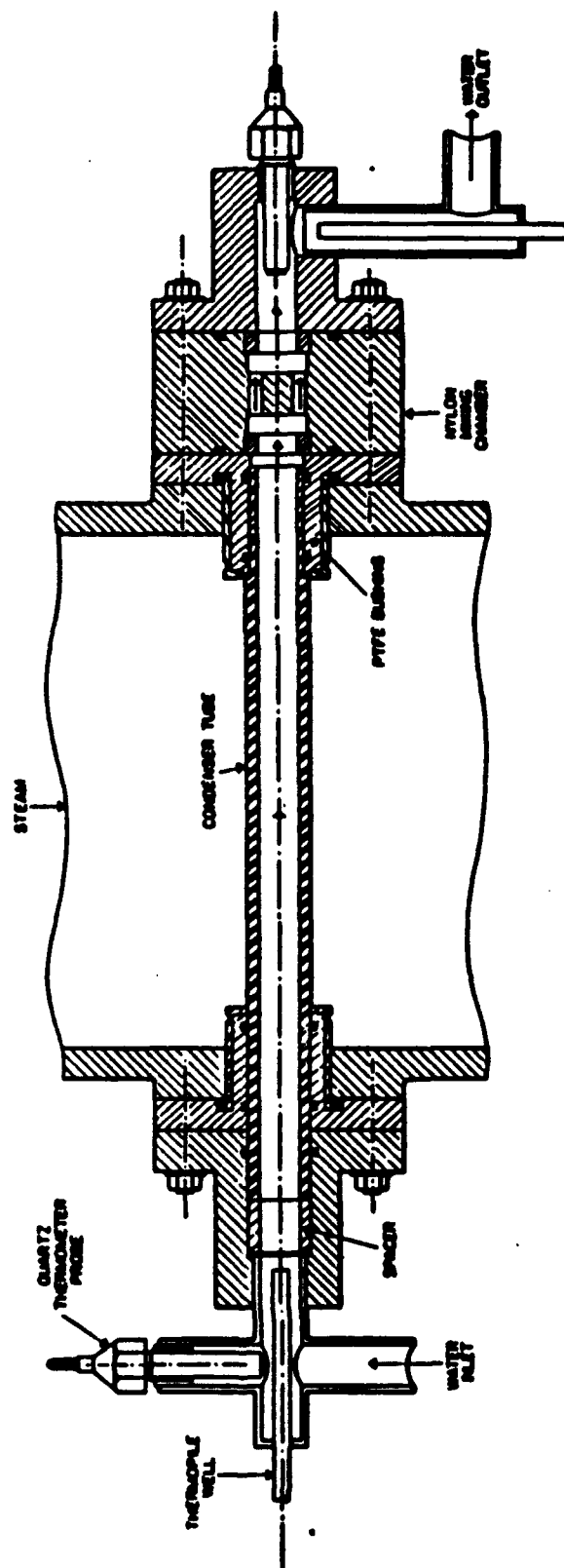


Figure 4. Schematic of the Test Section Insert



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 I. LISTING OF THE TUBES TESTED

Tube No.	Tube Type	Wire Diameter (mm)	Wire Spacing (mm)	Wire Pitch (mm)	P/D Ratio	F	Outside Diameter (mm)	Inside Diameter (mm)	Tube Material
0	Smooth	None	None	None	None	0	15.85	13.86	Titanium
1	Smooth	1.6	13.47	15.07	9.42	0.108	15.85	13.86	Titanium
2	Smooth	1.6	5.75	7.35	4.59	0.205	15.85	13.86	Titanium
3	Smooth	1.6	1.80	3.40	2.13	0.457	15.85	13.86	Titanium
4	Smooth	1.0	5.04	6.04	6.04	0.158	15.85	13.86	Titanium
5	Smooth	1.0	3.70	4.70	4.70	0.211	15.85	13.86	Titanium
6	Smooth	0.5	3.46	3.96	7.92	0.120	15.85	13.86	Titanium
7	Smooth	0.5	1.51	2.01	4.02	0.218	15.85	13.86	Titanium
L	LPD	None	None	None	None	0	15.85	13.47	Titanium
L1	LPD	1.6	5.40	7.00	4.38	0.252	15.85	13.47	Titanium
L2	LPD	1.0	6.00	7.00	7.00	0.152	15.85	13.47	Titanium
L3	LPD	0.5	6.50	7.00	14.00	0.074	15.85	13.47	Titanium
50	Smooth	None	None	None	None	0	19.05	12.70	Copper
68	Smooth	1.0	3.91	3.91	3.91	0.269	19.05	12.70	Copper
71	Smooth	0.5	3.13	3.63	7.26	0.141	19.05	12.71	Copper

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,

$$R_{total} = R_i + R_w + R_o \quad (4.1)$$

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

$$R_i = \frac{1}{h_i A_i} \quad (4.2)$$

$$R_o = \frac{1}{h_o A_o} \quad (4.3)$$

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 = 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:

$$A_i = \pi D_i (L + L_1 \eta_1 + L_2 \eta_2) \quad (4.4)$$

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)

η_1 = fin efficiency of the inlet portion of the tube

η_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:

$$A_o = \pi D_o L \quad (4.5)$$

The wall resistance assumes uniform radial conduction and is represented by the following equation:

$$R_w = \frac{\ln\left(\frac{D_o}{D_i}\right)}{2\pi L k_m} \quad (4.6)$$

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:

$$R_{total} = \frac{1}{U_o A_o} \quad (4.7)$$

where:

U_o = overall heat transfer coefficient (W/m²K)

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

$$\frac{1}{U_o A_o} = \frac{1}{h_i A_i} + R_w + \frac{1}{h_o A_o} \quad (4.8)$$

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:

$$Q = \dot{m}C_p(T_2 - T_1) \quad (4.9)$$

The overall heat transfer coefficient can then be calculated from:

$$Q = U_o A_o (LMTD) \quad (4.10)$$

where:

$$LMTD = \frac{(T_2 - T_1)}{\ln \left[\frac{T_{sat} - T_1}{T_{sat} - T_2} \right]} \quad (4.11)$$

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
- T₁ = inlet coolant temperature (K)
- T₂ = 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; there 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 an, 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 ΔT :

$$h_o = \alpha \left[\frac{k_f^3 \rho_f^2 g h_{fg}}{\mu_f D_o \Delta T_f} \right]^{1/4} = \alpha Z \quad (4.12)$$

where:

- α = dimensionless Nusselt coefficient
- k_f = thermal conductivity of the condensate film (W/mK)
- ρ_f = density of the condensate film (kg/m³)
- μ_f = dynamic viscosity of the condensate film (kg/ms)
- h_{fg} = specific enthalpy of vaporization (J/kg)
- ΔT_f = temperature difference across the condensate film (K)
- g = gravitational constant (9.81 m/s²)

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:

$$h_i = C_i \Omega \quad (4.13)$$

where Ω varies with the particular correlation used.

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

$$\Omega = \frac{k_c}{D_i} Re^x Pr^{1/3} \left(\frac{\mu_c}{\mu_w} \right)^{0.14} \quad (4.14)$$

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

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

$$\Omega = \frac{k_c}{D_i} (5 + 0.015 Re_f^c Pr_w^d) \quad (4.15)$$

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]:

$$\Omega = \frac{k_c}{D_i} \left[\frac{\left(\frac{\epsilon}{8} \right) Re Pr}{K_1 + K_2 \left(\frac{\epsilon}{8} \right)^{1/2} (Pr^{2/3} - 1)} \right] \quad (4.16)$$

where:

$$\epsilon = [1.82 \log(Re) - 1.64]^{-2}$$

$$K_1 = 1 + 3.4\epsilon$$

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

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

$$\left[\frac{1}{U_o} - R_w A_o \right] Z = \frac{A_o Z}{C_1 \Omega A_i} + \frac{1}{\alpha} \quad (4.17)$$

Letting:

$$Y = \left[\frac{1}{U_o} - R_w A_o \right] Z \quad (4.18)$$

and

$$X = \frac{A_o Z}{A_i \Omega} \quad (4.19)$$

a simplified linear equation results:

$$Y = mX + b \quad (4.20)$$

where

$$m = \frac{1}{C_1} \quad (4.21)$$

and

$$b = \frac{1}{\alpha} \quad (4.22)$$

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 α . 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 α and C_i between runs for the same types of tube.

D. ENHANCEMENT RATIO

From Nusselt theory, it can be shown that:

$$q = a \Delta T_f^n \quad (4.23)$$

where:

$$a = \alpha \left[\frac{k_f^3 \rho_f^2 g h_{fg}}{\mu_f D_o} \right]^{1/4}$$

q = the heat flux based on the outside area (W/m^2)

ΔT_f = the temperature drop across the condensate film (K)

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

$$q = h_o \Delta T_f \quad (4.24)$$

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

$$h_o = a \Delta T_f^{n-1} \quad (4.25)$$

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

$$E_T = \frac{h_{oe}}{h_{os}} = \frac{a_e}{a_s} = \frac{\alpha_e}{\alpha_s} \quad (4.26)$$

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

coefficient. 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

h_o vs. T_{cf} Atmospheric Pressure using the Swensen Correlations

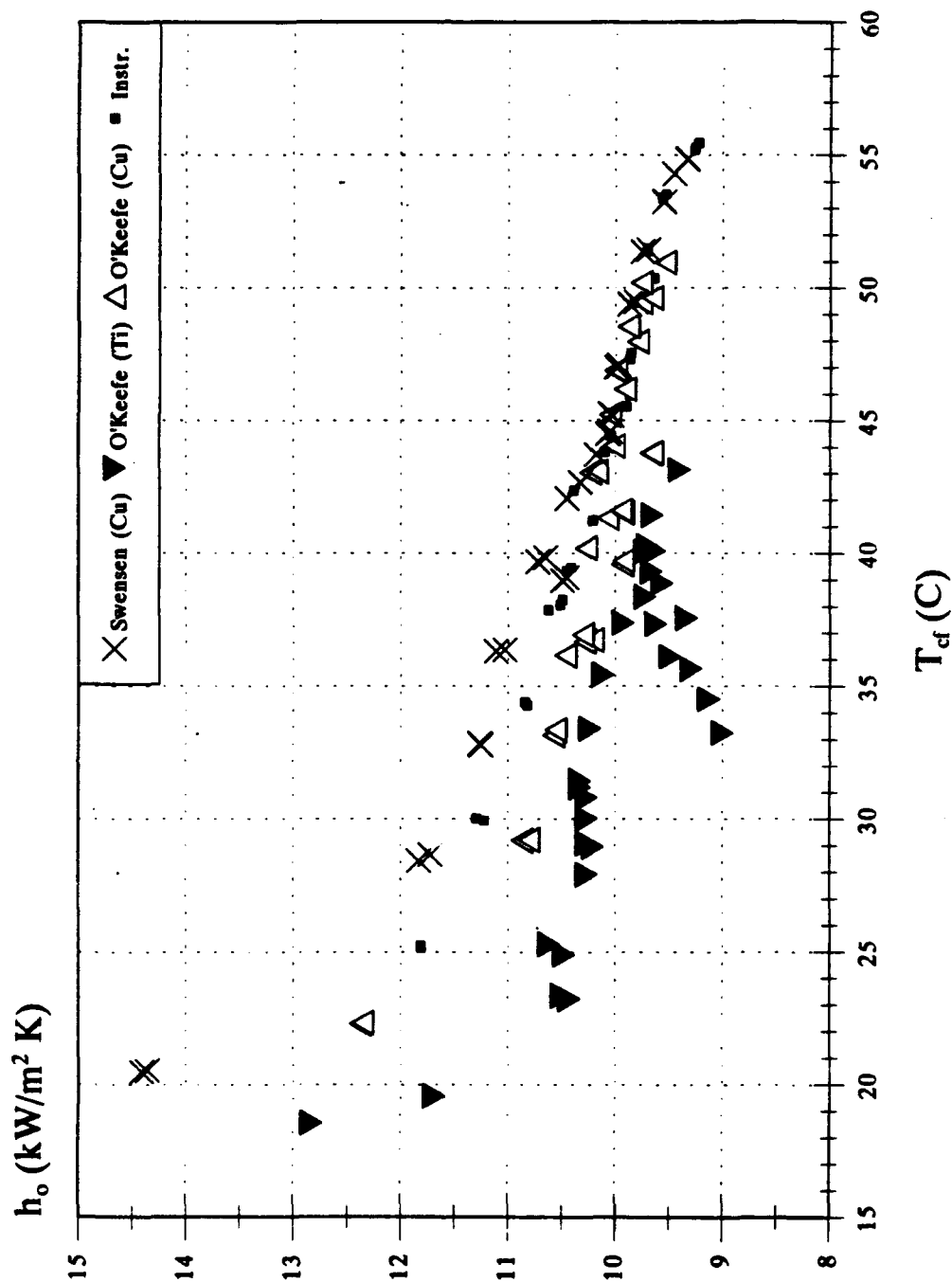


Figure 6. Comparison of Results for the Outside Heat Transfer Coefficient at Atmospheric Pressure Using the Swensen Correlations

h_o vs. T_{cf} Vacuum Pressure using the Swensen Correlations

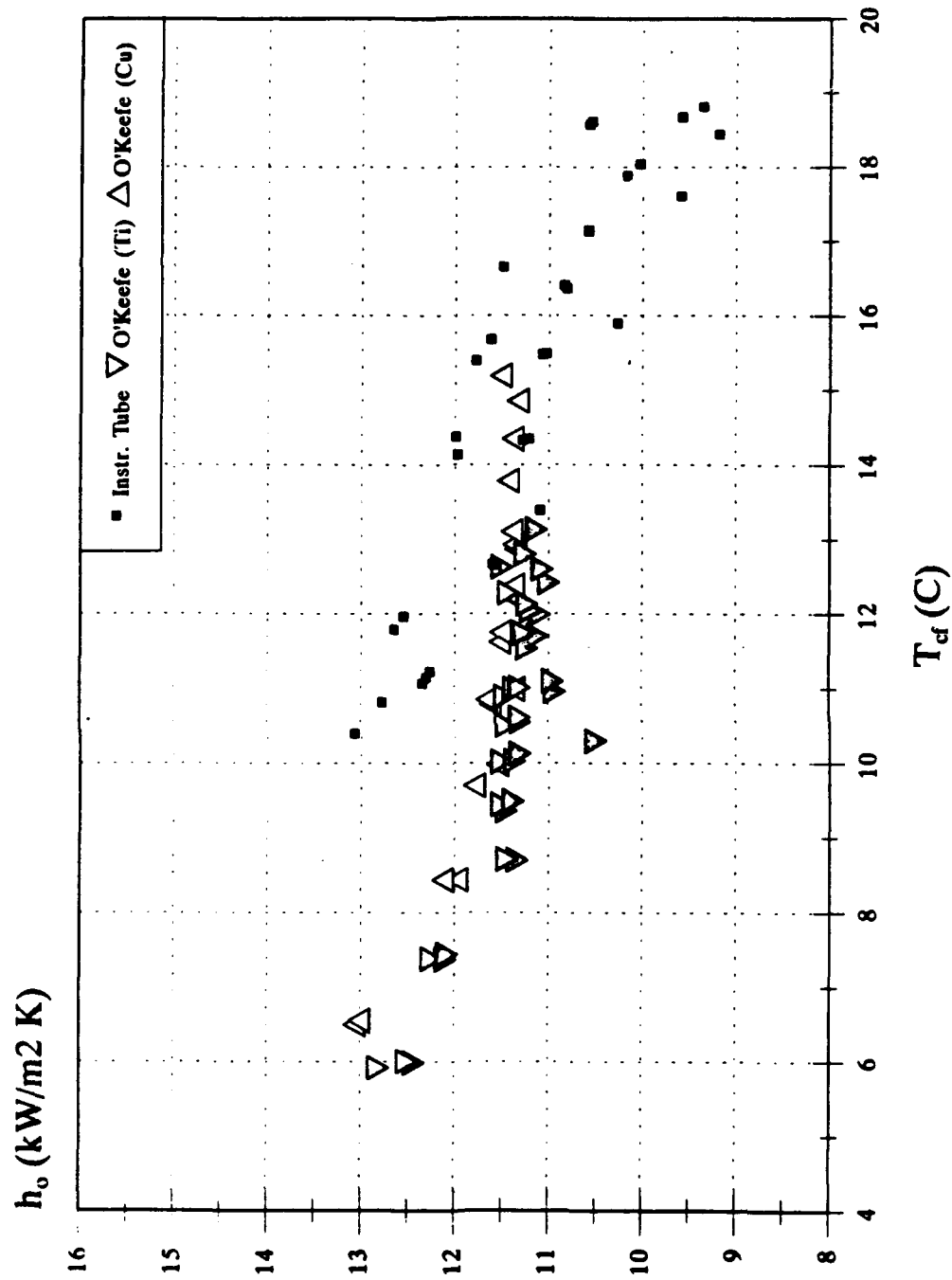


Figure 7. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure using the Swensen Correlations

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 ΔT_f , which is much lower for the titanium tube. The copper tube with the HEATEX insert had higher ΔT_f values for similar coolant flow rates. Swensen produced his correlations for the range of ΔT_f 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 ($\pm 5\%$) 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 $\pm 7\%$. 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

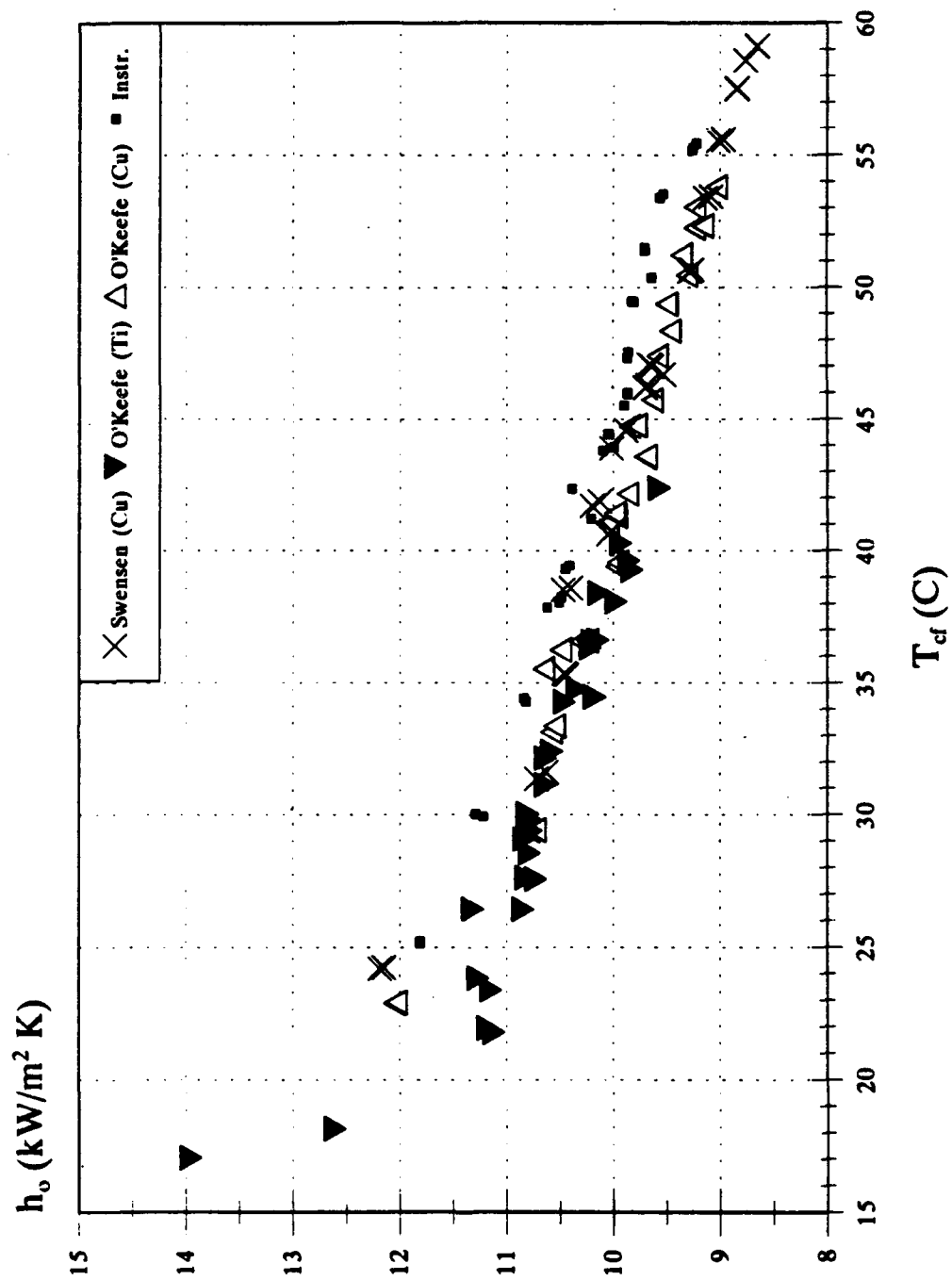


Figure 8. Comparison of the Outside Heat Transfer Coefficients at Atmospheric Pressure using the Petukhov-Popov Correlation

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

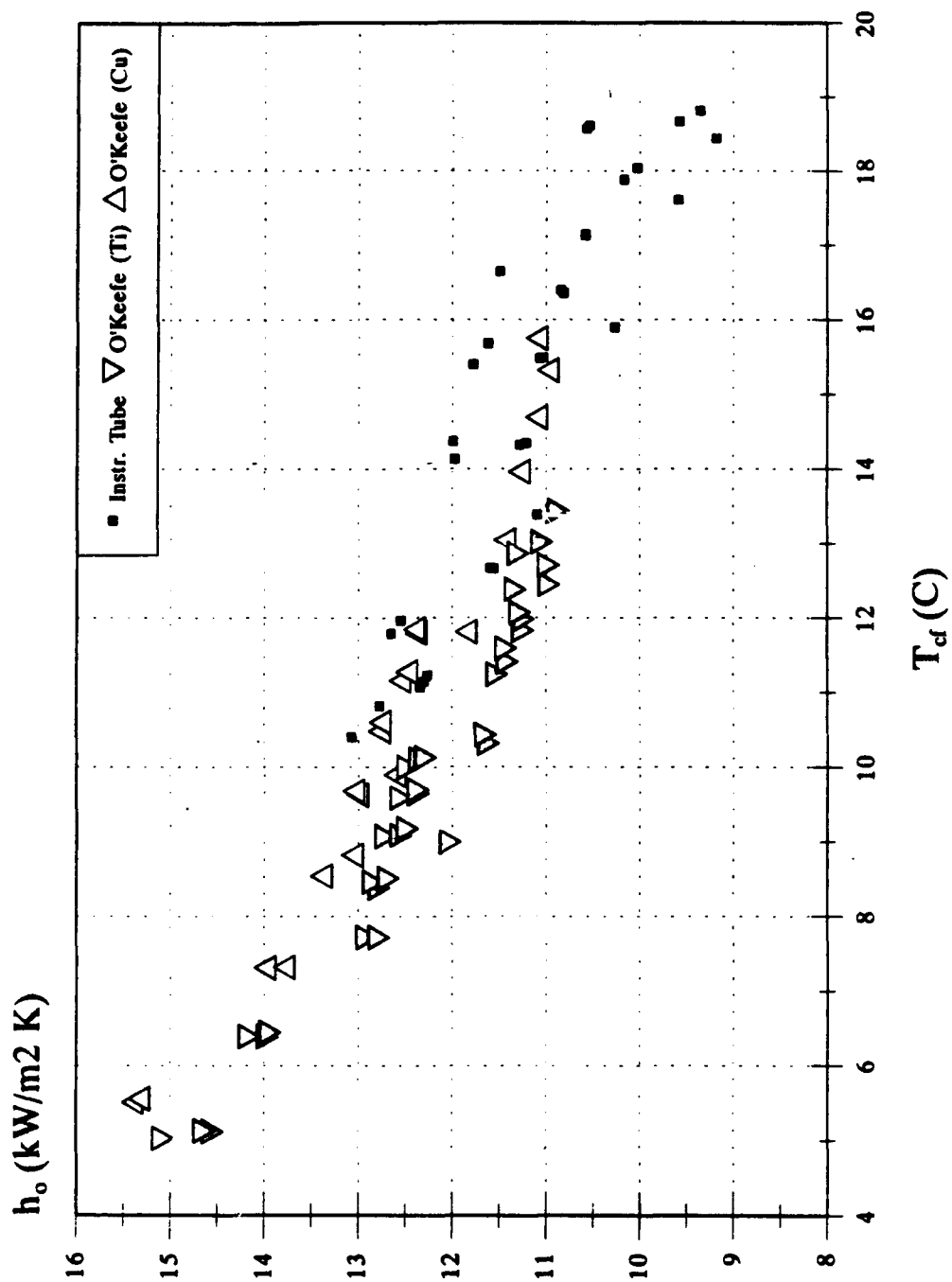


Figure 9. Comparison of the Outside Heat Transfer Coefficients at Vacuum Pressure Using the Petukhov-Popov Correlation

h_o VS. T_{cf} **Atmospheric Pressure Comparison of Petukhov-Popov and Sleicher-Rouse**

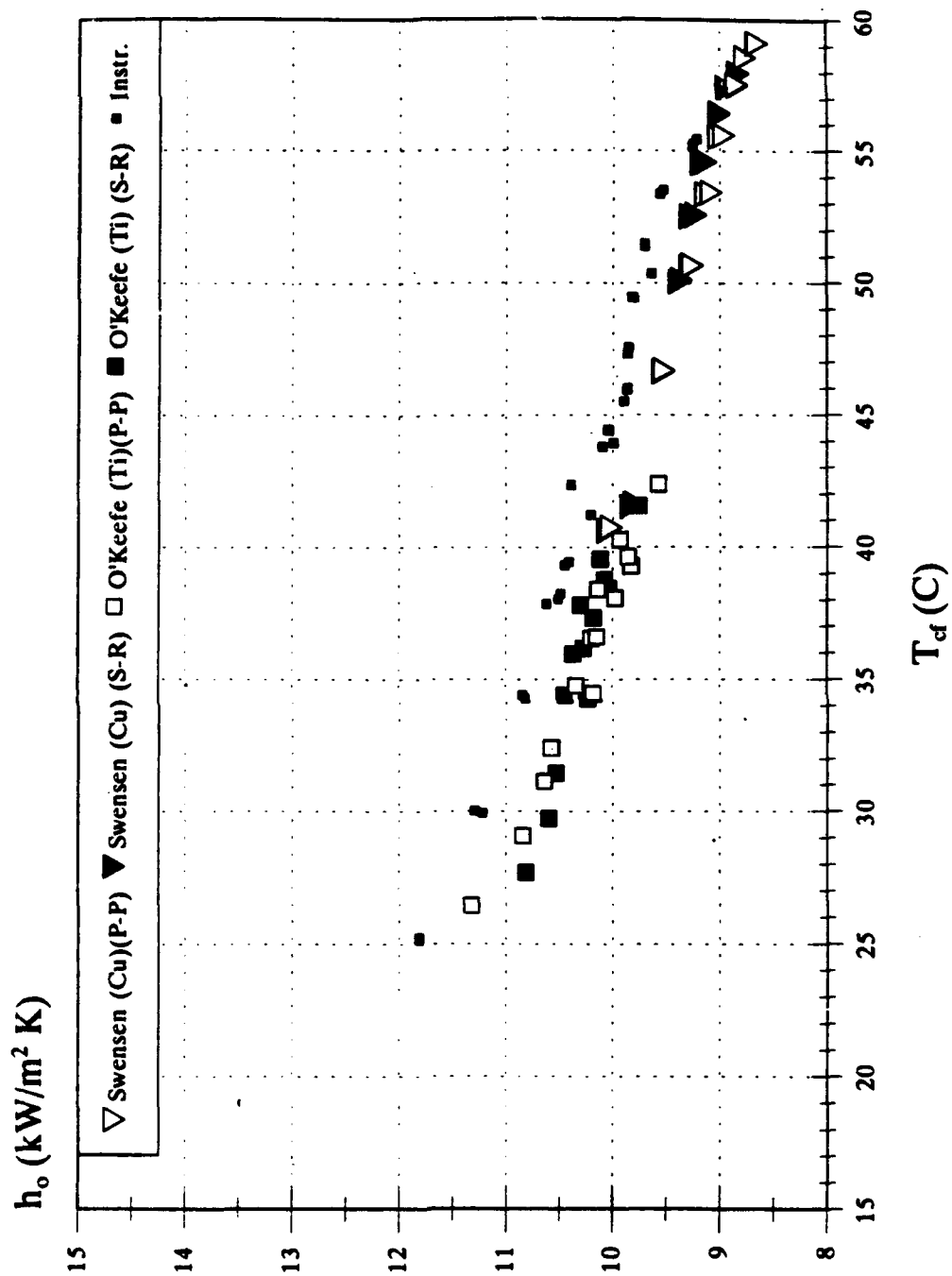


Figure 10. Comparison of the Inside Heat Transfer Coefficients using the Petukhov-Popov and Sleicher-Rouse Correlations

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

h_o vs. T_{cf} Atmospheric Pressure Comparison of Petukhov-Popov and Sieder Tate ($Re^{.85}$)

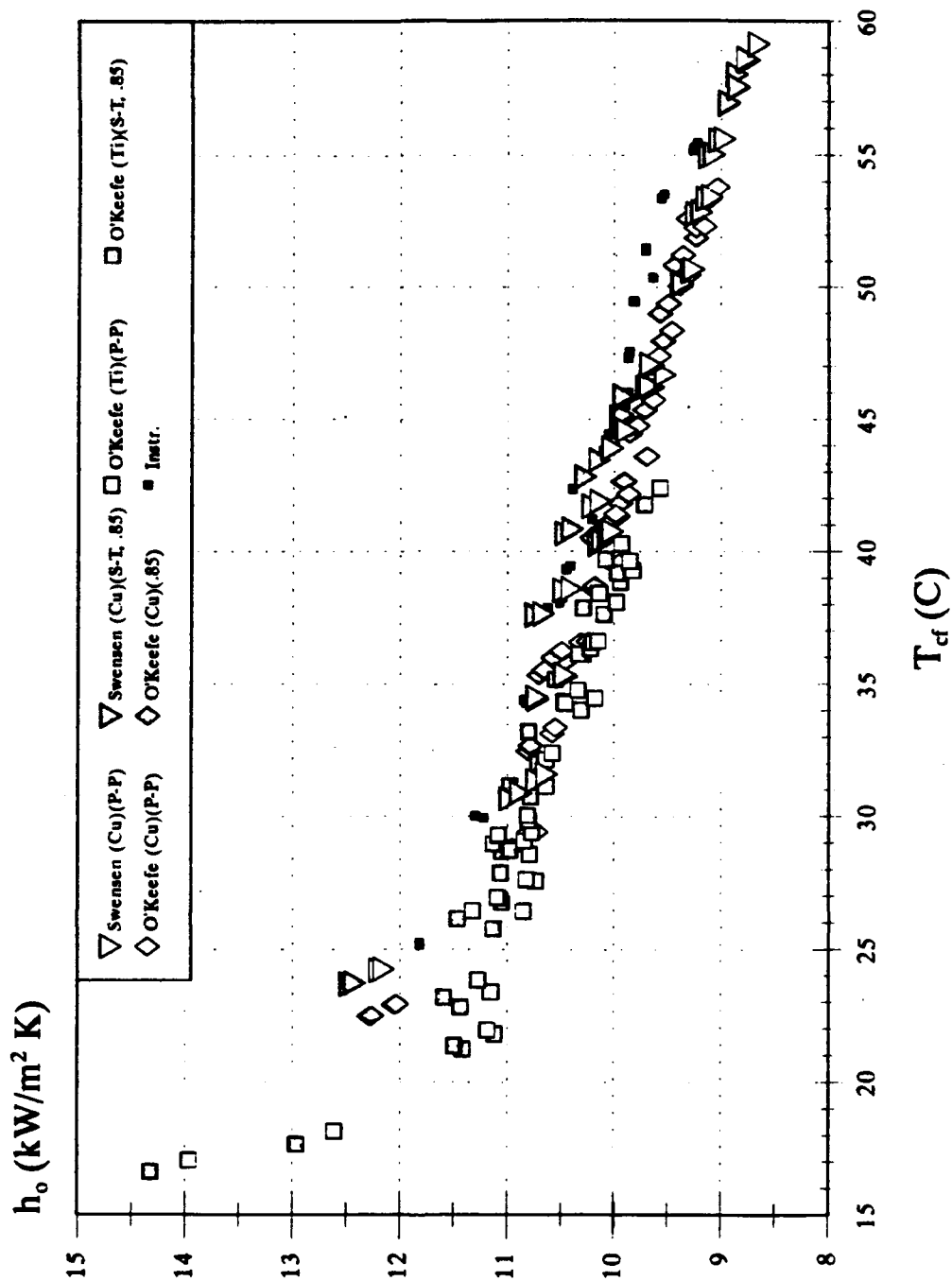


Figure 11. Comparison of the Outside Heat Transfer Coefficients for Atmospheric Pressure Using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) Correlations

coefficient.

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 ($\approx 18\%$ for the HEATEX insert data and $\approx 14\%$ 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

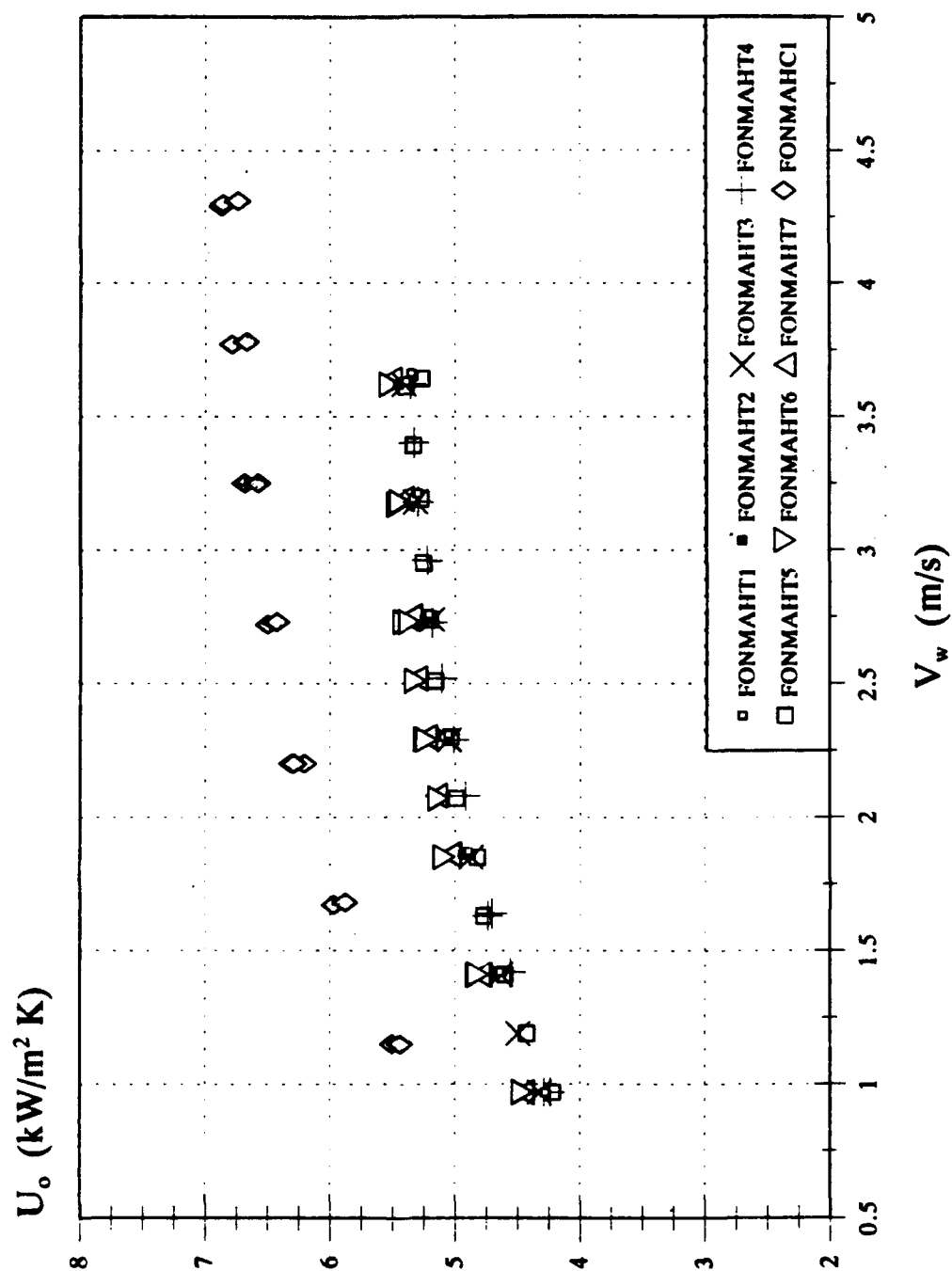


Figure 12. U_o vs. V_w for a Smooth Tube at Atmospheric Pressure with a HEATEX Insert

U_o vs. V_w
Smooth Tube at Atmospheric Pressure with No Insert

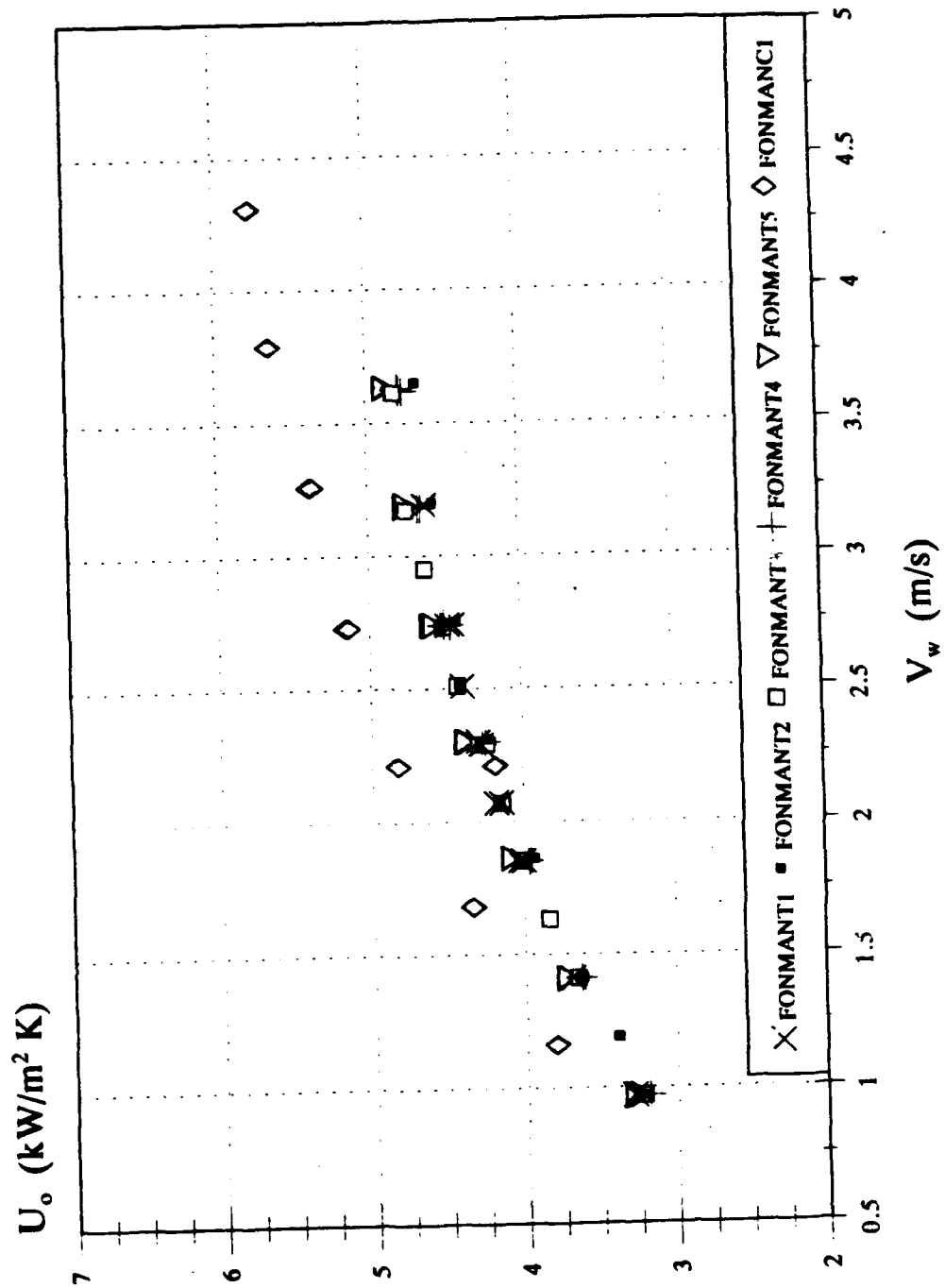


Figure 13. U_o vs. V_w for a Smooth at Atmospheric Pressure with No Insert

U_o vs. V_w Smooth Tube at Vacuum Pressure with a HEATEX Insert

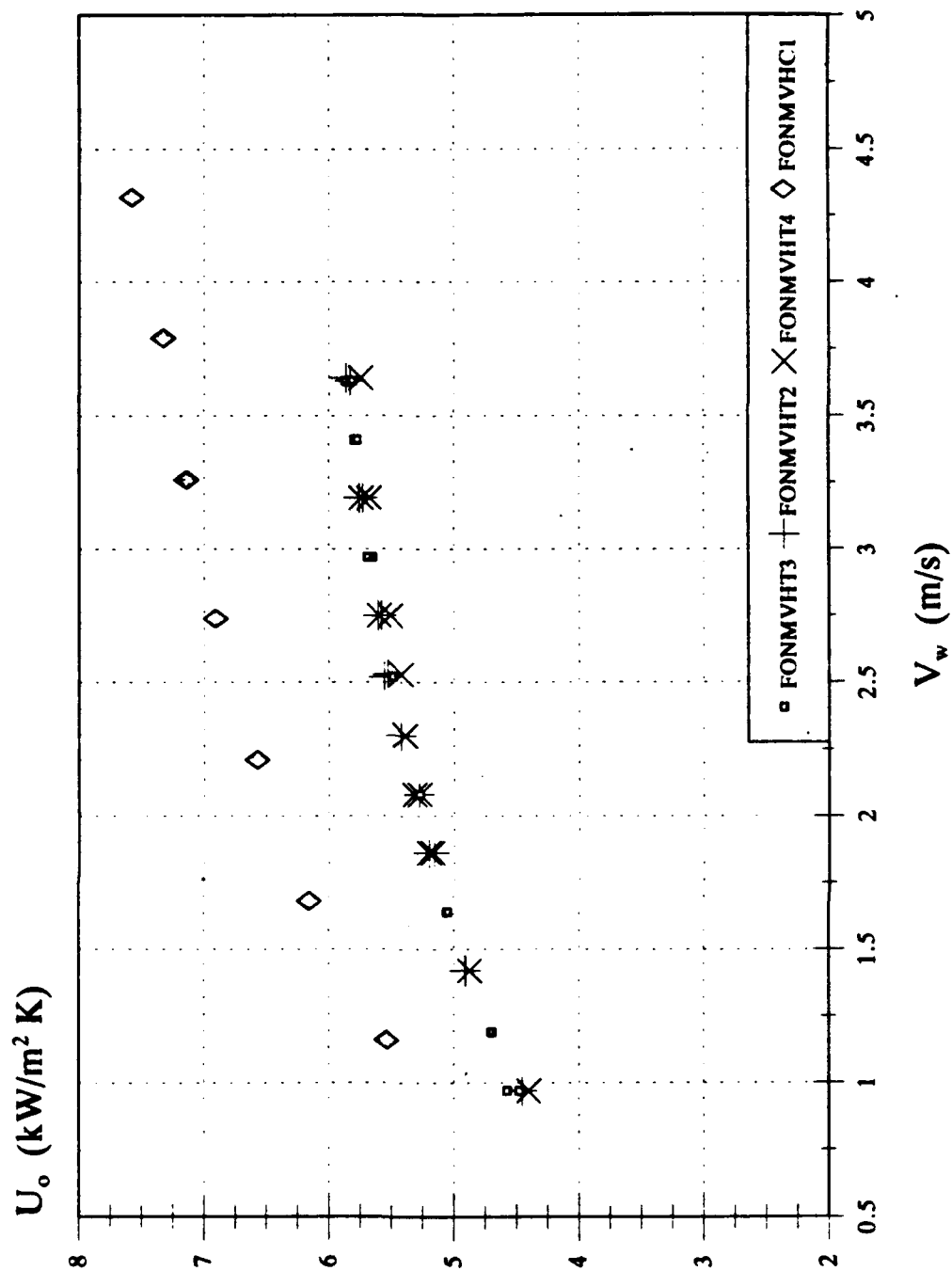


Figure 14. U_o vs. V_w for a Smooth Tube at Vacuum Pressure with a HEATEX Insert

U_o vs. V_w Smooth Tube at Vacuum Pressure with No Insert

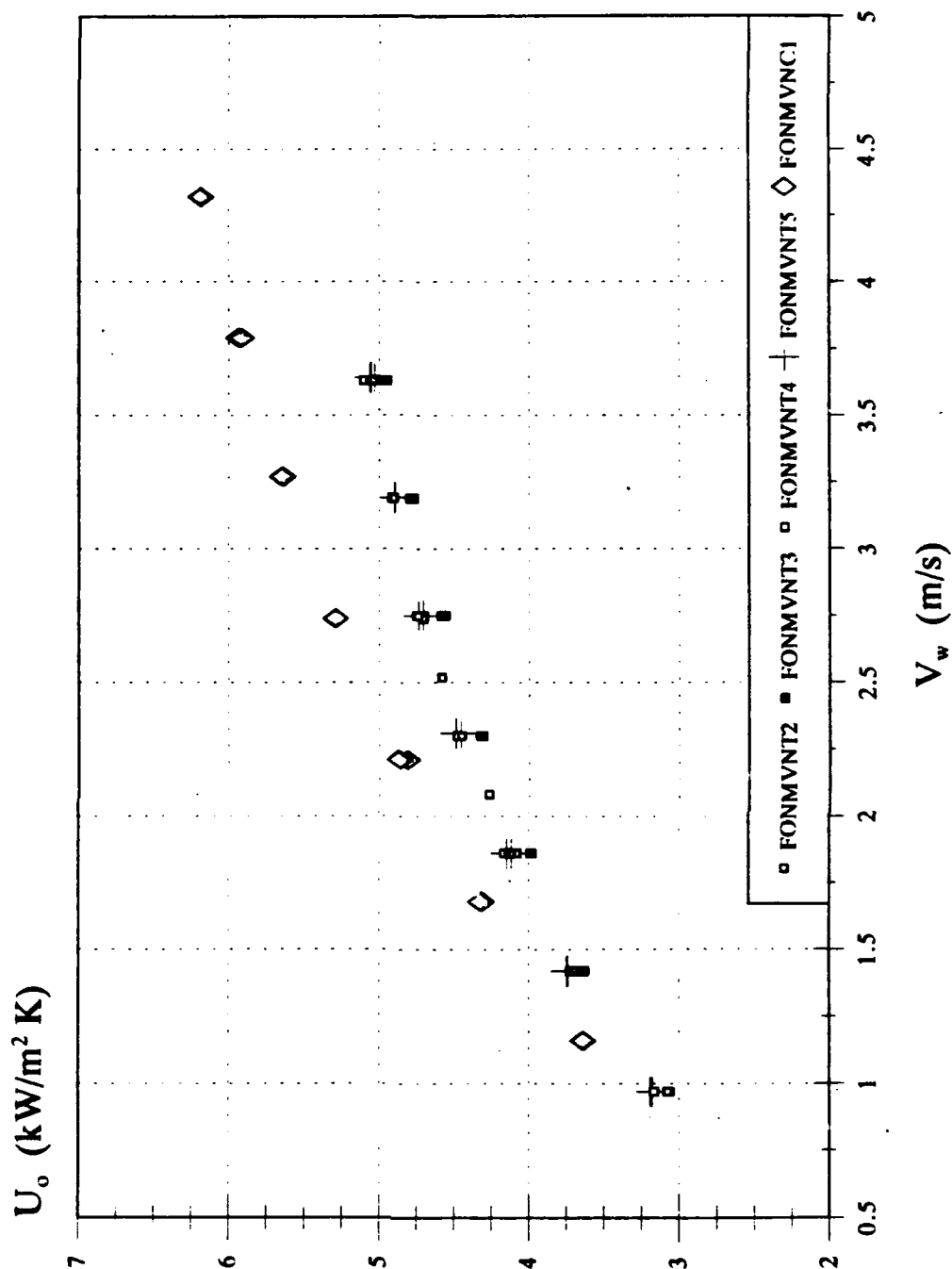


Figure 15. U_o vs. V_w for a Smooth Tube at Vacuum Pressure with No Insert

U_o vs. V_w Smooth Titanium Tube Average U_o Values

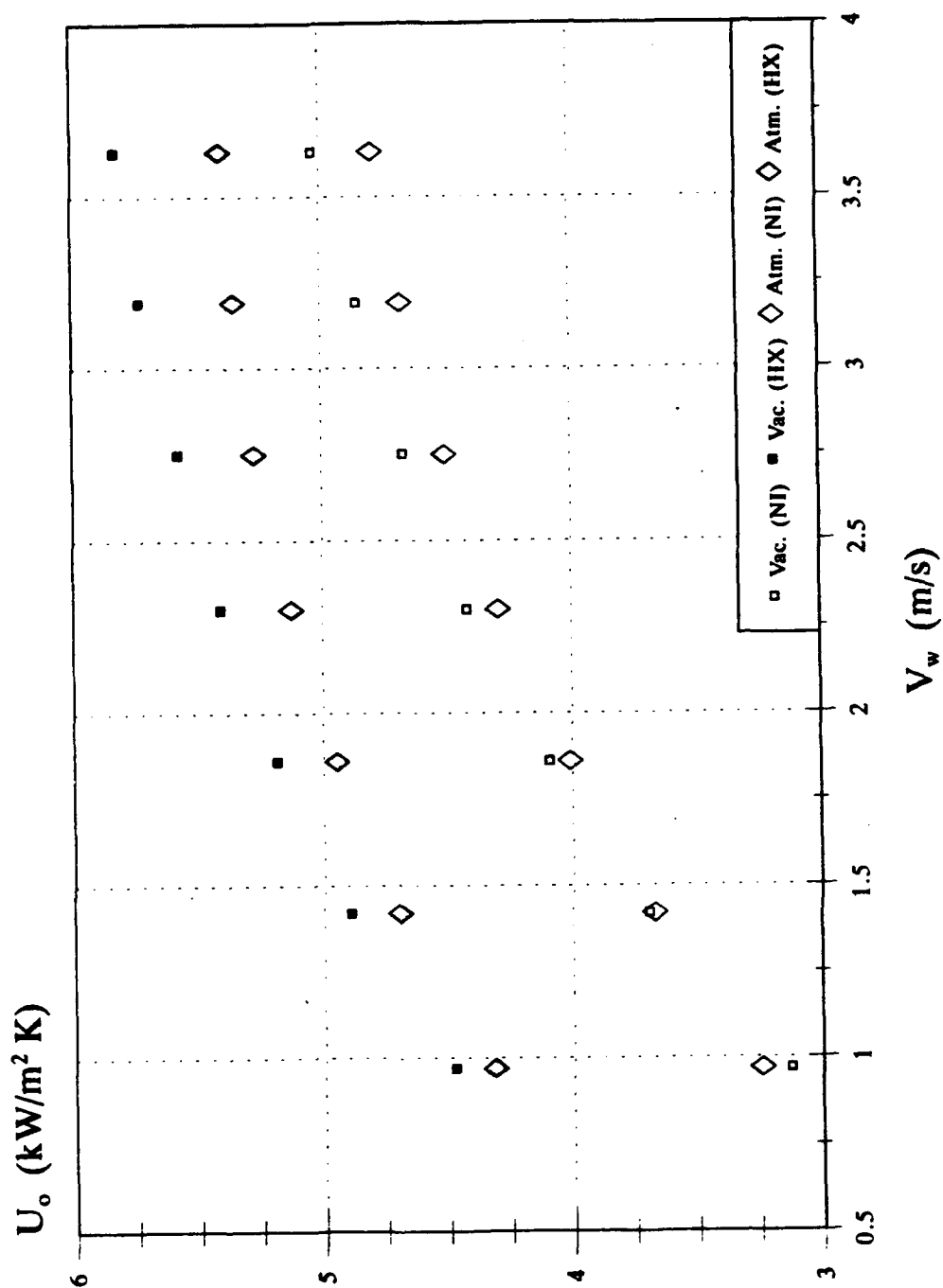


Figure 16. Effect of Vapor Velocity on Smooth Titanium Tubes Average U_o Values

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_f , 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_1)

h_o vs. T_{cf} Atmospheric Pressure

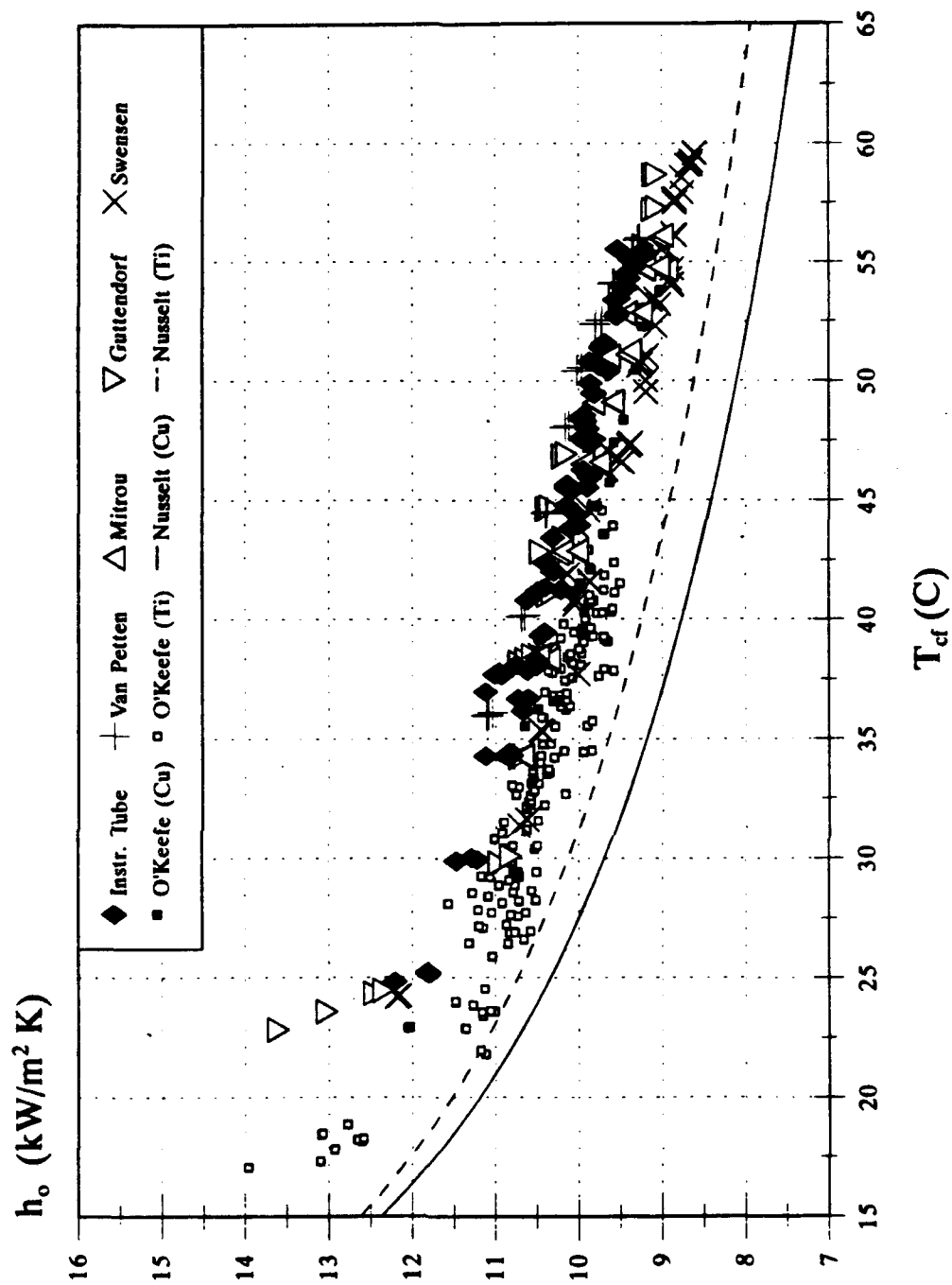


Figure 17. h_o vs. ΔT_f for Smooth Tubes at Atmospheric Pressure

h_o vs. T_{cf} Vacuum Pressure

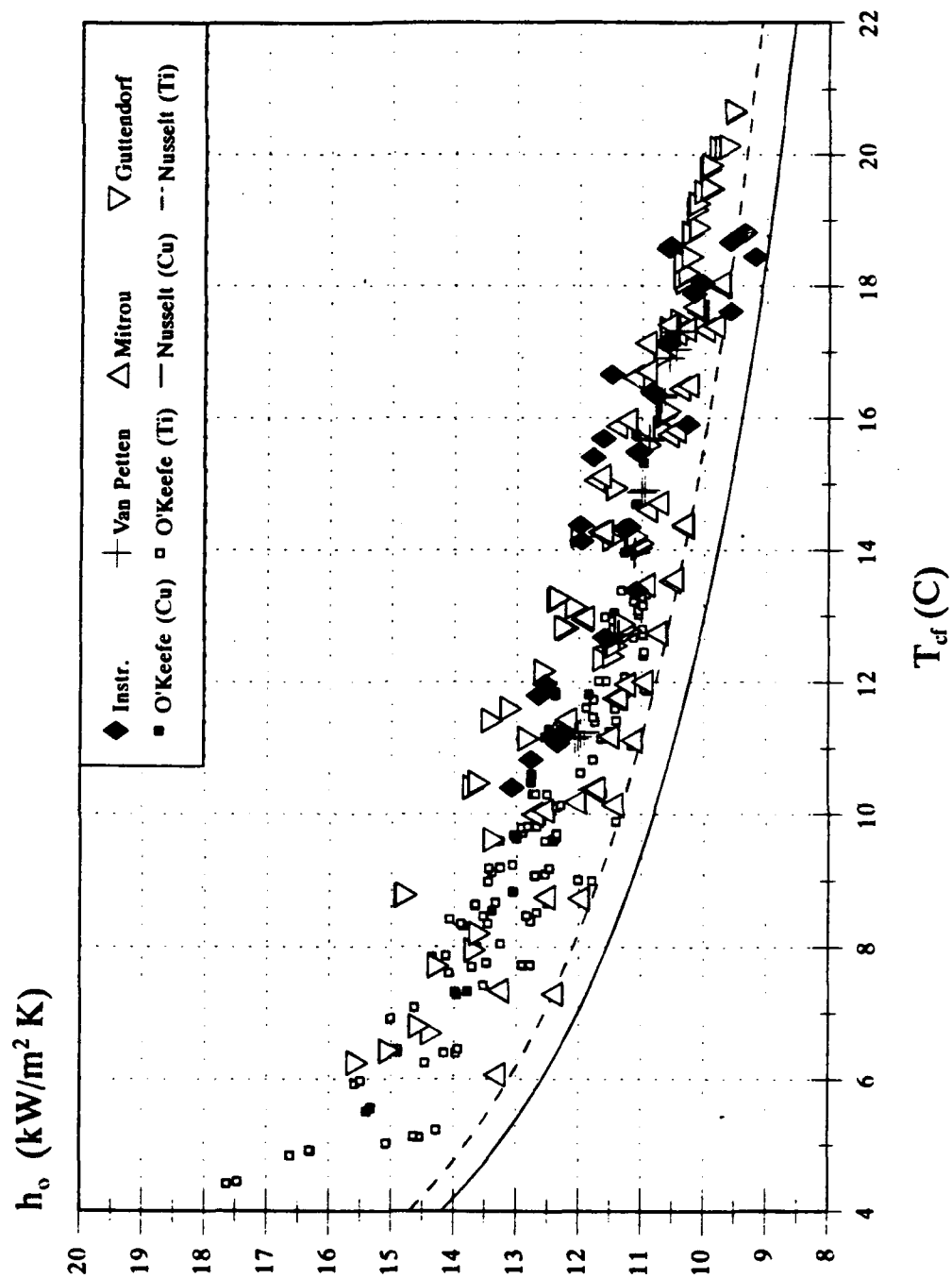


Figure 18. h_o vs. ΔT_c for a Smooth Tube at Vacuum Pressure

Table II. SMOOTH TITANIUM TUBE WITH A HEATEX INSERT (PRESENT WORK)

Atmospheric Pressure HEATEX Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run	C_1	α	C_1	α
FONMAHT1	2.372	0.780	0.038	0.787
FONMAHT2	2.383	0.774	0.038	0.780
FONMAHT3	2.392	0.755	0.038	0.761
FONMAHT4	2.410	0.748	0.038	0.753
FONMAHT5	2.201	0.770	0.035	0.777
FONMAHT6	2.541	0.776	0.040	0.781
FONMAHT7	2.511	0.793	0.040	0.799
Atm. Avg.	2.401	0.776	0.038	0.777
Vacuum Pressure HEATEX Insert				
FONMVHT3	2.547	0.748	0.043	0.748
FONMVHT4	2.278	0.790	0.038	0.791
FONMVHT5	2.422	0.763	0.041	0.763
Vac. Avg.	2.416	0.767	0.041	0.767
Total Avgs.	2.406	0.770	0.039	0.774

using the Petukhov-Popov and Sieder-Tate ($Re^{.85}$) correlations, and the Nusselt coefficients (α) 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)

Atmospheric Pressure No Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run	C_1	α	C_1	α
FONMANT1	1.211	0.750	0.019	0.765
FONMANT2	1.185	0.760	0.018	0.776
FONMANT3	1.169	0.765	0.018	0.777
FONMANT4	1.181	0.765	0.018	0.778
FONMANT5	1.237	0.786	0.019	0.801
Avgs.	1.197	0.765	0.018	0.779
Vacuum Pressure No Insert				
FONMVNT2	1.092	0.822	0.018	0.822
FONMVNT3	1.078	0.788	0.018	0.789
FONMVNT4	1.075	0.846	0.018	0.847
FONMVNT5	1.113	0.827	0.019	0.829
NI Avgs.	1.089	0.821	0.018	0.822
Total Avgs.	1.149	0.790	0.018	0.798

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 α 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 α increases between atmospheric ($U_{\infty} \approx 1.0$ m/s) and vacuum ($U_{\infty} \approx 2.0$ m/s) runs.

Table IV. SMOOTH COPPER TUBE WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run/Researcher	C_1	α	C_1	α
FONMAHC1 (O)	2.809	0.832	0.044	0.835
FNMAVSH4 (S)	3.187	0.819	0.051	0.823
FNMAVSH8 (S)	3.083	0.824	0.049	0.830
FSOMASH3 (S)	3.031	0.818	0.048	0.826
Atm. Avgs.	3.028	0.823	0.048	0.828
Vacuum Pressure HEATEX Insert				
FONMVHC1 (O)	2.482	0.838	0.042	0.838
Total Avgs.	2.918	0.826	0.047	0.830

When the titanium tube is compared to the copper tube, the value of α for the titanium tube is significantly less than the α for the copper tube at the same vapor velocity. The value of α 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

Table V. SMOOTH COPPER TUBE WITH A WIRE WRAP INSERT

Atmospheric Pressure Wire Wrap Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run/Researcher	C_1	α	C_1	α
SMTHSTA654 (V)	2.653	0.875	0.042	0.883
S001S1A3 (G)	2.722	0.855	0.043	0.862
S50A213 (M)	2.335	0.850	0.036	0.858
S50A220 (M)	2.272	0.834	0.035	0.841
Atm. Avgs.	2.495	0.853	0.039	0.861
Vacuum Pressure Wire Wrap Insert				
M1STV103 (V)	2.607	0.827	0.044	0.827
S001S1V3 (G)	2.538	0.818	0.043	0.820
S001S1V4 (G)	2.575	0.823	0.043	0.825
S001S1V5 (G)	2.644	0.815	0.044	0.817
S50V181 (M)	2.102	0.856	0.035	0.858
S50V184 (M)	2.142	0.802	0.036	0.804
Vac. Avgs.	2.435	0.823	0.041	0.825
Total Avgs.	2.459	0.835	0.040	0.839

tube, which in turn affect the values of α . 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 wettability 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

Atmospheric Pressure No Insert				
	Petukhov-Popov		Sieder-Tate ($Re^{.85}$)	
Data Run/Researcher	C_1	α	C_1	α
FONMANC1 (O)	1.265	0.816	0.019	0.828
FSONMASN1 (S)	1.355	0.833	0.021	0.847
S001S0A2 (G)	1.347	0.858	0.021	0.875
Atm. Avgs.	1.322	0.836	0.020	0.850
Vacuum Pressure No Insert				
FONMVNC1 (O)	1.085	0.866	0.018	0.867
S001S0V2 (G)	1.056	0.904	0.017	0.909
S001S0V3 (G)	1.147	0.872	0.019	0.876
S50V177 (M)	0.970	0.774	0.016	0.858
Vac. Avgs.	1.064	0.854	0.018	0.857
Total Avgs.	1.175	0.846	0.019	0.841

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 U_o 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 ($P/D_w = 7.92$) and 2 mm ($P/D_w = 4.02$) 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 ($P/D_w = 2.13$); 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_i and α for each data run. The leading coefficients in front of the inside heat transfer correlation

U_o vs. V_w Atmospheric Pressure with HEATEX Insert

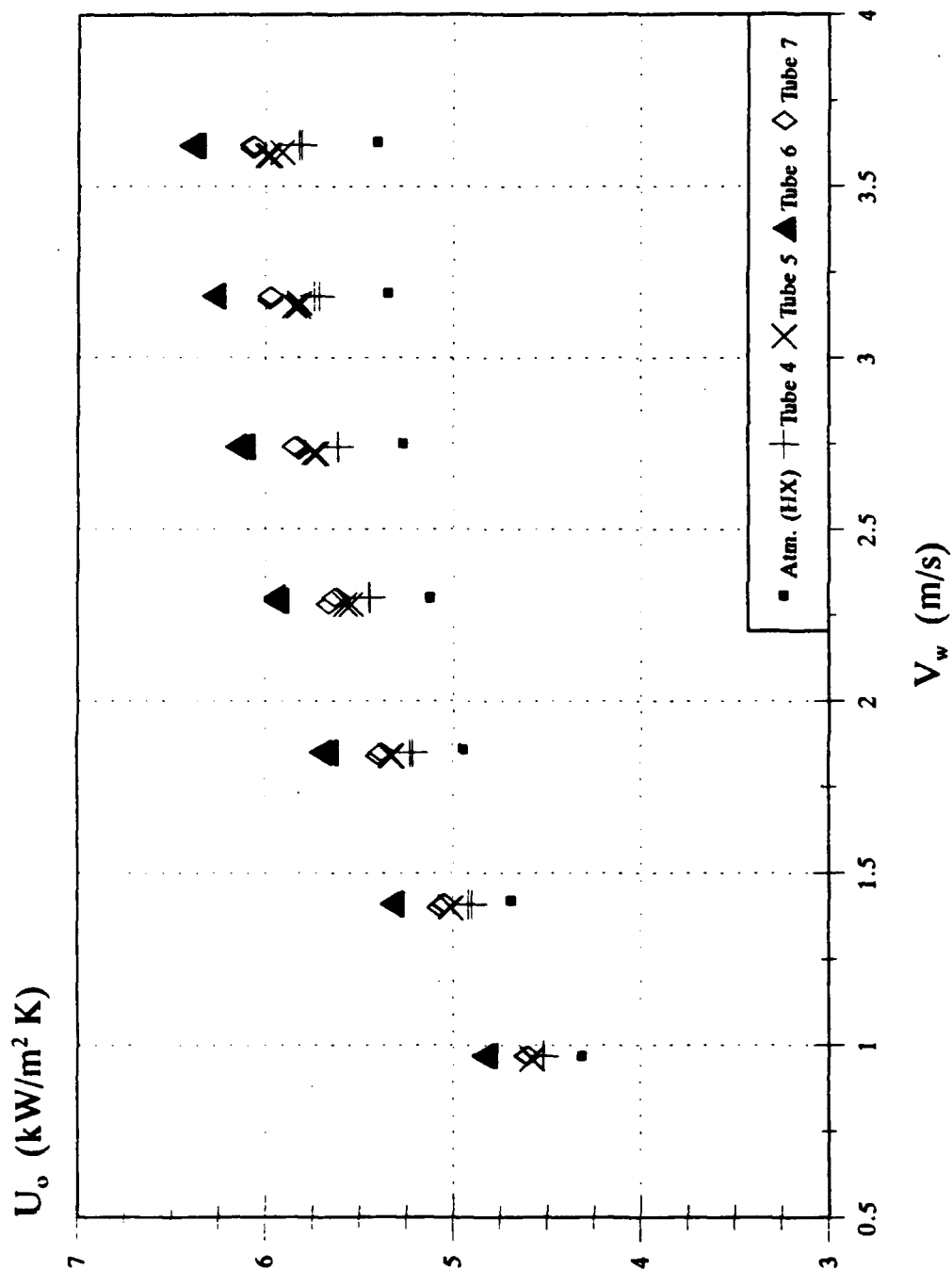


Figure 19. U_o vs V_w for Wire-Wrapped Tubes at Atmospheric Pressure with a Heatex Insert

Table VII. WIRE-WRAPPED SMOOTH TITANIUM TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run / Tube	C_1	α	E_T
FONMAH1T1 (1)	2.023	0.798	1.035
FONMAH2T3 (2)	2.448	0.806	1.046
FONMAH3T1 (3)	2.138	0.724	0.902
FONMAH4T1 (4)	2.379	0.853	1.106
FONMAH5T1 (5)	2.251	0.869	1.127
FONMAH6T2 (6)	2.389	0.993	1.289
FONMAH6T3 (6)	2.362	1.005	1.304
FONMAH7T1 (7)	2.237	0.925	1.200
Atm. Avg.	2.301		
Vacuum Pressure HEATEX Insert			
FONMVH1T1 (1)	1.892	0.802	1.045
FONMVH2T1 (2)	2.005	0.797	1.038
FONMVH2T2 (2)	1.948	0.787	1.026
FONMVH2T3 (2)	2.240	0.766	0.999
FONMVH3T2 (3)	1.866	0.618	0.714
FONMVH4T1 (4)	2.081	0.821	1.071
FONMVH5T1 (5)	2.014	0.842	1.097
FONMVH6T1 (6)	2.160	0.950	1.238
FONMVH6T2 (6)	2.214	0.946	1.233
FONMVH7T2 (7)	1.956	0.855	1.115
Vac. Avg.	1.967		
Total Avg.	2.115		

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

Atmospheric Pressure No Insert			
Data Run / Tube	C_1	α	E_r
FONMAN1T1 (1)	1.131	0.783	1.022
FONMAN2T1 (2)	1.095	0.801	1.047
FONMAN3T1 (3)	1.034	0.698	0.888
FONMAN4T1 (4)	1.377	0.791	1.034
FONMAN5T1 (5)	1.099	0.837	1.093
FONMAN6T1 (6)	1.120	1.019	1.331
FONMAN7T1 (7)	1.191	0.866	1.131
Atm. Avg.	1.150		
Vacuum Pressure No Insert			
FONMVN1T1 (1)	1.024	0.838	1.021
FONMVN2T1 (2)	0.998	0.818	0.997
FONMVN3T1 (3)	0.911	0.636	0.702
FONMAN4T1 (4)	1.139	0.825	1.005
FONMAN5T1 (5)	0.978	0.843	1.027
FONMAN6T1 (6)	1.043	1.013	1.235
FONMVN7T1 (7)	0.978	0.870	1.060
Vac. Avg.	1.010		
Total Avg.	1.080		

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

Atmospheric Pressure HEATEX Insert			
Data Run	C_i	α	E_T
FONMAH68C1	2.807	1.316	1.719
FONMAH71C1	3.069	1.722	2.192
Atm. Avg.	2.938		
Vacuum Pressure HEATEX Insert			
FONMVH68C1	2.549	1.289	1.570
FONMVH71C2	2.765	1.414	1.560
Vac. Avg.	2.657		
Total Avg.	2.797		

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 wettability characteristics or tube thermal conductivity may affect the outside heat transfer coefficient.

Table X. WIRE-WRAPPED SMOOTH COPPER TUBES WITH A WIRE WRAP INSERT

Atmospheric Pressure Wire Wrap Insert			
Data Run/Researcher	C_i	α	E_T
S68A311 (M)	2.686	1.360	1.616
S71A305 (M)	2.685	1.489	1.769
S71A314 (M)	2.692	1.473	1.749
Atm. Avg.	2.688		
Vacuum Pressure Wire Wrap Insert			
S68V283 (M)	2.452	1.182	1.401
S68V293 (M)	2.485	1.166	1.382
S71V296 (M)	2.503	1.267	1.501
Vac. Avg.	2.480		
Total Avg.	2.584		

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_w of about 5. The present data do not show such a clear maximum and tube 6 ($P/D_w = 7.96$) does not appear to be in line with the data of Sethumadhavan and Rao or Mitrou. Extra experiments were done

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

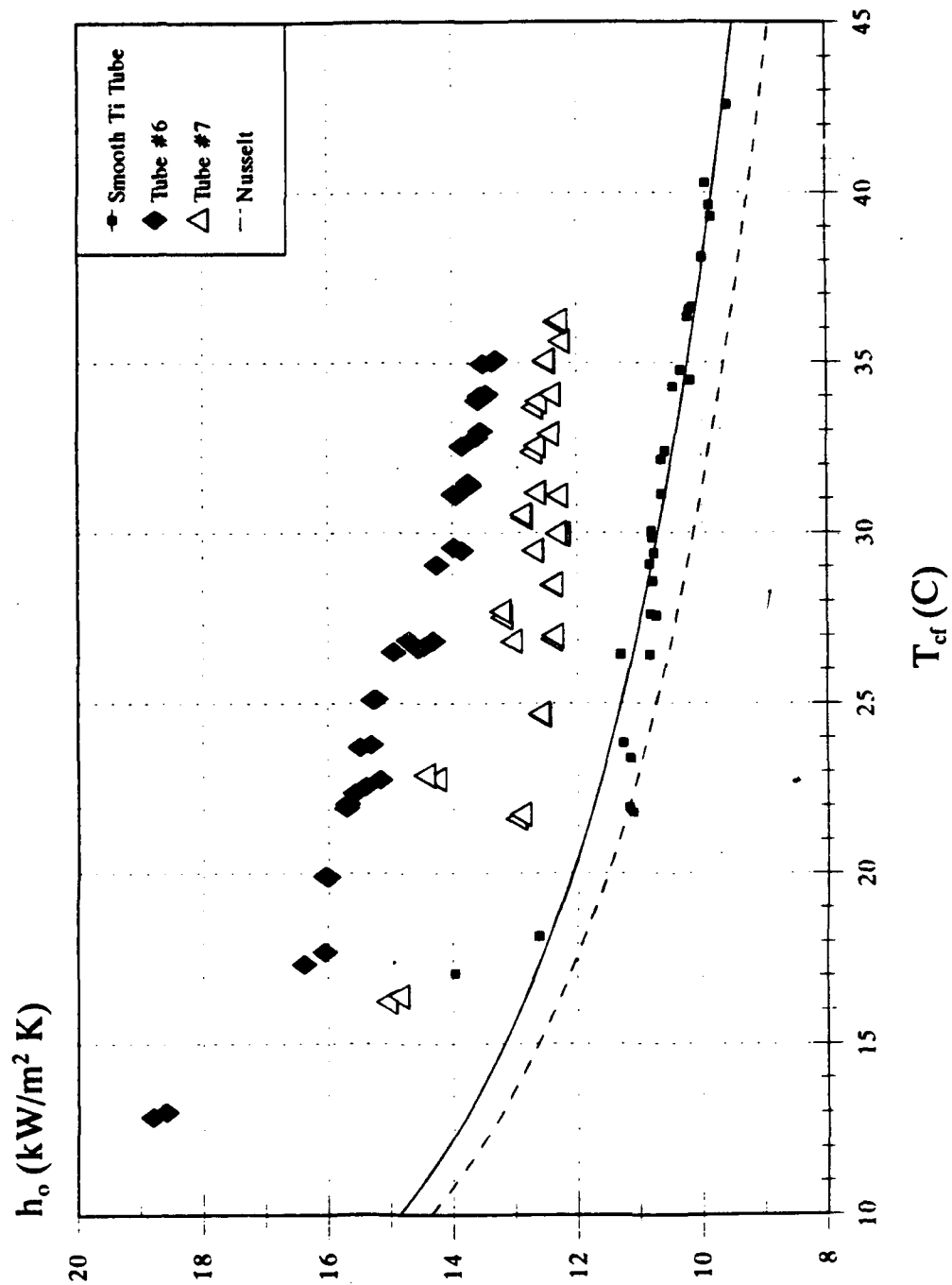


Figure 20. Comparison of the Outside Heat Transfer Coefficients of Tubes 6 and 7 with a Smooth Titanium Tube

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

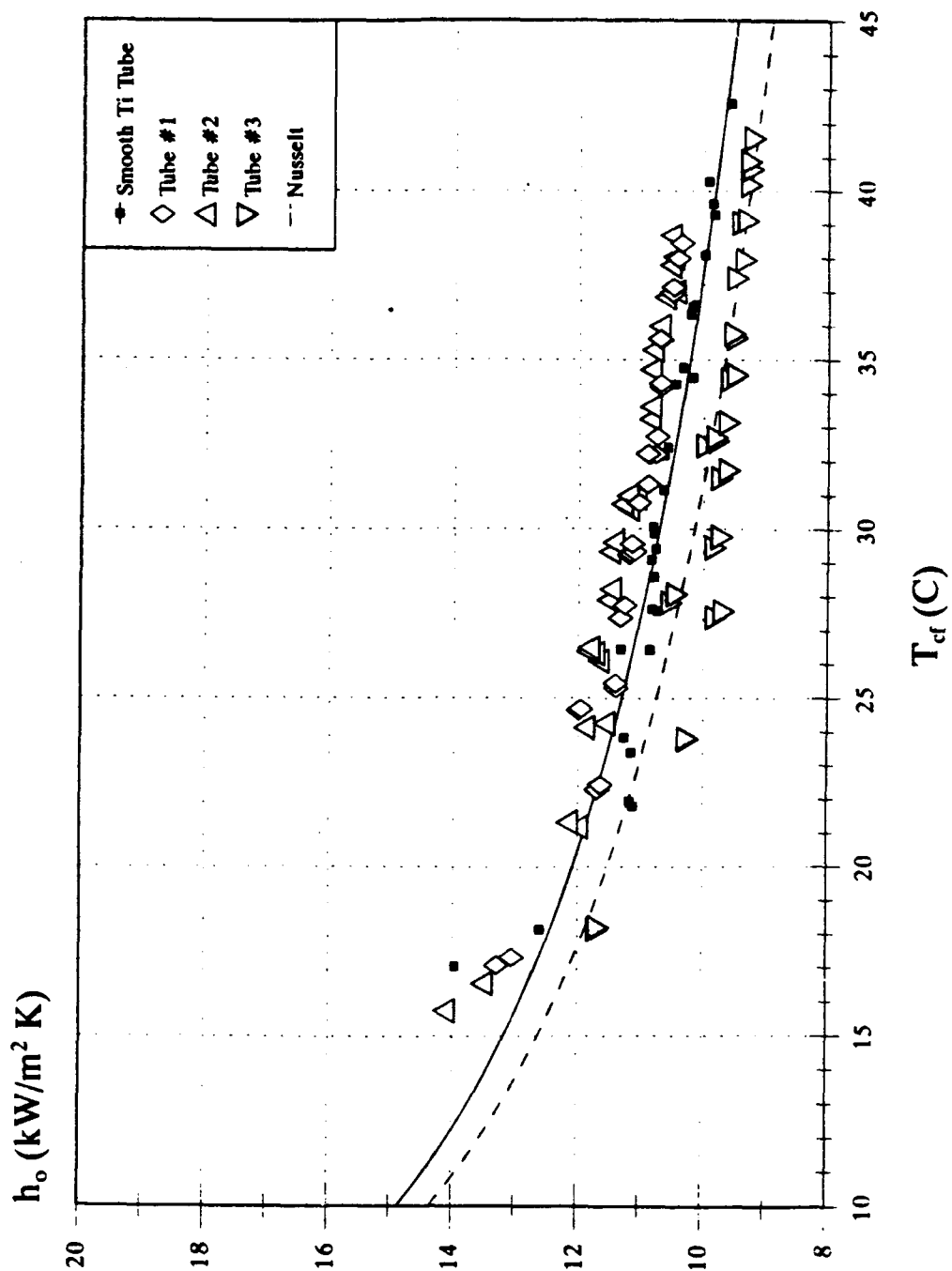


Figure 21. Comparison of the Outside Heat Transfer Coefficients of Tubes 1,2, and 3 to a Smooth Titanium Tube

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

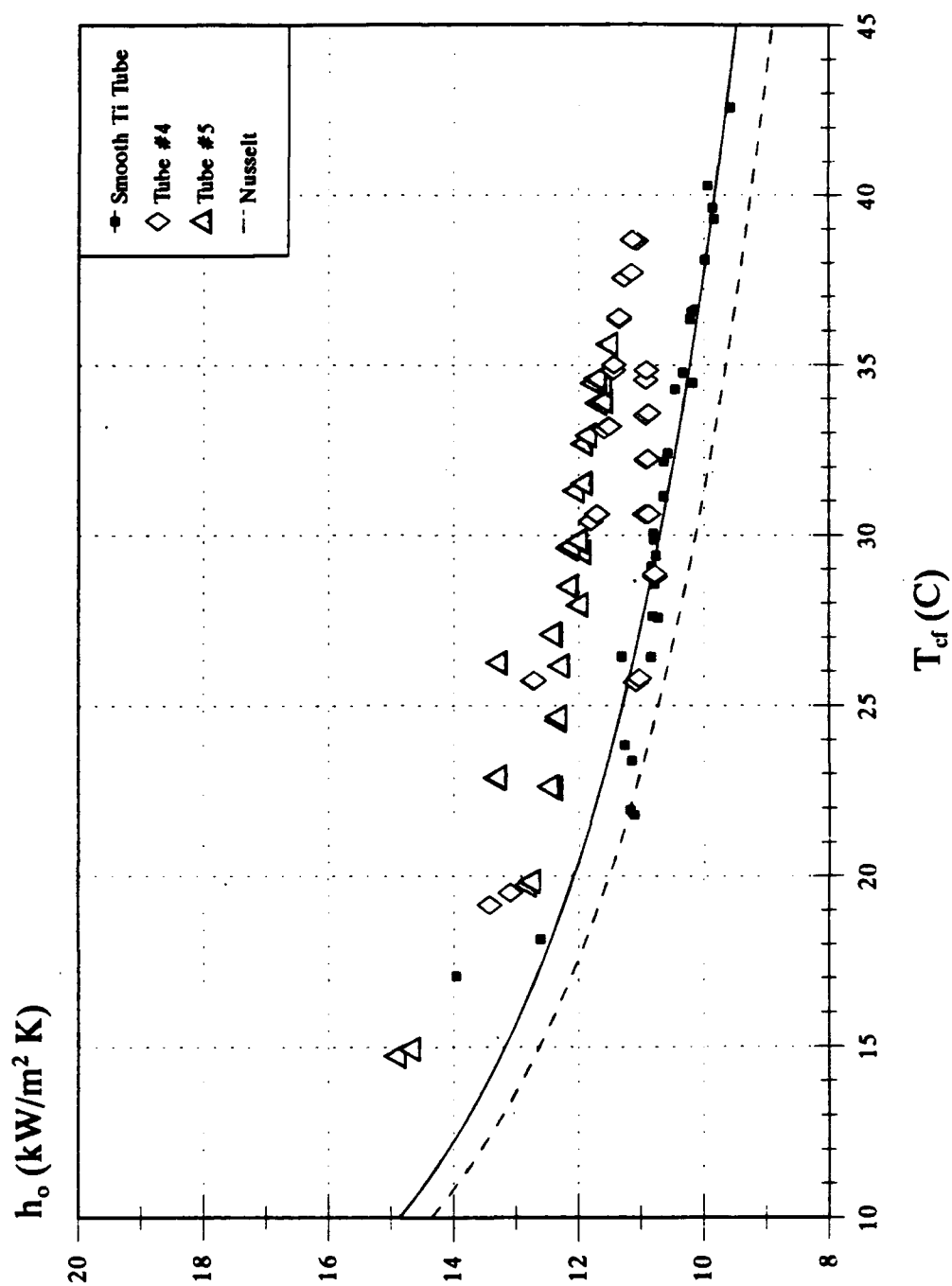


Figure 22. Comparison of the Outside Heat Transfer Coefficients for tubes 4 and 5 to a Smooth Titanium Tube

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

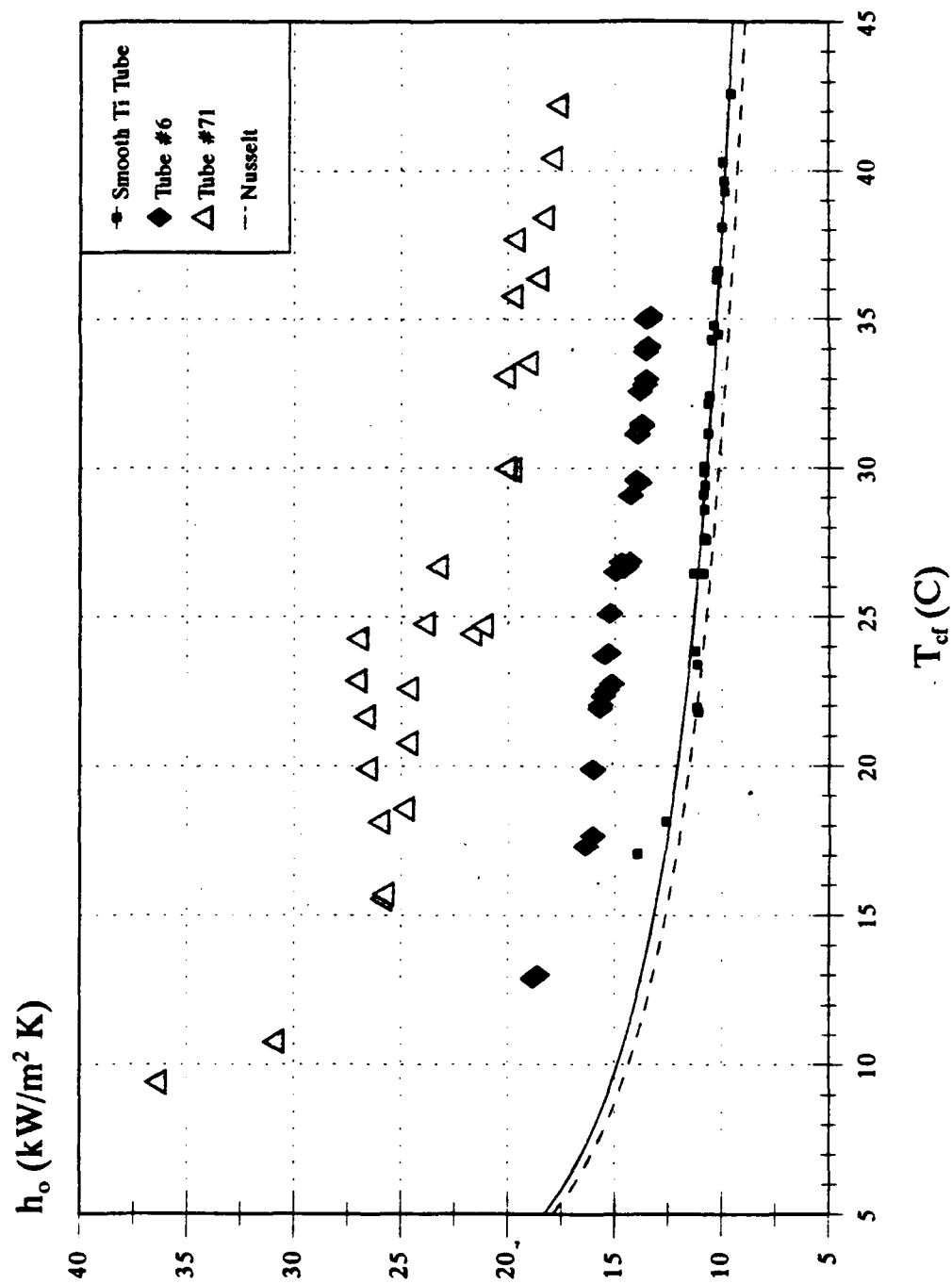


Figure 23. Comparison of the Outside Heat Transfer Coefficients between the Titanium and Copper Tubes

Enhancement vs. P/D_w Ratio Wire-Wrapped Smooth Tubes at Atmospheric Pressure

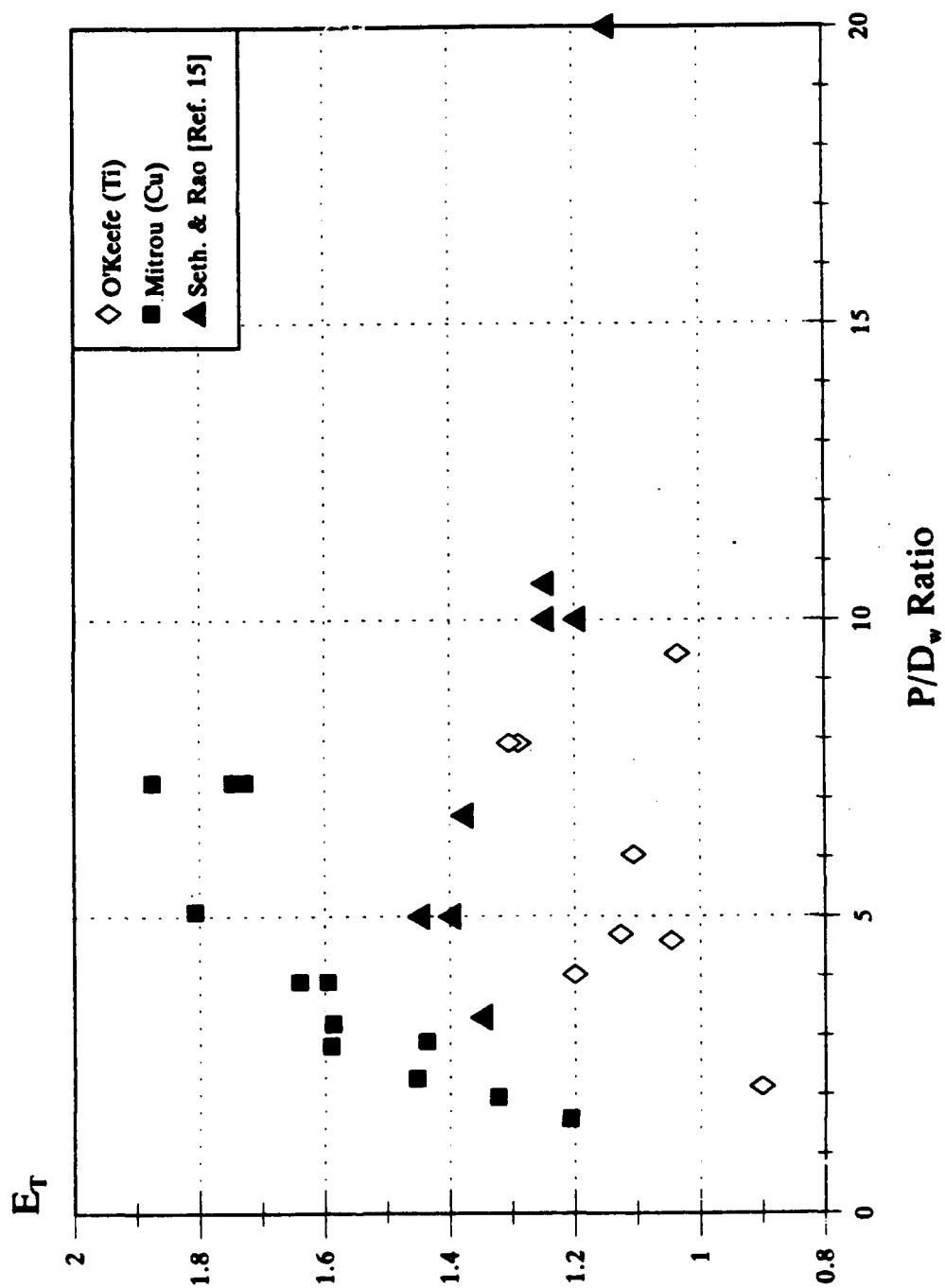


Figure 24. Comparison of the Enhancement vs. P/D_w Ratio of the Data from Mitrou, O'Keefe, and Sethumadhavan & Rao

on tube 6 to check the repeatability with essentially the same results. It would appear that P/D_w is not such a good correlating parameter.

Instead of looking at the P/D_w 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/D_w , 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.

Enhancement vs. F

Wire-Wrapped Smooth Tubes at Atmospheric Pressure

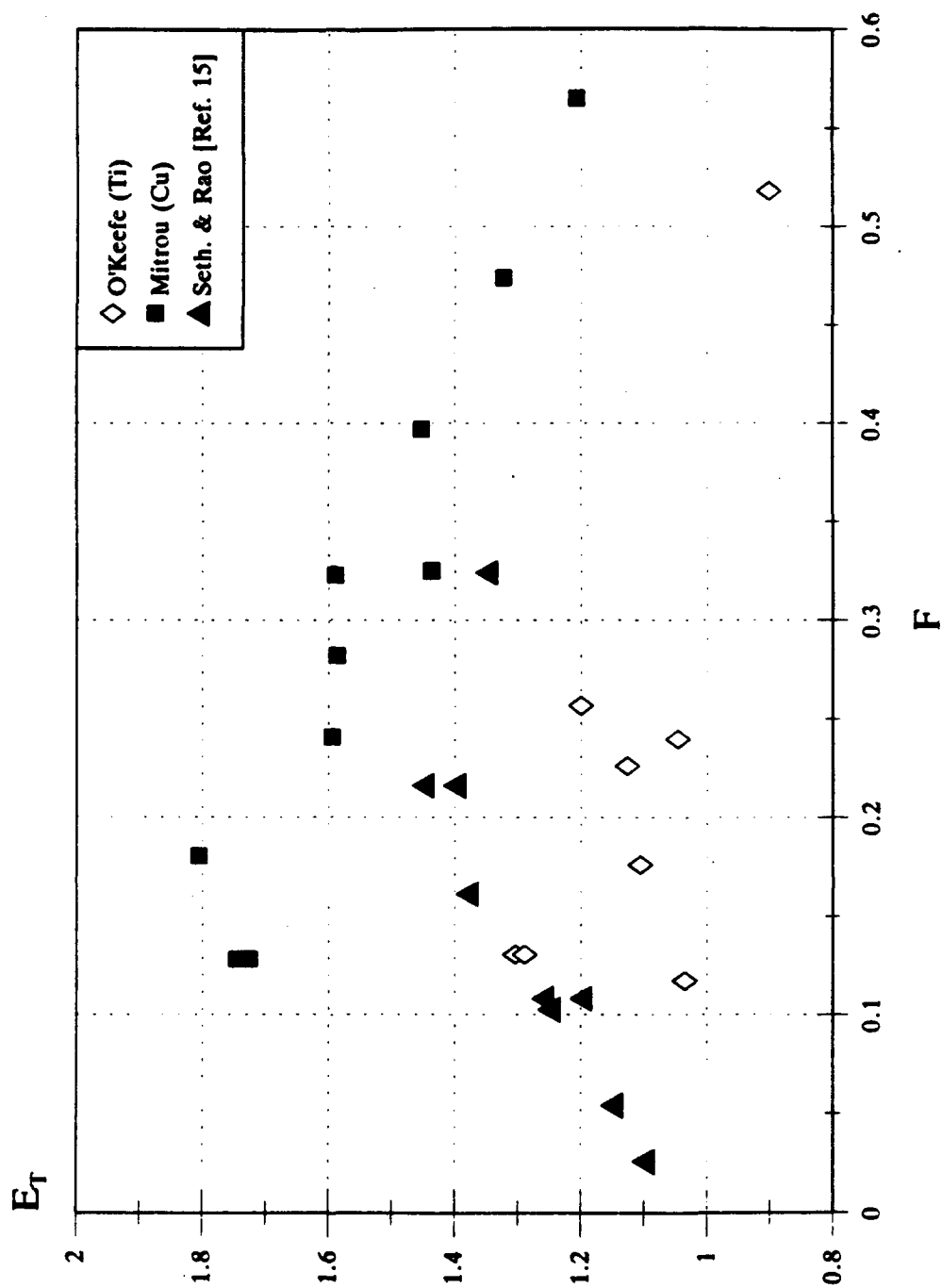


Figure 25. Comparison of the Enhancement vs. F for the data of Mitrou, O'Keefe, and Sethumadhavan & Rao

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 ($\approx 20\%$) 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 ($D_w = 0.5$ 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/D_w or F and the enhancement over a plain LPD tube (h_o/h_{LPD}). Figures 28 and 29

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

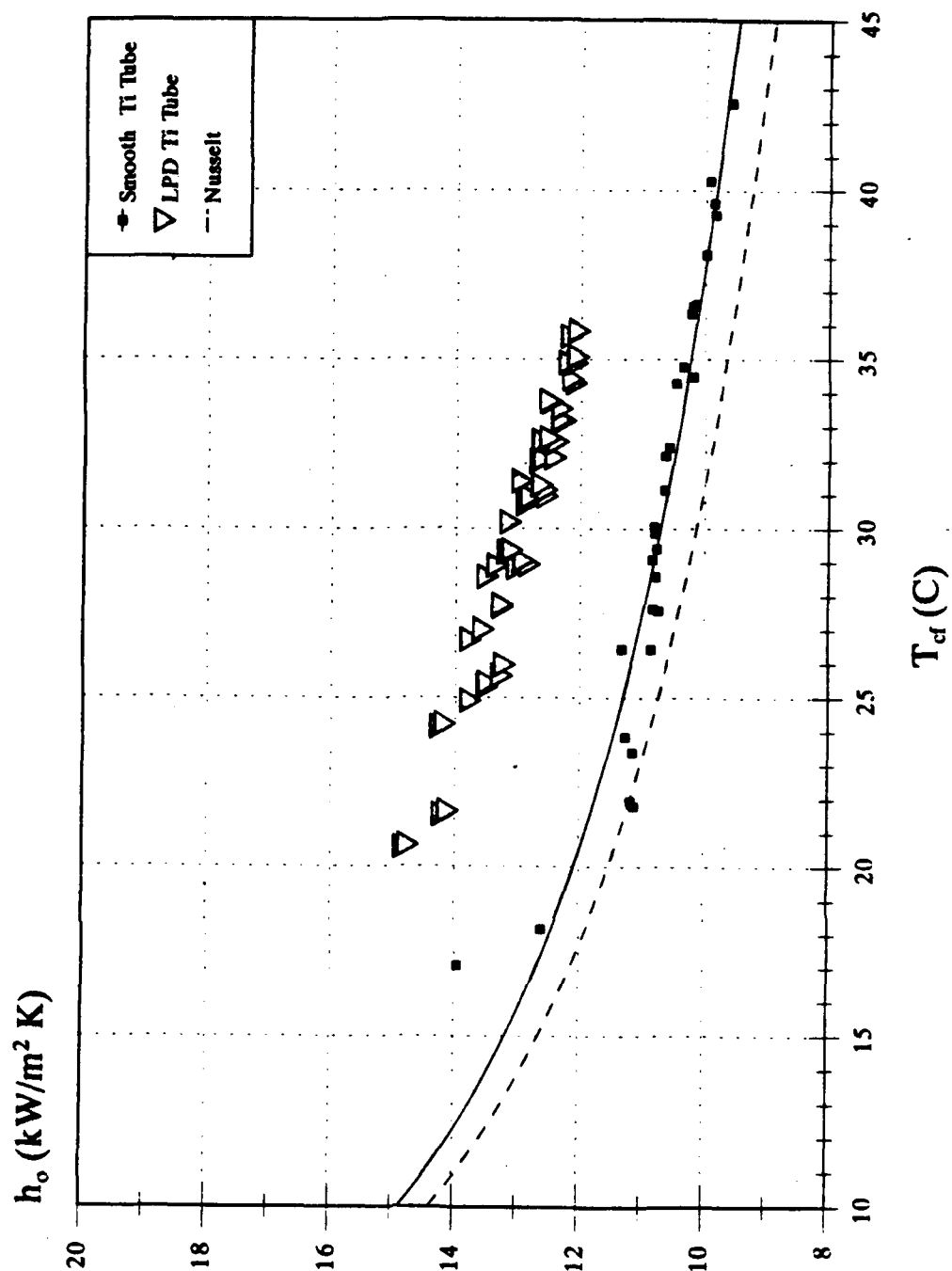


Figure 26. Comparison of the Outside Heat Transfer Coefficients for the plain LPD KORODENSE Tube and the Smooth Titanium Tube

Table XI. LPD KORODENSE TUBES WITH A HEATEX INSERT

Atmospheric Pressure HEATEX Insert			
Data Run / Tube	C_i	α	E_r
FONMAHLT2 (L)	2.903	0.903	1.171
FONMAHLT3 (L)	2.892	0.916	1.188
FONMAHL1T1 (L1)	2.667	0.890	1.154
FONMAHL2T1 (L2)	2.639	0.909	1.179
FONMAHL3T1 (L3)	2.835	0.968	1.256
Atm. Avg.	2.787		
Vacuum Pressure HEATEX Insert			
FONMVHLT1 (L)	2.717	0.945	1.232
FONMVHLT2 (L)	2.669	0.950	1.238
FONMVHL1T2 (L1)	2.317	0.880	1.147
FONMVHL2T3 (L2)	2.426	0.890	1.161
FONMVHL3T2 (L3)	2.609	0.995	1.297
Vac. Avg.	2.548		
Total Avg.	2.667		

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

Atmospheric Pressure No Insert			
Data Run / Tube	C_1	α	E_T
FONMANLT2 (L)	2.056	0.919	1.201
FONMANLT3 (L)	1.993	0.941	1.230
FONMANL1T1 (L1)	2.036	0.869	1.135
FONMANL2T1 (L2)	2.057	0.890	1.163
FONMANL3T1 (L3)	2.202	0.933	1.219
Atm. Avg.	2.069		
Vacuum Pressure No Insert			
FONMVNLT2 (L)	1.869	0.953	1.161
FONMVNLT3 (L)	1.862	0.956	1.165
FONMVNL1T2 (L1)	1.784	0.855	1.041
FONMVNL2T3 (L2)	1.839	0.869	1.059
FONMVNL3T2 (L3)	2.041	0.942	1.148
Vac. Avg.	1.879		
Total Avg.	1.974		

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

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

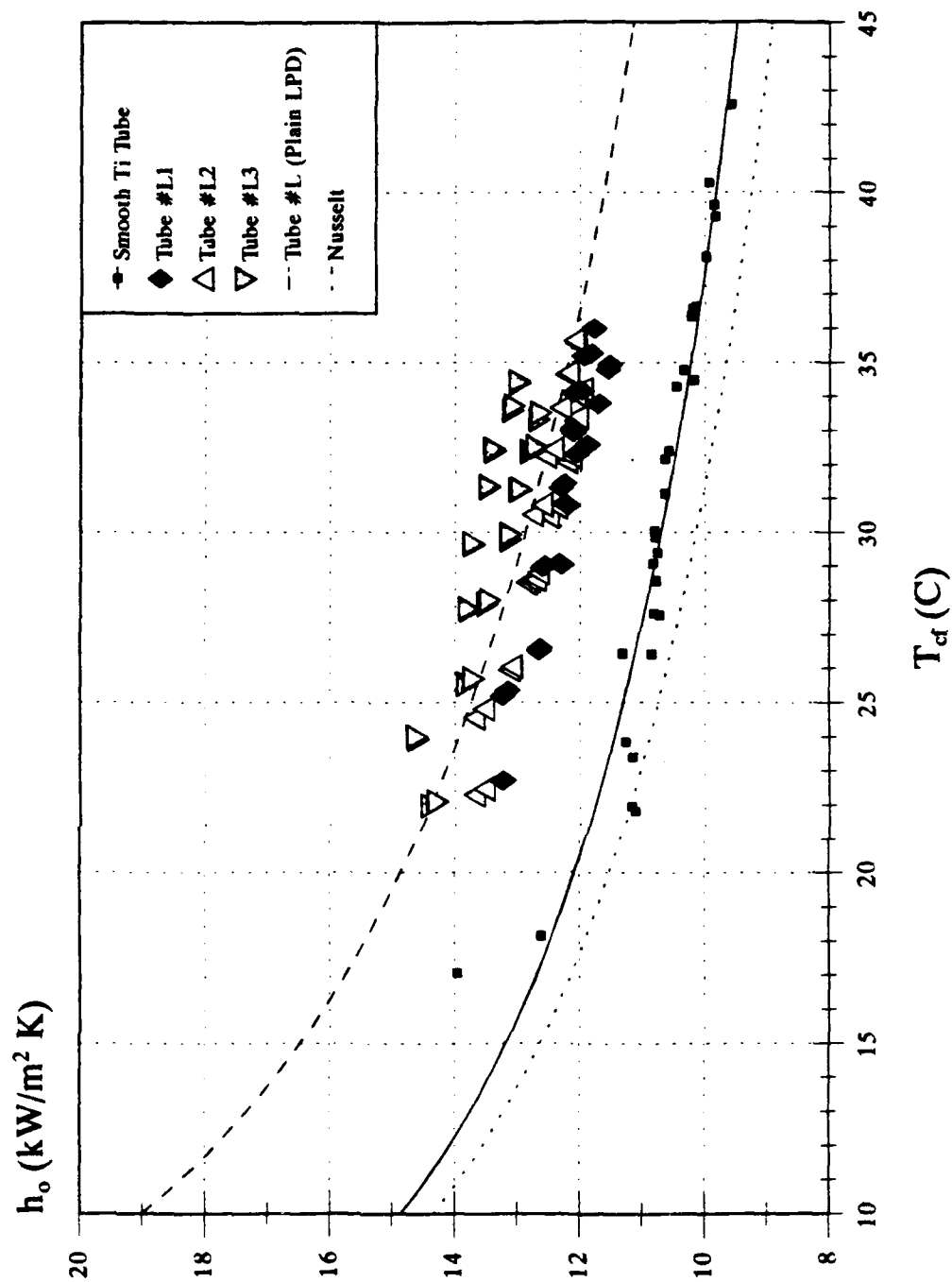


Figure 27. Comparison of the Outside Heat Transfer Coefficient for the Wire-Wrapped LPD KORODENSE Titanium Tubes and the Smooth Titanium Tube

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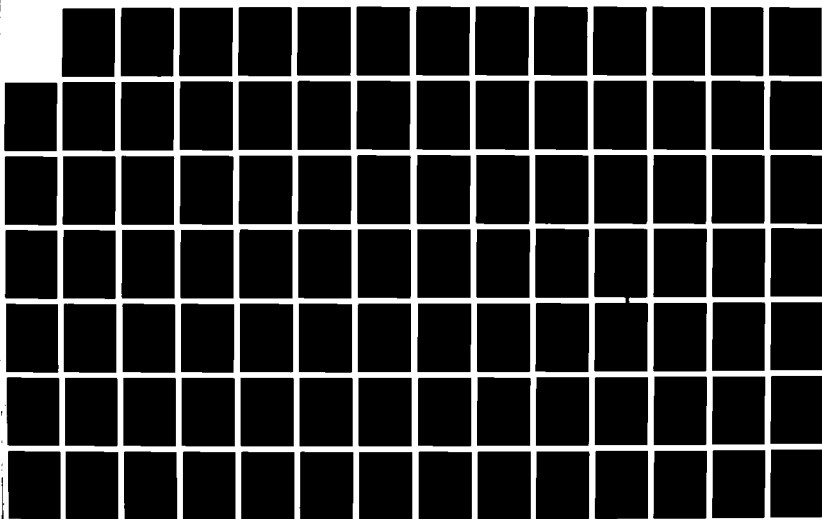
FILMISE CONDENSATION OF STEAM ON HORIZONTAL
WIRE-WRAPPED SMOOTH AND ROPED TITANIUM TUBES(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA T J O'KEEFE SEP 92

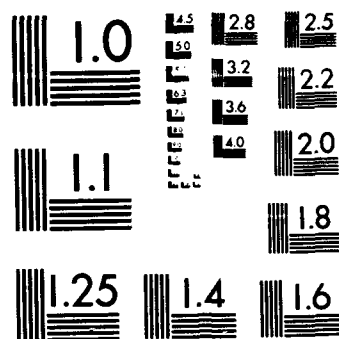
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RESOLUTION TEST CHART
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h_c/h_{LPD} vs. P/D_w
Wire-Wrapped LPD KORODENSE Titanium Tubes at Atmospheric Pressure

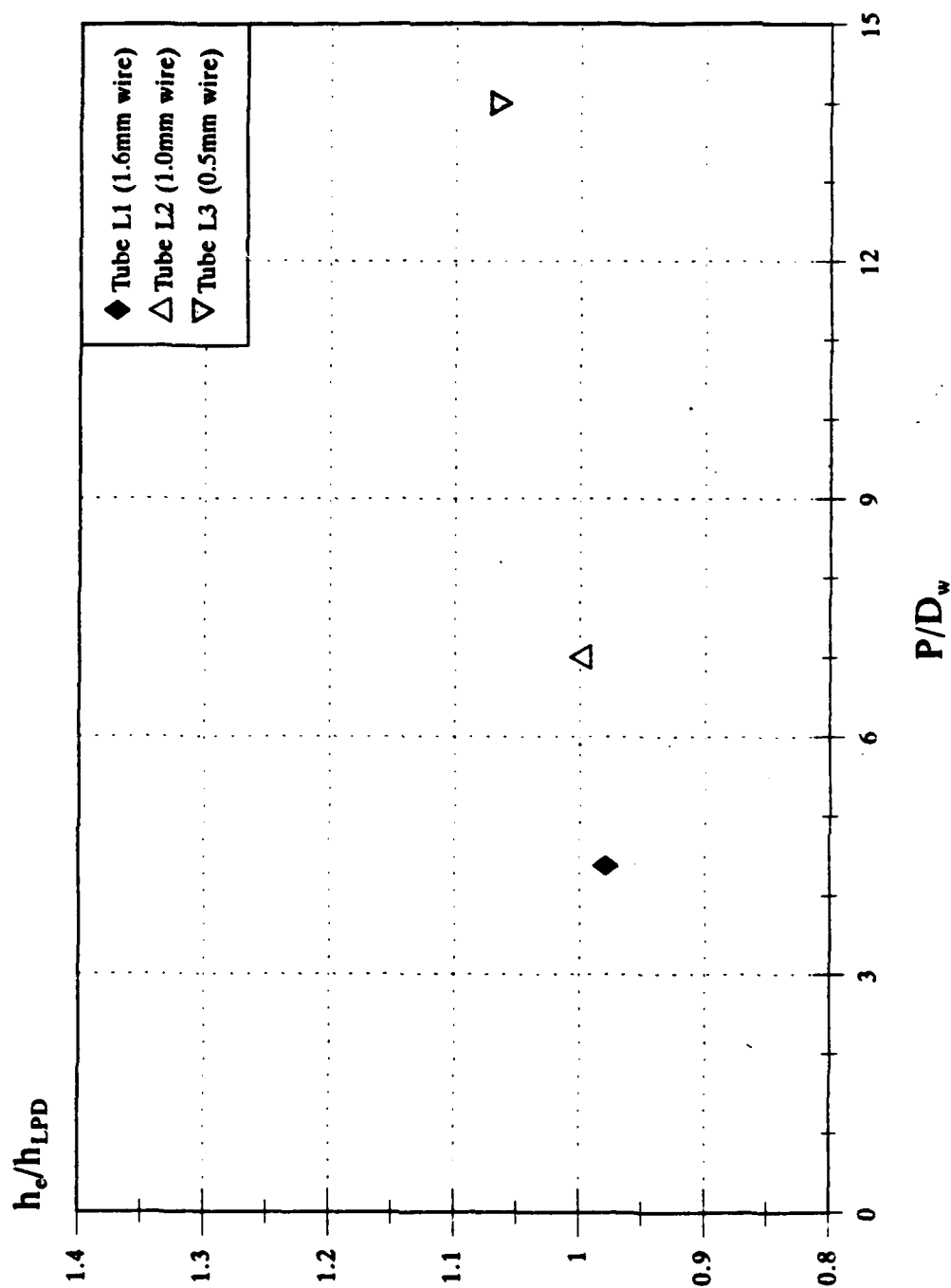


Figure 28. Comparison of h_c/h_{∞} vs. P/D_w Ratio for the Wire-Wrapped LPD KORODENSE Tubes

h_c/h_{LPD} vs. F Wire-Wrapped LPD KORODENSE Titanium Tubes

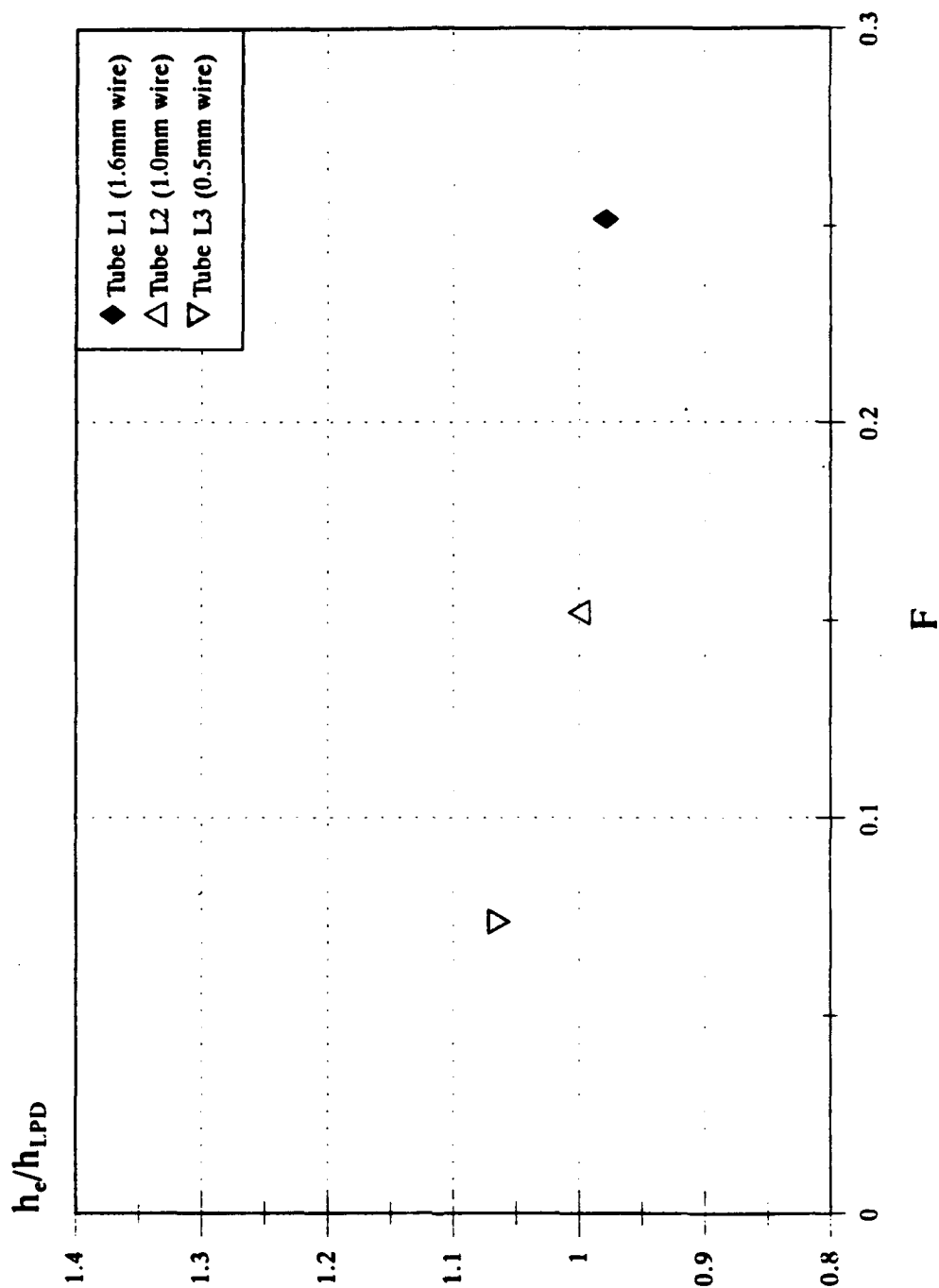


Figure 29. Comparison of h_c/h_{LPD} vs. F for the Wire-Wrapped LPD KORODENSE tubes

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 $\approx 30\%$ with a $P/D_w = 7.96$. A plain LPD KORODENSE tube showed consistent enhancements of $\approx 20\%$ 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. ($P/D_w = 7.92$)
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 α .
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

<u>Tube/Insert Type</u>	<u>Polynomial Equation</u>
Smooth/None	$T_{rise} = -8.843 \times 10^{-5} V^3 + 1.799 \times 10^{-3} V^2 - 7.526 \times 10^{-4} V - 4.617 \times 10^{-5}$
Smooth/HEATEX	$T_{rise} = -3.305 \times 10^{-5} V^3 + 2.122 \times 10^{-3} V^2 + 9.737 \times 10^{-4} V + 2.091 \times 10^{-4}$
LPD/None	$T_{rise} = 4.133 \times 10^{-5} V^3 + 6.013 \times 10^{-4} V^2 + 1.880 \times 10^{-3} V - 3.386 \times 10^{-4}$
LPD/HEATEX	$T_{rise} = -2.781 \times 10^{-5} V^3 + 1.893 \times 10^{-3} V^2 + 9.202 \times 10^{-4} V + 2.089 \times 10^{-4}$
where:	T_{rise} = temperature rise ($^{\circ}$ K) V = fluid velocity (m/s)

Smooth Titanium Tube

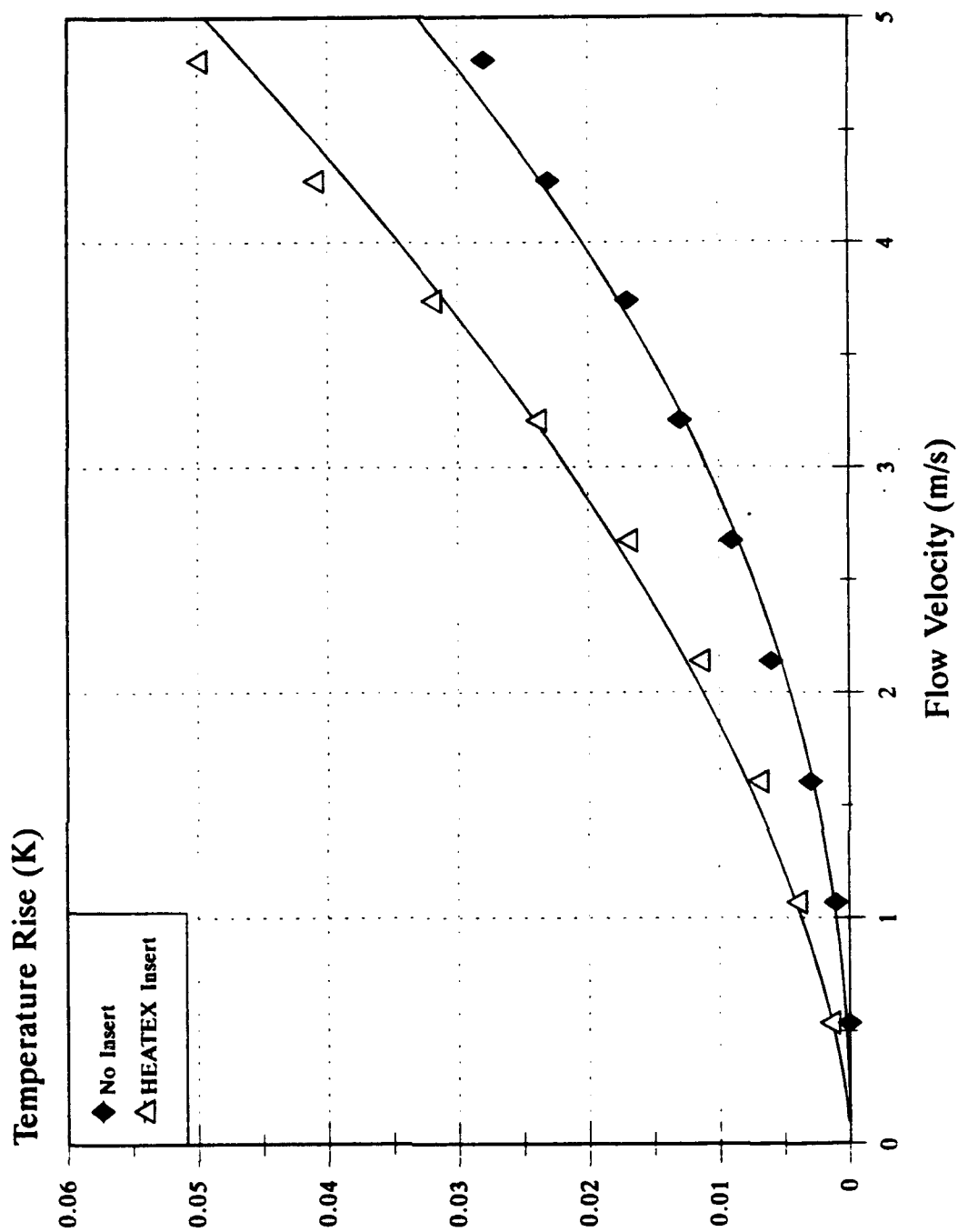


Figure A.1 Frictional Temperature Rise Curves for the Smooth Titanium Tube with a HEATEX Insert and No Insert.

LPD KORODENSE Titanium Tube

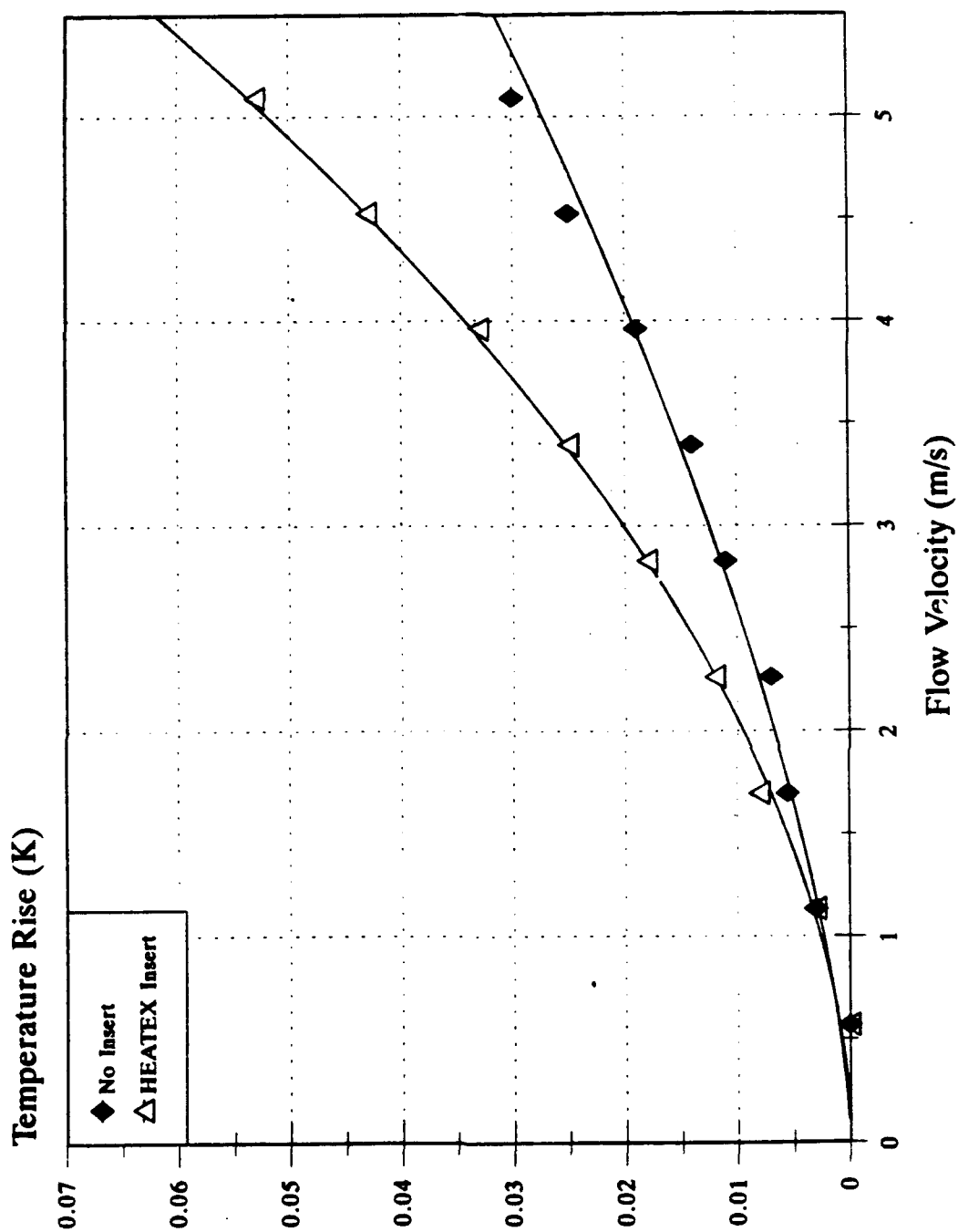


Figure A.2 Frictional Temperature Rise Curves for the LPD KORODENSE Titanium Tube with a HEATEX Insert and No Insert

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 snock 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-condensable gases need to be flushed out of the system by drawing a vacuum on the system following step 7. To ensure the non-condensable 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-condensable gases remain. To initially purge the system of non-condensable 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_1 ... 0 to find C_1 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 $T_{sat} \approx 48^{\circ}\text{C}$, and a vapor velocity of ≈ 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 $T_{sat} \approx 100^{\circ}\text{C}$, and a vapor velocity of ≈ 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:

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

where:

W_R = the uncertainty of the desired dependent variable

$x_1, x_2, \dots, x_n$ = the measured independent variables

$W_1, W_2, \dots, W_n$ = the uncertainties of the measured variables

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: FONMVNC1
 Pressure Condition: Vacuum
 Vapor Temperature = 48.625 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 4.32 (m/s)
 Heat Flux = 1.461E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (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: FONMVNC1
 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/m^2)
 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	11.46
Vapor-Side H.T.C., Ho	43.62

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHC1
 Pressure Condition: Vacuum
 Vapor Temperature = 48.745 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 4.32 (m/s)
 Heat Flux = 1.840E+05 (W/m^2)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0415

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.15
Heat Flux, q	1.43
Log-Mean-Tem Diff, LMTD	1.10
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	1.81
Water-Side H.T.C., H _i	4.92
Vapor-Side H.T.C., Ho	3.41

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHC1
 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. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0415

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.02
Reynolds Number, Re	3.13
Heat Flux, q	3.08
Log-Mean-Tem Diff, LMTD	.43
Wall Resistance, Rw	2.67
Overall H.T.C., Uo	3.11
Water-Side H.T.C., H _i	5.44
Vapor-Side H.T.C., Ho	10.09

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:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.16
Heat Flux, q	1.04
Log-Mean-Tem Diff, LMTD	.48
Wall Resistance, R _w	2.67
Overall H.T.C., U _o	1.14
Water-Side H.T.C., H _i	10.41
Vapor-Side H.T.C., H _o	7.38

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANC1
 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

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.02
Reynolds Number, Re	3.14
Heat Flux, q	3.06
Log-Mean-Tem Diff, LMTD	.20
Wall Resistance, R _w	2.67
Overall H.T.C., U _o	3.06
Water-Side H.T.C., H _i	10.67
Vapor-Side H.T.C., H _o	27.24

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHC1
 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/m²)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0442

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.17
Heat Flux, q	1.01
Log-Mean-Tem Diff, LMTD	.41
Wall Resistance, R _w	2.67
Overall H.T.C., U _o	1.09
Water-Side H.T.C., H _i	4.64
Vapor-Side H.T.C., H _o	2.01

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHC1
 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/m²)
 Tube-metal thermal conduc. = 385.0 (W/m.K)
 Sieder-Tate constant = 0.0442

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.03
Reynolds Number, Re	3.15
Heat Flux, q	3.06
Log-Mean-Tem Diff, LMTD	.14
Wall Resistance, R _w	2.67
Overall H.T.C., U _o	3.07
Water-Side H.T.C., H _i	5.20
Vapor-Side H.T.C., H _o	7.68

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMUNT3
 Pressure Condition: Vacuum
 Vapor Temperature = 48.670 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 3.63 (m/s)
 Heat Flux = 1.248E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, q	2.16
Log-Mean-Tem Diff, LMTD	1.95
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	2.91
Water-Side H.T.C., Hi	16.79
Vapor-Side H.T.C., Ho	17.15

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMUNT3
 Pressure Condition: Vacuum
 Vapor Temperature = 48.736 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 0.97 (m/s)
 Heat Flux = 7.590E+04 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.K)
 Sieder-Tate constant = 0.0179

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.01
Reynolds Number, Re	3.11
Heat Flux, q	3.16
Log-Mean-Tem Diff, LMTD	.86
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.28
Water-Side H.T.C., Hi	16.95
Vapor-Side H.T.C., Ho	58.73

Heat Flux
DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHT3
Pressure Condition: Vacuum
Vapor Temperature = 49.651 (Deg C)
Water Flow Rate (%) = 20.00
Water Velocity = 0.97 (m/s)
Heat Flux = 1.082E+05 (W/m^2)
Tube-metal thermal conduc. = 21.0 (W/m.K)
Sieder-Tate constant = 0.0431

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.01
Reynolds Number, Re	3.11
Heat Flux, q	3.10
Log-Mean-Tem Diff, LMTD	.60
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.16
Water-Side H.T.C., H1	7.40
Vapor-Side H.T.C., Ho	12.54

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMVHT3
Pressure Condition: Vacuum
Vapor Temperature = 48.684 (Deg C)
Water Flow Rate (%) = 80.00
Water Velocity = 3.63 (m/s)
Heat Flux = 1.471E+05 (W/m^2)
Tube-metal thermal conduc. = 21.0 (W/m.K)
Sieder-Tate constant = 0.0431

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.80
Reynolds Number, Re	1.12
Heat Flux, q	1.90
Log-Mean-Tem Diff, LMTD	1.66
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	2.52
Water-Side H.T.C., H1	7.03
Vapor-Side H.T.C., Ho	6.07

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANTS
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 100.026 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 3.63 (m/s)
 Heat Flux = 3.632E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.k)
 Sieder-Tate constant = 0.0191

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	0.81
Reynolds Number, Re	1.14
Heat Flux, q	1.14
Log-Mean-Tem Diff, LMTD	.67
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	1.32
Water-Side H.T.C., Hi	15.74
Vapor-Side H.T.C., Ho	11.68

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMANTS
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.958 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 0.97 (m/s)
 Heat Flux = 2.413E+05 (W/m^2)
 Tube-metal thermal conduc. = 21.0 (W/m.k)
 Sieder-Tate constant = 0.0191

UNCERTAINTY ANALYSIS:

VARIABLE	PERCENT UNCERTAINTY
Mass Flow Rate, Md	3.02
Reynolds Number, Re	3.12
Heat Flux, q	3.06
Log-Mean-Tem Diff, LMTD	.27
Wall Resistance, Rw	5.09
Overall H.T.C., Uo	3.07
Water-Side H.T.C., Hi	15.91
Vapor-Side H.T.C., Ho	41.47

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 100.020 (Deg C)
 Water Flow Rate (%) = 80.00
 Water Velocity = 3.62 (m/s)
 Heat Flux = 4.049E+05 (W/m^2)
 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, R _w	5.09
Overall H.T.C., U _o	1.25
Water-Side H.T.C., H _i	7.51
Vapor-Side H.T.C., H _o	4.13

DATA FOR THE UNCERTAINTY ANALYSIS:

File Name: FONMAHT6
 Pressure Condition: Atmospheric (101 kPa)
 Vapor Temperature = 99.922 (Deg C)
 Water Flow Rate (%) = 20.00
 Water Velocity = 0.97 (m/s)
 Heat Flux = 3.120E+05 (W/m^2)
 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, R _w	5.09
Overall H.T.C., U _o	3.08
Water-Side H.T.C., H _i	7.87
Vapor-Side H.T.C., H _o	11.47

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 : DRPOK
 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 = 13.96 (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 : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3715
 Alpha (based on Nusselt (Tdel)) = 0.7801
 Enhancement (q) = .963
 Enhancement (Del-T) = .972

Data #	Vw (m/s)	Uc (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.66	5.352E+03	9.727E+03	4.334E+05	44.55	100.11
2	3.21	5.297E+03	9.985E+03	4.242E+05	42.91	99.96
3	2.76	5.210E+03	1.003E+04	4.132E+05	41.19	99.97
4	2.31	5.054E+03	1.006E+04	3.969E+05	39.45	100.05
5	1.87	4.995E+03	1.030E+04	3.792E+05	36.81	100.01
6	1.42	4.639E+03	1.056E+04	3.546E+05	33.58	100.04
7	0.97	4.275E+03	1.128E+04	3.220E+05	29.53	100.07
8	1.42	4.619E+03	1.039E+04	3.486E+05	33.54	100.00
9	1.86	4.974E+03	1.011E+04	3.675E+05	36.35	99.94
10	2.30	5.091E+03	1.008E+04	3.845E+05	38.16	100.06
11	2.75	5.232E+03	9.967E+03	3.944E+05	39.57	99.99
12	3.19	5.335E+03	9.960E+03	4.014E+05	40.71	99.95
13	3.63	5.391E+03	9.692E+03	4.055E+05	41.84	100.05

Least-Squares Line for Ho vs q curve:
 Slope = -3.1043E-01
 Intercept = 7.7997E+05

Least-squares line for q = a+delta-Tip
 a = 2.5179E+04
 b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT1

NOTE: 13 X-Y 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 (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 : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.3233
 Alpha (based on Nusselt (Tdel)) = 0.7740
 Enhancement (q) = .953
 Enhancement (Del-T) = .965

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tef (C)	Ts (C)
1	3.65	5.332E+03	9.587E+03	4.209E+05	43.91	100.09
2	3.20	5.312E+03	9.853E+03	4.147E+05	42.08	99.94
3	2.75	5.197E+03	9.887E+03	4.016E+05	40.54	100.05
4	2.31	5.069E+03	1.000E+04	3.875E+05	39.74	100.08
5	1.42	4.657E+03	1.049E+04	3.474E+05	33.12	100.02
6	0.97	4.290E+03	1.109E+04	3.150E+05	29.40	99.91
7	1.41	4.675E+03	1.054E+04	3.459E+05	32.63	100.03
8	1.86	4.940E+03	1.029E+04	3.555E+05	35.51	99.96
9	2.30	5.114E+03	1.008E+04	3.785E+05	37.54	100.01
10	2.74	5.245E+03	9.944E+03	3.982E+05	39.04	100.03
11	3.18	5.329E+03	9.763E+03	3.939E+05	40.26	100.05
12	3.62	5.456E+03	9.657E+03	4.022E+05	40.60	99.99
13	3.62	5.448E+03	9.823E+03	4.006E+05	40.78	99.94

Least-Squares Line for Ho vs q curve:
 Slope = -3.1793E-01
 Intercept = 7.8191E+05

Least-squares line for q = a*delta-Tib
 a = 2.4999E-04
 b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT2

NOTE: 13 x-/- 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, Di = 13.36 (mm)
 Outside diameter, Do = 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 Ho

C₁ (based on Petukhov-Popov) = 2.3923
 Alpha (based on Nusselt (T_{del})) = 0.7551
 Enhancement (q) = .922
 Enhancement (Del-T) = .941

Data #	Vw (m/s)	Uc (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	5.411E+03	9.701E+03	4.000E+05	41.23	99.93
2	3.19	5.316E+03	9.717E+03	3.913E+05	40.27	100.01
3	2.74	5.185E+03	9.693E+03	3.796E+05	39.16	100.02
4	2.29	5.048E+03	9.766E+03	3.674E+05	37.63	100.05
5	1.85	4.872E+03	9.904E+03	3.520E+05	35.54	99.93
6	1.41	4.533E+03	1.017E+04	3.322E+05	32.68	99.95
7	1.19	4.494E+03	1.050E+04	3.205E+05	30.53	100.01
8	0.97	4.322E+03	1.105E+04	3.063E+05	27.72	100.08

Least-Squares Line for Ho vs q curve:

Slope = -3.1523E-01

Intercept = 7.7848E+05

Least-squares line for q = a+delta-T^{1.5}b

a = 2.4500E+04

b = 7.5000E-01

NOTE: 08 data points were stored in file FONMAHT3

NOTE: 08 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, Di = 13.96 (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 : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.4099
 Alpha (based on Nusselt (T_{del})) = 0.7484
 Enhancement (q) = .911
 Enhancement (Del-T) = .933

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	4.236E+03	1.079E+04	3.171E+05	29.40	100.04
2	1.42	4.556E+03	9.950E+03	3.427E+05	34.44	100.03
3	1.64	4.702E+03	9.843E+03	3.517E+05	35.74	99.99
4	2.08	4.919E+03	9.698E+03	3.678E+05	37.92	99.98
5	2.52	5.108E+03	9.703E+03	3.809E+05	39.26	100.03
6	2.96	5.221E+03	9.597E+03	3.881E+05	40.44	100.04
7	3.40	5.329E+03	9.570E+03	3.936E+05	41.13	99.99
8	3.62	5.358E+03	9.505E+03	3.946E+05	41.52	100.02
9	3.18	5.295E+03	9.612E+03	3.874E+05	40.30	100.10
10	2.73	5.186E+03	9.657E+03	3.774E+05	39.07	100.02
11	2.29	5.010E+03	9.583E+03	3.627E+05	37.85	100.02
12	1.63	4.739E+03	9.850E+03	3.398E+05	34.50	100.02
13	0.97	4.266E+03	1.072E+04	3.025E+05	28.21	100.03

Least-Squares Line for Ho vs q curve:
 Slope = -3.1839E-01
 Intercept = 7.7829E+05

Least-squares line for q = a*delta-T^{1/4}
 a = 2.4222E+04
 b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT4

NOTE: 13 4-7 pairs were stored in data file

NOTE: Program name : DRPOK

Data taken by : D'KEEFE

This analysis done on file : FONMAHTS

This analysis includes end-fin effect

Thermal conductivity = 21.0 (W/m.K)

Inside diameter, Di = 13.96 (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 : ATMOSPHERIC

Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 2.2011

Alpha (based on Nusselt (Tdel)) = 0.7700

Enhancement (q) = .947

Enhancement (Del-T) = .960

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.64	5.258E+03	9.574E+03	4.057E+05	42.38	99.90
2	3.19	5.273E+03	9.935E+03	4.002E+05	40.23	99.86
3	2.74	5.200E+03	1.014E+04	3.896E+05	36.41	99.95
4	2.30	5.035E+03	1.015E+04	3.717E+05	36.62	99.92
5	1.95	4.922E+03	1.018E+04	3.509E+05	34.47	100.00
6	1.41	4.599E+03	1.064E+04	3.313E+05	31.14	99.99
7	0.97	4.218E+03	1.132E+04	2.994E+05	25.44	100.05
8	1.19	4.423E+03	1.084E+04	3.152E+05	29.08	99.97
9	1.63	4.770E+03	1.058E+04	3.426E+05	32.40	100.02
10	2.07	4.992E+03	1.034E+04	3.595E+05	34.77	99.93
11	2.51	5.159E+03	1.020E+04	3.730E+05	36.56	100.02
12	2.95	5.253E+03	9.979E+03	3.800E+05	38.06	99.92
13	3.39	5.333E+03	9.832E+03	3.862E+05	39.23	99.86
14	3.61	5.394E+03	9.850E+03	3.908E+05	39.63	100.07

Least-Squares Line for Ho vs q curve:

Slope = -3.1391E-01

Intercept = 7.7964E+05

Least-squares line for q = a*delta-T^{1/4}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 : DRPOK

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 = 15.85 (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) = 2.5406

Alpha (based on Nusselt (T_{del})) = 0.7758

Enhancement (q) = .956

Enhancement (Δ₁-T) = .967

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tef (C)	Ts (C)
1	3.62	5.523E+03	9.871E+03	4.049E+05	41.01	100.02
2	3.18	5.441E+03	9.923E+03	3.969E+05	40.00	100.05
3	2.73	5.369E+03	1.010E+04	3.892E+05	38.54	99.99
4	2.29	5.247E+03	1.023E+04	3.765E+05	36.81	99.90
5	2.07	5.133E+03	1.016E+04	3.680E+05	36.21	99.98
6	1.41	4.826E+03	1.064E+04	3.410E+05	32.06	99.75
7	0.97	4.458E+03	1.121E+04	3.120E+05	27.93	99.92
8	1.41	4.816E+03	1.053E+04	3.411E+05	32.22	99.92
9	1.85	5.089E+03	1.044E+04	3.630E+05	34.76	99.99
10	2.29	5.230E+03	1.015E+04	3.744E+05	36.89	99.96
11	2.51	5.320E+03	1.017E+04	3.806E+05	37.14	99.94
12	2.73	5.411E+03	1.022E+04	3.876E+05	37.93	99.97
13	3.17	5.461E+03	9.960E+03	3.920E+05	39.36	100.04

Least-Squares Line for Ho vs q curve:

Slope = -3.0354E-01

Intercept = 7.7703E+05

Least-squares line for q = a-Δ₁-T₁b

a = 2.5178E+04

b = 7.5000E-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, 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 : 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 (T_{del})) = 0.7924
Enhancement (q) = .983
Enhancement (Δ_l-T) = .987

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tef (C)	Ts (C)
1	3.64	5.512E+03	9.985E+03	4.286E+05	42.93	100.05
2	3.19	5.415E+03	9.976E+03	4.142E+05	41.52	99.94
3	2.75	5.348E+03	1.019E+04	4.048E+05	39.79	99.90
4	2.52	5.309E+03	1.030E+04	3.998E+05	38.81	100.03
5	2.30	5.239E+03	1.037E+04	3.923E+05	37.84	99.94
6	2.08	5.150E+03	1.041E+04	3.847E+05	36.94	100.05
7	1.86	5.037E+03	1.043E+04	3.742E+05	35.37	99.91
8	1.41	4.791E+03	1.073E+04	3.538E+05	32.97	99.96
9	0.97	4.451E+03	1.157E+04	3.252E+05	28.10	100.06
10	1.41	4.799E+03	1.078E+04	3.551E+05	32.95	100.04
11	1.86	5.042E+03	1.045E+04	3.752E+05	35.99	100.03
12	2.30	5.231E+03	1.032E+04	3.896E+05	37.76	99.93
13	2.74	5.372E+03	1.022E+04	4.007E+05	39.20	99.93

Least-Squares Line for Ho vs q curve:

Slope = -3.1602E-01

Intercept = 7.8428E+05

Least-squares line for q = a+Δ_l-T^{1/4}b

a = 2.5669E+04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMAHT7

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMANT1

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 : ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2114

Alpha (based on Nusselt (Tdel)) = 0.7504

Enhancement (q) = .941

Enhancement (Del-T) = .955

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tef (C)	Ts (C)
1	2.74	4.483E+03	1.050E+04	3.315E+05	31.56	100.02
2	2.51	4.389E+03	1.053E+04	3.200E+05	30.39	99.68
3	2.29	4.273E+03	1.051E+04	3.091E+05	29.42	100.05
4	2.07	4.147E+03	1.052E+04	2.971E+05	29.25	99.99
5	1.85	4.006E+03	1.056E+04	2.851E+05	26.95	99.90
6	1.41	3.587E+03	1.106E+04	2.609E+05	23.60	99.69
7	0.97	3.293E+03	1.293E+04	2.304E+05	17.61	99.66
8	1.41	3.687E+03	1.101E+04	2.594E+05	23.57	99.99
9	1.85	4.030E+03	1.066E+04	2.837E+05	26.60	99.95
10	2.07	4.183E+03	1.064E+04	2.949E+05	27.72	100.18
11	2.30	4.295E+03	1.076E+04	3.161E+05	29.38	99.91
12	2.74	4.450E+03	1.042E+04	3.356E+05	32.21	100.23
13	3.19	4.623E+03	1.037E+04	3.498E+05	33.71	99.66

Least-Squares Line for Ho vs q curve:

Slope = -2.6012E-01

Intercept = 7.5036E+05

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

a = 2.4594E-04

b = 7.5000E-01

NOTE: 13 data points were stored in file FONMANT1

NOTE: 13 A-T pairs were stored in data file

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 = 13.85 (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 : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.1849
 Alpha (based on Nusselt (Tdel)) = 0.7603
 Enhancement (q) = .957
 Enhancement (Del-T) = .968

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.65	4.669E+03	1.022E+04	3.713E+05	36.34	99.99
2	3.20	4.572E+03	1.046E+04	3.566E+05	34.29	100.01
3	2.75	4.426E+03	1.064E+04	3.421E+05	32.15	100.01
4	2.31	4.228E+03	1.080E+04	3.226E+05	29.86	100.04
5	1.86	3.933E+03	1.073E+04	2.958E+05	27.57	99.94
6	1.41	3.618E+03	1.127E+04	2.686E+05	23.94	100.00
7	0.97	3.263E+03	1.396E+04	2.382E+05	17.06	99.99
8	1.19	3.387E+03	1.118E+04	2.454E+05	21.95	99.95
9	0.97	3.209E+03	1.261E+04	2.298E+05	18.15	99.93
10	1.19	3.399E+03	1.112E+04	2.424E+05	21.80	99.99
11	1.41	3.647E+03	1.115E+04	2.608E+05	23.39	99.99
12	1.86	4.000E+03	1.085E+04	2.868E+05	26.43	99.91
13	2.07	4.154E+03	1.082E+04	2.988E+05	27.62	100.11
14	2.29	4.286E+03	1.079E+04	3.082E+05	28.57	99.96
15	2.51	4.410E+03	1.077E+04	3.167E+05	29.40	99.97
16	2.73	4.530E+03	1.081E+04	3.249E+05	30.04	99.91

Least-Squares Line for Ho vs q curve:
 Slope = -2.5701E-01
 Intercept = 7.6050E+05

Least-squares line for q = a*delta-T^{1/4}
 a = 2.5129E+04
 b = 7.5000E-01

NOTE: 16 data points were stored in file FONMANT2

NOTE: 16 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, 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 : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

C_i (based on Petukhov-Popov) = 1.1636
 α (based on Nusselt (T_{del})) = 0.7650
 Enhancement (q) = .965
 Enhancement ($Del-T$) = .974

Data #	U_w (m/s)	U_o (W/m ² -K)	Ho (W/m ² -K)	Q_p (W/m ²)	T_{cf} (C)	T_s (C)
1	0.97	3.230E+03	1.310E+04	2.269E+05	17.32	99.88
2	1.41	3.652E+03	1.136E+04	2.595E+05	22.66	100.05
3	1.63	3.837E+03	1.113E+04	2.730E+05	24.53	99.92
4	1.85	4.008E+03	1.104E+04	2.857E+05	25.89	99.97
5	2.07	4.143E+03	1.087E+04	2.959E+05	27.21	99.96
6	2.29	4.236E+03	1.057E+04	3.028E+05	28.64	99.93
7	2.51	4.424E+03	1.096E+04	3.165E+05	28.97	99.99
8	2.73	4.513E+03	1.082E+04	3.229E+05	29.63	99.92
9	2.95	4.627E+03	1.088E+04	3.308E+05	30.41	99.92
10	3.17	4.745E+03	1.101E+04	3.394E+05	30.92	99.94
11	3.61	4.815E+03	1.055E+04	3.457E+05	32.78	100.01
12	2.29	4.291E+03	1.092E+04	3.070E+05	26.12	100.04

Least-Squares Line for Ho vs q curve:
 Slope = -2.4792E-01
 Intercept = 7.5635E+05

Least-squares line for $q = a + \Delta T^b$
 $a = 2.5250E-04$
 $b = 7.5000E-01$

NOTE: 12 data points were stored in file FONMANT3

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

NOTE: Program name : DRPOK

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, Di = 13.95 (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 : ATMOSPHERIC

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.1811

Alpha (based on Nusselt (T_{del})) = 0.7648

Enhancement (q) = .965

Enhancement (Δ_L-T) = .974

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	4.778E+03	1.036E+04	3.479E+05	33.59	100.00
2	0.97	3.192E+03	1.259E+04	2.295E+05	16.26	100.06
3	1.85	3.969E+03	1.083E+04	2.910E+05	26.87	99.97
4	2.30	4.246E+03	1.072E+04	3.133E+05	29.23	100.02
5	2.74	4.465E+03	1.064E+04	3.317E+05	31.19	100.21
6	3.18	4.648E+03	1.053E+04	3.453E+05	32.53	99.99
7	3.63	4.792E+03	1.047E+04	3.558E+05	33.99	99.96
8	3.62	4.755E+03	1.030E+04	3.525E+05	34.21	100.34
9	3.18	4.653E+03	1.061E+04	3.433E+05	32.36	100.24
10	2.74	4.506E+03	1.079E+04	3.294E+05	30.52	99.99
11	2.29	4.267E+03	1.077E+04	3.110E+05	26.86	100.01
12	1.85	3.971E+03	1.077E+04	2.895E+05	26.89	100.25
13	1.41	3.628E+03	1.116E+04	2.626E+05	23.54	99.92
14	0.97	3.193E+03	1.266E+04	2.305E+05	16.21	99.99

Least-Squares Line for Ho vs q curve:

Slope = -2.5738E-01

Intercept = 7.6096E+05

Least-squares line for q = a+Δ_L-T^{1/4}b

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-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 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 (T_{del})) = 0.7953
Enhancement (q) = 1.001
Enhancement (Del-T) = 1.001

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	4.877E+03	1.061E+04	3.632E+05	34.25	100.03
2	3.18	4.755E+03	1.076E+04	3.513E+05	32.64	99.97
3	2.74	4.591E+03	1.093E+04	3.394E+05	31.06	100.00
4	2.30	4.374E+03	1.107E+04	3.234E+05	29.22	100.00
5	1.86	4.083E+03	1.115E+04	3.021E+05	27.09	100.02
6	1.41	3.723E+03	1.149E+04	2.750E+05	23.95	100.00
7	0.97	3.297E+03	1.309E+04	2.413E+05	18.43	99.96
8	1.41	3.720E+03	1.148E+04	2.755E+05	23.99	99.97
9	0.97	3.283E+03	1.308E+04	2.416E+05	18.47	99.95
10	1.36	4.081E+03	1.120E+04	3.040E+05	27.15	100.01
11	2.30	4.320E+03	1.117E+04	3.267E+05	29.26	99.99
12	2.74	4.572E+03	1.091E+04	3.436E+05	31.49	100.04
13	3.19	4.748E+03	1.081E+04	3.573E+05	33.04	100.05
14	3.63	4.873E+03	1.064E+04	3.664E+05	34.45	99.95
15	2.30	4.355E+03	1.103E+04	3.263E+05	29.57	100.03
16	0.97	3.256E+03	1.272E+04	2.411E+05	18.86	99.94

Least-Squares Line for Ho vs q curve:

Slope = -2.6021E-01

Intercept = 7.6397E+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 = 15.85 (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

C₁ (based on Petukhov-Popov) = 2.5472

Alpha (based on Nusselt (T_{del})) = 0.7483

Enhancement (q) = .624

Enhancement (Δ_{el}-T) = .965

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	4.574E+03	1.251E+04	1.082E+05	8.65	48.65
2	1.64	5.049E+03	1.115E+04	1.231E+05	11.04	48.64
3	2.08	5.282E+03	1.096E+04	1.303E+05	11.89	48.68
4	2.52	5.490E+03	1.098E+04	1.362E+05	12.40	48.67
5	2.97	5.652E+03	1.099E+04	1.407E+05	12.80	48.67
6	3.41	5.797E+03	1.106E+04	1.446E+05	13.08	48.65
7	3.63	5.871E+03	1.113E+04	1.471E+05	13.22	48.66
8	3.63	5.915E+03	1.093E+04	1.457E+05	13.33	48.70
9	3.41	5.774E+03	1.098E+04	1.445E+05	13.16	48.72
10	2.97	5.690E+03	1.114E+04	1.412E+05	12.67	48.63
11	2.08	5.275E+03	1.092E+04	1.297E+05	11.87	48.67
12	1.64	5.052E+03	1.116E+04	1.232E+05	11.04	48.70
13	1.19	4.698E+03	1.142E+04	1.130E+05	9.99	48.69
14	0.97	4.474E+03	1.190E+04	1.060E+05	8.99	48.62

Least-Squares Line for Ho vs q curve:

Slope = -3.1158E-01

Intercept = 5.8173E+05

Least-squares line for q = a*Δ_{el}-T^{1.5}

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 : DRPOK
 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, 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 : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2780
 Alpha (based on Nusselt (Tdel)) = 0.7900
 Enhancement (q) = .985
 Enhancement (Del-T) = .913

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.54	5.867E+03	1.159E+04	1.505E+05	12.98	48.68
2	3.19	5.759E+03	1.167E+04	1.456E+05	12.43	48.65
3	2.75	5.583E+03	1.158E+04	1.392E+05	12.01	48.63
4	2.52	5.559E+03	1.189E+04	1.380E+05	11.60	48.67
5	2.30	5.421E+03	1.175E+04	1.339E+05	11.39	48.68
6	2.08	5.260E+03	1.166E+04	1.299E+05	11.14	48.67
7	1.86	5.203E+03	1.199E+04	1.273E+05	10.62	48.64
8	1.42	4.908E+03	1.242E+04	1.192E+05	9.59	48.70
9	0.97	4.453E+03	1.326E+04	1.066E+05	8.04	48.74
10	1.42	4.907E+03	1.243E+04	1.196E+05	9.62	48.65
11	1.96	5.161E+03	1.178E+04	1.274E+05	10.82	48.67
12	2.30	5.424E+03	1.178E+04	1.350E+05	11.46	48.68
13	2.53	5.530E+03	1.177E+04	1.380E+05	11.73	48.69
14	2.75	5.607E+03	1.169E+04	1.403E+05	12.01	48.74
15	3.19	5.731E+03	1.154E+04	1.435E+05	12.43	48.66
16	3.63	5.831E+03	1.143E+04	1.464E+05	12.91	48.68

Least-Squares Line for Ho vs q curve:

Slope = -3.2707E-01

Intercept = 5.9591E+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 : DRPOK
 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, 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 : SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.4221
 Alpha (based on Nusselt (Tdel)) = 0.7627
 Enhancement (q) = .845
 Enhancement (Del-T) = .881

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	4.402E+03	1.202E+04	1.082E+05	9.00	48.67
2	1.42	4.872E+03	1.165E+04	1.215E+05	10.43	48.64
3	1.86	5.173E+03	1.141E+04	1.301E+05	11.41	48.65
4	2.08	5.274E+03	1.125E+04	1.331E+05	11.83	48.72
5	2.30	5.395E+03	1.128E+04	1.362E+05	12.07	48.70
6	2.53	5.422E+03	1.097E+04	1.366E+05	12.45	48.65
7	2.75	5.510E+03	1.098E+04	1.395E+05	12.71	48.76
8	3.19	5.676E+03	1.105E+04	1.440E+05	13.02	48.78
9	3.64	5.745E+03	1.087E+04	1.461E+05	13.44	48.78
10	3.19	5.741E+03	1.130E+04	1.453E+05	12.86	48.62
11	2.75	5.600E+03	1.133E+04	1.404E+05	12.38	48.63
12	2.30	5.390E+03	1.124E+04	1.347E+05	11.96	48.73
13	2.08	5.317E+03	1.143E+04	1.324E+05	11.59	48.72
14	1.86	5.202E+03	1.152E+04	1.296E+05	11.24	48.60
15	1.42	4.874E+03	1.162E+04	1.198E+05	10.31	48.74

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 : FONMUNT2
 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) = .879
 Enhancement (Del-T) = .907

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.038E+03	1.269E+04	1.244E+05	9.81	48.66
2	3.19	4.901E+03	1.307E+04	1.206E+05	9.23	48.70
3	2.74	4.702E+03	1.334E+04	1.155E+05	8.66	48.76
4	2.52	4.581E+03	1.346E+04	1.122E+05	8.34	48.74
5	2.30	4.450E+03	1.363E+04	1.089E+05	7.99	48.77
6	2.08	4.267E+03	1.348E+04	1.045E+05	7.75	48.82
7	1.86	4.081E+03	1.353E+04	1.003E+05	7.41	48.66
8	1.42	3.698E+03	1.447E+04	9.028E+04	6.24	46.65
9	0.97	3.076E+03	1.429E+04	7.465E+04	5.23	48.70
10	1.86	4.119E+03	1.396E+04	1.015E+05	7.27	48.70
11	2.75	4.739E+03	1.367E+04	1.178E+05	8.61	48.79
12	3.63	5.059E+03	1.283E+04	1.258E+05	9.81	48.74

Least-Squares Line for Ho vs q curve:
 Slope = -2.5424E-01
 Intercept = 5.7915E+05

Least-squares line for q = a*delta-T^b
 a = 2.2680E+04
 b = 7.5000E-01

NOTE: 12 data points were stored in file FONMUNT2

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

NOTE: Program name : DRPOK
 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

Ci (based on Petukhov-Popov) = 1.0775
 Alpha (based on Nusselt (Tdel)) = 0.7876
 Enhancement (q) = .830
 Enhancement (Del-T) = .869

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	4.954E+03	1.235E+04	1.248E+05	10.11	48.67
2	3.19	4.794E+03	1.255E+04	1.204E+05	9.59	48.64
3	2.75	4.586E+03	1.271E+04	1.152E+05	9.07	48.66
4	2.30	4.325E+03	1.284E+04	1.086E+05	8.46	48.73
5	1.86	3.990E+03	1.291E+04	9.969E+04	7.72	48.70
6	1.42	3.629E+03	1.394E+04	8.986E+04	6.45	48.63
7	0.97	3.079E+03	1.508E+04	7.590E+04	5.03	48.74
8	1.42	3.643E+03	1.416E+04	9.041E+04	6.39	48.62
9	0.97	3.061E+03	1.464E+04	7.506E+04	5.13	48.63
10	2.30	4.305E+03	1.268E+04	1.080E+05	8.51	48.60
11	2.75	4.555E+03	1.248E+04	1.146E+05	9.18	48.67
12	3.19	4.767E+03	1.237E+04	1.200E+05	9.70	48.68
13	3.63	4.946E+03	1.229E+04	1.245E+05	10.13	48.73
14	3.19	4.768E+03	1.237E+04	1.193E+05	9.65	48.67
15	3.63	4.977E+03	1.248E+04	1.248E+05	10.00	48.71
16	2.75	4.568E+03	1.255E+04	1.140E+05	9.09	48.73
17	2.30	4.322E+03	1.278E+04	1.072E+05	8.38	48.63
18	1.86	3.981E+03	1.278E+04	9.859E+04	7.72	48.71
19	1.42	3.636E+03	1.397E+04	8.922E+04	6.39	48.67
20	0.97	3.062E+03	1.455E+04	7.448E+04	5.12	48.70

Least-Squares Line for Ho vs q curve:
 Slope = -2.8863E-01
 Intercept = 5.9155E+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 : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUNT4
 This analysis includes end-fin effect
 Thermal conductivity = 21.0 (W/m.K)
 Inside diameter, Di = 13.95 (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) = 1.0742
 Alpha (based on Nusselt (Tdel)) = 0.8455
 Enhancement (q) = .912
 Enhancement (Del-T) = .933

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.095E+03	1.328E+04	1.274E+05	9.59	48.68
2	3.19	4.910E+03	1.340E+04	1.222E+05	9.12	48.63
3	2.75	4.749E+03	1.407E+04	1.183E+05	8.41	48.66
4	2.30	4.459E+03	1.413E+04	1.110E+05	7.86	48.66
5	1.86	4.166E+03	1.502E+04	1.037E+05	6.91	48.70
6	1.42	3.726E+03	1.559E+04	9.234E+04	5.92	48.67
7	0.97	3.168E+03	1.764E+04	7.792E+04	4.42	48.72
8	1.42	3.719E+03	1.550E+04	9.256E+04	5.97	48.67
9	0.97	3.161E+03	1.747E+04	7.765E+04	4.45	48.66
10	1.86	4.133E+03	1.464E+04	1.037E+05	7.08	48.70
11	2.30	4.476E+03	1.435E+04	1.125E+05	7.64	48.72
12	2.75	4.699E+03	1.366E+04	1.180E+05	8.63	48.66
13	3.19	4.914E+03	1.345E+04	1.234E+05	9.18	48.66
14	3.63	5.100E+03	1.333E+04	1.279E+05	9.60	48.66

Least-Squares Line for Ho vs q curve:

Slope = -2.9438E-01

Intercept = 5.8472E+05

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

a = 2.4011E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUNT4

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE
 This analysis done on file : FONMUNTS
 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) = 1.1127
 Alpha (based on Nusselt (Tdel)) = 0.3274
 Enhancement (q) = .836
 Enhancement (Del-T) = .913

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.64	5.029E+03	1.251E+04	1.289E+05	10.30	48.70
2	3.19	4.895E+03	1.291E+04	1.255E+05	9.72	48.73
3	2.75	4.735E+03	1.346E+04	1.209E+05	8.98	48.68
4	2.31	4.454E+03	1.353E+04	1.143E+05	8.45	48.73
5	1.86	4.116E+03	1.371E+04	1.054E+05	7.69	48.67
6	1.42	3.746E+03	1.490E+04	9.534E+04	6.40	48.68
7	0.97	3.180E+03	1.629E+04	7.999E+04	4.91	48.64
8	1.42	3.742E+03	1.490E+04	9.590E+04	6.44	48.70
9	0.97	3.180E+03	1.631E+04	8.016E+04	4.92	48.64
10	1.86	4.146E+03	1.408E+04	1.071E+05	7.60	48.71
11	2.31	4.489E+03	1.389E+04	1.159E+05	8.34	48.65
12	2.75	4.705E+03	1.327E+04	1.220E+05	9.18	48.72
13	3.19	4.894E+03	1.293E+04	1.266E+05	9.79	48.66
14	3.64	5.053E+03	1.269E+04	1.307E+05	10.30	48.64
15	2.31	4.487E+03	1.386E+04	1.151E+05	8.31	48.62
16	0.97	3.194E+03	1.662E+04	8.039E+04	4.84	48.75
17	3.64	5.059E+03	1.274E+04	1.312E+05	10.30	48.63

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 FONMUNTS

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH11

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

C₁ (based on Petukhov-Popov) = 2.0225

Alpha (based on Nusselt (T_{del})) = 0.7981

Enhancement (q) = 1.047

Enhancement (Δ_l-T) = 1.035

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tef (C)	Ts (C)
1	3.62	5.446E+03	1.036E+04	3.995E+05	38.45	99.99
2	3.18	5.361E+03	1.049E+04	3.896E+05	37.14	99.95
3	2.73	5.268E+03	1.071E+04	3.814E+05	35.61	100.01
4	2.29	5.071E+03	1.069E+04	3.654E+05	34.13	99.93
5	1.85	4.858E+03	1.087E+04	3.496E+05	32.17	100.01
6	1.41	4.568E+03	1.119E+04	3.269E+05	29.22	99.89
7	0.97	4.150E+03	1.200E+04	2.957E+05	24.63	99.94
8	1.41	4.565E+03	1.118E+04	3.273E+05	29.23	99.95
9	0.97	4.147E+03	1.197E+04	2.955E+05	24.68	99.99
10	1.85	4.863E+03	1.090E+04	3.513E+05	32.21	100.05
11	2.29	5.073E+03	1.070E+04	3.670E+05	34.29	100.05
12	2.73	5.262E+03	1.069E+04	3.805E+05	35.60	99.97
13	3.17	5.373E+03	1.052E+04	3.889E+05	36.96	99.99
14	3.61	5.467E+03	1.041E+04	3.953E+05	38.00	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.8216E-01

Intercept = 7.7250E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.6057E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH11

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN1T1

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) = 1.1307

Alpha (based on Nusselt (Tdel)) = 0.7825

Enhancement (q) = 1.030

Enhancement (Del-T) = 1.022

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.61	4.807E+03	1.077E+04	3.467E+05	32.19	99.91
2	3.17	4.688E+03	1.104E+04	3.395E+05	30.76	99.99
3	2.73	4.497E+03	1.111E+04	3.257E+05	29.32	99.97
4	2.29	4.284E+03	1.133E+04	3.101E+05	27.36	99.93
5	1.85	3.979E+03	1.140E+04	2.883E+05	25.30	99.95
6	1.41	3.606E+03	1.170E+04	2.607E+05	22.28	99.95
7	0.97	3.138E+03	1.305E+04	2.259E+05	17.31	99.93
8	1.41	3.597E+03	1.165E+04	2.614E+05	22.43	99.99
9	0.97	3.150E+03	1.329E+04	2.272E+05	17.09	99.94
10	1.85	3.970E+03	1.141E+04	2.903E+05	25.44	99.93
11	2.29	4.261E+03	1.126E+04	3.122E+05	27.73	100.01
12	2.74	4.491E+03	1.115E+04	3.296E+05	29.55	99.99
13	3.18	4.650E+03	1.090E+04	3.412E+05	31.31	99.99
14	3.62	4.789E+03	1.075E+04	3.516E+05	32.71	100.05

Least-Squares Line for Ho vs q curve:

Slope = -2.4826E-01

Intercept = 7.6014E+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 FONMAN1T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVH1T1
 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 (based on Petukhov-Popov) = 1.8918
 Alpha (based on Nusselt (T_{del})) = 0.8018
 Enhancement (q) = 1.061
 Enhancement (Del-T) = 1.045

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.745E+03	1.196E+04	1.383E+05	11.56	48.65
2	3.19	5.661E+03	1.225E+04	1.364E+05	11.14	48.72
3	2.74	5.516E+03	1.244E+04	1.321E+05	10.62	48.65
4	2.30	5.291E+03	1.248E+04	1.269E+05	10.18	48.74
5	1.86	5.007E+03	1.256E+04	1.192E+05	9.49	48.65
6	1.41	4.660E+03	1.297E+04	1.105E+05	8.52	48.72
7	0.97	4.147E+03	1.379E+04	9.748E+04	7.07	48.68
8	1.41	4.655E+03	1.295E+04	1.107E+05	8.55	48.65
9	0.97	4.161E+03	1.396E+04	9.767E+04	6.99	48.59
10	1.86	5.005E+03	1.257E+04	1.203E+05	9.58	48.69
11	2.30	5.254E+03	1.228E+04	1.266E+05	10.31	48.73
12	2.74	5.500E+03	1.236E+04	1.321E+05	10.68	48.71
13	3.19	5.641E+03	1.215E+04	1.352E+05	11.13	48.69
14	3.63	5.740E+03	1.192E+04	1.365E+05	11.45	48.66

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 FONMVH1T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUNIT1
 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) = 1.0235
 Alpha (based on Nusselt (Tdel)) = 0.8381
 Enhancement (q) = 1.029
 Enhancement (Del-T) = 1.021

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.036E+03	1.333E+04	1.191E+05	8.93	48.64
2	3.18	4.903E+03	1.385E+04	1.147E+05	8.28	48.70
3	2.74	4.718E+03	1.437E+04	1.093E+05	7.61	48.74
4	2.30	4.410E+03	1.427E+04	1.012E+05	7.09	48.71
5	1.85	4.088E+03	1.479E+04	9.300E+04	6.29	48.71
6	1.41	3.653E+03	1.550E+04	8.244E+04	5.32	48.68
7	0.97	3.071E+03	1.645E+04	6.840E+04	4.16	48.68
8	1.41	3.655E+03	1.542E+04	8.279E+04	5.37	48.68
9	0.97	3.074E+03	1.652E+04	6.840E+04	4.14	48.65
10	1.85	4.083E+03	1.475E+04	9.302E+04	6.31	48.63
11	2.30	4.405E+03	1.422E+04	1.012E+05	7.11	48.67
12	2.74	4.729E+03	1.444E+04	1.084E+05	7.50	48.65
13	3.18	4.906E+03	1.381E+04	1.125E+05	8.14	48.70
14	3.62	5.058E+03	1.340E+04	1.160E+05	8.66	48.72

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 FONMUNIT1

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

NOTE: Program name : DRPOK

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 Ho

C₁ (based on Petukhov-Popov) = 2.4479
Alpha (based on Nusselt (T_{del})) = 0.8064
Enhancement (q) = 1.062
Enhancement (Del-T) = 1.046

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (°C)	Ts (°C)
1	3.60	5.719E+03	1.054E+04	3.982E+05	37.78	99.95
2	3.16	5.593E+03	1.047E+04	3.876E+05	37.02	99.99
3	2.72	5.523E+03	1.072E+04	3.857E+05	35.98	100.00
4	2.28	5.382E+03	1.086E+04	3.767E+05	34.70	100.03
5	1.85	5.151E+03	1.087E+04	3.612E+05	33.23	100.01
6	1.41	4.895E+03	1.121E+04	3.426E+05	30.58	100.00
7	0.97	4.499E+03	1.186E+04	3.130E+05	26.39	99.99
8	1.41	4.867E+03	1.109E+04	3.429E+05	30.31	100.01
9	0.97	4.492E+03	1.183E+04	3.132E+05	26.48	99.95
10	1.85	5.139E+03	1.086E+04	3.649E+05	33.60	100.02
11	2.29	5.362E+03	1.083E+04	3.821E+05	35.29	99.97
12	2.73	5.487E+03	1.064E+04	3.919E+05	36.84	100.00
13	3.17	5.582E+03	1.049E+04	3.990E+05	38.02	99.99
14	3.61	5.706E+03	1.054E+04	4.078E+05	38.57	99.95

Least-Squares Line for Ho vs q curve:

Slope = -2.8602E-01

Intercept = 7.7502E+05

Least-squares line for q = a*delta-T^{1.7}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 : DRPOK

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

C₁ (based on Petukhov-Popov) = 1.0949

Alpha (based on Nusselt (T_{del})) = 0.8014

Enhancement (q) = 1.063

Enhancement (Δ_l-T) = 1.047

Data #	U _w (m/s)	U _o (W/m ² -K)	Ho (W/m ² -K)	Q _p (W/m ²)	T _{cf} (C)	T _s (C)
1	0.97	3.104E+03	1.352E+04	2.237E+05	16.55	100.04
2	1.41	3.591E+03	1.217E+04	2.597E+05	21.33	99.99
3	1.85	3.987E+03	1.191E+04	2.875E+05	24.14	99.99
4	2.29	4.290E+03	1.175E+04	3.092E+05	26.32	99.95
5	2.73	4.512E+03	1.149E+04	3.242E+05	28.21	99.94
6	3.17	4.716E+03	1.145E+04	3.387E+05	29.60	100.01
7	3.61	4.853E+03	1.122E+04	3.475E+05	30.97	99.99
8	3.17	4.734E+03	1.151E+04	3.376E+05	29.32	99.97
9	3.61	4.873E+03	1.131E+04	3.477E+05	30.73	99.94
10	2.73	4.531E+03	1.154E+04	3.218E+05	27.89	99.93
11	2.29	4.298E+03	1.168E+04	3.047E+05	26.09	99.94
12	1.85	3.969E+03	1.159E+04	2.813E+05	24.26	99.95
13	1.41	3.602E+03	1.201E+04	2.543E+05	21.18	99.95
14	0.97	3.164E+03	1.413E+04	2.225E+05	15.75	100.07

Least-Squares Line for Ho vs q curves:

Slope = -2.3608E-01

Intercept = 7.5845E+05

Least-squares line for q = a*Δ_l-T_{fb}

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'KEEFE
 This analysis done on file : FONMVH2T1
 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) = 2.0049
 Alpha (based on Nusselt (Tdel)) = 0.7965
 Enhancement (q) = 1.052
 Enhancement (Del-T) = 1.038

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.64	5.753E+03	1.174E+04	1.466E+05	12.49	48.73
2	3.19	5.631E+03	1.181E+04	1.423E+05	12.04	48.69
3	2.75	5.462E+03	1.182E+04	1.363E+05	11.53	48.63
4	2.52	5.369E+03	1.186E+04	1.341E+05	11.31	48.80
5	2.30	5.263E+03	1.190E+04	1.315E+05	11.05	48.85
6	1.86	4.949E+03	1.172E+04	1.226E+05	10.46	48.70
7	1.42	4.621E+03	1.203E+04	1.132E+05	9.41	48.63
8	0.97	4.146E+03	1.277E+04	1.014E+05	7.94	48.80
9	0.97	4.229E+03	1.364E+04	1.035E+05	7.58	48.54
10	1.42	4.657E+03	1.230E+04	1.153E+05	9.37	48.65
11	1.86	5.011E+03	1.209E+04	1.247E+05	10.32	48.65
12	2.30	5.284E+03	1.203E+04	1.321E+05	10.98	48.66
13	2.53	5.348E+03	1.177E+04	1.341E+05	11.39	48.74

Least-Squares Line for Ho vs q curve:
 Slope = -2.9344E-01
 Intercept = 5.8163E+05

Least-squares line for q = a*delta-T^b
 a = 2.1707E+04
 b = 7.5000E-01

NOTE: 13 data points were stored in file FONMVH2T1

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

NOTE: Program name : DRPOK
 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-WRAPPED SMOOTH TUBE
 Tube material : TITANIUM
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C_i (based on Petukhov-Popov) = 1.9482
 Alpha (based on Nusselt (T_{del})) = 0.7873
 Enhancement (q) = 1.035
 Enhancement (Del-T) = 1.026

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.64	5.614E+03	1.134E+04	1.454E+05	12.92	48.64
2	3.19	5.552E+03	1.166E+04	1.425E+05	12.23	48.64
3	2.75	5.383E+03	1.168E+04	1.380E+05	11.82	48.75
4	2.53	5.288E+03	1.171E+04	1.348E+05	11.51	48.67
5	2.31	5.193E+03	1.181E+04	1.326E+05	11.22	48.77
6	1.86	4.952E+03	1.205E+04	1.263E+05	10.48	48.91
7	1.42	4.573E+03	1.213E+04	1.155E+05	9.52	48.68
8	0.97	4.107E+03	1.303E+04	1.024E+05	7.86	48.71
9	1.42	4.582E+03	1.219E+04	1.156E+05	9.49	48.70
10	0.97	4.121E+03	1.316E+04	1.025E+05	7.79	48.69
11	2.31	5.164E+03	1.167E+04	1.316E+05	11.28	48.66
12	3.64	5.630E+03	1.139E+04	1.443E+05	12.67	48.65
13	3.19	5.480E+03	1.134E+04	1.398E+05	12.33	48.68

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 = 7.5000E-01

NOTE: 13 data points were stored in file FONMVH2T2

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVH2T3
 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) = 2.2400
 Alpha (based on Nusselt (T_{del})) = 0.7662
 Enhancement (q) = .999
 Enhancement (Del-T) = .999

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.823E+03	1.143E+04	1.395E+05	12.20	48.63
2	3.18	5.684E+03	1.138E+04	1.353E+05	11.89	48.64
3	2.74	5.568E+03	1.155E+04	1.320E+05	11.43	48.63
4	2.30	5.354E+03	1.149E+04	1.267E+05	11.02	48.64
5	1.86	5.135E+03	1.170E+04	1.209E+05	10.33	48.65
6	1.41	4.825E+03	1.201E+04	1.132E+05	9.43	48.70
7	0.97	4.405E+03	1.300E+04	1.015E+05	7.81	48.71
8	1.41	4.827E+03	1.203E+04	1.138E+05	9.46	48.67
9	0.97	4.383E+03	1.292E+04	1.015E+05	7.92	48.72
10	1.86	5.126E+03	1.167E+04	1.223E+05	10.48	48.74
11	2.30	5.341E+03	1.145E+04	1.275E+05	11.14	48.62
12	2.74	5.553E+03	1.150E+04	1.334E+05	11.60	48.70
13	3.19	5.669E+03	1.133E+04	1.358E+05	11.99	48.61
14	3.63	5.802E+03	1.135E+04	1.400E+05	12.33	48.74

Least-Squares Line for Ho vs q curve:
 Slope = -3.3576E-01
 Intercept = 5.9581E+05

Least-squares line for q = a*delta-T^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 : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUN2T1
 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 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 (T_{del})) = 0.8181
 Enhancement (q) = .996
 Enhancement (Del-T) = .397

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	2.991E+03	1.622E+04	7.061E+04	4.35	48.71
2	1.41	3.543E+03	1.476E+04	8.456E+04	5.73	48.66
3	1.86	3.947E+03	1.394E+04	9.451E+04	6.79	48.66
4	2.30	4.306E+03	1.392E+04	1.032E+05	7.42	48.65
5	2.74	4.548E+03	1.342E+04	1.088E+05	8.10	48.67
6	2.74	4.582E+03	1.372E+04	1.092E+05	7.96	48.63
7	3.18	4.765E+03	1.322E+04	1.138E+05	8.61	48.69
8	3.63	5.009E+03	1.350E+04	1.194E+05	8.85	48.68
9	3.18	4.784E+03	1.334E+04	1.135E+05	8.51	48.66
10	3.63	4.978E+03	1.326E+04	1.182E+05	8.92	48.70
11	2.74	4.556E+03	1.345E+04	1.078E+05	8.02	48.72
12	2.30	4.311E+03	1.389E+04	1.016E+05	7.31	48.68
13	1.86	3.971E+03	1.413E+04	9.320E+04	6.59	48.70
14	1.41	3.548E+03	1.465E+04	8.254E+04	5.63	48.66
15	0.97	2.987E+03	1.585E+04	6.885E+04	4.34	48.71

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

Least-squares line for q = a*delta-T^{1/4}
 a = 2.2839E+04
 b = 7.5000E-01

NOTE: 15 data points were stored in file FONMUN2T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUN3T1
 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) = .624
 Enhancement (Del-T) = .702

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.64	4.261E+03	9.903E+03	1.078E+05	10.89	48.61
2	3.19	4.046E+03	9.629E+03	1.034E+05	10.73	48.86
3	2.75	3.864E+03	9.694E+03	9.833E+04	10.14	48.76
4	2.30	3.695E+03	1.016E+04	9.272E+04	9.13	48.43
5	1.86	3.435E+03	1.048E+04	8.615E+04	8.22	48.48
6	0.97	2.619E+03	1.170E+04	6.453E+04	5.52	48.49
7	1.42	3.070E+03	1.067E+04	7.722E+04	7.24	48.63
8	0.97	2.649E+03	1.238E+04	6.524E+04	5.27	48.32
9	1.42	3.072E+03	1.072E+04	7.736E+04	7.22	48.54
10	1.86	3.352E+03	9.765E+03	8.670E+04	8.98	49.08
11	2.31	3.716E+03	1.034E+04	9.406E+04	9.10	48.44
12	2.75	3.859E+03	9.681E+03	9.967E+04	10.30	48.92
13	3.19	4.091E+03	9.905E+03	1.040E+05	10.50	48.50
14	3.64	4.275E+03	9.995E+03	1.095E+05	10.96	48.49

Least-Squares Line for Ho vs q curve:

Slope = -3.4927E-01

Intercept = 5.8044E+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 FONMUN3T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAH3T1
 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

C₁ (based on Petukhov-Popov) = 2.1377
 Alpha (based on Nusselt (T_{del})) = 0.7239
 Enhancement (q) = .872
 Enhancement (Del-T) = .902

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	5.173E+03	9.249E+03	3.780E+05	40.88	99.86
2	3.18	5.068E+03	9.251E+03	3.717E+05	40.18	100.01
3	2.74	4.950E+03	9.289E+03	3.634E+05	39.12	100.09
4	2.30	4.830E+03	9.456E+03	3.538E+05	37.41	99.96
5	1.85	4.616E+03	9.475E+03	3.377E+05	35.64	99.91
6	1.41	4.409E+03	9.947E+03	3.229E+05	32.46	100.11
7	0.97	4.014E+03	1.042E+04	2.923E+05	29.06	100.13
8	1.41	4.374E+03	9.784E+03	3.200E+05	32.70	99.81
9	0.97	4.028E+03	1.051E+04	2.924E+05	27.81	99.90
10	1.85	4.619E+03	9.508E+03	3.400E+05	35.76	99.92
11	2.30	4.790E+03	9.326E+03	3.539E+05	37.95	99.98
12	2.74	4.971E+03	9.385E+03	3.665E+05	39.05	99.75
13	3.18	5.054E+03	9.224E+03	3.749E+05	40.65	100.17
14	3.62	5.149E+03	9.135E+03	3.821E+05	41.56	100.15

Least-Squares Line for Ho vs q curve:
 Slope = -3.3392E-01
 Intercept = 7.7974E+05

Least-squares line for q = a*delta-T^{1.4}
 a = 2.3441E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH3T1

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

NOTE: Program name : DRPOK
 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, 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

C₁ (based on Petukhov-Popov) = 1.0337
 Alpha (based on Nusselt (T_{del})) = 0.6976
 Enhancement (q) = .854
 Enhancement (Δ_{el}-T) = .888

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	4.380E+03	9.469E+03	3.271E+05	34.55	99.89
2	3.18	4.296E+03	9.764E+03	3.183E+05	32.60	99.60
3	2.74	4.068E+03	9.592E+03	3.044E+05	31.73	100.24
4	2.30	3.881E+03	9.813E+03	2.889E+05	29.44	99.97
5	1.86	3.576E+03	9.664E+03	2.665E+05	27.57	100.05
6	1.41	3.275E+03	1.023E+04	2.435E+05	23.79	99.97
7	0.97	2.867E+03	1.169E+04	2.120E+05	18.13	99.93
8	1.41	3.275E+03	1.025E+04	2.441E+05	23.81	99.99
9	0.97	2.863E+03	1.167E+04	2.123E+05	18.20	100.00
10	1.86	3.590E+03	9.795E+03	2.683E+05	27.40	100.01
11	2.30	3.860E+03	9.708E+03	2.989E+05	29.76	100.06
12	2.74	4.087E+03	9.713E+03	3.058E+05	31.49	100.00
13	3.18	4.250E+03	9.590E+03	3.178E+05	33.14	99.95
14	3.63	4.399E+03	9.560E+03	3.290E+05	34.42	99.97

Least-Squares Line for Ho vs q curve:

Slope = -2.8762E-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 : DRPOK
 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) = .638
 Enhancement (Del-T) = .714

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	0.97	3.760E+03	1.046E+04	8.859E+04	8.47	48.70
2	1.41	4.094E+03	9.489E+03	9.805E+04	10.33	48.72
3	1.86	4.370E+03	9.286E+03	1.049E+05	11.30	48.67
4	2.30	4.582E+03	9.216E+03	1.114E+05	12.09	48.83
5	2.74	4.733E+03	9.123E+03	1.144E+05	12.54	48.70
6	3.19	4.798E+03	9.870E+03	1.165E+05	13.14	48.78
7	3.63	4.986E+03	9.127E+03	1.207E+05	13.23	48.71
8	3.19	4.835E+03	8.993E+03	1.174E+05	13.06	48.88
9	3.63	4.991E+03	9.142E+03	1.206E+05	13.19	48.70
10	2.74	4.753E+03	9.191E+03	1.142E+05	12.43	48.74
11	2.30	4.573E+03	9.166E+03	1.093E+05	11.92	48.72
12	1.86	4.391E+03	9.369E+03	1.040E+05	11.10	48.65
13	1.41	4.130E+03	9.662E+03	9.732E+04	10.07	48.58
14	0.97	3.751E+03	1.036E+04	8.735E+04	8.43	48.72

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 = 7.5000E-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 : FONMAH4T1
 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) = 2.3785
 Alpha (based on Nusselt (Tdel)) = 0.8529
 Enhancement (q) = 1.144
 Enhancement (Del-T) = 1.106

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	5.824E+03	1.114E+04	4.309E+05	38.69	99.98
2	3.18	5.742E+03	1.128E+04	4.235E+05	37.56	100.02
3	2.74	5.616E+03	1.136E+04	4.128E+05	36.34	99.96
4	2.30	5.449E+03	1.145E+04	3.989E+05	34.84	99.89
5	1.85	5.213E+03	1.152E+04	3.825E+05	33.19	100.07
6	1.41	4.921E+03	1.181E+04	3.593E+05	30.41	100.04
7	0.97	4.520E+03	1.273E+04	3.276E+05	25.72	99.95
8	1.41	4.901E+03	1.171E+04	3.586E+05	30.62	100.02
9	0.97	4.519E+03	1.272E+04	3.274E+05	25.74	99.97
10	1.85	5.226E+03	1.160E+04	3.838E+05	33.10	99.96
11	2.30	5.444E+03	1.144E+04	4.006E+05	35.01	100.00
12	2.74	5.614E+03	1.136E+04	4.135E+05	36.40	99.95
13	3.18	5.713E+03	1.116E+04	4.209E+05	37.71	99.98
14	3.62	5.810E+03	1.108E+04	4.290E+05	38.64	99.99

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 FONMAH4T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAN4T1
 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) = 1.3768
 Alpha (based on Nusselt (Tdel)) = 0.7912
 Enhancement (q) = 1.045
 Enhancement (Del-T) = 1.034

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	T3 (C)
1	3.63	5.090E+03	1.092E+04	3.804E+05	34.85	99.98
2	3.18	4.936E+03	1.089E+04	3.658E+05	33.58	99.94
3	2.74	4.757E+03	1.092E+04	3.518E+05	32.20	99.99
4	2.30	4.522E+03	1.089E+04	3.336E+05	30.52	99.97
5	1.85	4.214E+03	1.078E+04	3.103E+05	28.79	99.95
6	1.41	3.972E+03	1.109E+04	2.848E+05	25.68	99.95
7	0.97	3.497E+03	1.310E+04	2.558E+05	19.52	100.00
8	1.41	3.964E+03	1.104E+04	2.848E+05	25.80	99.97
9	0.97	3.519E+03	1.343E+04	2.573E+05	19.15	99.91
10	1.86	4.211E+03	1.079E+04	3.114E+05	28.86	99.94
11	2.30	4.527E+03	1.094E+04	3.348E+05	30.61	99.95
12	2.74	4.751E+03	1.090E+04	3.513E+05	32.24	99.92
13	3.18	4.945E+03	1.093E+04	3.662E+05	33.50	99.97
14	3.62	5.101E+03	1.093E+04	3.776E+05	34.56	99.97

Least-Squares Line for Ho vs q curve:
 Slope = -2.4783E-01
 Intercept = 7.6032E+05

Least-squares line for q = a*delta-T^b
 a = 2.5008E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN4T1

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

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, 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) = 2.0810
 Alpha (based on Nusselt (T_{del})) = 0.8211
 Enhancement (q) = 1.095
 Enhancement (Δ_{el}-T) = 1.071

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.967E+03	1.241E+04	1.468E+05	11.83	48.70
2	3.19	5.798E+03	1.229E+04	1.417E+05	11.52	48.70
3	2.74	5.668E+03	1.251E+04	1.380E+05	11.03	48.74
4	2.30	5.424E+03	1.239E+04	1.313E+05	10.59	48.70
5	1.86	5.192E+03	1.272E+04	1.252E+05	9.85	48.73
6	1.41	4.872E+03	1.326E+04	1.168E+05	8.81	48.74
7	0.97	4.393E+03	1.440E+04	1.038E+05	7.21	48.67
8	1.41	4.884E+03	1.337E+04	1.175E+05	8.79	48.67
9	0.97	4.402E+03	1.451E+04	1.044E+05	7.20	48.70
10	1.86	5.207E+03	1.282E+04	1.263E+05	9.95	48.72
11	2.30	5.449E+03	1.254E+04	1.327E+05	10.58	48.69
12	2.74	5.653E+03	1.244E+04	1.377E+05	11.07	48.69
13	3.19	5.793E+03	1.225E+04	1.407E+05	11.48	48.76
14	3.63	5.943E+03	1.229E+04	1.441E+05	11.73	48.70

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

Least-squares line for q = a*Δ_{el}-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 : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN4T1
 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) = 1.1394
 Alpha (based on Nusselt (Tdel)) = 0.8245
 Enhancement (q) = 1.007
 Enhancement (Del-T) = 1.005

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.64	5.167E+03	1.309E+04	1.307E+05	9.99	48.71
2	3.19	4.973E+03	1.310E+04	1.248E+05	9.53	48.66
3	2.75	4.780E+03	1.339E+04	1.196E+05	8.93	48.68
4	2.30	4.490E+03	1.333E+04	1.121E+05	8.41	48.67
5	1.86	4.130E+03	1.322E+04	1.029E+05	7.79	48.70
6	1.42	3.722E+03	1.369E+04	9.235E+04	6.75	48.66
7	0.97	3.186E+03	1.500E+04	7.819E+04	5.21	48.70
8	1.42	3.727E+03	1.377E+04	9.296E+04	6.75	48.74
9	0.97	3.205E+03	1.544E+04	7.870E+04	5.10	48.70
10	1.86	4.125E+03	1.319E+04	1.032E+05	7.93	48.67
11	2.30	4.483E+03	1.330E+04	1.127E+05	8.47	48.67
12	2.75	4.737E+03	1.308E+04	1.197E+05	9.15	48.72
13	3.19	4.955E+03	1.299E+04	1.257E+05	9.68	48.74
14	3.64	5.165E+03	1.309E+04	1.311E+05	10.02	48.69
15	2.30	4.473E+03	1.321E+04	1.127E+05	8.53	48.72
16	0.97	3.210E+03	1.559E+04	7.913E+04	5.07	48.70
17	3.64	5.150E+03	1.301E+04	1.315E+05	10.11	48.71

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 FONMVN4T1

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

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, 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

C₁ (based on Petukhov-Popov) = 2.2507

Alpha (based on Nusselt (T_{del})) = 0.8691

Enhancement (q) = 1.173

Enhancement (Del-T) = 1.127

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.60	5.914E+03	1.155E+04	4.113E+05	35.61	99.96
2	3.16	5.820E+03	1.165E+04	4.011E+05	34.43	100.02
3	2.72	5.727E+03	1.189E+04	3.917E+05	32.93	100.03
4	2.28	5.544E+03	1.196E+04	3.769E+05	31.52	99.92
5	1.84	5.333E+03	1.220E+04	3.613E+05	29.62	100.03
6	1.40	5.012E+03	1.244E+04	3.367E+05	27.07	99.95
7	0.96	4.578E+03	1.333E+04	3.054E+05	22.91	99.99
8	1.40	5.013E+03	1.246E+04	3.375E+05	27.09	99.93
9	0.96	4.582E+03	1.335E+04	3.055E+05	22.88	100.02
10	1.84	5.323E+03	1.216E+04	3.607E+05	29.63	99.92
11	2.28	5.574E+03	1.209E+04	3.795E+05	31.30	99.97
12	2.72	5.745E+03	1.196E+04	3.907E+05	32.63	99.99
13	3.15	5.948E+03	1.173E+04	3.975E+05	33.88	99.96
14	3.59	5.979E+03	1.174E+04	4.064E+05	34.60	99.95
15	3.15	5.926E+03	1.164E+04	3.949E+05	33.93	99.99
16	3.59	5.992E+03	1.190E+04	4.066E+05	34.47	99.97

Least-Squares Line for Ho vs q curve:

Slope = -2.4930E-01

Intercept = 7.6900E+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 : FONMANST1
 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

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.16	4.852E+03	1.203E+04	3.362E+05	27.95	99.95
2	2.72	4.685E+03	1.233E+04	3.227E+05	26.16	99.92
3	2.28	4.429E+03	1.238E+04	3.042E+05	24.57	100.01
4	1.84	4.108E+03	1.244E+04	2.809E+05	22.58	99.95
5	1.40	3.720E+03	1.286E+04	2.539E+05	19.74	100.04
6	0.96	3.248E+03	1.494E+04	2.203E+05	14.74	99.91
7	1.40	3.709E+03	1.279E+04	2.538E+05	19.95	99.92
8	0.96	3.235E+03	1.471E+04	2.200E+05	14.95	99.96
9	1.84	4.106E+03	1.249E+04	2.825E+05	22.63	99.95
10	2.28	4.423E+03	1.237E+04	3.052E+05	24.67	100.02
11	2.72	4.682E+03	1.232E+04	3.235E+05	26.26	100.03
12	3.61	5.010E+03	1.198E+04	3.534E+05	29.50	100.00
13	3.17	4.845E+03	1.219E+04	3.473E+05	28.49	99.93
14	3.51	5.004E+03	1.204E+04	3.592E+05	29.84	100.02

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 FONMANST1

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 = 13.86 (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) = 2.0139
 Alpha (based on Nusselt (Tdel)) = 0.8415
 Enhancement (q) = 1.132
 Enhancement (Del-T) = 1.097

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	6.026E+03	1.281E+04	1.423E+05	11.11	48.66
2	3.18	5.928E+03	1.304E+04	1.376E+05	10.55	48.70
3	2.74	5.738E+03	1.301E+04	1.308E+05	10.05	48.61
4	2.30	5.558E+03	1.329E+04	1.254E+05	9.43	48.61
5	1.85	5.293E+03	1.354E+04	1.186E+05	8.76	48.71
6	1.41	4.928E+03	1.394E+04	1.093E+05	7.84	48.73
7	0.97	4.410E+03	1.497E+04	9.625E+04	6.43	48.70
8	1.41	4.910E+03	1.381E+04	1.091E+05	7.90	48.66
9	0.97	4.407E+03	1.493E+04	9.616E+04	6.44	48.71
10	1.85	5.301E+03	1.360E+04	1.188E+05	8.74	48.65
11	2.30	5.540E+03	1.318E+04	1.248E+05	9.47	48.68
12	2.74	5.772E+03	1.316E+04	1.302E+05	9.89	48.66
13	3.18	5.911E+03	1.292E+04	1.336E+05	10.34	48.72
14	3.62	6.113E+03	1.314E+04	1.371E+05	10.43	48.65
15	2.29	5.558E+03	1.325E+04	1.235E+05	9.32	48.73
16	3.62	6.097E+03	1.306E+04	1.364E+05	10.44	48.69

Least-Squares Line for Ho vs q curve:
 Slope = -2.8741E-01
 Intercept = 5.9357E+05

Least-squares line for q = a*delta-T^b
 a = 2.3376E+04
 b = 7.5000E-01

NOTE: 16 data points were stored in file FONMVHST1

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVNST1

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) = 0.9775

Alpha (based on Nusselt (Tdel)) = 0.8425

Enhancement (q) = 1.036

Enhancement (Del-T) = 1.027

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	4.995E+03	1.364E+04	1.180E+05	8.65	48.71
2	3.18	4.834E+03	1.401E+04	1.122E+05	8.01	48.62
3	2.74	4.638E+03	1.449E+04	1.068E+05	7.37	48.68
4	2.30	4.365E+03	1.480E+04	9.953E+04	6.73	48.65
5	1.85	3.996E+03	1.484E+04	9.080E+04	6.12	48.72
6	1.41	3.561E+03	1.539E+04	7.982E+04	5.19	48.62
7	0.97	2.998E+03	1.665E+04	6.614E+04	3.97	48.63
8	1.41	3.545E+03	1.511E+04	7.963E+04	5.27	48.62
9	0.97	2.989E+03	1.670E+04	6.637E+04	3.98	48.67
10	1.85	4.001E+03	1.493E+04	9.108E+04	6.10	48.67
11	2.30	4.334E+03	1.446E+04	9.877E+04	6.83	48.63
12	2.74	4.629E+03	1.436E+04	1.059E+05	7.37	48.70
13	3.18	4.830E+03	1.392E+04	1.104E+05	7.93	48.65
14	3.62	5.056E+03	1.401E+04	1.156E+05	8.25	48.72
15	2.29	4.348E+03	1.455E+04	9.797E+04	6.73	48.65
16	0.97	3.024E+03	1.763E+04	6.615E+04	3.75	48.69

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 FONMVNST1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAH6T2
 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

C_i (based on Petukhov-Popov) = 2.3893
 Alpha (based on Nusselt (T_{del})) = 0.9933
 Enhancement (q) = 1.402
 Enhancement (Del-T) = 1.299

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.85	5.666E+03	1.385E+04	4.083E+05	29.48	99.95
2	1.41	5.331E+03	1.432E+04	3.841E+05	26.83	99.98
3	0.97	4.821E+03	1.517E+04	3.453E+05	22.76	100.08
4	1.41	5.328E+03	1.432E+04	3.844E+05	26.84	99.99
5	0.97	4.842E+03	1.540E+04	3.475E+05	22.56	100.09
6	1.85	5.679E+03	1.397E+04	4.132E+05	29.58	100.05
7	2.29	5.932E+03	1.374E+04	4.326E+05	31.47	99.99
8	2.74	6.114E+03	1.354E+04	4.465E+05	32.98	99.97
9	3.18	6.271E+03	1.345E+04	4.584E+05	34.08	99.95
10	3.62	6.379E+03	1.330E+04	4.668E+05	35.10	100.01
11	3.18	6.278E+03	1.347E+04	4.585E+05	34.03	100.06
12	3.62	6.392E+03	1.335E+04	4.674E+05	35.01	100.04
13	2.74	6.130E+03	1.360E+04	4.460E+05	32.90	100.00
14	2.29	5.932E+03	1.372E+04	4.308E+05	31.40	100.02

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

Least-squares line for q = a*delta-T^{1/4}
 a = 3.2616E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAH6T2

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

NOTE: Program name : DRPOK
 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, 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) = 2.3616
 Alpha (based on Nusselt (Tdel)) = 1.0051
 Enhancement (q) = 1.425
 Enhancement (Del-T) = 1.304

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.62	6.405E+03	1.350E+04	4.721E+05	34.97	100.05
2	3.18	6.279E+03	1.358E+04	4.601E+05	33.89	99.89
3	2.74	6.154E+03	1.383E+04	4.500E+05	32.55	100.01
4	2.29	5.949E+03	1.394E+04	4.334E+05	31.09	99.93
5	1.85	5.704E+03	1.425E+04	4.142E+05	29.06	99.89
6	1.41	5.321E+03	1.446E+04	3.857E+05	26.68	100.01
7	0.97	4.825E+03	1.557E+04	3.481E+05	22.36	100.02
8	1.41	5.333E+03	1.456E+04	3.974E+05	26.61	100.05
9	2.30	5.951E+03	1.397E+04	4.349E+05	31.14	99.91
10	3.18	6.274E+03	1.355E+04	4.611E+05	34.02	100.01

Least-Squares Line for Ho vs q curve:

Slope = -2.1564E-01
 Intercept = 7.5915E+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 : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMAN6T1
 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

C1 (based on Petukhov-Popov) = 1.1204
 Alpha (based on Nusselt (Tdel)) = 1.0190
 Enhancement (q) = 1.465
 Enhancement (Del-T) = 1.331

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.62	5.436E+03	1.471E+04	3.946E+05	26.83	99.96
2	3.17	5.295E+03	1.527E+04	3.831E+05	25.10	99.96
3	2.73	5.044E+03	1.531E+04	3.643E+05	23.79	99.91
4	2.29	4.772E+03	1.571E+04	3.446E+05	21.93	99.93
5	1.85	4.410E+03	1.601E+04	3.196E+05	19.89	100.03
6	1.41	3.939E+03	1.638E+04	2.839E+05	17.33	99.93
7	0.97	3.365E+03	1.860E+04	2.419E+05	13.01	100.02
8	1.41	3.915E+03	1.605E+04	2.937E+05	17.63	100.07
9	0.97	3.370E+03	1.891E+04	2.421E+05	12.87	99.87
10	1.85	4.404E+03	1.605E+04	3.197E+05	19.92	99.93
11	2.29	4.762E+03	1.569E+04	3.458E+05	22.04	99.91
12	2.73	5.056E+03	1.548E+04	3.669E+05	23.71	99.97
13	3.17	5.290E+03	1.523E+04	3.926E+05	25.12	99.89
14	3.62	5.472E+03	1.495E+04	3.960E+05	26.50	99.98

Least-Squares Line for Ho vs q curve:
 Slope = -1.7416E-01
 Intercept = 7.5469E+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 FONMAN6T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVH6T1
 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

C₁ (based on Petukhov-Popov) = 2.1602
 Alpha (based on Nusselt (T_{del})) = 0.9498
 Enhancement (q) = 1.330
 Enhancement (Δ_l-T) = 1.238

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	6.503E+03	1.468E+04	1.602E+05	10.92	48.76
2	3.19	6.324E+03	1.459E+04	1.530E+05	10.48	48.55
3	2.74	6.140E+03	1.468E+04	1.489E+05	10.14	48.73
4	2.30	5.961E+03	1.514E+04	1.430E+05	9.45	48.59
5	1.86	5.626E+03	1.512E+04	1.352E+05	8.94	48.75
6	0.97	4.703E+03	1.707E+04	1.099E+05	6.44	48.65
7	1.41	5.222E+03	1.549E+04	1.246E+05	8.04	48.67
8	2.30	5.930E+03	1.495E+04	1.430E+05	9.57	48.64
9	3.19	6.329E+03	1.462E+04	1.540E+05	10.53	48.67
10	1.41	5.229E+03	1.554E+04	1.241E+05	7.99	48.59

Least-Squares Line for Ho vs q curve:

Slope = -2.4792E-01

Intercept = 5.8256E+05

Least-squares line for q = a*Δ_l-T^b

a = 2.5385E+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 : DRPOK
 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, 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 (based on Petukhov-Popov) = 2.2144
 Alpha (based on Nusselt (T_{del})) = 0.9460
 Enhancement (q) = 1.323
 Enhancement (Del-T) = 1.233

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	6.476E+03	1.438E+04	1.610E+05	11.20	48.70
2	3.19	6.318E+03	1.439E+04	1.570E+05	10.91	48.80
3	2.75	6.157E+03	1.459E+04	1.516E+05	10.39	48.54
4	2.30	5.945E+03	1.481E+04	1.454E+05	9.82	48.58
5	1.86	5.645E+03	1.498E+04	1.380E+05	9.21	48.55
6	1.42	5.228E+03	1.518E+04	1.278E+05	8.42	48.74
7	0.97	4.712E+03	1.663E+04	1.125E+05	6.77	48.55
8	1.42	5.250E+03	1.538E+04	1.287E+05	8.37	48.76
9	0.97	4.715E+03	1.667E+04	1.128E+05	6.77	48.56
10	1.86	5.635E+03	1.492E+04	1.382E+05	9.26	48.62
11	2.30	5.932E+03	1.474E+04	1.457E+05	9.88	48.56
12	2.75	6.159E+03	1.461E+04	1.523E+05	10.42	48.56
13	3.19	6.331E+03	1.447E+04	1.572E+05	10.86	48.71
14	3.63	6.490E+03	1.445E+04	1.610E+05	11.14	48.57

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVN6T1
 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) = 1.0427
 Alpha (based on Nusselt (Tdel)) = 1.0131
 Enhancement (q) = 1.325
 Enhancement (Del-T) = 1.235

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.63	5.471E+03	1.674E+04	1.360E+05	8.12	48.58
2	3.19	5.271E+03	1.713E+04	1.308E+05	7.64	48.53
3	2.75	5.035E+03	1.768E+04	1.244E+05	7.04	48.60
4	2.30	4.697E+03	1.769E+04	1.156E+05	6.53	48.58
5	1.86	4.296E+03	1.786E+04	1.059E+05	5.93	48.72
6	1.42	3.804E+03	1.838E+04	9.338E+04	5.08	48.70
7	0.97	3.210E+03	2.134E+04	7.770E+04	3.64	48.60
8	1.42	3.800E+03	1.834E+04	9.400E+04	5.13	48.75
9	0.97	3.201E+03	2.101E+04	7.757E+04	3.69	48.56
10	1.86	4.293E+03	1.790E+04	1.070E+05	5.98	48.77
11	2.30	4.693E+03	1.771E+04	1.169E+05	6.60	48.54
12	2.75	5.044E+03	1.784E+04	1.255E+05	7.04	48.57
13	3.19	5.276E+03	1.721E+04	1.313E+05	7.63	48.53
14	3.63	5.473E+03	1.677E+04	1.370E+05	8.17	48.69

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 = 2.8413E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVN6T1

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH7T1

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) = 2.2365

Alpha (based on Nusselt (Tdel)) = 0.9248

Enhancement (q) = 1.275

Enhancement (Del-T) = 1.200

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.61	6.067E+03	1.228E+04	4.375E+05	35.62	99.94
2	3.17	5.979E+03	1.243E+04	4.232E+05	34.06	99.94
3	2.73	5.823E+03	1.245E+04	4.095E+05	32.90	100.11
4	2.29	5.662E+03	1.267E+04	3.948E+05	31.17	99.96
5	1.84	5.397E+03	1.271E+04	3.745E+05	29.47	100.06
6	1.40	5.073E+03	1.306E+04	3.503E+05	26.82	99.95
7	0.97	4.609E+03	1.428E+04	3.254E+05	22.79	99.97
8	1.41	5.051E+03	1.321E+04	3.635E+05	27.52	99.93
9	0.97	4.604E+03	1.446E+04	3.310E+05	22.90	99.95
10	1.41	5.045E+03	1.323E+04	3.666E+05	27.70	100.00
11	1.85	5.380E+03	1.290E+04	3.936E+05	30.52	100.09
12	2.30	5.618E+03	1.267E+04	4.123E+05	32.55	100.06
13	2.74	5.829E+03	1.265E+04	4.282E+05	33.85	100.00
14	3.13	5.974E+03	1.253E+04	4.393E+05	35.06	99.97
15	3.62	6.062E+03	1.232E+04	4.465E+05	36.24	100.06
16	3.13	5.973E+03	1.252E+04	4.383E+05	35.01	99.95
17	3.62	6.070E+03	1.235E+04	4.467E+05	36.13	100.09
18	2.74	5.845E+03	1.271E+04	4.282E+05	33.63	99.97
19	2.30	5.630E+03	1.272E+04	4.117E+05	32.37	99.99
20	1.85	5.380E+03	1.288E+04	3.922E+05	30.44	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.2891E-01

Intercept = 7.6695E+05

Least-squares line for q = a*delta-T^{0.5}

a = 3.0311E+04

b = 7.5000E-01

NOTE: 20 data points were stored in file FONMAH7T1

NOTE: 20 X-Y pairs were stored in data file

NOTE: Program name : DRPGT
 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, Di = 13.96 (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) = 1.1913
 Alpha (based on Nusselt (Tdel)) = 0.8660
 Enhancement (q) = 1.179
 Enhancement (Del-T) = 1.131

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.149E+03	1.232E+04	3.830E+05	31.09	99.96
2	3.18	4.963E+03	1.228E+04	3.679E+05	29.95	99.92
3	2.74	4.764E+03	1.240E+04	3.532E+05	28.48	100.06
4	2.30	4.500E+03	1.242E+04	3.338E+05	26.88	100.08
5	1.86	4.189E+03	1.259E+04	3.100E+05	24.63	99.98
6	1.41	3.795E+03	1.299E+04	2.808E+05	21.61	100.08
7	0.97	3.319E+03	1.507E+04	2.442E+05	16.21	99.91
8	1.41	3.786E+03	1.292E+04	2.808E+05	21.73	100.06
9	0.97	3.308E+03	1.488E+04	2.439E+05	16.39	99.97
10	1.86	4.185E+03	1.261E+04	3.113E+05	24.69	99.97
11	2.30	4.491E+03	1.240E+04	3.345E+05	26.98	100.01
12	2.74	4.764E+03	1.243E+04	3.540E+05	28.47	99.90
13	3.18	4.968E+03	1.234E+04	3.698E+05	29.97	100.02
14	3.63	5.151E+03	1.232E+04	3.831E+05	31.09	100.04

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 : DR000T
 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

Ci (based on Petukhov-Popov) = 1.9559
 Alpha (based on Nusselt (Tdel)) = 0.8552
 Enhancement (q) = 1.156
 Enhancement (Del-T) = 1.115

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	2.30	5.539E+03	1.355E+04	1.303E+05	9.61	48.63
2	1.86	5.230E+03	1.359E+04	1.219E+05	8.97	48.53
3	1.41	4.865E+03	1.405E+04	1.131E+05	8.05	48.65
4	0.97	4.349E+03	1.526E+04	1.006E+05	6.59	48.72
5	1.41	4.842E+03	1.387E+04	1.135E+05	8.18	48.72
6	1.41	4.871E+03	1.412E+04	1.136E+05	8.05	48.63
7	1.86	5.237E+03	1.365E+04	1.239E+05	9.07	48.70
8	2.30	5.516E+03	1.343E+04	1.305E+05	9.71	48.58
9	2.74	5.738E+03	1.332E+04	1.364E+05	10.25	48.64
10	3.18	5.886E+03	1.309E+04	1.408E+05	10.76	48.75
11	3.63	6.067E+03	1.320E+04	1.441E+05	10.92	48.53
12	3.18	5.872E+03	1.301E+04	1.405E+05	10.79	48.80
13	2.74	5.721E+03	1.322E+04	1.355E+05	10.25	48.65
14	2.30	5.544E+03	1.359E+04	1.307E+05	9.62	48.62

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 : DRAGON
 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, 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) = 0.9775
 Alpha (based on Nusselt (Tdel)) = 0.8700
 Enhancement (q) = 1.081
 Enhancement (Del-T) = 1.060

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.63	5.069E+03	1.436E+04	1.240E+05	8.64	48.53
2	3.19	4.829E+03	1.413E+04	1.180E+05	8.35	48.74
3	2.74	4.658E+03	1.490E+04	1.125E+05	7.55	48.61
4	2.30	4.341E+03	1.480E+04	1.052E+05	7.11	48.78
5	1.86	3.967E+03	1.477E+04	9.574E+04	6.48	48.81
6	1.41	3.557E+03	1.583E+04	8.537E+04	5.39	48.75
7	0.97	2.997E+03	1.783E+04	7.072E+04	3.97	48.56
8	1.41	3.562E+03	1.596E+04	8.553E+04	5.36	48.68
9	0.97	2.977E+03	1.719E+04	7.082E+04	4.12	48.67
10	1.86	3.983E+03	1.505E+04	9.639E+04	6.41	48.68
11	2.30	4.339E+03	1.480E+04	1.051E+05	7.10	48.67
12	2.74	4.633E+03	1.465E+04	1.127E+05	7.70	48.76
13	3.19	4.828E+03	1.410E+04	1.180E+05	8.37	48.85
14	3.63	5.090E+03	1.447E+04	1.236E+05	8.54	48.72

Least-Squares Line for Ho vs q curve:

Slope = -2.4125E-01
 Intercept = 5.7963E+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 : DR80K
 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

C_i (based on Petukhov-Popov) = 2.9032
 Alpha (based on Nusselt (T_{del})) = 0.9029
 Enhancement (q) = 1.235
 Enhancement (Del-T) = 1.171

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.746E+03	1.321E+04	3.432E+05	25.98	100.00
2	1.49	5.182E+03	1.291E+04	3.747E+05	29.04	100.01
3	1.96	5.431E+03	1.255E+04	3.909E+05	31.14	100.05
4	2.43	5.611E+03	1.238E+04	4.029E+05	32.56	99.95
5	2.99	5.757E+03	1.231E+04	4.129E+05	33.54	99.99
6	3.36	5.842E+03	1.213E+04	4.175E+05	34.41	99.95
7	3.82	5.919E+03	1.204E+04	4.222E+05	35.07	99.99
8	3.35	5.833E+03	1.208E+04	4.143E+05	34.30	99.99
9	3.82	5.926E+03	1.206E+04	4.208E+05	34.89	100.02
10	2.89	5.755E+03	1.226E+04	4.069E+05	33.18	99.97
11	2.42	5.629E+03	1.242E+04	3.985E+05	32.09	99.95
12	1.96	5.433E+03	1.254E+04	3.881E+05	30.96	99.93
13	1.49	5.176E+03	1.282E+04	3.708E+05	29.93	100.00
14	1.03	4.765E+03	1.326E+04	3.401E+05	25.64	99.91

Least-Squares Line for Ho vs q curve:

Slope = -2.4802E-01

Intercept = 7.7226E+05

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

a = 2.9569E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAHLT2

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

NOTE: Program name : DRPOK
 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

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

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.83	5.902E+03	1.203E+04	4.313E+05	35.84	100.05
2	3.36	5.842E+03	1.219E+04	4.256E+05	34.90	99.93
3	2.90	5.778E+03	1.247E+04	4.206E+05	33.74	100.04
4	2.43	5.625E+03	1.250E+04	4.085E+05	32.67	100.01
5	1.96	5.466E+03	1.280E+04	3.958E+05	30.93	99.97
6	1.49	5.195E+03	1.302E+04	3.754E+05	28.83	99.94
7	1.03	4.782E+03	1.348E+04	3.429E+05	25.44	99.94
8	1.96	5.431E+03	1.262E+04	3.949E+05	31.29	100.03
9	2.43	5.647E+03	1.262E+04	4.114E+05	32.59	99.97
10	2.90	5.783E+03	1.250E+04	4.219E+05	33.76	99.99
11	3.83	5.929E+03	1.215E+04	4.335E+05	35.67	99.95

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 : DR09K
 Data taken by : O'KEEFE
 This analysis done on file : FONMANLT2
 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 : ATMOSPHERIC
 Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 2.0556
 Alpha (based on Nusselt (T_{del})) = 0.9191
 Enhancement (q) = 1.276
 Enhancement (Δ_l-T) = 1.201

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	2.43	5.306E+03	1.317E+04	3.858E+05	29.30	99.96
2	1.96	5.055E+03	1.324E+04	3.664E+05	27.68	100.07
3	1.49	4.759E+03	1.376E+04	3.428E+05	24.91	99.88
4	1.03	4.246E+03	1.411E+04	3.054E+05	21.64	100.03
5	1.49	4.724E+03	1.350E+04	3.419E+05	25.32	99.98
6	1.03	4.253E+03	1.420E+04	3.057E+05	21.53	99.90
7	1.96	5.053E+03	1.325E+04	3.677E+05	27.74	100.05
8	2.43	5.297E+03	1.310E+04	3.847E+05	29.35	99.95
9	2.90	5.451E+03	1.293E+04	3.960E+05	30.85	99.94
10	3.36	5.578E+03	1.266E+04	4.051E+05	31.99	99.96
11	3.83	5.632E+03	1.231E+04	4.086E+05	33.20	99.97
12	3.36	5.569E+03	1.261E+04	4.042E+05	32.05	100.07
13	3.83	5.636E+03	1.232E+04	4.088E+05	33.19	100.02
14	2.89	5.460E+03	1.286E+04	3.951E+05	30.73	100.11

Least-Squares Line for Ho vs q curve:

Slope = -2.2963E-01

Intercept = 7.6648E+05

Least-squares line for q = a·Δ_l-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 : DR~~FRONT~~
 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, 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

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

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	2.43	5.283E+03	1.333E+04	3.852E+05	29.91	99.85
2	1.96	5.049E+03	1.355E+04	3.662E+05	27.02	99.94
3	1.49	4.761E+03	1.425E+04	3.439E+05	24.13	100.03
4	1.03	4.246E+03	1.475E+04	3.046E+05	20.64	99.96
5	1.49	4.751E+03	1.417E+04	3.432E+05	24.22	100.00
6	1.03	4.253E+03	1.482E+04	3.048E+05	20.56	99.97
7	1.96	5.078E+03	1.375E+04	3.674E+05	26.72	99.93
8	2.43	5.316E+03	1.349E+04	3.855E+05	28.57	100.03
9	2.89	5.464E+03	1.313E+04	3.963E+05	30.18	99.94
10	3.36	5.593E+03	1.294E+04	4.063E+05	31.40	100.09
11	3.83	5.664E+03	1.263E+04	4.113E+05	32.57	100.04

Least-Squares Line for Ho vs q curve:
 Slope = -2.2725E-01
 Intercept = 7.6793E+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 : DRPOT
 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, 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 : 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

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.900E+03	1.624E+04	1.195E+05	7.36	48.68
2	1.50	5.386E+03	1.546E+04	1.316E+05	8.51	48.69
3	1.97	5.700E+03	1.506E+04	1.397E+05	9.28	48.64
4	2.44	5.912E+03	1.473E+04	1.456E+05	9.89	48.73
5	2.91	6.143E+03	1.492E+04	1.503E+05	10.07	48.61
6	3.38	6.209E+03	1.442E+04	1.526E+05	10.58	48.72
7	3.84	6.311E+03	1.431E+04	1.550E+05	10.83	48.72
8	3.37	6.240E+03	1.459E+04	1.519E+05	10.41	48.63
9	3.84	6.326E+03	1.438E+04	1.543E+05	10.73	48.65
10	2.91	6.112E+03	1.472E+04	1.485E+05	10.09	48.74
11	2.44	5.937E+03	1.485E+04	1.430E+05	9.63	48.54
12	1.97	5.729E+03	1.520E+04	1.375E+05	9.05	48.70
13	1.50	5.370E+03	1.525E+04	1.277E+05	8.38	48.69
14	1.03	4.890E+03	1.597E+04	1.152E+05	7.21	48.70

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 : DR20K
 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, 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 : VACUUM
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.6688
 Alpha (based on Nusselt (Tdel)) = 0.9496
 Enhancement (q) = 1.729
 Enhancement (Del-T) = 1.238

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tsf (C)	Ts (C)
1	3.84	6.322E+03	1.446E+04	1.542E+05	10.66	48.63
2	3.37	6.238E+03	1.469E+04	1.519E+05	10.34	48.70
3	2.91	6.078E+03	1.466E+04	1.473E+05	10.05	48.68
4	2.44	5.927E+03	1.495E+04	1.429E+05	9.56	48.63
5	1.97	5.730E+03	1.541E+04	1.371E+05	8.90	48.66
6	1.50	5.388E+03	1.565E+04	1.281E+05	8.18	48.69
7	1.03	4.878E+03	1.622E+04	1.149E+05	7.08	48.65
8	1.97	5.706E+03	1.525E+04	1.377E+05	9.03	48.68
9	2.44	5.941E+03	1.505E+04	1.442E+05	9.58	48.64
10	2.91	6.095E+03	1.477E+04	1.489E+05	10.08	48.69
11	3.84	6.329E+03	1.451E+04	1.554E+05	10.71	48.68
12	1.03	4.891E+03	1.636E+04	1.149E+05	7.02	48.63

Least-Squares Line for Ho vs q curve:
 Slope = -2.5633E-01
 Intercept = 5.8376E+05

Least-squares line for q = a*delta-T^b
 a = 2.6375E+04
 b = 7.5000E-01

NOTE: 12 data points were stored in file FONMVHLT2

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

NOTE: Program name : DR59K

Data taken by : O'KEEFE

This analysis done on file : FONMUNLT2

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 Ho

Di (based on Petukhov-Popov) = 1.8686

Alpha (based on Nusselt (Tdel)) = 0.9526

Enhancement (q) = 1.220

Enhancement (Del-T) = 1.161

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	1.03	4.188E+03	1.659E+04	1.007E+05	6.07	48.69
2	1.50	4.779E+03	1.625E+04	1.164E+05	7.16	48.67
3	1.97	5.207E+03	1.624E+04	1.286E+05	7.92	48.72
4	2.44	5.441E+03	1.550E+04	1.349E+05	8.70	48.74
5	2.91	5.660E+03	1.532E+04	1.403E+05	9.16	48.68
6	3.38	5.782E+03	1.483E+04	1.432E+05	9.66	48.64
7	3.85	5.873E+03	1.442E+04	1.455E+05	10.08	48.65
8	2.91	5.689E+03	1.552E+04	1.405E+05	9.05	48.72
9	3.85	5.894E+03	1.455E+04	1.462E+05	10.05	48.72
10	2.44	5.475E+03	1.576E+04	1.340E+05	8.51	48.60
11	1.97	5.189E+03	1.604E+04	1.270E+05	7.91	48.70
12	1.03	4.239E+03	1.736E+04	1.013E+05	5.83	48.70

Least-Squares Line for Ho vs q curve:

Slope = -2.5018E-01

Intercept = 5.8313E+05

Least-squares line for q = a*delta-T^{1/4}b

a = 2.6547E+04

b = 7.5000E-01

NOTE: 12 data points were stored in file FONMUNLT2

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

NOTE: Program name : DRE~~901~~

Data taken by : O'KEEFE

This analysis done on file : FONMUNLT3

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 Ho

C₁ (based on Petukhov-Popov) = 1.8615

Alpha (based on Nusselt (T_{del})) = 0.9563

Enhancement (q) = 1.226

Enhancement (Δ_l-T) = 1.165

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.50	4.781E+03	1.636E+04	1.161E+05	7.10	48.61
2	1.03	4.190E+03	1.678E+04	1.009E+05	6.02	48.64
3	1.50	4.813E+03	1.675E+04	1.177E+05	7.03	48.74
4	1.97	5.180E+03	1.604E+04	1.273E+05	7.93	48.69
5	2.44	5.470E+03	1.576E+04	1.348E+05	8.54	48.63
6	2.91	5.675E+03	1.547E+04	1.408E+05	9.10	48.72
7	3.38	5.781E+03	1.486E+04	1.434E+05	9.65	48.67
8	3.85	5.924E+03	1.477E+04	1.470E+05	9.96	48.69
9	3.38	5.791E+03	1.485E+04	1.433E+05	9.65	48.74
10	3.85	5.881E+03	1.450E+04	1.456E+05	10.04	48.70
11	2.91	5.693E+03	1.558E+04	1.397E+05	8.97	48.65
12	2.44	5.473E+03	1.579E+04	1.340E+05	8.19	48.68
13	1.97	5.198E+03	1.618E+04	1.262E+05	7.80	48.63
14	1.03	4.217E+03	1.717E+04	1.011E+05	5.99	48.67

Least-Squares Line for Ho vs q curve:

Slope = -2.4579E-01

Intercept = 5.8265E+05

Least-squares line for q = a*Δ_l-T_{fb}

a = 2.6648E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUNLT3

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

NOTE: Program name : DRP05T
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHLIT1
 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 Ho

C_i (based on Petukhov-Popov) = 2.6673
 Alpha (based on Nusselt (T_{del})) = 0.8897
 Enhancement (q) = 1.211
 Enhancement (Δ_i-T) = 1.154

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	2.43	5.447E+03	1.212E+04	3.997E+05	32.98	100.05
2	1.96	5.263E+03	1.230E+04	3.850E+05	31.29	99.98
3	1.50	5.002E+03	1.260E+04	3.649E+05	28.96	99.96
4	1.03	4.605E+03	1.323E+04	3.332E+05	25.19	99.87
5	1.50	4.996E+03	1.257E+04	3.648E+05	29.03	99.98
6	1.03	4.594E+03	1.315E+04	3.334E+05	25.35	99.99
7	1.96	5.251E+03	1.225E+04	3.848E+05	31.42	99.91
8	2.43	5.443E+03	1.211E+04	4.003E+05	33.05	99.98
9	2.90	5.607E+03	1.210E+04	4.124E+05	34.08	100.01
10	3.37	5.698E+03	1.193E+04	4.195E+05	35.16	100.04
11	3.83	5.767E+03	1.178E+04	4.241E+05	35.99	99.96
12	3.37	5.675E+03	1.182E+04	4.170E+05	35.27	100.02
13	3.83	5.767E+03	1.178E+04	4.243E+05	36.00	100.02
14	2.90	5.583E+03	1.198E+04	4.092E+05	34.16	100.01
15	2.43	5.445E+03	1.210E+04	3.983E+05	32.91	100.01

Least-Squares Line for Ho vs q curve:

Slope = -2.4945E-01
 Intercept = 7.7129E+05

Least-squares line for q = a*Δ_i-T^b

a = 2.9099E+04
 b = 7.5000E-01

NOTE: 15 data points were stored in file FONMAHLIT1

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

NOTE: Program name : DRPOINT
 Data taken by : O'KEEFE
 This analysis done on file : FONMANLIT1
 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 : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0362
 Alpha (based on Nusselt (Tdel)) = 0.8688
 Enhancement (q) = 1.184
 Enhancement (Del-T) = 1.135

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qo (W/m^2)	Tef (C)	Ts (C)
1	3.84	5.440E+03	1.152E+04	4.025E+05	34.93	99.97
2	3.37	5.362E+03	1.170E+04	3.954E+05	33.79	99.98
3	2.90	5.285E+03	1.206E+04	3.893E+05	32.28	100.07
4	2.43	5.121E+03	1.220E+04	3.752E+05	30.76	99.85
5	1.96	4.889E+03	1.230E+04	3.571E+05	29.03	99.89
6	1.49	4.591E+03	1.265E+04	3.355E+05	26.52	100.04
7	1.03	4.135E+03	1.324E+04	3.003E+05	22.89	99.96
8	1.50	4.586E+03	1.263E+04	3.359E+05	26.60	100.08
9	1.03	4.132E+03	1.322E+04	3.003E+05	22.71	99.94
10	1.96	4.891E+03	1.234E+04	3.589E+05	29.09	99.90
11	2.43	5.125E+03	1.224E+04	3.774E+05	30.83	99.95
12	2.90	5.247E+03	1.197E+04	3.866E+05	32.58	99.97
13	3.37	5.363E+03	1.171E+04	3.956E+05	33.79	99.94
14	3.84	5.447E+03	1.155E+04	4.017E+05	34.79	99.91

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 FONMANLIT1

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

NOTE: Program name : DR89T
 Data taken by : O'KEEFE
 This analysis done on file : FONMVHLIT1
 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) = 2.3166
 Alpha (based on Nusselt (T_{del})) = 0.8799
 Enhancement (q) = 1.201
 Enhancement (T_{del}-T) = 1.147

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.84	6.001E+03	1.363E+04	1.471E+05	10.80	48.64
2	3.37	5.859E+03	1.355E+04	1.427E+05	10.53	48.66
3	2.91	5.700E+03	1.355E+04	1.390E+05	10.26	48.78
4	2.44	5.510E+03	1.360E+04	1.340E+05	9.85	48.74
5	1.97	5.275E+03	1.378E+04	1.281E+05	9.30	48.81
6	1.50	5.002E+03	1.450E+04	1.195E+05	8.24	48.54
7	1.03	4.510E+03	1.520E+04	1.074E+05	7.07	48.65
8	1.50	4.998E+03	1.448E+04	1.202E+05	8.30	48.59
9	1.03	4.507E+03	1.516E+04	1.079E+05	7.11	48.74
10	1.97	5.292E+03	1.391E+04	1.286E+05	9.24	48.60
11	2.44	5.516E+03	1.366E+04	1.347E+05	9.86	48.57
12	2.91	5.698E+03	1.355E+04	1.400E+05	10.33	48.67
13	3.38	5.863E+03	1.359E+04	1.436E+05	10.57	48.61
14	3.84	5.998E+03	1.361E+04	1.470E+05	10.79	48.53

Least-Squares Line for Ho vs q curve:

Slope = -2.7629E-01

Intercept = 5.8368E+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 FONMVHLIT1

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

NOTE: Program name : DREF9H

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, 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

Ci (based on Petukhov-Popov) = 1.7837

Alpha (based on Nusselt (Tdel)) = 0.8545

Enhancement (q) = 1.056

Enhancement (Del-T) = 1.041

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.38	5.480E+03	1.334E+04	1.347E+05	10.10	48.60
2	2.91	5.342E+03	1.359E+04	1.305E+05	9.60	48.56
3	2.44	5.123E+03	1.363E+04	1.255E+05	9.21	48.79
4	1.97	4.852E+03	1.377E+04	1.180E+05	8.57	48.73
5	1.50	4.519E+03	1.434E+04	1.093E+05	7.62	48.74
6	1.03	3.996E+03	1.508E+04	9.583E+04	6.35	48.67
7	1.50	4.528E+03	1.447E+04	1.096E+05	7.52	48.53
8	1.03	3.992E+03	1.504E+04	9.598E+04	6.38	48.63
9	1.97	4.854E+03	1.381E+04	1.188E+05	8.60	48.67
10	2.44	5.132E+03	1.371E+04	1.264E+05	9.22	48.71
11	2.91	5.309E+03	1.338E+04	1.307E+05	9.77	48.74
12	3.38	5.470E+03	1.327E+04	1.336E+05	10.07	48.59
13	3.84	5.597E+03	1.317E+04	1.375E+05	10.44	48.70
14	3.37	5.464E+03	1.323E+04	1.338E+05	10.11	48.70
15	3.84	5.589E+03	1.312E+04	1.371E+05	10.46	48.73

Least-Squares Line for Ho vs q curve:

Slope = -2.8007E-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 : DR80K

Data taken by : O'KEEFE

This analysis done on file : FONMAHL2T1

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 Ho

Ci (based on Petukhov-Popov) = 2.6388

Alpha (based on Nusselt (Tdel)) = 0.9089

Enhancement (q) = 1.246

Enhancement (Del-T) = 1.179

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.84	5.829E+03	1.210E+04	4.313E+05	35.63	99.96
2	3.37	5.755E+03	1.223E+04	4.238E+05	34.64	99.99
3	2.90	5.641E+03	1.231E+04	4.143E+05	33.64	99.96
4	2.43	5.520E+03	1.255E+04	4.043E+05	32.23	99.99
5	1.96	5.331E+03	1.276E+04	3.892E+05	30.51	99.93
6	1.49	5.020E+03	1.281E+04	3.661E+05	28.58	100.08
7	1.03	4.643E+03	1.369E+04	3.362E+05	24.55	100.01
8	1.50	5.026E+03	1.286E+04	3.667E+05	28.51	99.96
9	1.03	4.622E+03	1.353E+04	3.356E+05	24.81	100.12
10	1.96	5.304E+03	1.261E+04	3.883E+05	30.79	99.96
11	2.43	5.494E+03	1.243E+04	4.030E+05	32.43	99.92
12	2.90	5.640E+03	1.231E+04	4.143E+05	33.66	99.97
13	3.37	5.747E+03	1.219E+04	4.228E+05	34.62	99.99
14	3.83	5.824E+03	1.207E+04	4.290E+05	35.55	100.02

Least-Squares Line for Ho vs q curve:

Slope = -2.4705E-01

Intercept = 7.7249E+05

Least-squares line for $q = a \cdot \Delta T^b$

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 : DRPOK

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, 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 : ATMOSPHERIC

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.0573

Alpha (based on Nusselt (Tdel)) = 0.8901

Enhancement (q) = 1.223

Enhancement (Del-T) = 1.163

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.84	5.574E+03	1.207E+04	4.108E+05	34.03	99.92
2	3.37	5.450E+03	1.207E+04	4.012E+05	33.25	99.99
3	2.90	5.330E+03	1.222E+04	3.918E+05	32.06	100.00
4	2.43	5.189E+03	1.251E+04	3.811E+05	30.46	100.04
5	1.96	4.967E+03	1.272E+04	3.639E+05	28.61	99.95
6	1.49	4.670E+03	1.313E+04	3.407E+05	25.95	99.94
7	1.03	4.182E+03	1.353E+04	3.038E+05	22.46	100.02
8	1.50	4.663E+03	1.309E+04	3.410E+05	26.04	99.95
9	1.03	4.195E+03	1.369E+04	3.052E+05	22.29	100.03
10	1.96	4.957E+03	1.267E+04	3.650E+05	28.80	100.06
11	2.43	5.165E+03	1.238E+04	3.805E+05	30.73	100.08
12	2.90	5.315E+03	1.215E+04	3.911E+05	32.19	99.93
13	3.37	5.444E+03	1.204E+04	4.019E+05	33.37	100.05
14	3.84	5.552E+03	1.197E+04	4.094E+05	34.20	99.98

Least-Squares Line for Ho vs q curve:

Slope = -2.4184E-01

Intercept = 7.6857E+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

NOTE: Program name : DR20R

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)) = 0.8901

Enhancement (q) = 1.220

Enhancement (Del-T) = 1.161

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.85	6.075E+03	1.377E+04	1.517E+05	11.02	48.53
2	3.38	5.908E+03	1.355E+04	1.474E+05	10.87	48.68
3	2.91	5.778E+03	1.368E+04	1.436E+05	10.49	48.68
4	2.44	5.580E+03	1.367E+04	1.385E+05	10.13	48.74
5	1.97	5.372E+03	1.400E+04	1.326E+05	9.47	48.73
6	1.50	5.052E+03	1.432E+04	1.238E+05	8.64	48.71
7	1.03	4.605E+03	1.535E+04	1.113E+05	7.25	48.62
8	1.50	5.045E+03	1.428E+04	1.242E+05	8.70	48.75
9	1.03	4.591E+03	1.521E+04	1.117E+05	7.34	48.70
10	1.97	5.364E+03	1.396E+04	1.331E+05	9.54	48.69
11	2.44	5.596E+03	1.378E+04	1.398E+05	10.14	48.72
12	2.91	5.779E+03	1.370E+04	1.445E+05	10.55	48.65
13	3.38	5.881E+03	1.342E+04	1.475E+05	10.99	48.66
14	3.85	5.989E+03	1.334E+04	1.511E+05	11.33	48.77

Least-Squares Line for Ho vs q curve:

Slope = -2.8095E-01

Intercept = 5.8479E+05

Least-squares line for q = a*delta-T^{1.5}b

a = 2.4663E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMVHL2T1

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

NOTE: Program name : DRROK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVNL2T1
 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

Ci (based on Petukhov-Popov) = 1.8387
 Alpha (based on Nusselt (Tdel)) = 0.8688
 Enhancement (q) = 1.079
 Enhancement (Del-T) = 1.059

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.85	5.651E+03	1.326E+04	1.405E+05	10.59	48.72
2	3.38	5.521E+03	1.335E+04	1.373E+05	10.28	48.74
3	2.91	5.371E+03	1.352E+04	1.339E+05	9.90	48.78
4	2.44	5.217E+03	1.400E+04	1.293E+05	9.23	48.65
5	1.97	4.929E+03	1.405E+04	1.225E+05	8.72	48.73
6	1.50	4.582E+03	1.451E+04	1.133E+05	7.81	48.72
7	1.03	4.061E+03	1.530E+04	9.942E+04	6.50	48.66
8	1.50	4.576E+03	1.448E+04	1.142E+05	7.89	48.81
9	1.03	4.043E+03	1.507E+04	9.939E+04	6.59	48.66
10	1.97	4.934E+03	1.412E+04	1.239E+05	8.78	48.73
11	2.44	5.188E+03	1.383E+04	1.302E+05	9.42	48.63
12	2.91	5.379E+03	1.360E+04	1.356E+05	9.97	48.66
13	3.38	5.514E+03	1.334E+04	1.395E+05	10.46	48.75
14	3.85	5.642E+03	1.324E+04	1.418E+05	10.71	48.67

Least-Squares Line for Ho vs q curve:
 Slope = -2.7794E-01
 Intercept = 5.8363E+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 FONMVNL2T1

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

NOTE: Program name : DRUM

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, 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 Ho

C₁ (based on Petukhov-Popov) = 2.8352

Alpha (based on Nusselt (T_{del})) = 0.9682

Enhancement (q) = 1.355

Enhancement (Δ_l-T) = 1.256

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.03	4.880E+03	1.461E+04	3.506E+05	24.00	99.94
2	1.49	5.280E+03	1.378E+04	3.824E+05	27.75	100.01
3	1.96	5.597E+03	1.371E+04	4.070E+05	29.67	100.00
4	2.43	5.793E+03	1.345E+04	4.219E+05	31.35	100.04
5	2.90	5.940E+03	1.337E+04	4.337E+05	32.45	99.99
6	3.36	6.009E+03	1.305E+04	4.397E+05	33.70	100.02
7	3.33	6.100E+03	1.297E+04	4.465E+05	34.42	99.99
8	3.36	6.014E+03	1.307E+04	4.388E+05	33.57	99.90
9	3.83	6.100E+03	1.297E+04	4.460E+05	34.38	99.95
10	2.90	5.939E+03	1.336E+04	4.326E+05	32.39	99.93
11	2.43	5.763E+03	1.344E+04	4.210E+05	31.32	100.07
12	1.96	5.597E+03	1.370E+04	4.060E+05	29.64	100.08
13	1.49	5.278E+03	1.375E+04	3.811E+05	27.73	100.04
14	1.03	4.883E+03	1.459E+04	3.492E+05	23.93	99.96

Least-Squares Line for Ho vs q curve:

Slope = -2.2538E-01

Intercept = 7.6980E+05

Least-squares line for q = a*Δ_l-T^{1.1}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 : DRPDKT
 Data taken by : O'KEEFE
 This analysis done on file : FONMANL3T1
 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 : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.2023
 Alpha (based on Nusselt (Tdel)) = 0.9330
 Enhancement (q) = 1.302
 Enhancement (Del-T) = 1.219

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	3.83	5.767E+03	1.262E+04	4.229E+05	33.50	99.98
2	3.36	5.682E+03	1.279E+04	4.139E+05	32.36	99.92
3	2.90	5.564E+03	1.297E+04	4.050E+05	31.23	100.07
4	2.43	5.398E+03	1.312E+04	3.908E+05	29.79	99.90
5	1.96	5.197E+03	1.348E+04	3.759E+05	27.89	100.00
6	1.49	4.867E+03	1.370E+04	3.519E+05	25.69	100.12
7	1.03	4.390E+03	1.428E+04	3.154E+05	22.09	100.03
8	1.49	4.877E+03	1.380E+04	3.523E+05	25.53	99.90
9	1.03	4.398E+03	1.438E+04	3.160E+05	21.97	99.95
10	1.96	5.189E+03	1.344E+04	3.763E+05	28.00	99.96
11	2.43	5.394E+03	1.311E+04	3.924E+05	29.93	100.02
12	2.90	5.558E+03	1.294E+04	4.045E+05	31.25	99.91
13	3.36	5.663E+03	1.259E+04	4.127E+05	32.51	99.97
14	3.83	5.776E+03	1.265E+04	4.211E+05	33.30	100.01

Least-Squares Line for Ho vs q curve:
 Slope = -2.2866E-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 FONMANL3T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVHL3T1
 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

C_i (based on Petukhov-Popov) = 2.6094
 Alpha (based on Nusselt (T_{del})) = 0.9949
 Enhancement (q) = 1.415
 Enhancement (T_{del}-T) = 1.297

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.84	6.544E+03	1.581E+04	1.570E+05	9.93	48.61
2	3.37	6.381E+03	1.565E+04	1.526E+05	9.75	48.70
3	2.90	6.240E+03	1.580E+04	1.481E+05	9.38	48.68
4	2.43	6.057E+03	1.598E+04	1.425E+05	8.91	48.60
5	1.97	5.839E+03	1.645E+04	1.370E+05	8.33	48.69
6	1.50	5.451E+03	1.649E+04	1.268E+05	7.63	48.65
7	1.03	4.959E+03	1.761E+04	1.151E+05	6.54	48.75
8	1.50	5.441E+03	1.642E+04	1.271E+05	7.74	48.62
9	1.03	4.961E+03	1.764E+04	1.146E+05	6.50	48.53
10	1.97	5.781E+03	1.603E+04	1.367E+05	8.53	48.65
11	2.43	6.023E+03	1.577E+04	1.431E+05	9.07	48.62
12	2.90	6.221E+03	1.568E+04	1.483E+05	9.45	48.65
13	3.37	6.393E+03	1.572E+04	1.529E+05	9.73	48.67
14	3.84	6.490E+03	1.549E+04	1.554E+05	10.03	48.74

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 FONMVHL3T1

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMVNL3T1
 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

Ci (based on Petukhov-Popov) = 2.0410
 Alpha (based on Nusselt (Tdel)) = 0.9419
 Enhancement (q) = 1.202
 Enhancement (Del-T) = 1.148

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	3.37	5.954E+03	1.506E+04	1.439E+05	9.55	48.73
2	3.84	6.043E+03	1.469E+04	1.462E+05	9.95	48.77
3	3.37	5.937E+03	1.494E+04	1.424E+05	9.53	48.67
4	3.84	6.031E+03	1.461E+04	1.443E+05	9.87	48.59
5	2.90	5.754E+03	1.493E+04	1.373E+05	9.20	48.69
6	2.43	5.565E+03	1.523E+04	1.330E+05	8.73	48.74
7	1.97	5.292E+03	1.543E+04	1.254E+05	8.13	48.69
8	1.50	4.917E+03	1.576E+04	1.158E+05	7.35	48.68
9	1.03	4.397E+03	1.686E+04	1.032E+05	6.12	48.73
10	1.50	4.940E+03	1.602E+04	1.172E+05	7.31	48.72
11	1.03	4.393E+03	1.682E+04	1.032E+05	6.13	48.72
12	1.97	5.295E+03	1.548E+04	1.265E+05	8.17	48.67
13	2.44	5.561E+03	1.522E+04	1.334E+05	8.77	48.61
14	2.90	5.771E+03	1.507E+04	1.388E+05	9.21	48.66

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 FONMVNL3T1

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

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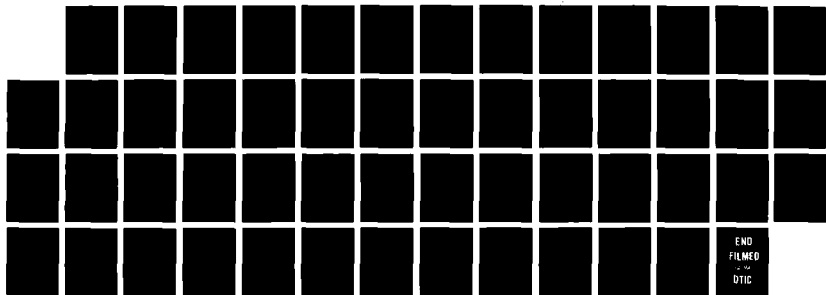
FILMWISE CONDENSATION OF STEAM ON HORIZONTAL
WIRE-WRAPPED SMOOTH AND ROPED TITANIUM TUBES(U) NAVAL
POSTGRADUATE SCHOOL MONTEREY CA T J O'KEEFE SEP 92

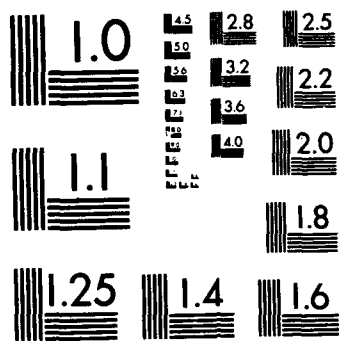
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NOTE: Program name : DRACO
 Data taken by : O'KEEFE
 This analysis done on file : FONMAHC1
 This analysis includes end-fin effect
 Thermal conductivity = 385.0 (W/m.K)
 Inside diameter, Di = 12.70 (mm)
 Outside diameter, Do = 19.05 (mm)
 This analysis 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

Ci (based on Petukhov-Popov) = 2.8086
 Alpha (based on Nusselt (Tdel)) = 0.8318
 Enhancement (q) = 1.049
 Enhancement (Del-T) = 1.037

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.31	6.736E+03	9.034E+03	4.860E+05	53.80	99.89
2	3.78	6.667E+03	9.157E+03	4.792E+05	52.33	100.04
3	3.25	6.574E+03	9.307E+03	4.697E+05	50.47	100.02
4	2.73	6.427E+03	9.463E+03	4.576E+05	48.35	99.97
5	2.20	6.207E+03	9.636E+03	4.405E+05	45.72	99.99
6	1.68	5.880E+03	9.868E+03	4.160E+05	42.16	100.03
7	1.15	5.439E+03	1.049E+04	3.803E+05	36.24	99.99
8	4.30	6.955E+03	9.234E+03	4.898E+05	53.04	99.94
9	3.77	6.785E+03	9.358E+03	4.794E+05	51.23	99.88
10	3.25	6.684E+03	9.498E+03	4.689E+05	49.37	99.96
11	2.72	6.501E+03	9.584E+03	4.541E+05	47.39	100.03
12	2.20	6.290E+03	9.787E+03	4.380E+05	44.75	100.11
13	1.67	5.971E+03	1.005E+04	4.128E+05	41.07	100.05
14	1.15	5.504E+03	1.065E+04	3.783E+05	35.53	100.34
15	2.20	6.310E+03	9.845E+03	4.402E+05	44.72	99.94
16	3.25	6.682E+03	9.491E+03	4.686E+05	49.37	100.05
17	4.29	6.869E+03	9.235E+03	4.825E+05	52.25	100.10

Least-Squares Line for Ho vs q curve:
 Slope = -3.4908E-01
 Intercept = 7.5868E+05

Least-squares line for q = a*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 : DB20K
 Data taken by : O'KEEFE
 This analysis done on file : FONMANC1
 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 : ATMOSPHERIC
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.2653
 Alpha (based on Nusselt (Tdel)) = 0.8158
 Enhancement (q) = 1.052
 Enhancement (Del-T) = 1.039

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tof (C)	Ts (C)
1	4.31	5.764E+03	9.703E+03	4.227E+05	43.56	99.92
2	3.79	5.643E+03	9.971E+03	4.120E+05	41.32	99.98
3	3.26	5.366E+03	9.971E+03	3.929E+05	39.40	100.05
4	2.73	5.144E+03	1.024E+04	3.749E+05	36.60	99.99
5	2.21	4.827E+03	1.058E+04	3.505E+05	33.13	99.92
6	1.68	4.341E+03	1.073E+04	3.157E+05	29.42	100.02
7	1.16	3.805E+03	1.203E+04	2.757E+05	22.92	100.02
8	1.68	4.344E+03	1.079E+04	3.172E+05	29.41	100.00
9	1.16	3.804E+03	1.205E+04	2.757E+05	22.89	99.94
10	2.21	4.812E+03	1.055E+04	3.521E+05	33.36	100.00
11	2.73	5.157E+03	1.031E+04	3.772E+05	36.57	99.95
12	3.26	5.374E+03	9.959E+03	3.939E+05	39.56	99.97
13	3.79	5.643E+03	9.988E+03	4.137E+05	41.41	99.86
14	4.31	5.762E+03	9.693E+03	4.224E+05	43.53	99.89

Least-Squares Line for Ho vs q curve:

Slope = -2.8166E-01

Intercept = 7.2938E+05

Least-squares line for q = a+delta-T^{1.5}b

a = 2.5317E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMANC1

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

NOTE: Program name : DR~~ORT~~
 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, 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 : VACUUM
 Nusselt theory is used for Ho

Di (based on Petukhov-Popov) = 2.4815
 Alpha (based on Nusselt (Tdel)) = 0.8379
 Enhancement (q) = .958
 Enhancement (Del-T) = .968

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.32	7.578E+03	1.110E+04	1.749E+05	15.75	48.74
2	3.79	7.327E+03	1.098E+04	1.683E+05	15.32	48.69
3	3.26	7.140E+03	1.110E+04	1.631E+05	14.69	48.63
4	2.74	6.907E+03	1.128E+04	1.575E+05	13.98	48.63
5	2.21	6.573E+03	1.144E+04	1.492E+05	13.04	48.63
6	1.68	6.158E+03	1.185E+04	1.399E+05	11.81	48.72
7	1.16	5.538E+03	1.261E+04	1.249E+05	9.90	49.73

Least-Squares Line for Ho vs q curve:
 Slope = -3.2813E-01
 Intercept = 5.5448E+05

Least-squares line for q = a*delta-T^{1.5}
 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 : DRIFT

Data taken by : O'KEEFE
 This analysis done on file : FONMUNC1
 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

Ci (based on Petukhov-Popov) = 1.0847
 Alpha (based on Nusselt (Tdel)) = 0.8663
 Enhancement (q) = .942
 Enhancement (Del-T) = .956

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.32	6.182E+03	1.238E+04	1.461E+05	11.80	48.63
2	3.79	5.937E+03	1.255E+04	1.401E+05	11.16	48.64
3	3.27	5.646E+03	1.277E+04	1.336E+05	10.48	48.77
4	2.74	5.290E+03	1.301E+04	1.252E+05	9.63	48.78
5	2.21	4.865E+03	1.339E+04	1.144E+05	8.54	48.71
6	1.68	4.309E+03	1.379E+04	1.009E+05	7.32	48.64
7	1.16	3.641E+03	1.540E+04	8.492E+04	5.51	48.62
8	1.68	4.323E+03	1.399E+04	1.023E+05	7.31	48.67
9	1.16	3.637E+03	1.533E+04	8.518E+04	5.56	48.73
10	2.21	4.811E+03	1.306E+04	1.151E+05	8.92	48.74
11	2.74	5.290E+03	1.305E+04	1.254E+05	9.68	48.68
12	3.27	5.637E+03	1.276E+04	1.353E+05	10.60	48.75
13	3.79	5.915E+03	1.248E+04	1.408E+05	11.26	48.69
14	4.32	6.185E+03	1.240E+04	1.470E+05	11.95	48.64

Least-Squares Line for Ho vs q curve:

Slope = -2.7240E-01
 Intercept = 5.4643E+05

Least-squares line for q = a*delta-T^{1/4}

a = 2.2954E+04
 b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUNC1

NOTE: 14 (q-T) 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, 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 : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 2.8065
 Alpha (based on Nusselt (Tdel)) = 1.2643
 Enhancement (q) = 1.934
 Enhancement (Del-T) = 1.640

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tsf (C)	Ts (C)
1	4.29	9.492E+03	1.466E+04	6.577E+05	44.97	100.04
2	3.76	9.328E+03	1.488E+04	6.388E+05	42.93	99.97
3	3.24	9.132E+03	1.522E+04	6.213E+05	40.83	99.96
4	2.72	8.827E+03	1.553E+04	5.975E+05	38.48	99.92
5	2.19	8.375E+03	1.581E+04	5.666E+05	35.84	100.01
6	1.67	7.795E+03	1.637E+04	5.249E+05	32.06	100.02
7	1.15	6.985E+03	1.771E+04	4.679E+05	26.42	100.07
8	1.67	7.804E+03	1.647E+04	5.292E+05	32.13	100.00
9	1.15	6.992E+03	1.776E+04	4.684E+05	26.37	100.08
10	2.20	8.478E+03	1.623E+04	5.785E+05	35.64	100.01
11	2.72	8.949E+03	1.593E+04	6.088E+05	38.21	99.92
12	3.24	9.254E+03	1.559E+04	6.313E+05	40.50	100.01
13	3.76	9.531E+03	1.537E+04	6.466E+05	42.06	99.95
14	4.29	9.743E+03	1.520E+04	6.612E+05	43.50	99.97

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-WRAPPED SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : ATMOSPHERIC
 Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.2431
 Alpha (based on Nusselt (Tdel)) = 1.3153
 Enhancement (q) = 2.053
 Enhancement (Del-T) = 1.719

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.29	7.797E+03	1.712E+04	5.462E+05	31.90	100.00
2	3.77	7.478E+03	1.747E+04	5.242E+05	30.00	100.03
3	3.25	7.128E+03	1.807E+04	4.989E+05	27.61	99.95
4	2.72	6.596E+03	1.812E+04	4.635E+05	25.58	99.99
5	2.20	5.980E+03	1.823E+04	4.200E+05	23.05	100.02
6	1.68	5.287E+03	1.914E+04	3.723E+05	19.45	100.04
7	1.15	4.502E+03	2.354E+04	3.170E+05	13.47	100.10
8	1.68	5.263E+03	1.901E+04	3.730E+05	19.62	100.01
9	1.15	4.450E+03	2.252E+04	3.153E+05	14.00	100.04
10	2.20	6.006E+03	1.874E+04	4.275E+05	22.91	99.95
11	2.73	6.655E+03	1.877E+04	4.724E+05	25.17	99.86
12	3.25	7.209E+03	1.878E+04	5.113E+05	27.23	99.99
13	3.77	7.658E+03	1.862E+04	5.423E+05	29.12	99.97
14	4.30	8.034E+03	1.837E+04	5.663E+05	30.83	100.02

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 : DRPOK
 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, 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

C₁ (based on Petukhov-Popov) = 2.5490
 Alpha (based on Nusselt (T_{del})) = 1.1854
 Enhancement (q) = 1.787
 Enhancement (Δ_l-T) = 1.546

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.32	9.811E+03	1.641E+04	2.246E+05	13.69	48.74
2	3.79	9.448E+03	1.628E+04	2.148E+05	13.19	48.81
3	3.26	9.165E+03	1.658E+04	2.062E+05	12.43	48.78
4	2.73	8.699E+03	1.660E+04	1.946E+05	11.72	48.77
5	2.21	8.209E+03	1.703E+04	1.826E+05	10.72	48.72
6	1.68	7.523E+03	1.755E+04	1.668E+05	9.51	48.76
7	1.15	6.670E+03	1.944E+04	1.451E+05	7.46	48.62
8	1.68	7.515E+03	1.754E+04	1.687E+05	9.62	48.91
9	1.15	6.668E+03	1.946E+04	1.455E+05	7.48	48.55
10	2.21	8.220E+03	1.713E+04	1.848E+05	10.79	48.63
11	2.74	8.740E+03	1.678E+04	1.968E+05	11.73	48.59
12	3.26	9.189E+03	1.668E+04	2.073E+05	12.43	48.63
13	3.79	9.446E+03	1.627E+04	2.139E+05	13.15	48.71
14	4.31	9.846E+03	1.649E+04	2.212E+05	13.42	48.60

Least-Squares Line for Ho vs q curve:

Slope = -2.0791E-01
 Intercept = 5.4980E+05

Least-squares line for q = a*Δ_l-T^b

a = 3.1228E+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 : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMVN68C1

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-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : VACUUM

Nusselt theory is used for Ho

Ci (based on Petukhov-Popov) = 1.0378

Alpha (based on Nusselt (Tdel)) = 1.2885

Enhancement (q) = 1.825

Enhancement (Del-T) = 1.570

Data #	Vw (m/s)	Uo (W/m^2-K)	Ho (W/m^2-K)	Qp (W/m^2)	Tcf (C)	Ts (C)
1	4.32	7.410E+03	1.952E+04	1.749E+05	8.93	48.82
2	3.79	7.037E+03	1.994E+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	3.882E+03	2.496E+04	8.997E+04	3.60	48.78
8	1.68	4.765E+03	2.277E+04	1.127E+05	4.95	48.81
9	1.16	3.877E+03	2.492E+04	8.988E+04	3.61	48.63
10	2.21	5.572E+03	2.308E+04	1.315E+05	5.70	48.67
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	8.882E+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 FONMVN68C1

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAH71C1

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

Ci (based on Petukhov-Popov) = 3.0634

Alpha (based on Nusselt (Tdel)) = 1.5049

Enhancement (q) = 2.313

Enhancement (Del-T) = 1.875

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.29	1.097E+04	1.770E+04	7.469E+05	42.20	99.96
2	3.76	1.075E+04	1.796E+04	7.258E+05	40.42	99.96
3	3.24	1.050E+04	1.835E+04	7.052E+05	38.42	99.99
4	2.72	1.007E+04	1.860E+04	6.764E+05	36.37	99.97
5	2.19	9.574E+03	1.911E+04	6.407E+05	33.53	99.94
6	1.67	8.871E+03	1.986E+04	5.945E+05	29.94	100.00
7	1.15	7.842E+03	2.121E+04	5.237E+05	24.69	99.94
8	1.67	9.896E+03	2.011E+04	6.029E+05	29.97	99.92
9	1.15	7.902E+03	2.174E+04	5.310E+05	24.43	100.03
10	2.20	9.801E+03	2.017E+04	6.671E+05	33.06	100.00
11	2.72	1.039E+04	1.979E+04	7.079E+05	35.77	99.95
12	3.24	1.090E+04	1.970E+04	7.425E+05	37.69	100.07

Least-Squares Line for Ho vs q curve:

Slope = -1.4745E-01

Intercept = 7.2637E+05

Least-squares line for q = a*delta-T^{1/4}

a = 4.6853E+04

b = 7.5000E-01

NOTE: 12 data points were stored in file FONMAH71C1

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

NOTE: Program name : DRPOK

Data taken by : O'KEEFE

This analysis done on file : FONMAN7101

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-WRAPPED SMOOTH TUBE

Tube material : COPPER

Pressure condition : ATMOSPHERIC

Nusselt theory is used for Ho

C₁ (based on Petukhov-Popov) = 1.2503

Alpha (based on Nusselt (Tdel)) = 1.7215

Enhancement (q) = 2.247

Enhancement (Del-T) = 2.132

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	4.29	8.928E+03	2.330E+04	6.214E+05	25.67	99.97
2	3.77	8.503E+03	2.393E+04	5.928E+05	24.77	100.01
3	3.25	8.042E+03	2.471E+04	5.581E+05	22.59	99.93
4	2.72	7.374E+03	2.471E+04	5.131E+05	20.77	99.94
5	2.20	6.613E+03	2.490E+04	4.625E+05	18.57	100.05
6	1.68	5.750E+03	2.532E+04	4.028E+05	15.54	99.99
7	1.15	4.756E+03	3.095E+04	3.333E+05	10.77	99.95
8	1.68	5.724E+03	2.502E+04	4.054E+05	15.70	100.09
9	1.15	4.874E+03	3.643E+04	3.424E+05	9.40	100.10
10	2.20	6.658E+03	2.605E+04	4.720E+05	18.12	100.04
11	2.73	7.500E+03	2.659E+04	5.292E+05	19.90	100.03
12	3.25	8.213E+03	2.671E+04	5.776E+05	21.64	100.10
13	3.77	8.991E+03	2.713E+04	6.202E+05	22.86	99.99
14	4.29	9.435E+03	2.704E+04	6.561E+05	24.27	99.93

Least-Squares Line for Ho vs q curve:

Slope = -3.6527E-02

Intercept = 7.0340E+05

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

a = 5.5185E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMAN7101

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

NOTE: Program name : DRPOK
 Data taken by : O'KEEFE
 This analysis done on file : FONMUN7101
 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-WRAPPED SMOOTH TUBE
 Tube material : COPPER
 Pressure condition : VACUUM
 Nusselt theory is used for Ho

C1 (based on Petukhov-Popov) = 1.0863
 Alpha (based on Nusselt (Tdel)) = 1.4135
 Enhancement (q) = 1.809
 Enhancement (Del-T) = 1.560

Data #	Uw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Op (W/m ²)	Tcf (C)	Ts (C)
1	4.32	7.865E+03	2.150E+04	1.844E+05	8.58	48.53
2	3.79	7.432E+03	2.168E+04	1.751E+05	8.07	48.74
3	3.26	7.045E+03	2.292E+04	1.647E+05	7.18	48.71
4	2.74	6.532E+03	2.410E+04	1.529E+05	6.35	48.78
5	2.21	5.872E+03	2.512E+04	1.376E+05	5.48	48.63
6	1.68	5.029E+03	2.523E+04	1.187E+05	4.70	48.74
7	1.16	4.063E+03	2.738E+04	9.574E+04	3.90	48.73
8	1.68	5.056E+03	2.616E+04	1.204E+05	4.60	48.69
9	1.16	4.073E+03	2.775E+04	9.599E+04	3.46	48.66
10	2.21	5.381E+03	2.559E+04	1.402E+05	5.48	48.58
11	2.74	6.521E+03	2.427E+04	1.563E+05	6.44	48.67
12	3.27	7.074E+03	2.350E+04	1.693E+05	7.21	48.61
13	3.79	7.497E+03	2.278E+04	1.802E+05	8.05	48.82
14	4.32	7.870E+03	2.160E+04	1.882E+05	8.71	48.63

Least-Squares Line for Ho vs q curve:

Slope = -1.4850E-01

Intercept = 5.4553E+05

Least-squares line for q = a*delta-T^{1.5}b

a = 3.7811E+04

b = 7.5000E-01

NOTE: 14 data points were stored in file FONMUN7101

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

NOTE: Program name : DRFOK
 Data taken by : O'KEEFE
 This analysis done on file : FQNMVH7102
 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

C₁ (based on Petukhov-Popov) = 2.7647
 Alpha (based on Nusselt (T_{del})) = 1.2803
 Enhancement (q) = 1.626
 Enhancement (Del-T) = 1.479

Data #	Vw (m/s)	Uo (W/m ² -K)	Ho (W/m ² -K)	Qp (W/m ²)	Tcf (C)	Ts (C)
1	1.16	7.118E+03	2.072E+04	1.563E+05	7.64	46.64
2	1.66	8.035E+03	1.862E+04	1.832E+05	9.73	46.77
3	2.21	8.775E+03	1.833E+04	2.015E+05	10.99	46.83
4	2.74	9.287E+03	1.784E+04	2.147E+05	12.03	46.73
5	3.26	9.855E+03	1.605E+04	2.262E+05	12.53	46.55
6	3.79	1.015E+04	1.766E+04	2.354E+05	13.33	46.75
7	4.32	1.038E+04	1.736E+04	2.413E+05	13.90	46.79
8	3.26	9.950E+03	1.602E+04	2.245E+05	12.46	46.60
9	2.21	8.857E+03	1.865E+04	1.992E+05	10.66	46.55
10	1.16	7.142E+03	2.088E+04	1.571E+05	7.53	46.57

Least-Squares Line for Ho vs q curve:
 Slope = -1.9477E-01
 Intercept = 5.5020E+05

Least-squares line for q = a+delta-T^{1/4}
 a = 3.3765E+04
 b = 7.5000E-01

NOTE: 10 data points were stored in file FQNMVH7102

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.

```

1000! DRPOK (O'KEEFE)
1006! REVISED FROM DRP12B: JUL 1992 (S. MEMORY)
1007!
1008! TO BE USED WITH NON-INSTRUMENTED TUBES ONLY
1009! TAKES DATA IN THE FORMAT OF SWENSEN/O'KEEFE
1010! CAN REPROCESS ANY NON-INSTRUMENTED DATA
1012!
1013! THIS PROGRAM WAS USED TO COLLECT ALL THE NON-
1014! INSTRUMENTED DATA TAKEN BY O'KEEFE (APR-SEP 1992) FOR TITANIUM TUBES
1015!
1017! MEANING OF ALL FLAGS IN PROGRAM
1018!
1019! IFT: FLUID TYPE
1020! ISO: OPTION WITHIN PROGRAM
1021! IM: INPUT MODE
1022! IWIL: VALUE OF C1 USED
1023! IF6: FINNED OR SMOOTH
1024! INN: INSERT TYPE
1025! IWT: LOOP NO. WITHIN PROGRAM
1026! IWTH: ALTERNATIVE CONDENSER TUBES
1027! IMC: TUBE MATERIAL
1028! ITDS: TUBE DIAMETER
1029! IPC: PRESSURE CONDITION
1030! INF: DIMENSIONLESS FILE REQUIRED
1031! IPF: PLOT FILE REQUIRED
1032! IOV: OUTPUT REQUIRED
1033! IHI: INSIDE HTC CORRELATION
1034! IOC: OUTSIDE HTC THEORY/CORRELATION
1035 COM /Cc/ C(7)
1036 COM /Cc55/ T55(5)
1037 COM /Cc56/ T56(5)
1038 COM /Cc57/ T57(5)
1039 COM /Cc58/ T58(5)
1040 COM /Fld/ Ift,Istu
1041 DIM Emf(20),Tw(6)
1042 COM /Pr/ Qpa(20),Tfm(20),Tfmr,Ipc,Qpr
1043 COM /W11/ Nrun,Itm,Iwth,Imc,Ife,Ijob,Iwd,Ifg,Ipc0,Ifto,Iw11,Ihi,Ioc,Inam,K
cu,Rexp,Rm
1044 COM /Geom/ D1,D2,D1,Do,L,L1,L2
1046 DATA 0.10086091,25727.94369,-767345.8295,78025595.81
1047 DATA -9247486589,6.97680E+11,-2.66192E+13,3.94078E+14
1048 READ C(*)
1049 DATA 273.15,2.5943E-2,-7.2671E-7,3.2941E-11,-9.7719E-16,9.7121E-20
1050 READ T55(*)
1051 DATA 273.15,2.5878E-2,-5.9853E-7,-3.1242E-11,1.3275E-14,-1.0138E-18
1052 READ T56(*)
1053 DATA 273.15,2.5923E-2,-7.3933E-7,2.8625E-11,1.9717E-15,-2.2486E-19

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1054 READ T57(*)
1055 DATA 273.15,2.5931E-2,-7.5232E-7,4.0657E-11,-1.2791E-15,6.4402E-20
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 PRINTER IS 1
1065 BEEP
1066 PRINT USING "4X,""Select option:"""
1069 PRINT USING "6X,"" 0 Take data or re-process previous data""
1084 PRINT USING "6X,"" 1 Print raw data""
1090 PRINT USING "6X,"" 2 WILSON Analysys""
1093 PRINT USING "6X,"" 3 MODIFY""
1096 PRINT USING "6X,"" 4 PURGE""
1102 PRINT USING "6X,"" 5 RENAME""
1105 INPUT Iso
1109 Iso=Iso+1
1111 IF Iso>1 THEN 3094
1112 BEEP
1115 INPUT "SELECT FLUID (0=WATER, 1=R-113, 2=EG)",Ift
1116 Ifto=Ift
1117 BEEP
1118 Ijob=0
1119 INPUT "ENTER INPUT MODE (0=3054A,1=FILE)",Im
1120 Im=Im+1
1123 BEEP
1124 IF Im=1 THEN
1126 INPUT "ENTER MONTH, DATE AND TIME (MM:DD:HH:MM:SS)",Date$
1129 OUTPUT 709;"TD";Date$
1132 OUTPUT 709;"TD"
1133 ENTER 709;Date$
1135 END IF
1136 IF Ijob=1 THEN
1138 BEEP
1141 INPUT "SKIP PAGE AND HIT ENTER",OI
1144 END IF
1145 PRINTER IS 701
1146 IF Im=1 THEN
1148 ENTER 709;Date$
1150 PRINT "          Month, date and time :";Date$
1151 END IF
1153 PRINT

```

```

1156 PRINT USING "10X,""NOTE: Program name : DRPOK""
1171 IF Ijob=1 THEN 1189
1174 BEEP
1186 INPUT "SELECT (C1:0=FIND,1=STORED C1)",Iw1
1189 IF Im=1 THEN
1192 BEEP
1195 INPUT "GIVE A NAME FOR THE RAW DATA FILE",D_file$
1198 PRINT USING "16X,""File name      : """,14A";D_file$
1201 CREATE BDAT D_file$,30
1204 ASSIGN @File TO D_file$
1207 BEEP
1210 INPUT "ENTER GEOMETRY CODE (1=FINNED,0=PLAIN)",Ifg
1211 Inn=0
1212 PRINTER IS 1
1216 BEEP
1217 PRINT "    ENTER INSERT TYPE:"
1218 PRINT "        0=NONE (DEFAULT)"
1219 PRINT "        1=TWISTED TAPE"
1220 PRINT "        2=WIRE WRAP"
1221 PRINT "        3=HEATEX"
1222 INPUT Inn
1226 OUTPUT @File;Ifg,Inn
1227 Iwt=0 ! FOR UNINSTRUMENTED TUBE
1228 Fh=0
1231 Fp=0
1234 Fw=0
1235 Istu=0
1237 IF Ifg=0 THEN 1241
1238 INPUT "FIN PITCH, HEIGHT AND WIDTH, Fp,Fh,Fw",Fp,Fh,Fw
1241 OUTPUT @File;Iwt,Fp,Fw,Fh
1242 ELSE
1249 BEEP
1250 PRINTER IS 1
1252 PRINT "    STUDENT'S DATA TO BE REPROCESSED:"
1253 PRINT "        0=SWENSEN/O'KEEFE (DEFAULT)"
1254 PRINT "        1=VAN PETTEN/MITROU/COUMES/GUTTENDORF"
1255 INPUT Istu
1256 BEEP
1257 PRINT
1259 IF Istu=1 THEN
1260 PRINT "    STUDENT NAME:"
1261 PRINT "        0=VAN PETTEN"
1262 PRINT "        1=MITROU"
1263 PRINT "        2=COUMES"
1264 PRINT "        3=GUTTENDORF"
1265 ELSE

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```

1267 PRINT " 4=SWENSEN"
1268 PRINT " 5=O'KEEFE"
1271 END IF
1272 INPUT Inam
1273 BEEP
1274 INPUT "GIVE THE NAME OF THE EXISTING DATA FILE",D_file$
1275 PRINTER IS 701
1276 IF Inam=0 THEN PRINT USING "16X, ""Data taken by           : VAN PETTEN""
""
1277 IF Inam=1 THEN PRINT USING "16X, ""Data taken by           : MITROU""
1278 IF Inam=2 THEN PRINT USING "16X, ""Data taken by           : COUMES""
1279 IF Inam=3 THEN PRINT USING "16X, ""Data taken by           : GUTTENDORF""
""
1280 IF Inam=4 THEN PRINT USING "16X, ""Data taken by           : SWENSEN""
1281 IF Inam=5 THEN PRINT USING "16X, ""Data taken by           : O'KEEFE""
1282 PRINT USING "16X, ""This analysis done on file : "",10A";D_file$
1283 PRINTER IS 1
1285 BEEP
1286 INPUT "ENTER NUMBER OF DATA SETS STORED",Nrun
1287 ASSIGN @File TO D_file$
1288 ENTER @File;Ifg,Inn
1289 IF Istu=0 THEN
1290 ENTER @File;Iwt,Fp,Fw,Fh
1291 ELSE
1292 IF Ifg=0 THEN ENTER @File;Iwt
1293 IF Ifg=1 THEN ENTER @File;Fp,Fw,Fh
1294 END IF
1295 END IF
1296 IF Ijob=1 THEN 1537
1297 IF Ift=0 THEN 1345
1298 BEEP
1299 PRINTER IS 1
1300 PRINT USING "4X, ""Select tube type: ""
1301 PRINT USING "6X, ""0 Thick wall Copper""
1306 PRINT USING "6X, ""1 Wolverine Korodense LPD Titanium Tube""
1320 PRINT USING "6X, ""2 Smooth Titanium Tube""
1321 INPUT Iwth
1322 BEEP
1324 PRINT USING "4X, ""Select tube Enhancement used: ""
1325 PRINT USING "6X, ""0 SMOOTH TUBE""
1326 PRINT USING "6X, ""1 FINNED TUBE""
1327 PRINT USING "6X, ""2 WIRE-WRAPPED SMOOTH TUBE""
1328 PRINT USING "6X, ""3 LPD KORODENSE TUBE""
1329 PRINT USING "6X, ""4 WIRE-WRAPPED LPD KORODENSE TUBE""
1330 INPUT Ityp
1331 PRINTER IS 701

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1332 BEEP
1333 PRINTER IS 1
1334 PRINT USING "4X,""Select Material Code:"""
1336 PRINT USING "6X,""0 Copper      1 Stainless steel""
1339 PRINT USING "6X,""2 Aluminum  3 90:10 Cu-Ni""
1340 PRINT USING "6X,""4 Titanium  ""
1342 INPUT Imc
1345 PRINTER IS 1
1348 BEEP
1349 Itds=1
1351 IF Iwth=0 THEN
1352 PRINT USING "4X,""SELECT TUBE DIA TYPE:"""
1357 PRINT USING "6X,""0  SMALL""
1360 PRINT USING "6X,""1  MEDIUM (DEFAULT)""
1363 PRINT USING "6X,""2  LARGE""
1366 INPUT Itds
1367 END IF
1369 PRINTER IS 701
1372 IF Iwth=0 THEN
1375 D1=.0127      ! ID OF MEDIUM AND LARGE TUBES
1378 Do=.01905    ! OD OF MEDIUM TUBE
1383 END IF
1384 IF Iwth=1 THEN
1399 D1=.01347
1402 Do=.01585
1405 END IF
1457 IF Iwth=2 THEN
1458 Do=.01585
1459 D1=.01386
1460 END IF
1461 D1=.01905
1462 D2=.01587
1465 IF Itds=0 THEN
1468 Do=.0127
1471 D1=.009525
1474 END IF
1477 IF Itds=2 THEN Do=.025
1478 IF Iwth=1 THEN D1=.01585
1479 IF Iwth=1 THEN D2=.01585
1484 IF Iwth=2 THEN D1=.01587
1485 IF Iwth=2 THEN D2=.01587
1487 IF Imc=0 THEN Kcu=385
1489 IF Imc=1 THEN Kcu=16
1492 IF Imc=2 THEN Kcu=167
1495 IF Imc=3 THEN Kcu=45
1496 IF Imc=4 THEN Kcu=20.1

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1498 Rm=Do*LOG(Do/D1)/(2*Kcu) ! Wall resistance based on outside area
1501 BEEP
1504 INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",lpc
1507 Ipc=Ipc
1508 Inf=0
1510 BEEP
1537 Ife=1
1538 PRINTER IS 701
1543 PRINT USING "16X,""This analysis includes end-fin effect""
1548 PRINT USING "16X,""Thermal conductivity      = "" ,3D.D,"" (W/m.K)"";kcu
1549 PRINT USING "16X,""Inside diameter, D1      = "" ,DD.DD,"" (mm)"";D1*1000
1552 PRINT USING "16X,""Outside diameter, Do     = "" ,DD.DD,"" (mm)"";Do*1000
1555 BEEP
1556 Ih1=0
1557 PRINTER IS 1
1558 PRINT "      SELECT INSIDE CORRELATION:"
1559 PRINT "          0=SIDER-TATE (DEFAULT)"
1560 PRINT "          1=SLEICHER-ROUSE"
1561 PRINT "          2=PETUKHOV-POPOV"
1562 INPUT Ih1
1563 IF Ih1=0 THEN
1564 BEEP
1566 INPUT "      SELECT REYNOLDS EXPONENT",Rexp
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 THERMO
PILE readings""
1587 Iic=1 ! FOR MODIFIED WILSON
1588 IF Ih1=0 THEN C1=.027
1589 IF Inn=2 AND D1=.009525 THEN C1=.051 ! TO BE MODIFIED
1590 IF Inn=2 AND D1=.0127 THEN C1=.052
1591 IF Inn=3 THEN C1=.22

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1592! IF Inn=0 THEN C1=.012
1593! IF Ift=2 THEN C1=.035
1594! END IF
1595 IF Ih1=1 THEN C1=1.
1596 IF Ih1=2 THEN C1=1.
1597 IF Iw1=1 THEN
1598 BEEP
1599 INPUT "ENTER C1 IF DIFFERENT FROM STORED VALUE",C1
1600 END IF
1601 PRINTER IS 701
1602 IF Ih1=0 THEN PRINT USING "16X","Modified Sieder-Tate coefficient = ",Z
.40";C1
1603 IF Ih1=0 THEN PRINT USING "16X","Chosen Reynolds No. exponent = ",D
.00";Rexp
1604 IF Ih1=1 THEN PRINT USING "16X","Modified Sleicher-Rouse coefficient = "
",Z.40";C1
1605 IF Ih1=2 THEN PRINT USING "16X","Modified Petukhov-Popov coefficient = "
",Z.40";C1
1606 IF Inn=0 THEN PRINT USING "16X","Using no insert inside tube""
1607 IF Inn=2 THEN PRINT USING "16X","Using wire wrap insert inside tube""
1608 IF Inn=3 THEN PRINT USING "16X","Using HEATEX insert inside tube""
1609 IF Istu=0 THEN
1610 IF Inn=1 THEN PRINT USING "16X","Using twisted tape insert inside tube""
1612 ELSE
1613 IF Inn=1 THEN PRINT USING "16X","Using wire wrap insert inside tube""
1615 END IF
1617 IF I1c=0 AND Ife=1 THEN Ac=26.4
1618 IF I1c=1 THEN Ac=0.
1619 BEEP
1620 IF Ijob=1 THEN 1648
1621 PRINTER IS 1
1622! INPUT "NAME FOR A TEMPORARY PLOT FILE (TO BE PURGED)",P_file$
1623 P_file$="DUMMY"
1624 BEEP
1634 CREATE BDAT P_file$,10
1644 ASSIGN @filep TO P_file$
1648 IF Ijob=1 THEN
1651 Iov=1
1654 GOTO 1689
1657 END IF
1660 BEEP
1661 INPUT "SELECT OUTPUT (0=SHORT, 1=LONG)",Iov
1666 Iov=Iov+1
1667 PRINTER IS 701
1672 IF Ityp=0 THEN PRINT USING "16X","Tube Enhancement : SMOOTH TUBE""
1673 IF Ityp=1 THEN PRINT USING "16X","Tube Enhancement : FINNED TUBE""

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1674 IF Ityp=2 THEN PRINT USING "16X,""Tube Enhancement : WIRE-WRAPPED SMOOTH
TUBE""
1675 IF Ityp=3 THEN PRINT USING "16X,""Tube Enhancement : LPD KORODENSE TUBE
""
1676 IF Ityp=4 THEN PRINT USING "16X,""Tube Enhancement : WIRE-WRAPPED LPD KO
RODENSE TUBE""
1679 BEEP
1681 IF Imc=0 THEN PRINT USING "16X,""Tube material : COPPER""
1682 IF Imc=1 THEN PRINT USING "16X,""Tube material : STAINLESS-STEEL""
1683 IF Imc=2 THEN PRINT USING "16X,""Tube material : ALUMINUM""
1684 IF Imc=3 THEN PRINT USING "16X,""Tube material : 90/10 CU/NI""
1685 IF Imc=4 THEN PRINT USING "16X,""Tube material : TITANIUM""
1686 IF lpc=0 THEN PRINT USING "16X,""Pressure condition : VACUUM""
1687 IF lpc=1 THEN PRINT USING "16X,""Pressure condition : ATMOSPHERIC""
1689 PRINT USING "16X,""Fin pitch, width, and height (mm): ",DD.DD,2x,Z.DD,2x,
Z.DD";Fp,Fw,Fh
1699 IF (Iw1=0 OR Iw1=2) AND Im=2 THEN
1690 Ijob=1
1693 Iwd=1
1696 CALL Wilson(Ci)
1699 END IF
1702 J=0
1712 IF Iov=1 THEN
1722 PRINT
1723 IF Ih1=1 THEN
1724 PRINT USING "10X,""Data Vw Uo Ho Qp Tcf Ts
Reap""
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 Tc
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 Zx=0
1750 Zx2=0
1753 Zxy=0
1756 Zy=0
1759 Sx=0
1762 Sy=0
1765 Sxs=0
1768 Sxy=0
1771 Go_on=1
1774 Repeat:

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1777 J=J+1
1780 IF Im=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 VR5"
1795 OUTPUT 709;"AS SA"
1798 END IF
1801 BEEP
1804 INPUT "ENTER FLOWMETER READING",Fm
1807 OUTPUT 709;"AR AF60 AL62 VR5"
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",Ok
1834 IF Bvol<.1 THEN
1837 BEEP
1840 BEEP
1843 INPUT "INVALID VOLTAGE - TRY AGAIN!",Ok
1846 GOTO 1819
1849 END IF
1858 OUTPUT 709;"AS SA"
1861 ENTER 709;Bamp
1862 Etp=Etp*1.E+6
1863 OUTPUT 709;"AR AF40 AL47 VR5"
1874 Nn=7
1876 FOR I=0 TO Nn
1879 OUTPUT 709;"AS SA"
1885 Se=0
1888 FOR K=1 TO 10
1891 ENTER 709;E
1894 Se=Se+E
1897 NEXT K
1900 Emf(I)=ABS(Se/10)
1916 Emf(I)=Emf(I)*1.E+6
1918 NEXT I
1921 OUTPUT 709;"AS SA"
1924 OUTPUT 713;"T1R2E"
1927 WAIT 2
1930 ENTER 713;T11
1933 OUTPUT 713;"T2P2E"
1936 WAIT 2

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1939 ENTER 713;T2
1942 OUTPUT 713;"T1R2E"
1945 WAIT 2
1948 ENTER 713;T12
1951 T1=(T11+T12)*.5
1954 OUTPUT 713;"T3R2E"
1960 BEEP
1970 INFUT "ENTER PRESSURE GAGE READING (Pga)",Pga
1971 Pvap1=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)*6894.7
1985 ELSE
1986 IF Istu=0 THEN
1989 ENTER @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
1990 ELSE
1992 ENTER @File;Bvol,Bamp,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,T
2,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
2009 Tsteam1=FNTvsv57(Emf(0))
2009 Tsteam1=Tsteam1-273.15
2010 Tsteam2=FNTvsv56(Emf(1))
2011 Tsteam2=Tsteam2-273.15
2012 Tsteam=Tsteam1
2015 Troom=FNTvsv58(Emf(2))
2023 Troom=Troom-273.15
2038 Tcon=FNTvsv58(Emf(7))
2039 Tcon=Tcon-273.15
2042 ELSE
2043 Tsteam=FNTvsv(Emf(0))
2044 Troom=FNTvsv(Emf(3))

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2045 Tcon=FNTvsv(Emf(4))
2046 END IF
2048 Psat=FNpvst(Tsteam)
2050 Rohg=13529-122*(Troom-26.85)/50
2053 Rowater=FNrhov(Troom)
2063 IF Istu=0 THEN
2061 Ptest1=Pvap1
2062 Ptest2=Pvap2
2063 ELSE
2064 Ptest2=(Phg*Rohg-Pwater*Rowater)*9.81/1000
2065 END IF
2067 Pls=Psat*1.E-3
2068 Plp=Ptest2*1.E-3
2069 Plt=Pls
2072 Tsat=FNTvsp(Psat)
2078 Vst=FNvst(Tsteam)
2104 Ppng=(Ptest2-Psat)/Ptest2
2121 Ppst=1-Ppng
2122 Muv=18.016
2123 IF Ift=1 THEN Muv=137      ! TO BE CORRECTED
2124 IF Ift=2 THEN Muv=62
2125 Vfng=(Ptest2-Psat)/Ptest2
2126 Mfng=1/(1+(1/Vfng-1)*Muv/28.97)
2127 Mfng=Mfng*100
2128 Vfng=Vfng*100
2131 BEEP
2134 IF Iov=2 THEN
2137 PRINT
2139 RECORD TIME OF TAKING DATA
2139 IF Im=1 THEN
2140     OUTPUT 709;"TD"
2141     ENTER 709;Told$
2142 END IF
2144 PRINT USING "10X,";"Data set number"           = "",DD,4X,14A";J,Told$
2145 OUTPUT 709;"AP AF40 AL40 VRS"
2146 OUTPUT 709;"AS SA"
2149 END IF
2152 IF Iov=2 AND Ng=1 THEN
2155 PRINT USING "10X,";"    Psat    Ptran    Tmeas    Tsat    NG %""
2158 PRINT USING "10X,";"    (kPa)    (kPa)    (C)    (C)    Molal ""
2161 PRINT USING "11X,1(30.00,2X),1(30.00,3X),2(30.00,2X),2X,1(M30.0,2X)";F1$,P
    Ip,Tsteam,Tsat,Mfng
2164 PRINT
2167 END IF
2170 IF Mfng .5 THEN
2173 BEEP

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2176 IF Im=1 AND Ng=1 THEN
2179 BEEP
2182 PRINT
2185 PRINT USING "10X,";"Energize the vacuum system ""
2188 BEEP
2191 INPUT "DO YOU ACCEPT THIS RUN (1=Y,0=N)?",O1
2194 IF O1=0 THEN
2197 BEEP
2200 DISP "NOTE: THIS DATA SET WILL BE DISCARDED!!"
2203 WAIT 5
2206 GOTO 1790
2209 END IF
2212 END IF
2215 END IF
2216 IF Im=1 THEN
2221 IF Fm 10 OR Fm 100 THEN
2224 Ifm=0
2227 BEEP
2230 INPUT "INCORRECT FM (1=ACCEPT,0=DELETE)",Ifm
2233 IF Ifm=0 THEN 1804
2236 END IF
2239 END IF
2242 ANALYSIS BEGINS
2243 IF Istu=0 THEN
2252 T11=FNTvs.55(Emf(3))
2262 T12=FNTvs.55(Emf(5))
2272 T01=FNTvs.55(Emf(4))
2282 T02=FNTvs.55(Emf(6))
2292 T11=T11-273.15
2302 T12=T12-273.15
2312 T01=T01-273.15
2322 T02=T02-273.15
2332 Tdel1=T01-T11
2342 Tdel2=T02-T12
2352 Tdel3=T2-T1
2353 Etp1=Emf(3)+Etp/20.
2354 Dtde=2.5931E-2-1.50464E-6•Etp1+1.21701E-10•Etp1 2-5.1164E-15•Etp1 3+3.222E-19•Etp1 4
2355 Tris=Dtde•Etp/10.
2358 T03=T11+Tris
2359 IF Iov=2 THEN
2361 PRINT USING "1X,";" TINI TOUT1 TINF TOUT3 DELT1 DELT2 TFILE
2362 PRINT USING "1X,";" (TEFLON) (QUARTZ)"
2364 PRINT USING "2X,(30.00,2X)";T11,T01,T1,T2,Tdel1,Tdel3,Tris
2365 END IF

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2367 Er1=ABS(T11-T1)
2368 Er3=ABS(T12-T1)
2369 PRINTER IS 1
2370 BEEP
2375 Er2=ABS((T2-T1)-(T1s))/(T2-T1)
2377 IF Er2<.05 AND Im=1 THEN
2378 BEEP
2379 PRINT "QCT AND T-PILE DIFFER BY MORE THAN 5%"
2380 O12=1
2381 IF O12=0 AND Er2<.05 AND Im=1 THEN 1780
2382 END IF
2383 PRINTER IS 701
2384 ELSE
2385 T1=FNTvsv(Emf(2))
2386 Grad=FNGrad((T1+T2)*.5)
2387 To=T1+ABS(Etp)/(10*Grad)*1.E+6
2388 T11=T1
2389 To3=To
2391 END IF
2392 IF Istu=0 AND Itm=0 THEN
2393 T11=T11
2394 T2c=To1
2395 END IF
2396 IF Itm=1 THEN
2397 T11=T1
2398 T2c=T2
2399 END IF
2400 IF Itm=2 THEN
2401 T11=T11
2402 T2c=To3
2403 END IF
2404 Tavg=(T11+T2c)*.5
2405 Ift=0
2406 Cpw=FNCPw(Tavg)
2407 Phow=FNPhow(Tavg)
2408 IF Istu=0 THEN
2410 Md=(5.7409*Fm+13.027)/1000.
2411 Md=Md*(1.0365-1.96644E-3*T11+5.252E-6*T11^2)+1.0037
2412 ELSE
2413 Md=1.04805E-2+6.80932E-3*Fm
2414 Md=Md*(1.0365-1.96644E-3*T11+5.252E-6*T11^2)+.995434
2415 END IF
2417 Mf=Md/Phow
2418 Uw=Mf*(F1*D1^2/4)
2419 Uws=Uw*(D1/1.27E-2)^2
2421 IF Istu=0 AND Iwth=0 THEN 'SWENSEN FRIC. SMOOTH COPPER TUBE

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2422 IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.96E-5*
Vw^3)
2423 IF Inn=1 THEN T2o=T2o-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
2424 IF Inn=2 THEN T2o=T2o-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
2425 IF Inn=3 THEN T2o=T2o-(-8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
2426 END IF
2428 IF Istu=0 AND Iwth=2 THEN IFRIC FACTOR SMTH TITANIUM TUBE
2429 IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-8.64E-5*
Vw^3)
2430 IF Inn=3 THEN T2o=T2o-(-2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
2431 END IF
2433 IF Istu=0 AND Iwth=1 THEN IFRIC FACTORS FOR KORODENSE
2434 IF Inn=0 AND Vw<.5 THEN T2o=T2o-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4.133E
-5*Vw^3)
2435 IF Inn=3 THEN T2o=T2o-(-2.059E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.781E-5*Vw^3)
2436 END IF
2437 IF Istu=1 THEN
2439 IF Inn=0 THEN T2o=T2o-(-.0138+.001*Vw^2)
2440 IF Inn=1 THEN T2o=T2o-(-.004*Vw^2)
2441 IF Inn=2 THEN T2o=T2o-(-.004*Vw^2)
2444 END IF
2445 Q=Md*Qpw*(T2o-T11)
2446 Qp=Q/(PI*Do*L)
2447 Ift=0
2448 Kw=FNKw(Tavg)
2449 Muw=FNMuw(Tavg)
2450 Re1=Rhow*Vw*Di/Muw I ASSUMED SAME FOR KORODENSE
2451 Prw=FNPrw(Tavg)
2452 Fe1=0.
2453 Fe2=0.
2454 Cf=1.
2455 Prwf=Prw
2456 Re1f=Re1
2461 IF In1=0 THEN
2463 Ome=Re1*Re1f*Prw*.3333*Cf
2465 END IF
2466 IF In1=1 THEN
2467 Sra=.88-((.24/(4.+Prwf))
2468 Sra=.333333+.5*EXP(-.6*Prwf)
2470 Ome=(5.+.015*Re1f**Sra*Prwf**Sra)
2471 END IF
2472 IF In1=2 THEN
2473 Eps1=(1.82*LGT(Re1)-1.64)*(-2)
2474 Pp1=1.+3.4*Eps1
2475 Pp1=11.7+1.8*Prw*(-1/3)
2476 Pp1=(Eps1/8)*Re1*Prw

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2477 Pp2=(Ppk1+Ppk2*(Epsi/8)^(.5*(Prw-.6666-1)))
2478 Ome=Pp1/Pp2
2479 END IF
2481 H1=Kw/D1*C1+Ome
2482 IF Ife=0 THEN GOTO 2491
2483 P1=PI*(Do+D1)
2484 A1=(D1-D1)*PI*(D1+D1)*.5
2485 M1=(H1*P1/(Kcu*A1))^(.5)
2486 P2=PI*(D1+D2)
2487 A2=(D2-D1)*PI*(D1+D2)*.5
2488 M2=(H1*P2/(Kcu*A2))^(.5)
2489 Fe1=FNTanh(M1*L1)/(M1*L1)
2490 Fe2=FNTanh(M2*L2)/(M2*L2)
2491 Dt=Q/(PI*D1*(L+L1*Fe1+L2*Fe2)*H1)
2492 IF Ihi=0 THEN
2494 Cfc=(Mw/FNMw(Tavg+Dt))^(.14)
2495 IF ABS((Cfc-Cf)/Cfc)>.001 THEN
2497 Cf=(Cf+Cfc)*.5
2500 GOTO 2461
2501 END IF
2503 END IF
2504 IF Ihi=1 THEN
2505 Prwfc=FNPrw(Tavg+Dt)
2506 Reifc=Uw*D1*FNRehow(Tavg+Dt)/FNMw(Tavg+Dt)
2507 IF ABS((Prwfc-Prwf)/Prwfc)>.001 OR ABS((Reifc-Reif)/Reifc)>.001 THEN
2508 Prwf=(Prwfc+Prwf)/2.
2509 Reif=(Reifc+Reif)/2.
2510 GOTO 2461
2511 END IF
2513 END IF
2516 Ift=Ifto
2517 Lmt=(T2o-T11)/LOG((Tsteam-T11)/(Tsteam-T2o))
2518 Uo=Q/(Lmt*PI*Do*L)
2519 Ho=1/(1/Uo-Do*L/(D1*(L+L1*Fe1+L2*Fe2)*H1)-Rm)
2520 Tcf=Qp/Ho
2521 Cpse=FNCPw((Tcon+Tsteam)*.5)
2522 Hfg=FNHfg(Tsteam)
2524 Two=Tsteam-Qp/Ho
2527 Tfilm=Tsteam/3+Two*2/3
2530 Kf=FNKw(Tfilm)
2533 Rhof=FNRehow(Tfilm)
2536 Muf=FNMw(Tfilm)
2539 Hpq=.651*Kf*(Rhof^2*9.81*Hfg/(Muf*Do*Qp))^(.3333)
2541 Hnuss=.728*(Kf^3*9.81*Hfg*Rhof^2/(Muf*Do*Tcf))^(.25)
2542 Alpi=.728*Ho/Hnuss
2548 Tfm(J-1)=Tfilm
2551 Qpe(J-1)=Qp

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2554 Y=Hpq*Qp .3333
2557 X=Qp
2560 Sx=Sx+X
2563 Sy=Sy+Y
2566 Sx=s=Sx+X**2
2569 Sy=s=Sy+X*Y
2572 Q1=500
2575 Qloss=Q1/(100-25)*(Tsteam-Troom) ! TO BE MODIFIED
2578 Hfc=FNHf(Tcon)
2584 Mdv=0
2587 Bp=(Bvol*100)**2/5.76
2590 Hsc=Cpsc*(Tsteam-Tcon)
2593 Mdv=((Bp-Qloss)-Mdv*Hsc)/Hfg
2596 IF ABS((Mdv-Mdv)/Mdv)>.01 THEN
2599 Mdv=(Mdv+Mdv)*.5
2602 GOTO 2593
2605 END IF
2608 Mdv=(Mdv+Mdv)*.5
2611 Vg=FNVvst(Tsteam)
2614 Vv=Mdv*Vg/Ax
2620 F=(9.81*Do*Muf*Hfg)/(Vv**2*Kf*(Tsteam-Two))
2623 Nu=Ho*Do/Kf
2626 Ret=Vv*Rhof*Do/Muf
2629 Nr=Nu/Ret**.5
2630 Hfuj=.96*(9.81*Hfg/Tcf)**.2*Kf**.8*Vv**.1*Rhof**.5/(Do*Muf)**.3
2635 IF Iov=2 THEN
2645 PRINT
2647 PRINT USING "5X,"" Vw      Re1      H1      Uo      Hfuj(DT)
      Hnu(Q)""
2650 PRINT USING "5X,Z.00,1X,3(MZ.3DE,1X),3X,2(MZ.3DE,3X)";Vw,Re1,H1,Uo,Hfuj,Hp
q
2651 PRINT
2653 PRINT USING "5X,"" Vv      Ho      q      Tcf      NuRe      F
      Hnu(DT)""
2655 PRINT USING "5X,Z.00,1X,2(MZ.3DE,1X),2X,3D.00,2X,3(MZ.3DE,1X)";Vv,Ho,Qp,Tc
f,Nr,F,Hnu
2656 PRINT
2658 END IF
2659 IF Iov=1 THEN
2660 IF Ih1=1 THEN
2661 PRINT USING "11X,00,2X,Z.00,1X,3(MD.3DE,1X),2(3D.00,1X),D.000";J,Vw,Uo,Ho,
Qp,Tcf,Tsteam,Sra
2662 ELSE
2663 PRINT USING "11X,00,4X,Z.00,2X,2(MD.3DE,2X),Z.3DE,3X,3D.00,2X,3D.00";J,Vw,
Uo,Ho,Qp,Tcf,Tsteam
2671 END IF

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```

2674 END IF
2675 IF Im=2 THEN
2684 IF (Iw1=0 AND Ijob=1) OR Iw1>0 THEN OUTPUT @Filep;Qp,Ho
2694 END IF
2707 BEEP
2708 IF Im=1 THEN
2709 IF (Iw1=0 AND Ijob=1) OR Iw1=1 THEN OUTPUT @Filep;Qp,Ho
2711 INPUT "CHANGE TCOOL RISE? 1=Y, 2=N",Itr
2712 IF Itr=1 THEN GOTO 2384
2713 INPUT "OK TO STORE THIS DATA SET (1=Y,0=N)?",Oks
2714 IF Oks=1 THEN
2725 OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
2735 Alp2=Alp1+Alp2
2749 ELSE
2752 J=J-1
2755 END IF
2758 BEEP
2761 INPUT "WILL THERE BE ANOTHER RUN (1=Y,0=N)?",Go_on
2764 Nrun=J
2767 IF Go_on<>0 THEN Repeat
2770 ELSE
2773 IF J<Nrun THEN Repeat
2776 END IF
2779 IF Ijob=1 THEN 2809
2782 IF Iw1=0 THEN
2785 ASSIGN @File TO *
2788 Ijob=1
2791 Iwd=1
2794 CALL Wilson(C1)
2797 Im=2
2800 ASSIGN @File TO D_file$
2803 GOTO 1136
2806 END IF
2809 IF Ifg=0 THEN
2812 PRINT
2815 S1=(Nrun*Sxy-Sy*Sx)/(Nrun*Sx-Sx^2)
2818 Ac=(Sy-S1*Sx)/Nrun
2822 PRINT USING "10X," "Least-Squares Line for Ho vs q curve:"""
2824 PRINT USING "10X," " Slope = ",MD.4DE";S1
2827 PRINT USING "10X," " Intercept = ",MD.4DE";Ac
2830 END IF
2833 BEEP
2843 INPUT "ENTER SAME TEMPORARY PLOT FILE NAME",Fplot$
2853 ASSIGN @Filep TO P_file$
2863 FOR I=1 TO Nrun
2873 ENTER @Filep;Qp,Ho

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2873 ENTER @Filep;Qp,Ho
2883 Xc=LOG(Qp/Ho)
2884 Yc=LOG(Qp)
2885 Zx=Zx+Xc
2886 Zx2=Zx2+Xc^2
2887 Zxy=Zxy+Xc*Yc
2888 Zy=Zy+Yc
2889 NEXT I
2890 Bb=.75
2891 Aa=EXP((Zy-Bb*Zx)/Nrun)
2892 PRINT
2893 PRINT USING "10X","Least-squares line for q = a*delta-T^b"
2894 PRINT USING "12X","a = ",MZ.4DE;Aa
2895 PRINT USING "12X","b = ",MZ.4DE;Bb
2896 IF Ift=0 THEN
2897 IF Ipc=0 THEN
2898 Qps=2.5E+5
2899 IF Iic=0 THEN Hop=9326
2902 IF Iic=1 THEN Hop=10165*(.01905/Do)^.33333
2905 END IF
2908 IF Ipc=1 THEN
2911 Qps=7.5E+5
2914 IF Iic=0 THEN Hop=7176
2917 IF Iic=1 THEN Hop=7569*(.01905/Do)^.33333
2920 END IF
2923 Hos=Aa^(1/Bb)*Qps^((Bb-1)/Bb)
2926 IF Ipc=0 THEN Aas=2.32E+4
2929 IF Ipc=1 THEN Aas=2.59E+4
2930 Alpsm=.876 !SWENSEN DATA
2931 IF Iw1=0 THEN GOTO 2959
2933 Enrat=Alp2/Alpsm
2934 Enr=Hos/Hop
2935 Enr=Aa/Aas
2938 PRINT
2941 PRINT USING "10X","Values computed at q = ",Z.DD," (MW/m^2):";Qps;1.E+
6
2944 PRINT USING "12X","Heat-transfer coefficient = ",DDD.DDD," (W/m^2.K)";
Hos/1000
2947 PRINT USING "12X","Enhancement ratio (Del-T) = ",ZD.3D;Enrat
2950 PRINT USING "10X","Enhancement ratio at constant Delta-T = ",DD.DD;Enr
2953 PRINT USING "10X","Enhancement ratio at constant q = ",DD.DD;Enr
1.3333
2956 ELSE
2959 PRINT
2962 IF Ift=1 THEN
2965 Aas=2687.2 ! ZEBROWSKI (U = 0.4 m/s)
2968 Aas=2557.0*(.01905/Do)^.33333 ! VAN PETTEN (U = 0.25 m/s)

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2968 Aas=2557.0*(.01905/Do)^(.33333 ! VAN PETTEN (V = 0.25 m/s)
2971 END IF
2974 IF Ift=2 THEN Aas=9269.7*(.01905/Do)^(.33333
2977 Edt=Aa/Aas
2980 Eq=Edt^(4/3)
2983! PRINT USING "10X","Enhancement (q)      = ","DD.3D";Eq
2986! PRINT USING "10X","Enhancement (Del-T) = ","DD.3D";Edt
2989 END IF
2992! IF Im=1 THEN
2995 BEEP
2998 PRINT
3001 PRINT USING "10X","NOTE: ","ZZ"," data points were stored in file ","10A";
J,D_file$
3004! END IF
3007 BEEP
3013 PRINT
3016 PRINT USING "10X","NOTE: ","ZZ"," X-Y pairs were stored in data file ","10
A";J,Plot$
3031 BEEP
3073 ASSIGN @File TO *
3079 ASSIGN @Filep TO *
3080 PURGE "DUMMY"
3094 IF Iso=2 THEN CALL Raw
3100 IF Iso=3 THEN CALL Wilson(C1)
3103 IF Iso=4 THEN CALL Modify
3106 IF Iso=5 THEN CALL Purg
3112 IF Iso=6 THEN CALL Renam
3116 END
3118 DEF FNPvst(Tc)
3121 COM /F1d/ Ift,Istu
3124 DIM K(8)
3127 IF Ift=0 THEN
3130 DATA -7.691234564,-26.08023696,-168.1706546,64.23285504,-118.9646225
3133 DATA 4.16711732,20.9750676,1.E9,6
3136 READ K(*)
3139 T=(Tc+273.15)/647.3
3142 Sum=0
3145 FOR N=0 TO 4
3148 Sum=Sum+K(N)*((1-T)^(N+1))
3151 NEXT N
3154 Br=Sum/(T*(1+K(5)*((1-T)+K(6)*((1-T)^2))-(1-T)/(K(7)*((1-T)^2+K(8)))
3157 Pr=EXP(Br)
3160 P=22120000*Pr
3163 END IF
3166 IF Ift=1 THEN
3169 Tf=Tc*1.8+32+459.6
3172 P=10^(33.0655-4330.98/Tf-9.2635*LGT(Tf)+2.0539E-3*Tf)

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3175 P=P*101325/14.696
3178 END IF
3181 IF Ift=2 THEN
3184 A=9.394685-3066.1/(Tc+273.15)
3187 P=133.32*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*(T-10)
3211 END IF
3214 IF Ift=1 THEN
3217 Tf=T*1.8+32
3220 Hfg=7.0557857E+1-Tf*(4.838052E-2+1.2619048E-4*Tf)
3223 Hfg=Hfg*2326
3226 END IF
3229 IF Ift=2 THEN
3232 Tk=T+273.15
3235 Hfg=1.35264E+6-Tk*(6.38263E+2+Tk*.747462)
3238 END IF
3241 RETURN Hfg
3244 FNEND
3247 DEF FNMuw(T)
3250 COM /Fld/ Ift,Istu
3253 IF Ift=0 THEN
3256 A=247.8/(T+133.15)
3259 Mu=2.4E-5*10^A
3262 END IF
3265 IF Ift=1 THEN
3268 Mu=8.9629819E-4-T*(1.1094609E-5-T*5.566829E-8)
3271 END IF
3274 IF Ift=2 THEN
3277 Tk=1/(T+273.15)
3280 Mu=EXP(-11.0179+Tk*(1.744E+3-Tk*(2.80335E+5-Tk*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=FNpvst(Tt)
3304 T=Tt+273.15
3307 X=1500/T
3310 F1=1/(1+T*1.E-4)

```

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3313 F2=(1-EXP(-X))^2.5*EXP(X)/X^.5
3316 B=.0015*F1-.000942*F2-.0004882*X
3319 K=2*P/(461.52*T)
3322 V=(1+(1+2*B*K)^.5)/K
3325 END IF
3328 IF Ift=1 THEN
3331 Tf=Tt*1.8+32
3334 V=13.955357-Tf*(.16127262-Tf*5.1726190E-4)
3337 V=V/16.018
3340 END IF
3343 IF Ift=2 THEN
3346 Tk=Tt+273.15
3349 P=FNpvst(Tt)
3352 V=133.95*Tk/P
3355 END IF
3358 RETURN V
3361 FNEND
3364 DEF FNCpw(T)
3367 COM /F1d/ Ift,Istu
3370 IF Ift=0 THEN
3373 Cpw=4.21120858-T*(2.26826E-3-T*(4.42361E-5+2.71428E-7*T))
3376 END IF
3379 IF Ift=1 THEN
3382 Cpw=9.2507273E-1+T*(9.3400433E-4+1.7207792E-6*T)
3385 END IF
3388 IF Ift=2 THEN
3391 Tl=T+273.15
3394 Cpw=4.1868*(1.6884E-2+Tk*(3.35083E-3-Tk*(7.224E-6-Tk*7.61748E-9)))
3397 END IF
3400 RETURN Cpw*1000
3403 FNEND
3406 DEF FNRhow(T)
3409 COM /F1d/ Ift,Istu
3412 IF Ift=0 THEN
3415 Ro=999.52946+T*(.01269-T*(5.482513E-3-T*1.234147E-5))
3418 END IF
3421 IF Ift=1 THEN
3424 Ro=1.6207479E+3-T*(2.2186346+T*2.3578291E-3)
3427 END IF
3430 IF Ift=2 THEN
3433 Tk=T+273.15-338.15
3436 Vf=9.24848E-4+Tl*(6.2796E-7+Tl*(9.2444E-10+Tl*3.057E-12))
3439 Ro=1/Vf
3442 END IF
3445 RETURN Ro
3448 FNEND

```

```

3451 DEF FNPrw(T)
3454 Prw=FNCpw(T)*FNMuw(T)/FNKw(T)
3457 RETURN Prw
3460 FNEND
3463 DEF FNKw(T)
3466 COM /Fld/ Ift,Istu
3469 IF Ift=0 THEN
3472 X=(T+273.15)/273.15
3475 Kw=-.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*8.077927E-5)
3547 RETURN T
3550 FNEND
3553 DEF FNHf(T)
3556 COM /Fld/ 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=8.2078571+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

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3589 END IF
3592 RETURN Hf*1000
3595 FNEND
3598 DEF FNGrad(T)
3601 Grad=37.9853+.104388*T
3604 RETURN Grad
3607 FNEND
3610 DEF FNTvsp(P)
3613 Tu=190
3616 Tl=10
3619 Ta=(Tu+Tl)*.5
3622 Pc=FNpvt(Ta)
3625 IF ABS((P-Pc)/P)>.0001 THEN
3628 IF Pc<P THEN Tl=Ta
3631 IF Pc>P THEN Tu=Ta
3634 GOTO 3619
3637 END IF
3640 RETURN Ta
3643 FNEND
6646 DEF FNSigma(T)
6649 X=647.3-T-273.15
6652 S=.1160936807/((1+.83*X))+1.121404688E-3-5.75280518E-6*X+1.28627465E-8*X^2-1
.14971929E-11*X^3
6655 RETURN S*.001*X^2
6658 FNEND
6661 SUB Raw
6662 COM /F1d/ Ift,Istu
6664 DIM X(28)
6670 INPUT "ENTER TUBE NUMBER",Itn
6676 INPUT "ENTER FILE NAME",File$
6679 ASSIGN @File TO File$
6680 INPUT "STUDENT (0=Swensen)",Istu
6681 INPUT "SMOOTH OR FINNED (0=SMOOTH, 1=FINNED)",Ifg
6683 INPUT "ENTER TUBE SIZE (0=S,1=M,2=L,3=QMC)",ItDs
6685 INPUT "ENTER PRESSURE CONDITION (0=V,1=A)",Ipc
6688 IF Ipc=0 AND Ift=0 THEN Vs=2
6691 IF Ipc=0 AND Ift=2 THEN Vs=10
6692 IF Ipc=1 AND Ift=0 THEN Vs=1
6693 IF Ipc=1 AND Ift=1 THEN Vs=.25
6694 IF Istu=1 THEN Vs=2
6696 Nrun=10
6700 INPUT "ENTER NUMBER OF RUNS",Nrun
6703 PRINTER IS 701
6706 PRINT
6709 PRINT
6710 IF Istu=0 THEN PRINT USING "10X, ""Data of Swensen""

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6715 IF Ift=0 THEN PRINT USING "10X,""Vapor is steam""
6716 IF Ift=1 THEN PRINT USING "10X,""Vapor is R-113""
6717 IF Ift=2 THEN PRINT USING "10X,""Vapor is ethylene glycol""
6719 IF Itds=0 THEN PRINT USING "10X,""Tube diameter: Small""
6720 IF Itds=1 THEN PRINT USING "10X,""Tube diameter: Medium""
6721 IF Itds=2 THEN PRINT USING "10X,""Tube diameter: Large""
6722 IF Itds=3 THEN PRINT USING "10X,""Tube diameter: QMC""
6724 PRINT
6725 PRINT USING "10X,""Tube Number: "" ,ZZ";Itn
6726 PRINT USING "10X,""File Name: "" ,14A";File$
6727 IF Ifg=0 THEN PRINT USING "10X,""Tube Type: Smooth""
6728 IF Ifg=1 THEN PRINT USING "10X,""Tube Type: Finned""
6730 IF Ipc=0 THEN
6731 PRINT USING "10X,""Pressure Condition: Vacuum""
6732 ELSE
6733 PRINT USING "10X,""Pressure Condition: Atmospheric""
6734 END IF
6735 PRINT USING "10X,""Vapor Velocity: "" ,DD.DD,"" (m/s)"";Vs
6736 ENTER @File;Ifg,Inn
6739 IF Itds=1 OR Itds=2 THEN Di=.0127
6742 IF Itds=0 OR Itds=3 THEN Di=.009525
6747 ENTER @File;Iwt,Fp,Fw,Fh
6748 IF Istu=0 AND Ifg=1 THEN
6750 Fp=Fp-1
6751 PRINT USING "10X,""Fin spacing, width and height (mm): "" ,DD.DD,2X,Z.DD,2X
,Z.DD";Fp,Fw,Fh
6752 END IF
6756 PRINT
6757 PRINT USING "10X,""Data Vw Tin Tout Ts""
6758 PRINT USING "10X,"" # (m/s) (C) (C) (C)""
6760 PRINT
6763 FOR I=1 TO Nrun
6766 ENTER @File;X(*)
6769 Ts=FNTvsv57((X(8)+X(9))/2.)
6770 Ts=Ts-273.15
6772 Fm=X(3)
6775 T1=X(4)
6778 T2=X(5)
6781 Tavg=(T1+T2)*.5
6784 Ift=0
6785 Rhov=FNRhow(Tavg)
6787 Md=(6.7409*Fm+13.027)/1000.
6790 Md=Md*(1.0365-1.96644E-3*T1+5.252E-6*T1^2)/1.0037
6793 Mf=Md/Rhov
6796 Vw=Mf/(FI*Di^2/4)
6799 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)

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6809 IF Inn=1 THEN T2=T2-(-6.44E-5+1.71E-3*Uw+4.45E-4*Uw2+4.07E-5*Uw3)
6810 IF Inn=2 THEN T2=T2-(-3.99E-4+2.75E-3*Uw+1.45E-3*Uw2+8.16E-5*Uw3)
6811 IF Inn=3 THEN T2=T2-(-8.57E-5+1.23E-3*Uw+1.08E-3*Uw2+8.16E-5*Uw3)
6814 PRINT USING "10X,DD,5X,D.DD,3X,2(DD.DD,3X),DDD.DD";I,Uw,T1,T2,Ts
6817 NEXT I
6820 ASSIGN @File TO *
6823 SUBEND
6826 SUB Wilson(C1)
6829 COM /Wil/ Nrun,ltm,lwth,lmc,lfe,ljob,lwd,lfg,lpc,lfto,lwll,lhl,lcc,lnc,lrc,
cu,Rexp,Rm
6832 COM /Fld/ lft,lstu
6833 COM /Geom/ D1,D2,D1,Do,L,L1,L2
6835 DIM Emf(20),Bvo(25),Bam(25),Eata(25),Ear(25,7),Fma(25),T1a(25),T2a(25)
6845 IF lcc=0 THEN
6847 PRINT USING "16X,""Nusselt theory is used for Ho""
6848 ELSE
6849 PRINT USING "16X,""Fujii correlation used for Ho""
6850 END IF
6853 BEEP
6856 INPUT "RE-ENTER DATA FILE BEING PROCESSED",D_file$
6859 BEEP
6862 INPUT "GIVE A NAME FOR XY PLOT-DATA FILE",Plot$
6865 CREATE BDAT Plot$,10
6868 ASSIGN @lo_path TO Plot$
6871 Jj=0
6874 ASSIGN @File TO D_file$
6877 ENTER @File;lfg,Inn
6878 IF lstu=0 THEN
6883 ENTER @File;Ddd,Ddd,Ddd,Ddd
6884 ELSE
6885 IF lfg=0 THEN ENTER @File;lwt
6886 IF lfg=1 THEN ENTER @File;Fp,Fw,Fh
6887 END IF
6888 IF Jj=0 THEN
6895 IF lhl=0 THEN C1=.027
6896 IF lhl=1 THEN C1=1.00
6897 IF lhl=2 THEN C1=1.00
6899 IF lfg=0 THEN Alp=1.2
6900 IF lfg=1 THEN Alp=2.6
6901 IF lft=2 AND lfg=1 THEN Alp=5.0
6904 END IF
6907 J=0
6910 Sx=0
6913 Sy=0
6916 Sxs=0
6919 Sxy=0

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69221 READ DATA FROM A USER-SPECIFIED FILE IF INPUT MODE (Im) = 2
6925  IF Jj=0 THEN
6926  IF Istu=0 THEN
6931  ENTER @File:Bvol,Bamp,Etp,Fm,T1,T2,Ddd,Ddd,Emf(*)
6932  ELSE
6934  ENTER @File:Bvol,Bamp,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,T
2,Phg,Pwater
6936  END IF
6938  Bvol(J)=Bvol
6939  Bam(J)=Bamp
6940  Eata(J)=Etp
6943  Ear(J,0)=Emf(0)
6946  Ear(J,1)=Emf(1)
6949  Ear(J,2)=Emf(2)
6952  Ear(J,3)=Emf(3)
6955  Ear(J,4)=Emf(4)
6956  IF Istu=1 THEN GOTO 6961
6958  Ear(J,5)=Emf(5)
6959  Ear(J,6)=Emf(6)
6960  Ear(J,7)=Emf(7)
6961  Fma(J)=Fm
6962  T1a(J)=T1
6964  T2a(J)=T2
6967  ELSE
6970  Bvol=Bvol(J)
6973  Bamm=Bam(J)
6975  Etp=Eata(J)
6979  Emf(0)=Ear(J,0)
6982  Emf(1)=Ear(J,1)
6985  Emf(2)=Ear(J,2)
6988  Emf(3)=Ear(J,3)
6991  Emf(4)=Ear(J,4)
6992  IF Istu=1 THEN GOTO 6997
6994  Emf(5)=Ear(J,5)
6995  Emf(6)=Ear(J,6)
6996  Emf(7)=Ear(J,7)
6997  Fm=Fma(J)
6998  T1=T1a(J)
7000  T2=T2a(J)
7003  END IF
7004  IF Istu=0 THEN
7005  Tsat=FNTvsv57((Emf(0)+Emf(1))/2.)
7007  Tsat=Tsat-273.15
7009  T1=FNTvsv58(Emf(3))
7010  T1=FNTvsv58(Emf(4))
7012  T1=T1-273.15

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7013 Tol=Tol-273.15
7015 Etp1=Emf(3)+Etp/20.
7016 Dtde=2.5931E-2-1.50464E-6•Etp1+1.21701E-10•Etp12-5.1164E-15•Etp13+3.220
E-19•Etp14
7017 Tris=Dtde•Etp/10.
7018 Tc=T1+Tris
7019 ELSE
7020 Tsat=FNTvsv(Emf(0))
7021 T1=FNTvsv(Emf(2))
7022 Grad=FNGrad((T1+T2)•.5)
7023 To=T1+ABS(Etp)/(10•Grad)•1.E+6
7024 END IF
7025 CALCULATE THE LOG-MEAN-TEMPERATURE DIFFERENCE
7026 IF Istu=0 AND Itm=0 THEN
7027 Tf=T1
7028 Tl=To1
7029 END IF
7030 IF Itm=1 THEN
7031 Tf=T1
7032 Tl=T2
7033 END IF
7034 IF Itm=2 THEN
7035 Tf=T1
7036 Tl=To
7037 END IF
7038 Tavg=(Tf+Tl)•.5
7039 Trise=Tl-Tf
7040 Lmtd=Trise/LOG((Tsat-Tf)/(Tsat-Tl))
7041 Ift=0
7042 Cpw=FNCPw(Tavg)
7043 Rhov=FN Rhov(Tavg)
7044 Kw=FNkw(Tavg)
7045 Muwa=FN Muw(Tavg)
7046 Prw=FN Prw(Tavg)
7047 Ift=If to
7048 IF Istu=0 THEN
7049 Mdt=(6.7409•Fm+13.027)/1000.
7050 Md=Mdt•(1.0365-Tf•(1.96644E-3-Tf•5.252E-6))/1.0037
7051 ELSE
7052 Mdt=1.04505E-2+6.80932E-3•Fm
7053 Md=Mdt•(1.0365-Tf•(1.96644E-3-Tf•5.252E-6))/1.995434
7054 END IF
7055 Vf=Md/Rhov
7056 Vw=Vf/(FI•Di2.4)
7057 Vws=Vw•(Di/1.27E-2)1.2
7070 IF Istu=0 AND Iwth=0 THEN 'SWENSEN FRICTION FAC. FOR COPPER TUBE

```

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7075 IF Inn=0 AND Vw<.5 THEN Trise=Trise-(-2.73E-4+1.75E-4*Vw+9.35E-4*Vw^2-1.9E
E-5*Vw^3)
7078 IF Inn=1 THEN Trise=Trise-(-6.44E-5+1.71E-3*Vw+4.45E-4*Vw^2+4.07E-5*Vw^3)
7079 IF Inn=2 THEN Trise=Trise-(-3.99E-4+2.75E-3*Vw+1.45E-3*Vw^2+8.16E-5*Vw^3)
7080 IF Inn=3 THEN Trise=Trise-(8.57E-5+1.23E-3*Vw+1.08E-3*Vw^2+8.16E-5*Vw^3)
7081 END IF
7083 IF Istu=0 AND Iwth=2 THEN !ORKEFE FRIC. FAC. FOR SMOOTH TITANIUM TUBE.
7085 IF Inn=0 AND Vw<.5 THEN Trise=Trise-(-4.62E-5-7.53E-4*Vw+1.80E-3*Vw^2-6.84
E-5*Vw^3)
7086 IF Inn=3 THEN Trise=Trise-(2.09E-4+9.74E-4*Vw+2.12E-3*Vw^2-3.31E-5*Vw^3)
7087 END IF
7088 IF Istu=0 AND Iwth=1 THEN !FRICTION FACTORS FOR KORODENSE
7089 IF Inn=0 AND Vw<.5 THEN Trise=Trise-(-3.386E-4+1.88E-3*Vw+6.013E-4*Vw^2+4.
133E-5*Vw^3)
7090 IF Inn=3 THEN Trise=Trise-(2.089E-4+9.202E-4*Vw+1.893E-3*Vw^2-2.761E-5*Vw
3)
7091 END IF
7092 IF Istu=1 THEN
7093 IF Inn=0 THEN Trise=Trise-(.0138+.001*Vw^2)
7094 IF Inn=1 THEN Trise=Trise-.004*Vws^2
7095 IF Inn=2 THEN Trise=Trise-.004*Vws^2
7100 END IF
7108 Q=Md*Qpw*Trise
7111 Qp=Q/(PI*Do*L)
7114 Up=Qp/Lmtd
7117 Re=Rhow*Vw*Di/Muwa
7120 Fe1=0
7123 Fe2=0
7126 Cf=1.
7127 Prwf=Prw
7129 Re1f=Re
7129 Ift=0
7131 Two=Tsat-5
7132 Tfilm=Tsat/3+Two*2/3
7135 Kf=FNKfw(Tfilm)
7138 Rhof=FNHfhw(Tfilm)
7141 Muf=FMUfw(Tfilm)
7144 Hfgp=FNHfg(Tsat)+.68*FNCpw(Tfilm)*(Tsat-Two)
7147 New=Kf*(Rhof^2*9.81+Hfgp/(Muf*Do*Qp))^-.3333
7148 New=(Kf^3*9.81+Hfgp*Rhof^2/(Muf*Do*(Tsat-Two)))^-.25
7150 IF Ioc=1 THEN
7153 New=Kf*((9.81+Hfgp/Qp)^.25)*((Muf*Do)^(-.375))*(Rhof^1.625)*(Vw^1.125)
7154 New=(9.81+Hfgp/(Tsat-Two))^1.2*Kf^1.8*Vw^1.1*Rhof^1.5/(Do*Muf)^1.3
7156 END IF
7159 Ho=Alp*New
7162 Twoc=Tsat-Qp/Ho

```

```

7165 IF ABS((Twoc-Two)/Twoc)>.001 THEN
7166 Two=Twoc
7171 GOTO 7132
7174 END IF
7175 Rexp1=Rexp
7184 IF Ih1=0 THEN
7185 Omega=Re^Rexp1*Prw^.3333*Cf
7187 END IF
7188 IF Ih1=1 THEN
7189 Sra=.88-(.24/(4.+Prwf))
7190 Srb=.333333+.5*EXP(-6*Prwf)
7191 Omega=(5+.015*Reif^Sra*Prwf^Srb)
7192 END IF
7193 IF Ih1=2 THEN
7194 Eps1=(1.82*LGT(Re)-1.64)^(-2)
7195 Ppk1=1.+3.4*Eps1
7196 Ppk2=11.7+1.8*Prw^(-1/3)
7197 Pp1=(Eps1/8)*Re*Prw
7198 Pp2=(Ppk1+Ppk2*(Eps1/8)^.5*(Prw^.6666-1))
7199 Omega=Pp1/Pp2
7200 END IF
7202 H1=Kw/D1*Ci*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*P1/(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=Q/(PI*D1*(L+L1*Fe1+L2*Fe2)*H1)
7217 IF Ih1=0 THEN
7219 Muw1=FNMuw(Tavg+Dt)
7222 Cfc=(Muwa/Muw1)^.14
7225 IF ABS((Cfc-Cf)/Cfc)>.001 THEN
7228 Cf=(Cf+Cfc)*.5
7231 GOTO 7184
7232 END IF
7234 END IF
7235 IF Ih1=1 THEN
7236 Prwfc=FNPrw(Tavg+Dt)
7237 Reifc=Vw*D1*FNRRhow(Tavg+Dt)/FNMuw(Tavg+Dt)
7239 IF ABS((Prwfc-Prwf)/Prwfc)>.001 OR ABS((Reifc-Reif)/Reifc)>.001 THEN
7240 Prwf=(Prwfc+Prwf)/2.
7241 Reif=(Reifc+Reif)/2.

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7242 GOTO 7184
7243 END IF
7245 END IF
7246 Ift=Ifto
7247  $\lambda = Do * New * L / (\Omega * kw * (L + L1 * Fe1 + L2 * Fe2))$ 
7248  $Y = New * (1 / Uo - Rm)$ 
7249 COMPUTE COEFFICIENTS FOR THE LEAST-SQUARES-FIT STRAIGHT LINE
7250 IF Jp=1 THEN OUTPUT @Io_path;X,Y
7252 Sx=Sx+X
7255 Sy=Sy+Y
7258 Sxs=Sxs+X*X
7261 Sxy=Sxy+X*Y
7264 IF Im=1 AND Jj=0 THEN OUTPUT @File;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(
*)
7267 J=J+1
7270 IF J<Nrun THEN 6925
7273  $S1 = (Nrun * Sxy - Sy * Sx) / (Nrun * Sxs - Sx^2)$ 
7276 IF Iw1=2 THEN
7279 IF Inn=1 AND D1=.009525 THEN S1=1/.051 !TO BE MODIFIED
7282 IF Inn=0 THEN S1=1/.012
7283 IF Inn=3 THEN S1=1/.22
7285 IF Inn=1 AND D1=.0127 THEN S1=1/.052
7286 IF Ift=2 THEN S1=1/.035
7287 IF Ih1=0 THEN S1=1/.027
7288 IF Ih1=1 THEN S1=1/1.00
7289 IF Ih1=2 THEN S1=1/1.00
7291 END IF
7294  $Ac = (Sy - S1 * Sx) / Nrun$ 
7297  $Cic = 1 / S1$ 
7300  $Alpc = 1 / Ac$ 
7303 Jj=Jj+1
7306 IF Jp=1 THEN Jp=2
7309  $Cerr = ABS((Cic - Ci) / Cic)$ 
7312  $Aerr = ABS((Alpc - Alp) / Alpc)$ 
7315 IF Cerr>.001 OR Aerr>.001 THEN
7318  $Ci = (Cic + Ci) * .5$ 
7321  $Alp = (Alpc + Alp) * .5$ 
7324 BEEP
7327 IF Ijob=1 THEN 6907
7330 ELSE
7333 IF Jp=0 THEN Jp=1
7336 END IF
7339 IF Jp=1 THEN 6874
7342  $Ci = (Ci + Cic) * .5$ 
7345 PRINT
7346 IF Ih1=0 THEN

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7348 PRINT USING "10X,""Ci (based on Sieder-Tate)      =  "",Z.4D";Ci
7349 END IF
7350 IF Ihi=1 THEN
7351 PRINT USING "10X,""Ci (based on Sieder-Rouse)      =  "",Z.4D";Ci
7352 PRINT USING "10X,""Re exponent for Sieder-Rouse    =  "",D.DDD";Sra
7353 END IF
7354 IF Ihi=2 THEN
7355 PRINT USING "10X,""Ci (based on Petukhov-Popov)     =  "",Z.4D";Ci
7356 END IF
7357 IF Ioc=0 THEN
7358 PRINT USING "10X,""Alpha (based on Nusselt (Tdel)) =  "",Z.4D";Alp
7359 END IF
7360 IF Ioc=1 THEN
7361 PRINT USING "10X,""Alpha (based on Fujii (Tdel))    =  "",Z.4D";Alp
7362 END IF
7363 IF Inam=5 THEN
7364 IF Ihi=0 THEN
7366 IF Ipco=0 AND Inn=0 THEN Alpsm=.8218 !NO INSERT,VACUUM,S-T
7367 IF Ipco=1 AND Inn=0 THEN Alpsm=.7793 !NO INSERT,ATMOSPHERIC,S-T
7368 IF Ipco=0 AND Inn=3 THEN Alpsm=.7854 !HEATEX,VACUUM,S-T
7369 IF Ipco=1 AND Inn=3 THEN Alpsm=.7769 !HEATEX,ATMOSPHERIC,S-T
7371 END IF
7372 IF Ihi=1 THEN
7373 IF Ipco=0 AND Inn=0 THEN Alpsm=.8613 !NO INSERT,VACUUM,S-R
7374 IF Ipco=1 AND Inn=0 THEN Alpsm=.8218 !NO INSERT,ATMOSPHERIC,S-R
7375 IF Ipco=0 AND Inn=3 THEN Alpsm=.7791 !HEATEX,VACUUM,S-R
7376 IF Ipco=1 AND Inn=3 THEN Alpsm=.7929 !HEATEX,ATMOSPHERIC,S-R
7378 END IF
7379 IF Ihi=2 THEN
7380 IF Ipco=0 AND Inn=0 THEN Alpsm=.8205 !NO INSERT,VACUUM,P-P
7381 IF Ipco=1 AND Inn=0 THEN Alpsm=.7654 !NO INSERT,ATMOSPHERIC,P-P
7382 IF Ipco=0 AND Inn=3 THEN Alpsm=.7670 !HEATEX,VACUUM,P-P
7383 IF Ipco=1 AND Inn=3 THEN Alpsm=.7708 !HEATEX,ATMOSPHERIC,P-P
7385 END IF
7386 END IF
7387 IF Inam=4 THEN
7390 IF Ipco=1 THEN Alpsm=.876 !SWENSEN DATA BASED ON DEL-T
7391 END IF
7392 IF Inam=0 OR Inam=3 THEN
7393 IF Ipco=0 THEN Alpsm=.83 !VP MISTV103
7394 IF Ipco=1 THEN Alpsm=.86 !VP SMTHSTA65
7396 IF Ift=1 THEN Alpsm=.733 !ZEBROWSKI (V = 0.45 m/s)
7397 IF Ift=1 THEN Alpsm=.677 !VAN PETTEN (V = 0.25 m/s)
7398 IF Ift=2 THEN Alpsm=1.262
7399 END IF
7401 IF Inam=1 THEN !MITROU ALPHA FOR P-P FROM REPROCESSING

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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
7519 SUB Modify
7520 COM /Fld/ 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
7559 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,Utran,Etp,Emf(0),Emf(1),Emf(2),Emf(3),Emf(4),Fm,T1,
T2,Phg,Pwater
7568 END IF
7570! PERFORM CORRECTIONS
7571 PRINT USING "2X,""DO YOU WISH TO DELETE POINT""",DD,""?""";I
7572 INPUT "0=YES, 1=NO",Idel
7573 IF Idel=0 THEN 7580
7576 IF Istu=0 THEN

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7577 OUTPUT @Filed;Bvol,Bamp,Etp,Fm,T1,T2,Pvap1,Pvap2,Emf(*)
7578 ELSE
7579 OUTPUT @Filed;Bvol,Bamp,Utran,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 @Filed TO *
7584 SUBEND
7585 SUB Purg
7588 BEEP
7591 INPUT "ENTER FILE NAME TO BE DELETED",File$
7594 PURGE File$
7597 GOTO 7588
7600 SUBEND
7690 SUB Renam
7693 BEEP
7696 INPUT "ENTER FILE NAME TO BE RENAMED",File1$
7699 BEEP
7702 INPUT "ENTER NEW NAME FOR FILE",File2$
7705 RENAME File1$ TO File2$
7708 GOTO 7593
7711 SUBEND
7721 DEF FNTvsv55(V)
7731 COM /Cc55/ T55(5)
7741 T=T55(0)
7751 FOR I=1 TO 5
7761 T=T+T55(I)*V^I
7771 NEXT I
7781 RETURN T
7791 FNEND
7801 DEF FNTvsv56(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 FNTvsv57(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 FNTvsv58(V)
7971 COM /Cc58/ T58(5)
7981 T=T58(0)
7991 FOR I=1 TO 5

```

```
8001  T=T+T58(I)*V^I
8011  NEXT I
8021  RETURN T
8031  FNEND
```

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