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THESIS

THE EFFECT OF A NOVEL COATING TECHNIQUE ON FILMWISE AND DROPWISE CONDENSATION OF STEAM ON HORIZONTAL TUBES

by

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June, 1996

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13. ABSTRACT *(maximum 200 words)* Steam condensation heat transfer on smooth horizontal tubes and on a Korodense horizontal tube was experimentally studied at atmospheric pressure and at vacuum. The overall heat transfer coefficient was measured and the outside heat transfer coefficient was determined from the modified Wilson Plot Technique. A hydrophobic coating of a self-assembling monolayer (SAM) with a composition of $HS(CH_2)_{15}CH_3$ promoted excellent dropwise condensation (DWC) on tubes. Coexisting strips with varying widths of filmwise condensation (FWC) and DWC, but at a constant area ratio of 50%, were also investigated.

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THE EFFECT OF A NOVEL COATING TECHNIQUE ON FILMWISE AND DROPWISE CONDENSATION OF STEAM ON HORIZONTAL TUBES

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Smooth tubes coated with the hydrophobic SAM produced DWC heat transfer coefficients of up to 10 times that of FWC at atmospheric conditions and up to 4 times at vacuum. The Korodense tube coated with the hydrophobic SAM produced heat transfer coefficients of up to about 3 times that of FWC at atmospheric conditions and up to about 2.5 times at vacuum. Data with coexisting strips of FWC and DWC showed that the heat transfer performance was influenced by the width of strips, size of drops, condensate turbulence, and loss of drop sweeping action, indicating an optimum combination of strips may exist.

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I. INTRODUCTION

A. DESCRIPTION

Two types of condensation exist, filmwise and dropwise. When a liquid fully wets a cold surface in contact with a vapor, filmwise condensation (FWC) takes place. Dropwise condensation (DWC) takes place when a cold surface is poorly wetted.

B. BACKGROUND

1. Dropwise Condensation Process

Dropwise condensation has been studied extensively since the 1930s when it was reported by Schmidt et al. [Ref. 1] that DWC produces greater heat transfer coefficients than filmwise condensation. Subsequently, DWC has been known to produce heat transfer coefficients of up to 20 times that of FWC. Figure 1 depicts the relationship between heat flux and surface temperature subcooling during both dropwise and filmwise condensation. [Ref. 2] This behavior is referred to as the "condensation curve".

The process of DWC is complex and random. It can be described by a cycle consisting of drop nucleation, growth, coalescence, and departure.

The cycle of DWC begins with the formation of droplets on the condensing surface. Two viewpoints exist on the mechanism of drop nucleation. The first view is that a thin liquid film exists on the condensing surface at all times and the subsequent fracture of the liquid film results in drop formation [Ref. 3,4]. With this model, when a departing drop passes over a surface, it leaves behind an ultra-thin liquid film. The second view suggests that nucleation of droplets occurs at discrete sites because of impurities and irregularities on the surface and between these sites the surface is dry. With this model, when a departing drop sweeps over a surface the area left behind is dry [Ref. 5].

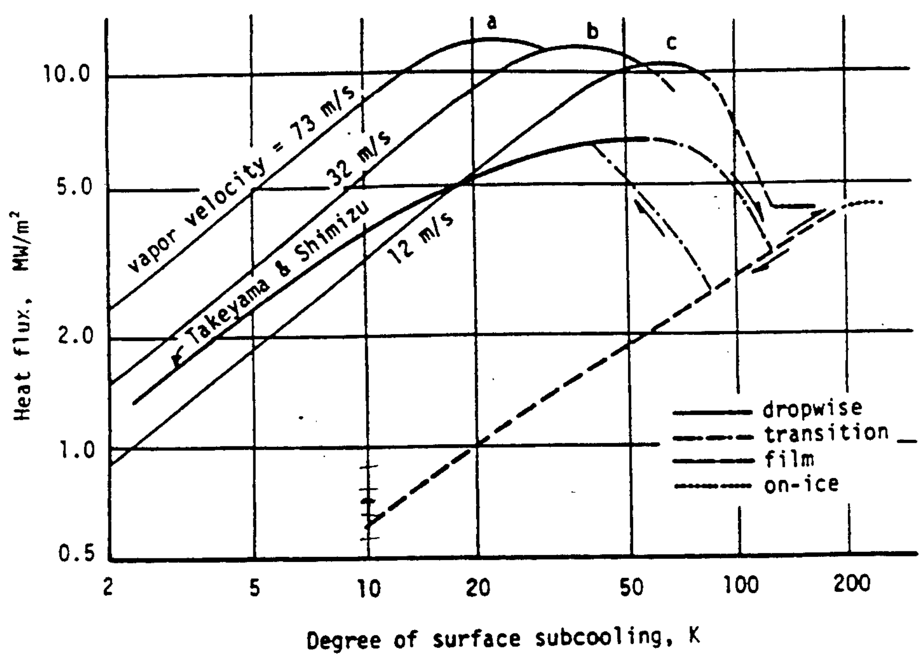

Figure 1. Condensation Curve. From Ref. [2]

A study done by Westwater [Ref. 6] using high speed motion picture photography concluded that no layer thicker than a monolayer of liquid film exists between drops during DWC.

Growth and coalescence of drops characterize the next phase of the cycle. Microscopic drops grow due to intense heat transfer and merge with neighboring drops to form larger drops.

Finally, once a critical drop diameter, a size large enough to overcome surface tension forces, is reached, the drop departs the surface. The departing drop sweeps the surface clean of all other drops in its path. Fresh surface is then available for the cycle to begin again.

Adhesive forces and the contact angle of drops play critical roles in the DWC cycle. The criteria for the existence of DWC is determined by the interrelation of three interfacial energies of the liquid-solid (ls), solid-vapor (sv), and liquid-vapor (lv) phases as shown in Figure 2.

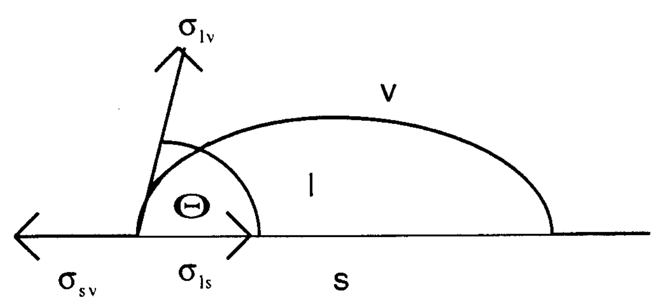

Figure 2. Interfacial Energy. From Ref. [7]

The balance of the three interfacial energies leads to

$$\sigma_{sv} - \sigma_{ls} = \sigma_{lv}\cos\Theta \,. \tag{1.1}$$

The criterion for spreading of a liquid drop depends on whether the adhesion force between the liquid and the solid is greater than the cohesion force within the liquid. A spreading coefficient may be defined as [Ref. 8]

$$Sp_{ls} = \sigma_{sv} - \sigma_{lv} - \sigma_{ls} \tag{1.2}$$

which from Eq. (1.1), yields

$$Sp_{ls} = \sigma_{lv}(\cos\Theta - 1) \tag{1.3}$$

Therefore, the spreading coefficient is a function of the liquid - vapor surface energy and the contact angle of the liquid on the surface.[Ref. 7]

When a drop does not spread over a surface, $Sp_{ls} < 0$, because $\cos\Theta \le 1$ and $0 < \Theta \le 180^\circ$. If $\Theta = 0$, then $\cos\Theta = 1$ and $Sp_{ls} = 0$, representing the situation that the liquid spreads over the surface spontaneously. Although any contact angle Θ fails to yield $Sp_{ls} > 0$, Tanasawa [Ref. 7] points out that it is possible if the solid-vapor interfacial energy σ_{sv} is sufficiently large in Eq. (1.2).

2. Challenges in Maintaining DWC

Pure, organic free metal surfaces used in industrial heat transfer applications have high surface energies. Therefore in the common use of steam, water will wet the metal surface because its surface tension is lower than the metal's surface energy. To attain DWC, another surface, a DWC promoter, must be applied to the metal surface to lower its surface energy. Being solely a surface phenomenon, DWC is most preferably obtained by preparing special surfaces with coatings of impure noble metals* or organics that yield contact angles greater than 90°. Amongst the noble metals, gold and silver have been known to consistently show excellent dropwise characteristics [Ref. 9,10].

In general, organic coatings are difficult to maintain, and require a strong, long-term adhesion between the coating and the metal substrate. Usually, the thicker the coating, the better its resistance to substrate corrosion. On the other hand, due to very low thermal conductivity, the organic coating must be extremely thin or the coating itself will create a thermal resistance that deteriorates the DWC performance [Ref. 11]. Moreover, the coating material, if removed by the erosion effects of the steam, may contaminate

*Noble metals which are contaminated with traces of carbon.

the system, e.g. as impurities in the boiler feedwater of a power plant.

The use of fluorocarbon polymers and silicon polymers as promoters has been studied extensively. Both have a very low surface energy but exhibit the following problems: low thermal conductivity requiring a thin coating, and physical deterioration of the coating over extended use.[Ref. 12]

Due to these difficulties in finding a reliable, "permanent" promoter, DWC at present is not the preferred mode of condensation, despite its much superior heat transfer coefficient. As a consequence, all condenser designs in industry are based on FWC. There exists, therefore, a need to develop innovative, novel organic materials and coating techniques which could eliminate the above difficulties associated with DWC.

3. Novel Coating Technique

In the early 1990s, a group of chemists at Harvard University developed a technique to coat patterned layers of self-assembled monolayers (SAMs) (hydrophobic and/or hydrophilic organic molecules) on a few select surfaces.[Ref. 13,14,15] Originally, these SAMs were considered useful for etching and plating, as substrates for microscopic studies of surface interactions in scanning probe microscopies, and as surfaces for the attachment of proteins and cells [Ref. 15].

The SAM, applied in a heat transfer application, is a novel coating. It is a structured system, closely packed with a uniform thickness of 12-15Å. This insignificant thickness eliminates the problem of having thick promoters which produce a large thermal barrier. In addition, the hydrophobic SAM has low surface energy. Moreover, the SAM adheres to a metal surface through a particularly strong bond. Although the exact surface chemistry is not known, the adhesive bond of the SAM is stronger than that of other organic DWC promoters. SAMs form when appropriate organic molecules chemisorb on solid surfaces. The most resilient SAMs are those that form upon chemisorption of alkylthiols on gold surfaces. The sulfur molecule at one end of these SAMs bonds very strongly with gold through a covalent bond, as noted below:

$$Au + SH-(CH_2)_{15}-R$$

By appropriately choosing the terminal group (R) on these alkylthiol molecules, one can predetermine the chemical and physical properties of the resulting SAM surface. For example, $HS(CH_2)_{15}CH_3$ exhibits hydrophobic characteristics*. CH_3 has a non- polar bond. When water comes into contact with

*If the terminal group (R) was OH instead of CH_3, the SAM would exhibit hydrophylic characteristics. This hydrophylic coating must be tested further, however, for reliability before it can be implemented.

it, water molecules are not attracted to the CH_3 and hence "bead up." Water prefers to be near polar bonds, such as OH and finds them within the water molecule itself.

The hydrophobic SAM is a very stable compound, able to withstand temperatures, of up to 115°C and perhaps higher. At higher temperatures, the breakdown of the SAM is due to cleavage of the sulfur-gold bond. The SAM lays at a 73° angle with the surface, Figure 3. The molecules structure themselves in a closly packed fashion. They do not cross over onto other SAMs, thereby, allowing the full exposure of the end molecule, CH_3, to act hydrophobically. Water,

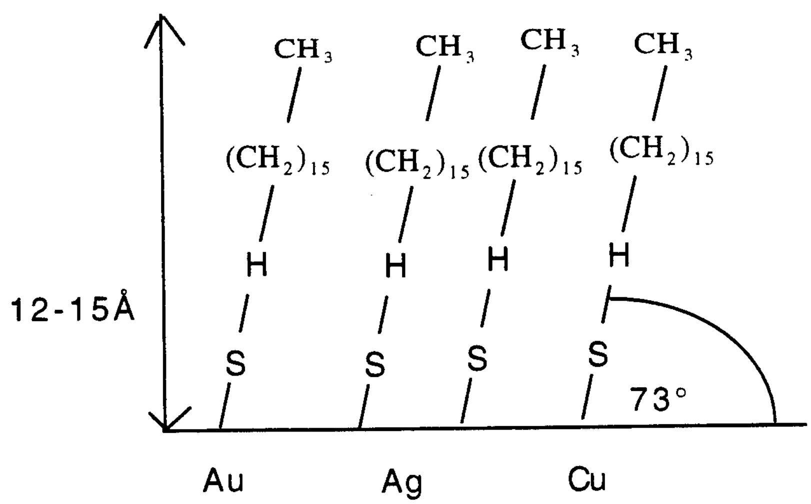

Figure 3. Hydrophobic SAM Molecule.

therefore, can not come in contact with the substrate and cause erosion. Initial study was done on the SAMs on a flat silicon substrate coated with 2000Å of gold.[Ref. 14] SAMs formed from hexadecylthiol $HS(CH_2)_{15}CH_3$ exhibited extremely low free-energy surfaces by having large advancing contact angles of 110-112° for water.

Finally, SAMs are potentially promising coatings to obtain enhanced condensation heat transfer. The ability to change the surface properties of a substrate to make the surface either hydrophobic or hydrophylic by simply changing the chemisorbed molecule provides a powerful novel technique to alter condensation heat transfer.

Preliminary condensation tests by Das [Ref. 16] on gold-coated aluminum horizontal tubes showed that heat transfer coefficients about four times higher than complete filmwise condensation were achieved by the hydrophobic tube at vacuum conditions and about six times higher at atmospheric pressure. The hydrophobic coating, therefore, shows a strong potential as a DWC promoter.

4. Coexistence of FWC and DWC

In the 1980s, numerous mechanisms to improve heat transfer coefficients were studied. One such mechanism for condensation on a vertical disc was patterning the surface with alternating sections of DWC and FWC. Kumagai et al. [Ref. 17] reported experimental results that indicate the resulting heat flux of a patterned surface is not simply the arithmetic mean of the heat fluxes of the dropwise zones and the filmwise zones, but is larger. The heat transfer mechanism with the patterns is characterized, first of all, by drops in the dropwise zones coalescing with the neighboring film sections without sweeping down the surface, thereby disturbing the film and making it turbulent. In addition, drop departure sizes are also controlled by the width of the dropwise zones. Figure 4 illustrates a combined pattern on a disc.

Das [Ref. 16] conducted preliminary tests on horizontal aluminum tubes coated with titanium, followed by gold and then a pattern of hydrophilic and hydrophobic bars using the hydrophilic and hydrophobic SAMs. Hydrophilic and hydrophobic bars were at the top of the tube and covered an arc of 45° along the circumference (2mm bars separated by 2mm, I.e. W=2mm, S=2mm, alpha ≈22°), Figure 5. The first macro-pattern test was conducted with the tube placed such that the patterns extended symmetrically on both sides of the tube. In the second test, the tube was rotated such that the patterns extended on only one side.

Preliminary results, Figure 6, clearly indicate that despite no effort to optimize the pattern, the heat transfer performance was as good with the pattern as the best all hydrophobic case. Thus, one is left with the general question of whether there exists a pattern of FWC and DWC that would perform better than the all DWC case.

Figure 4. Coexisting Condensation on a Patterned Surface DWC on Gold, FWC on Bare Copper. From Ref. [17]

In particular, a variety of specific questions remain unanswered:

1. How can large drops be removed from the top and bottom of a tube?
2. How can drop departure diameters be reduced?
3. How can drainage at the top, sides and bottom of a tube be controlled?
4. How can drainage be promoted without large filmwise coverage?
5. What is the maximum achievable heat transfer coefficient with this coexisting pattern on a horizontal tube?

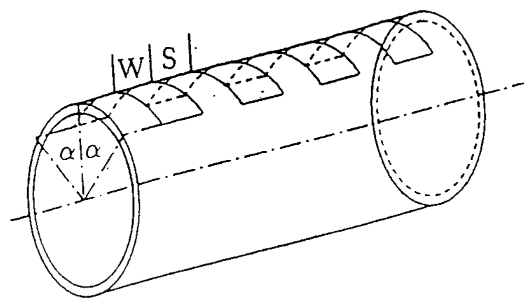

Figure 5. Pattern Tested by Das 1995. From Ref. [18]

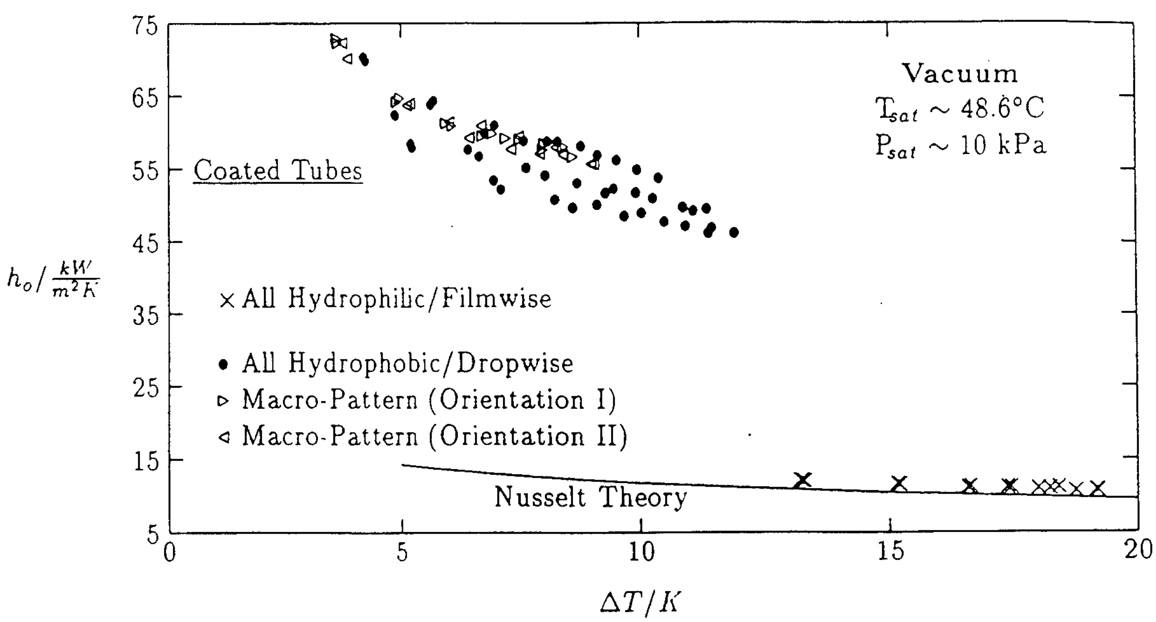

Figure 6. Steam Condensation Heat Transfer Coefficient vs Vapor-to-Tube Wall Temperature Difference. From Ref. [18].

C. OBJECTIVES

Therefore, the main objectives of this study are to condense steam on these novel-coated tubes and to:

1. Investigate the use of a SAM coating to promote DWC.

2. Determine DWC heat transfer coefficients of horizontal tubes with SAM applied.

3. Explore coexisting film and dropwise regions on a horizontal tube to determine what mechanisms are occurring.

D. UNIQUENESS OF PROJECT

This project requires an interdisciplinary effort involving organic chemistry, heat transfer, surface chemistry, and coating and patterning techniques. This thesis is part of an overall effort involving the Naval Postgraduate School, SRI International, and Optigon Technology. If the novel technique is successful, it would lead to improved heat transfer and smaller, more compact industrial condensers.

II. LITERATURE SURVEY

A. FILMWISE CONDENSATION

When a downward flowing vapor condenses on a smooth horizontal tube, and the condensate wets the solid surface, a continuous film of liquid is created that flows around the tube due to both gravity and to vapor shear forces. This film does not, however, have a constant thickness. The film is thinnest at the top of the tube and grows to its thickest at the bottom of the tube. The film provides a thermal resistance and hence as the film thickness increases so does its thermal resistance. The Nusselt study of laminar film condensation, developed in 1916, is the primary theory used today for low vapor velocity applications. The theory is based on four major assumptions: [Ref. 19]

1. Laminar flow of condensate film with constant properties
2. The gas is a pure vapor and at a constant temperature, T_{sat}
3. Shear stress at the liquid-vapor interface is negligible; vapor is quiescent
4. Momentum and energy transfer by convection in the film are negligible

Nusselt [Ref. 20] developed the following expression for the average heat transfer coefficient:

$$h_o = 0.728\left[\frac{k_f^3 g \rho_f(\rho_f - \rho_v)h'_{fg}}{\mu_f D_o(T_{sat} - T_{wo})}\right]^{1/4} \qquad (2.1)$$

with h_{fg}' computed as [Ref. 19]

$$h'_{fg} = h_{fg} + 0.68c_p(T_{sat} - T_{wo}) \qquad (2.2)$$

The fluid properties are evaluated at a film temperature given by:

$$T_f = \frac{1}{3}T_{sat} + \frac{2}{3}T_{wo} \qquad (2.3)$$

B. DROPWISE CONDENSATION

1. Promotion of DWC

Dropwise condensation can be promoted by:

1. Applying a suitable organic chemical such as oleic acid or wax to a surface.
2. Injecting non-wetting chemicals into the vapor which are deposited on the surface.
3. Using a "permanent" low surface energy polymer or a noble-metal coating. [Ref. 12]

Applying oleic acid or montan wax to a surface has been proven to produce good DWC; however, the dropwise behavior is not permanent. Injection techniques require additional equipment and injection of chemicals may contaminate the overall condensate system.

At Dalian University of Technology in China, work has been done in the field of ion implantation on vertical copper surfaces with a thin polymer film and with a thin polytetrafluoroethylene (PTFE) film. [Ref. 21] Excellent DWC was reported but no long term conclusions were made.

Recently, Gavrish et al. [Ref. 22] tested fluorinated carbon disulfide as an additive to the boiler feed water to obtain DWC. An increase of the condensation heat transfer coefficient at atmospheric pressure by a factor of 5 to 10 was obtained for about 4200 hours before DWC reverted to the film mode.

The hydrophobic characteristics of the noble metals as a DWC promoter have been controversial in the literature [Ref. 7,11,12]. The noble metals have very high surface energy and tend to be completely wet by water [Ref. 23]. But, on contamination with carbon, gold plated surfaces gradually become hydrophobic, exhibiting excellent dropwise characteristics. Woodruff & Westwater [Ref. 9] have shown that promotion of DWC on gold-plated vertical surfaces is directly related to the surface gold and carbon concentrations.

On the other hand, "permanent" organic materials have received significant attention for their hydrophobic capabilities to promote DWC. Such studies have generally been done with fluorocarbon or silicone polymers. While several studies were done in the 1950s and 1960s with PTFE, commercially known as Teflon [Ref. 24,25], and silicone [Ref. 26], Erb & Thalen [Ref. 27,28] conducted an extensive investigation of several permanent hydrophobic coatings, including PTFE, sulfide films, noble metals of copper, gold, and silver, and parylene-N, a para-xylene polymer which contained no fluoride. These coatings were tested on vertical tubes of several types of substrates: Cu-Ni, Cr on Ni, Au on Ni, 316 stainless steel and Pd on Ni. They concluded that a silver coating showed the best performance. In 1986, Holden et al. [Ref. 12] conducted experiments on 14 polymers and showed an increase in the steam side condensation heat transfer coefficient of about 3 to 8 as compared to filmwise on horizontal copper tubes at atmospheric pressure. Moreover, Marto et al [Ref. 11] evaluated organic coatings on Cu-Ni, Al, and stainless steel horizontal tubes and their results also showed that a surface coated with electroplated silver performed much better than any organic coating. In general, the organic coatings exhibited a lack of adherence to the copper tube surface, and were found to be too thick (the thickness of the coating must be less than 1μm) to obtain any reasonable enhancement. It was concluded that a detailed study of the surface chemistry was needed to improve upon the organic coating technology.

Most studies of DWC promoters to date have been done on small vertical flat surfaces. Very little data exist on studies conducted with horizontal tubes.

2. Dependence of DWC Heat Transfer Coefficient on Drop Departure Diameter

DWC is characterized by the presence of different sized drops. Tanasawa et al. [Ref. 7] measured the dependence of the average heat transfer coefficient on the departing drop diameter. They found, as shown in Figure 7, that the average heat transfer coefficient is proportional to the departing drop diameter to the power -0.31 [Ref. 7].

During DWC, virtually all heat is transferred through small drops.[Ref. 8] The very large drops tend to insulate the surface and reduce heat transfer. So the large drops must be removed in order to increase the DWC heat transfer coefficient.

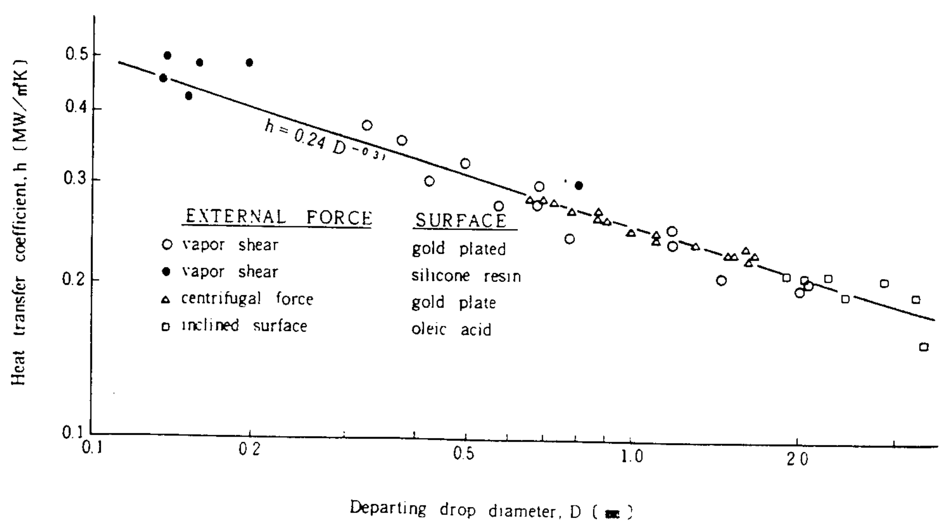

Figure 7. Dependence of DWC Heat Transfer Coefficient on Departing Drop Diameter. From Ref. [7]

On a horizontal tube, DWC is characterized by large drops on the top and bottom of the tube and smaller drops on the sides. The outside heat transfer coefficient may be improved if the larger drops at the top and bottom are removed. The question that remains is, how to reduce the size of these large drops?

3. Effect of Substrate Material on Heat Transfer Coefficient

A nonuniformity of heat flux exists in DWC due to the drop size distribution on the surface. This condition leads to a phenomenon similar to contact resistance in solids. Constriction resistance is the constriction of heat flow lines near the surface which increases thermal resistance as seen in Figure 8. [Ref. 8]

Two schools of thought exist on the effect of substrate material on the heat transfer coefficient. One theory, held by Aksan and Rose [Ref. 29], suggests that the type of substrate has no effect on the heat transfer rate. Aksan and Rose [Ref. 29] say that differences in the heat transfer rate between different substrates can be attributed to discrepancies in how a promoter bonds to a substrate and in the resulting surface conditions. In addition, Holden et al. [Ref. 12] concluded, through their evaluation of organic coatings, that no evidence existed of substrate thermal conductivity influence upon the heat transfer coefficient. The other theory held by Tanasawa [Ref. 7] and Mikic [Ref.

30], states that the heat transfer rate in DWC must be lower on a poorly conducting surface. Tsuruta and Tanaka [Ref. 31] compared DWC on quartz glass, stainless steel, and carbon steel. They found that, in fact, the heat transfer coefficient does decrease with surface thermal conductivity and that the decrease of surface thermal conductivity raises the constriction resistance.

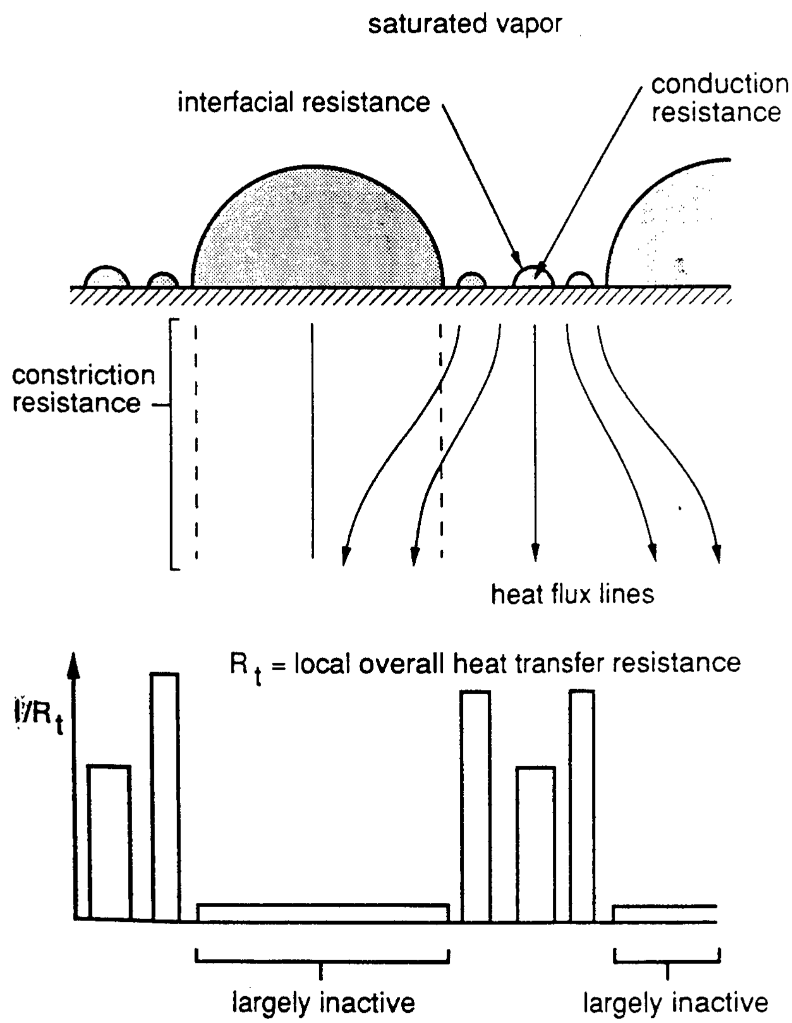

Figure 8. Model of Heat Transfer Resistance Components for Dropwise Condensation. From Ref. [8]

C. COEXISTENCE OF DROPWISE AND FILMWISE CONDENSATION

Vertical surfaces with coexisting DWC and FWC produce a heat flux that is higher than the arithmetic mean of the FWC and DWC sections, as discovered by Kumagai et al. [Ref. 32]. Tests were conducted on a vertical flat copper disk. DWC sections were achieved by applying Teflon pieces and FWC sections were achieved on a bare copper surface. The area ratio between FWC and DWC was held constant at 50%. Figure 9 shows how the heat flux of coexisting condensation approaches the all DWC case by increasing the number of vertical divisions of DWC and FWC on the surface.

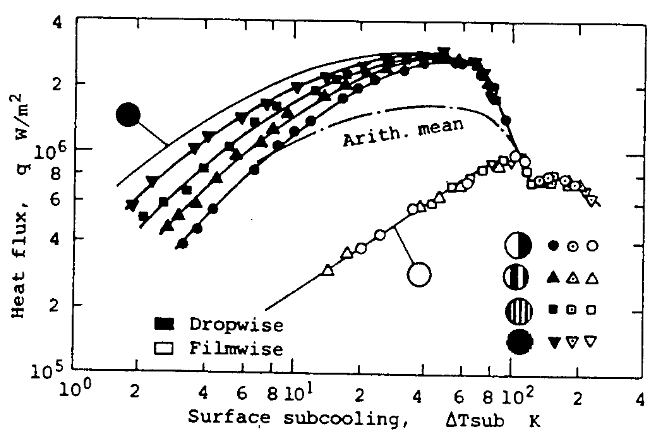

Figure 9. Condensation Curves on Vertical Stripe Patterns, Area Ratio 50%. From Ref. [17]

It was concluded that an optimal width in both the dropwise and filmwise areas exists for a vertical flat surface. [Ref. 32] This same data needs to be ascertained for a horizontal tube.

circumference due to a variable gravitational force aligned with the tube surface.

In addition to the coexistence of FWC and DWC sections, surface preparation plays a critical role in the heat flux attained for DWC and FWC. Rough surfaces reveal interesting characteristics as found by Izumi and Yamakawa. [Ref. 33] They roughened vertical copper plates with sand paper and concluded that for DWC:

1. On rough surfaces, drops become flatter and more irregular with increasing surface roughness, leading to reduced heat transfer
2. At the same heat flux, the sweeping cycle for a drop is longest for the roughest surface.
3. At the same $(T_s - T_w)$, heat flux on the rough surfaces showed smaller values than that on the smooth surface.
4. Heat flux is lowest for horizontal scratches and increases as scratches become vertical; heat flux for a smooth surface is the largest.

There is evidence that roughness may effect FWC in an opposite way. As surface roughness increases for FWC, heat transfer increases. This may be explained by the condensate film being disturbed and becoming turbulent because of the roughness.[Ref. 33]

III. SYSTEM OVERVIEW

A. EXPERIMENTAL APPARATUS

The system apparatus and instrumentation are identical to that as described by Incheck [Ref. 34]. Figure 10 contains a general schematic of the overall system. The boiler is filled with distilled water, heated, and steam rises through the tubing with a diameter of 0.15m. The steam flows downward over the tube in the test section at a velocity of between one and two meters per second. Meanwhile, cold water is pumped from a sump through the tube. Steam condenses on the tube and any steam not condensed, passes through an auxilliary condenser and the condensate is fed back to the boiler by gravity.

Operating instructions for the apparatus are contained in Appendix A. Calibration procedures and correlations are addressed in Appendix B.

B. DATA ACQUISITION

The data acquisition procedure is the same procedure used by Incheck [Ref.34], however, the program was rewritten into Qbasic by Das [Ref. 16]. The program can be found in Appendix C.

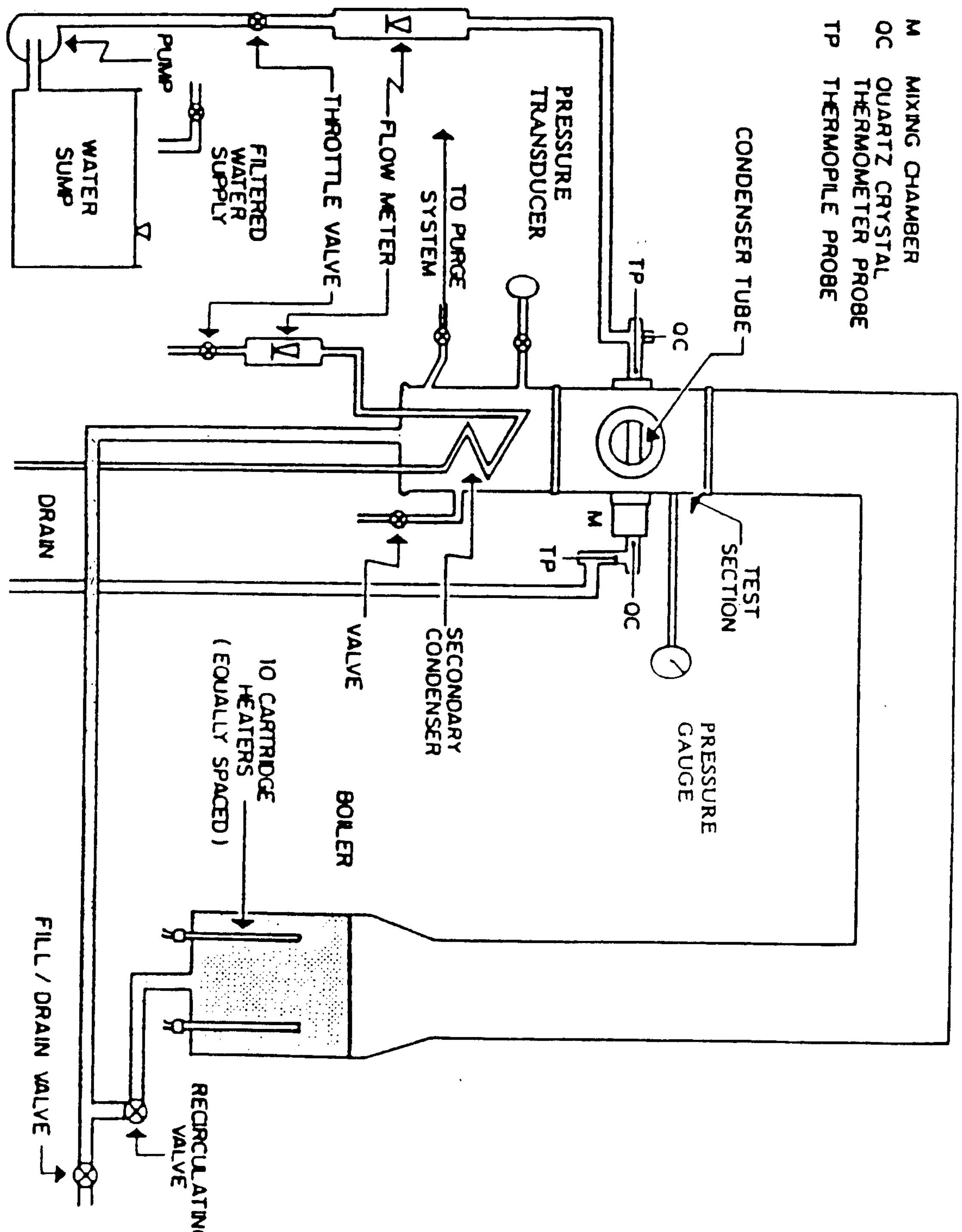

Figure 10. Schematic of the Single Test Tube Apparatus. From Ref. [34]

IV. EXPERIMENTAL PROCEDURES

A. TUBE PREPARATION

1. Surface Preparation

Surface preparation of the tubes prior to application of any coating was critical. Each tube was identically polished on a lathe at approximately 1600 RPM by the following method.

1. While the tube was rotating, it was polished with wet P500 grit sandpaper. The sandpaper was submersed in tap water before polishing and was kept wet throughout the procedure. Polishing was continued until large scratches were eliminated.
2. The tube was polished with wet P1000 grit sandpaper until evidence of large scratches was eliminated.
3. The tube was polished with wet P2400 grit sandpaper until evidence of large scratches was eliminated.
4. The tube was polished with wet P4000 grit sandpaper until evidence of large scratches was eliminated.
5. The tube was then polished with Pol metal polish* until evidence of visible scratches was eliminated.

The final surface of the tube was shiny with no visible horizontal scratches and if any, very faint circumferential scratches. The entire procedure took approximately two hours.

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*A commercial metal polish.

Cleaning the tubes was also crucial. Any oil or debris left on the tube from polishing or handling could affect the adherence of any coating. Each tube was therefore cleaned by the following method.

1. Clean inside and outside of the tube with a mild soap. Use a soft bristle brush on the inside and a polishing cloth* on the outside of the tube. Rinse with distilled water.
2. Spray the tube with acetone. Hold the tube vertically and with a spray bottle spray the tube while rotating it. Continue spraying for a least one minute.
3. Spray the tube with ethanol following the identical procedure described in step 2 above.
4. Rinse the tube with distilled water. The tube should exhibit filmwise characteristics and water should run clear. Avoid touching the condensing surface after this step. If film irregularities exist, soak the tube in acetone for at least one hour and rinse with distilled water.

2. Metal Deposition Procedure

Prior to the hydrophobic SAM application, aluminum

*Crew 2 extra low lint clean room wipes, PN G-33670-30.

tubes were coated with titanium and gold* and the titanium Korodense tube was coated with gold using a sputtering technique, [Ref. 35]. The tubes were placed in a vacuum chamber with a small amount of argon present. The argon was ionized by an electron bombardment. The ions were first directed toward the tube in order to clean a thin layer of the surface. The ions were then directed toward metal targets, first titanium, for the case of aluminum tubes, then gold. The metal removed from the targets was deposited onto the tube surface which was grounded. The vacuum system was opened twice to rotate the tube in order to get full 360° coverage. The thickness of the deposition was estimated after the fact by measuring the deposition of a test coupon.

Copper tubes did not require application of titanium or gold. Sulfur bonds strongly with all the coinage metals of copper, gold and silver. Although the gold-sulfur bond is the strongest of the metals, the SAM adheres to the copper directly and does not require a coating of gold.

3. Filmwise Tube Preparations

Three separate methods were tried to obtain FWC: oxidation with an iodine solution, thermal oxidation, and oxidation with a sodium hydroxide (NaOH) solution. In the first method, the iodine oxidation was accomplished by dipping the tubes twice in a solution of iodine in ethanol

*The titanium was needed as an interlayer to ensure a good bond between the aluminum and the gold.

(10-50 millimolar range) for 30 seconds at a time [Ref. 36]. In the second method, tubes were thermally oxidized with an oxyacetylene torch in the same way as that used by Incheck [Ref. 34]. In the third method, tubes were oxidized with a sodium hydroxide solution in the same way as that used by Incheck [Ref. 34].

The oxidation layer promoted by iodine was very thin and cracks in the oxide layer were observed. Oxidation by heat produced a good quality, but thick, oxide layer which, upon cooling in air flaked off the tube. Therefore, the best filmwise condensation was achieved by oxidation with NaOH.

4. Dropwise Tube Preparations

All DWC was attained by the hydrophobic SAM. Hydrophobic SAM application was accomplished by the following process [Ref. 36]: The SAM chemicals were dissolved in ethanol. The concentration was in the nanomolar to micromolar range. A precise amount of alkythiol to be dissolved in the ethanol is not specified. The concentration is "forgiving" and is not necessarily an exact value. In this case, one microdrop of hydrophobic SAM was added to approximately one liter of ethanol. The solution was dripped on to the surface from a pipet. The surface was then rinsed with ethanol and then with distilled water and dried in air. As an alternative to this process, the tube may also be dipped in the hydrophobic SAM solution.

The CH_3 in the hydrophobic SAM is non-polar. Water, H_2O or HOH, is not attracted to the CH_3. Water looks for other polar groups to interact with. The hydrophobic SAM, not having any polar groups, causes the water to bead up.

5. Patterned Tube Preparations

When patterned tubes were manufactured, all FWC was achieved by NaOH oxidation and all DWC was achieved by the hydrophobic SAM. Oxidation was accomplished first. During oxidation, the dropwise areas were masked with Con-Tact* paper in order that the surface remain bare.

The half FWC and half DWC tube described below was first oxidized by exposing the unmasked portion of the tube to the NaOH solution and then, following the removal of the masking, the DWC half was dipped into the hydrophobic SAM solution. This procedure produced good FWC and excellent DWC.

Subsequent striped patterns were made by masking strips of the tube and then oxidizing the bare surfaces. After oxidation, the hydrophobic SAM was applied to the previously masked strips with an acrylic chisel nib pen**.

6. HEATEX Tube Insert

The use of tube inserts has been studied by NPS

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*A transparent covering with an adhesive back manufactured by Rubbermaid Inc.

**The flux pen, PN FV-100 and the nib, PN 381-8425-AC are manufactured by I&J Fisnar Inc., Fair Lawn, NJ.

researchers for several years. Incheck [Ref. 34] summarized the reasons the HEATEX insert is used: the heatex enhances the coolant side heat transfer coefficient and improves the accuracy of the experimentally determined overall heat transfer coefficient; it reduces circumferential wall temperature variation; and, it reduces thermal entrance effects by inducing quicker turbulent mixing.

B. TUBES TESTED

The nomenclature used to identify tubes tested may be explained by the following example of A B C D/E F G H;

A = type of substrate: C, copper, A, aluminum, S stainless steel, K, Korodense titanium tube

B = code for inside and outside diameters of tubes, see Table 1

C = surface of tube: M, monolayer, O, oxidation

D/E = type of condensation: D, DWC, F, FWC, DF, mix of FWC and DWC

F = tube identification number, arbitrary number assigned to each tube for tracking

G = operating pressure condition: V, vacuum, A, atmosphere

H = run number

For example, A1OF2A2 is an aluminum tube with an inside diameter of 12.5mm and an outside diameter of 13.2mm. Its surface has been oxidized and exhibits FWC. The tube identification number is 2. This is run #2 at an operating pressure of one atmosphere.

Tables 2, 3, 4, and 5 list all tubes tested.

Table 1. Inside and Outside Diameters of Tubes.

DIAMETER NUMBER	INSIDE DIAMETER (mm)	OUTSIDE DIAMETER (mm)
1	12.5	13.2
2	13.9	15.9
3	12.7	13.3
4	13.0	14.4
5	13.2	14.1
6	13.5	16.1
7	12.4	13.0

Table 2. FWC Tubes.

TUBE NUMBER	SURFACE PREPARATION
S4OF9A2	Oxidized with heat
A1OF2A2	Oxidized with iodine
A1OF7A1	Oxidized with sodium hydroxide
A1OF7V1	Oxidized with sodium hydroxide
A1OF7V2	Oxidized with sodium hydroxide
A1OF7V3	Oxidized with sodium hydroxide

Table 3. DWC Tubes.

TUBE NUMBER	SURFACE PREPARATION
A3MD8A1	Al-Ti-Au-SAM hydrophobic
A3MD8A2	Al-Ti-Au-SAM hydrophobic
C3MD1A1	Cu-SAM hydrophobic
C3MD1A2	Cu-SAM hydrophobic
C3MD1A3	Cu-SAM hydrophobic
A3MD8V1	Al-Ti-Au-SAM hydrophobic
A3MD8V2	Al-Ti-Au-SAM hydrophobic
C3MD1V1	Cu-SAM hydrophobic
C3MD1V2	Cu-SAM hydrophobic
C3MD1V3	Cu-SAM hydrophobic

Table 4. Korodense Tube.

TUBE NUMBER	SURFACE PREPARATION
K6MD1A1	Au-SAM hydrophobic
K6MD1A2	Au-SAM hydrophobic
K6MD1A3	Au-SAM hydrophobic
K6MD1A4	Au-SAM hydrophobic
K6MD1V1	Au-SAM hydrophobic
K6MD1V2	Au-SAM hydrophobic
K6MD1V3	Au-SAM hydrophobic

Table 5. Coexisting FWC and DWC Tubes.

C7MDF5A1	Cu: 1 region oxidized with sodium hydroxide 1 region SAM hydrophobic
C7MDF5A2	Cu: 1 region oxidized with sodium hydroxide 1 region SAM hydrophobic
C7MDF5V1	Cu: 1 region oxidized with sodium hydroxide 1 region SAM hydrophobic
C7MDF5V2	Cu: 1 region oxidized with sodium hydroxide 1 region SAM hydrophobic
C3MDF1A1	Cu: 22 strips, 3mm each oxidized with sodium hydroxide 22 strips, 3mm each SAM hydrophobic
C3MDF1A2	Cu: 22 strips, 3mm each oxidized with sodium hydroxide 22 strips, 3mm each SAM hydrophobic
C3MDF1V1	Cu: 22 strips, 3mm each oxidized with sodium hydroxide 22 strips, 3mm each SAM hydrophobic
C3MDF1V2	Cu: 22 strips, 3mm each oxidized with sodium hydroxide 22 strips, 3mm each SAM hydrophobic
C7MDF6A1	Cu: 33 strips, 2mm each oxidized with sodium hydroxide 33 strips, 2mm each SAM hydrophobic
C7MDF6A2	Cu: 33 strips, 2mm each oxidized with sodium hydroxide 33 strips, 2mm each SAM hydrophobic
C7MDF6V1	Cu: 33 strips, 2mm each oxidized with sodium hydroxide 33 strips, 2mm each SAM hydrophobic
C7MDF6V2	Cu: 33 strips, 2mm each oxidized with sodium hydroxide 33 strips, 2mm each SAM hydrophobic

C. DATA REDUCTION

1. Introduction

The ultimate goal of the data reduction scheme is to calculate an inside and an outside heat transfer coefficient. First, the total heat transfer rate (Q) is calculated from the measured coolant mass flow rate ($\dot{m}$) and the coolant temperature rise through the tube, $(T_{out}-T_{in})$. These quantities are related to one another by

$$Q = \dot{m}c_p(T_{out} - T_{in}) . \qquad (4.1)$$

In addition, Q can be expressed as a function of the overall heat transfer coefficient (U_o), the log mean temperature difference (LMTD), and the outside condensing area (A_o) by

$$Q = U_o A_o (LMTD) \qquad (4.2)$$

where LMTD is

$$LMTD = \frac{T_{out} - T_{in}}{\ln\left(\frac{T_{sat} - T_{in}}{T_{sat} - T_{out}}\right)} . \qquad (4.3)$$

and where the outside condensing area of the tube is given by

$$A_o = \pi D_o L . \qquad (4.4)$$

By substitution, U_o may be calculated from the measured temperature values in the LMTD and the calculated heat flux (q″) by

$$U_o = \frac{q''}{LMTD}. \tag{4.5}$$

The overall thermal resistance (R_t) from vapor to coolant is calculated by summing the inside resistance (R_i), wall resistance (R_w), and the outside resistance (R_o). Note that the thermal resistances due to fouling and to any noncondensible gases are neglected.

$$R_t = R_i + R_w + R_o \tag{4.6}$$

where

$$R_i = \frac{1}{h_i A_i} \tag{4.7}$$

$$R_w = \frac{\ln(D_o / D_i)}{2\pi L k_m} \tag{4.8}$$

$$R_o = \frac{1}{h_o A_o} \tag{4.9}$$

The total thermal resistance can also be calculated from

$$R_t = \frac{1}{U_o A_o}. \tag{4.10}$$

Substituting (4.7), (4.9) and (4.10) into (4.6) forms

$$\frac{1}{U_o A_o} = \frac{1}{h_i A_i} + R_w + \frac{1}{h_o A_o}. \tag{4-11}$$

To calculate the inside condensing area, both radial heat transfer and axial heat transfer must be taken into account. Radial heat transfer takes place over the inside of the active tube length. Axial heat transfer takes place along the inlet (L_1) and outlet (L_2) tube lengths. To account for these end fin effects, an effective inside condensing area is calculated by

$$A_i = \pi D_i (L + L_1 \eta_1 + L_2 \eta_2). \tag{4.12}$$

Fin efficiencies are defined in the program Qbasic found in Appendix C.

Knowing the overall heat transfer coefficient in Eq. (4-11), the outside and inside heat transfer coefficients are left to be calculated.

2. Outside Heat Transfer Coefficient Correlations

Recall that one of the assumptions in Nusselt's film condensation analysis was that the vapor was quiescent. This is not the case in the current experimental setup. A downward velocity of between 1 and 2 m/s exists. Therefore, it is expected that during FWC the outside heat transfer coefficient calculated with a downward velocity will be greater than one calculated by the Nusselt theory.

Nevertheless, the proposed correlation is of the Nusselt form:

$$h_o = C_o Z \tag{4.13}$$

with

$$Z = \left[\frac{k_f^3 g \rho_f (\rho_f - \rho_v) h'_{fg}}{\mu_f D_o (T_{sat} - T_{wo})} \right]^{1/4} \tag{4.14}$$

where Z is taken from the Nusselt relationship, Eq. (2.1), but instead of multiplying by 0.728, a new coefficient, C_o is sought to incorporate the effect of vapor velocity as well as any surface tension effects.

3. Inside Heat Transfer Coefficient Correlations

The form of the inside heat transfer coefficient is assumed to be

$$h_i = C_i \Omega \tag{4.15}$$

where the Petukhov-Popov correlation for turbulent single phase forced convection is used so that:

$$\Omega = \frac{k_w}{D_i} * \frac{(\gamma/8) Re Pr}{K_1 + K_2 (\gamma/8)^{1/2} (Pr^{2/3} - 1).} \tag{4.16}$$

where

$$K_1 = 1 + 3.4\gamma \qquad (4.17)$$

$$K_2 = 11.7 + 1.8Pr^{-1/3} \qquad (4.18)$$

Several assumptions and requirements go along with the Petukhov-Popov correlation, as noted by Incheck [Ref. 34]. First, the correlation was derived for fully developed turbulent flow in smooth tubes with constant heat flux along the tube wall. Second, it assumes a long straight inlet section prior to the test section. Third, properties are determined from the coolant bulk mean temperature (T_m).

The current circumstances may be incorporated into the Petukhov-Popov correlation. At Prandtl numbers of water or air, thermal resistance is primarily very close to the wall. The temperature profile is therefore essentially flat over most of the tube cross section. Turbulent, fully developed flow is induced in the tube because of the Heatex insert. The Petukhov-Popov correlation may therefore be applied to the current tube size using the Heatex insert and as in the outside case, an unknown coefficient of C_i is used to account for differences.

4. Modified Wilson Plot Technique

The challenge still remains to determine h_i and h_o. Recall the equations for h_o and h_i developed from correlations, Eq. (4.13) and (4.15). When substituted into Eq. (4.11) the result is

$$\frac{1}{U_oA_o} = \frac{1}{C_i\Omega A_i} + R_w + \frac{1}{C_oZA_o}. \qquad (4.19)$$

A modified Wilson Plot Technique [Ref. 37] is used.

The modified Wilson Plot Technique must be used because the tube wall temperature was not measured during this thesis. In this technique, we obtain the values of C_i and C_o by iteration. However, to use this technique we need to obtain the condensate properties for Z in Eq. 4.14 at the film temperature, which in turn needs T_{wo}. Therefore, for each iterative step on C_i and C_o, T_{wo} is also computed. An initial value of T_{wo} is guessed and Z is evaluated to obtain h_o. The guessed value of T_{wo} is checked against a calculated value

$$T_{wo} = T_{sat} - \frac{q''}{h_o} \qquad (4.20)$$

After T_{wo} converges to within an acceptable tolerance, the values of C_i and C_o are calculated in the following manner.

Multiplying equation (4.19) by ZA_o, after subtracting the term R_w gives

$$\left(\frac{1}{U_o} - R_w A_o\right) Z = \frac{Z A_o}{C_i \Omega A_i} + \frac{1}{C_o} \tag{4.21}$$

which can be rearranged into the equation of a straight line, Y=mX+b, where

$$Y = \left(\frac{1}{U_o} - R_w A_o\right) Z, \quad X = \frac{A_o Z}{A_i \Omega}, \quad m = \frac{1}{C_i}, \text{ and } \quad b = \frac{1}{C_o} \tag{4.22}$$

Eq. 4.21 is obtained for each of the 14 sets of test data points and the values of C_i and C_o are found with a least squares fit. Once C_i and C_o are determined, outside and inside heat transfer coefficients may now be determined by solving Eqs. 4.13 and 4.15. To finally compute h_o, Eqs. 4.13 and 4.20 are solved iteratively for ΔT_{wo} and h_o is ultimately computed by Eq. 4.13.

5. FWC Heat Transfer Coefficients

C_i for each FWC run was initially calculated from the Modified Wilson Plot method described above. An arithmetic average of C_i for all atmospheric pressure and vacuum runs was then obtained, $\overline{C_i}$. With the known value of $\overline{C_i}$, h_i was calculated from Eq. (4.15) and applied to Eq. (4.11) in the following form to get a new value of h_o:

$$h_o = \left[\frac{1}{U_o} - \left(\frac{A_o}{h_i A_i} + R_w A_o \right) \right]^{-1} \tag{4.23}$$

A least-squares best fit of the reprocessed h_o data was calculated and the resulting C_o's for each run were computed from Eq. (4.13).

6. DWC Heat Transfer Coefficients

The previous method of calculating h_o was not used for DWC and coexisting FWC and DWC. For DWC, when calculating h_o by Eq. (4.24) a negative value of h_o was common. This was caused by the very small outside thermal resistance in DWC in relation to the inside resistance. A small variation in the measured value of h_i could cause negative values of h_o to result. To avoid the differencing of large numbers, Eq. (4.13) was used to calculate h_o.

From the data provided by Takeyama and Shimizu of Figure 1 [Ref. 2], it is apparent that for a surface subcooling of between 2-50K, the slopes of heat flux vs. surface subcooling for FWC and DWC are nearly parallel. Because no specific correlation for DWC is available, the Nusselt correlation, Eq. (4.13), was therefore used to calculate the form of the outside heat transfer coefficient. In this case, it is assumed that DWC is an enhancement of FWC in magnitude only and the slopes are identical.

Figure 1 also shows that, at lower values of surface subcooling the slope is unity. As an alternative to using the Nusselt correlation during DWC, the outside heat transfer coefficient may therefore be assumed to be constant, so that the heat flux is directly proportional to the ΔT_{wo}.

Both methods were tried, with their results reported in Chapter V. In order to calculate a meaningful enhancement ratio, as described below, the Nusselt correlation was used to calculate the outside heat transfer coefficients for DWC and coexisting FWC and DWC condensation.

D. ENHANCEMENT RATIO

The enhancement ratio is used to compare the heat transfer coefficients, at the same $(T_{sat}-T_{wo})$, of various tubes to a smooth FWC tube. This ratio was discussed by Incheck [Ref. 34] and the same relationship was applied in this thesis. With the definition, and using Eq. (4.13), the enhancement ratio is determined by:

$$\varepsilon_{\Delta T}=\left(\frac{C_o}{C_{o,\ \mathrm{smooth\ FWC}}}\right)_{\Delta T}. \qquad (4.24)$$

V. RESULTS AND DISCUSSION

A. GENERAL DISCUSSION

A total of 35 experiments were conducted at atmospheric pressure and at vacuum; six runs were FWC, 10 runs were DWC, 12 runs were coexisting condensation, and seven runs were with Korodense DWC. Substrate materials included stainless steel, aluminum, copper, and titanium. For each run, in addition to the data recorded, the condensation mechanisms were observed using a VHS video recorder.

Vacuum runs invariably gave outside heat transfer coefficient values lower than those at atmospheric pressure. This observation is consistent with data from other researchers as provided by Tanasawa [Ref. 7].

B. UNCERTAINTY ANALYSIS

The Kline and McClintock method [Ref. 38] was used to determine the uncertainties of several quantities. An uncertainty program was written by Das [Ref. 16] based on the program used by Incheck [Ref. 34]. The program is located in Appendix E.

The major difference between the program used in this thesis and that used by Incheck [Ref. 34] is in the calculation of uncertainty in h_o. H_o is calculated from Eq. (4.13). In order to calculate the uncertainty in h_o, an uncertainty in ΔT_{wo} must be found. An iterative loop is needed because of the dependence of h_o on ΔT_{wo}, as discussed earlier. The dependence of h_o on ΔT_{wo} is relieved by replacing ΔT_{wo} with q''/h_o. Now, the uncertainty in h_o may be solved directly.

An example of typical uncertainty values for the outside heat transfer coefficient for all FWC at vacuum is about 4% and at atmospheric pressure the uncertainty is about 2%. For all DWC, uncertainty in the outside heat transfer coefficient is about 7% at vacuum and about 20% at atmospheric pressure. The difference in uncertainty between DWC and FWC can be explained by the initial assumptions of DWC and FWC behavior. FWC behavior was accurately calculated by the Nusselt theory. DWC, however, was forced to conform to the Nusselt theory. The higher uncertainty would indicate that the Nusselt theory does not predict DWC behavior as accurately as FWC.

C. TRENDS IN FILMWISE CONDENSATION

The taking of filmwise data proved to be the most challenging aspect of the project, since a smooth film covering 100% of the tube surface was difficult to achieve. The aluminum tubes oxidized with iodine appeared to initially give good FWC; however, during the course of an experimental run, irregularities appeared on the surface. Irregularly-shaped lines appearing as "cracks" or random "rivers" emerged on the tube and seemed to disrupt the film. This was also noticed, although to a lesser degree, on the aluminum tubes oxidized with sodium hydroxide. The copper tubes oxidized with sodium hydroxide did not appear to have the same surface characteristics as the aluminum tubes and they produced a good film. In order to improve upon the filmwise behavior, after a tube was mounted in the test section, the viewing window was opened and the tube was rubbed with a cloth. It was then flooded with distilled water using a spray bottle. In some cases, this procedure produced a smooth film. Oxidizing in a solution of sodium hydroxide provided the best film. For this reason, during all the coexisting condensation runs, FWC was established using the sodium hydroxide solution. Figure 11 indicates visually the best quality of FWC achieved on an aluminum tube. Notice the solid horizontal white line of light. Very few ripples in the film are observed from distortions in this line, indicating a good quality, laminar film.

Table 6 summarizes all the FWC data. It lists the experimentally determined inside and outside heat transfer correlation leading coefficients, enhancement (equal to unity for these tubes), and the high and low heat flux of each of the runs. Notice that for a given pressure, the C_i values are the same. C_i values vary by about 10% between vacuum and atmospheric pressure.

Also, notice that the C_o values are in the range of 0.77-0.88 compared to the well known Nusselt value, Eq. (2.1) of 0.728. $C_{o,smooth}$ for both vacuum and atmospheric pressure is 0.83.

Figure 12 shows all of the outside FWC heat transfer coefficient data at vacuum versus the calculated temperature difference across the condensate film. A "best fit" curve of the data is also included. Figure 13 is a similar plot for all the atmospheric pressure data. Figures 14 and 15 compare the FWC results at vacuum and atmospheric pressure respectively, to the Nusselt theory. The smooth tube data are higher than Nusselt theory because of a downward vapor velocity of between 1 and 2 m/s causing vapor shear to thin the film.

Table 6. FWC Tube Data.

TUBE NUMBER	C_i	C_o	$\varepsilon_{\Delta T}$	Heat Flux kw/m^2 High	Low
S4OF9A2	2.1	.88	1.0	491	393
A1OF2A2	2.1	.81	1.0	583	436
A1OF7A1	2.1	.81	1.0	578	436
A1OF7V1	1.9	.87	1.0	224	167
A1OF7V2	1.9	.77	1.0	207	153
A1OF7V3	1.9	.84	1.0	224	161

D. TRENDS IN DROPWISE CONDENSATION

Ten runs were made with the entire tube operating with DWC, 5 runs at vacuum and 5 runs at atmospheric pressure. Utilizing Super VHS recording equipment and analyzing still pictures of the DWC video, the sweeping frequency of the drops was calculated. Figures 16 through 21 show still pictures of six consecutive video frames. The time between frames is 0.033s. It is clear that the SAM provided excellent DWC, as evident by the large contact angle of the drops. Notice also that at any instant of time, the surface exhibits a droplet distribution with large drops (2-3mm in diameter) at the top and bottom, small drops predominately in the middle and sweeping drops (blurs in the picture) going around the tube. Viewing a drop at the top of the tube, as it began to sweep the surface, to when it had departed the surface, 0.165s elapsed. Therefore, the sweeping frequency of a drop on a copper tube coated with the SAM was approximately 0.2s. Table 7 summarizes the experimentally determined inside and outside heat transfer correlation leading coefficients, the enhancement ratio, and the high and low heat flux of each experimental run. The C_i values have increased from the C_i values of FWC. Apparently, C_i is sensitive to the magnitude of heat flux and to heat flux variation around the tube. Recall the circumferentially varying heat flux that exists on a tube of FWC. The top of

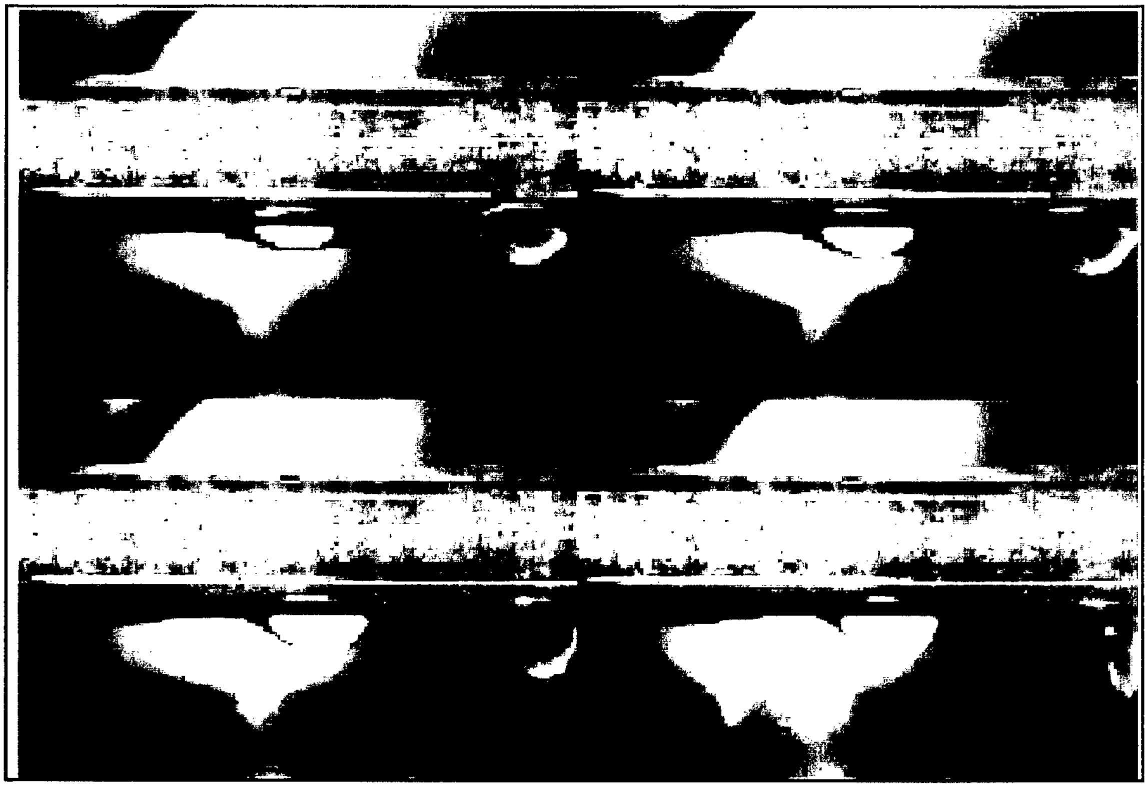

Figure 11. Four Sequential Frames of FWC on an Aluminum Tube.

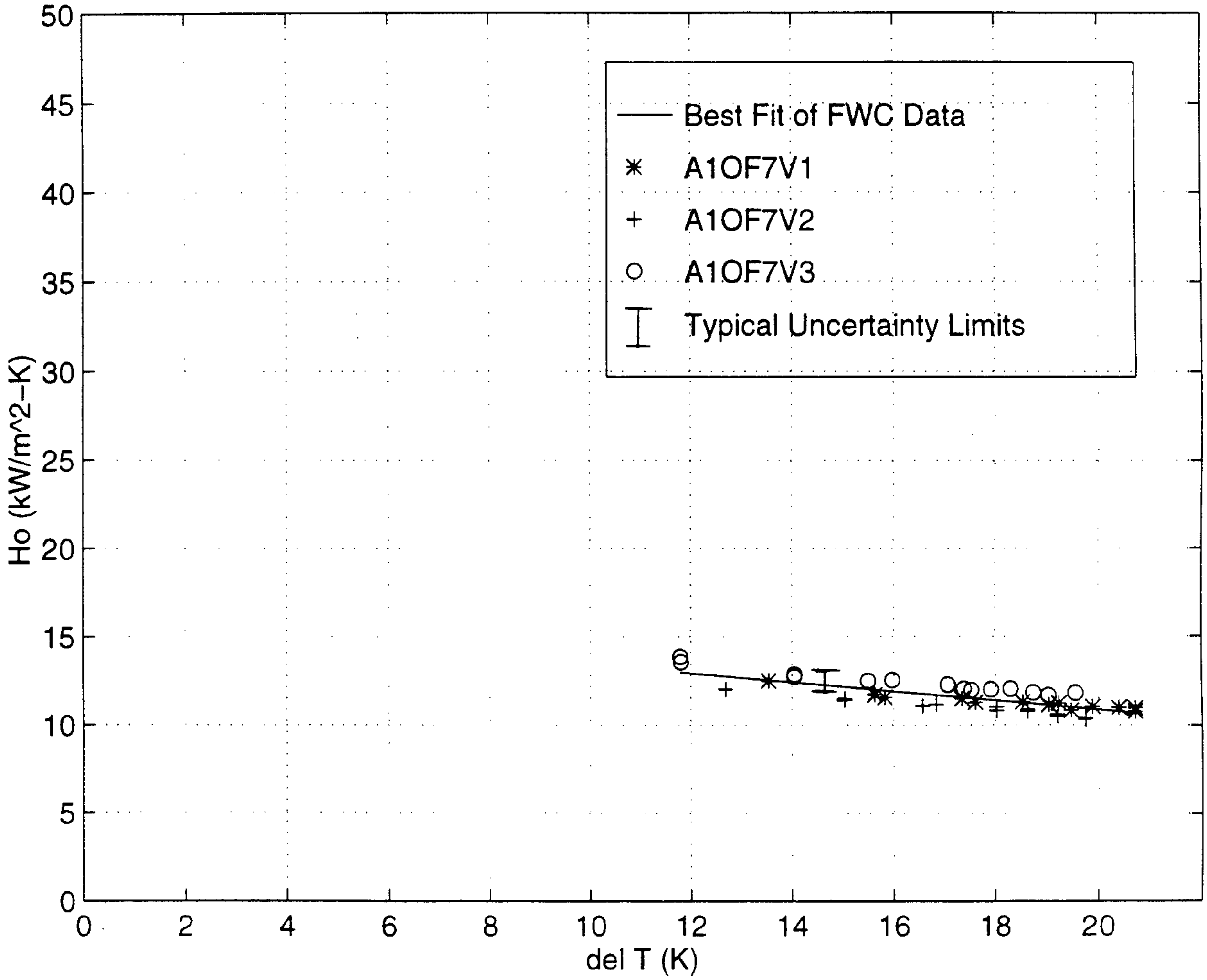

Figure 12. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All FWC Data and Best Fit Data at Vacuum.

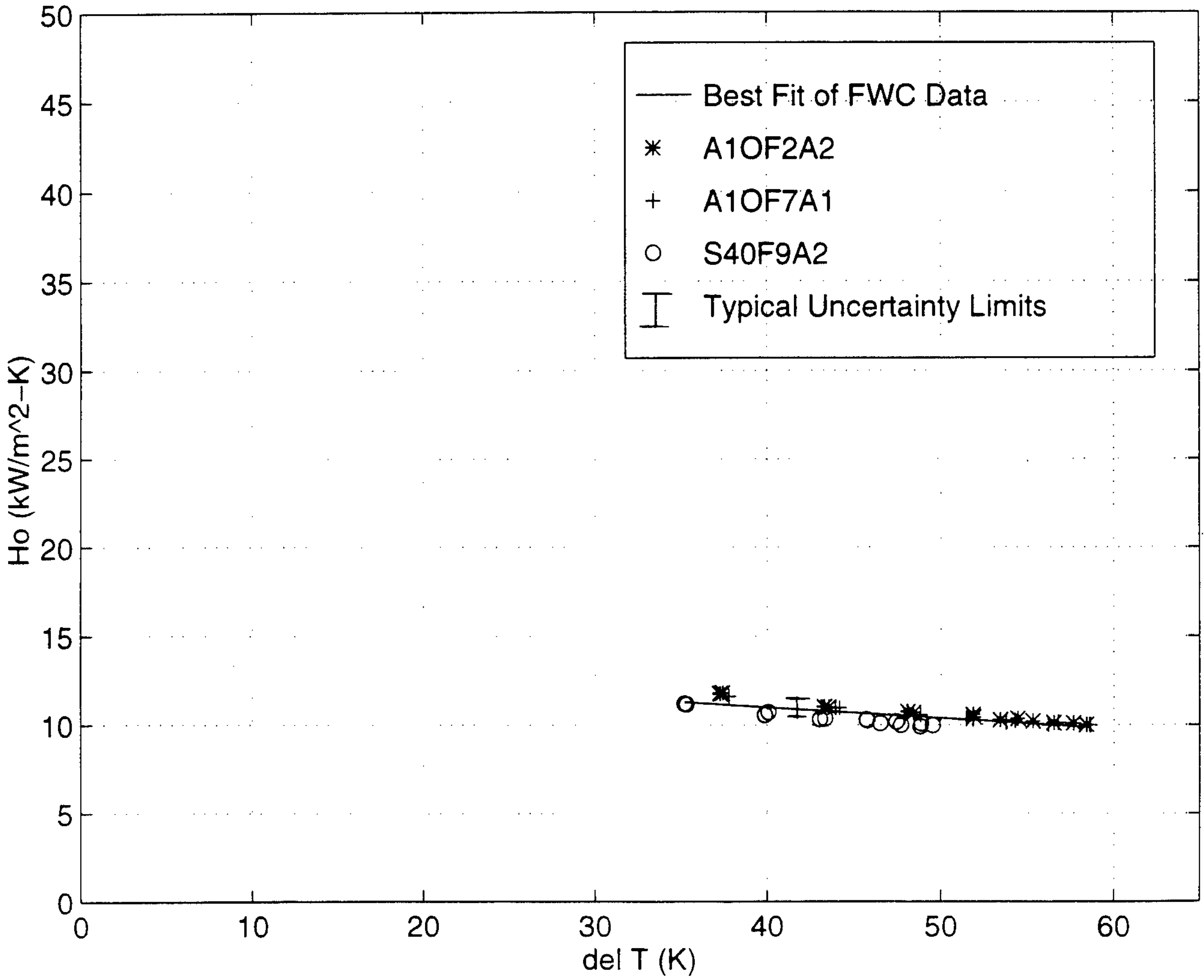

Figure 13. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All FWC Data and Best Fit Data at Atmospheric Pressure.

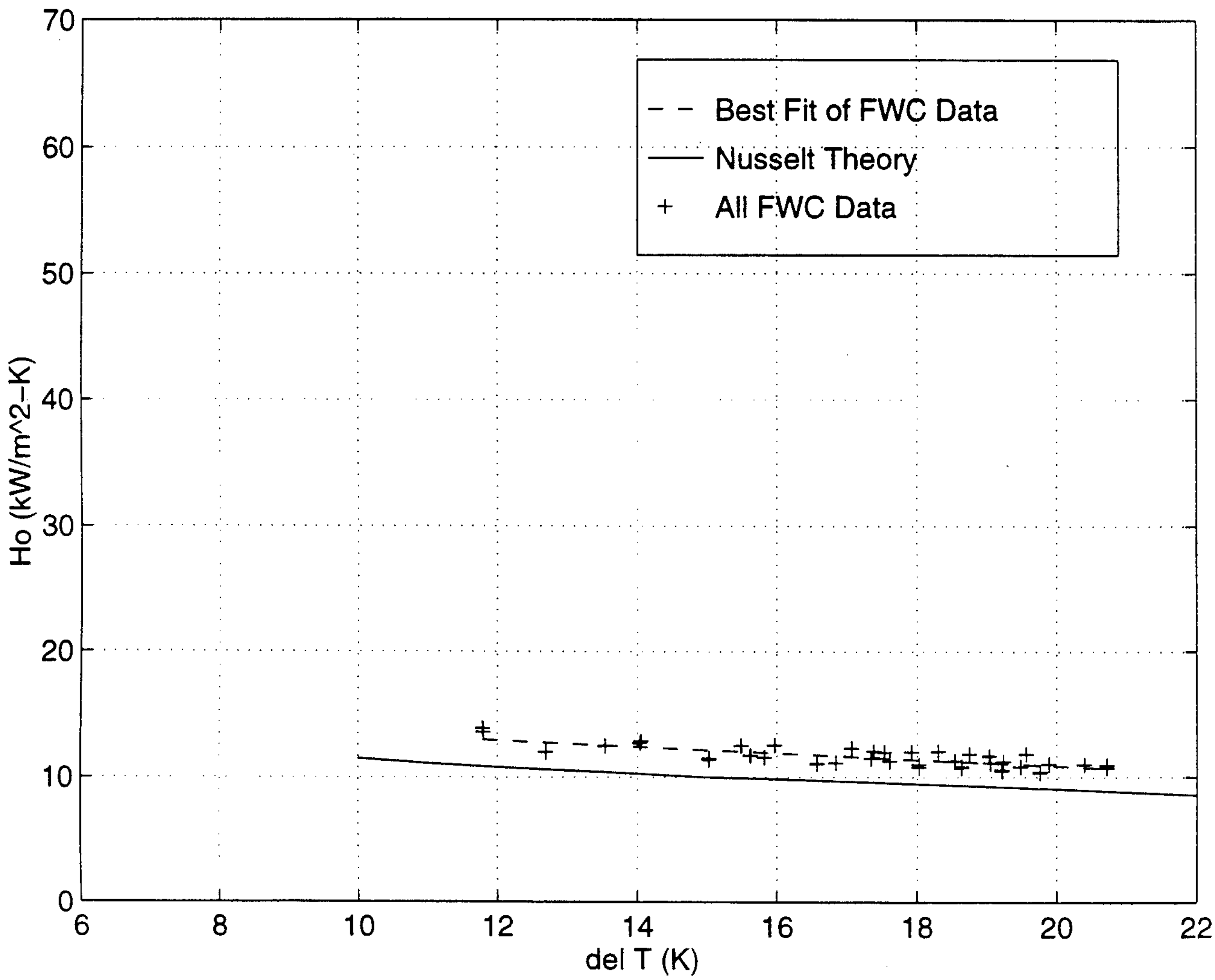

Figure 14. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Comparison of FWC Data to Nusselt Theory at Vacuum.

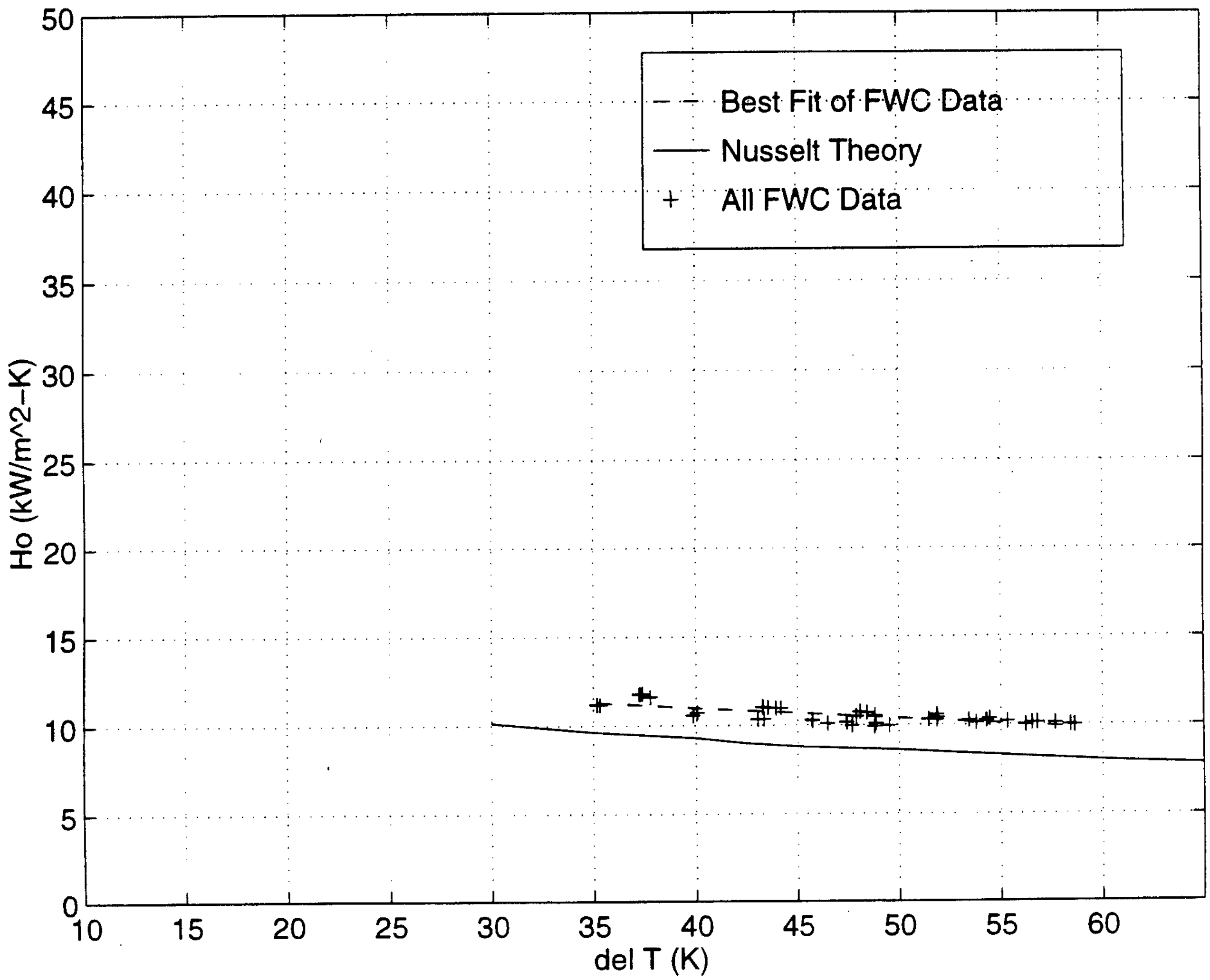

Figure 15. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Comparison of FWC Data to Nusselt Theory at Atmospheric Pressure.

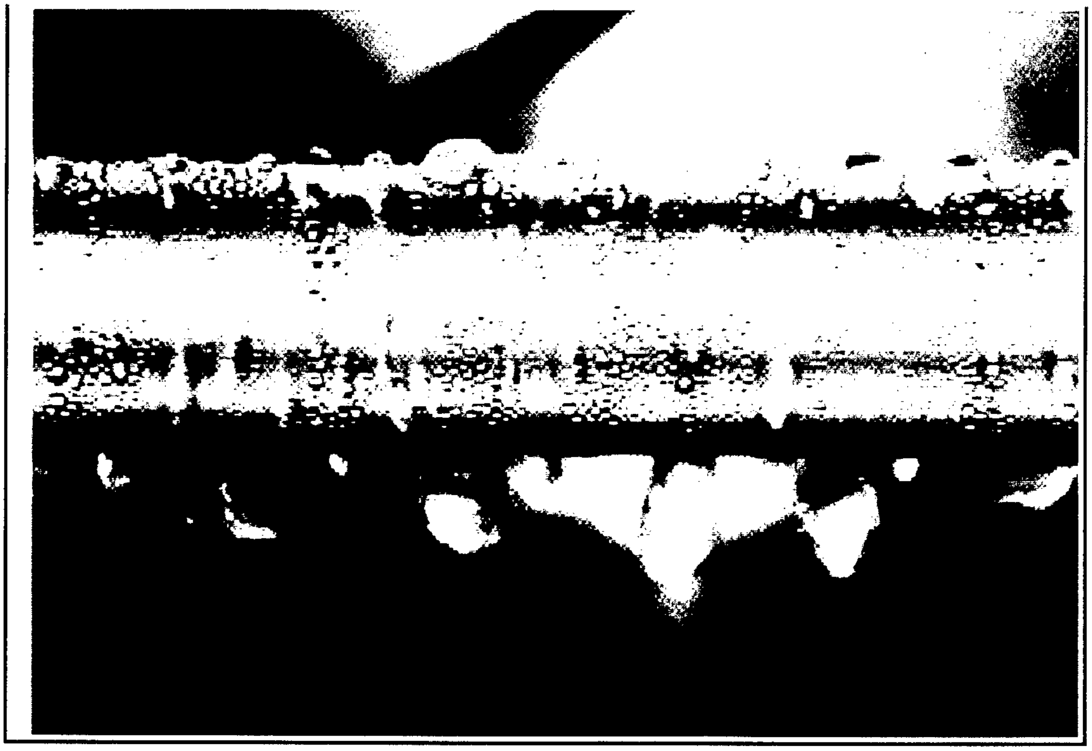

Figure 16. DWC on a Cu Tube Sequence #1 Time = 0s.

Figure 17. DWC on a Cu Tube Sequence #2 Time = 0.033s.

Figure 18. DWC on a Cu Tube Sequence #3 Time = 0.066s.

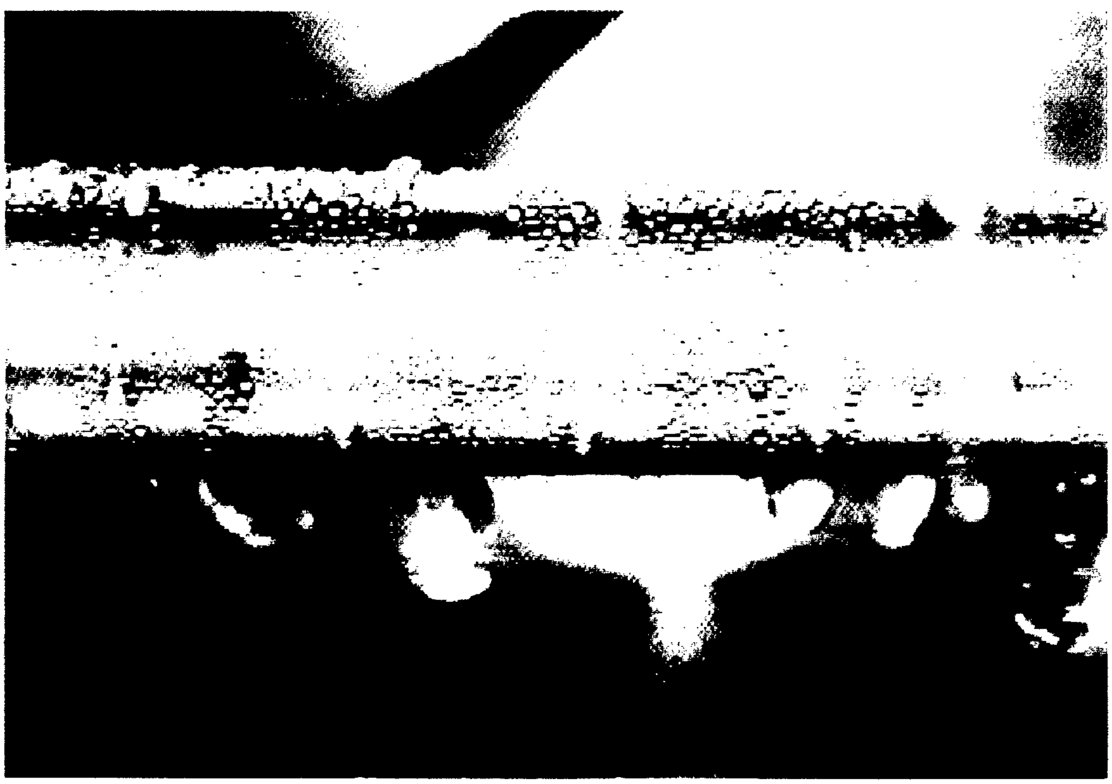

Figure 19. DWC on a Cu Tube Sequence #4 Time = 0.099s.

Figure #20. DWC on a Cu Tube Sequence #5 Time = 0.132s.

Figure 21. DWC on a Cu Tube Sequence #6 Time = 0.165s.

the tube, having the thinnest film, has higher heat flux than the bottom of the tube which has a thicker film. In the DWC case, a higher heat flux exists on the sides of the tube because of the presence of small drops. DWC has higher heat flux than FWC and hence all DWC data will exhibit higher C_i values, because of the presence of small drops. Figure 22 and $\varepsilon_{\Delta T}$ in Table 7 indicate that DWC on a copper tube gives an enhancement factor of about four above the all FWC case at vacuum. At atmospheric pressure, the enhancement is even higher, about ten, as shown in Figure 23 and in Table 7. The mechanism for this improvement is the presence of numerous microscopic-sized drops that do not exist during FWC. These small droplets continue to form on the surface due to very active sweeping of larger drops from above. Smaller drops are formed after a larger drop sweeps off the surface and the DWC cycle repeats itself. This sweeping effect controls the size of drops on the lower part of the tube, as they are not able to grow too large because they are coalesced into the sweeping drop.

Figures 24 and 25 show the condensing curves for the copper tubes at vacuum and atmospheric pressure respectively. The heat flux for DWC is larger than the heat flux for FWC at the same temperature difference but the slope has been kept at 3/4 in order to conform to the Nusselt theory. If, over the measured heat flux range, the slope of heat flux versus subcooling was unity, the outside heat transfer coefficient would be constant. When the data were reprocessed assuming h_o equal to a constant, the results shown in Figures 26 and 27 occur. The dash-dot line through the data in Figures 26 and 27 represents the constant outside heat transfer coefficient for vacuum and atmospheric conditions. When compared to the constant h_o line, the high and low values of the data vary by about 15% for vacuum conditions and by about 10% for atmospheric pressure.

1. Effect of Substrate Material on DWC

In Figures 28 and 29, aluminum tube DWC data have been added to the copper tube DWC data at vacuum and atmospheric pressure respectively. There is an approximate 15% decrease in the outside heat transfer coefficient of aluminum tubes over that of copper tubes at vacuum and about a 30% decrease at atmospheric pressure. The trend is consistent and adds credence to the theory that substrate conduction plays an important role in DWC as proposed by Mikic [Ref. 7]. Mikic states that the heat transfer coefficient during DWC must be lower on a condensing surface made of a poor conductivity material. [Ref. 7] Since the thermal conductivity of aluminum is about half of the thermal conductivity of copper, the aluminum tube should produce lower heat transfer coefficients.

Table 7. DWC Tube Data.

TUBE NUMBER	C_i	C_o	$\varepsilon_{\Delta T}$	Heat Flux kw/m^2 High	Low
A3MD8A1	2.7	6.1	7.3	2234	1030
A3MD8A2	2.6	6.1	7.34	2245	1037
C3MD1A1	2.4	8.6	10.4	2375	1010
C3MD1A2	2.4	8.5	10.2	2391	1001
C3MD1A3	2.4	8.8	10.6	2357	990
A3MD8V1	2.5	3.0	3.6	581	317
A3MD8V2	2.5	2.9	3.5	598	324
C3MD1V1	2.2	3.4	4.1	577	294
C3MD1V2	2.2	3.4	4.1	582	291
C3MD1V3	2.2	3.4	4.1	590	296

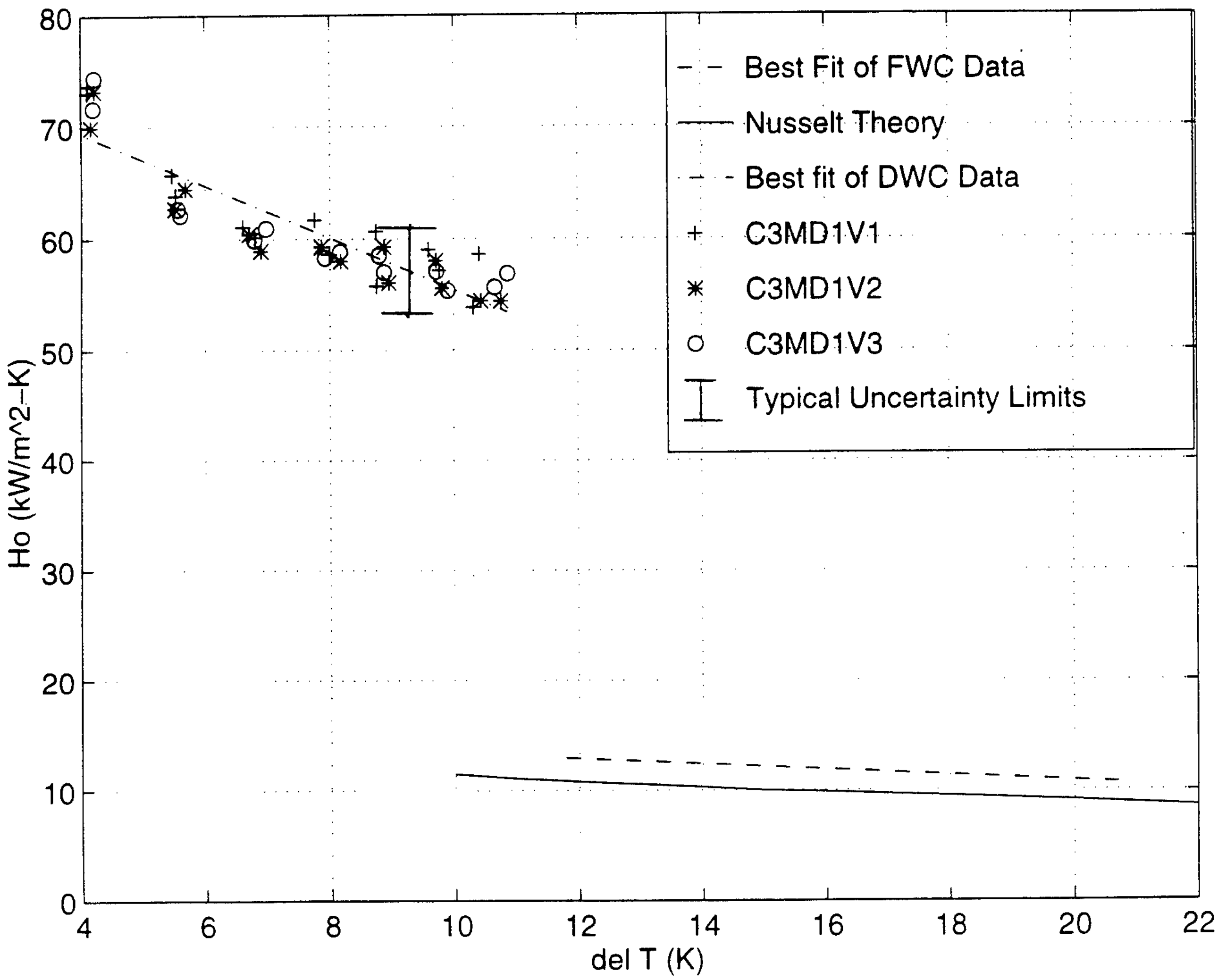

Figure 22. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All DWC on a Copper Tube at Vacuum.

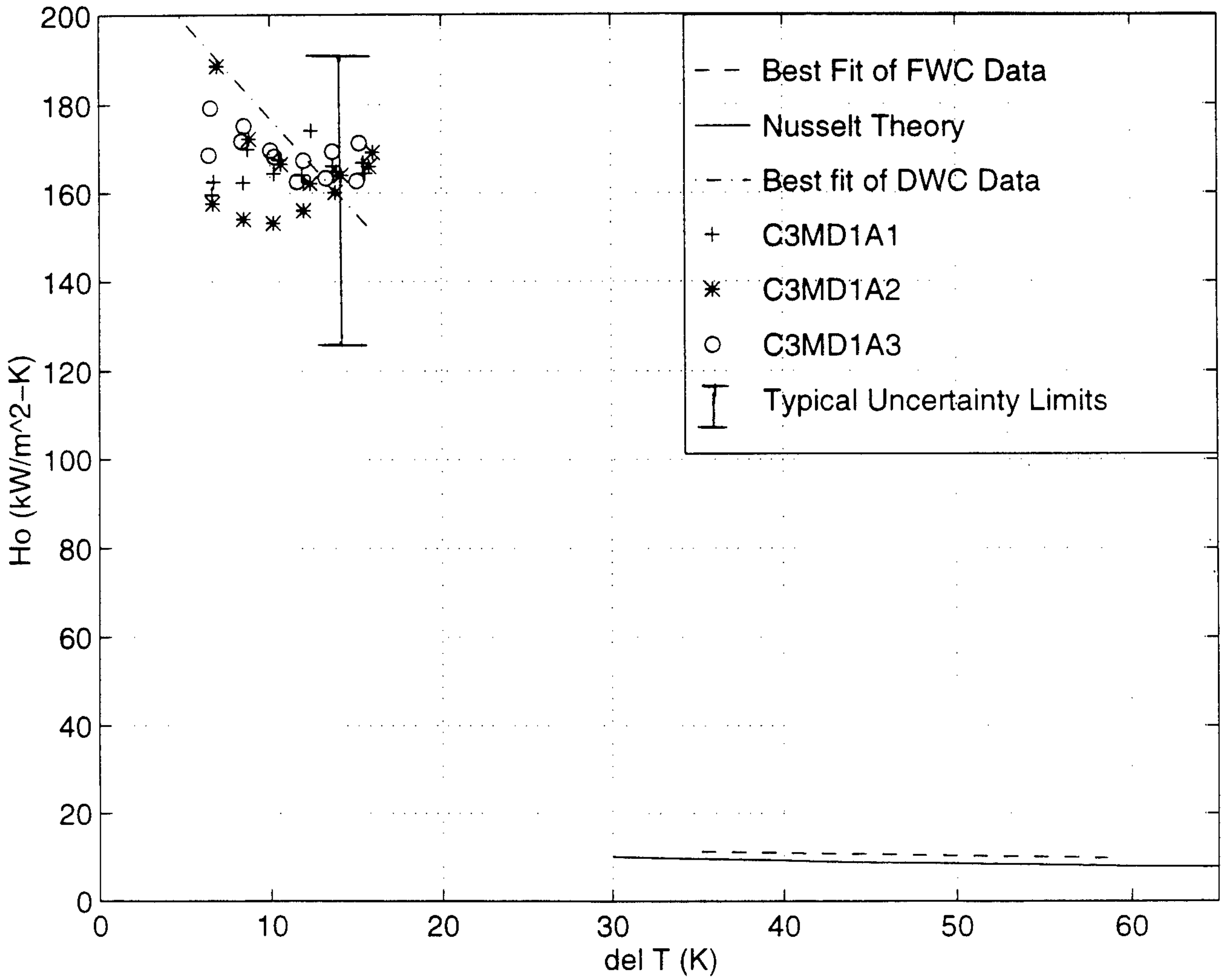

Figure 23. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All DWC on a Copper Tube at Atmospheric Pressure.

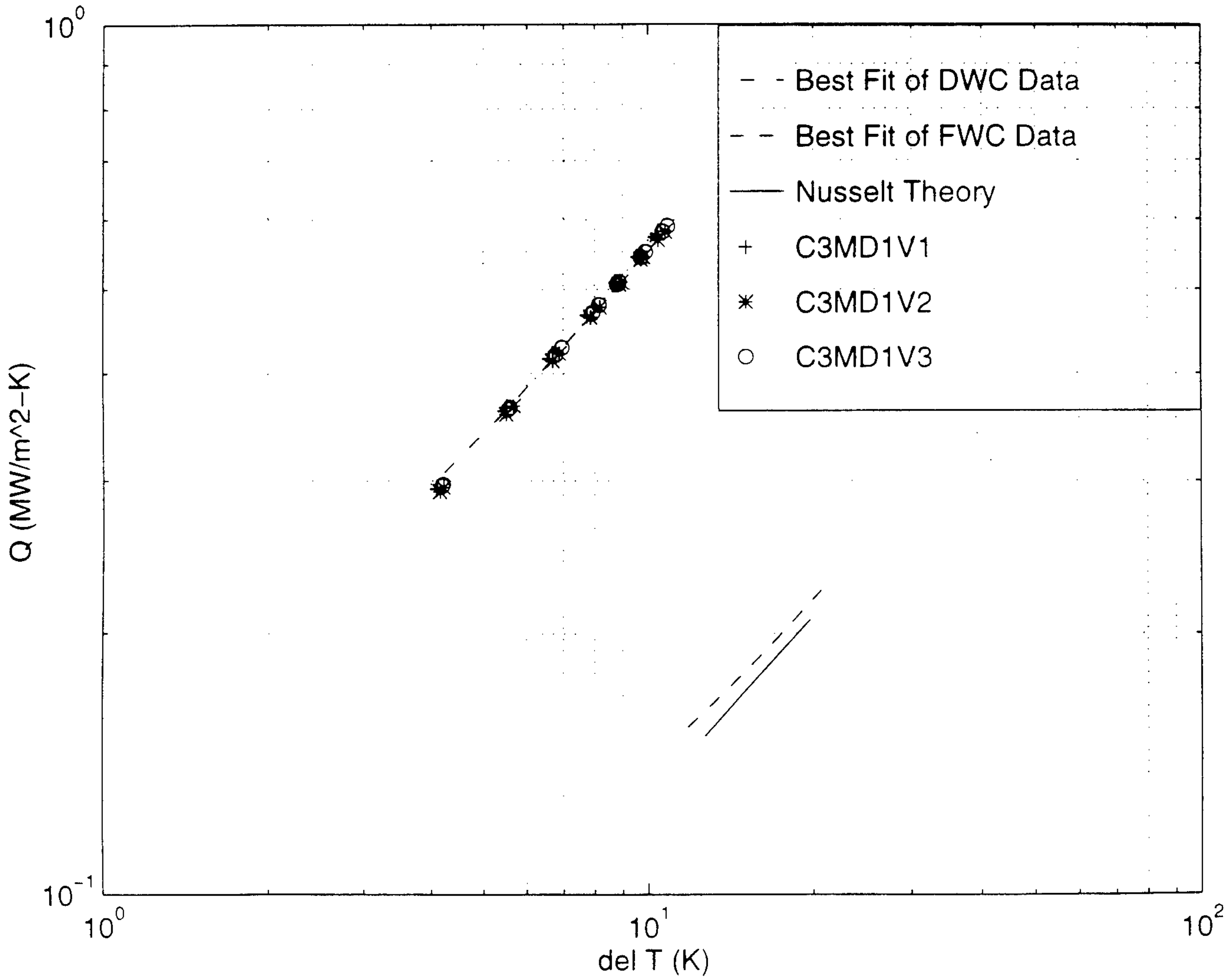

Figure 24. Experimentally Determined Values of Heat Flux vs. Temperature Difference Across the Condensate Film. All DWC on a Copper Tube at Vacuum.

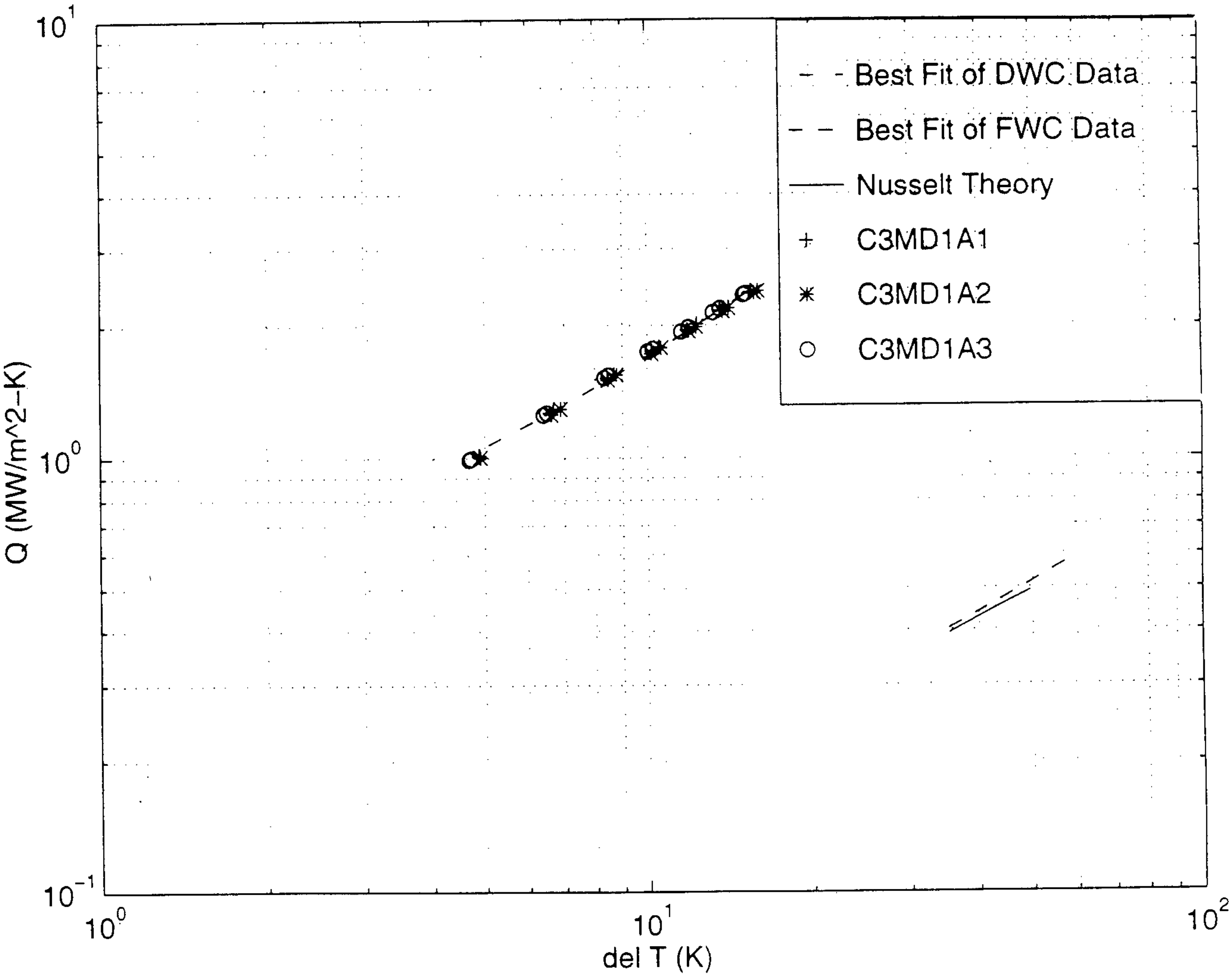

Figure 25. Experimentally Determined Values of Heat Flux vs. Temperature Difference Across the Condensate Film. All DWC on a Copper Tube at Atmospheric Pressure.

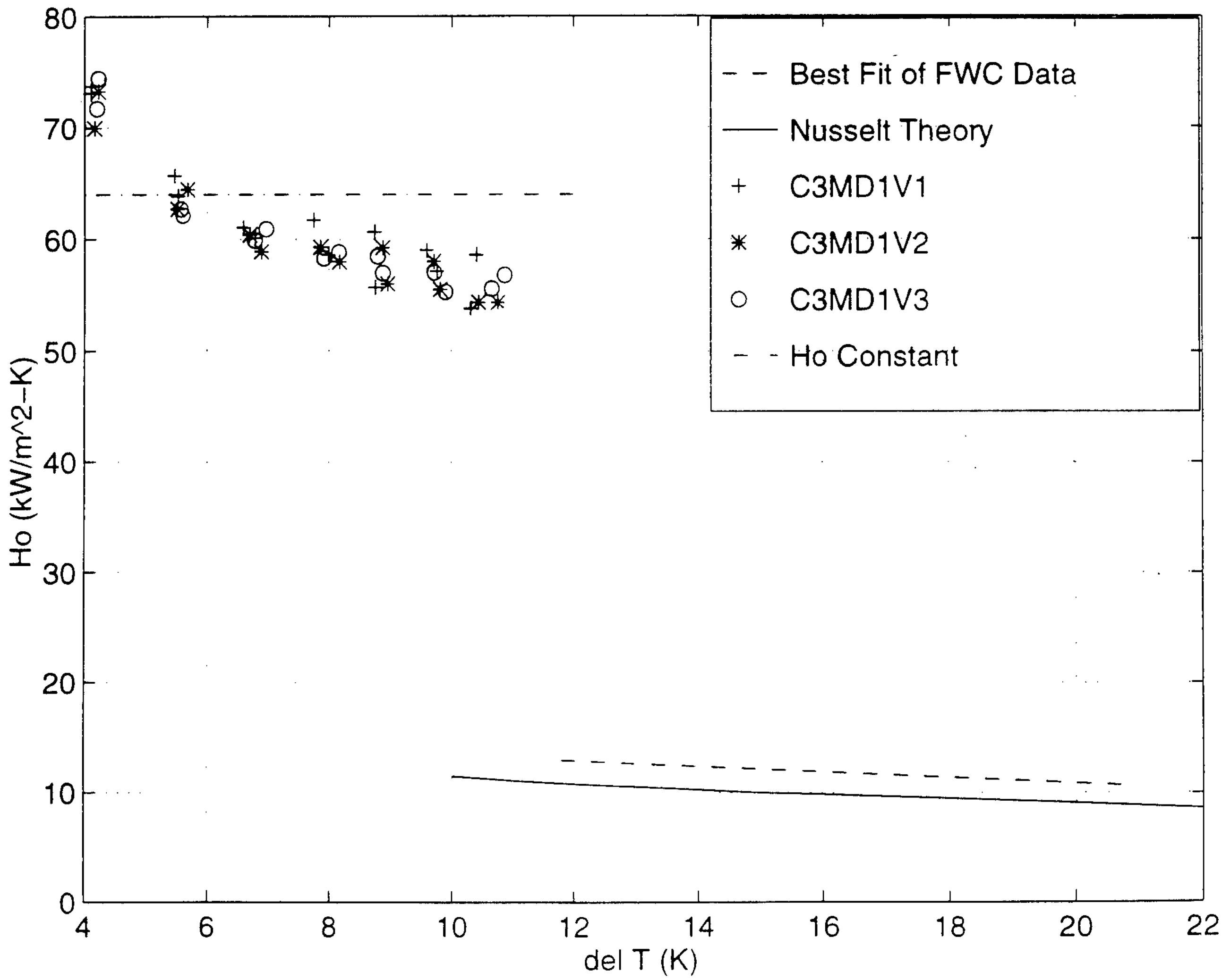

Figure 26. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All DWC and h_o Constant data on a Copper Tube at Vacuum.

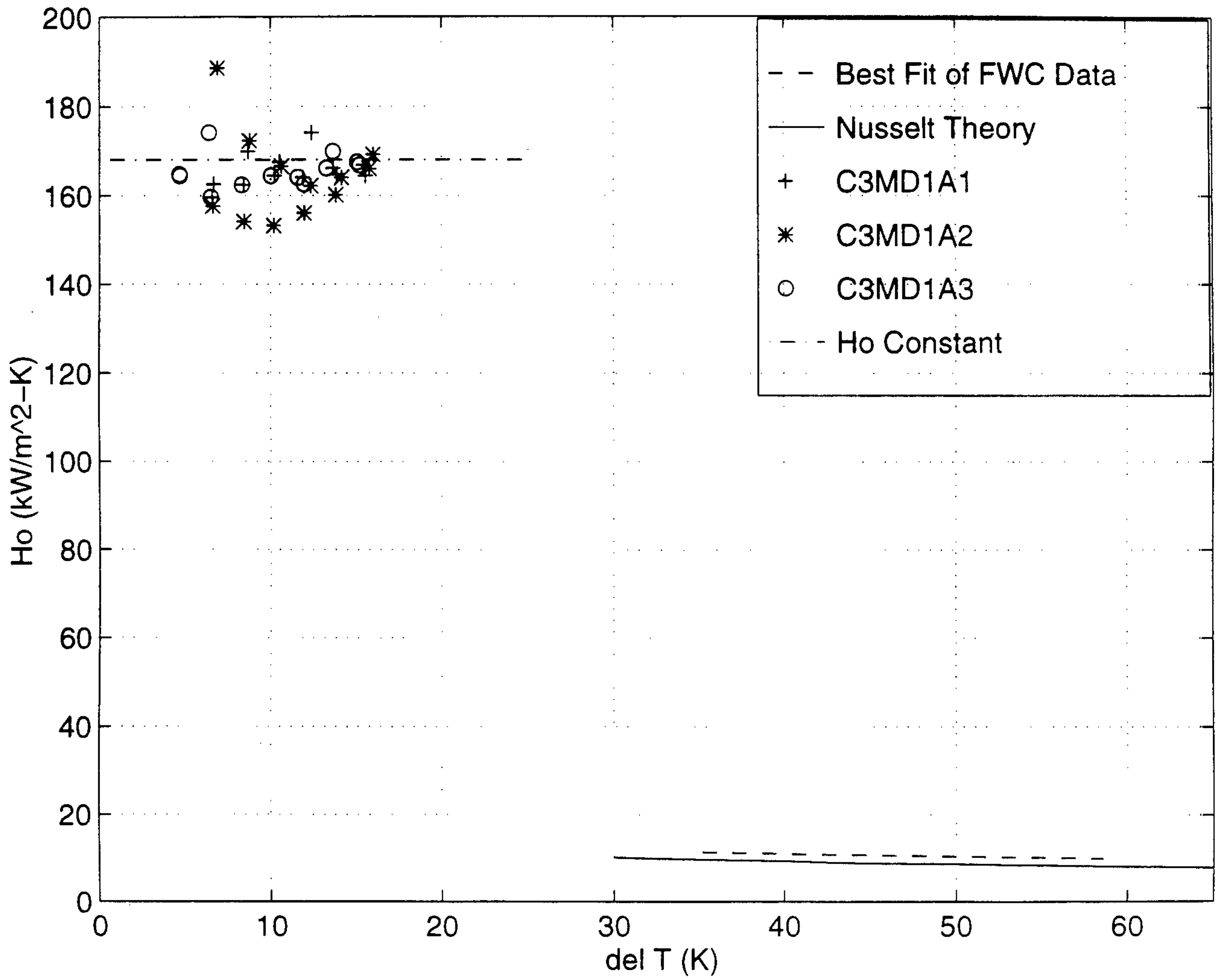

Figure 27. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All DWC and h_o Constant data on a Copper Tube at Atmospheric Pressure.

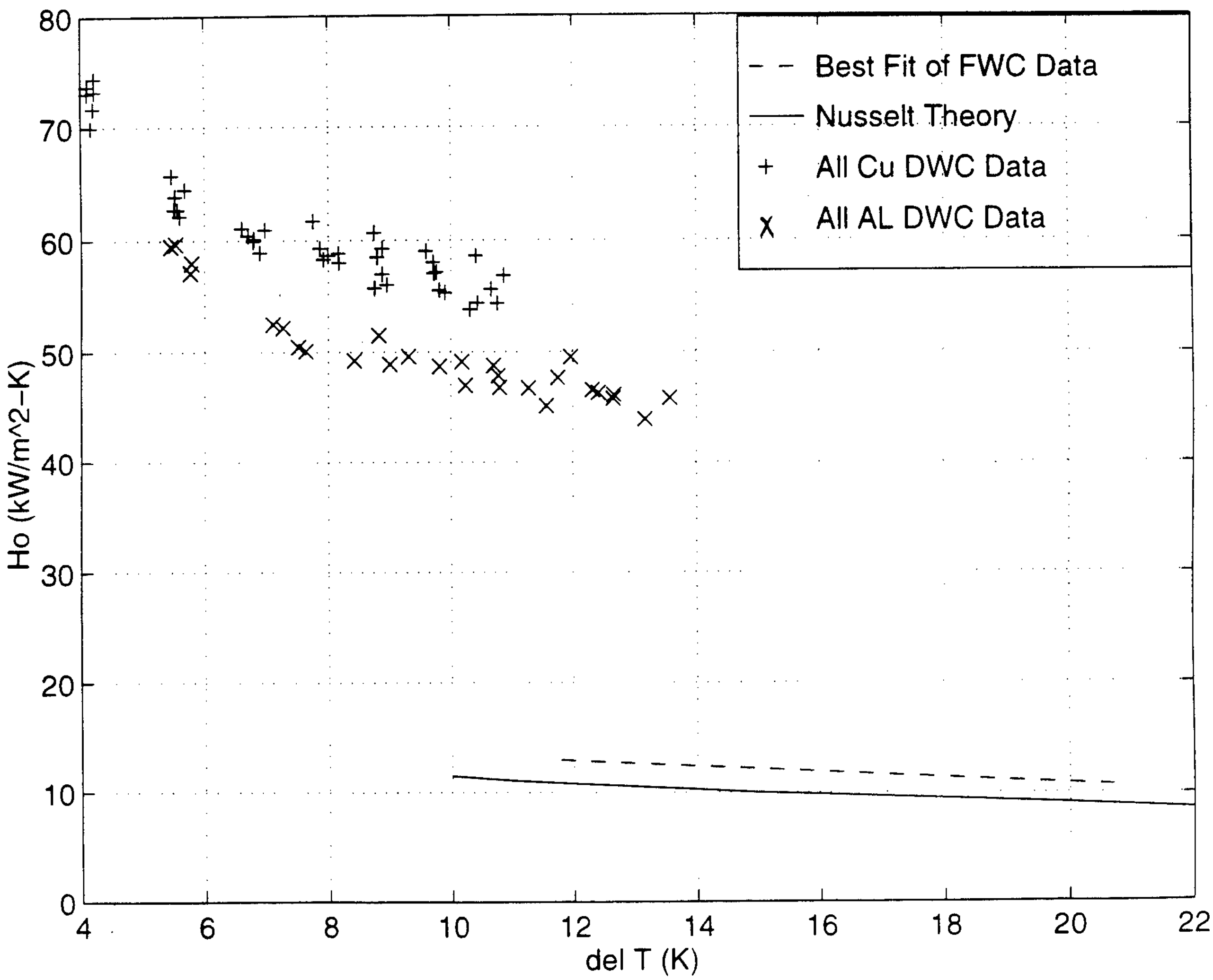

Figure 28. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Effect of Substrate Material at Vacuum.

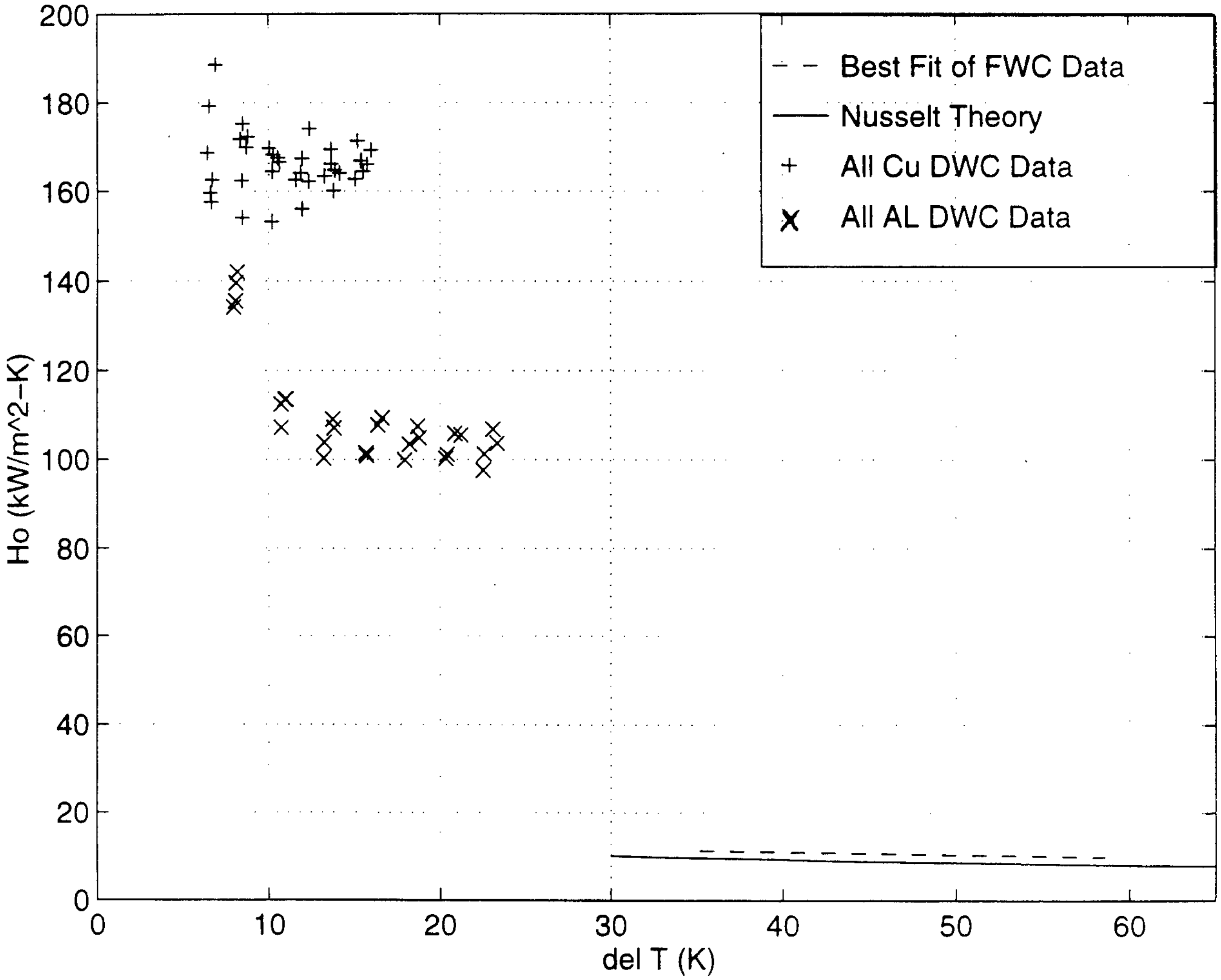

Figure 29. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Effect of Substrate Material at Atmospheric Pressure.

2. Effect of Surface Preparation on DWC

Another possible explanation of the reduction in heat transfer of aluminum DWC tubes is roughness effects. The aluminum DWC tubes were not polished prior to the coating of titanium, gold, and SAM. They had a machine finish. On the other hand, the copper tubes were polished in the five step polishing procedure as mentioned in Chapter IV. As discussed previously in Chapter II, roughness on a surface tends to decrease DWC heat transfer. One way to eliminate the ambiguity of the results is to polish aluminum tubes in the five step procedure and retest. Results in this case may then be better compared to results for the polished copper tube case.

E. COEXISTING FWC AND DWC

1. One region each of FWC and DWC

During this thesis, for coexisting FWC and DWC, a 50% area ratio was used and held constant. The first tube of this type tested had one region each of FWC and DWC. The FWC region was oxidized with sodium hydroxide and the DWC region was promoted by the SAM. Figure 30 shows the regions on the tube in relation to the cooling water flow path.

Figure 31 is a photograph of the interface region between the FWC and DWC zones. In the region near the interface, drops were seen moving into the film, by coalescence, especially on the top of the tube. By this local action, drops were prevented from growing. The

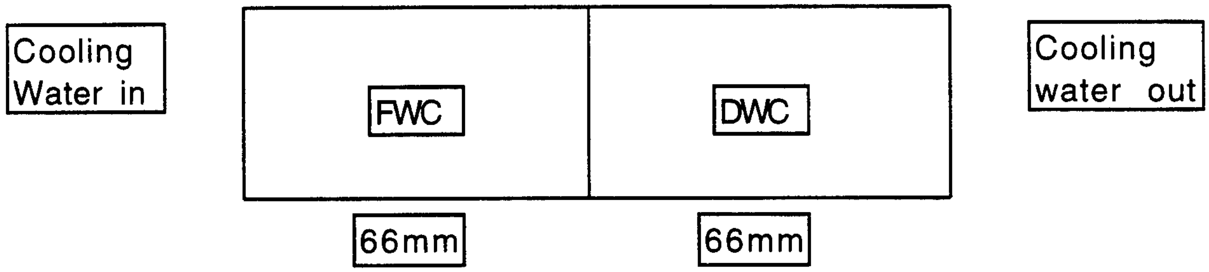

Figure 30. Sketch Showing One Region each of FWC and DWC.

entering drops from the DWC region into the FWC entering drops from the DWC region into the FWC region affected a small portion of the FWC zone, approximately 6mm in width. This portion of FWC showed turbulent-like ripples on the condensate surface, indicating that heat transfer was perhaps enhanced over the laminar flow case. Table 8 summarizes the data taken. In Figure 32, the coexisting FWC and DWC vacuum data have been plotted as well as the arithmetic mean of all FWC and all DWC from earlier runs. We would expect that the average heat flux, or average h_o, should be the simple arithmetic mean of FWC and DWC or even slightly higher due to the one interface zone where drops are coalescing into the FWC zone and disturbing the film. The reason why the data is lower is not clear. It may be that the data is lower due to the location of the FWC and DWC surfaces. The FWC zone is on the cooling water inlet side and the DWC zone is on the cooling water outlet side. The FWC zone is therefore

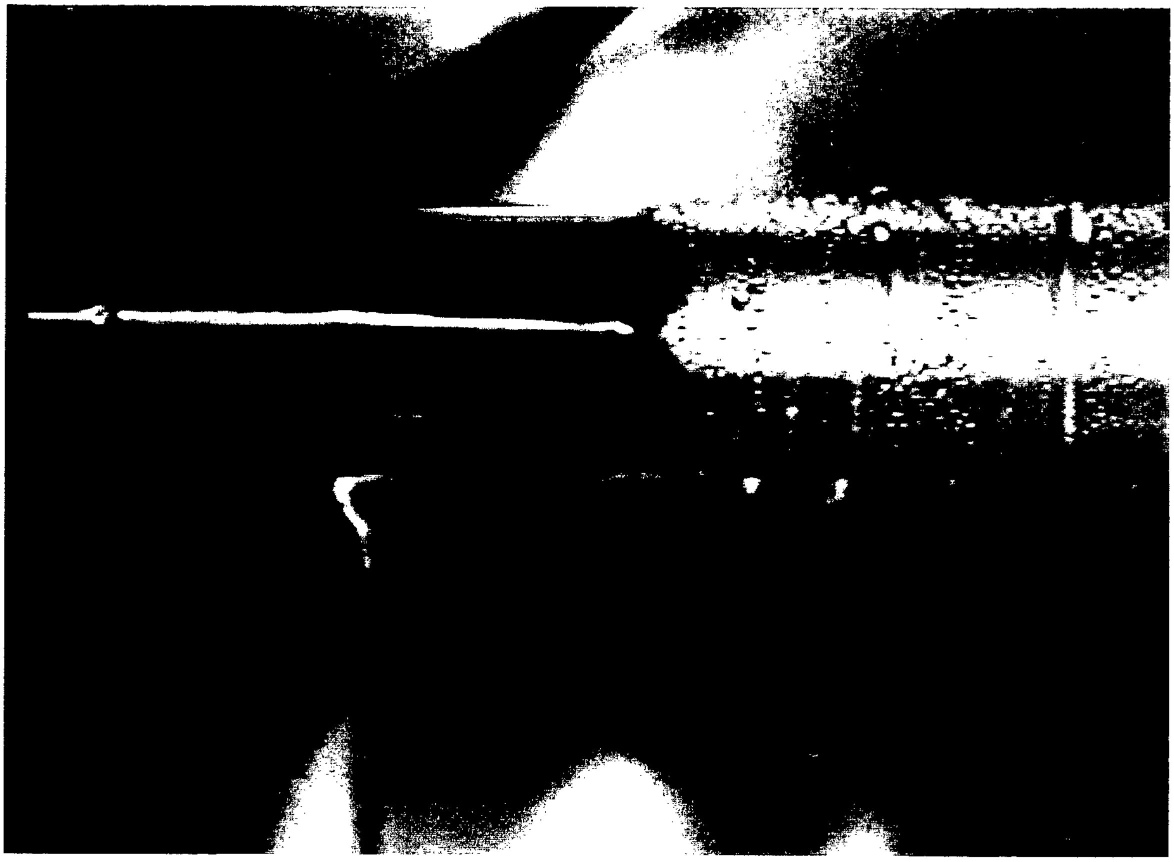

Figure 31. Photo of Cu Tube with 66mm Strip of FWC and 66mm Strip of DWC. Dark Strip on Left is FWC, Light Strip on Right is DWC.

TABLE 8. One Region Each of FWC and DWC Data.

TUBE NUMBER	C_i	C_o	$\varepsilon_{\Delta T}$	Heat Flux kw/m^2 High	Low
C7MDF5A1	1.8	3.2	3.8	1461	738
C7MDF5A2	1.8	3.2	3.8	1460	742
C7MDF5V1	1.8	1.8	2.2	377	221
C7MDF5V2	1.9	1.9	2.8	397	227

"seeing" cooler water and the DWC zone is "seeing" warmer water. Thus, the temperature driving potential is greater for the FWC region than the DWC region and thus should skew the average heat transfer coefficient value to a somewhat lower value. The same trend is observed for atmospheric data, as seen in Figure 33. It is therefore recommended to switch the location of the FWC and DWC zones to see if the outside heat transfer coefficient can be enhanced above the mean by increasing the DWC contribution, ie. using a higher temperature driving potential, in relation to the FWC contribution.

2. 22 Regions Each of FWC and DWC

Keeping the area ratio constant at 50%, the tube was divided into finer strips to form the second coexisting FWC and DWC tube. Three millimeter wide strips of FWC and DWC covered the tube as shown in Figure 34. Thus, the tube had

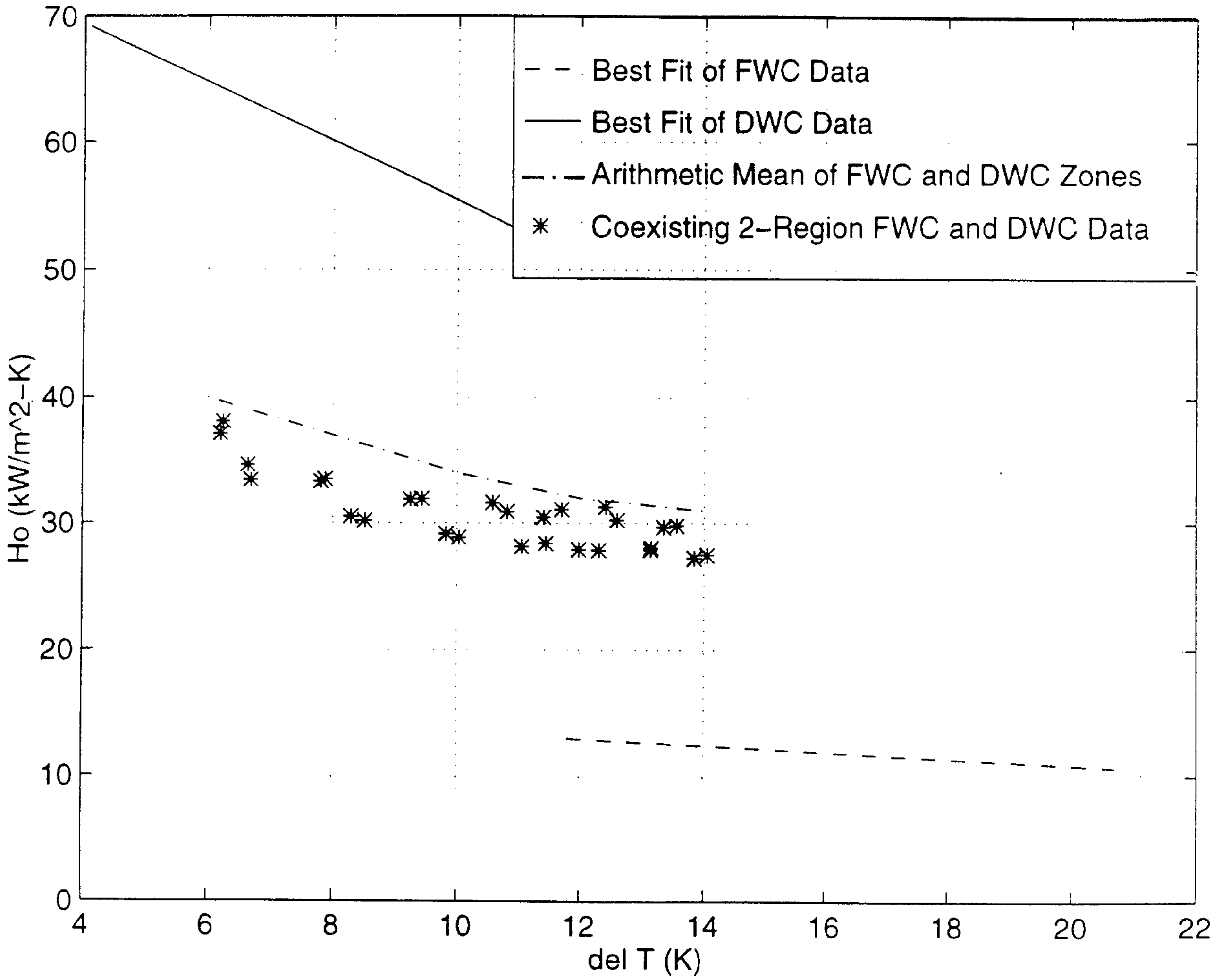

Figure 32. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Coexisting FWC and DWC 2 Region Tube at Vacuum.

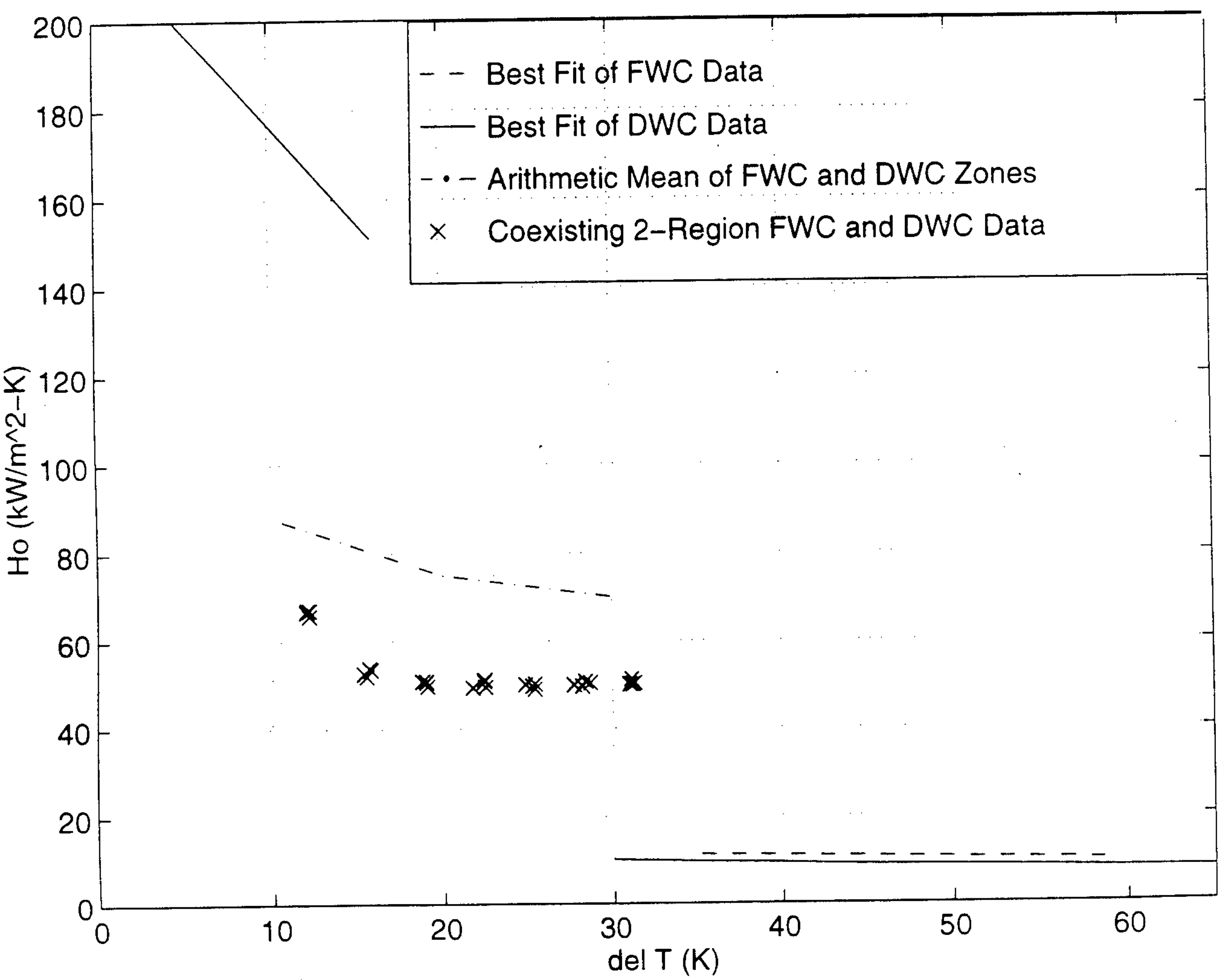

Figure 33. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Coexisting FWC and DWC 2 Region Tube at Atmospheric Pressure.

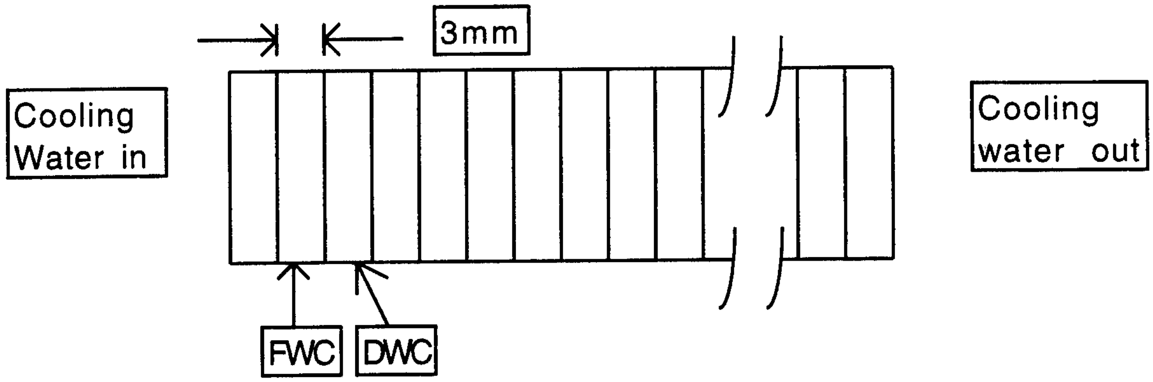

Figure 34. Sketch Showing 3mm Wide Regions Each of FWC and DWC.

22 FWC strips or zones and 22 DWC strips or zones.

Figure 35 is a photograph illustrating the quality of FWC and DWC achieved. Notice that the drop sizes in the DWC region are small as compared to the all DWC tube, Figure 16. In addition, drops are departing the tube from the FWC regions only. Table 9 summarizes the data taken. Figure 36 shows the vacuum data of two experimental runs. The higher outside heat transfer coefficients of tube number C3MDF1V1 are attributed to DWC existing on some of the oxidized strips which should otherwise exhibit all FWC. Some of these drops may be seen in Figure 35. The SAM does not normally bond to copper oxide; perhaps, however, the oxidation process was not complete and bare copper was exposed to the SAM bonding to it.

Conducting a second experiment on the tube (C7MDF1V2) improved the FWC in the oxidized regions and this data exhibits expected lower values of the outside heat transfer coefficient.

TABLE 9. 22 Regions Each of FWC and DWC Data.

TUBE NUMBER	C_i	C_o	$\varepsilon_{\Delta T}$	Heat Flux kw/m^2 High	Low
C3MDF1A1	2.3	4.7	5.7	1877	895
C3MDF1A2	2.2	4.5	5.4	1801	1793
C3MDF1V1	2.1	3.1	3.7	516	264
C3MDF1V2	2.1	2.3	2.8	442	244

Atmospheric pressure data, as shown in Figure 37, did not exhibit this mixed DWC behavior because of the higher heat flux causing an increase in condensate to flow in the FWC regions. Therefore, the FWC zones were properly flooded and the two runs were more consistent.

At both pressures, the outside heat transfer coefficient was increased over that of the two region tube by about 25%. The mechanism of heat transfer enhancement over that of the two region tube (Figures 32 and 33) is due to the numerous interfaces separating the DWC zones from the FWC zones. In

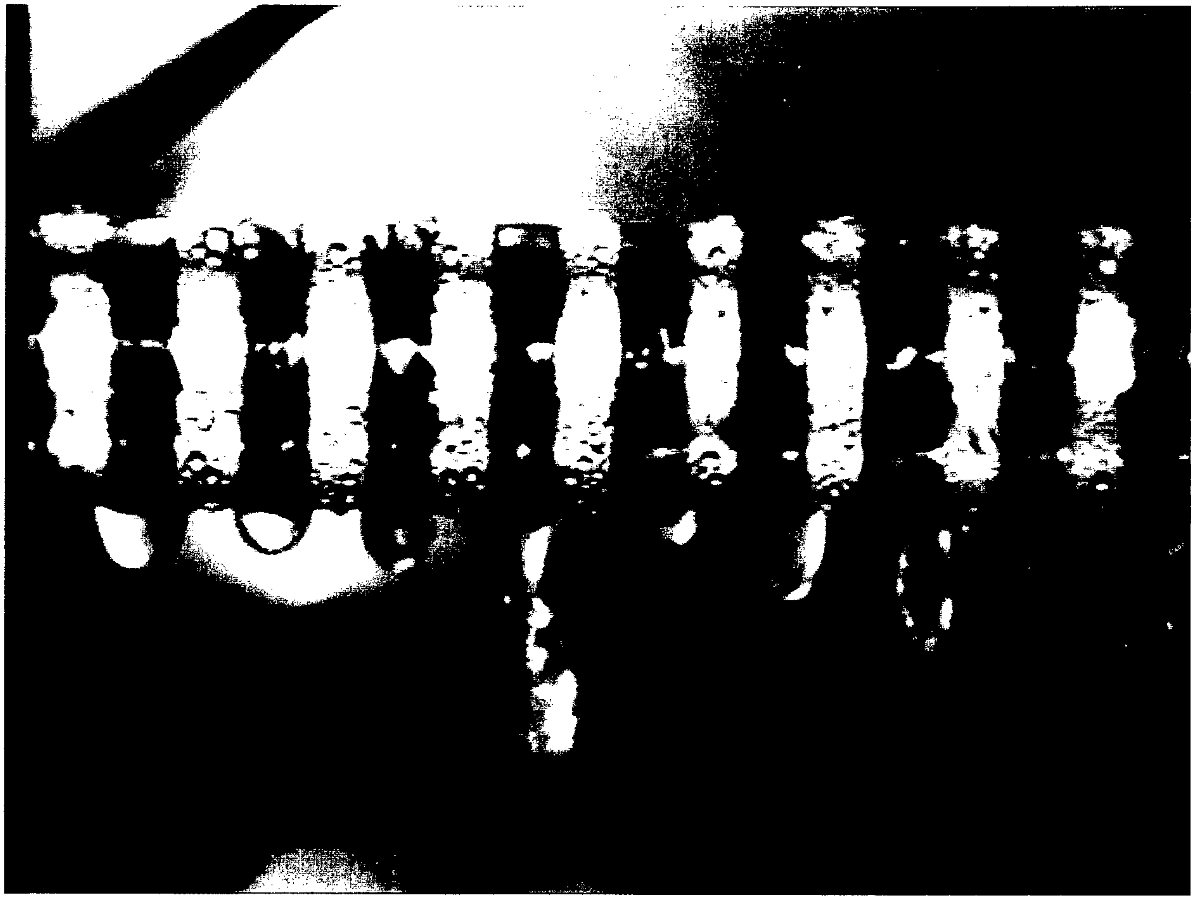

Figure 35. Photo of Cu Tube with 3mm Strips of FWC and DWC.

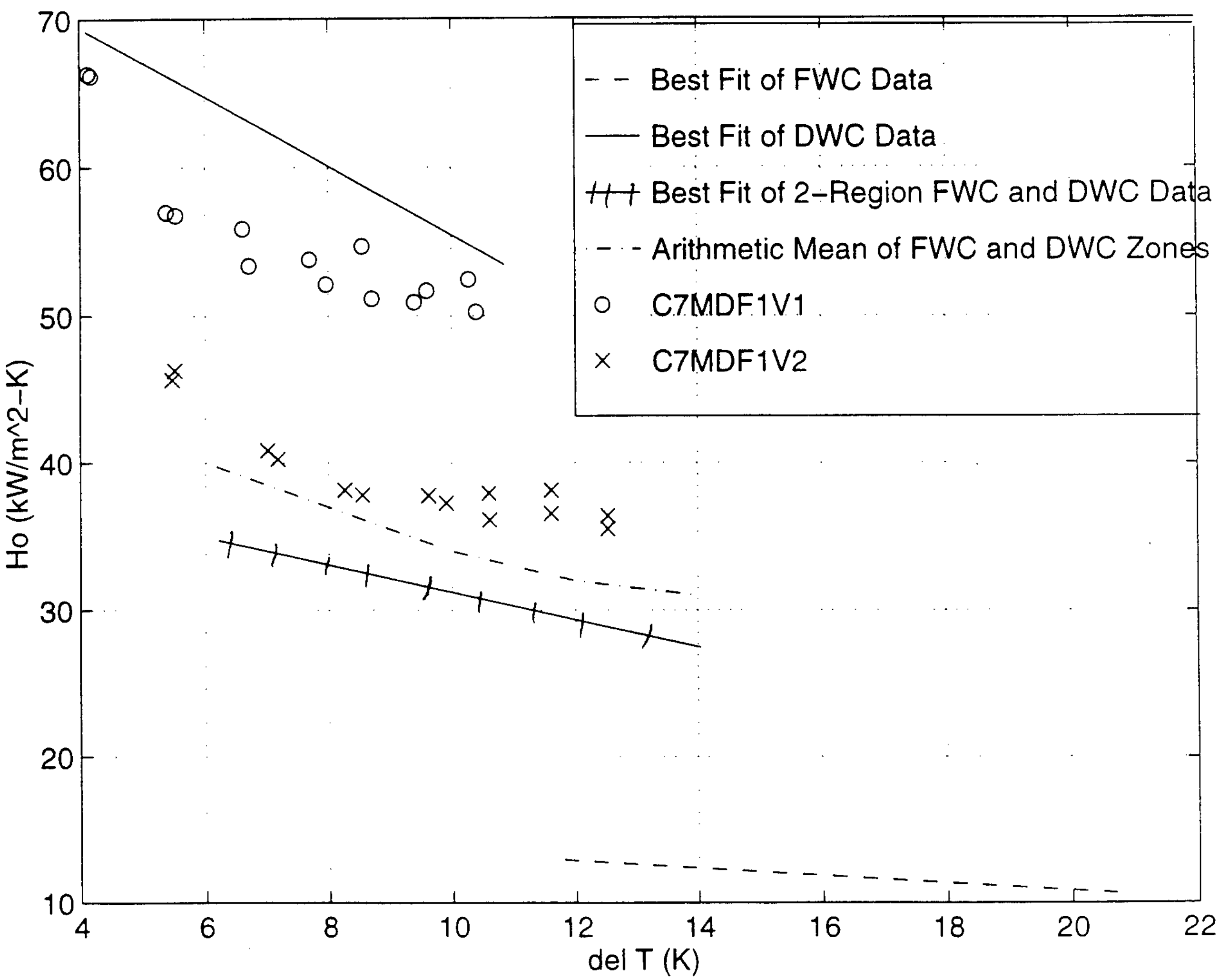

Figure 36. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Coexisting FWC and DWC 22 Regions Each of FWC and DWC at Vacuum.

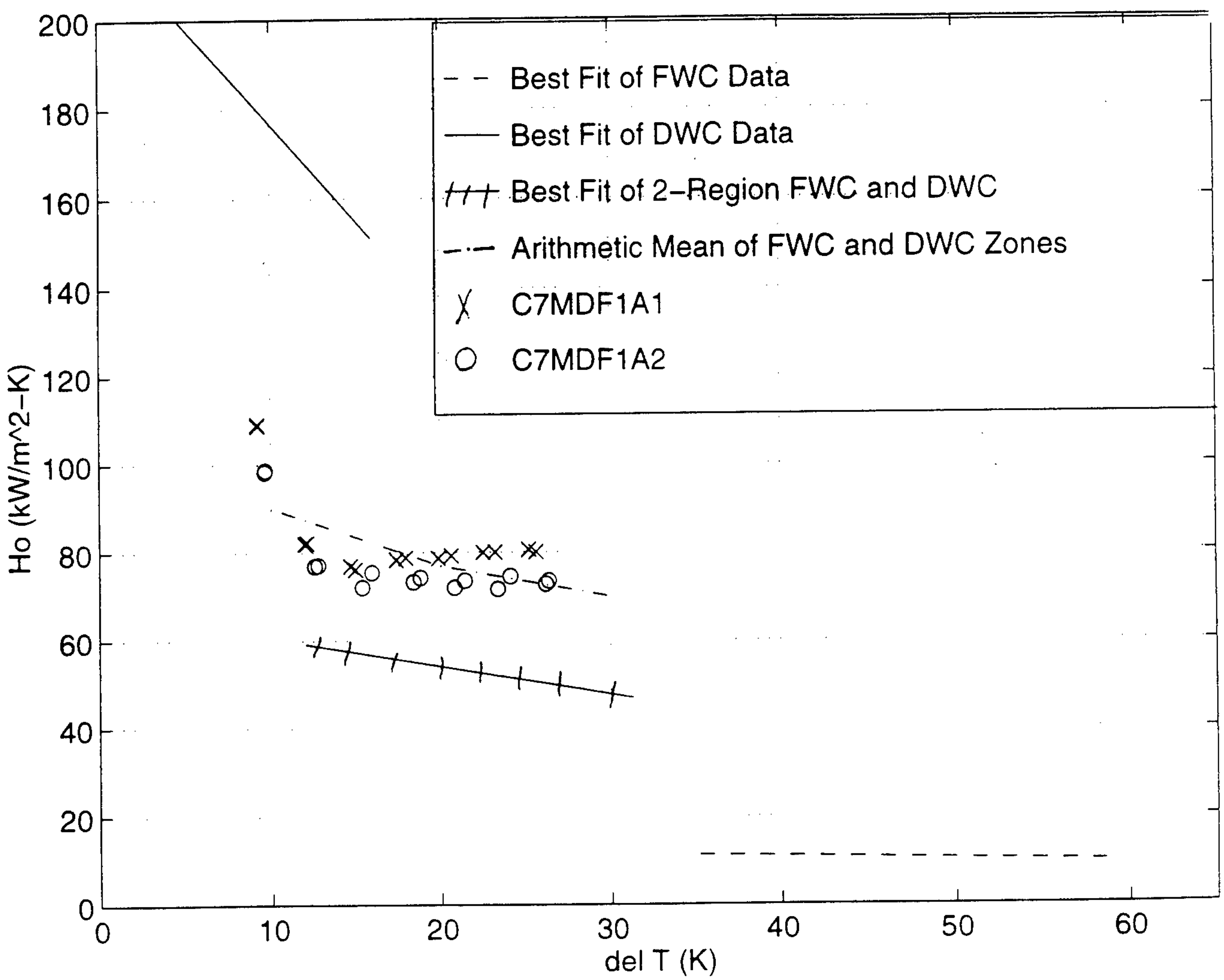

Figure 37. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Across the Condensate Film. Coexisting FWC and DWC 22 Regions Each of FWC and DWC at Atmospheric Pressure.

regions near these interfaces, drops are pulled into the FWC regions before growing too large, causing turbulence in the FWC film. This mechanism has more opportunity to occur because of the increase in the number of interfaces.

While the 3mm strip tube displayed higher heat transfer coefficients than the two region tube, it was still about 30% lower than the DWC only case at vacuum and about 40% lower than the DWC only case at atmospheric pressure. This decrease in performance is attributed to the loss of sweeping action with the 3mm wide strips since larger drops are prevented from forming due to coalescence with the FWC strips. Another contributing factor may be due to a limited amount of condensate that the FWC strips can carry away.

3. 33 Regions Each of FWC and DWC

Continuing to keep the area ratio constant at 50%, the tube was further divided into finer strips to form a third coexisting FWC and DWC tube. Two millimeter wide strips of FWC and DWC covered the tube as shown in Figure 38.* This tube therefore nominally had 33 FWC strips and 33 DWC strips. Figure 39 is a photograph showing this tube. Table 10 summarizes the data taken. Figures 40 and 41 show the performance of the tube compared to previously tested tubes. The performance of the 2mm wide strip tube is very poor. The data fall below that of even the tube with one FWC and DWC

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*Nominally strips were 2mm in width. The actual width was 2.1mm, resulting in 31 FWC strips and 32 DWC strips.

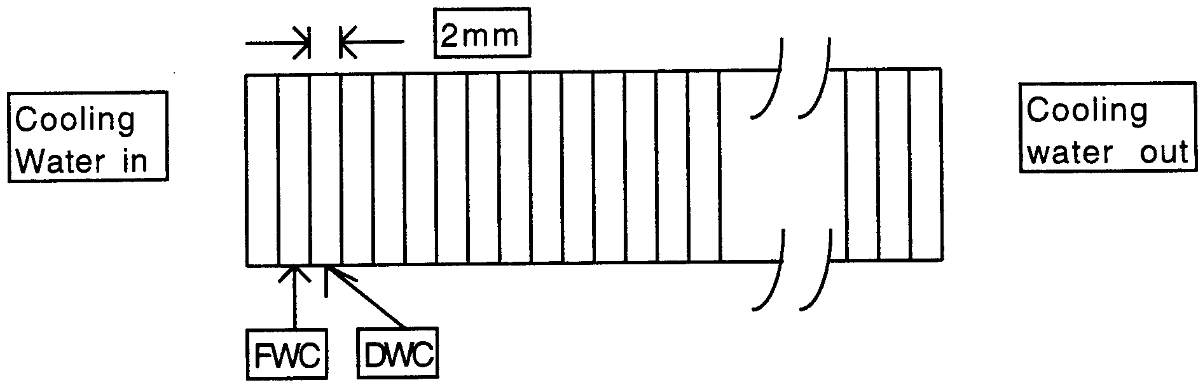

Figure 38. Sketch Showing 33 Regions each of FWC and DWC.

interface. The drops at the top of the tube were kept small. The same mechanism as seen in previous tubes took place, that is, drops coalesced into the FWC regions creating turbulence. Some of the condensate appeared to bridge over the DWC zones. For example, a filmwise region is seen on the DWC strips three and six from the right in Figure 39. This is especially evident at the bottom of the tube where large drops are seen to bridge over the DWC strips. Typically, drops covered three regions, 6mm wide, and large drops hung on the bottom for prolonged periods of time. This reduced drainage may have impaired the heat transfer performance of this tube and indicates that there must be an optimum strip width for a 50% area ratio tube with FWC and DWC that is somewhat larger that 3mm. Also, because of the observations of film drainage, the area fraction most desirable is not 50%, but more surface should be covered by DWC than by FWC.

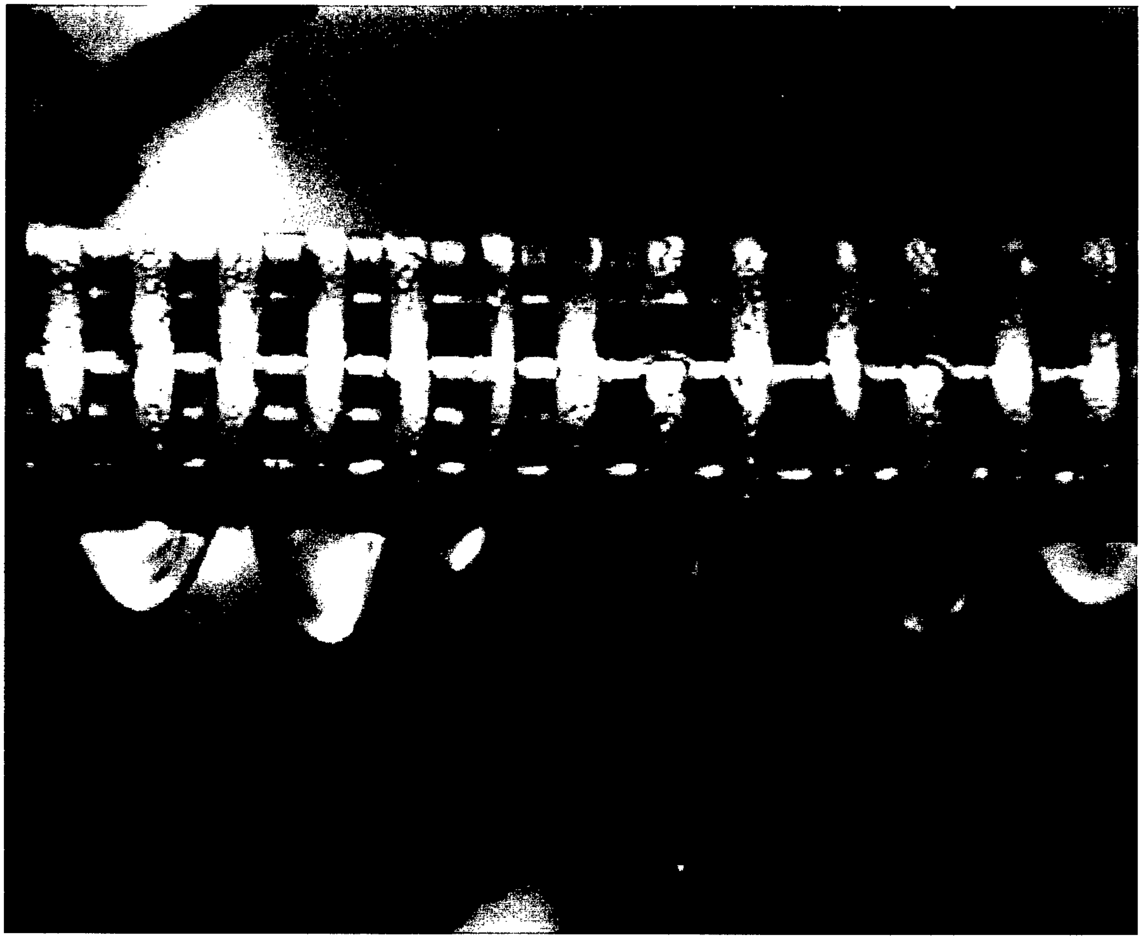

Figure 39. Photo of Cu Tube with 2mm Strips of FWC and DWC.

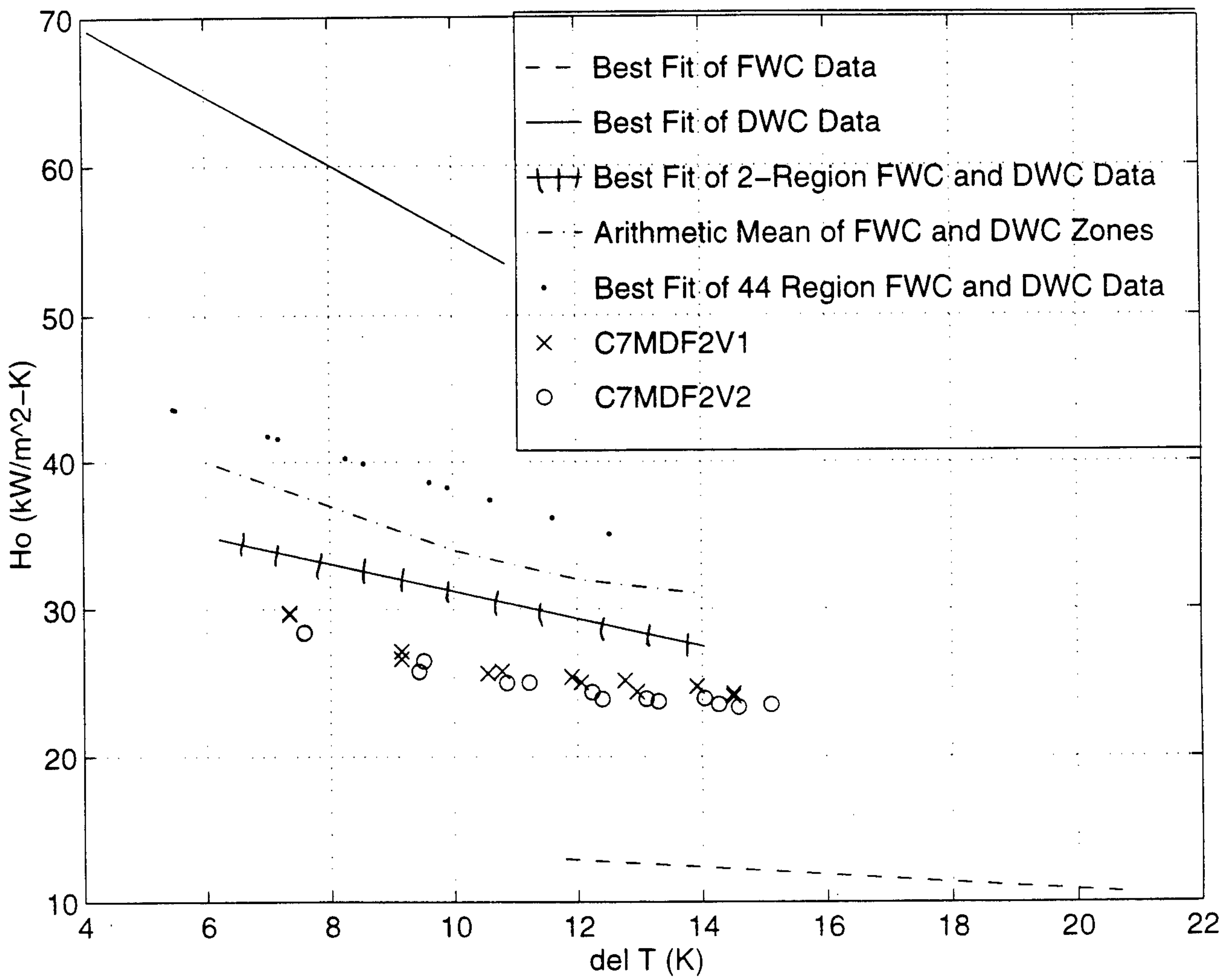

Figure 40. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Coexisting FWC and DWC 33 Regions Each of FWC and DWC at Vacuum.

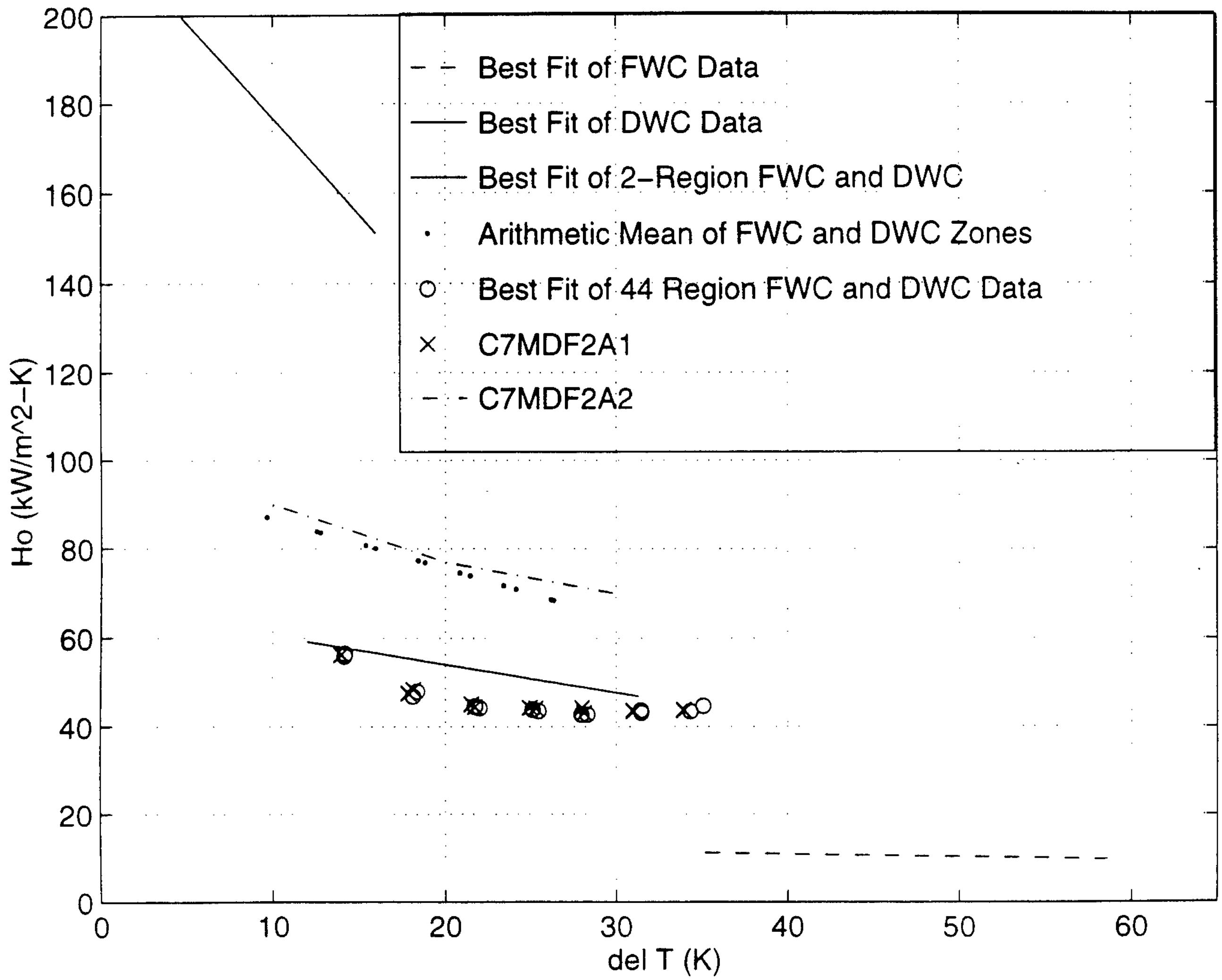

Figure 41. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. Coexisting FWC and DWC 33 Regions Each of FWC and DWC at Atmospheric Pressure.

TABLE 10. 33 Regions Each of FWC and DWC Data.

TUBE NUMBER	C_i	C_o	$\varepsilon_{\Delta T}$	Heat Flux kw/m^2 High	Low
C7MDF2A1	1.9	2.9	3.5	1431	752
C7MDF2A2	1.9	2.9	3.5	1406	748
C7MDF2V1	1.9	1.6	1.9	347	214
C7MDF2V2	2.0	1.6	1.9	347	213

F. GOLD-COATED TITANIUM KORODENSE TUBE

One titanium Korodense tube was tested with all DWC during this thesis. As mentioned earlier, this tube was coated with gold and then dipped into the hydrophobic SAM to get a good hydrophobic coating. A Korodense tube is shown schematically in Figure 42. Figure 43 indicates the quality of DWC achieved by the SAM on a gold coated Korodense tube and Table 11 summarizes the experimentally determined inside and outside heat transfer correlations, enhancement, and the high and low heat flux of each experimental run. In figure 43, the dark longitudinal line seen at the bottom of the tube is an indication of imperfect coverage of the titanium by gold during the sputtering process. Long [Ref. 39] tested titanium Korodense tubes during FWC at vacuum and his data is plotted in Figure 44 along with the DWC data promoted by the SAM taken during this thesis.

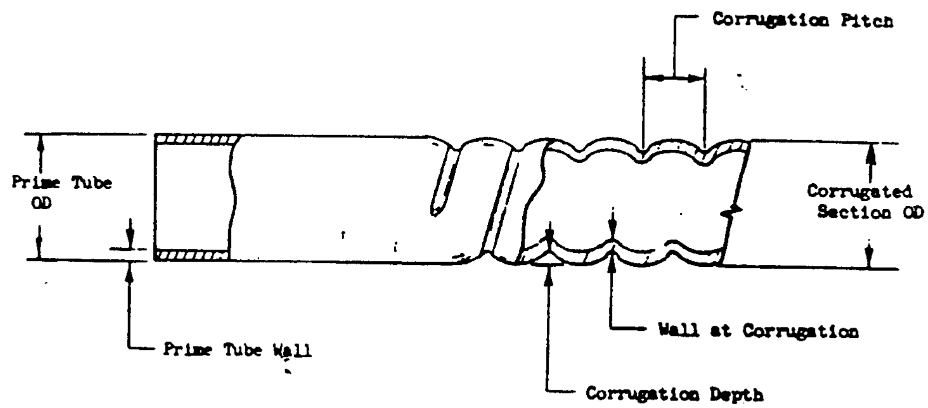

Figure 42. Sketch Showing a Korodense Tube.

The C_i values of the titanium gold-coated Korodense tube are the highest of any tube tested. Recall that this tube is corrugated on its inside surface. This corrugation acts to enhance the inside heat transfer coefficient by disturbing the flow through the tube.

The reduction in C_o from that of an all DWC copper tube is further evidence of the role that substrate material may play in effecting the outside heat transfer coefficient as proposed by Mikic [Ref. 7].

After application of the hydrophobic SAM to a gold coated Korodense tube, a heat transfer enhancement of about two times that of a FWC Korodense tube at vacuum was achieved. At atmospheric pressure, an enhancement of about three was achieved as seen in Figure 45.

Because Korodense tubes are primarily used to improve inside heat transfer coefficients, the improvement on the outside is especially favorable. This enhancement has potential for commercial application.

Table 11. Korodense Tube Data.

TUBE NUMBER	C_i	C_o	$\varepsilon_{\Delta T}$	Heat Flux kw/m^2 High	Low
K6MD1A1	3.5	2.0	2.4	642	476
K6MD1A2	3.4	2.1	2.5	652	480
K6MD1A3	3.2	2.3	2.8	645	466
K6MD1A4	3.2	2.2	2.6	641	467
K6MD1V1	3.1	1.8	2.2	222	163
K6MD1V2	3.0	1.9	2.3	215	153
K6MD1V3	3.1	1.9	2.3	219	155

Figure 43. Photo of DWC on a Gold Coated Titanium Korodense

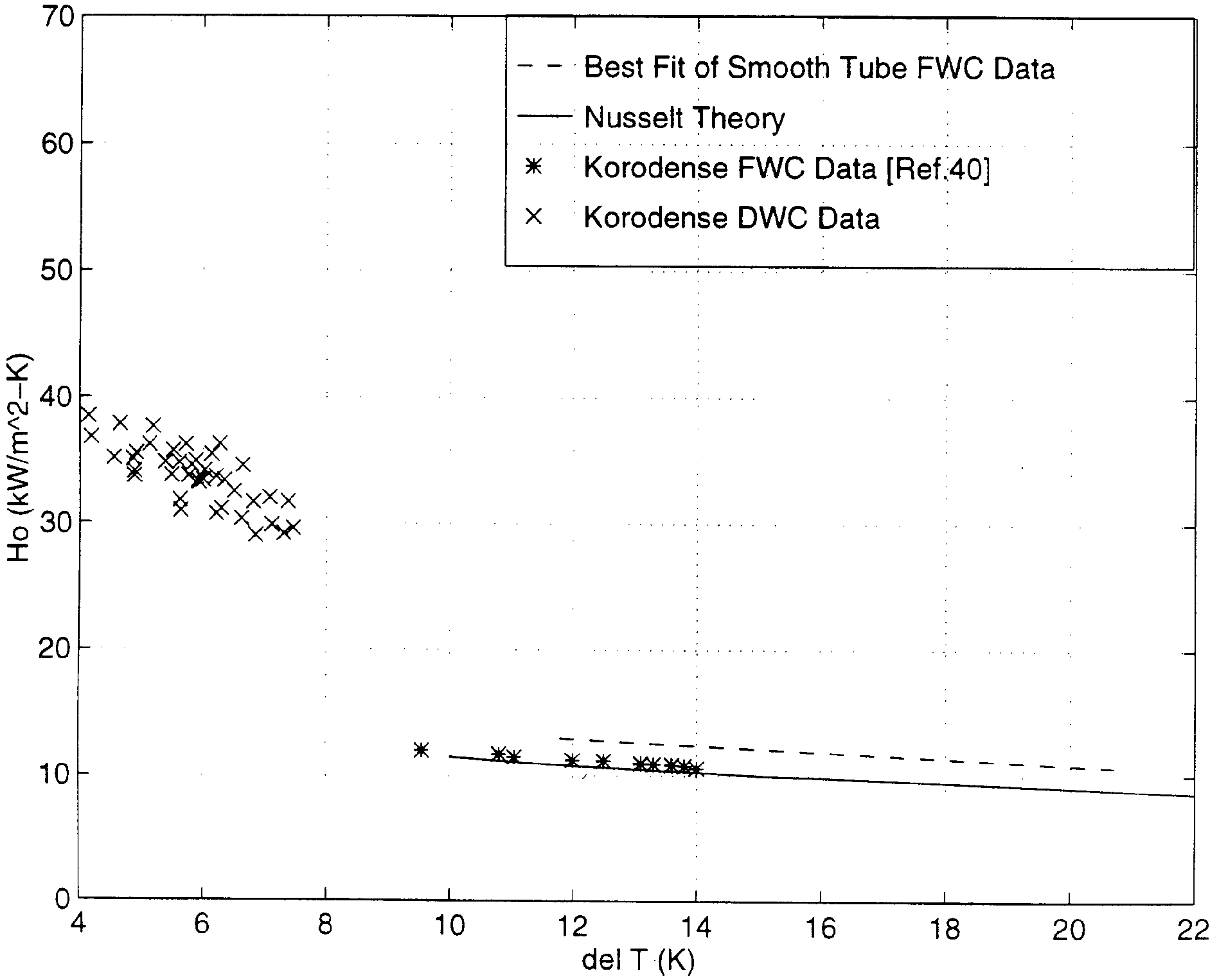

Figure 44. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Difference Across the Condensate Film. All DWC titanium gold-coated Korodense tube at Vacuum.

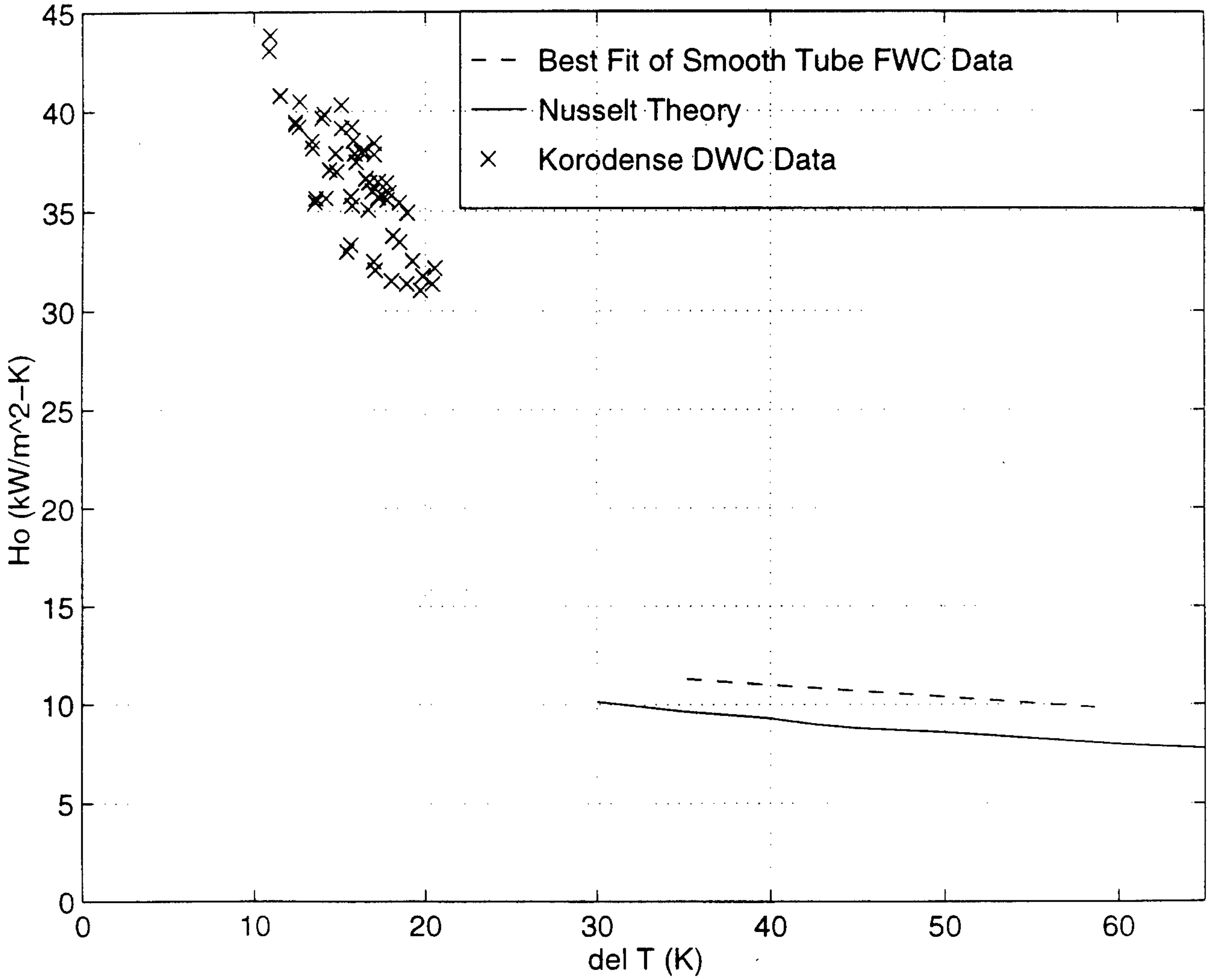

Figure 45. Experimentally Determined Values of the Outside Heat Transfer Coefficient vs. Temperature Across the Condensate Film. All DWC titanium gold-coated Korodense tube at Atmospheric Pressure.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. The SAM coating provided excellent DWC. Contact angles were usually 90° or larger.

2. With application of the SAM on a copper tube, the outside heat transfer coefficient was enhanced by a factor of about ten for atmospheric pressure and by a factor of about four for vacuum.

3. With application of SAM on a titanium-gold-coated aluminum tube, the outside heat transfer coefficient was enhanced by a factor of about seven for atmospheric pressure and by a factor of about three and one half for vacuum.

4. The outside heat transfer coefficient of the coexisting FWC and DWC tube with 3mm strips of FWC and DWC was higher than the 66mm strip tube and higher than the 2mm strip tube. This indicates an optimum strip width exists somewhere above 3mm.

5. With application of the SAM on a gold-coated titanium Korodense tube, the outside heat transfer coefficient was enhanced by a factor of about three at atmospheric pressure and by a factor of about two at vacuum. This decrease in performance from copper tubes is further indication that substrate material may have an important effect on the outside heat transfer coefficient.

B. RECOMMENDATIONS

1. Find the optimum strip width on a tube with coexisting FWC and DWC with a 50% area ratio.

2. Investigate different area ratios of FWC and DWC.

3. Investigate different kinds of patterns. Perhaps a pattern surrounding the tube is not optimum. Investigate DWC patterns on the top half of the tube and at different angles. Investigate different FWC zones so as to improve FWC drainage.

4. Because the Wilson Plot Technique does not provide for direct calculation of T_{wo}, h_i and h_o, the use of an instrumented tube to measure wall temperatures should be used to verify calculations.

5. Other interesting and promising chemistries include replacing the methane group of the SAM with a fluorine group, thereby reducing the surface free energy even further.

6. Try application of the SAM on a copper-nickel tube.

7. The sputtering process to apply gold and titanium can be improved by installing a rotating mechanism so that the vacuum does not have to be disturbed to rotate the tube.

8. Explore ways to fabricate a reliable hydrophilic SAM surface to create good FWC.

APPENDIX A. OPERATING INSTRUCTIONS

The operating instructions are identical to those in Incheck [Ref. 34] with the following exceptions;

A. START-UP

No changes

B. PROCEEDING FROM A COLD BOILER TO VACUUM OPERATION

1. Energize boiler heater

   f. Plug in one cooling water pump to about 50% flow to avoid the thermal shock of starting the cooling water when a high steam temperature is present.

   g. Fully open head tank supply valve CW-1. [Ref. 34]

2. Warmup and purge system

   a. If rig is already at vacuum, start vacuum pump when gage pressure reaches 2 psig. If rig is at atmospheric pressure start vacuum pump immediately. Pump should run for at least 45 minutes to evacuate air and noncondensible gases.

4. Prepare system for operation

   a. Turn on computer and change directories to SRI. Type in Qbasic. Follow directions on the screen and open DPRSRI.BAS.

   b. Press F5 to run.

   c. Choose "Take Data" and type in the barometric pressure. The barometric pressure may be found in Root Hall Meteorology Department.

C. PROCEEDING FROM A COLD BOILER TO ATMOSPHERIC OPERATION

2. Energize boiler heater

   f. Plug in one cooling water pump to about 50% flow to avoid the thermal shock of starting the cooling water when a high steam temperature is present.

APPENDIX B. CALIBRATION AND THERMOPHYSICAL PROPERTY CORRELATIONS

A. ROTAMETER

The cooling water rotameter reading (in percent) (f_r) was calibrated by weighing (W) a quantity of water in a prescribed period of time (t). Average water temperature was 23°C. The volumetric flow rate (f_v) was sought by;

$$f_v = \frac{W}{\rho t}. \qquad \text{(B.1)}$$

A summary of the raw data and flow rates is contained in Table (B.1). A polynomial curve fit was applied to the data to obtain an expression for the mass flow rate in kg/s. The rotameter reading is entered as 20, 30, etc..

$$\dot{m} = (4.646E-6f_r^{\,2} + 6.185E-3f_r + .02264)\frac{\rho}{\rho_{T=23^\circ C}} \qquad \text{(B.2)}$$

Table B.1. Rotameter Calibration Data.

f_r (pct)	W (lbf)	t (s)	W/t (kg/s)	f_v (gpm)
20	20	61.4	.148	2.35
40	20	32.6	.278	4.41
60	20	22.1	.41	6.55
90	20	14.7	.617	9.8

B. DATA ACQUISITION VOLTMETER

The voltmeter was compared to a test voltmeter by Incheck [Ref. 34] in 1995. No additional calibration was done during this thesis.

C. THERMOCOUPLES

Test data for the thermocouples are in Table (B.2). A polynomial curve fit was applied to the steam temperature data to obtain an expression for the temperature in °C;

1. 16°C < T < 25°C

$$T_{ch21} = -1.2981Emf^2 + 26.814Emf - .2328$$
$$T_{ch24} = -1.2981Emf^2 + 26.816Emf - .2596 \tag{B.3}$$

2. 48°C < T < 50.05°C

$$T_{ch21} = 1.1574Emf^2 + 18.5431Emf - 7.4748$$
$$T_{ch24} = 19.7403Emf^2 - 55.7806Emf + 81.7896 \tag{B.4}$$

3. 98°C < T < 102°C

$$T_{ch21} = .4141Emf^2 + 17.8096Emf + 16.2353$$
$$T_{ch24} = -1.2269Emf^2 + 32.0078Emf - 14.3873 \tag{B.5}$$

A polynomial curve fit was applied to the cooling water temperature data to obtain an expression for the temperature in °C;

1. 16°C < T < 25°C

$$T_{ch20} = -1.2813Emf^2 + 26.8505Emf - .2656$$
$$T_{ch22} = 1.5538Emf^2 + 27.3201Emf - .482 \tag{B.6}$$

D. PRESSURE TRANSDUCER

The Setra pressure transducer and Heise pressure gage were not calibrated during this thesis.

E. THERMODYNAMIC PROPERTIES

The correlations as a function of temperature in °C are identical to those listed by Incheck [Ref. 34].

Table B.2. Thermocouple Calibration Data.

Test Temp (°C)	CH20 (mv)	CH21 (mv)	CH22 (mv)	CH24 (mv)
16.36	.639	.639	.640	.640
17.52	.684	.684	.685	.685
18.64	.730	.730	.731	.731
20.67	.811	.811	.811	.812
22.38	.880	.881	.881	.882
23.22	.915	.916	.916	.917
24.15	.953	.953	.953	.954
24.90	.983	.984	.984	.985
48.38	1.962	1.965	1.960	1.964
48.94	1.986	1.989	1.984	1.989
49.21	1.998	2.001	1.996	2.001
50.05	2.033	2.037	2.032	2.036
98.36	4.194	4.201	4.189	4.198
98.90	4.219	4.226	4.213	4.223
99.38	4.241	4.249	4.236	4.245
100.56	4.296	4.304	4.292	4.300
102.10	4.369	4.376	4.372	4.372

APPENDIX C. PROGRAM DRPSAM2.bas

A. INTRODUCTION

The data acquisition and reduction programs are identical to that used by Incheck [Ref. 34]. The program DRPSAMUN.bas is used for DWC tubes and coexisting FWC and DWC tubes. The program DRPSAM2.bas is used for FWC tubes. The programs were rewritten by Das [Ref. 16] into Qbasic and DRPSAM2.bas follows here. DRPSAMUN.bas is listed in Appendix E.

```
'
'Program for data acquisition, reduction and processing for
SINGLE tube condensation experimental setup.
'
' Created by Ashok K. Das. Date: April, 1995.
'
' Please save a copy of this program before running or making
any changes (required or accidental)  in this program.
'      You can do this at the DOS prompt by COPY command, or
from within QBasic by File/SaveAs command.
'
' To run the program:
'
'         1. Simply press the key F5 or <Shift>F5
'         2. Select Run/Start from the menu.
'
' This program is tailored for SRI organic coated plain
tubes. For other tubes, the program must be modified.
However, the modification will be required mostly for input
and output data. For data acquisition and processing, only
the inside and end outside dia are required, which will
remain the same for all tubes.
'
'
'
DECLARE FUNCTION Cpw! (temp!)
DECLARE FUNCTION ftanh! (X#)
DECLARE FUNCTION FTCgen! (Emf!)
DECLARE FUNCTION FTfric! (Vcw!)
DECLARE FUNCTION hfgw! (temp!)
DECLARE FUNCTION kfw! (temp!)
DECLARE FUNCTION mufw! (temp!)
DECLARE FUNCTION rhofw! (temp!)
DECLARE FUNCTION rhogw! (temp!)
DECLARE FUNCTION psw! (temp!)
DECLARE FUNCTION sigmaw! (temp!)
DECLARE SUB CheckSensor ()
DECLARE SUB FWAIT (sec!)
DECLARE SUB MergeData ()
DECLARE SUB PROCESS ()
DECLARE SUB RawData ()
DECLARE SUB SENSOR ()
DECLARE SUB TakeData ()
      '****************************************
      COMMON SHARED Ipc, Itb, Patm, kt!
      COMMON SHARED TC1!, TC2!, TQ1!, TQ2!, DTQ!, Tstm1!,
Tstm2!, Trm!, Pxdcr!, Volts!, Amps!
      CLS
      PRINT "If taking data or operating sensors"
      INPUT "Enter atmospheric pressure (in Hg)"; Patm
      IF Patm = 0 THEN
```

```
        PRINT
        PRINT "Atm Press set to 30.06 in Hg"
        PRINT
        Patm = 30.06
    END IF
    Patm = Patm / 2.041795  'convert to psi
    PRINT "Atm. Pressure in psi is", Patm
    INPUT "Press ENTER to continue.", OK
    DO
        CLS
    DO
        BEEP
        PRINT " Select Option"
        PRINT "     0 Exit Program"
        PRINT "     1 Check Remote Sensors"
        PRINT "     2 Take Data"
        PRINT "     3 Print Raw Data"
        PRINT "     4 Process Data"
        PRINT "     5 Merge Data"
        PRINT
        INPUT " Option"; Iopt
        IF Iopt < 0 OR Iopt > 5 THEN
            BEEP
            PRINT "  Invalid Option. Please select again."
            END IF
        LOOP WHILE Iopt < 0 OR Iopt > 5
        '
        SELECT CASE Iopt
            CASE 0
                PRINT "Exiting Program!"

            CASE 1
                CALL CheckSensor

            CASE 2
                CALL TakeData

            CASE 3
                CALL RawData

            CASE 4
                CALL PROCESS

            CASE 5
                CALL MergeData

        END SELECT
    LOOP WHILE Iopt > 0
END

SUB CheckSensor              ' Check Sensors...
```

```
                  CLS
                  BEEP
                  PRINT " Select Approximate Temperature Range"
                       PRINT "     0 for 16-25 deg C"
                       PRINT "     1 for 48-51 deg C"
                       PRINT "     2 for 98-102 deg C"
                       PRINT "     3 for Other "
                       PRINT
                       INPUT " Range"; Ipc
                       '
Call subroutine SENSOR to read the data from HP 3794A and
the HP 2804A Quartz Thermometer
                       '
                       CALL SENSOR
                       '
                       PRINT
                  PRINT "TC1, TC2, DTC =", TC1, TC2, TC2 - TC1
                  PRINT "TQ1, TQ2, DTQ =", TQ1, TQ2, DTQ
                  PRINT "Tstm1, Tstm2, Troom =", Tstm1, Tstm2,
Trm
                  PRINT "Pxdcr (psi), Volts, Amps =", Pxdcr /
6.89473, Volts, Amps
                       PRINT
                       PRINT
                       INPUT "Press ENTER to continue.", OK
                       CLS
END SUB
```

FUNCTION Cpw (temp)

```
          DIM poly(10)
'
' By curve fit between 10 and 100 C
'
' Cp in J/kg-K
'
          poly(0) = -.000000048411511#
          poly(1) = 1.529196E-06
          poly(2) = -.0018467209#
          poly(3) = .1145064#
          poly(4) = -3.431451
          poly(5) = 4216.853
          Cp = poly(0)
          FOR i = 1 TO 5
               Cp = Cp * temp + poly(i)
          NEXT i
'       RETURN Cp
          Cpw = Cp
END FUNCTION
```

FUNCTION ftanh (X#)

```
     ex1 = EXP(X#)
     ex2 = EXP(-X#)
     ftanh = (ex1 - ex2) / (ex1 + ex2)
END FUNCTION
```

FUNCTION FTCgen (Emf)

```
     DIM coef(5)
     coef(0) = 25.661297#
     coef(1) = -.61954869#
     coef(2) = .022181644#
     coef(3) = -3.55009E-04
     Tc = 0
     FOR i = 1 TO 4
          Tc = Tc + coef(i - 1) * Emf ^ i
     NEXT i
'    RETURN Tc
     FTCgen = Tc
END FUNCTION
```

FUNCTION FTfric (Vcw)

```
FTfric = .0024669874# * Vcw ^ 2 - .00066467689# * Vcw -
5.010371E-04
END FUNCTION
```

SUB FWAIT (sec!)

```
'
' Subroutine to make the computer wait for 'sec' seconds
'
     TIMER ON
     startime = TIMER
     elapsedtime = TIMER
     WHILE elapsedtime < sec
          elapsedtime = TIMER - starttime
     WEND
END SUB
```

FUNCTION hfgw (temp)

```
'
'     hfg in kJ/kg = 1000 J/kg = 1000 N-m/kg
'
Data obtained by curve fitting between 10 and 100 C from NIST
databook
'
'   VariX    VariY     R^2    RegDOF   RgSmSq   ErrDOF   ErSmSq
' 791.667 4709.589  100.00   5.00  84772.60   13.00 0.72e-02
'
          DIM poly(10)
'
          poly(5) = 2500.5197#
          poly(4) = -2.3700473#
          poly(3) = .0010148364#
```

```
        poly(2) = -.000030487402#
        poly(1) = .00000023213696#
        poly(0) = -9.6917486D-10
'
        hfg = poly(0)
        FOR i = 1 TO 5
             hfg = poly(i) + hfg * temp
        NEXT i
'
'     hfg in J/kg = N-m/kg
'
        hfg = hfg * 1000#
'      RETURN hfg
        hfgw = hfg
END FUNCTION
```

FUNCTION kfw (temp)

```
'
'NIST Conductivity in Watt/m-K for liquid water at saturation
pressure
'
'Data obtained by curve fitting between 10 and 100 C from
NIST databook
'
'   VariX   VariY     R^2    RegDOF  RgSmSq     ErrDOF  ErSmSq
' 916.667 1160.223  100.00    5.00  10442.00  0.40e+01 0.65e-
03
'
        DIM poly(10)
        poly(5) = 561.03333#
        poly(4) = 1.8883438#
        poly(3) = .0030282634#
        poly(2) = -.00023712121#
        poly(1) = .0000018735431#
        poly(0) = -.0000000051282051#
'
'   conductivity in mWatt/m-K
'
        kf = poly(0)
        FOR i = 1 TO 5
             kf = kf * temp + poly(i)
        NEXT i
'
'     convert to Watt/m-K
'
        kfw = kf * .001#
END FUNCTION
```

SUB MergeData

```
PRINT "Enter the name of the first  file to merge", Ifn1$
PRINT "Enter the name of the second file to merge", Ifn2$
```

```
END SUB

FUNCTION mufw (temp)
'
'NIST Viscosity for liquid water at saturation pressure
'
'Data obtained by curve fitting between 10 and 100 C from
NIST databook
'  NBS/NRC Steam Table, pp. 263 & 267
'
'    R^2        ErrDOF    ErSmSq
'  100.00     0.10e+01  0.14e-01
'
          DIM poly(10)
          poly(8) = 1800.19#
          poly(7) = -63.745948#
          poly(6) = 1.8275094#
          poly(5) = -.04512923#
          poly(4) = .0008736755#
          poly(3) = -.000011878223#
          poly(2) = .00000010329146#
          poly(1) = -5.0954132D-10
          poly(0) = 1.078869D-12
'
'   viscosity in 1d-6 kg/m-s
'
          muf = poly(0)
          FOR i = 1 TO 8
               muf = temp * muf + poly(i)
          NEXT i
'
'  convert to kg/m-s
'
          mufw = muf * .000001#
END FUNCTION

SUB PROCESS
'
'Program to process data using Modified Wilson Plot Technique
'
     DIM DTQ!(50), LMTD!(50), kc!(50), Omega!(50), Z!(50),
Qflux!(50), Tstm!(50), Uo!(50), Vcw!(50), X!(50), Y!(50),
Nuq!(50)
          CLS
          BEEP
INPUT "Enter data file name to process (no extensions)";
name$
INPUT "Enter number of data points in this file"; Nrun
          namedat$ = name$ + ".dat"
          nameres$ = name$ + ".res"
          namehqt$ = name$ + ".hqt"
```

```
        'namehoq$ = name$ + ".hoq"

     OPEN namedat$ FOR INPUT AS #5        'Input data file..
     OPEN nameres$ FOR OUTPUT AS #6       'Processed data
file..
     OPEN namehqt$ FOR OUTPUT AS #7       'Ho,Qf,Nu vs DTwo
are stored in this file
     'OPEN namehoq$ FOR OUTPUT AS #8       'Ho vs Qflux is
saved in this file

        PRINT #6, "         Program Name:
DRPSAM2.BAS"
        PRINT #6, "         Tube Number:
"; name$
        PRINT #6, "         Raw Data File:
"; namedat$
        PRINT #6, "         Processed Data File:
"; nameres$

        INPUT #5, Itb, kt!, Ipc
        INPUT #5, Di!, Dr!

        'PRINT #6, "         Tube Number:
"; Itb
        SELECT CASE Ipc
             CASE 1
                  PRINT #6, "         Pressure Condition:
Vacuum"
             CASE 2
                  PRINT #6, "         Pressure Condition:
Atmospheric"
        END SELECT
        PRINT #6,
        PRINT #6, USING "         Thermal Conductivity (W/m-
K):  ###.##"; kt!
        PRINT #6, USING "         Tube Inside Diameter (mm):
###.##"; Di
        PRINT #6, USING "         Tube Outside Diameter (mm):
###.##"; Dr
        '
        ' Initialize geometry and constants
        '
        Di = Di / 1000!                'Convert from mm to m
        Dr = Dr / 1000!
        PI# = 3.141592656#
L! = .13335                  'Active tube length 5 1/4 inch
L1! = .060325                'Inlet end length 2 3/8 inch
L2! = .034925                'Exit end length 1 3/8 inch
Dout! = 5 / 8 * .0254        'Tube end outside diameter = 5/8
                              inch X 0.0254 m/inch
Dc! = .1524                  'Condenser tube inside diameter
```

```
                                    (m)
Perim! = PI# * Di              'Perimeter over which convective
                                    cooling take place
AreaX = .25 * PI# * (Dout + Di) * (Dout - Di)    'X-sec area
       for fin efficiency at the ends
'AreaX! = .25 * PI# * (Dr + Di) * (Dr - Di)
AreaCorr! = 9.18214E-06       'Area correction for Heatex
                                    insert
          '
          'PRINT "Di, Dr, Dout =", Di, Dr, Dout
          'PRINT "PI, Di, L, kt", PI#, Di, L, kt
          'INPUT "Press ENTER to continue.", Ok
          Rw = LOG(Dr / Di) / (2 * PI# * L * kt)    'Tube wall
resistance

          PRINT #6, USING "      Wall Resistance Rw (m/W/m-
K): ##.#####"; Rw

          '
          ' Initialize Ci and Co. Set CoSmooth and Qloss
          '
          SELECT CASE Ipc
               CASE 1      'Vacumm Condition
                    CoSmooth! = .815
                    Qloss! = 125!
                    Ci! = 2.11
                    Co! = 2!

               CASE 2      'Atmospheric Condition
                    CoSmooth! = .827
                    Qloss! = 348!
                    Ci! = 2.11
                    Co! = 3!

          END SELECT

          VoltAvg! = 0!
          TstmAvg! = 0!
          '
          ' Read data from raw data file...
          '
          CLS
          PRINT "Reading data from the data file:", namedat$
          PRINT
          FOR j = 1 TO Nrun
               INPUT #5, Fm, Trm, TQ1, TQ2, DTQ(j), Tstm(j),
Pgage, Pxdcr, Volts, Amps
               'PRINT "Fm, Trm", Fm, Trm
               'PRINT "TQ1, TQ2, DTQ", TQ1, TQ2, DTQ(j)
               'PRINT "Tstm, Pgage, Pxdcr", Tstm(j), Pgage,
Pxdcr
```

```
                'PRINT "Volts, Amps", Volts, Amps
                'INPUT "Press ENTER to continue.", Ok
                VoltAvg = VoltAvg + Volts
                TstmAvg = TstmAvg + Tstm(j)
'
'    Compute Hi using Petukov-Popov Correlation
'    Ref: Advances in Heat Transfer, Vol 6, pp. 503+, 1970.
'
                Tc! = (TQ1 + TQ2) / 2!
                Cp! = Cpw(Tc)
                kc!(j) = kfw(Tc)
                mc! = (.0004646 * Fm * Fm + .6185 * Fm +
2.2639) * rhofw(TQ1) * .00001
                mu! = mufw(Tc)
                rhoc! = rhofw(Tc)
                Vcw!(j) = 4 * mc / (rhoc * (PI# * Di ^ 2 -
AreaCorr))
                'PRINT "rhoc =", rhoc, " mc = ", mc
                'PRINT "Fm   =", Fm, "  Vcw =", Vcw(j)
                'PRINT "Di   =", Di, "   mu =", mu
                Re! = rhoc * Vcw(j) * Di / mu
                Pr! = mu * Cp / kc(j)
                'PRINT "Re   =", Re, "   Pr =", Pr
                '
                ' log_10 (z) = ln (z) / ln(10)
                '
                xi! = (1.82 * LOG(Re) / LOG(10!) - 1.64) ^ (-
2)
                K1! = 1! + 3.4 * xi
                K2! = 11.7 + 1.8 * Pr ^ (-1! / 3!)
                xi = xi / 8!
                Omega!(j) = xi * Re * Pr / (K1 + K2 * SQR(xi)
* (Pr ^ (2! / 3!) - 1!))
                '
                'Compute temperature rise correction for
frictional heating
                '
                Tcor! = FTfric(Vcw(j))
                Trise! = DTQ(j) - Tcor
                LMTD!(j) = Trise / LOG((Tstm(j) - TQ1) /
(Tstm(j) - TQ2 + Tcor))
                'PRINT "Tcor, Trise, LMTD: ", Tcor, Trise,
LMTD(j)
                Q! = mc * Cp * Trise
                Qflux!(j) = Q / (PI# * Dr * L)
                Uo!(j) = Qflux(j) / LMTD(j)
                'PRINT "Q, Qflux, Uo: ", Q, Qflux(j), Uo(j)
                'INPUT "Press ENTER to continue.", Ok
            NEXT j
            VoltAvg = VoltAvg / Nrun
            TstmAvg = TstmAvg / Nrun
```

```
          Power! = VoltAvg ^ 2 / 5.76      'Resistance of
Steam Boiler Heater Rods = 5.76 Ohms
          VapVel! = 4 * (Power - Qloss) / (PI# *
rhogw(TstmAvg) * hfgw(TstmAvg) * Dc ^ 2)

          PRINT #6,
          PRINT #6, USING "      Average System Power (kW):
###.##"; Power * .001
          PRINT #6, USING "      Average Steam Velocity
(m/s):  ###.##"; VapVel
          PRINT #6,
          PRINT #6, "      This analysis takes into account
the following:"
          PRINT #6, "            1. HEATEX insert inside the
tube"
          PRINT #6, "            2. End-fin effects"
          PRINT #6, "            3. Petukhov-Popov
correlation for Hi"
          PRINT #6, "            4. Nusselt type correlation
for Ho"
          PRINT #6,
          PRINT #6,
          '
          'Compute final values of hi and ho based on Ci and
Co obtained above
          '

          PRINT #6, "Data Vcw   DTCW   Qflux   LMTD    Tstm
DTwo    Om     Hi     Z     Ho     Nu(Ho)   Uo"
          PRINT #6, " #  (m/s) (C)    (kW/m^2)  (C)      (C)
(C)    -----------------(kW/m^2-K)---------------"
          PRINT #6,
          frmres$ = "##   ##.## ##.## #####.## ###.##   ###.##
##.## ###.## ###.## ###.## ###.## ###.##   ##.##"
          frmavg$ = "Average          #####.## ###.##
##.##                        ###.## ###.##"

          'PRINT #7, " DTwo       Ho          Qf           Nu"
          'PRINT #7, " (C)    (kW/m^2-K)    (MW/m^2)    (kW/m^2-
K)"
          'PRINT #7,
          frmhqt$ = "###.##    ###.##        ##.####
###.##"

          'PRINT #8, "   Qf         Ho"
          'PRINT #8, "(MW/m^2)   (kW/m^2-K)"
          'PRINT #8,
          'frmhoq$ = "##.####     ###.##"

          DTwoAvg = 0
          HoAvg = 0
```

```
        QfluxAvg = 0
        PRINT
        FOR j = 1 TO Nrun
            Hi! = Ci * Omega(j) * kc(j) / Di
            m! = SQR(Hi * Perim / (kt * AreaX))
            eff1! = ftanh(m * L1) / (m * L1)
            eff2! = ftanh(m * L2) / (m * L2)
            'PRINT "eff1,eff2"; eff1, eff2
            'INPUT "Press enter", OK
            Ho! = 1! / Uo(j) - Dr * L / (Di * (L + L1 *
eff1 + L2 * eff2) * Hi) - Rw * L * PI# * Dr
            Ho! = 1! / Ho
            DTwo! = Qflux(j) / Ho
            Two! = Tstm(j) - DTwo
            Tfilm! = (Tstm(j) + 2! * Two) / 3!
            rhof! = rhofw(Tfilm)
            kf! = kfw(Tfilm)
            muf! = mufw(Tfilm)
            hfgf! = hfgw(Tfilm) + .68 * Cpw(Tfilm) *
(DTwo)
            'PRINT "Hi,Uo(j),Ho,DTwo"; Hi, Uo(j), Ho, DTwo
            'INPUT "Press Enter", OK
            Z! = SQR(SQR(9.81 * kf ^ 3 * hfgf * rhof *
rhof / (muf * Dr * (DTwo))))
            'HoZ! = Co * Z
            Nu! = .728 * Z
            Nuq!(j) = Nu * DTwo
            'PRINT "Hi, Ho, : Nu", Hi, Ho, Nu, Nuq
            PRINT #6, USING frmres$; j; Vcw(j); DTQ(j);
Qflux(j) * .001; LMTD(j); Tstm(j); DTwo; Omega(j) * .001 *
kc(j) / Di; Hi * .001; Z * .001; Ho * .001; Nu * .001; Uo(j)
* .001
            PRINT #7, USING frmhqt$; DTwo; Ho * .001;
Qflux(j) * .000001; Nu * .001; Nuq(j) * .000001
            'PRINT #8, USING frmhoq$; Qflux(j) * .000001;
Ho * .001
            '
            'Compute averages....
            '
            DTwoAvg = DTwoAvg + DTwo
            HoAvg = HoAvg + Ho
            NuAvg = NuAvg + Nu
            QfluxAvg = QfluxAvg + Qflux(j)
            LMTDAvg = LMTDAvg + LMTD(j)
        NEXT j
        DTwoAvg = DTwoAvg / Nrun
        HoAvg = HoAvg / Nrun
        NuAvg = NuAvg / Nrun
        QfluxAvg = QfluxAvg / Nrun
        LMTDAvg = LMTDAvg / Nrun
        DTwAvg2 = QfluxAvg / HoAvg
```

```
        'PRINT
        'PRINT "HoAvg, QfluxAvg: ", HoAvg, QfluxAvg
        'PRINT "DTwAvg, DTwAvg2: ", DTwoAvg, DTwAvg2
        'PRINT
        PRINT #6, USING frmavg$; QfluxAvg * .001; LMTDAvg;
DTwoAvg; HoAvg * .001; NuAvg * .001
        PRINT #6,
        CLOSE    'Close ALL input and output files...

        PRINT
        PRINT "The PROCESSED data were written to the file
", nameres$
        PRINT "Delta Two,Qf,Nu vs Ho were written to the
file ", namehqt$
        'PRINT "Heat Flux vs Ho    were written to the file
", namehoq$
        PRINT
        PRINT " To get a hard copy of these files, do one
of the following:"
        PRINT "        1. Print the file from the DOS
prompt, OR"
        PRINT "        2. Load the file into QBasic, and
select FILE/PRINT."
        PRINT
        INPUT "Press ENTER to continue.", OK
END SUB
```

FUNCTION psw (temp)

```
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'      VariX    VariY    R^2    RegDOF   RgSmSq  ErrDOF   ErSmSq
'    791.667    0.093  100.00    6.00     1.67  0.12e+02  0.12e-
09
'
        DIM poly(10)
        poly(6) = .0060209213#
        poly(5) = .00046443261#
        poly(4) = .00001262479#
        poly(3) = .00000033316902#
        poly(2) = .0000000015146197#
        poly(1) = 3.8793438D-11
        poly(0) = -3.8075649D-14
'
        ps = poly(0)
'
'     pressure in bar = 0.1MPa
'
        FOR i = 1 TO 6
             ps = ps * temp + poly(i)
```

```
          NEXT i
'
'     pressure in kPa
'
          psw = ps * 100!
END FUNCTION
```

SUB RawData

```
          CLS
          PRINT
          INPUT " Give the NAME of the Data File (NO
extensions)"; name$
          PRINT
          INPUT " Enter the number of data points in this
file"; Nrun
          PRINT
          namedat$ = name$ + ".dat"
          nameraw$ = name$ + ".raw"
          OPEN namedat$ FOR INPUT AS #5
          OPEN nameraw$ FOR OUTPUT AS #6
          INPUT #5, Itb, kt!, Ipc
          INPUT #5, Di, Dr
          frmdat$ = " ##  ##.##  ##.##  ##.##  ##.##  ###.##
###.##  ###.##  ###.##  ###.##"

          PRINT #6, "       Program Name:
DRPSRI.BAS"
          PRINT #6, "       Data File:
"; namedat$
          PRINT #6, "       Raw Data File:
"; nameraw$
          PRINT #6, "       Tube Number:
"; Itb
          SELECT CASE Ipc
               CASE 1
                    PRINT #6, "       Pressure Condition:
Vacuum"
               CASE 2
                    PRINT #6, "       Pressure Condition:
Atmospheric"
          END SELECT
          PRINT #6,
          PRINT #6, USING "       Thermal Conductivity (W/m-
K):  ####.#"; kt!
          PRINT #6, USING "       Tube Inside Diameter (mm):
###.##"; Di
          PRINT #6, USING "       Tube Outside Diameter (mm):
###.##"; Dr
          PRINT #6,
          PRINT #6, "Data  Flow   Room   CW In  CW Out  CW
Temp.  Steam   Gage    Xducer  Volts  Curnt"
```

```
          PRINT #6, "  #    Meter  Temp.   Temp.    Temp.
Diff.     Temp.   Press    Press"
          PRINT #6, "         (%)    (C)     (C)      (C)      (C)
(C)     (kPa)   (kPa)      (V)    (Amp)"
          PRINT #6,
          frmraw$ = " ##     ##     ##.##   ##.##    ##.##
##.##   ###.##   ###.##  ###.##  ###.##  ##.##"

          FOR j = 1 TO Nrun  'Loop for reading and writing
Nrun data runs
                INPUT #5, Fm, Trm, TQ1, TQ2, DTQ, Tstm, Pgage,
Pxdcr, Volts, Amps
                PRINT #6, USING frmraw$; j; Fm; Trm; TQ1; TQ2;
DTQ; Tstm; Pgage; Pxdcr; Volts; Amps
          NEXT j

          CLOSE    'Close ALL input and output files...

          PRINT
          PRINT " The RAW data were written on the file ",
nameraw$
          PRINT
          PRINT " To get a hard copy of the saved RAW data,
do one of these:"
          PRINT "          1. Print the file from the DOS
prompt, OR"
          PRINT "          2. Load the file into QBasic, and
select file/print."
          PRINT
          INPUT " Press ENTER to continue.", OK
END SUB
```

FUNCTION rhofw (temp)

```
'
'     rhof in kg/m^3
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'   VariX   VariY    R^2   RegDOF  RgSmSq  ErrDOF  ErSmSq
'  791.667 178.092  100.00   6.00 3205.66   12.00 0.10e-03
'
          DIM poly(10)
          poly(6) = 999.81032#
          poly(5) = .070640968#
          poly(4) = -9.073794200000001D-03
          poly(3) = .000088129446#
          poly(2) = -7.631863099999999D-07
          poly(1) = .0000000039067797#
          poly(0) = -8.624459699999999D-12
          rhof = poly(0)
```

```
        FOR i = 1 TO 6
            rhof = rhof * temp + poly(i)
        NEXT i
        rhofw = rhof
END FUNCTION
```

FUNCTION rhogw (temp)

```
'
'     rhog in kg/m^3
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'   VariX     VariY     R^2    RegDOF   RgSmSq   ErrDOF   ErSmSq
' 791.667    0.032   100.00    5.00     0.58    13.00   0.12e-08
'
        DIM poly(10)
        poly(5) = .0049353625#
        poly(4) = .00031822098#
        poly(3) = .000011268464#
        poly(2) = .00000013911252#
        poly(1) = .0000000022447156#
        poly(0) = 8.446448600000001D-12
'
        rhog = poly(0)
        FOR i = 1 TO 5
            rhog = rhog * temp + poly(i)
        NEXT i
        rhogw = rhog
END FUNCTION
```

SUB SENSOR

```
    '
    ' Subroutine for data acquisition using National
      Instruments PC2A IEEE-488 BOARD TO HP-3497 AND 2804A
    ' WRITTEN BY Ashok Das 4/11/95
    ' (Data Acqisition commands by TomC 4/15/94)
    ' This uses the Universal Language Interface
    ' ULI.COM must be run prior to running the program
    ' This is usally done in the AUTOEXEC.BAT
    ' -----------------------------------------------------
    DIM Emf(5)
    ' Prepare interface between program and PC2A board
    'CLOSE
    OPEN "GPIB0" FOR OUTPUT AS #1
    OPEN "GPIB0" FOR INPUT AS #2

    'Initialize the bus and reset to default parameters

    PRINT #1, "ABORT"
    PRINT #1, "RESET"
```

```
     PRINT #1, "GPIBEOS CR LF"          'SET TERMINATOR
     '
     PRINT #1, "CLEAR "                 'CLEAR ALL INSTRUMENTS ON
THE BUS
     PRINT #1, "REMOTE"                 'PLACE ALL INSTRUMENTS IN
REMOTE MODE
     PRINT #1, "OUTPUT 13;T3R2EX"       'Set Quartz Thermometer
to T1-T2
     '
     ' Initialize ...
     '
     FOR i = 0 TO 4
     Emf(i) = 0
     NEXT i
     TC1 = 0
     TC2 = 0
     TQ1 = 0
     TQ2 = 0
     DTQ = 0
     Trm = 0
     Tstm1 = 0
     Tstm2 = 0
     Exdcr = 0
     Volts = 0
     Amps = 0
     '
     'PREPARE 3497
     'CHANNELS 61 THRU 62 : FOR VOLTAGE AN CURRENT
     PRINT #1, "OUTPUT 9; AR AF61 AL61 VR5"
     PRINT #1, "OUTPUT 9; ASSA"          'ANALOG STEP AND BEEP
     PRINT
     BEEP
     INPUT "Connect Voltage Line.", OK
     'BEGIN TO TAKE DATA
     PRINT #1, "OUTPUT 9; AR AF61 AL61 VR5" 'CH 61 for
voltage
     PRINT #1, "OUTPUT 9; ASSA"              'ANALOG STEP AND
BEEP
     FOR j = 1 TO 5
          CALL FWAIT(2)
          PRINT #1, "ENTER 9"
          INPUT #2, DAT$
          Volts = Volts + VAL(DAT$)               'CONVERT STRING
TO NUMBER
     NEXT j
     Volts = Volts / 5!                'Take the average..
     Volts = Volts * 100!               'Scaling factor for data
acquisition
     BEEP
     INPUT "Disconnect Voltage Line.", OK
     PRINT #1, "OUTPUT 9; AR AF62 AL62 VR5"
```

```
    PRINT #1, "OUTPUT 9; ASSA"              'ANALOG STEP AND
BEEP
    FOR j = 1 TO 5
         PRINT #1, "ENTER 9"
         INPUT #2, DAT$
         Amps = Amps + VAL(DAT$)                'CONVERT STRING
TO NUMBER
    NEXT j
    Amps = Amps / 5!
    PRINT #1, "OUTPUT 9; AR AF24 AL24 VR5"     'Reset the HP
display to CH 24 Thermocouple
    PRINT #1, "OUTPUT 9; ASSA"
    '--------------------
    'Take 5 sets of data for temperatures and pressure
    '--------------------
    PRINT
    FOR j = 1 TO 5
         PRINT "Getting data set number", j
         '
         'TAKE DATA FROM 2804A Q. Thermometer
         '
         PRINT #1, "OUTPUT 13;T1R2EX"     'MESSAGE TO SELECT
SENSOR 1
         CALL FWAIT(8)                     'WAIT FOR READING
         PRINT #1, "ENTER 13"
         INPUT #2, DAT$
         TQ1 = TQ1 + VAL(DAT$)
         PRINT #1, "OUTPUT 13;T2R2EX"     'MESSAGE TO SELECT
SENSOR 2
         CALL FWAIT(8)                     'WAIT FOR READING
         PRINT #1, "ENTER 13"
         INPUT #2, DAT$
         TQ2 = TQ2 + VAL(DAT$)
         PRINT #1, "OUTPUT 13;T3R2EX"     'MESSAGE TO SELECT
DIFFERENTIAL
         CALL FWAIT(8)                     'WAIT FOR READING
         PRINT #1, "ENTER 13"
         INPUT #2, DAT$
         DTQ = DTQ + ABS(VAL(DAT$))
         'CHANNELS 64 : FOR Pressure Transducer EMF Reading
         PRINT #1, "OUTPUT 9; AR AF64 AL64 VR5"
         PRINT #1, "OUTPUT 9; ASSA"      'ANALOG STEP AND
BEEP
         PRINT #1, "ENTER 9"
         INPUT #2, DAT$
         Exdcr = Exdcr + VAL(DAT$)      'CONVERT STRING TO
NUMBER
         '
         'Take Data from the Thermocouples...
         '
         'CHANNELS 20 THRU 24 : FOR Thermocouple Temperature
```

```
EMFs
          PRINT #1, "OUTPUT 9; AR AF20 AL24 VR5"
          FOR i = 0 TO 4
               'ANALOG STEP AND BEEP
               PRINT #1, "OUTPUT 9; ASSA"
               PRINT #1, "ENTER 9"
               INPUT #2, DAT$
               'CONVERT STRING TO NUMBER  and Volts to
Millivolts
               Emf(i) = Emf(i) + VAL(DAT$) * 1000
          NEXT i
     NEXT j
     'PRINT #1, "CLEAR "                    'CLEAR ALL INSTRUMENTS
ON BUS
     'PRINT #1, "LOCAL "                    'PLACE ALL INSTRUMENTS
IN LOCAL MODE
     CLOSE #1
     CLOSE #2
     'Compute Average values...
     TQ1 = TQ1 / 5! + .013
     TQ2 = TQ2 / 5! + .013
     DTQ = DTQ / 5!
     Exdcr = Exdcr / 5!
     FOR i = 0 TO 4
          Emf(i) = ABS(Emf(i)) / 5!
     NEXT i
     Pxdcr = Patm - 2.94 * Exdcr                 'Emf to Psi
     Pxdcr = Pxdcr * 6.89473                     'PSI to kPa
     '
     SELECT CASE Ipc
          CASE 0                                 '16-25 deg C range
Tstm1 = -1.2981 * Emf(0) * Emf(0) + 26.8138 * Emf(0) - .2328
Tstm2 = -1.2981 * Emf(4) * Emf(4) + 26.8164 * Emf(4) - .2596

          CASE 1                                 '48-51 deg C range
Tstm1 = 1.1574 * Emf(0) * Emf(0) + 18.5431 * Emf(0) + 7.4748
Tstm2 = 19.7403 * Emf(4) * Emf(4) - 55.7806 * Emf(4) +
81.7896

          CASE 2                                 '98-102 deg C range
Tstm1 = .4141 * Emf(0) * Emf(0) + 17.8096 * Emf(0) + 16.2353
Tstm2 = -1.2269 * Emf(4) * Emf(4) + 32.0078 * Emf(4) -
14.3873

          CASE 3                           'All other temp range
               Tstm1 = FTCgen(Emf(0))
               Tstm2 = FTCgen(Emf(4))
     END SELECT
     '
     DTstm = Tstm1 - Tstm2
     IF ABS(DTstm) > .1 THEN
```

```
          BEEP
          PRINT
          PRINT USING " Steamside thermocouples differ by
###.##  deg C"; DTstm
     END IF
TC1 = -1.5538 * Emf(1) * Emf(1) + 27.3201 * Emf(1) - .482
TC2 = -1.2813 * Emf(2) * Emf(2) + 26.8505 * Emf(2) - .2656
     DTC = TC2 - TC1 - DTQ
     IF ABS(DTC) > .05 THEN
          PRINT USING " TC and Quartz Delta-T differ by
###.##  deg C"; DTC
     END IF
     Trm = FTCgen(Emf(3))
END SUB
```

FUNCTION sigmaw (temp)

```
'
' ASME/NIST surface tension in N/m (Kg-m/s^2/m = Kg/s^2)
'
          tempK = (273.15# + temp) / 647.15#
          sigmaw = .2358# * (1 - tempK) ^ 1.256 * (1 - .625#
* (1 - tempK))
END FUNCTION
```

SUB TakeData

```
     DIM Fmv(20), timev(20), Trmv(20), TQ1v(20), TQ2v(20),
DTQv(20), Tstmv(20), Pxdcrv(20), Pgagev(20), Psatv(20),
Voltsv(20), Ampsv(20), mfngv(20)
          CLS
          BEEP
          INPUT "Today's Date"; today$
          PRINT
          DO
               PRINT " Enter Pressure Condition"
               BEEP
               INPUT "    1 for Vacuum, 2 for Atmospheric";
Ipc
               IF Ipc < 1 OR Ipc > 2 THEN
                    PRINT " Invalid Pressure Option."
                    PRINT
               END IF
          LOOP WHILE Ipc < 1 OR Ipc > 2
          BEEP
          'INPUT " Enter Tube Number"; Itb
          INPUT " Enter Tube Name (NO extensions)"; name$
          INPUT " Enter Thermal Conductivity (W/m-K)"; kt!
          INPUT " Enter Tube ID, OD (mm)"; Di, Dr
          PRINT
          BEEP
          namedat$ = name$ + ".dat"
          nameraw$ = name$ + ".raw"
```

```
          OPEN namedat$ FOR OUTPUT AS #5
          OPEN nameraw$ FOR OUTPUT AS #6
          PRINT #5, Itb, kt!, Ipc
          PRINT #5, Di, Dr
          frmdat$ = " ##  ##.##  ##.##  ##.##  ##.##  ###.##
###.##  ###.##  ###.##  ###.##"

          LPRINT "       Test Date:                    ";
today$
          LPRINT "       Program Name:
DRPSAM2.BAS"
          LPRINT "       Data File:                    ";
namedat$
          LPRINT "       Raw Data File:                ";
nameraw$
          'LPRINT "      Tube Number:                   ";
Itb
          SELECT CASE Ipc
               CASE 1
                    LPRINT "       Pressure Condition:
Vacuum"
               CASE 2
                    LPRINT "       Pressure Condition:
Atmospheric"
          END SELECT
          LPRINT
          LPRINT USING "      Thermal Conductivity (W/m-K):
####.#"; kt!
          LPRINT USING "      Tube Inside Diameter (mm):
###.##"; Di
          LPRINT USING "      Tube Outside Diameter (mm):
###.##"; Dr
          LPRINT
          LPRINT " Flow  Room  CW In CW Out CW Temp. Steam
Gage  Xducer Volts Curnt MfNG"
          LPRINT " Meter Temp. Temp. Temp. Diff.  Temp.
Press  Press"
          LPRINT "  (%)  (C)   (C)   (C)   (C)    (C)
(kPa)  (kPa)    (V)  (Amp)"
          LPRINT
          frmlpr$ = "  ##   ##.##  ##.##  ##.##  ##.##
###.##  ###.##  ###.##  ###.## ##.## ###.##"
          frmprn$ = "  ##    ###  ##.#  ##.##  ##.##  ###.##
##.##  ##.##  ###.## ###.##"

          PRINT #6, "      Test Date:
"; today$
          PRINT #6, "      Program Name:
DRPSAM2.BAS"
          PRINT #6, "      Tube Number:
"; name$
```

```
          'PRINT #6, "        Raw Data File:
"; nameraw$
          'PRINT #6, "        Tube Number:
"; Itb
          SELECT CASE Ipc
               CASE 1
                    PRINT #6, "        Pressure Condition:
Vacuum"
               CASE 2
                    PRINT #6, "        Pressure Condition:
Atmospheric"
          END SELECT
          PRINT #6,
          PRINT #6, USING "        Thermal Conductivity (W/m-
K):  ####.#"; kt!
          PRINT #6, USING "        Tube Inside Diameter (mm):
###.##"; Di
          PRINT #6, USING "        Tube Outside Diameter (mm):
###.##"; Dr
          PRINT #6,
          PRINT #6, "Data  Flow   Room   CW In  CW Out  CW
Temp.  Steam   Gage    Xducer  Volts  Curnt"
          PRINT #6, "  #   Meter  Temp.  Temp.   Temp.
Diff.    Temp.   Press   Press"
          PRINT #6, "        (%)    (C)     (C)      (C)      (C)
(C)     (kPa)   (kPa)      (V)    (Amp)"
          PRINT #6,
          frmraw$ = " ##     ##     ##.##  ##.##    ##.##
##.##   ###.##  ###.##   ###.##  ###.##  ##.##"

          MWstm = 18.016
          MWair = 28.97
          Nrun = 0
          Fmp = 0
          TIMER ON
          timestart = TIMER
          DO    'Loop for taking Nrun data runs
               DO    'Loop for flowmeter reading input
                    BEEP
                    PRINT
                    INPUT " Enter Flowmeter Reading"; Fm
                    WHILE Fm < 20 OR Fm > 80
                         BEEP
                         INPUT " Incorrect Flowmeter Reading.
Please Re-enter"; Fm
                    WEND
                    PRINT " You Entered Flowmeter = ", Fm
                    BEEP
          INPUT " Is it Correct? Yes (y) or No (n)"; Iflg$
                    IF Fm = Fmp THEN
          PRINT "New FM reading is same as the last one."
```

```
                    BEEP: BEEP
        INPUT "Is it Okay? Yes (y) or No (n)"; Iflg$
                END IF
            LOOP WHILE Iflg$ = "N" OR Iflg$ = "n"
            i = 0
            CLS
    DO    'Loop for data acquisition for "one" flowrate

                BEEP
    PRINT USING "Taking data for ##% flow rate."; Fm
    INPUT "Press ENTER to begin data acquisition.", OK

                CALL SENSOR

                PRINT
                timenow = TIMER - timestart
                BEEP
    INPUT " Enter Pressure Gage Reading (psi)"; Pgage

                i = i + 1
        Pgage = Pgage * 6.8947        'convert to kPa
                Tstm = (Tstm1 + Tstm2) / 2!
                Psat = psw(Tstm)
                vfng = (Pxdcr - Psat) / Pxdcr
                mfng = 100! / (1! + (1! / vfng - 1!) *
MWstm / MWair)
                timev(i) = timenow
                Fmv(i) = Fm
                Trmv(i) = Trm
                TQ1v(i) = TQ1
                TQ2v(i) = TQ2
                DTQv(i) = DTQ
                Tstmv(i) = Tstm
                Pxdcrv(i) = Pxdcr
                Pgagev(i) = Pgage
                Psatv(i) = Psat
                Voltsv(i) = Volts
                Ampsv(i) = Amps
                mfngv(i) = mfng
                PRINT
                PRINT USING "Summary of last ## data
taken for this flow rate.."; i
                PRINT
                PRINT " Data  Time Flow  CW In  CW Temp.
Steam  Xducr  Sat.  Volts  MfNG"
                PRINT "   #       Meter  Temp.  Diff.
Temp.  Pres.  Pres. "
                PRINT "           (m)  (%)    (C)    (C)
(C)   (Psi)  (Psi)   (V)    (%)"
                PRINT
                FOR j = 1 TO i
```

```
                              PRINT USING frmprn$; j; timev(j) /
60; Fmv(j); TQ1v(j); DTQv(j); Tstmv(j); Pxdcrv(j) / 6.8947;
Psatv(j) / 6.8947; Voltsv(j); mfngv(j)
                         NEXT j
                         PRINT
                         BEEP
                         INPUT "OK to accept one of these data?
Yes (y) or No (n)"; OK$
                         PRINT
                         IF OK$ = "Y" OR OK$ = "y" THEN
                              Okd$ = "n"
                              WHILE Okd$ = "n" OR Okd$ = "N"
                                   BEEP
     INPUT "Which data set do you want to accept"; k
                                   PRINT
     PRINT USING "You chose to accept data set no. ##"; k
                                   BEEP
     INPUT "Is it Okay? Yes (y) or No (n)"; Okd$
                                   PRINT
                              WEND
                         END IF
                    LOOP WHILE OK$ = "N" OR OK$ = "n"
                    Nrun = Nrun + 1
                    LPRINT USING frmlpr$; Fmv(k); Trmv(k);
TQ1v(k); TQ2v(k); DTQv(k); Tstmv(k); Pgage; Pxdcrv(k);
Voltsv(k); Ampsv(k); mfngv(k)
                    PRINT #5, USING frmdat$; Fmv(k); Trmv(k);
TQ1v(k); TQ2v(k); DTQv(k); Tstmv(k); Pgagev(k); Pxdcrv(k);
Voltsv(k); Ampsv(k)
                    PRINT #6, USING frmraw$; Nrun; Fmv(k);
Trmv(k); TQ1v(k); TQ2v(k); DTQv(k); Tstmv(k); Pgagev(k);
Pxdcrv(k); Voltsv(k); Ampsv(k)
                    Fmp = Fm
                    CLS
                    PRINT USING "Last data was taken for ##% flow
rate"; Fm
                    BEEP
                    INPUT "Will there be another data run (Y or
N)"; Nflg$
                    WHILE Nflg$ <> "Y" AND Nflg$ <> "y" AND Nflg$
<> "N" AND Nflg$ <> "n"
                         BEEP
                         INPUT "Will there be another data run (Y
or N)"; Nflg$
                    WEND
                    IF Nflg$ = "N" OR Nflg$ = "n" THEN
                         BEEP
                         INPUT "Once Again, will there be another
data run (Y or N)"; Nflg$
                    END IF
               LOOP WHILE Nflg$ = "Y" OR Nflg$ = "y"
```

```
        PRINT #5,
        PRINT #5, "No. of DATA sets :", Nrun

        CLOSE       'Close all output files..

PRINT USING " ## Data sets were stored in the file &"; Nrun;
namedat$
PRINT " The RAW data were written on the file ", nameraw$
        PRINT
        BEEP
        INPUT "Press ENTER to continue.", OK
END SUB
```

APPENDIX D. PROCESSED DATA

Processed data from the experimental runs follow.

Program Name:	DRPSAM2.BAS
Tube Number:	S4OF9A2
Raw Data File:	S4OF9A2.dat
Processed Data File:	S4OF9A2.res
Pressure Condition:	Atmospheric
Thermal Conductivity (W/m-K):	14.30
Tube Inside Diameter (mm):	13.21
Tube Outside Diameter (mm):	14.10
Wall Resistance Rw (m/W/m-K):	0.00544
Average System Power (kW):	25.74
Average Steam Velocity (m/s):	1.04

This analysis takes into account the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correlation for Hi
4. Nusselt type correlation for Ho

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD (C)	Tstm (C)	DTwo (C)	Hi	Z	Ho	Nu(Ho)	Uo
							-------------(kW/m^2-K)----------				
1	4.06	1.30	487.32	76.54	99.88	45.53	33.52	12.65	10.70	9.21	6.37
2	3.55	1.45	479.82	77.33	99.90	44.96	29.86	12.71	10.67	9.25	6.21
3	3.05	1.65	471.96	77.43	99.85	43.28	26.19	12.88	10.90	9.37	6.10
4	2.55	1.94	467.02	78.28	99.93	41.29	22.36	13.09	11.31	9.53	5.97
5	2.06	2.30	448.87	78.56	99.87	38.80	18.62	13.36	11.57	9.73	5.71
6	1.58	2.86	428.08	78.25	99.87	34.44	14.94	13.89	12.43	10.11	5.47
7	1.10	3.75	392.05	77.62	99.88	28.27	11.16	14.76	13.87	10.74	5.05
8	1.10	3.76	393.13	78.01	99.88	28.45	11.14	14.73	13.82	10.72	5.04
9	1.58	2.85	426.65	78.59	99.88	34.82	14.89	13.84	12.25	10.07	5.43
10	2.06	2.31	450.90	78.89	99.86	38.86	18.55	13.35	11.60	9.72	5.72
11	2.55	1.94	467.21	78.70	99.91	41.49	22.15	13.07	11.26	9.51	5.94
12	3.05	1.67	478.06	78.29	99.85	43.43	25.82	12.86	11.01	9.36	6.11
13	3.55	1.47	486.84	79.05	99.89	46.00	29.48	12.61	10.58	9.18	6.16
14	4.06	1.31	491.50	77.89	99.90	46.41	33.04	12.57	10.59	9.15	6.31
Average			454.96	78.10		39.72			11.61	9.69	

Program Name: DRPSAM2.BAS
Tube Number: A1OF7A1
Raw Data File: A1OF7A1.dat
Processed Data File: A1OF7A1.res
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 200.90
Tube Inside Diameter (mm): 12.50
Tube Outside Diameter (mm): 13.19
Wall Resistance Rw (m/W/m-K): 0.00032

Average System Power (kW): 25.74
Average Steam Velocity (m/s): 1.04

This analysis takes into account the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correlation for Hi
4. Nusselt type correlation for Ho

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD (C)	Tstm (C)	DTwo (C)	Hi	Z	Ho	Nu(Ho)	Uo
							-----------	-----	(kW/m^2-K)	-----	-----------
1	4.54	1.45	578.40	75.99	99.92	59.50	37.65	11.64	9.72	8.47	7.61
2	3.97	1.61	567.48	75.77	99.91	57.84	33.66	11.77	9.81	8.57	7.49
3	3.41	1.80	548.72	75.55	99.91	56.05	29.64	11.92	9.79	8.68	7.26
4	2.85	2.08	533.92	75.85	99.90	53.98	25.43	12.09	9.89	8.80	7.04
5	2.30	2.45	510.02	75.67	99.90	51.02	21.29	12.35	10.00	8.99	6.74
6	1.76	3.02	482.38	75.45	99.89	46.76	17.06	12.75	10.32	9.28	6.39
7	1.23	3.91	436.37	75.07	99.91	40.82	12.71	13.36	10.69	9.73	5.81
8	1.23	3.91	436.38	75.12	99.91	40.86	12.70	13.36	10.68	9.72	5.81
9	1.76	3.03	484.05	75.76	99.91	46.88	17.01	12.74	10.33	9.27	6.39
10	2.30	2.48	516.40	76.41	99.92	51.35	21.20	12.32	10.06	8.97	6.76
11	2.85	2.09	536.63	76.38	99.97	54.30	25.31	12.07	9.88	8.79	7.03
12	3.41	1.81	551.94	75.54	99.89	55.84	29.51	11.93	9.88	8.69	7.31
13	3.97	1.60	563.96	76.07	99.89	58.19	33.56	11.74	9.69	8.55	7.41
14	4.54	1.45	578.44	76.11	99.88	59.59	37.59	11.63	9.71	8.47	7.60
Average			523.22	75.77		52.35			10.03	8.93	

Program Name:	DRPSAM2.BAS
Tube Number:	A1OF2A2
Raw Data File:	A1OF2A2.dat
Processed Data File:	A1OF2A2.res
Pressure Condition:	Atmospheric

Thermal Conductivity (W/m-K):	200.90
Tube Inside Diameter (mm):	12.50
Tube Outside Diameter (mm):	13.19
Wall Resistance Rw (m/W/m-K):	0.00032

Average System Power (kW):	25.74
Average Steam Velocity (m/s):	1.04

This analysis takes into account the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correlation for Hi
4. Nusselt type correlation for Ho

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD (C)	Tstm (C)	DTwo (C)	Hi	Z	Ho	Nu(Ho)	Uo
							------------(kW/m^2-K)				-----------
1	4.54	1.45	578.31	75.67	99.88	59.22	37.76	11.66	9.77	8.49	7.64
2	3.97	1.60	563.86	75.21	99.89	57.40	33.69	11.81	9.82	8.59	7.50
3	3.41	1.81	551.86	75.70	99.91	56.07	29.60	11.92	9.84	8.68	7.29
4	2.85	2.11	541.73	76.00	99.90	53.77	25.39	12.11	10.07	8.82	7.13
5	2.30	2.48	516.39	76.01	99.89	50.96	21.22	12.36	10.13	9.00	6.79
6	1.76	3.02	482.46	75.83	99.92	47.03	17.00	12.72	10.26	9.26	6.36
7	1.23	3.91	436.45	75.41	99.90	41.04	12.66	13.34	10.63	9.71	5.79
8	1.23	3.92	437.60	75.54	99.90	41.04	12.64	13.34	10.66	9.71	5.79
9	1.76	3.03	484.21	76.41	99.92	47.34	16.90	12.69	10.23	9.24	6.34
10	2.30	2.49	518.67	76.77	99.91	51.43	21.05	12.32	10.09	8.97	6.76
11	2.85	2.11	542.01	77.04	99.89	54.57	25.11	12.04	9.93	8.77	7.04
12	3.41	1.83	558.37	76.41	99.90	56.32	29.25	11.89	9.91	8.66	7.31
13	3.97	1.62	571.42	76.94	99.92	58.68	33.27	11.70	9.74	8.52	7.43
14	4.54	1.46	582.81	76.95	99.88	60.18	37.26	11.58	9.68	8.43	7.57
Average			526.15	76.13		52.50			10.06	8.92	

Program Name: DRPSAM2.BAS
Tube Number: A1OF7V1
Raw Data File: A1OF7V1.dat
Processed Data File: A1OF7V1.res
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 200.90
Tube Inside Diameter (mm): 12.50
Tube Outside Diameter (mm): 13.19
Wall Resistance Rw (m/W/m-K): 0.00032

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.96

This analysis takes into account the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correlation for Hi
4. Nusselt type correlation for Ho

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD (C)	Tstm (C)	DTwo (C)	Hi	Z	Ho	Nu(Ho)	Uo
							-------------	(kW/m^2-K)		----------	
1	4.54	0.59	223.96	26.88	48.70	19.83	33.80	13.29	11.30	9.68	8.33
2	3.97	0.64	218.02	26.70	48.70	19.09	30.22	13.46	11.42	9.80	8.17
3	3.41	0.71	211.80	26.61	48.72	18.28	26.58	13.65	11.59	9.94	7.96
4	2.85	0.82	207.93	27.03	48.71	17.58	22.76	13.82	11.83	10.06	7.69
5	2.30	0.96	198.65	27.00	48.71	16.33	19.03	14.14	12.16	10.30	7.36
6	1.76	1.16	184.89	26.91	48.69	14.67	15.23	14.62	12.61	10.64	6.87
7	1.23	1.50	167.43	26.73	48.72	12.08	11.31	15.50	13.86	11.28	6.26
8	1.23	1.50	167.43	26.71	48.70	12.06	11.31	15.50	13.89	11.29	6.27
9	1.76	1.17	186.52	27.37	48.69	15.00	15.19	14.52	12.44	10.57	6.81
10	2.30	0.97	200.78	27.66	48.70	16.84	18.95	14.01	11.93	10.20	7.26
11	2.85	0.84	213.16	27.87	48.69	18.14	22.64	13.68	11.75	9.96	7.65
12	3.41	0.72	214.96	27.60	48.67	19.10	26.39	13.45	11.26	9.79	7.79
13	3.97	0.65	221.68	27.26	48.72	19.48	30.04	13.37	11.38	9.73	8.13
14	4.54	0.59	224.00	27.27	48.70	20.19	33.66	13.21	11.09	9.62	8.21
Average			202.94	27.11		17.05			12.04	10.20	

Program Name: DRPSAM2.BAS
Tube Number: A1OF7V2
Raw Data File: A1OF7V2.dat
Processed Data File: A1OF7V2.res
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 200.90
Tube Inside Diameter (mm): 12.50
Tube Outside Diameter (mm): 13.19
Wall Resistance Rw (m/W/m-K): 0.00032

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.97

This analysis takes into account the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correlation for Hi
4. Nusselt type correlation for Ho

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD (C)	Tstm (C)	DTwo (C)	Hi	Z	Ho	Nu(Ho)	Uo
							-------------(kW/m^2-K)-----------				
1	4.54	0.55	207.43	26.68	48.71	20.16	33.88	13.22	10.29	9.62	7.78
2	3.97	0.60	203.57	26.60	48.68	19.50	30.24	13.36	10.44	9.73	7.65
3	3.41	0.67	199.41	26.51	48.69	18.67	26.60	13.55	10.68	9.87	7.52
4	2.85	0.77	194.95	26.89	48.70	18.05	22.80	13.70	10.80	9.98	7.25
5	2.30	0.89	183.99	26.88	48.68	17.01	19.05	13.96	10.82	10.17	6.85
6	1.76	1.08	172.07	26.80	48.69	15.42	15.24	14.40	11.16	10.48	6.42
7	1.23	1.37	152.89	26.61	48.70	13.24	11.33	15.08	11.55	10.98	5.75
8	1.23	1.37	152.89	26.63	48.72	13.26	11.33	15.07	11.53	10.97	5.74
9	1.76	1.08	172.08	26.95	48.70	15.55	15.22	14.36	11.06	10.45	6.39
10	2.30	0.90	186.10	27.10	48.68	17.09	19.00	13.94	10.89	10.15	6.87
11	2.85	0.77	194.99	27.28	48.72	18.40	22.70	13.62	10.60	9.92	7.15
12	3.41	0.67	199.43	26.71	48.69	18.85	26.54	13.51	10.58	9.84	7.47
13	3.97	0.60	203.59	26.79	48.70	19.67	30.19	13.33	10.35	9.70	7.60
14	4.54	0.55	207.44	26.83	48.72	20.30	33.83	13.19	10.22	9.60	7.73
Average			187.92	26.80		17.51			10.78	10.10	

Program Name:	DRPSAM2.BAS
Tube Number:	A1OF73V
Raw Data File:	A1OF73V.dat
Processed Data File:	A1OF73V.res
Pressure Condition:	Vacuum
Thermal Conductivity (W/m-K):	200.90
Tube Inside Diameter (mm):	12.50
Tube Outside Diameter (mm):	13.19
Wall Resistance Rw (m/W/m-K):	0.00032
Average System Power (kW):	6.81
Average Steam Velocity (m/s):	1.96

This analysis takes into account the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correlation for Hi
4. Nusselt type correlation for Ho

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD (C)	Tstm (C)	DTwo (C)	Hi	Z	Ho	Nu(Ho)	Uo
							-----------(kW/m^2-K)------------				
1	4.54	0.59	223.92	26.46	48.69	19.44	33.95	13.38	11.52	9.74	8.46
2	3.97	0.64	217.98	25.94	48.71	18.36	30.33	13.63	11.87	9.92	8.40
3	3.41	0.71	211.77	26.28	48.72	17.98	26.67	13.72	11.78	9.99	8.06
4	2.85	0.82	207.89	26.67	48.72	17.26	22.86	13.90	12.05	10.12	7.80
5	2.30	0.94	194.43	26.30	48.68	15.90	19.11	14.26	12.23	10.38	7.39
6	1.76	1.14	181.66	26.51	48.69	14.53	15.29	14.66	12.50	10.67	6.85
7	1.23	1.44	160.69	26.07	48.69	12.07	11.37	15.50	13.32	11.28	6.16
8	1.23	1.44	160.69	26.33	48.69	12.32	11.36	15.40	13.04	11.21	6.10
9	1.76	1.14	181.67	26.70	48.71	14.70	15.26	14.61	12.36	10.64	6.80
10	2.30	0.96	198.64	26.87	48.70	16.22	19.05	14.18	12.25	10.32	7.39
11	2.85	0.83	210.52	27.36	48.72	17.80	22.77	13.77	11.83	10.02	7.69
12	3.41	0.72	214.90	26.65	48.70	18.20	26.56	13.67	11.81	9.95	8.06
13	3.97	0.65	221.63	26.74	48.72	19.00	30.21	13.48	11.66	9.81	8.29
14	4.54	0.60	228.07	26.72	48.71	19.56	33.86	13.35	11.66	9.72	8.53
Average			201.03	26.54		16.67			12.13	10.27	

Program Name: DRPSAMUN.BAS
Raw Data File: A3MD8A1.dat
Processed Data File: A3MD8A1.res
Tube Number: 8
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 200.90
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00029

Average System Power (kW): 25.73
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 2.675
Outside leading coeff., Co: 6.091

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	4.40	5.44	2194.78	70.72	99.85	22.52	31.04	49.66	97.44
2	3.85	5.79	2045.48	69.54	99.83	20.41	29.42	44.84	100.22
3	3.30	6.14	1864.30	69.09	99.80	17.94	26.99	39.55	103.90
4	2.76	6.65	1692.95	69.48	99.81	15.70	24.37	33.90	107.81
5	2.23	7.27	1496.96	69.64	99.85	13.26	21.50	28.29	112.90
6	1.71	8.13	1282.45	69.73	99.84	10.73	18.39	22.61	119.49
7	1.19	9.35	1029.62	69.45	99.85	7.96	14.83	16.83	129.30
8	1.19	9.45	1041.44	70.62	99.81	8.09	14.75	16.64	128.78
9	1.71	8.24	1301.21	71.54	99.84	10.95	18.19	22.24	118.84
10	2.23	7.45	1536.05	71.77	99.84	13.74	21.40	27.75	111.82
11	2.76	6.85	1746.39	71.68	99.86	16.39	24.36	33.23	106.58
12	3.30	6.32	1921.16	70.51	99.80	18.70	27.25	39.01	102.71
13	3.85	5.88	2078.19	69.95	99.85	20.86	29.71	44.63	99.60
14	4.40	5.54	2233.83	69.54	99.81	23.09	32.12	50.17	96.73
Average			1676.06			15.74			110.01

Wilson Plot X-Y data points...

X	Y	X	Y
0.87	0.49	3.34	1.40
0.99	0.53	2.32	1.04
1.16	0.60	1.76	0.83
1.40	0.70	1.41	0.69
1.75	0.83	1.16	0.59
2.30	1.03	0.99	0.52
3.31	1.40	0.86	0.47

Program Name: DRPSAMUN.BAS
Raw Data File: A3MD8A2.dat
Processed Data File: A3MD8A2.res
Tube Number: 11
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 200.90
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00029

Average System Power (kW): 25.73
Average Steam Velocity (m/s): 1.03

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 2.659
Outside leading coeff., Co: 6.073

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	5.44	2193.51	69.75	99.91	22.59	31.45	49.77	97.08
2	3.85	5.76	2034.85	69.64	99.91	20.34	29.22	44.56	100.05
3	3.30	6.19	1880.05	69.46	99.91	18.22	27.07	39.19	103.20
4	2.76	6.64	1690.76	69.92	99.92	15.73	24.18	33.60	107.46
5	2.23	7.23	1489.06	70.26	99.90	13.22	21.19	28.02	112.68
6	1.71	8.10	1278.55	70.94	99.91	10.73	18.02	22.25	119.16
7	1.19	9.41	1037.25	71.11	99.94	8.07	14.59	16.48	128.49
8	1.19	9.48	1045.29	71.61	99.93	8.16	14.60	16.40	128.12
9	1.71	8.25	1303.43	72.47	99.91	11.02	17.99	21.93	118.32
10	2.23	7.46	1539.10	73.08	99.92	13.83	21.06	27.29	111.31
11	2.76	6.90	1760.39	72.92	99.90	16.63	24.14	32.65	105.85
12	3.30	6.32	1922.61	71.85	99.90	18.79	26.76	38.33	102.30
13	3.85	5.93	2098.15	71.67	99.92	21.23	29.27	43.70	98.84
14	4.40	5.56	2244.65	71.54	99.93	23.34	31.38	49.03	96.18
Average			1679.83			15.85			109.62

Wilson Plot X-Y data points...

X	Y	X	Y
0.86	0.48	3.36	1.41
0.99	0.54	2.34	1.05
1.16	0.60	1.78	0.84
1.40	0.70	1.42	0.69
1.76	0.85	1.17	0.60
2.32	1.06	1.00	0.53
3.35	1.42	0.87	0.48

Program Name: DRPSAMUN.BAS
Raw Data File: A3MD8V1.dat
Processed Data File: A3MD8V1.res
Tube Number: 8
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 200.90
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00029

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.97

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 2.519
Outside leading coeff., Co: 3.014

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	1.45	573.72	26.60	48.71	12.42	21.57	43.54	46.20
2	3.85	1.60	558.95	26.63	48.70	11.97	20.99	38.91	46.70
3	3.30	1.71	516.11	26.53	48.71	10.70	19.46	34.23	48.26
4	2.76	1.91	485.25	27.28	48.69	9.81	17.79	29.30	49.45
5	2.23	2.11	434.68	27.18	48.70	8.42	15.99	24.47	51.64
6	1.71	2.43	384.22	27.40	48.68	7.10	14.02	19.49	54.12
7	1.19	2.87	317.13	27.24	48.70	5.45	11.64	14.49	58.15
8	1.19	2.90	320.48	27.57	48.69	5.53	11.63	14.45	57.93
9	1.71	2.47	390.65	28.00	48.71	7.26	13.95	19.39	53.79
10	2.23	2.18	449.37	27.89	48.69	8.82	16.11	24.21	50.98
11	2.76	1.96	498.33	28.14	48.70	10.18	17.71	28.94	48.94
12	3.30	1.72	519.37	27.27	48.66	10.80	19.04	33.93	48.11
13	3.85	1.58	551.90	26.78	48.67	11.76	20.61	38.76	46.94
14	4.40	1.47	581.96	27.07	48.72	12.67	21.50	43.41	45.93
Average			470.15			9.49			50.55

Wilson Plot X-Y data points...

X	Y	X	Y
0.89	0.69	3.27	1.62
1.01	0.71	2.29	1.25
1.18	0.80	1.75	1.02
1.41	0.90	1.41	0.89
1.75	1.04	1.19	0.81
2.29	1.25	1.02	0.73
3.28	1.63	0.89	0.68

```
Program Name:                     DRPSAMUN.BAS
Raw Data File:                    A3MD8V2.dat
Processed Data File:              A3MD8V2.res
Tube Number:                      11
Pressure Condition:               Vacuum

Thermal Conductivity (W/m-K):    200.90
Tube Inside Diameter (mm):        12.70
Tube Outside Diameter (mm):       13.34
Wall Resistance, Rw (m/W/m-K):    0.00029

Average System Power (kW):         6.80
Average Steam Velocity (m/s):      1.96

This analysis takes into account of the following:
      1. HEATEX insert inside the tube
      2. End-fin effects
      3. Petukhov-Popov correltation for Hi
      4. Nusselt type correlation for Ho

Regression Coefficient,  R :  1.000
Inside leading coeff.,   Ci:  2.548
Outside leading coeff.,  Co:  2.955
```

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	1.48	586.21	27.85	48.71	13.17	21.05	43.64	44.50
2	3.85	1.60	559.19	27.34	48.67	12.32	20.45	38.98	45.39
3	3.30	1.74	525.53	27.46	48.72	11.28	19.14	34.28	46.59
4	2.76	1.93	490.59	27.93	48.69	10.24	17.56	29.34	47.89
5	2.23	2.17	447.30	28.02	48.69	9.00	15.97	24.49	49.67
6	1.71	2.48	392.27	28.19	48.71	7.51	13.91	19.57	52.26
7	1.19	2.93	323.89	28.00	48.71	5.77	11.57	14.52	56.16
8	1.19	2.94	325.00	28.03	48.68	5.79	11.60	14.51	56.09
9	1.71	2.51	397.12	28.72	48.70	7.63	13.83	19.45	52.02
10	2.23	2.22	457.83	28.71	48.71	9.30	15.95	24.28	49.24
11	2.76	2.00	508.78	28.96	48.71	10.78	17.57	29.01	47.21
12	3.30	1.77	534.94	28.52	48.72	11.57	18.76	33.95	46.25
13	3.85	1.63	570.07	28.18	48.69	12.66	20.23	38.70	45.03
14	4.40	1.51	598.59	27.93	48.69	13.57	21.44	43.41	44.11
Average			479.81			10.04			48.78

Wilson Plot X-Y data points...

X	Y	X	Y
0.89	0.69	3.26	1.61
1.01	0.73	2.28	1.24
1.17	0.80	1.74	1.02
1.40	0.90	1.40	0.88
1.74	1.03	1.18	0.81
2.27	1.24	1.01	0.73
3.26	1.61	0.88	0.67

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1A1.dat
Processed Data File: C3MD1A1.res
Tube Number: 1
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 390.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 25.74
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:
1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 2.385
Outside leading coeff., Co: 8.605

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	5.86	2360.62	67.58	99.89	15.42	34.93	45.53	153.14
2	3.85	6.12	2159.22	67.16	99.92	13.64	32.15	40.80	158.35
3	3.30	6.43	1949.94	67.07	99.91	11.86	29.07	35.88	164.37
4	2.76	6.87	1747.28	68.01	99.88	10.22	25.69	30.63	171.03
5	2.23	7.37	1516.29	68.51	99.91	8.43	22.13	25.51	179.97
6	1.71	8.02	1264.45	69.16	99.92	6.59	18.28	20.29	191.86
7	1.19	9.18	1010.58	69.05	99.88	4.87	14.64	15.06	207.54
8	1.19	9.21	1014.07	69.32	99.88	4.89	14.63	15.02	207.20
9	1.71	8.10	1278.18	70.48	99.92	6.69	18.14	20.04	191.14
10	2.23	7.52	1549.32	70.66	99.91	8.68	21.93	25.04	178.57
11	2.76	7.01	1786.13	70.63	99.90	10.53	25.29	29.93	169.68
12	3.30	6.62	2011.73	69.78	99.90	12.38	28.83	35.04	162.53
13	3.85	6.19	2187.31	69.07	99.89	13.88	31.67	40.08	157.57
14	4.40	5.89	2374.63	68.65	99.90	15.54	34.59	45.12	152.80
Average			1729.27			10.26			176.38

Wilson Plot X-Y data points...

X	Y	X	Y
0.92	0.49	3.64	1.63
1.06	0.56	2.55	1.21
1.25	0.64	1.92	0.93
1.52	0.76	1.54	0.76
1.90	0.93	1.27	0.64
2.53	1.20	1.08	0.56
3.64	1.63	0.93	0.50

Program Name:	DRPSAMUN.BAS
Raw Data File:	C3MD1A2.dat
Processed Data File:	C3MD1A2.res
Tube Number:	1
Pressure Condition:	Atmospheric

Thermal Conductivity (W/m-K):	385.00
Tube Inside Diameter (mm):	12.70
Tube Outside Diameter (mm):	13.34
Wall Resistance, Rw (m/W/m-K):	0.00015

Average System Power (kW):	25.74
Average Steam Velocity (m/s):	1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	1.000
Inside leading coeff.,	Ci:	2.384
Outside leading coeff.,	Co:	8.489

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	5.87	2365.78	68.11	99.91	15.75	34.73	45.28	150.18
2	3.85	6.09	2149.22	67.56	99.91	13.80	31.81	40.65	155.70
3	3.30	6.38	1935.13	67.33	99.89	11.96	28.74	35.79	161.78
4	2.76	6.77	1721.21	67.60	99.91	10.19	25.46	30.75	168.84
5	2.23	7.29	1499.38	68.11	99.88	8.45	22.02	25.59	177.36
6	1.71	7.95	1252.56	68.16	99.88	6.63	18.38	20.46	188.97
7	1.19	9.10	1001.29	68.41	99.92	4.90	14.64	15.16	204.40
8	1.19	9.12	1003.58	68.42	99.89	4.91	14.67	15.14	204.26
9	1.71	8.18	1290.14	69.63	99.91	6.90	18.53	20.20	187.10
10	2.23	7.48	1540.55	69.90	99.87	8.77	22.04	25.16	175.62
11	2.76	6.97	1775.21	69.99	99.88	10.63	25.37	30.10	166.94
12	3.30	6.52	1980.67	69.39	99.91	12.34	28.54	35.16	160.48
13	3.85	6.19	2186.95	69.05	99.89	14.14	31.67	40.16	154.67
14	4.40	5.93	2391.29	68.88	99.89	15.99	34.72	45.02	149.57
Average			1720.93			10.38			173.09

Wilson Plot X-Y data points...

X	Y	X	Y
0.92	0.49	3.62	1.62
1.06	0.56	2.51	1.17
1.25	0.65	1.91	0.92
1.51	0.76	1.53	0.76
1.90	0.93	1.26	0.65
2.51	1.19	1.07	0.56
3.61	1.62	0.93	0.49

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1A3.dat
Processed Data File: C3MD1A3.res
Tube Number: 1
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 25.75
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 2.358
Outside leading coeff., Co: 8.681

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	5.85	2356.95	67.82	99.90	15.20	34.76	44.93	155.11
2	3.85	6.05	2134.68	67.32	99.88	13.26	31.71	40.27	160.93
3	3.30	6.37	1932.26	67.38	99.92	11.58	28.68	35.35	166.92
4	2.76	6.84	1739.67	68.06	99.90	10.03	25.56	30.28	173.39
5	2.23	7.37	1516.48	68.79	99.91	8.33	22.04	25.18	182.09
6	1.71	8.02	1264.17	68.81	99.90	6.51	18.37	20.12	194.13
7	2.23	7.46	1536.91	70.51	99.88	8.48	21.80	24.76	181.23
8	2.76	6.94	1768.01	70.44	99.92	10.26	25.10	29.64	172.40
9	3.30	6.51	1978.34	69.81	99.89	11.95	28.34	34.59	165.53
10	3.85	6.17	2179.67	68.94	99.89	13.65	31.62	39.74	159.70
11	4.40	5.81	2341.18	68.21	99.89	15.06	34.32	44.82	155.48
12	1.71	7.94	1250.82	68.11	99.92	6.42	18.37	20.27	194.90
13	1.19	9.00	990.04	68.04	99.89	4.68	14.55	15.03	211.45
14	1.19	9.05	995.79	68.38	99.88	4.72	14.56	14.98	211.07
Average			1713.21			10.01			178.20

Wilson Plot X-Y data points...

X	Y	X	Y
0.93	0.50	1.55	0.77
1.07	0.57	1.28	0.66
1.26	0.65	1.08	0.57
1.52	0.76	0.93	0.51
1.91	0.93	2.52	1.20
2.53	1.20	3.64	1.65
1.94	0.94	3.65	1.65

Program Name:	DRPSAMUN.BAS
Raw Data File:	C3MD1V1.dat
Processed Data File:	C3MD1V1.res
Tube Number:	1
Pressure Condition:	Vacuum
Thermal Conductivity (W/m-K):	390.00
Tube Inside Diameter (mm):	12.70
Tube Outside Diameter (mm):	13.34
Wall Resistance, Rw (m/W/m-K):	0.00015
Average System Power (kW):	6.81
Average Steam Velocity (m/s):	1.96

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	1.000
Inside leading coeff.,	Ci:	2.217
Outside leading coeff.,	Co:	3.438

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	1.46	577.40	24.99	48.72	10.41	23.10	38.91	55.47
2	3.85	1.56	544.31	25.10	48.70	9.59	21.69	34.74	56.79
3	3.30	1.69	509.65	25.18	48.72	8.74	20.24	30.56	58.28
4	2.76	1.84	466.97	25.33	48.69	7.75	18.43	26.21	60.27
5	2.23	2.02	415.77	25.58	48.72	6.60	16.25	21.86	62.98
6	1.71	2.29	361.73	25.67	48.69	5.46	14.09	17.48	66.30
7	1.19	2.66	293.70	25.72	48.72	4.10	11.42	12.96	71.55
8	1.19	2.66	293.71	25.71	48.71	4.11	11.43	12.94	71.53
9	1.71	2.31	364.98	26.16	48.70	5.52	13.95	17.39	66.08
10	2.23	2.06	424.18	26.33	48.68	6.79	16.11	21.70	62.48
11	2.76	1.88	477.44	26.49	48.71	7.99	18.03	25.93	59.76
12	3.30	1.69	509.83	26.05	48.71	8.75	19.57	30.33	58.26
13	3.85	1.58	551.59	25.83	48.71	9.76	21.36	34.54	56.49
14	4.40	1.45	573.44	25.75	48.69	10.31	22.27	38.73	55.60
Average			454.62			7.56			61.63

Wilson Plot X-Y data points...

X	Y	X	Y
0.91	0.68	3.37	1.80
1.04	0.75	2.35	1.36
1.21	0.82	1.80	1.11
1.45	0.94	1.45	0.95
1.80	1.11	1.21	0.85
2.35	1.35	1.04	0.76
3.37	1.80	0.91	0.71

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1V2.dat
Processed Data File: C3MD1V2.res
Tube Number: 1
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.96

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 2.225
Outside leading coeff., Co: 3.383

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	4.40	1.44	569.24	25.36	48.71	10.44	22.45	39.04	54.53
2	3.85	1.55	540.73	25.04	48.69	9.71	21.59	34.88	55.66
3	3.30	1.68	506.59	25.18	48.72	8.87	20.12	30.66	57.12
4	2.76	1.83	464.44	25.48	48.71	7.86	18.23	26.27	59.07
5	2.23	2.01	413.68	25.45	48.70	6.70	16.25	21.96	61.71
6	1.71	2.27	358.55	25.64	48.72	5.51	13.98	17.55	65.08
7	1.19	2.64	291.47	25.63	48.71	4.16	11.37	13.01	70.14
8	1.19	2.67	294.81	25.76	48.71	4.22	11.44	13.00	69.89
9	1.71	2.32	366.57	26.17	48.71	5.68	14.01	17.45	64.55
10	2.23	2.05	422.10	26.29	48.70	6.89	16.06	21.80	61.24
11	2.76	1.88	477.41	26.50	48.71	8.17	18.01	26.06	58.44
12	3.30	1.69	509.85	25.97	48.71	8.95	19.63	30.41	56.97
13	3.85	1.56	544.49	25.75	48.69	9.81	21.15	34.63	55.51
14	4.40	1.47	581.61	25.98	48.69	10.76	22.39	38.85	54.06
Average			452.97			7.69			60.33

Wilson Plot X-Y data points...

X	Y	X	Y
0.91	0.70	3.35	1.79
1.03	0.75	2.34	1.35
1.20	0.83	1.79	1.11
1.44	0.94	1.44	0.94
1.79	1.11	1.21	0.84
2.34	1.36	1.04	0.76
3.36	1.81	0.90	0.70

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1V3.dat
Processed Data File: C3MD1V3.res
Tube Number: 1
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.97

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 2.221
Outside leading coeff., Co: 3.405

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	1.47	581.54	25.73	48.69	10.66	22.61	38.88	54.56
2	3.85	1.56	544.36	25.44	48.68	9.72	21.40	34.73	56.02
3	3.30	1.68	506.64	25.36	48.68	8.79	19.98	30.54	57.63
4	2.76	1.85	469.65	26.00	48.68	7.92	18.06	26.10	59.33
5	2.23	2.04	419.97	26.01	48.72	6.78	16.15	21.82	61.92
6	1.71	2.30	363.37	26.09	48.71	5.56	13.92	17.45	65.33
7	1.19	2.68	295.94	26.03	48.69	4.20	11.37	12.94	70.41
8	1.19	2.69	297.05	25.98	48.71	4.22	11.43	12.94	70.32
9	1.71	2.31	365.02	26.34	48.70	5.60	13.86	17.38	65.21
10	2.23	2.08	428.35	26.51	48.72	6.97	16.16	21.71	61.46
11	2.76	1.89	480.04	26.61	48.70	8.16	18.04	25.94	58.85
12	3.30	1.69	509.86	25.86	48.70	8.87	19.72	30.33	57.48
13	3.85	1.58	551.64	26.16	48.71	9.90	21.08	34.54	55.73
14	4.40	1.49	589.81	25.92	48.71	10.87	22.75	38.74	54.26
Average			457.37			7.73			60.66

Wilson Plot X-Y data points...

X	Y	X	Y
0.90	0.70	3.36	1.79
1.04	0.75	2.35	1.37
1.21	0.83	1.79	1.10
1.45	0.95	1.44	0.94
1.79	1.11	1.21	0.84
2.34	1.36	1.04	0.76
3.36	1.80	0.90	0.69

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF5A1.dat
Processed Data File: C7MDF5A1.res
Tube Number: 5
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.39
Tube Outside Diameter (mm): 13.00
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 25.74
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 1.807
Outside leading coeff., Co: 3.206

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.63	3.54	1456.61	70.95	99.92	31.02	20.53	35.15	46.95
2	4.05	3.73	1346.12	69.56	99.92	27.70	19.35	31.71	48.59
3	3.47	4.01	1245.76	69.35	99.91	24.82	17.96	27.92	50.19
4	2.91	4.35	1134.13	69.72	99.88	21.75	16.27	23.95	52.15
5	2.35	4.84	1021.33	69.97	99.91	18.79	14.60	20.01	54.36
6	1.80	5.46	883.18	70.14	99.92	15.37	12.59	15.96	57.47
7	1.25	6.53	737.66	69.90	99.90	12.00	10.55	11.86	61.46
8	1.25	6.55	740.12	70.30	99.88	12.06	10.53	11.82	61.38
9	1.80	5.54	896.78	71.36	99.90	15.69	12.57	15.79	57.14
10	2.35	4.88	1030.86	71.43	99.89	19.03	14.43	19.71	54.16
11	2.91	4.44	1159.03	71.37	99.90	22.42	16.24	23.55	51.70
12	3.47	4.07	1265.97	71.08	99.91	25.39	17.81	27.48	49.87
13	4.05	3.79	1369.11	70.78	99.91	28.38	19.34	31.36	48.24
14	4.63	3.55	1460.69	70.40	99.89	31.15	20.75	35.19	46.89
Average			1124.81			21.83			53.08

Wilson Plot X-Y data points...

X	Y	X	Y
0.74	0.70	2.74	1.80
0.84	0.77	1.94	1.40
0.99	0.86	1.49	1.16
1.19	0.99	1.20	0.98
1.47	1.15	0.99	0.86
1.93	1.41	0.85	0.77
2.73	1.80	0.74	0.69

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF5A2.dat
Processed Data File: C7MDF5A2.res
Tube Number: 5
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.39
Tube Outside Diameter (mm): 13.00
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 25.74
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 1.821
Outside leading coeff., Co: 3.193

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.63	3.55	1460.42	70.53	99.90	31.34	20.71	35.56	46.61
2	4.05	3.76	1357.42	70.15	99.92	28.20	19.35	31.85	48.13
3	3.47	4.04	1255.46	69.89	99.91	25.24	17.96	28.05	49.73
4	2.91	4.43	1155.22	69.92	99.91	22.45	16.52	24.10	51.46
5	2.35	4.86	1025.67	69.96	99.88	19.01	14.66	20.13	53.94
6	1.80	5.48	886.39	70.18	99.90	15.54	12.63	16.09	57.06
7	1.25	6.57	742.21	70.09	99.92	12.17	10.59	11.95	60.97
8	1.25	6.58	743.38	70.01	99.88	12.20	10.62	11.94	60.93
9	1.80	5.54	896.58	70.88	99.91	15.78	12.65	15.97	56.81
10	2.35	4.87	1028.57	71.15	99.89	19.09	14.46	19.91	53.88
11	2.91	4.43	1156.29	71.34	99.88	22.48	16.21	23.78	51.44
12	3.47	4.05	1259.61	70.94	99.88	25.37	17.76	27.73	49.66
13	4.05	3.80	1372.83	70.84	99.90	28.67	19.38	31.59	47.89
14	4.63	3.54	1456.47	70.56	99.89	31.21	20.64	35.48	46.66
Average			1128.32			22.05			52.70

Wilson Plot X-Y data points...

X	Y	X	Y
0.73	0.69	2.73	1.78
0.84	0.77	1.93	1.39
0.98	0.85	1.48	1.15
1.18	0.96	1.19	0.98
1.47	1.14	0.99	0.86
1.92	1.40	0.84	0.76
2.73	1.79	0.74	0.70

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF51V.dat
Processed Data File: C7MDF51V.res
Tube Number: 5
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.39
Tube Outside Diameter (mm): 13.00
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.96

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 1.856
Outside leading coeff., Co: 1.803

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)		---------
1	4.63	0.95	376.80	24.74	48.71	14.05	15.23	34.44	26.81
2	4.05	1.02	359.40	24.59	48.72	13.13	14.62	30.77	27.36
3	3.47	1.10	336.70	24.43	48.70	11.98	13.78	27.06	28.12
4	2.90	1.23	318.22	24.82	48.70	11.06	12.82	23.19	28.78
5	2.35	1.39	292.48	24.75	48.72	9.82	11.82	19.36	29.77
6	1.80	1.60	258.81	24.55	48.72	8.29	10.54	15.49	31.23
7	1.25	1.95	220.70	24.51	48.69	6.65	9.00	11.49	33.19
8	1.25	1.96	221.84	24.89	48.72	6.70	8.91	11.48	33.13
9	1.80	1.63	263.75	25.19	48.72	8.51	10.47	15.41	31.01
10	2.35	1.41	296.81	25.31	48.68	10.03	11.73	19.24	29.59
11	2.90	1.26	326.24	25.45	48.69	11.45	12.82	22.99	28.48
12	3.47	1.12	343.12	25.02	48.69	12.30	13.71	26.84	27.89
13	4.05	1.02	359.54	24.60	48.73	13.14	14.61	30.53	27.36
14	4.63	0.94	372.71	24.64	48.71	13.84	15.13	34.28	26.94
Average			310.51			10.78			29.27

Wilson Plot X-Y data points...

X	Y	X	Y
0.79	0.96	2.78	2.05
0.89	1.03	1.97	1.63
1.04	1.12	1.52	1.39
1.23	1.23	1.23	1.22
1.52	1.38	1.04	1.12
1.97	1.63	0.90	1.03
2.78	2.03	0.79	0.98

Program Name:	DRPSAMUN.BAS
Raw Data File:	C7MDF5V2.dat
Processed Data File:	C7MDF5V2.res
Tube Number:	5
Pressure Condition:	Vacuum

Thermal Conductivity (W/m-K):	385.00
Tube Inside Diameter (mm):	12.39
Tube Outside Diameter (mm):	13.00
Wall Resistance, Rw (m/W/m-K):	0.00015

Average System Power (kW):	6.81
Average Steam Velocity (m/s):	1.97

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	0.999
Inside leading coeff.,	Ci:	1.903
Outside leading coeff.,	Co:	1.953

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	4.63	0.99	393.49	24.48	48.71	13.34	16.07	35.38	29.50
2	4.05	1.06	373.98	23.81	48.69	12.41	15.71	31.62	30.13
3	3.47	1.15	352.35	24.17	48.70	11.41	14.58	27.81	30.88
4	2.90	1.29	333.94	24.38	48.72	10.58	13.70	23.83	31.58
5	2.35	1.44	303.03	24.36	48.70	9.24	12.44	19.92	32.81
6	1.80	1.66	268.51	24.29	48.68	7.81	11.05	15.94	34.38
7	1.25	2.01	227.44	24.32	48.69	6.21	9.35	11.83	36.61
8	1.25	2.02	228.59	24.30	48.72	6.25	9.41	11.82	36.56
9	1.80	1.67	270.17	24.45	48.69	7.88	11.05	15.89	34.30
10	2.35	1.46	307.34	24.75	48.68	9.42	12.42	19.84	32.62
11	2.90	1.31	339.29	25.09	48.69	10.82	13.52	23.70	31.36
12	3.47	1.17	358.72	24.43	48.68	11.70	14.68	27.67	30.66
13	4.05	1.07	377.73	24.52	48.71	12.59	15.40	31.48	30.01
14	4.63	1.00	397.72	24.71	48.69	13.55	16.10	35.30	29.36
Average			323.73			10.23			32.21

Wilson Plot X-Y data points...

X	Y	X	Y
0.80	0.93	2.82	1.97
0.91	0.97	2.00	1.57
1.05	1.07	1.54	1.33
1.25	1.17	1.25	1.17
1.54	1.34	1.05	1.06
2.00	1.58	0.91	0.98
2.82	1.99	0.79	0.92

Program Name: DRPSAMUN.BAS
Raw Data File: C3MDF1A1.dat
Processed Data File: C3MDF1A1.res
Tube Number: 1
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 25.74
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 2.296
Outside leading coeff., Co: 4.753

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	4.40	4.62	1854.58	66.00	99.90	25.20	28.10	44.43	73.60
2	3.85	4.87	1712.94	65.37	99.91	22.53	26.20	39.87	76.05
3	3.30	5.18	1566.82	65.25	99.89	19.89	24.01	35.07	78.78
4	2.76	5.61	1423.53	65.87	99.89	17.41	21.61	30.02	81.78
5	2.23	6.13	1258.61	66.43	99.90	14.69	18.95	25.01	85.69
6	1.71	6.90	1085.57	66.62	99.90	11.99	16.29	19.98	90.52
7	1.19	8.15	895.32	66.44	99.88	9.22	13.48	14.85	97.08
8	1.19	8.15	895.46	66.58	99.90	9.22	13.45	14.82	97.08
9	1.71	6.95	1094.39	67.64	99.88	12.13	16.18	19.78	90.25
10	2.23	6.21	1276.78	68.30	99.90	14.98	18.69	24.63	85.23
11	2.76	5.73	1456.67	68.20	99.92	17.97	21.36	29.43	81.06
12	3.30	5.31	1609.69	67.85	99.90	20.65	23.72	34.32	77.96
13	3.85	4.97	1751.59	67.62	99.88	23.25	25.90	39.12	75.35
14	4.40	4.67	1877.02	67.45	99.91	25.63	27.83	43.90	73.24
Average			1411.36			17.48			83.63

Wilson Plot X-Y data points...

X	Y	X	Y
0.79	0.54	3.02	1.50
0.91	0.60	2.13	1.16
1.07	0.68	1.63	0.94
1.29	0.78	1.30	0.78
1.61	0.94	1.08	0.68
2.11	1.15	0.92	0.60
3.01	1.50	0.80	0.54

```
Program Name:                    DRPSAMUN.BAS
Raw Data File:                   C3MDF1A2.dat
Processed Data File:             C3MDF1A2.res
Tube Number:                     1
Pressure Condition:              Atmospheric

Thermal Conductivity (W/m-K):   385.00
Tube Inside Diameter (mm):       12.70
Tube Outside Diameter (mm):      13.34
Wall Resistance, Rw (m/W/m-K):   0.00015

Average System Power (kW):       25.73
Average Steam Velocity (m/s):     1.04

This analysis takes into account of the following:
      1. HEATEX insert inside the tube
      2. End-fin effects
      3. Petukhov-Popov correltation for Hi
      4. Nusselt type correlation for Ho

Regression Coefficient,  R :  0.999
Inside leading coeff.,   Ci:  2.213
Outside leading coeff.,  Co:  4.472
```

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.40	4.46	1793.11	68.48	99.91	26.19	26.18	41.94	68.46
2	3.85	4.70	1656.10	67.97	99.92	23.40	24.37	37.60	70.76
3	3.30	5.03	1524.40	67.77	99.91	20.84	22.50	33.06	73.15
4	2.76	5.49	1395.48	68.35	99.90	18.43	20.42	28.35	75.73
5	2.23	5.96	1225.23	68.18	99.91	15.39	17.97	23.74	79.59
6	1.71	6.71	1056.95	68.31	99.90	12.57	15.47	18.97	84.10
7	1.19	7.91	870.18	68.41	99.90	9.64	12.72	14.07	90.28
8	1.19	7.93	872.60	68.75	99.88	9.68	12.69	14.02	90.18
9	1.71	6.79	1070.71	69.89	99.93	12.79	15.32	18.71	83.71
10	2.23	6.11	1257.77	70.07	99.91	15.96	17.95	23.35	78.82
11	2.76	5.57	1417.52	69.90	99.90	18.83	20.28	27.93	75.27
12	3.30	5.13	1556.63	69.37	99.92	21.45	22.44	32.60	72.56
13	3.85	4.80	1692.80	68.94	99.91	24.14	24.56	37.28	70.12
14	4.40	4.48	1801.31	68.56	99.93	26.36	26.27	41.91	68.34
Average			1370.77			18.26			77.50

Wilson Plot X-Y data points...

X	Y	X	Y
0.80	0.57	3.03	1.57
0.92	0.64	2.13	1.21
1.08	0.71	1.62	0.97
1.29	0.82	1.30	0.82
1.61	0.98	1.08	0.71
2.11	1.20	0.92	0.63
3.02	1.57	0.80	0.57

Program Name: DRPSAMUN.BAS
Raw Data File: C3MDF1V1.dat
Processed Data File: C3MDF1V1.res
Tube Number: 1
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.97

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 2.157
Outside leading coeff., Co: 3.073

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	4.40	1.30	511.64	23.30	48.70	10.28	21.96	38.57	49.76
2	3.85	1.38	479.64	23.53	48.71	9.40	20.38	34.46	51.05
3	3.30	1.49	448.00	23.07	48.68	8.55	19.42	30.31	52.43
4	2.76	1.64	415.35	23.67	48.70	7.69	17.55	25.98	53.98
5	2.23	1.81	371.94	23.57	48.70	6.61	15.78	21.71	56.28
6	1.71	2.03	320.23	23.60	48.71	5.38	13.57	17.36	59.48
7	1.19	2.39	263.58	23.58	48.69	4.13	11.18	12.87	63.84
8	1.19	2.41	265.81	23.82	48.69	4.18	11.16	12.86	63.65
9	1.71	2.07	326.64	24.18	48.68	5.53	13.51	17.27	59.04
10	2.23	1.83	376.21	24.28	48.69	6.71	15.49	21.55	56.04
11	2.76	1.68	425.78	24.65	48.69	7.96	17.27	25.75	53.46
12	3.30	1.51	454.31	24.08	48.71	8.71	18.87	30.06	52.15
13	3.85	1.40	486.94	23.84	48.68	9.60	20.42	34.23	50.74
14	4.40	1.31	515.85	23.98	48.70	10.40	21.51	38.38	49.59
Average			404.42			7.51			55.17

Wilson Plot X-Y data points...

X	Y	X	Y
0.89	0.72	3.29	1.84
1.02	0.80	2.30	1.41
1.19	0.86	1.77	1.16
1.42	0.99	1.42	0.99
1.76	1.14	1.19	0.88
2.31	1.41	1.02	0.79
3.29	1.84	0.90	0.74

Program Name: DRPSAMUN.BAS
Raw Data File: C3MDF1V2.dat
Processed Data File: C3MDF1V2.res
Tube Number: 1
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.70
Tube Outside Diameter (mm): 13.34
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.96

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 2.069
Outside leading coeff., Co: 2.311

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo ------	Hi (kW/m^2-K)	HoZ ---------
1	4.40	1.13	442.53	24.41	48.70	12.53	18.13	36.74	35.32
2	3.85	1.21	419.25	23.92	48.68	11.61	17.53	32.80	36.12
3	3.30	1.31	393.15	24.04	48.70	10.60	16.35	28.85	37.08
4	2.76	1.45	366.89	24.48	48.72	9.62	14.99	24.72	38.12
5	2.23	1.60	328.65	24.27	48.71	8.26	13.54	20.67	39.80
6	1.71	1.85	291.86	24.31	48.72	7.01	12.01	16.53	41.64
7	1.19	2.21	243.78	24.31	48.71	5.47	10.03	12.27	44.53
8	1.19	2.22	244.90	24.35	48.71	5.51	10.06	12.27	44.46
9	1.71	1.88	296.65	24.87	48.71	7.17	11.93	16.48	41.38
10	2.23	1.64	337.00	25.03	48.70	8.55	13.46	20.57	39.41
11	2.76	1.48	374.68	25.21	48.71	9.91	14.86	24.58	37.80
12	3.30	1.31	393.27	24.64	48.71	10.61	15.96	28.67	37.07
13	3.85	1.21	419.37	24.46	48.69	11.61	17.14	32.62	36.11
14	4.40	1.13	442.61	24.76	48.69	12.53	17.88	36.61	35.31
Average			356.76			9.36			38.90

Wilson Plot X-Y data points...

X	Y	X	Y
0.85	0.83	3.07	1.90
0.97	0.88	2.15	1.49
1.13	0.97	1.66	1.25
1.34	1.09	1.34	1.09
1.67	1.26	1.13	0.99
2.16	1.49	0.97	0.90
3.07	1.91	0.85	0.84

Program Name:	DRPSAMUN.BAS
Raw Data File:	C7MDF2A1.dat
Processed Data File:	C7MDF2A1.res
Tube Number:	2
Pressure Condition:	Atmospheric

Thermal Conductivity (W/m-K):	385.00
Tube Inside Diameter (mm):	12.39
Tube Outside Diameter (mm):	13.00
Wall Resistance, Rw (m/W/m-K):	0.00015

Average System Power (kW):	25.73
Average Steam Velocity (m/s):	1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	0.999
Inside leading coeff.,	Ci:	1.941
Outside leading coeff.,	Co:	2.896

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	4.63	3.48	1431.17	70.29	99.89	35.08	20.36	37.91	40.80
2	4.05	3.68	1328.06	69.71	99.88	31.45	19.05	34.01	42.22
3	3.47	3.94	1223.95	69.47	99.90	27.97	17.62	29.96	43.75
4	2.91	4.35	1134.03	69.45	99.89	25.10	16.33	25.75	45.19
5	2.35	4.85	1023.29	69.56	99.87	21.72	14.71	21.54	47.11
6	1.80	5.56	899.07	69.69	99.88	18.13	12.90	17.23	49.58
7	1.25	6.66	751.98	69.15	99.91	14.17	10.87	12.83	53.08
8	1.25	6.67	753.22	69.22	99.89	14.20	10.88	12.81	53.05
9	1.80	5.61	907.52	70.16	99.90	18.37	12.93	17.14	49.41
10	2.35	4.89	1032.43	70.73	99.90	21.99	14.60	21.34	46.95
11	2.91	4.39	1145.37	70.78	99.92	25.45	16.18	25.49	45.00
12	3.47	3.97	1234.11	70.39	99.89	28.31	17.53	29.71	43.60
13	4.05	3.68	1328.56	70.28	99.88	31.47	18.90	33.84	42.21
14	4.63	3.43	1410.10	70.08	99.90	34.32	20.12	37.99	41.09
Average			1114.49			24.84			46.02

Wilson Plot X-Y data points...

X	Y	X	Y
0.71	0.68	2.61	1.67
0.82	0.75	1.84	1.31
0.95	0.85	1.42	1.10
1.14	0.94	1.15	0.95
1.41	1.09	0.96	0.85
1.84	1.31	0.82	0.76
2.61	1.67	0.71	0.69

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF2A2.dat
Processed Data File: C7MDF2A2.res
Tube Number: 2
Pressure Condition: Atmospheric

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.39
Tube Outside Diameter (mm): 13.00
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 25.74
Average Steam Velocity (m/s): 1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 1.928
Outside leading coeff., Co: 2.909

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.63	3.42	1405.76	69.89	99.89	33.94	20.11	37.79	41.42
2	4.05	3.66	1320.48	69.42	99.90	30.99	19.02	33.87	42.61
3	3.47	3.96	1229.95	68.95	99.88	27.99	17.84	29.84	43.95
4	2.91	4.35	1133.85	69.39	99.91	24.93	16.34	25.64	45.48
5	2.35	4.84	1020.95	69.28	99.91	21.51	14.74	21.46	47.47
6	1.80	5.53	893.90	69.08	99.92	17.87	12.94	17.19	50.02
7	1.25	6.62	747.30	68.85	99.92	13.96	10.85	12.78	53.54
8	1.25	6.63	748.55	69.04	99.89	13.99	10.84	12.76	53.50
9	1.80	5.59	904.17	69.96	99.89	18.16	12.92	17.05	49.79
10	2.35	4.87	1028.05	70.52	99.91	21.72	14.58	21.24	47.33
11	2.91	4.39	1145.24	70.59	99.91	25.28	16.22	25.36	45.30
12	3.47	3.97	1234.05	70.30	99.88	28.12	17.55	29.53	43.88
13	4.05	3.66	1321.10	69.90	99.88	31.01	18.90	33.66	42.60
14	4.63	3.42	1405.86	69.80	99.90	33.94	20.14	37.76	41.42
Average			1109.94			24.53			46.37

Wilson Plot X-Y data points...

X	Y	X	Y
0.71	0.70	2.61	1.68
0.82	0.76	1.85	1.31
0.95	0.83	1.42	1.10
1.14	0.94	1.15	0.95
1.41	1.09	0.96	0.85
1.84	1.31	0.82	0.76
2.61	1.68	0.71	0.70

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF2V1.dat
Processed Data File: C7MDF2V1.res
Tube Number: 2
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 385.00
Tube Inside Diameter (mm): 12.39
Tube Outside Diameter (mm): 13.00
Wall Resistance, Rw (m/W/m-K): 0.00015

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.96

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 1.000
Inside leading coeff., Ci: 1.979
Outside leading coeff., Co: 1.581

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.63	0.88	347.44	24.32	48.71	15.11	14.29	36.87	22.99
2	4.04	0.94	330.06	23.86	48.70	14.04	13.84	32.95	23.51
3	3.47	1.03	314.66	23.99	48.71	13.11	13.12	28.98	23.99
4	2.90	1.16	299.74	24.22	48.68	12.24	12.37	24.87	24.49
5	2.35	1.31	275.39	23.97	48.71	10.86	11.49	20.80	25.36
6	1.80	1.54	248.97	24.12	48.72	9.43	10.32	16.63	26.40
7	1.25	1.88	212.67	23.82	48.72	7.57	8.93	12.35	28.08
8	1.25	1.88	212.67	23.82	48.69	7.58	8.93	12.35	28.07
9	1.80	1.55	250.63	24.05	48.71	9.51	10.42	16.59	26.34
10	2.35	1.34	281.82	24.58	48.70	11.22	11.47	20.71	25.12
11	2.90	1.17	302.45	24.74	48.69	12.40	12.23	24.74	24.40
12	3.47	1.04	317.86	24.38	48.72	13.30	13.04	28.87	23.89
13	4.04	0.95	333.77	24.40	48.71	14.27	13.68	32.86	23.40
14	4.63	0.86	339.09	23.85	48.72	14.59	14.22	36.83	23.24
Average			290.52			11.80			24.95

Wilson Plot X-Y data points...

X	Y	X	Y
0.77	1.01	2.67	1.97
0.87	1.06	1.89	1.59
1.01	1.14	1.46	1.37
1.19	1.24	1.20	1.25
1.47	1.38	1.01	1.15
1.89	1.60	0.87	1.07
2.67	1.97	0.78	1.02

```
Program Name:                    DRPSAMUN.BAS
Raw Data File:                   C7MDF2V2.dat
Processed Data File:             C7MDF2V2.res
Tube Number:                     2
Pressure Condition:              Vacuum

Thermal Conductivity (W/m-K):   385.00
Tube Inside Diameter (mm):       12.39
Tube Outside Diameter (mm):      13.00
Wall Resistance, Rw (m/W/m-K):   0.00015

Average System Power (kW):        6.81
Average Steam Velocity (m/s):     1.96

This analysis takes into account of the following:
      1. HEATEX insert inside the tube
      2. End-fin effects
      3. Petukhov-Popov correltation for Hi
      4. Nusselt type correlation for Ho

Regression Coefficient,  R :  1.000
Inside leading coeff.,   Ci:  1.979
Outside leading coeff.,  Co:  1.581
```

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	4.63	0.88	347.44	24.32	48.71	15.11	14.29	36.87	22.99
2	4.04	0.94	330.06	23.86	48.70	14.04	13.84	32.95	23.51
3	3.47	1.03	314.66	23.99	48.71	13.11	13.12	28.98	23.99
4	2.90	1.16	299.74	24.22	48.68	12.24	12.37	24.87	24.49
5	2.35	1.31	275.39	23.97	48.71	10.86	11.49	20.80	25.36
6	1.80	1.54	248.97	24.12	48.72	9.43	10.32	16.63	26.40
7	1.25	1.88	212.67	23.82	48.72	7.57	8.93	12.35	28.08
8	1.25	1.88	212.67	23.82	48.69	7.58	8.93	12.35	28.07
9	1.80	1.55	250.63	24.05	48.71	9.51	10.42	16.59	26.34
10	2.35	1.34	281.82	24.58	48.70	11.22	11.47	20.71	25.12
11	2.90	1.17	302.45	24.74	48.69	12.40	12.23	24.74	24.40
12	3.47	1.04	317.86	24.38	48.72	13.30	13.04	28.87	23.89
13	4.04	0.95	333.77	24.40	48.71	14.27	13.68	32.86	23.40
14	4.63	0.86	339.09	23.85	48.72	14.59	14.22	36.83	23.24
Average			290.52			11.80			24.95

Wilson Plot X-Y data points...

X	Y	X	Y
0.77	1.01	2.67	1.97
0.87	1.06	1.89	1.59
1.01	1.14	1.46	1.37
1.19	1.24	1.20	1.25
1.47	1.38	1.01	1.15
1.89	1.60	0.87	1.07
2.67	1.97	0.78	1.02

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1A1.dat
Processed Data File:	K6MD1A1.res
Tube Number:	1
Pressure Condition:	Atmospheric
Thermal Conductivity (W/m-K):	21.00
Tube Inside Diameter (mm):	13.53
Tube Outside Diameter (mm):	16.07
Wall Resistance, Rw (m/W/m-K):	0.00978
Average System Power (kW):	25.74
Average Steam Velocity (m/s):	1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	0.999
Inside leading coeff.,	Ci:	3.472
Outside leading coeff.,	Co:	1.991

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi (kW/m^2-K)	HoZ
1	3.87	1.92	638.54	76.22	99.91	20.42	8.38	54.28	31.26
2	3.38	2.13	622.72	76.08	99.91	19.73	8.19	48.69	31.57
3	2.90	2.40	604.60	75.60	99.86	18.93	8.00	42.96	31.93
4	2.43	2.76	583.79	75.50	99.90	18.03	7.73	36.91	32.37
5	1.96	3.27	559.90	75.32	99.87	17.02	7.43	30.91	32.90
6	1.50	3.98	522.26	74.86	99.86	15.46	6.98	24.79	33.78
7	1.05	5.19	475.60	74.83	99.87	13.59	6.36	18.43	34.99
8	1.05	5.20	476.53	74.91	99.91	13.63	6.36	18.43	34.97
9	1.50	4.02	527.66	75.60	99.88	15.68	6.98	24.65	33.65
10	1.96	3.28	561.80	75.94	99.87	17.10	7.40	30.71	32.85
11	2.43	2.81	594.64	75.97	99.87	18.50	7.83	36.62	32.14
12	2.90	2.43	612.43	76.00	99.90	19.27	8.06	42.66	31.78
13	3.38	2.14	625.79	76.06	99.89	19.86	8.23	48.51	31.51
14	3.87	1.93	641.88	76.10	99.92	20.57	8.43	54.35	31.20
Average			574.87			17.70			32.65

Wilson Plot X-Y data points...

X	Y	X	Y
1.18	0.84	3.86	1.61
1.33	0.89	2.78	1.31
1.52	0.95	2.19	1.14
1.79	1.03	1.80	1.00
2.17	1.14	1.53	0.93
2.78	1.32	1.33	0.88
3.86	1.61	1.18	0.83

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1A2.dat
Processed Data File:	K6MD1A2.res
Tube Number:	1
Pressure Condition:	Atmospheric
Thermal Conductivity (W/m-K):	21.00
Tube Inside Diameter (mm):	13.53
Tube Outside Diameter (mm):	16.07
Wall Resistance, Rw (m/W/m-K):	0.00978
Average System Power (kW):	25.74
Average Steam Velocity (m/s):	1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	0.999
Inside leading coeff.,	Ci:	3.393
Outside leading coeff.,	Co:	2.145

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi (kW/m^2-K)	HoZ
1	3.87	1.96	652.01	75.99	99.91	18.94	8.58	53.18	34.42
2	3.38	2.16	631.50	75.81	99.94	18.12	8.33	47.74	34.85
3	2.90	2.44	614.68	74.78	99.92	17.46	8.22	42.10	35.21
4	2.43	2.81	594.38	75.37	99.88	16.67	7.89	36.12	35.66
5	1.96	3.32	568.50	75.38	99.88	15.68	7.54	30.19	36.27
6	1.50	4.04	530.17	75.39	99.91	14.24	7.03	24.21	37.24
7	1.05	5.24	480.20	74.87	99.88	12.43	6.41	18.01	38.63
8	1.05	5.24	480.21	74.93	99.87	12.43	6.41	18.00	38.63
9	1.50	4.08	535.56	75.70	99.93	14.44	7.07	24.08	37.10
10	1.96	3.33	570.40	75.98	99.87	15.75	7.51	30.01	36.22
11	2.43	2.84	601.01	75.93	99.88	16.92	7.91	35.81	35.51
12	2.90	2.47	622.59	76.01	99.93	17.77	8.19	41.71	35.04
13	3.38	2.19	640.60	76.11	99.92	18.48	8.42	47.41	34.66
14	3.87	1.96	652.01	76.01	99.91	18.95	8.58	53.17	34.42
Average			583.84			16.31			36.00

Wilson Plot X-Y data points...

X	Y	X	Y
1.20	0.81	3.96	1.62
1.36	0.88	2.85	1.31
1.55	0.92	2.24	1.14
1.83	1.01	1.84	1.00
2.23	1.13	1.56	0.92
2.85	1.33	1.36	0.86
3.96	1.62	1.20	0.81

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1A3.dat
Processed Data File:	K6MD1A3.res
Tube Number:	1
Pressure Condition:	Atmospheric

Thermal Conductivity (W/m-K):	21.00
Tube Inside Diameter (mm):	13.53
Tube Outside Diameter (mm):	16.07
Wall Resistance, Rw (m/W/m-K):	0.00978

Average System Power (kW):	25.73
Average Steam Velocity (m/s):	1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	1.000
Inside leading coeff.,	Ci:	3.222
Outside leading coeff.,	Co:	2.292

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	3.87	1.94	644.47	74.13	99.89	17.02	8.69	51.63	37.87
2	3.38	2.14	624.92	73.48	99.92	16.30	8.50	46.22	38.33
3	2.90	2.42	608.95	73.15	99.93	15.73	8.32	40.75	38.71
4	2.43	2.80	591.66	73.48	99.87	15.12	8.05	34.95	39.13
5	1.96	3.27	559.28	73.29	99.91	14.00	7.63	29.29	39.96
6	1.50	3.97	520.36	73.00	99.88	12.68	7.13	23.49	41.04
7	1.05	5.09	465.83	72.50	99.89	10.90	6.43	17.52	42.75
8	1.05	5.11	467.70	72.64	99.89	10.96	6.44	17.50	42.68
9	1.50	3.96	519.13	73.31	99.91	12.64	7.08	23.42	41.07
10	1.96	3.29	562.87	73.79	99.92	14.12	7.63	29.15	39.87
11	2.43	2.80	591.83	74.04	99.90	15.13	7.99	34.77	39.13
12	2.90	2.43	611.75	73.89	99.91	15.83	8.28	40.45	38.63
13	3.38	2.15	628.03	73.87	99.89	16.42	8.50	46.02	38.25
14	3.87	1.94	644.53	73.90	99.88	17.02	8.72	51.55	37.88
Average			574.38			14.56			39.68

Wilson Plot X-Y data points...

X	Y	X	Y
1.21	0.81	4.00	1.67
1.37	0.87	2.88	1.35
1.57	0.92	2.25	1.14
1.85	1.00	1.86	1.01
2.25	1.14	1.58	0.93
2.87	1.33	1.37	0.86
4.00	1.68	1.21	0.81

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1A4.dat
Processed Data File:	K6MD1A4.res
Tube Number:	1
Pressure Condition:	Atmospheric
Thermal Conductivity (W/m-K):	21.00
Tube Inside Diameter (mm):	13.53
Tube Outside Diameter (mm):	16.07
Wall Resistance, Rw (m/W/m-K):	0.00978
Average System Power (kW):	25.73
Average Steam Velocity (m/s):	1.04

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	1.000
Inside leading coeff.,	Ci:	3.222
Outside leading coeff.,	Co:	2.292

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)---------		
1	3.87	1.94	644.47	74.13	99.89	17.02	8.69	51.63	37.87
2	3.38	2.14	624.92	73.48	99.92	16.30	8.50	46.22	38.33
3	2.90	2.42	608.95	73.15	99.93	15.73	8.32	40.75	38.71
4	2.43	2.80	591.66	73.48	99.87	15.12	8.05	34.95	39.13
5	1.96	3.27	559.28	73.29	99.91	14.00	7.63	29.29	39.96
6	1.50	3.97	520.36	73.00	99.88	12.68	7.13	23.49	41.04
7	1.05	5.09	465.83	72.50	99.89	10.90	6.43	17.52	42.75
8	1.05	5.11	467.70	72.64	99.89	10.96	6.44	17.50	42.68
9	1.50	3.96	519.13	73.31	99.91	12.64	7.08	23.42	41.07
10	1.96	3.29	562.87	73.79	99.92	14.12	7.63	29.15	39.87
11	2.43	2.80	591.83	74.04	99.90	15.13	7.99	34.77	39.13
12	2.90	2.43	611.75	73.89	99.91	15.83	8.28	40.45	38.63
13	3.38	2.15	628.03	73.87	99.89	16.42	8.50	46.02	38.25
14	3.87	1.94	644.53	73.90	99.88	17.02	8.72	51.55	37.88
Average			574.38			14.56			39.68

Wilson Plot X-Y data points...

X	Y	X	Y
1.21	0.81	4.00	1.67
1.37	0.87	2.88	1.35
1.57	0.92	2.25	1.14
1.85	1.00	1.86	1.01
2.25	1.14	1.58	0.93
2.87	1.33	1.37	0.86
4.00	1.68	1.21	0.81

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1V1.dat
Processed Data File:	K6MD1V1.res
Tube Number:	1
Pressure Condition:	Vacuum
Thermal Conductivity (W/m-K):	21.00
Tube Inside Diameter (mm):	13.53
Tube Outside Diameter (mm):	16.07
Wall Resistance, Rw (m/W/m-K):	0.00978
Average System Power (kW):	6.81
Average Steam Velocity (m/s):	1.97

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient,	R :	0.998
Inside leading coeff.,	Ci:	3.122
Outside leading coeff.,	Co:	1.763

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	3.87	0.68	218.97	27.32	48.69	7.31	8.02	47.63	29.97
2	3.38	0.75	214.64	27.24	48.69	7.11	7.88	42.54	30.20
3	2.90	0.84	208.86	27.49	48.68	6.85	7.60	37.41	30.51
4	2.43	0.97	203.75	27.58	48.66	6.62	7.39	32.04	30.79
5	1.96	1.14	194.62	27.65	48.70	6.21	7.04	26.77	31.33
6	1.50	1.38	181.00	27.46	48.69	5.62	6.59	21.45	32.18
7	1.05	1.78	163.27	27.49	48.70	4.88	5.94	15.91	33.43
8	1.05	1.78	163.27	27.55	48.71	4.88	5.93	15.90	33.43
9	1.50	1.38	181.03	27.66	48.67	5.63	6.54	21.35	32.17
10	1.96	1.15	196.38	27.86	48.71	6.29	7.05	26.64	31.23
11	2.43	0.99	208.06	27.92	48.68	6.81	7.45	31.83	30.56
12	2.90	0.86	214.02	27.52	48.69	7.08	7.78	37.13	30.24
13	3.38	0.77	220.60	27.59	48.67	7.38	8.00	42.37	29.89
14	3.87	0.69	222.39	27.65	48.68	7.46	8.04	47.45	29.79
Average			199.35			6.44			31.15

Wilson Plot X-Y data points...

X	Y	X	Y
1.31	1.00	4.34	1.95
1.48	1.05	3.12	1.59
1.69	1.14	2.43	1.35
1.99	1.21	1.99	1.19
2.43	1.36	1.69	1.08
3.10	1.57	1.47	1.00
4.34	1.95	1.31	0.99

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1V2.dat
Processed Data File: K6MD1V2.res
Tube Number: 1
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 21.00
Tube Inside Diameter (mm): 13.53
Tube Outside Diameter (mm): 16.07
Wall Resistance, Rw (m/W/m-K): 0.00978

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.97

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 2.999
Outside leading coeff., Co: 1.937

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------	(kW/m^2-K)	---------
1	3.87	0.66	211.98	25.26	48.70	6.14	8.39	46.77	34.55
2	3.38	0.72	205.54	25.19	48.72	5.88	8.16	41.77	34.94
3	2.90	0.80	198.49	25.11	48.69	5.61	7.91	36.73	35.39
4	2.43	0.93	195.04	25.88	48.69	5.48	7.54	31.45	35.61
5	1.96	1.09	185.84	25.64	48.72	5.13	7.25	26.29	36.26
6	1.50	1.30	170.31	25.51	48.69	4.55	6.68	21.05	37.41
7	1.05	1.67	153.01	25.33	48.68	3.93	6.04	15.64	38.90
8	1.05	1.67	153.01	25.38	48.71	3.93	6.03	15.64	38.90
9	1.50	1.32	172.96	25.58	48.70	4.65	6.76	20.99	37.23
10	1.96	1.10	187.59	25.71	48.68	5.19	7.30	26.19	36.14
11	2.43	0.96	201.47	26.37	48.68	5.72	7.64	31.29	35.20
12	2.90	0.82	203.61	25.81	48.69	5.81	7.89	36.58	35.05
13	3.38	0.73	208.54	25.85	48.68	6.00	8.07	41.63	34.74
14	3.87	0.67	215.39	25.54	48.70	6.27	8.43	46.63	34.34
Average			190.20			5.31			36.08

Wilson Plot X-Y data points...

X	Y	X	Y
1.34	0.95	4.49	2.01
1.52	1.02	3.21	1.58
1.75	1.11	2.50	1.33
2.05	1.23	2.04	1.18
2.50	1.35	1.74	1.10
3.21	1.62	1.52	1.04
4.49	2.00	1.34	0.94

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1V3.dat
Processed Data File: K6MD1V3.res
Tube Number: 1
Pressure Condition: Vacuum

Thermal Conductivity (W/m-K): 21.00
Tube Inside Diameter (mm): 13.53
Tube Outside Diameter (mm): 16.07
Wall Resistance, Rw (m/W/m-K): 0.00978

Average System Power (kW): 6.81
Average Steam Velocity (m/s): 1.96

This analysis takes into account of the following:

1. HEATEX insert inside the tube
2. End-fin effects
3. Petukhov-Popov correltation for Hi
4. Nusselt type correlation for Ho

Regression Coefficient, R : 0.999
Inside leading coeff., Ci: 3.074
Outside leading coeff., Co: 1.888

Data #	Vcw (m/s)	DTCW (C)	Qflux (kW/m^2)	LMTD	Tstm (C)	DTwo (C)	Uo	Hi	HoZ
							------(kW/m^2-K)	---------	
1	3.87	0.67	215.41	26.11	48.70	6.50	8.25	47.71	33.15
2	3.38	0.73	208.55	25.67	48.72	6.21	8.13	42.60	33.56
3	2.90	0.81	201.08	25.56	48.72	5.91	7.87	37.48	34.01
4	2.43	0.94	197.21	26.02	48.71	5.76	7.58	32.10	34.26
5	1.96	1.10	187.59	25.91	48.68	5.38	7.24	26.86	34.88
6	1.50	1.33	174.29	25.92	48.72	4.86	6.72	21.49	35.84
7	1.05	1.69	154.87	25.51	48.70	4.14	6.07	15.98	37.41
8	1.05	1.70	155.79	25.85	48.70	4.18	6.03	15.97	37.31
9	1.50	1.34	175.62	26.07	48.71	4.91	6.74	21.45	35.74
10	1.96	1.12	191.06	26.28	48.70	5.51	7.27	26.76	34.66
11	2.43	0.96	201.50	26.71	48.70	5.93	7.54	31.96	33.98
12	2.90	0.82	203.67	25.78	48.70	6.02	7.90	37.26	33.86
13	3.38	0.74	211.56	26.12	48.70	6.34	8.10	42.39	33.38
14	3.87	0.68	218.84	26.15	48.72	6.64	8.37	47.50	32.96
Average			192.65			5.59			34.65

Wilson Plot X-Y data points...

X	Y	X	Y
1.33	0.97	4.43	1.98
1.51	1.02	3.17	1.56
1.73	1.10	2.47	1.32
2.04	1.20	2.03	1.20
2.47	1.34	1.74	1.09
3.17	1.57	1.50	1.02
4.44	1.96	1.33	0.94

APPENDIX E. UNCERTAINTY ANALYSIS

A. INTRODUCTION

The uncertainty program DRPSAMUN.bas was rewritten by Das [Ref. 16] into Qbasic. The same procedures and derivations as used by Incheck [Ref. 34] are incorporated. Processed data and the program follow.

Program Name: DRPSAM.BAS
Raw Data File: S4OF9A2.dat
Uncertainty Data File: S4OF9A2.unc
Tube Number: 9
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0003805

Uncertainty in Ci = 2.35%
Uncertainty in Co = 1.18%
Uncertainty in Enahncement (const DT): 1.49%
Uncertainty in Enahncement (const q) : 1.99%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	5.63	6.16	9.71	2.47	2.49
2	0.71	5.02	5.54	8.66	2.50	2.34
3	0.82	4.42	4.93	7.58	2.53	2.20
4	0.98	3.80	4.33	6.46	2.59	2.07
5	1.22	3.32	3.86	5.51	2.70	1.97
6	1.59	2.94	3.50	4.60	2.90	1.90
7	2.28	2.96	3.52	4.02	3.36	1.90
8	2.28	2.96	3.51	4.01	3.36	1.90
9	1.59	2.95	3.51	4.62	2.90	1.90
10	1.22	3.31	3.85	5.48	2.70	1.97
11	0.98	3.80	4.33	6.44	2.59	2.07
12	0.82	4.37	4.88	7.47	2.53	2.19
13	0.71	4.96	5.47	8.56	2.49	2.32
14	0.62	5.59	6.12	9.63	2.47	2.48

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.025	27.46	3.01	0.62	1.02	0.25
2	0.025	24.10	2.64	0.54	0.91	0.24
3	0.025	20.85	2.29	0.46	0.81	0.22
4	0.025	17.75	1.98	0.39	0.71	0.21
5	0.025	14.89	1.66	0.31	0.62	0.21
6	0.025	12.60	1.40	0.25	0.53	0.20
7	0.025	11.61	1.24	0.20	0.46	0.21
8	0.025	11.63	1.24	0.20	0.46	0.21
9	0.025	12.59	1.40	0.25	0.53	0.20
10	0.025	14.90	1.67	0.31	0.61	0.20
11	0.025	17.76	1.98	0.38	0.70	0.21
12	0.025	20.87	2.32	0.46	0.80	0.22
13	0.025	24.12	2.67	0.53	0.90	0.23
14	0.025	27.48	3.03	0.61	1.00	0.25

Program Name: DRPSAMUN.BAS
Raw Data File: A1OF7A1.dat
Uncertainty Data File: A1OF7A1.unc
Tube Number: 7
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000016

Uncertainty in Ci = 2.33%
Uncertainty in Co = 1.32%
Uncertainty in Enahncement (const DT): 1.61%
Uncertainty in Enahncement (const q) : 2.15%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	5.08	5.66	8.77	2.45	2.49
2	0.71	4.55	5.13	7.83	2.47	2.37
3	0.82	4.07	4.66	6.97	2.51	2.27
4	0.98	3.57	4.18	6.04	2.57	2.18
5	1.22	3.15	3.78	5.20	2.68	2.10
6	1.59	2.84	3.50	4.40	2.88	2.05
7	2.28	2.91	3.56	3.91	3.34	2.05
8	2.28	2.91	3.56	3.91	3.34	2.05
9	1.59	2.83	3.49	4.38	2.88	2.05
10	1.22	3.11	3.75	5.14	2.68	2.09
11	0.98	3.55	4.16	6.02	2.57	2.17
12	0.82	4.05	4.64	6.92	2.51	2.27
13	0.71	4.58	5.16	7.88	2.47	2.38
14	0.62	5.08	5.66	8.77	2.45	2.49

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.028	29.38	3.32	0.67	0.84	0.25
2	0.028	25.81	2.91	0.59	0.75	0.24
3	0.028	22.33	2.51	0.51	0.68	0.23
4	0.028	19.05	2.15	0.43	0.59	0.23
5	0.028	16.04	1.81	0.35	0.52	0.22
6	0.028	13.68	1.54	0.28	0.45	0.22
7	0.028	12.71	1.35	0.23	0.39	0.24
8	0.028	12.71	1.35	0.23	0.39	0.24
9	0.028	13.69	1.54	0.28	0.44	0.22
10	0.028	16.07	1.83	0.35	0.51	0.22
11	0.028	19.06	2.16	0.42	0.59	0.22
12	0.028	22.34	2.52	0.51	0.67	0.23
13	0.028	25.81	2.90	0.58	0.75	0.24
14	0.028	29.38	3.32	0.67	0.83	0.25

Program Name: DRPSAMUN.BAS
Raw Data File: A1OF7V2.dat
Uncertainty Data File: A1OF7V2.unc
Tube Number: 7
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000016

Uncertainty in Ci = 2.24%
Uncertainty in Co = 1.41%
Uncertainty in Enahncement (const DT): 2.23%
Uncertainty in Enahncement (const q) : 2.97%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	14.08	14.97	24.39	2.37	5.08
2	0.71	12.55	13.37	21.74	2.39	4.61
3	0.82	11.01	11.76	19.05	2.43	4.15
4	0.98	9.45	10.15	16.33	2.49	3.69
5	1.22	8.14	8.79	14.01	2.60	3.33
6	1.59	6.77	7.40	11.54	2.81	2.97
7	2.28	5.65	6.26	9.27	3.29	2.70
8	2.28	5.65	6.26	9.27	3.29	2.70
9	1.59	6.77	7.40	11.54	2.81	2.97
10	1.22	8.05	8.70	13.85	2.60	3.30
11	0.98	9.45	10.15	16.33	2.49	3.69
12	0.82	11.01	11.76	19.05	2.43	4.15
13	0.71	12.55	13.37	21.74	2.39	4.61
14	0.62	14.08	14.97	24.39	2.37	5.08

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.028	29.21	2.96	1.90	0.77	0.53
2	0.028	25.55	2.57	1.66	0.69	0.49
3	0.028	21.95	2.19	1.43	0.62	0.44
4	0.028	18.42	1.83	1.18	0.55	0.40
5	0.028	14.97	1.46	0.96	0.48	0.37
6	0.028	11.66	1.11	0.74	0.41	0.34
7	0.028	8.64	0.79	0.53	0.36	0.33
8	0.028	8.64	0.79	0.53	0.36	0.33
9	0.028	11.66	1.11	0.74	0.41	0.34
10	0.028	14.98	1.47	0.95	0.47	0.37
11	0.028	18.43	1.83	1.17	0.54	0.40
12	0.028	21.96	2.19	1.42	0.62	0.44
13	0.028	25.56	2.57	1.65	0.69	0.49
14	0.028	29.22	2.96	1.89	0.77	0.53

Program Name: DRPSAMUN.BAS
Raw Data File: A1OF7V3.dat
Uncertainty Data File: A1OF7V3.unc
Tube Number: 7
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000016

Uncertainty in Ci = 2.14%
Uncertainty in Co = 1.50%
Uncertainty in Enahncement (const DT): 2.29%
Uncertainty in Enahncement (const q) : 3.05%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo (%)	uHi (%)	uHoZ (%)
1	0.62	13.05	13.91	22.60	2.27	4.81
2	0.71	11.72	12.53	20.19	2.29	4.42
3	0.82	10.37	11.12	17.94	2.34	4.02
4	0.98	8.87	9.57	15.32	2.40	3.60
5	1.22	7.71	8.38	13.22	2.51	3.29
6	1.59	6.44	7.09	10.95	2.73	2.97
7	2.28	5.42	6.07	8.84	3.22	2.74
8	2.28	5.42	6.07	8.86	3.22	2.74
9	1.59	6.44	7.09	10.95	2.73	2.97
10	1.22	7.55	8.22	12.99	2.51	3.25
11	0.98	8.76	9.46	15.19	2.40	3.57
12	0.82	10.22	10.97	17.68	2.34	3.98
13	0.71	11.53	12.33	19.97	2.29	4.36
14	0.62	12.81	13.66	22.19	2.27	4.74

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo (kW/m^2K)	uHi (kW/m^2K)	uHo (kW/m^2K)
1	0.028	29.22	2.65	1.91	0.74	0.57
2	0.028	25.56	2.29	1.70	0.67	0.53
3	0.028	21.96	1.95	1.45	0.60	0.49
4	0.028	18.44	1.63	1.19	0.53	0.44
5	0.028	14.99	1.30	0.98	0.46	0.41
6	0.028	11.69	1.00	0.75	0.40	0.38
7	0.028	8.71	0.72	0.54	0.35	0.37
8	0.028	8.71	0.72	0.54	0.35	0.37
9	0.028	11.69	1.00	0.74	0.40	0.38
10	0.028	15.00	1.31	0.96	0.46	0.40
11	0.028	18.44	1.64	1.17	0.53	0.43
12	0.028	21.97	1.97	1.43	0.60	0.48
13	0.028	25.56	2.31	1.66	0.67	0.52
14	0.028	29.22	2.67	1.89	0.74	0.55

Program Name: DRPSAMUN.BAS
Raw Data File: A3MD8A1.dat
Uncertainty Data File: A3MD8A1.unc
Tube Number: 8
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000015

Uncertainty in Ci = 1.87%
Uncertainty in Co = 7.96%
Uncertainty in Enahncement (const DT): 8.02%
Uncertainty in Enahncement (const q) : 10.69%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	1.45	10.73	2.42	2.03	10.64
2	0.71	1.42	10.73	2.32	2.06	10.64
3	0.82	1.42	10.73	2.25	2.10	10.64
4	0.98	1.45	10.73	2.17	2.18	10.64
5	1.22	1.56	10.75	2.16	2.30	10.64
6	1.59	1.81	10.79	2.27	2.53	10.64
7	2.28	2.40	10.92	2.69	3.05	10.65
8	2.28	2.40	10.92	2.69	3.05	10.65
9	1.59	1.81	10.79	2.25	2.53	10.64
10	1.22	1.55	10.75	2.12	2.30	10.64
11	0.98	1.43	10.73	2.12	2.17	10.63
12	0.82	1.39	10.73	2.19	2.10	10.63
13	0.71	1.40	10.73	2.29	2.06	10.64
14	0.62	1.43	10.73	2.39	2.03	10.64

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	31.81	2.42	0.75	1.01	10.36
2	0.027	28.99	2.19	0.68	0.92	10.66
3	0.027	26.47	1.93	0.61	0.83	11.05
4	0.027	24.57	1.69	0.53	0.74	11.47
5	0.027	23.36	1.43	0.46	0.65	12.01
6	0.027	23.27	1.16	0.42	0.57	12.71
7	0.027	24.75	0.87	0.40	0.51	13.77
8	0.027	25.01	0.88	0.40	0.51	13.72
9	0.027	23.54	1.18	0.41	0.56	12.65
10	0.027	23.74	1.48	0.45	0.64	11.89
11	0.027	24.95	1.76	0.52	0.72	11.33
12	0.027	26.76	2.01	0.60	0.82	10.92
13	0.027	29.12	2.24	0.68	0.92	10.59
14	0.027	31.89	2.48	0.77	1.02	10.29

```
Program Name:                        DRPSAMUN.BAS
Raw Data File:                       A3MD8A2.dat
Uncertainty Data File:               A3MD8A2.unc
Tube Number:                         11
Pressure Condition:                  Atmospheric
```

Assumed/Measured Uncertainties

```
: Conductivity (W/m-K)  :     1.00
: Quartz Thermometer (C):     0.05
: Water Flowmeter (%)   :     0.50
: Steam Temperature (C) :     0.40
```

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000015

Uncertainty in Ci = 2.21%
Uncertainty in Co = 9.53%
Uncertainty in Enahncement (const DT):   9.57%
Uncertainty in Enahncement (const q) : 12.76%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	1.45	12.80	2.42	2.35	12.71
2	0.71	1.42	12.79	2.33	2.37	12.71
3	0.82	1.41	12.79	2.23	2.41	12.71
4	0.98	1.45	12.80	2.17	2.48	12.71
5	1.22	1.56	12.81	2.17	2.58	12.71
6	1.59	1.82	12.85	2.27	2.79	12.72
7	2.28	2.40	12.95	2.69	3.27	12.73
8	2.28	2.40	12.95	2.68	3.27	12.73
9	1.59	1.81	12.85	2.25	2.79	12.72
10	1.22	1.54	12.81	2.12	2.58	12.71
11	0.98	1.42	12.79	2.11	2.47	12.71
12	0.82	1.39	12.79	2.19	2.41	12.71
13	0.71	1.39	12.79	2.27	2.37	12.71
14	0.62	1.42	12.79	2.38	2.34	12.71

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	31.79	2.89	0.76	1.17	12.34
2	0.027	28.96	2.60	0.68	1.06	12.72
3	0.027	26.55	2.33	0.60	0.95	13.12
4	0.027	24.56	2.01	0.53	0.83	13.66
5	0.027	23.28	1.69	0.46	0.72	14.33
6	0.027	23.22	1.38	0.41	0.62	15.15
7	0.027	24.92	1.05	0.39	0.54	16.35
8	0.027	25.09	1.06	0.39	0.54	16.31
9	0.027	23.58	1.42	0.40	0.61	15.05
10	0.027	23.78	1.77	0.45	0.70	14.15
11	0.027	25.05	2.13	0.51	0.81	13.46
12	0.027	26.78	2.40	0.59	0.92	13.01
13	0.027	29.21	2.71	0.66	1.04	12.57
14	0.027	31.95	2.99	0.75	1.15	12.23

```
Program Name:                    DRPSAMUN.BAS
Raw Data File:                   A3MD8V1.dat
Uncertainty Data File:           A3MD8V1.unc
Tube Number:                     8
Pressure Condition:              Vacuum

Assumed/Measured Uncertainties
         : Conductivity (W/m-K)   :   1.00
         : Quartz Thermometer (C):    0.05
         : Water Flowmeter (%)    :   0.50
         : Steam Temperature (C)  :   0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K):  0.0000015

Uncertainty in Ci =  1.82%
Uncertainty in Co =  4.06%
Uncertainty in Enahncement (const DT):   4.41%
Uncertainty in Enahncement (const q) :   5.88%
```

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo (%)	uHi (%)	uHoZ (%)
1	0.62	5.07	7.62	8.75	1.97	5.69
2	0.71	4.57	7.26	7.89	2.00	5.64
3	0.82	4.27	7.06	7.36	2.05	5.62
4	0.98	3.86	6.79	6.61	2.12	5.59
5	1.22	3.58	6.62	6.02	2.25	5.56
6	1.59	3.32	6.47	5.35	2.49	5.55
7	2.28	3.36	6.49	4.91	3.01	5.55
8	2.28	3.34	6.48	4.87	3.01	5.55
9	1.59	3.28	6.44	5.28	2.49	5.54
10	1.22	3.48	6.56	5.81	2.25	5.56
11	0.98	3.77	6.73	6.42	2.12	5.58
12	0.82	4.25	7.04	7.31	2.05	5.62
13	0.71	4.63	7.30	7.97	2.00	5.65
14	0.62	5.00	7.57	8.65	1.97	5.68

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo (kW/m^2K)	uHi (kW/m^2K)	uHo (kW/m^2K)
1	0.027	29.08	0.95	1.89	0.86	2.63
2	0.027	25.54	0.87	1.66	0.78	2.64
3	0.027	22.06	0.76	1.43	0.70	2.71
4	0.027	18.74	0.67	1.18	0.62	2.76
5	0.027	15.57	0.56	0.96	0.55	2.87
6	0.027	12.77	0.46	0.75	0.48	3.00
7	0.027	10.65	0.35	0.57	0.44	3.23
8	0.027	10.71	0.36	0.57	0.44	3.21
9	0.027	12.82	0.47	0.74	0.48	2.98
10	0.027	15.64	0.58	0.94	0.54	2.83
11	0.027	18.78	0.69	1.14	0.61	2.73
12	0.027	22.08	0.76	1.39	0.70	2.70
13	0.027	25.53	0.86	1.64	0.78	2.65
14	0.027	29.09	0.96	1.86	0.86	2.61

Program Name: DRPSAMUN.BAS
Raw Data File: A3MD8V2.dat
Uncertainty Data File: A3MD8V2.unc
Tube Number: 8
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000015

Uncertainty in Ci = 1.68%
Uncertainty in Co = 3.60%
Uncertainty in Enahncement (const DT): 3.99%
Uncertainty in Enahncement (const q) : 5.32%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	4.96	7.11	8.61	1.83	5.09
2	0.71	4.57	6.81	7.87	1.87	5.05
3	0.82	4.20	6.54	7.23	1.92	5.02
4	0.98	3.82	6.28	6.52	2.00	4.98
5	1.22	3.49	6.06	5.85	2.13	4.96
6	1.59	3.27	5.92	5.26	2.38	4.94
7	2.28	3.32	5.96	4.82	2.93	4.94
8	2.28	3.32	5.95	4.81	2.93	4.94
9	1.59	3.24	5.91	5.20	2.38	4.94
10	1.22	3.42	6.02	5.71	2.13	4.95
11	0.98	3.70	6.20	6.29	1.99	4.97
12	0.82	4.13	6.49	7.12	1.92	5.01
13	0.71	4.49	6.75	7.74	1.87	5.04
14	0.62	4.86	7.03	8.40	1.83	5.08

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	29.10	0.94	1.81	0.80	2.27
2	0.027	25.55	0.84	1.61	0.73	2.29
3	0.027	22.09	0.74	1.38	0.66	2.34
4	0.027	18.76	0.64	1.15	0.59	2.39
5	0.027	15.63	0.55	0.93	0.52	2.46
6	0.027	12.83	0.44	0.73	0.47	2.58
7	0.027	10.76	0.34	0.56	0.42	2.78
8	0.027	10.78	0.34	0.56	0.42	2.77
9	0.027	12.87	0.45	0.72	0.46	2.57
10	0.027	15.68	0.56	0.91	0.52	2.44
11	0.027	18.82	0.67	1.11	0.58	2.35
12	0.027	22.11	0.75	1.34	0.65	2.32
13	0.027	25.57	0.85	1.57	0.72	2.27
14	0.027	29.12	0.95	1.80	0.80	2.24

Program Name:	DRPSAMUN.BAS
Raw Data File:	C3MD1A2.dat
Uncertainty Data File:	C3MD1A2.unc
Tube Number:	1
Pressure Condition:	Atmospheric

Assumed/Measured Uncertainties

: Conductivity (W/m-K) :	1.00
: Quartz Thermometer (C):	0.05
: Water Flowmeter (%) :	0.50
: Steam Temperature (C) :	0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.86%
Uncertainty in Co = 13.47%
Uncertainty in Enahncement (const DT): 13.50%
Uncertainty in Enahncement (const q) : 17.99%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	1.36	18.02	2.27	2.02	17.97
2	0.71	1.37	18.02	2.23	2.06	17.97
3	0.82	1.38	18.02	2.18	2.10	17.97
4	0.98	1.44	18.02	2.15	2.17	17.97
5	1.22	1.56	18.03	2.16	2.30	17.97
6	1.59	1.82	18.06	2.29	2.53	17.97
7	2.28	2.41	18.14	2.71	3.05	17.98
8	2.28	2.41	18.14	2.71	3.05	17.98
9	1.59	1.81	18.06	2.26	2.53	17.97
10	1.22	1.54	18.03	2.12	2.29	17.97
11	0.98	1.42	18.02	2.10	2.17	17.97
12	0.82	1.37	18.02	2.14	2.10	17.97
13	0.71	1.35	18.02	2.19	2.05	17.97
14	0.62	1.35	18.02	2.25	2.02	17.97

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	32.23	2.84	0.79	0.92	26.98
2	0.027	29.34	2.49	0.71	0.84	27.97
3	0.027	26.79	2.16	0.63	0.75	29.06
4	0.027	24.74	1.84	0.55	0.67	30.33
5	0.027	23.37	1.52	0.48	0.59	31.87
6	0.027	22.85	1.20	0.42	0.52	33.96
7	0.027	24.14	0.89	0.40	0.46	36.74
8	0.027	24.19	0.89	0.40	0.46	36.72
9	0.027	23.38	1.25	0.42	0.51	33.62
10	0.027	23.78	1.58	0.47	0.58	31.55
11	0.027	25.13	1.92	0.53	0.65	29.99
12	0.027	27.04	2.22	0.61	0.74	28.83
13	0.027	29.50	2.55	0.69	0.83	27.79
14	0.027	32.31	2.88	0.78	0.91	26.87

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1A3.dat
Uncertainty Data File: C3MD1A3.unc
Tube Number: 1
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.37%
Uncertainty in Co = 10.31%
Uncertainty in Enahncement (const DT): 10.35%
Uncertainty in Enahncement (const q) : 13.79%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				(%)		
1	0.62	1.37	13.82	2.28	1.58	13.75
2	0.71	1.37	13.82	2.24	1.62	13.75
3	0.82	1.39	13.82	2.18	1.68	13.75
4	0.98	1.43	13.83	2.13	1.77	13.75
5	1.22	1.55	13.84	2.15	1.92	13.75
6	1.59	1.82	13.88	2.28	2.19	13.76
7	1.22	1.54	13.84	2.13	1.91	13.75
8	0.98	1.42	13.82	2.10	1.76	13.75
9	0.82	1.37	13.82	2.14	1.67	13.75
10	0.71	1.35	13.82	2.20	1.62	13.75
11	0.62	1.37	13.82	2.29	1.58	13.75
12	1.59	1.82	13.88	2.30	2.19	13.76
13	2.28	2.41	13.98	2.72	2.77	13.77
14	2.28	2.41	13.98	2.72	2.77	13.77

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				(kW/m^2K)		
1	0.027	32.20	2.10	0.79	0.71	21.33
2	0.027	29.28	1.83	0.71	0.65	22.13
3	0.027	26.78	1.60	0.63	0.59	22.95
4	0.027	24.87	1.39	0.55	0.54	23.85
5	0.027	23.54	1.15	0.47	0.48	25.04
6	0.027	23.01	0.90	0.42	0.44	26.71
7	0.027	23.74	1.17	0.46	0.47	24.93
8	0.027	25.08	1.42	0.53	0.52	23.71
9	0.027	27.04	1.65	0.61	0.58	22.76
10	0.027	29.47	1.89	0.70	0.64	21.96
11	0.027	32.16	2.08	0.79	0.71	21.38
12	0.027	22.83	0.89	0.42	0.44	26.81
13	0.027	23.89	0.65	0.40	0.42	29.11
14	0.027	24.02	0.66	0.40	0.42	29.06

Program Name:	DRPSAMUN.BAS
Raw Data File:	C3MD1V2.dat
Uncertainty Data File:	C3MD1V2.unc
Tube Number:	1
Pressure Condition:	Vacuum

Assumed/Measured Uncertainties

: Conductivity (W/m-K) :	1.00
: Quartz Thermometer (C):	0.05
: Water Flowmeter (%) :	0.50
: Steam Temperature (C) :	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.31%
Uncertainty in Co = 3.78%
Uncertainty in Enahncement (const DT): 4.15%
Uncertainty in Enahncement (const q) : 5.54%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	5.10	7.39	8.84	1.51	5.34
2	0.71	4.72	7.09	8.13	1.55	5.30
3	0.82	4.35	6.83	7.49	1.61	5.26
4	0.98	4.02	6.60	6.86	1.70	5.23
5	1.22	3.74	6.41	6.29	1.86	5.21
6	1.59	3.51	6.26	5.70	2.14	5.19
7	2.28	3.52	6.27	5.24	2.73	5.19
8	2.28	3.50	6.26	5.19	2.73	5.19
9	1.59	3.45	6.23	5.58	2.14	5.19
10	1.22	3.67	6.37	6.18	1.86	5.21
11	0.98	3.92	6.53	6.71	1.70	5.23
12	0.82	4.32	6.81	7.44	1.61	5.26
13	0.71	4.69	7.07	8.08	1.55	5.29
14	0.62	5.00	7.30	8.68	1.51	5.33

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	29.06	0.77	1.98	0.59	2.91
2	0.027	25.50	0.69	1.76	0.54	2.95
3	0.027	22.03	0.61	1.51	0.49	3.01
4	0.027	18.68	0.52	1.25	0.45	3.09
5	0.027	15.47	0.43	1.02	0.41	3.22
6	0.027	12.57	0.35	0.80	0.38	3.38
7	0.027	10.26	0.26	0.60	0.36	3.64
8	0.027	10.31	0.26	0.59	0.36	3.63
9	0.027	12.63	0.35	0.78	0.37	3.35
10	0.027	15.51	0.44	0.99	0.40	3.19
11	0.027	18.72	0.53	1.21	0.44	3.05
12	0.027	22.05	0.61	1.46	0.49	3.00
13	0.027	25.51	0.69	1.71	0.54	2.94
14	0.027	29.07	0.79	1.94	0.59	2.88

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1V3.dat
Uncertainty Data File: C3MD1V3.unc
Tube Number: 1
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.51%
Uncertainty in Co = 4.42%
Uncertainty in Enahncement (const DT): 4.75%
Uncertainty in Enahncement (const q) : 6.33%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	5.00	7.92	8.68	1.69	6.15
2	0.71	4.69	7.71	8.10	1.73	6.12
3	0.82	4.35	7.48	7.49	1.78	6.09
4	0.98	3.98	7.25	6.80	1.87	6.06
5	1.22	3.69	7.08	6.21	2.01	6.04
6	1.59	3.47	6.96	5.64	2.27	6.03
7	2.28	3.49	6.97	5.18	2.84	6.03
8	2.28	3.48	6.96	5.16	2.84	6.03
9	1.59	3.46	6.95	5.60	2.27	6.03
10	1.22	3.63	7.04	6.09	2.01	6.04
11	0.98	3.90	7.20	6.66	1.86	6.06
12	0.82	4.32	7.47	7.43	1.78	6.09
13	0.71	4.63	7.67	8.01	1.73	6.11
14	0.62	4.93	7.87	8.54	1.69	6.14

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.027	29.07	0.84	1.96	0.66	3.35
2	0.027	25.51	0.75	1.73	0.60	3.43
3	0.027	22.04	0.66	1.50	0.54	3.51
4	0.027	18.69	0.57	1.23	0.49	3.60
5	0.027	15.50	0.48	1.00	0.44	3.74
6	0.027	12.61	0.39	0.78	0.40	3.94
7	0.027	10.33	0.29	0.59	0.37	4.25
8	0.027	10.34	0.29	0.59	0.37	4.24
9	0.027	12.62	0.39	0.78	0.39	3.93
10	0.027	15.54	0.49	0.98	0.44	3.71
11	0.027	18.72	0.59	1.20	0.48	3.56
12	0.027	22.05	0.66	1.46	0.54	3.50
13	0.027	25.52	0.76	1.69	0.60	3.41
14	0.027	29.08	0.86	1.94	0.65	3.33

Program Name:	DRPSAMUN.BAS
Raw Data File:	C7MDF5A1.dat
Uncertainty Data File:	C7MDF5A1.unc
Tube Number:	0
Pressure Condition:	Atmospheric

Assumed/Measured Uncertainties

: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 3.34%
Uncertainty in Co = 9.26%
Uncertainty in Enahncement (const DT): 9.31%
Uncertainty in Enahncement (const q) : 12.41%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	2.12	12.56	3.61	3.43	12.38
2	0.71	2.04	12.54	3.44	3.45	12.37
3	0.82	1.96	12.53	3.24	3.48	12.37
4	0.98	1.91	12.52	3.05	3.52	12.37
5	1.22	1.91	12.52	2.88	3.60	12.37
6	1.59	2.05	12.54	2.81	3.75	12.37
7	2.28	2.53	12.64	3.01	4.12	12.38
8	2.28	2.52	12.64	3.01	4.12	12.38
9	1.59	2.04	12.54	2.79	3.75	12.37
10	1.22	1.90	12.51	2.85	3.60	12.37
11	0.98	1.88	12.51	2.99	3.52	12.37
12	0.82	1.93	12.52	3.19	3.48	12.37
13	0.71	2.01	12.54	3.39	3.45	12.37
14	0.62	2.11	12.55	3.60	3.43	12.38

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.029	30.85	3.90	0.74	1.21	5.81
2	0.029	27.48	3.47	0.67	1.09	6.01
3	0.029	24.38	3.11	0.58	0.97	6.21
4	0.029	21.62	2.72	0.50	0.84	6.45
5	0.029	19.46	2.35	0.42	0.72	6.72
6	0.029	18.14	1.93	0.35	0.60	7.11
7	0.029	18.63	1.52	0.32	0.49	7.61
8	0.029	18.68	1.52	0.32	0.49	7.60
9	0.029	18.31	1.97	0.35	0.59	7.07
10	0.029	19.55	2.38	0.41	0.71	6.70
11	0.029	21.77	2.81	0.49	0.83	6.39
12	0.029	24.48	3.18	0.57	0.96	6.17
13	0.029	27.56	3.56	0.66	1.08	5.97
14	0.029	30.86	3.91	0.75	1.21	5.80

```
Program Name:                        DRPSAMUN.BAS
Raw Data File:                       C7MDF5A2.dat
Uncertainty Data File:               C7MDF5A2.unc
Tube Number:                         5
Pressure Condition:                  Atmospheric

Assumed/Measured Uncertainties
         : Conductivity (W/m-K)   :    1.00
         : Quartz Thermometer (C):     0.05
         : Water Flowmeter (%)    :    0.50
         : Steam Temperature (C)  :    0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K):  0.0000004

Uncertainty in Ci =  3.40%
Uncertainty in Co =  9.29%
Uncertainty in Enahncement (const DT):   9.34%
Uncertainty in Enahncement (const q) :  12.44%
```

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	2.11	12.59	3.61	3.49	12.41
2	0.71	2.03	12.58	3.42	3.51	12.41
3	0.82	1.95	12.56	3.22	3.54	12.41
4	0.98	1.88	12.55	3.00	3.58	12.41
5	1.22	1.90	12.55	2.86	3.66	12.41
6	1.59	2.05	12.58	2.81	3.81	12.41
7	2.28	2.52	12.67	3.00	4.17	12.42
8	2.28	2.52	12.67	3.00	4.17	12.42
9	1.59	2.04	12.58	2.79	3.81	12.41
10	1.22	1.90	12.55	2.86	3.66	12.41
11	0.98	1.88	12.55	3.00	3.58	12.41
12	0.82	1.94	12.56	3.21	3.54	12.41
13	0.71	2.01	12.57	3.38	3.51	12.41
14	0.62	2.12	12.59	3.61	3.49	12.41

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.029	30.85	3.95	0.75	1.24	5.79
2	0.029	27.51	3.55	0.66	1.12	5.97
3	0.029	24.42	3.17	0.58	0.99	6.17
4	0.029	21.73	2.82	0.50	0.86	6.39
5	0.029	19.50	2.39	0.42	0.74	6.69
6	0.029	18.18	1.95	0.35	0.61	7.08
7	0.029	18.73	1.54	0.32	0.50	7.57
8	0.029	18.75	1.55	0.32	0.50	7.57
9	0.029	18.31	1.98	0.35	0.61	7.05
10	0.029	19.53	2.40	0.41	0.73	6.69
11	0.029	21.75	2.82	0.49	0.85	6.38
12	0.029	24.45	3.19	0.57	0.98	6.16
13	0.029	27.57	3.60	0.66	1.11	5.94
14	0.029	30.85	3.93	0.75	1.24	5.79

Program Name:	DRPSAMUN.BAS
Raw Data File:	C7MDF5V1.dat
Uncertainty Data File:	C7MDF5V1.unc
Tube Number:	5
Pressure Condition:	Vacuum

Assumed/Measured Uncertainties

: Conductivity (W/m-K)	:	1.00
: Quartz Thermometer (C)	:	0.05
: Water Flowmeter (%)	:	0.50
: Steam Temperature (C)	:	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci 2.12%
Uncertainty in Co 3.29%
Uncertainty in Enhancement (const DT): 3.71%
Uncertainty in Enhancement (const q) : 4.95%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	7.87	9.40	13.69	2.25	5.13
2	0.71	7.23	8.80	12.56	2.28	5.02
3	0.82	6.64	8.27	11.51	2.32	4.93
4	0.98	5.92	7.64	10.22	2.38	4.83
5	1.22	5.27	7.09	9.01	2.50	4.75
6	1.59	4.71	6.64	7.88	2.71	4.68
7	2.28	4.29	6.31	6.73	3.20	4.63
8	2.28	4.27	6.30	6.72	3.20	4.63
9	1.59	4.64	6.58	7.75	2.71	4.67
10	1.22	5.20	7.03	8.88	2.50	4.74
11	0.98	5.78	7.52	9.95	2.38	4.81
12	0.82	6.52	8.17	11.27	2.32	4.91
13	0.71	7.23	8.80	12.43	2.27	5.02
14	0.62	7.96	9.48	13.74	2.25	5.14

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.029	29.67	1.32	2.09	0.77	1.38
2	0.029	25.98	1.16	1.84	0.70	1.37
3	0.029	22.36	0.99	1.59	0.63	1.39
4	0.029	18.83	0.84	1.31	0.55	1.39
5	0.029	15.42	0.70	1.06	0.48	1.41
6	0.029	12.20	0.55	0.83	0.42	1.46
7	0.029	9.46	0.42	0.61	0.37	1.54
8	0.029	9.48	0.42	0.60	0.37	1.53
9	0.029	12.23	0.56	0.81	0.42	1.45
10	0.029	15.44	0.71	1.04	0.48	1.40
11	0.029	18.86	0.86	1.28	0.55	1.37
12	0.029	22.38	1.00	1.55	0.62	1.37
13	0.029	25.99	1.16	1.82	0.69	1.37
14	0.029	29.68	1.31	2.08	0.77	1.39

```
Program Name:                        DRPSAMUN.BAS
Raw Data File:                       C7MDF5V2.dat
Uncertainty Data File:               C7MDF5V2.unc
Tube Number:                         5
Pressure Condition:                  Vacuum
```

Assumed/Measured Uncertainties

: Conductivity (W/m-K)	:	1.00
: Quartz Thermometer (C)	:	0.05
: Water Flowmeter (%)	:	0.50
: Steam Temperature (C)	:	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 2.07%
Uncertainty in Co = 3.46%
Uncertainty in Enahncement (const DT): 3.86%
Uncertainty in Enahncement (const q) : 5.15%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				(%)		
1	0.62	7.54	9.20	13.11	2.21	5.27
2	0.71	6.95	8.67	11.99	2.24	5.18
3	0.82	6.35	8.14	11.01	2.28	5.09
4	0.98	5.65	7.54	9.72	2.35	5.00
5	1.22	5.10	7.10	8.70	2.46	4.94
6	1.59	4.56	6.68	7.62	2.68	4.88
7	2.28	4.20	6.41	6.58	3.17	4.84
8	2.28	4.18	6.40	6.54	3.17	4.84
9	1.59	4.54	6.66	7.56	2.68	4.87
10	1.22	5.03	7.04	8.59	2.46	4.93
11	0.98	5.56	7.47	9.60	2.35	4.99
12	0.82	6.24	8.05	10.78	2.28	5.08
13	0.71	6.88	8.61	11.91	2.24	5.17
14	0.62	7.46	9.13	12.98	2.21	5.26

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				(kW/m^2K)		
1	0.029	29.68	1.23	2.11	0.78	1.55
2	0.029	25.99	1.08	1.88	0.71	1.56
3	0.029	22.37	0.93	1.60	0.63	1.57
4	0.029	18.86	0.80	1.33	0.56	1.58
5	0.029	15.45	0.66	1.08	0.49	1.62
6	0.029	12.25	0.52	0.84	0.43	1.68
7	0.029	9.55	0.40	0.62	0.38	1.77
8	0.029	9.56	0.40	0.62	0.38	1.77
9	0.029	12.26	0.52	0.84	0.43	1.67
10	0.029	15.46	0.66	1.07	0.49	1.61
11	0.029	18.87	0.81	1.30	0.56	1.56
12	0.029	22.39	0.94	1.58	0.63	1.56
13	0.029	26.00	1.08	1.84	0.70	1.55
14	0.029	29.68	1.24	2.09	0.78	1.54

```
Program Name:                        DRPSAMUN.BAS
Raw Data File:                       C3MDF1A1.dat
Uncertainty Data File:               C3MDF1A1.unc
Tube Number:                         1
Pressure Condition:                  Atmospheric

Assumed/Measured Uncertainties
        : Conductivity (W/m-K)   :     1.00
        : Quartz Thermometer (C):     0.05
        : Water Flowmeter (%)    :     0.50
        : Steam Temperature (C)  :     0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K):  0.0000004

Uncertainty in Ci =  3.43%
Uncertainty in Co = 12.15%
Uncertainty in Enahncement (const DT):  12.18%
Uncertainty in Enahncement (const q) :  16.24%
```

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	1.66	16.30	2.82	3.52	16.21
2	0.71	1.62	16.29	2.70	3.54	16.21
3	0.82	1.60	16.29	2.59	3.56	16.21
4	0.98	1.60	16.29	2.48	3.61	16.21
5	1.22	1.68	16.30	2.42	3.68	16.21
6	1.59	1.89	16.32	2.46	3.83	16.21
7	2.28	2.44	16.40	2.80	4.19	16.22
8	2.28	2.44	16.40	2.80	4.19	16.22
9	1.59	1.89	16.32	2.45	3.83	16.21
10	1.22	1.67	16.30	2.40	3.68	16.21
11	0.98	1.58	16.29	2.43	3.61	16.21
12	0.82	1.57	16.29	2.53	3.56	16.21
13	0.71	1.60	16.29	2.65	3.54	16.21
14	0.62	1.65	16.30	2.79	3.52	16.21

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.027	30.87	4.11	0.79	1.56	11.93
2	0.027	27.82	3.67	0.71	1.41	12.33
3	0.027	25.07	3.24	0.62	1.25	12.77
4	0.027	22.81	2.84	0.54	1.08	13.26
5	0.027	21.14	2.39	0.46	0.92	13.89
6	0.027	20.56	1.96	0.40	0.77	14.68
7	0.027	21.86	1.51	0.38	0.62	15.75
8	0.027	21.86	1.51	0.38	0.62	15.75
9	0.027	20.69	1.98	0.40	0.76	14.63
10	0.027	21.31	2.44	0.45	0.91	13.82
11	0.027	23.04	2.93	0.52	1.06	13.14
12	0.027	25.29	3.36	0.60	1.22	12.64
13	0.027	27.98	3.79	0.69	1.38	12.22
14	0.027	30.95	4.18	0.78	1.54	11.87

Program Name: DRPSAMUN.BAS
Raw Data File: C3MDF1A2.dat
Uncertainty Data File: C3MDF1A2.unc
Tube Number: 1
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 2.71%
Uncertainty in Co = 9.41%
Uncertainty in Enahncement (const DT): 9.46%
Uncertainty in Enahncement (const q) : 12.60%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	1.72	12.68	2.90	2.83	12.57
2	0.71	1.67	12.68	2.78	2.85	12.57
3	0.82	1.64	12.67	2.65	2.88	12.57
4	0.98	1.62	12.67	2.52	2.94	12.56
5	1.22	1.70	12.68	2.47	3.03	12.57
6	1.59	1.91	12.71	2.49	3.21	12.57
7	2.28	2.45	12.81	2.82	3.63	12.58
8	2.28	2.45	12.81	2.82	3.63	12.58
9	1.59	1.90	12.71	2.48	3.21	12.57
10	1.22	1.68	12.68	2.42	3.03	12.57
11	0.98	1.61	12.67	2.48	2.93	12.56
12	0.82	1.61	12.67	2.60	2.88	12.56
13	0.71	1.64	12.67	2.73	2.85	12.57
14	0.62	1.71	12.68	2.89	2.83	12.57

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.027	30.78	3.32	0.76	1.19	8.60
2	0.027	27.69	2.97	0.68	1.07	8.89
3	0.027	24.93	2.64	0.60	0.95	9.19
4	0.027	22.67	2.33	0.51	0.83	9.52
5	0.027	20.86	1.95	0.44	0.72	10.00
6	0.027	20.19	1.60	0.39	0.61	10.57
7	0.027	21.33	1.24	0.36	0.51	11.36
8	0.027	21.38	1.24	0.36	0.51	11.34
9	0.027	20.38	1.63	0.38	0.60	10.52
10	0.027	21.16	2.02	0.43	0.71	9.90
11	0.027	22.82	2.39	0.50	0.82	9.46
12	0.027	25.09	2.72	0.58	0.94	9.12
13	0.027	27.82	3.06	0.67	1.06	8.81
14	0.027	30.80	3.34	0.76	1.18	8.59

```
Program Name:                       DRPSAMUN.BAS
Raw Data File:                      C3MDF1V1.dat
Uncertainty Data File:              C3MDF1V1.unc
Tube Number:                        1
Pressure Condition:                 Vacuum
```

Assumed/Measured Uncertainties

: Conductivity (W/m-K) :	1.00
: Quartz Thermometer (C):	0.05
: Water Flowmeter (%) :	0.50
: Steam Temperature (C) :	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.83%
Uncertainty in Co = 4.90%
Uncertainty in Enahncement (const DT): 5.19%
Uncertainty in Enahncement (const q) : 6.92%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	5.67	8.86	9.79	1.99	6.81
2	0.71	5.30	8.60	9.19	2.02	6.78
3	0.82	4.89	8.33	8.43	2.07	6.74
4	0.98	4.47	8.06	7.66	2.14	6.71
5	1.22	4.11	7.85	6.96	2.26	6.69
6	1.59	3.84	7.69	6.31	2.50	6.67
7	2.28	3.74	7.64	5.68	3.02	6.66
8	2.28	3.72	7.63	5.64	3.02	6.66
9	1.59	3.78	7.66	6.20	2.50	6.66
10	1.22	4.07	7.83	6.88	2.26	6.68
11	0.98	4.36	8.00	7.49	2.14	6.70
12	0.82	4.83	8.29	8.33	2.06	6.74
13	0.71	5.22	8.55	9.01	2.02	6.77
14	0.62	5.62	8.83	9.74	1.99	6.81

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	28.99	0.91	2.15	0.77	3.39
2	0.027	25.41	0.81	1.87	0.70	3.46
3	0.027	21.93	0.71	1.64	0.63	3.54
4	0.027	18.55	0.62	1.34	0.56	3.62
5	0.027	15.30	0.52	1.10	0.49	3.76
6	0.027	12.29	0.41	0.86	0.43	3.97
7	0.027	9.85	0.32	0.63	0.39	4.25
8	0.027	9.89	0.32	0.63	0.39	4.24
9	0.027	12.34	0.42	0.84	0.43	3.94
10	0.027	15.32	0.53	1.07	0.49	3.75
11	0.027	18.58	0.64	1.29	0.55	3.58
12	0.027	21.94	0.72	1.57	0.62	3.51
13	0.027	25.43	0.82	1.84	0.69	3.44
14	0.027	29.00	0.92	2.10	0.76	3.38

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1A4.dat
Uncertainty Data File:	K6MD1A4.unc
Tube Number:	1
Pressure Condition:	Atmospheric

Assumed/Measured Uncertainties

: Conductivity (W/m-K)	:	1.00
: Quartz Thermometer (C)	:	0.05
: Water Flowmeter (%)	:	0.50
: Steam Temperature (C)	:	0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 1.24%
Uncertainty in Co = 1.95%
Uncertainty in Enahncement (const DT): 2.16%
Uncertainty in Enahncement (const q) : 2.88%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)---------		
1	0.62	3.80	4.79	6.54	1.46	2.91
2	0.71	3.42	4.46	5.87	1.50	2.86
3	0.82	3.07	4.16	5.22	1.56	2.81
4	0.98	2.73	3.89	4.55	1.66	2.78
5	1.22	2.49	3.71	3.99	1.82	2.75
6	1.59	2.39	3.64	3.52	2.11	2.74
7	2.28	2.67	3.85	3.36	2.71	2.77
8	2.28	2.67	3.85	3.36	2.71	2.77
9	1.59	2.39	3.63	3.51	2.10	2.74
10	1.22	2.48	3.70	3.98	1.82	2.75
11	0.98	2.72	3.89	4.54	1.66	2.77
12	0.82	3.05	4.15	5.18	1.56	2.81
13	0.71	3.42	4.46	5.85	1.50	2.86
14	0.62	3.78	4.77	6.51	1.45	2.91

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.024	24.24	0.85	0.56	0.75	1.05
2	0.024	21.37	0.77	0.49	0.69	1.04
3	0.024	18.62	0.69	0.43	0.64	1.03
4	0.024	16.10	0.62	0.36	0.58	1.03
5	0.024	13.91	0.55	0.30	0.53	1.04
6	0.024	12.44	0.49	0.25	0.50	1.06
7	0.024	12.47	0.44	0.21	0.47	1.12
8	0.024	12.47	0.44	0.21	0.47	1.12
9	0.024	12.46	0.49	0.25	0.49	1.06
10	0.024	13.93	0.55	0.30	0.53	1.04
11	0.024	16.11	0.62	0.36	0.58	1.03
12	0.024	18.64	0.69	0.42	0.63	1.03
13	0.024	21.37	0.77	0.49	0.69	1.04
14	0.024	24.25	0.85	0.56	[illegible]	1.04

Program Name: DRPSAMUN.BAS
Raw Data File: C3MDF1V2.dat
Uncertainty Data File: C3MDF1V2.unc
Tube Number: 1
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 2.31%
Uncertainty in Co = 4.53%
Uncertainty in Enahncement (const DT): 4.84%
Uncertainty in Enahncement (const q) : 6.46%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				--------- (%)	-----------	
1	0.62	6.54	9.18	11.37	2.43	6.43
2	0.71	6.05	8.79	10.44	2.46	6.38
3	0.82	5.56	8.43	9.60	2.49	6.33
4	0.98	5.03	8.05	8.64	2.56	6.28
5	1.22	4.61	7.76	7.83	2.66	6.24
6	1.59	4.15	7.47	6.87	2.87	6.21
7	2.28	3.93	7.34	6.06	3.33	6.19
8	2.28	3.92	7.33	6.04	3.33	6.19
9	1.59	4.09	7.43	6.79	2.87	6.20
10	1.22	4.51	7.69	7.68	2.66	6.24
11	0.98	4.93	7.98	8.49	2.55	6.27
12	0.82	5.56	8.43	9.60	2.49	6.33
13	0.71	6.05	8.79	10.44	2.46	6.38
14	0.62	6.54	9.18	11.37	2.43	6.43

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				------- (kW/m^2K)	-------	
1	0.027	28.95	1.15	2.06	0.89	2.27
2	0.027	25.37	1.02	1.83	0.81	2.30
3	0.027	21.86	0.89	1.57	0.72	2.35
4	0.027	18.45	0.77	1.30	0.63	2.39
5	0.027	15.16	0.64	1.06	0.55	2.48
6	0.027	12.12	0.52	0.82	0.47	2.59
7	0.027	9.59	0.40	0.61	0.41	2.76
8	0.027	9.60	0.40	0.61	0.41	2.75
9	0.027	12.15	0.53	0.81	0.47	2.57
10	0.027	15.19	0.66	1.03	0.55	2.46
11	0.027	18.48	0.79	1.26	0.63	2.37
12	0.027	21.87	0.89	1.53	0.72	2.35
13	0.027	25.38	1.02	1.79	0.80	2.30
14	0.027	28.96	1.15	2.03	0.89	2.27

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF2A1.dat
Uncertainty Data File: C7MDF2A1.unc
Tube Number: 2
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 3.28%
Uncertainty in Co = 7.30%
Uncertainty in Enahncement (const DT): 7.36%
Uncertainty in Enahncement (const q) : 9.81%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	2.15	10.00	3.67	3.37	9.77
2	0.71	2.07	9.98	3.49	3.39	9.77
3	0.82	1.99	9.96	3.29	3.42	9.76
4	0.98	1.91	9.95	3.05	3.46	9.76
5	1.22	1.90	9.94	2.87	3.54	9.76
6	1.59	2.04	9.97	2.78	3.70	9.76
7	2.28	2.52	10.09	2.99	4.07	9.77
8	2.28	2.52	10.09	2.99	4.07	9.77
9	1.59	2.03	9.97	2.77	3.70	9.76
10	1.22	1.89	9.94	2.85	3.54	9.76
11	0.98	1.89	9.94	3.02	3.46	9.76
12	0.82	1.97	9.96	3.27	3.42	9.76
13	0.71	2.07	9.98	3.49	3.39	9.77
14	0.62	2.18	10.01	3.72	3.37	9.77

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.029	30.80	3.51	0.75	1.28	3.99
2	0.029	27.44	3.14	0.66	1.15	4.12
3	0.029	24.31	2.79	0.58	1.02	4.27
4	0.029	21.62	2.50	0.50	0.89	4.41
5	0.029	19.47	2.16	0.42	0.76	4.60
6	0.029	18.33	1.81	0.36	0.64	4.84
7	0.029	18.93	1.43	0.33	0.52	5.19
8	0.029	18.95	1.43	0.32	0.52	5.19
9	0.029	18.44	1.83	0.36	0.63	4.82
10	0.029	19.55	2.19	0.42	0.76	4.58
11	0.029	21.69	2.53	0.49	0.88	4.39
12	0.029	24.36	2.82	0.57	1.02	4.26
13	0.029	27.45	3.14	0.66	1.15	4.12
14	0.029	30.76	3.44	0.75	1.28	4.01

Program Name: DRPSAMUN.BAS
Raw Data File: C7MDF2A2.dat
Uncertainty Data File: C7MDF2A2.unc
Tube Number: 2
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 2.74%
Uncertainty in Co = 6.17%
Uncertainty in Enahncement (const DT): 6.24%
Uncertainty in Enahncement (const q) : 8.31%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo (%)	uHi (%)	uHoZ (%)
1	0.62	2.19	8.55	3.73	2.85	8.27
2	0.71	2.08	8.52	3.50	2.87	8.26
3	0.82	1.98	8.49	3.27	2.90	8.26
4	0.98	1.91	8.48	3.05	2.96	8.26
5	1.22	1.91	8.47	2.87	3.05	8.26
6	1.59	2.04	8.51	2.79	3.23	8.26
7	2.28	2.52	8.65	3.00	3.65	8.27
8	2.28	2.52	8.65	2.99	3.65	8.27
9	1.59	2.03	8.51	2.77	3.23	8.26
10	1.22	1.90	8.47	2.86	3.05	8.26
11	0.98	1.89	8.47	3.03	2.95	8.26
12	0.82	1.97	8.49	3.27	2.90	8.26
13	0.71	2.08	8.52	3.50	2.87	8.26
14	0.62	2.19	8.55	3.73	2.85	8.27

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo (kW/m^2K)	uHi (kW/m^2K)	uHo (kW/m^2K)
1	0.029	30.75	2.90	0.75	1.08	3.42
2	0.029	27.41	2.64	0.67	0.97	3.52
3	0.029	24.33	2.38	0.58	0.87	3.63
4	0.029	21.62	2.11	0.50	0.76	3.76
5	0.029	19.45	1.82	0.42	0.65	3.92
6	0.029	18.26	1.52	0.36	0.55	4.13
7	0.029	18.83	1.21	0.33	0.47	4.43
8	0.029	18.86	1.21	0.32	0.47	4.43
9	0.029	18.40	1.54	0.36	0.55	4.11
10	0.029	19.52	1.84	0.42	0.65	3.91
11	0.029	21.69	2.14	0.49	0.75	3.74
12	0.029	24.36	2.39	0.57	0.86	3.62
13	0.029	27.43	2.64	0.66	0.97	3.52
14	0.029	30.75	2.90	0.75	1.08	3.42

Program Name:	DRPSAMUN.BAS
Raw Data File:	C7MDF2V1.dat
Uncertainty Data File:	C7MDF2V1.unc
Tube Number:	2
Pressure Condition:	Vacuum

Assumed/Measured Uncertainties

: Conductivity (W/m-K) :	1.00
: Quartz Thermometer (C):	0.05
: Water Flowmeter (%) :	0.50
: Steam Temperature (C) :	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 2.00%
Uncertainty in Co = 2.62%
Uncertainty in Enahncement (const DT): 3.14%
Uncertainty in Enahncement (const q) : 4.18%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	8.53	9.66	14.79	2.14	4.53
2	0.71	7.70	8.84	13.37	2.17	4.36
3	0.82	7.03	8.21	12.15	2.22	4.23
4	0.98	6.22	7.44	10.72	2.28	4.09
5	1.22	5.54	6.82	9.48	2.40	3.98
6	1.59	4.85	6.21	8.14	2.63	3.88
7	2.28	4.39	5.82	6.93	3.13	3.82
8	2.28	4.39	5.82	6.93	3.13	3.82
9	1.59	4.85	6.21	8.14	2.63	3.88
10	1.22	5.46	6.75	9.34	2.40	3.97
11	0.98	6.17	7.40	10.62	2.28	4.08
12	0.82	6.96	8.14	12.07	2.22	4.22
13	0.71	7.70	8.84	13.32	2.17	4.36
14	0.62	8.53	9.66	14.79	2.14	4.53

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.029	29.65	1.40	2.13	0.77	1.08
2	0.029	25.96	1.23	1.87	0.70	1.06
3	0.029	22.34	1.05	1.62	0.63	1.05
4	0.029	18.81	0.89	1.34	0.55	1.04
5	0.029	15.38	0.72	1.09	0.49	1.05
6	0.029	12.15	0.57	0.85	0.43	1.06
7	0.029	9.38	0.43	0.62	0.38	1.11
8	0.029	9.38	0.43	0.62	0.38	1.11
9	0.029	12.16	0.57	0.84	0.43	1.06
10	0.029	15.39	0.73	1.07	0.49	1.04
11	0.029	18.81	0.89	1.31	0.55	1.03
12	0.029	22.35	1.06	1.58	0.62	1.05
13	0.029	25.97	1.23	1.86	0.70	1.06
14	0.029	29.65	1.40	2.12	0.77	1.08

```
Program Name:                         DRPSAMUN.BAS
Raw Data File:                        C7MDF2V2.dat
Uncertainty Data File:                C7MDF2V2.unc
Tube Number:                          2
Pressure Condition:                   Vacuum
```

Assumed/Measured Uncertainties

: Conductivity (W/m-K)	:	1.00
: Quartz Thermometer (C)	:	0.05
: Water Flowmeter (%)	:	0.50
: Steam Temperature (C)	:	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.70%
Uncertainty in Co = 2.09%
Uncertainty in Enahncement (const DT): 2.71%
Uncertainty in Enahncement (const q) : 3.61%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo (%)	uHi (%)	uHoZ (%)
1	0.62	8.53	9.43	14.85	1.86	4.01
2	0.71	7.86	8.76	13.62	1.89	3.85
3	0.82	7.10	8.00	12.31	1.94	3.68
4	0.98	6.27	7.19	10.84	2.02	3.51
5	1.22	5.58	6.53	9.55	2.15	3.38
6	1.59	4.88	5.87	8.21	2.40	3.26
7	2.28	4.40	5.43	6.97	2.94	3.18
8	2.28	4.40	5.43	6.97	2.94	3.18
9	1.59	4.85	5.84	8.12	2.40	3.25
10	1.22	5.46	6.41	9.36	2.15	3.36
11	0.98	6.22	7.14	10.75	2.02	3.50
12	0.82	7.03	7.93	12.19	1.94	3.67
13	0.71	7.78	8.67	13.52	1.89	3.83
14	0.62	8.74	9.64	15.09	1.86	4.06

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo (kW/m^2K)	uHi (kW/m^2K)	uHo (kW/m^2K)
1	0.029	29.65	1.42	2.12	0.69	0.92
2	0.029	25.96	1.23	1.88	0.62	0.91
3	0.029	22.33	1.05	1.62	0.56	0.88
4	0.029	18.80	0.88	1.34	0.50	0.86
5	0.029	15.37	0.71	1.10	0.45	0.86
6	0.029	12.14	0.55	0.85	0.40	0.86
7	0.029	9.37	0.41	0.62	0.36	0.89
8	0.029	9.37	0.41	0.62	0.36	0.89
9	0.029	12.15	0.56	0.85	0.40	0.86
10	0.029	15.39	0.72	1.07	0.45	0.84
11	0.029	18.81	0.88	1.31	0.50	0.85
12	0.029	22.34	1.05	1.59	0.56	0.88
13	0.029	25.96	1.24	1.85	0.62	0.90
14	0.029	29.65	1.41	2.14	0.68	0.94

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1A1.dat
Uncertainty Data File: K6MD1A1.unc
Tube Number: 1
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C) : 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 2.66%
Uncertainty in Co = 3.46%
Uncertainty in Enahncement (const DT): 3.58%
Uncertainty in Enahncement (const q) : 4.77%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo (%)	uHi (%)	uHoZ (%)
1	0.62	3.80	6.12	6.55	2.76	4.79
2	0.71	3.43	5.87	5.90	2.79	4.76
3	0.82	3.08	5.65	5.24	2.82	4.74
4	0.98	2.76	5.46	4.60	2.88	4.71
5	1.22	2.49	5.31	3.98	2.97	4.70
6	1.59	2.39	5.26	3.51	3.15	4.69
7	2.28	2.66	5.40	3.33	3.58	4.71
8	2.28	2.66	5.40	3.32	3.58	4.71
9	1.59	2.37	5.26	3.48	3.15	4.69
10	1.22	2.48	5.31	3.97	2.97	4.70
11	0.98	2.71	5.44	4.51	2.87	4.71
12	0.82	3.05	5.63	5.17	2.82	4.73
13	0.71	3.42	5.86	5.86	2.79	4.76
14	0.62	3.78	6.10	6.51	2.76	4.79

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo (kW/m^2K)	uHi (kW/m^2K)	uHo (kW/m^2K)
1	0.024	24.26	1.25	0.55	1.50	1.50
2	0.024	21.38	1.16	0.48	1.36	1.50
3	0.024	18.63	1.07	0.42	1.21	1.51
4	0.024	16.09	0.98	0.36	1.06	1.53
5	0.024	13.92	0.90	0.30	0.92	1.55
6	0.024	12.47	0.81	0.24	0.78	1.58
7	0.024	12.64	0.73	0.21	0.66	1.65
8	0.024	12.66	0.74	0.21	0.66	1.65
9	0.024	12.53	0.82	0.24	0.78	1.58
10	0.024	13.94	0.91	0.29	0.91	1.54
11	0.024	16.13	1.01	0.35	1.05	1.51
12	0.024	18.65	1.08	0.42	1.20	1.50
13	0.024	21.39	1.16	0.48	1.35	1.50
14	0.024	24.26	1.26	0.55	1.50	1.50

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1A2.dat
Uncertainty Data File: K6MD1A2.unc
Tube Number: 1
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 2.39%
Uncertainty in Co = 3.51%
Uncertainty in Enahncement (const DT): 3.63%
Uncertainty in Enahncement (const q) : 4.84%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	3.72	6.12	6.41	2.51	4.86
2	0.71	3.39	5.90	5.82	2.53	4.83
3	0.82	3.03	5.68	5.15	2.57	4.80
4	0.98	2.71	5.50	4.52	2.63	4.78
5	1.22	2.46	5.36	3.93	2.73	4.76
6	1.59	2.37	5.31	3.47	2.93	4.76
7	2.28	2.65	5.46	3.31	3.39	4.77
8	2.28	2.65	5.46	3.31	3.39	4.77
9	1.59	2.35	5.31	3.44	2.93	4.76
10	1.22	2.45	5.36	3.92	2.73	4.76
11	0.98	2.69	5.48	4.47	2.63	4.78
12	0.82	3.00	5.66	5.09	2.57	4.80
13	0.71	3.34	5.87	5.73	2.53	4.82
14	0.62	3.72	6.12	6.41	2.51	4.86

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.024	24.27	1.16	0.55	1.33	1.67
2	0.024	21.39	1.07	0.48	1.21	1.68
3	0.024	18.65	0.99	0.42	1.08	1.69
4	0.024	16.12	0.92	0.36	0.95	1.70
5	0.024	13.98	0.84	0.30	0.83	1.73
6	0.024	12.55	0.76	0.24	0.71	1.77
7	0.024	12.73	0.68	0.21	0.61	1.84
8	0.024	12.73	0.68	0.21	0.61	1.84
9	0.024	12.61	0.77	0.24	0.71	1.77
10	0.024	13.99	0.84	0.29	0.82	1.73
11	0.024	16.15	0.93	0.35	0.94	1.70
12	0.024	18.68	1.01	0.42	1.07	1.68
13	0.024	21.41	1.08	0.48	1.20	1.67
14	0.024	24.27	1.16	0.55	1.33	1.67

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1A3.dat
Uncertainty Data File: K6MD1A3.unc
Tube Number: 1
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C) : 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 1.74%
Uncertainty in Co = 2.90%
Uncertainty in Enahncement (const DT): 3.04%
Uncertainty in Enahncement (const q) : 4.06%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	3.76	5.55	6.49	1.90	4.08
2	0.71	3.42	5.30	5.86	1.93	4.05
3	0.82	3.06	5.04	5.20	1.98	4.01
4	0.98	2.72	4.83	4.54	2.06	3.99
5	1.22	2.49	4.68	3.99	2.19	3.97
6	1.59	2.39	4.63	3.52	2.43	3.96
7	2.28	2.67	4.79	3.36	2.97	3.98
8	2.28	2.67	4.79	3.36	2.97	3.98
9	1.59	2.39	4.63	3.52	2.43	3.96
10	1.22	2.48	4.68	3.96	2.19	3.97
11	0.98	2.72	4.83	4.54	2.06	3.99
12	0.82	3.05	5.04	5.17	1.98	4.01
13	0.71	3.40	5.28	5.83	1.93	4.04
14	0.62	3.76	5.55	6.48	1.90	4.08

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.024	24.24	0.94	0.56	0.98	1.54
2	0.024	21.36	0.86	0.50	0.89	1.55
3	0.024	18.62	0.79	0.43	0.81	1.55
4	0.024	16.10	0.73	0.37	0.72	1.56
5	0.024	13.91	0.66	0.30	0.64	1.59
6	0.024	12.44	0.59	0.25	0.57	1.63
7	0.024	12.45	0.52	0.22	0.52	1.70
8	0.024	12.48	0.53	0.22	0.52	1.70
9	0.024	12.43	0.58	0.25	0.57	1.63
10	0.024	13.93	0.66	0.30	0.64	1.58
11	0.024	16.10	0.73	0.36	0.72	1.56
12	0.024	18.63	0.80	0.43	0.80	1.55
13	0.024	21.37	0.87	0.50	0.89	1.55
14	0.024	24.24	0.94	0.57	0.98	1.55

Program Name:	DRPSAMUN.BAS
Raw Data File:	K6MD1V1.dat
Uncertainty Data File:	K6MD1V1.unc
Tube Number:	1
Pressure Condition:	Vacuum

Assumed/Measured Uncertainties

: Conductivity (W/m-K)	:	1.00
: Quartz Thermometer (C)	:	0.05
: Water Flowmeter (%)	:	0.50
: Steam Temperature (C)	:	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 3.54%
Uncertainty in Co = 5.07%
Uncertainty in Enahncement (const DT): 5.36%
Uncertainty in Enahncement (const q) : 7.14%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	10.96	13.39	18.98	3.62	7.70
2	0.71	9.79	12.34	16.94	3.63	7.52
3	0.82	8.65	11.36	15.01	3.66	7.36
4	0.98	7.45	10.37	12.85	3.70	7.22
5	1.22	6.36	9.53	10.91	3.78	7.10
6	1.59	5.38	8.84	9.07	3.92	7.01
7	2.28	4.58	8.32	7.29	4.28	6.95
8	2.28	4.58	8.32	7.29	4.28	6.95
9	1.59	5.38	8.84	9.05	3.92	7.01
10	1.22	6.31	9.49	10.79	3.78	7.09
11	0.98	7.30	10.25	12.55	3.70	7.20
12	0.82	8.44	11.18	14.54	3.66	7.34
13	0.71	9.52	12.11	16.48	3.63	7.48
14	0.62	10.79	13.24	18.69	3.62	7.67

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.024	24.00	0.98	1.52	1.72	2.31
2	0.024	21.00	0.88	1.33	1.55	2.27
3	0.024	18.06	0.78	1.14	1.37	2.25
4	0.024	15.18	0.69	0.95	1.19	2.22
5	0.024	12.38	0.59	0.77	1.01	2.22
6	0.024	9.74	0.50	0.60	0.84	2.26
7	0.024	7.48	0.41	0.43	0.68	2.32
8	0.024	7.48	0.41	0.43	0.68	2.32
9	0.024	9.74	0.50	0.59	0.84	2.25
10	0.024	12.39	0.60	0.76	1.01	2.22
11	0.024	15.19	0.70	0.94	1.18	2.20
12	0.024	18.07	0.79	1.13	1.36	2.22
13	0.024	21.01	0.89	1.32	1.54	2.24
14	0.024	24.01	0.99	1.50	1.72	2.29

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1V2.dat
Uncertainty Data File: K6MD1V2.unc
Tube Number: 1
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 3.18%
Uncertainty in Co = 5.37%
Uncertainty in Enahncement (const DT): 5.64%
Uncertainty in Enahncement (const q) : 7.52%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	11.31	13.91	19.59	3.27	8.11
2	0.71	10.21	12.93	17.67	3.29	7.94
3	0.82	9.08	11.97	15.71	3.31	7.79
4	0.98	7.77	10.89	13.46	3.36	7.63
5	1.22	6.65	10.03	11.41	3.44	7.51
6	1.59	5.68	9.35	9.62	3.60	7.42
7	2.28	4.81	8.79	7.73	3.98	7.35
8	2.28	4.81	8.79	7.73	3.98	7.35
9	1.59	5.60	9.30	9.45	3.60	7.42
10	1.22	6.59	9.99	11.27	3.44	7.50
11	0.98	7.53	10.70	13.03	3.36	7.60
12	0.82	8.86	11.78	15.39	3.31	7.76
13	0.71	10.06	12.81	17.50	3.28	7.92
14	0.62	11.13	13.76	19.28	3.27	8.08

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.024	23.97	0.85	1.64	1.53	2.80
2	0.024	20.98	0.76	1.44	1.37	2.78
3	0.024	18.03	0.67	1.24	1.22	2.76
4	0.024	15.15	0.60	1.01	1.06	2.72
5	0.024	12.35	0.51	0.83	0.90	2.72
6	0.024	9.68	0.43	0.64	0.76	2.78
7	0.024	7.36	0.35	0.47	0.62	2.86
8	0.024	7.36	0.35	0.47	0.62	2.86
9	0.024	9.69	0.43	0.64	0.76	2.76
10	0.024	12.36	0.52	0.82	0.90	2.71
11	0.024	15.16	0.61	1.00	1.05	2.68
12	0.024	18.04	0.68	1.21	1.21	2.72
13	0.024	20.98	0.77	1.41	1.37	2.75
14	0.024	23.98	0.86	1.63	1.52	2.77

Program Name: DRPSAMUN.BAS
Raw Data File: K6MD1V3.dat
Uncertainty Data File: K6MD1V3.unc
Tube Number: 1
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0004656

Uncertainty in Ci = 2.12%
Uncertainty in Co = 3.37%
Uncertainty in Enahncement (const DT): 3.79%
Uncertainty in Enahncement (const q) : 5.05%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	11.13	12.58	19.39	2.25	5.85
2	0.71	10.06	11.53	17.42	2.28	5.63
3	0.82	8.97	10.48	15.52	2.32	5.42
4	0.98	7.69	9.28	13.27	2.39	5.20
5	1.22	6.59	8.29	11.31	2.50	5.03
6	1.59	5.57	7.41	9.41	2.72	4.89
7	2.28	4.77	6.76	7.63	3.21	4.79
8	2.28	4.75	6.74	7.62	3.21	4.79
9	1.59	5.53	7.38	9.34	2.72	4.88
10	1.22	6.47	8.19	11.11	2.50	5.01
11	0.98	7.53	9.13	13.03	2.38	5.17
12	0.82	8.86	10.38	15.26	2.32	5.40
13	0.71	9.92	11.39	17.18	2.28	5.60
14	0.62	10.96	12.41	18.98	2.25	5.81

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.024	23.98	0.82	1.60	1.07	1.94
2	0.024	20.98	0.72	1.42	0.97	1.89
3	0.024	18.04	0.62	1.22	0.87	1.84
4	0.024	15.16	0.53	1.01	0.77	1.78
5	0.024	12.36	0.45	0.82	0.67	1.75
6	0.024	9.70	0.36	0.63	0.58	1.75
7	0.024	7.39	0.28	0.46	0.51	1.79
8	0.024	7.40	0.28	0.46	0.51	1.79
9	0.024	9.71	0.36	0.63	0.58	1.75
10	0.024	12.37	0.45	0.81	0.67	1.74
11	0.024	15.17	0.54	0.98	0.76	1.76
12	0.024	18.04	0.62	1.21	0.86	1.83
13	0.024	20.99	0.72	1.39	0.97	1.87
14	0.024	23.99	0.82	1.59	1.07	1.92

Program Name:	DRPSAMUN.BAS
Raw Data File:	C3MD11A.dat
Uncertainty Data File:	C3MD11A.unc
Tube Number:	1
Pressure Condition:	Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 2.01%
Uncertainty in Co = 14.82%
Uncertainty in Enahncement (const DT): 14.85%
Uncertainty in Enahncement (const q) : 19.80%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	1.36	19.82	2.28	2.16	19.77
2	0.71	1.36	19.82	2.22	2.19	19.77
3	0.82	1.38	19.82	2.17	2.23	19.77
4	0.98	1.43	19.82	2.13	2.30	19.77
5	1.22	1.55	19.83	2.15	2.42	19.77
6	1.59	1.82	19.86	2.28	2.64	19.78
7	2.28	2.41	19.93	2.71	3.14	19.78
8	2.28	2.41	19.93	2.70	3.14	19.78
9	1.59	1.82	19.86	2.27	2.64	19.78
10	1.22	1.54	19.83	2.12	2.41	19.77
11	0.98	1.41	19.82	2.09	2.30	19.77
12	0.82	1.35	19.82	2.11	2.23	19.77
13	0.71	1.35	19.82	2.19	2.19	19.77
14	0.62	1.36	19.82	2.26	2.16	19.77

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.027	32.20	3.06	0.80	0.98	30.28
2	0.027	29.37	2.70	0.71	0.89	31.31
3	0.027	26.86	2.35	0.63	0.80	32.50
4	0.027	24.92	2.03	0.55	0.70	33.82
5	0.027	23.53	1.67	0.47	0.62	35.59
6	0.027	23.02	1.31	0.42	0.54	37.94
7	0.027	24.34	0.97	0.40	0.47	41.06
8	0.027	24.42	0.98	0.40	0.47	40.99
9	0.027	23.22	1.33	0.41	0.53	37.80
10	0.027	23.86	1.72	0.46	0.60	35.31
11	0.027	25.21	2.09	0.53	0.69	33.55
12	0.027	27.20	2.45	0.61	0.78	32.14
13	0.027	29.51	2.75	0.69	0.88	31.15
14	0.027	32.26	3.08	0.78	0.97	30.21

Program Name:	DRPSAMUN.BAS
Raw Data File:	A1OF7V1.dat
Uncertainty Data File:	A1OF7V1.unc
Tube Number:	7
Pressure Condition:	Vacuum

Assumed/Measured Uncertainties

: Conductivity (W/m-K) :	1.00
: Quartz Thermometer (C):	0.05
: Water Flowmeter (%) :	0.50
: Steam Temperature (C) :	0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000016

Uncertainty in Ci = 3.13%
Uncertainty in Co = 1.76%
Uncertainty in Enahncement (const DT): 2.47%
Uncertainty in Enahncement (const q) : 3.29%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi (%)	uHoZ
1	0.62	13.05	13.96	22.60	3.22	4.97
2	0.71	11.72	12.59	20.30	3.24	4.58
3	0.82	10.37	11.19	17.94	3.27	4.21
4	0.98	8.87	9.65	15.32	3.32	3.81
5	1.22	7.55	8.31	12.99	3.40	3.48
6	1.59	6.33	7.09	10.76	3.56	3.19
7	2.28	5.24	6.03	8.53	3.95	2.97
8	2.28	5.24	6.03	8.53	3.95	2.97
9	1.59	6.28	7.04	10.70	3.56	3.18
10	1.22	7.47	8.23	12.90	3.40	3.46
11	0.98	8.66	9.43	15.01	3.32	3.75
12	0.82	10.22	11.04	17.77	3.27	4.17
13	0.71	11.53	12.39	19.97	3.24	4.53
14	0.62	13.05	13.96	22.60	3.22	4.97

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi (kW/m^2K)	uHo
1	0.028	29.22	2.89	1.88	1.21	0.54
2	0.028	25.56	2.50	1.66	1.08	0.50
3	0.028	21.96	2.13	1.43	0.96	0.47
4	0.028	18.44	1.79	1.18	0.84	0.43
5	0.028	15.00	1.44	0.96	0.72	0.40
6	0.028	11.71	1.11	0.74	0.60	0.38
7	0.028	8.78	0.82	0.53	0.49	0.37
8	0.028	8.78	0.82	0.53	0.49	0.37
9	0.028	11.71	1.11	0.73	0.60	0.38
10	0.028	15.01	1.45	0.94	0.71	0.39
11	0.028	18.45	1.81	1.15	0.83	0.42
12	0.028	21.97	2.15	1.38	0.96	0.46
13	0.028	25.57	2.53	1.62	1.08	0.49
14	0.028	29.23	2.89	1.86	1.20	0.54

Program Name: DRPSAMUN.BAS
Raw Data File: A1OF2A2.dat
Uncertainty Data File: A1OF2A2.unc
Tube Number: 2
Pressure Condition: Atmospheric

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.40

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000016

Uncertainty in Ci = 1.81%
Uncertainty in Co = 1.07%
Uncertainty in Enahncement (const DT): 1.41%
Uncertainty in Enahncement (const q) : 1.88%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	5.08	5.56	8.77	1.96	2.26
2	0.71	4.58	5.05	7.87	2.00	2.14
3	0.82	4.05	4.52	6.94	2.04	2.01
4	0.98	3.52	4.00	5.96	2.12	1.90
5	1.22	3.11	3.60	5.14	2.24	1.81
6	1.59	2.84	3.34	4.40	2.48	1.76
7	2.28	2.91	3.41	3.91	3.01	1.77
8	2.28	2.91	3.40	3.91	3.01	1.77
9	1.59	2.83	3.33	4.38	2.48	1.76
10	1.22	3.10	3.59	5.12	2.24	1.81
11	0.98	3.52	4.00	5.96	2.11	1.90
12	0.82	4.01	4.48	6.85	2.04	2.00
13	0.71	4.52	4.99	7.78	1.99	2.12
14	0.62	5.04	5.52	8.71	1.96	2.25

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.028	29.38	3.21	0.67	0.66	0.23
2	0.028	25.80	2.79	0.59	0.60	0.22
3	0.028	22.34	2.42	0.51	0.54	0.21
4	0.028	19.07	2.07	0.42	0.48	0.20
5	0.028	16.07	1.73	0.35	0.42	0.19
6	0.028	13.68	1.44	0.28	0.38	0.20
7	0.028	12.71	1.27	0.23	0.34	0.21
8	0.028	12.73	1.27	0.23	0.34	0.21
9	0.028	13.70	1.45	0.28	0.37	0.20
10	0.028	16.09	1.74	0.35	0.42	0.19
11	0.028	19.08	2.08	0.42	0.47	0.20
12	0.028	22.36	2.44	0.50	0.53	0.21
13	0.028	25.82	2.82	0.58	0.59	0.21
14	0.028	29.40	3.23	0.66	0.65	0.22

Program Name: DRPSAMUN.BAS
Raw Data File: C3MD1V1.dat
Uncertainty Data File: C3MD1V1.unc
Tube Number: 1
Pressure Condition: Vacuum

Assumed/Measured Uncertainties
: Conductivity (W/m-K) : 1.00
: Quartz Thermometer (C): 0.05
: Water Flowmeter (%) : 0.50
: Steam Temperature (C) : 0.20

Uncertainty in Wall Resistance, uRw (m/W/m-K): 0.0000004

Uncertainty in Ci = 1.66%
Uncertainty in Co = 4.91%
Uncertainty in Enahncement (const DT): 5.21%
Uncertainty in Enahncement (const q) : 6.94%

Data #	uVcw (%)	uQflux (%)	uDTwo (%)	uUo	uHi	uHoZ
				---------(%)-----------		
1	0.62	5.03	8.44	8.68	1.82	6.78
2	0.71	4.69	8.22	8.08	1.86	6.75
3	0.82	4.32	7.99	7.45	1.91	6.72
4	0.98	4.00	7.80	6.83	1.99	6.70
5	1.22	3.72	7.65	6.26	2.12	6.68
6	1.59	3.48	7.52	5.65	2.37	6.67
7	2.28	3.51	7.54	5.21	2.92	6.67
8	2.28	3.51	7.54	5.20	2.92	6.67
9	1.59	3.46	7.51	5.60	2.37	6.67
10	1.22	3.66	7.62	6.15	2.12	6.68
11	0.98	3.92	7.76	6.69	1.98	6.70
12	0.82	4.32	7.99	7.46	1.90	6.72
13	0.71	4.63	8.18	7.99	1.85	6.75
14	0.62	5.07	8.47	8.78	1.82	6.78

Data #	uVcw (m/s)	uQflux (kW/m^2)	uDTwo (C)	uUo	uHi	uHo
				-------(kW/m^2K)-------		
1	0.027	29.06	0.88	2.00	0.71	3.76
2	0.027	25.51	0.79	1.75	0.64	3.83
3	0.027	22.04	0.70	1.51	0.58	3.92
4	0.027	18.68	0.60	1.26	0.52	4.04
5	0.027	15.48	0.51	1.02	0.46	4.21
6	0.027	12.59	0.41	0.80	0.41	4.42
7	0.027	10.29	0.31	0.59	0.38	4.77
8	0.027	10.29	0.31	0.59	0.38	4.77
9	0.027	12.62	0.41	0.78	0.41	4.41
10	0.027	15.52	0.52	0.99	0.46	4.17
11	0.027	18.72	0.62	1.21	0.51	4.00
12	0.027	22.05	0.70	1.46	0.58	3.92
13	0.027	25.52	0.80	1.71	0.64	3.81
14	0.027	29.06	0.87	1.95	0.71	3.77

```
'
'Program for data acquisition, reduction and processing for
SINGLE tube condensation experimental setup.
'
' Created by Ashok K. Das. Date: April, 1995.
'
'Please save a copy of this program before running or making
any
changes (required or accidental)  in this program.
'You can do this at the DOS prompt by COPY command, or from
within
'QBasic by File/SaveAs command.
'
' To run the program:
'
'         1. Simply press the key F5 or <Shift>F5
'         2. Select Run/Start from the menu.
'
' This program is tailored for SAM organic coated plain
tubes. For other tubes, the program must be modified.
However, the modification will be required mostly for input
and output data. For data acquisition and processing, only
the inside and end outside dia are required, which will
remain the same for all tubes.
'
'
'
DECLARE FUNCTION uhfgw! (T!, uT!)
DECLARE FUNCTION Cpw! (temp!)
DECLARE FUNCTION ftanh! (x!)
DECLARE FUNCTION FTCgen! (Emf!)
DECLARE FUNCTION FTfric! (Vcw!)
DECLARE FUNCTION hfgw! (temp!)
DECLARE FUNCTION kfw! (temp!)
DECLARE FUNCTION mufw! (temp!)
DECLARE FUNCTION rhofw! (temp!)
DECLARE FUNCTION rhogw! (temp!)
DECLARE FUNCTION psw! (temp!)
DECLARE FUNCTION sigmaw! (temp!)
DECLARE FUNCTION uCpw! (T!, uT!)
DECLARE FUNCTION urhofw! (T!, uT!)
DECLARE FUNCTION umufw! (T!, uT!)
DECLARE FUNCTION ukfw! (T!, uT!)
DECLARE FUNCTION uFTfric! (Vcw!, uVcw!)
DECLARE SUB CheckSensor ()
DECLARE SUB FWAIT (sec!)
DECLARE SUB MergeData ()
DECLARE SUB PROCESS ()
DECLARE SUB RawData ()
DECLARE SUB SENSOR ()
DECLARE SUB TakeData ()
```

```
'****************************************
COMMON SHARED Ipc, Itb, Patm, kt!
COMMON SHARED TC1!, TC2!, TQ1!, TQ2!, DTQ!, Tstm1!,
Tstm2!, Trm!, Pxdcr!, Volts!, Amps!
CLS
PRINT "If taking data or operating sensors"
INPUT "Enter atmospheric pressure (in Hg)"; Patm
IF Patm = 0 THEN
     PRINT
     PRINT "Atm Press set to 30.06 in Hg"
     PRINT
     Patm = 30.06
END IF
Patm = Patm / 2.041795  'convert to psi
PRINT "Atm. Pressure in psi is", Patm
INPUT "Press ENTER to continue.", Ok
DO
     CLS
     DO
          BEEP
          PRINT " Select Option"
          PRINT "     0 Exit Program"
          PRINT "     1 Check Remote Sensors"
          PRINT "     2 Take Data"
          PRINT "     3 Print Raw Data"
          PRINT "     4 Process Data"
          PRINT "     5 Merge Data"
          PRINT
          INPUT " Option"; Iopt
          IF Iopt < 0 OR Iopt > 5 THEN
               BEEP
               PRINT "  Invalid Option. Please select
again."
          END IF
     LOOP WHILE Iopt < 0 OR Iopt > 5
     '
     SELECT CASE Iopt
          CASE 0
               PRINT "Exiting Program!"

          CASE 1
               CALL CheckSensor

          CASE 2
               CALL TakeData

          CASE 3
               CALL RawData

          CASE 4
               CALL PROCESS
```

```
                CASE 5
                     CALL MergeData

          END SELECT
     LOOP WHILE Iopt > 0
END

SUB CheckSensor                ' Check Sensors...

                    CLS
                    BEEP
                    PRINT " Select Approximate Temperature
Range"
                    PRINT "     0 for 16-25 deg C"
                    PRINT "     1 for 48-51 deg C"
                    PRINT "     2 for 98-102 deg C"
                    PRINT "     3 for Other "
                    PRINT
                    INPUT " Range"; Ipc
                    '
                    ' Call subroutine SENSOR to read the data
from HP 3794A and
                    ' the HP 2804A Quartz Thermometer
                    '
                    CALL SENSOR
                    '
                    PRINT
                    PRINT "TC1, TC2, DTC =", TC1, TC2, TC2 -
TC1
                    PRINT "TQ1, TQ2, DTQ =", TQ1, TQ2, DTQ
                    PRINT "Tstm1, Tstm2, Troom =", Tstm1,
Tstm2, Trm
                    PRINT "Pxdcr (psi), Volts, Amps =", Pxdcr
/ 6.89473, Volts, Amps
                    PRINT
                    PRINT
                    INPUT "Press ENTER to continue.", Ok
                    CLS
END SUB

FUNCTION Cpw (temp)
          DIM poly(10)
'
' By curve fit between 10 and 100 C
'
' Cp in J/kg-K
'
          poly(0) = -.000000048411511#
          poly(1) = 1.529196E-06
          poly(2) = -.0018467209#
```

```
        poly(3) = .1145064#
        poly(4) = -3.431451
        poly(5) = 4216.853
        Cp = poly(0)
        FOR i = 1 TO 5
             Cp = Cp * temp + poly(i)
        NEXT i
'    RETURN Cp
        Cpw = Cp
END FUNCTION
```

FUNCTION ftanh (x)

```
     'ex1 = EXP(x)
     ex1! = 1!
     ex2! = EXP(-2 * x)
     'ex2 = EXP(-x)
     ftanh = (ex1 - ex2) / (ex1 + ex2)
     'ftanh = tanh
     'PRINT "x,ftanh =", x, tanh
END FUNCTION
```

FUNCTION FTCgen (Emf)

```
     DIM coef(5)
     coef(0) = 25.661297#
     coef(1) = -.61954869#
     coef(2) = .022181644#
     coef(3) = -3.55009E-04
     Tc = 0
     FOR i = 1 TO 4
          Tc = Tc + coef(i - 1) * Emf ^ i
     NEXT i
'   RETURN Tc
     FTCgen = Tc
END FUNCTION
```

FUNCTION FTfric (Vcw)

```
          FTfric = .0024669874# * Vcw ^ 2 - .00066467689# *
Vcw - 5.010371E-04
END FUNCTION
```

SUB FWAIT (sec!)

```
'
' subroutine to make the computer wait for 'sec' seconds
'
     TIMER ON
     startime = TIMER
     elapsedtime = TIMER
     WHILE elapsedtime < sec
          elapsedtime = TIMER - starttime
     WEND
END SUB
```

```
FUNCTION hfgw (temp)
'
'     hfg in kJ/kg = 1000 J/kg = 1000 N-m/kg
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'   VariX    VariY     R^2    RegDOF  RgSmSq   ErrDOF  ErSmSq
' 791.667 4709.589  100.00   5.00  84772.60   13.00 0.72e-02
'
          DIM poly(10)
'
          poly(5) = 2500.5197#
          poly(4) = -2.3700473#
          poly(3) = .0010148364#
          poly(2) = -.000030487402#
          poly(1) = .00000023213696#
          poly(0) = -9.6917486D-10
'
          hfg = poly(0)
          FOR i = 1 TO 5
               hfg = poly(i) + hfg * temp
          NEXT i
'
'     hfg in J/kg = N-m/kg
'
          hfg = hfg * 1000#
'       RETURN hfg
          hfgw = hfg
END FUNCTION

FUNCTION kfw (temp)
'
'NIST Conductivity in Watt/m-K for liquid water at saturation
pressure
'
'Data obtained by curve fitting between 10 and 100 C from
NIST databook
'
'   VariX    VariY     R^2    RegDOF  RgSmSq    ErrDOF  ErSmSq
' 916.667 1160.223  100.00   5.00  10442.00  0.40e+01 0.65e-
03
'
          DIM poly(10)
          poly(5) = 561.03333#
          poly(4) = 1.8883438#
          poly(3) = .0030282634#
          poly(2) = -.00023712121#
          poly(1) = .0000018735431#
          poly(0) = -.0000000051282051#
```

```
'
'   conductivity in mWatt/m-K
'
          kf = poly(0)
          FOR i = 1 TO 5
               kf = kf * temp + poly(i)
          NEXT i
'
'     convert to Watt/m-K
'
          kfw = kf * .001#
END FUNCTION
```

SUB MergeData

```
     PRINT "Enter the name of the first  file to merge",
Ifn1$
     PRINT "Enter the name of the second file to merge",
Ifn2$
END SUB
```

FUNCTION mufw (temp)

```
'
' NIST Viscosity for liquid water at saturation pressure
'
'Data obtained by curve fitting between 10 and 100 C from
NIST databook NBS/NRC Steam Table, pp. 263 & 267
'
'    R^2       ErrDOF    ErSmSq
'  100.00     0.10e+01  0.14e-01
'
          DIM poly(10)
          poly(8) = 1800.19#
          poly(7) = -63.745948#
          poly(6) = 1.8275094#
          poly(5) = -.04512923#
          poly(4) = .0008736755#
          poly(3) = -.000011878223#
          poly(2) = .00000010329146#
          poly(1) = -5.0954132D-10
          poly(0) = 1.078869D-12
'
'   viscosity in 1d-6 kg/m-s
'
          muf = poly(0)
          FOR i = 1 TO 8
               muf = temp * muf + poly(i)
          NEXT i
'
'  convert to kg/m-s
```

```
'
          mufw = muf * .000001#
END FUNCTION
```

SUB PROCESS

```
'
' Program to process data using Modified Wilson Plot
Technique
'
     DIM DTQ!(50), LMTD!(50), kc!(50), Omega!(50),
Qflux!(50), Tstm!(50)
     DIM Uo!(50), Vcw!(50), x!(50), y!(50), ukc!(50),
uOmega!(50)
     DIM uQflux!(50), uUo!(50), uVcw!(50), DTwo!(50),
uDTwo!(50)
     DIM Hi!(50), uHi!(50), Ho!(50), uHo!(50), HoZ!(50),
uHoZ!(50)
     CLS
          BEEP
          INPUT "Enter data file name to process (no
extensions)"; name$
          INPUT "Enter number of data points in this file";
Nrun
          namedat$ = name$ + ".dat"
          nameres$ = name$ + ".res"
          namehqt$ = name$ + ".hqt"
          namewxy$ = name$ + ".wxy"
          nameunc$ = name$ + ".unc"

OPEN namedat$ FOR INPUT AS #5       'Input data file..
OPEN nameres$ FOR OUTPUT AS #6      'Processed data file..
OPEN namehqt$ FOR OUTPUT AS #7      'Ho & Q vs DTwo is stored
in this file
OPEN namewxy$ FOR OUTPUT AS #9      'Wilson Plot X,Y data is
in this file
OPEN nameunc$ FOR OUTPUT AS #1      'Uncertainty data file..

          PRINT #6,
          PRINT #6,
PRINT #6, "       Program Name:                  DRPSAM.BAS"
PRINT #6, "       Raw Data File:                 "; namedat$
PRINT #6, "       Processed Data File:           "; nameres$

          PRINT #1,
          PRINT #1,
PRINT #1, "       Program Name:                  DRPSAM.BAS"
PRINT #1, "       Raw Data File:                 "; namedat$
PRINT #1, "       Uncertainty Data File:         "; nameunc$

          INPUT #5, Itb, kt!, Ipc
          INPUT #5, Di!, Dr!
```

```
PRINT #6, "        Tube Number:                                    "; Itb
PRINT #1, "        Tube Number:                                    "; Itb
          SELECT CASE Ipc
               CASE 1
PRINT #6, "        Pressure Condition:                              Vacuum"
PRINT #1, "        Pressure Condition:                              Vacuum"
               CASE 2
PRINT #6, "        Pressure Condition:
Atmospheric"
PRINT #1, "        Pressure Condition:
Atmospheric"
          END SELECT
          PRINT #6,
PRINT #6, USING "       Thermal Conductivity (W/m-K):
###.##";t!
PRINT #6, USING "       Tube Inside Diameter (mm):
###.##"; Di
PRINT #6, USING "       Tube Outside Diameter (mm):
###.##"; Dr
          '
          ' Initialize geometry and constants
          '
          Di = Di / 1000!              'Convert from mm to m
          Dr = Dr / 1000!
          pi# = 3.141592656#
L! = .13335                   'Active tube length 5 1/4 inch
L1! = .060325                 'Inlet end length 2 3/8 inch
L2! = .034925                 'Exit end length 1 3/8 inch
Dout! = 5 / 8 * .0254         'Tube end outside diameter = 5/8
inch X 0.0254 m/inch
Dc! = .1524                   'Condenser tube inside diameter
(m)
          '
          ' Initialize the instrument errors
          '
          uTqrtz = .05
          ukt = 1!
          ufm = .5

          PRINT #1,
          PRINT #1, "     Assumed/Measured Uncertainties";
          PRINT #1,
PRINT #1, USING "            : Conductivity (W/m-K)   :
###.##"; ukt!
PRINT #1, USING "            : Quartz Thermometer (C):
###.##"; uTqrtz
PRINT #1, USING "            : Water Flowmeter (%)    :
###.##"; ufm
          'Compute Geometrical Parameters
          '
```

```
Perim! = pi# * Di           'Perimeter over which convective
cooling take place
AreaX! = .25 * pi# * (Dout + Di) * (Dout - Di)  'X-sec area
for fin efficiency at the ends
'AreaX! = .25 * PI# * (Dr + Di) * (Dr - Di)
AreaCorr# = 9.18214E-06     'Area correction for Heatex
insert
          '
          'PRINT "Di, Dr, Dout =", Di, Dr, Dout
          'PRINT "PI, Di, L, kt", PI#, Di, L, kt
          'INPUT "Press ENTER to continue.", Ok
          '
          ' Initialize Ci and Co. Set CoSmooth and Qloss
          ' Initialize Uncertainties
          '
          SELECT CASE Ipc
               CASE 1      'Vacumm Condition
                    Cofilm! = .817
                    Qloss! = 125
                    Ci! = 2.5
                    Co! = 2!
          ' Uncertainties
                    ucofilm = .0141
                    uTstm! = .2

               CASE 2      'Atmospheric Condition
                    Cofilm! = .827
                    Qloss! = 348!
                    Ci! = 3!
                    Co! = 3!
          ' Uncertainties
                    ucofilm = .0076
                    uTstm! = .4

          END SELECT
PRINT #1, USING "             : Steam Temperature (C) :
###.##"; uTstm
          PRINT #1,
          'Compute Wall Resistance and uncertainty
          '
Rw! = LOG(Dr / Di) / (2 * pi# * L! * kt)   'Tube wall
resistance
          rkt! = ukt / kt
          uRw! = Rw * rkt
PRINT #6, USING "       Wall Resistance, Rw (m/W/m-K):
##.#####"; Rw
PRINT #1, USING "       Uncertainty in Wall Resistance, uRw
(m/W/m-K): ##.#######"; uRw
          PRINT #1,

          VoltAvg! = 0!
```

```
        TstmAvg! = 0!
        '
        ' Read data from raw data file...
        '
        CLS
        PRINT "Reading data from the data file:", namedat$
        PRINT
        FOR j = 1 TO Nrun
INPUT #5, Fm, Trm, TQ1, TQ2, DTQ(j), Tstm(j), Pgage, Pxdcr,
Volts, Amps
                'PRINT "Fm, Trm", Fm, Trm
                'PRINT "TQ1, TQ2, DTQ", TQ1, TQ2, DTQ(j)
                'PRINT "Tstm, Pgage, Pxdcr", Tstm(j), Pgage,
Pxdcr
                'PRINT "Volts, Amps", Volts, Amps
                'INPUT "Press ENTER to continue.", ok
                VoltAvg = VoltAvg + Volts
                TstmAvg = TstmAvg + Tstm(j)
'
'    Compute Hi unsing Petukov-Popov Correlation
'    Ref: Advances in Heat Transfer, Vol 6, pp. 503+, 1970.
'
                Tc! = (TQ1 + TQ2) / 2!
                uTc! = uTqrtz * SQR(2!) / 2!
                Cp! = Cpw(Tc)
                uCp! = uCpw(Tc, uTc)
                kc!(j) = kfw(Tc)
                ukc!(j) = ukfw(Tc, uTc)
'mc! = (.6763 * Fm + 1.34212) * rhofw(TQ1) * .00001
mc! = (.0004646 * Fm * Fm + .6185 * Fm + 2.2639) * rhofw(TQ1)
* .00001
                urhot1! = urhofw(TQ1, uTqrtz)
                umc1! = urhot1 * (Fm + 1.9845)
                umc2! = ufm * rhofw(TQ1)
                umc! = 6.763E-06 * SQR(umc1 ^ 2 + umc2 ^ 2)
                mu! = mufw(Tc)
                umu! = umufw(Tc, uTc)
                rhoc! = rhofw(Tc)
                urhoc! = urhofw(Tc, uTc)
Vcw!(j) = 4 * mc / (rhoc * (pi# * Di ^ 2 - AreaCorr#))
                rmc! = (umc / mc) ^ 2
                rrhoc! = (urhoc / rhoc) ^ 2
                uVcw!(j) = Vcw(j) * SQR(rmc + rrhoc)
                'PRINT "Fm    =", Fm, "   Vcw =", Vcw(j)
                'PRINT "Di    =", Di, "   mu =", mu
                'INPUT "Enter to Continue", ok
                Re! = rhoc * Vcw(j) * Di / mu
                rVcw! = (uVcw(j) / Vcw(j)) ^ 2
                rmu! = (umu / mu) ^ 2
'PRINT "Vcw, uVcw, rVcw = ", Vcw(j), uVcw(j), rVcw
                'PRINT "rhoc =", rhoc, " mu = ", mu
```

```
                'PRINT "urhoc =", urhoc, " umu = ", umu
                'PRINT "rrhoc =", rrhoc, " rmu = ", rmu
                uRe! = Re * SQR(rrhoc + rVcw + rmu)
                Pr! = mu * Cp / kc(j)
                rCp! = (uCp / Cp) ^ 2
                rkc! = (ukc(j) / kc(j)) ^ 2
                uPr! = Pr * SQR(rmu + rCp + rkc)
                '
                'PRINT "Re   =", Re, "   Pr =", Pr
                'PRINT "uRe  =", uRe, " uPr =", uPr
                '
                ' log_10 (z) = ln (z) / ln(10)
                '
xi! = (1.82 * LOG(Re) / LOG(10!) - 1.64) ^ (-2)
                uxi! = 1.58 * xi ^ 1.5 * uRe / Re
                K1! = 1! + 3.4 * xi
                uK1! = 3.4 * uxi
                K2! = 11.7 + 1.8 * Pr ^ (-1! / 3!)
                uK2! = .6 * Pr ^ (-4! / 3!) * uPr
                xi! = xi / 8!
                uxi! = uxi / 8!
                OmegaN! = xi * Re * Pr
                rxi! = uxi / xi
                rRe! = uRe / Re
                rPr! = uPr / Pr
uOmegaN! = OmegaN * SQR(rxi ^ 2 + rRe ^ 2 + rPr ^ 2)
OmegaD! = K1 + K2 * SQR(xi) * (Pr ^ (2! / 3!) - 1!)
                rK1! = uK1 / (OmegaD - K1)
                rK2! = uK2 / K2

rPrK! = (2 * Pr ^ (-1! / 3!) * uPr) / (3 * (Pr ^ (2! / 3!) -
1))
uOmegaD! = (OmegaD - K1) * SQR(rK1 ^ 2 + rK2 ^ 2 + (.5 * rxi)
^ 2 + rPrK ^ 2)
                Omega!(j) = OmegaN / OmegaD
uOmega!(j) = Omega(j) * SQR((uOmegaN / OmegaN) ^ 2 + (uOmegaD
/ OmegaD) ^ 2)
                'PRINT "K1,K2", K1, K2
                'PRINT "uK1,uK2", uK1, uK2
                'PRINT "rxi, rPrK", rxi, rPrK
                'PRINT "OmegaD, OmegaN", OmegaD, OmegaN
                'PRINT "uOmegaD, uOmegaN", uOmegaD, uOmegaN
                'PRINT "Omega, uOmega", Omega(j), uOmega(j)
                '
Compute temperature rise correction for frictional heating
                '
                Tcor! = FTfric(Vcw(j))
                uTcor! = uFTfric(Vcw(j), uVcw(j))
                '
                Trise! = DTQ(j) - Tcor
                uTrise! = SQR(2 * uTqrtz ^ 2 + uTcor ^ 2)
```

```
LMTD!(j) = Trise / LOG((Tstm(j) - TQ1) / (Tstm(j) - TQ2 +
Tcor))
                rTrise! = uTrise / LMTD(j)
                rTQ1! = uTqrtz / (Tstm(j) - TQ1)
                rTQ2! = uTqrtz / (Tstm(j) - TQ2 + Tcor)
                rTcor! = uTcor / (Tstm(j) - TQ2 + Tcor)
rTstm! = (DTQ(j) + Tcor) * uTstm / ((Tstm(j) - TQ1) *
(Tstm(j) - TQ2 + Tcor))
uLMTD! = LMTD(j) ^ 2 / Trise * SQR(rTrise ^ 2 + rTQ1 ^ 2 +
rTQ2 ^ 2 + rTcor ^ 2 + rTstm ^ 2)
                rLMTD! = uLMTD / LMTD(j)
'PRINT "Tcor, Trise, LMTD: ", Tcor, Trise, LMTD(j)
'PRINT "rTrise, rTQ1, rTQ2, rTcor, rTstm", rTrise, rTQ1,
rTQ2, rTcor, rTstm
'PRINT "uTrise, uLMTD, rLMTD: ", uTrise, uLMTD, rLMTD
                Q! = mc * Cp * Trise
                Qflux!(j) = Q / (pi# * Dr * L!)
                rTrise! = (uTrise / Trise) ^ 2
'PRINT "rmc,rCp,rTrise", SQR(rmc), SQR(rCp), SQR(rTrise)
                'PRINT "umc,uCp,uTrise", umc, uCp, uTrise
                'PRINT "mc,Cp,Trise", mc, Cp, Trise
                rQflux! = SQR(rCp + rmc + rTrise)
                uQflux!(j) = rQflux! * Qflux(j)
                Uo!(j) = Qflux(j) / LMTD(j)
                rUo! = SQR(rQflux ^ 2 + rLMTD ^ 2)
                uUo!(j) = rUo * Uo(j)
                'PRINT "rQflux, rUo =", rQflux, rUo
                'PRINT "Qflux, Uo: ", Qflux(j), Uo(j)
                'PRINT "uQflux, uUo: ", uQflux(j), uUo(j)
                'INPUT "Press ENTER to continue.", Ok
          NEXT j

          VoltAvg = VoltAvg / Nrun
          TstmAvg = TstmAvg / Nrun
Power! = VoltAvg ^ 2 / 5.76      'Resistance of Steam Boiler
Heater Rods = 5.76 Ohms
VapVel! = 4 * (Power - Qloss) / (pi# * rhogw(TstmAvg) *
hfgw(TstmAvg) * Dc ^ 2)

          PRINT #6,
          PRINT #6, USING "        Average System Power (kW):
###.##"; Power * .001
          PRINT #6, USING "        Average Steam Velocity
(m/s):  ###.##"; VapVel
          PRINT #6,
          PRINT #6, "      This analysis takes into account
of the following:"
          PRINT #6, "              1. HEATEX insert inside the
tube"
          PRINT #6, "              2. End-fin effects"
          PRINT #6, "              3. Petukhov-Popov
```

```
correltation for Hi"
          PRINT #6, "                  4. Nusselt type correlation
for Ho"
          '
          'Start Wilson Plot Iteration...for Ci and Co
          '
          PRINT "Starting Wilson Plot Iteration"
          PRINT
          DO
               'BEEP
               sumx! = 0
               sumy! = 0
               sumx2! = 0
               sumy2! = 0
               sumxy! = 0
               FOR j = 1 TO Nrun
                    Two! = Tstm(j) - 5
                    '
                    'Iterate for computing Two
                    '
                    DO
                         Twop = Two
                         DTwo(j) = Tstm(j) - Two
                         Tfilm! = (Tstm(j) + 2 * Two) / 3!
                         rhof! = rhofw(Tfilm)
                         kf! = kfw(Tfilm)
                         muf! = mufw(Tfilm)
     hfgf! = hfgw(Tfilm) + .68 * Cpw(Tfilm) * DTwo(j)
                         'PRINT "Tstm, Tf : ", Tstm(j), Tfilm
                         'PRINT "rhof, kf : ", rhof, kf
                         'PRINT "muf, hfgf: ", muf, hfgf
                         'PRINT "Two, DTwo: ", Two, DTwo(j)
                         'INPUT "Press ENTER to continue.",
Ok
Z! = SQR(SQR(9.81 * kf ^ 3 * hfgf * rhof * rhof / (muf * Dr *
DTwo(j))))
                         Ho!(j) = Co * Z
                         Two = Tstm(j) - Qflux(j) / Ho(j)
                         'PRINT "Two, Twop : ", Two, Twop
                         'PRINT "Z,    Ho   : ", Z, Ho(j)
                         'INPUT "Press ENTER to continue.",
Ok
                    LOOP WHILE ABS(1 - Two / Twop) > .0001
                    '
                    'PRINT "J, Two, DTwo : ", j, Two, DTwo(j)
                    'PRINT "Z,    Ho    : ", Z, Ho(j)
                    Hi!(j) = Ci * Omega(j) * kc(j) / Di
                    m! = SQR(Hi(j) * Perim / (kt * AreaX))
                    ml1! = m! * L1!
                    ml2! = m! * L2!
                    eff1! = ftanh(ml1!) / ml1!
```

```
                    eff2! = ftanh(ml2!) / ml2!
                    'PRINT "eff1,eff2 ="; eff1, eff2
                    eff1! = ftanh(m * L1) / (m * L1)
                    eff2! = ftanh(m * L2) / (m * L2)
                    'PRINT "eff1,eff2 ="; eff1, eff2
                    'INPUT "Press Enter to Continue"; Ok
                    '
Compute X and Y Wilson data points for Linear Regression
                    '
x!(j) = Dr * Z * L! / (Omega(j) * kc(j) * (L! + L1! * eff1! +
L2! * eff2!))
                    Uoi = 1! / Uo(j)
                    Rwt = Rw * pi# * Dr * L!
                    y!(j) = Z * (Uoi - Rwt)
                    'PRINT "Uo, Uoi: ", Uo(j), Uoi
                    'PRINT "Rw, Rwt: ", Rw, Rwt
                    'PRINT "Omega, kc, Hi: ", Omega(j),
kc(j), Hi(j)
                    'PRINT "eff1, eff2: ", eff1!, eff2!
                    'PRINT "J, X, Y: ", j, X(j), Y(j)
                    'INPUT "Press ENTER to continue.", Ok
                    sumx = sumx + x(j)
                    sumy = sumy + y(j)
                    sumx2 = sumx2 + x(j) * x(j)
                    sumy2 = sumy2 + y(j) * y(j)
                    sumxy = sumxy + x(j) * y(j)
                NEXT j
                '
                'Compute slope and intercept
                '
                sxx! = sumx2 - sumx ^ 2 / Nrun
                sxy! = sumxy - sumx * sumy / Nrun
                Xbar! = sumx / Nrun
                Ybar! = sumy / Nrun
                slope! = sxy / sxx
                intercept! = Ybar - slope * Xbar
                '
                'Store the current values of Ci and Co
                '
                Cic = Ci
                Coc = Co
                '
                'Compute new values of Ci and Co
                '
                Ci! = 1! / slope
                Co! = 1! / intercept
                '
 Ci = CiNew and Co = (Coc+CoNew)/2 seems to give the best
 convergence
                '
                Co = (Co + Coc) * .5
```

```
            errCi! = ABS(1! - Ci / Cic)
            errCo! = ABS(1! - Co / Coc)
            iter = iter + 1
            PRINT
            PRINT "Iteration No. : ", iter
            PRINT "Cic, Ci, errCi: ", Cic, Ci, errCi
            PRINT "Coc, Co, errCo: ", Coc, Co, errCo
            PRINT
            'INPUT "Press ENTER to continue.", Ok
        LOOP WHILE errCi > .0005 OR errCo > .0005
        PRINT
        PRINT "Wilson Plot iteration completed"
        '
        'compute final regression coefficients
        '
        syy! = sumy2 - Nrun * Ybar ^ 2
        sse! = syy - slope * sxy
        R! = SQR(1! - sse / syy)

        PRINT #6,
        PRINT #6, USING "       Regression Coefficient,  R
: ##.###"; R
        PRINT #6, USING "       Inside leading coeff.,
Ci: ##.###"; Ci
        PRINT #6, USING "       Outside leading coeff.,
Co: ##.###"; Co
        PRINT #6,

        PRINT
        PRINT "Regression Coefficient,  R  ="; R
        PRINT "Inside leading coeff.,   Ci ="; Ci
        PRINT "Outside leading coeff.,  Co ="; Co
        PRINT
        INPUT "Press ENTER to continue.", Ok
        '
        'Compute Uncertainties
        '
        sigmahat2! = sse / (Nrun - 2!)
tau! = 2.179                    'For a 95% confidence level with
12 deg of freedom
        IF (Nrun = 28) THEN tau! = 2.056
        uslope! = tau * SQR(sigmahat2 / sxx)
        'PRINT "slope, uslope", slope, uslope
        uCi! = uslope / (slope * slope)
        uintercept! = tau * SQR(sigmahat2 * (1! / Nrun +
Xbar ^ 2 / sxx))
        'PRINT "intercept, uintercept", intercept,
uintercept
        uCo! = uintercept / (intercept * intercept)
        PRINT #1, USING "       Uncertainty in Ci =
##.##%"; uCi * 100 / Ci
```

```
        PRINT #1, USING "       Uncertainty in Co =
##.##%"; uCo * 100 / Co
        enht! = Co / Cofilm
        uenht! = enht * ((uCo / Co) ^ 2 + (ucofilm /
Cofilm) ^ 2) ^ .5
        enhq! = enht ^ (4! / 3!)
        uenhq! = 1.333 * uenht * enht ^ (1! / 3!)
        PRINT #1, USING "       Uncertainty in Enahncement
(const DT):  ##.##%"; uenht * 100 / enht
        PRINT #1, USING "       Uncertainty in Enahncement
(const q) :  ##.##%"; uenhq * 100 / enhq

        '
        'Compute final values of hi and ho based on Ci and
Co obtained above
        '

        'PRINT #6, " Data    Vcw      DTCW     Qflux      LMTD
Tstm     DTwo       Uo         Hi          Ho     HoZ"
        'PRINT #6, "   #      (m/s)      (C)     (kW/m^2)
(C)      (C)     ------(kW/m^2-K)--------------"
        PRINT #6, "     Data    Vcw      DTCW     Qflux
LMTD      Tstm   DTwo       Uo         Hi         HoZ"
        PRINT #6, "      #      (m/s)      (C)      (kW/m^2)
(C)      (C)     ------(kW/m^2-K)---------"
        PRINT #6,
        frmres$ = "      ##      ##.##     ##.##    #####.##
###.##    ###.##   ##.##    ###.##    ###.##     ###.##"
        frmavg$ = "     Average                        #####.##
##.##                       ###.##"

        'PRINT #7, " DTwo       HoZ            Qf
HoNu"
        'PRINT #7, " (C)     (kW/m^2-K)    (MW/m^2)
(kW/m^2-K)"
        PRINT #7,
        frmhqt$ = "###.##     ###.##        ##.####
###.##"
        PRINT #1,
        PRINT #1, "       Data   uVcw     uQflux      uDTwo
uUo       uHi        uHoZ"
        'PRINT #1, "   #     (m/s)   (kW/m^2)       (C)       ----
---(kW/m^2K)-------  "
        PRINT #1, "        #       (%)        (%)         (%)
---------(%)-----------  "
        PRINT #1,
        frmunc$ = "       ##      ##.##     ###.##      ###.##
###.##    ###.##     ###.##"
        frmuavg$ = "     Average         ###.##      ###.##
###.##"
```

```
        DTwoAvg = 0
        HoAvg = 0
        QfluxAvg = 0
        'PRINT
        rCi! = uCi / Ci
        rCo! = uCo / Co
        'PRINT "Ci, rCi", Ci, rCi
        'PRINT "Co, rCo", Co, rCo

        FOR j = 1 TO Nrun
             Hi!(j) = Ci * Omega(j) * kc(j) / Di
             rOmega! = uOmega(j) / Omega(j)
             rkc! = ukc(j) / kc(j)
             uHi!(j) = Hi(j) * SQR(rOmega ^ 2 + rkc ^ 2 +
rCi ^ 2)
             'PRINT "rCi,rkc,rOmega", rCi, rkc, rOmega
             rHi = uHi(j) / Hi(j)
             'PRINT "Hi, rHi", Hi(j), rHi
             m! = SQR(Hi(j) * Perim / (kt * AreaX))
             rm! = SQR(rHi ^ 2 + rkt ^ 2)
             um! = rm * m
             'PRINT "m,um,rm", m, um, rm
             ml1! = m! * L1!
             ml2! = m! * L2!
             'PRINT "ml1,ml2", ml1!, ml2!
             tanh1! = ftanh(ml1!)
             tanh2! = ftanh(ml2!)
             eff1! = tanh1! / ml1!
             eff2! = tanh2! / ml2!
             'sech2x1 = 1 - tanh1 ^ 2
             'sech2x2 = 1 - tanh2 ^ 2
             'ueff1! = ABS(rm * (sech2x1 - eff1!))
             'ueff2! = ABS(rm * (sech2x2 - eff2!))
             'PRINT " eff1, eff2", eff1!, eff2!
             'PRINT "ueff1,ueff2", ueff1!, ueff2!
             ceff! = Dr * L! / (Di * (L! + L1! * eff1! +
L2! * eff2!))
             Ho!(j) = 1! / Uo(j) - ceff / Hi(j) - Rw * L! *
pi# * Dr
             Ho!(j) = 1! / Ho(j)
             'PRINT "Ho, ceff = ", Ho(j), ceff
             'rUo = uUo(j) / Uo(j)
             'rRw = Ho(j) * uRw * L! * pi# * Dr
             'reff1! = cHi / (Di * (L! + L1! * eff1! + L2!
* eff2!)) * L1! * ueff1!
             'reff2! = cHi / (Di * (L! + L1! * eff1! + L2!
* eff2!)) * L2! * ueff2!
             'reff1! = ceff / (L! + L1! * eff1! + L2! *
eff2!) * L1! * ueff1!
             'reff2! = ceff / (L! + L1! * eff1! + L2! *
eff2!) * L2! * ueff2!
```

```
'PRINT "rUo,rRw", rUo, rRw
'PRINT "reff1,reff2", reff1!, reff2!
'HoUo = Ho(j) / Uo(j)
'HoHi = Ho(j) / Hi(j)
'PRINT "HoUo,HoHi: ", HoUo, HoHi
'rHo! = SQR((HoUo * rUo) ^ 2 + (rRw) ^ 2 +
(HoHi * reff1!) ^ 1 + (HoHi * reff2!) ^ 2 + (rHi * HoHi) ^ 2)
'uHo!(j) = Ho(j) * rHo
'PRINT "rHo,uHo", rHo, uHo(j)
DTwo!(j) = Qflux(j) / Ho(j)
rQf = uQflux(j) / Qflux(j)
rDTwo! = SQR(rQf ^ 2 + rHo ^ 2)
uDTwo!(j) = DTwo(j) * rDTwo
'PRINT "rQf, DTwo", rQf, DTwo(j)
'PRINT "rDTwo,uDTwo", rDTwo, uDTwo(j)
'INPUT "Press ENTER to Continue", Ok
Two! = Tstm(j) - DTwo(j)
iter = 0
rDTwo = uTstm / DTwo(j)
'PRINT "DTwo(j),rDTwo", DTwo(j), rDTwo
'INPUT "Press ENTER to Continue", Ok

DO
     iter = iter + 1
     Twop = Two
     Tfilm! = (Tstm(j) + 2! * Two) / 3!
     rhof! = rhofw(Tfilm)
     urhof! = urhofw(Tfilm, uTqrtz)
     kf! = kfw(Tfilm)
     ukf! = ukfw(Tfilm, uTqrtz)
     muf! = mufw(Tfilm)
     umuf! = umufw(Tfilm, uTqrtz)
     hfgf! = hfgw(Tfilm) + .68 * Cpw(Tfilm) *
(Tstm(j) - Two)
     uhfgf! = SQR((uhfgw(Tfilm, uTqrtz)) ^ 2 +
(.68 * DTwo(j) * uCpw(Tfilm, uTqrtz)) ^ 2 + (.68 * uDTwo(j) *
Cpw(Tfilm)) ^ 2)
     Z! = SQR(SQR(9.81 * kf ^ 3 * hfgf * rhof
* rhof / (muf * Dr * (Tstm(j) - Two))))
     HoZ!(j) = Co * Z
     HoNu! = .728 * Z
     rkf! = 3 * ukf / kf
     rrhof! = 2 * urhof / rhof
     rmuf! = umuf / muf
     rhfgf! = uhfgf / hfgf
     'PRINT "rkf,rrhof: ", rkf, rrhof
     'PRINT "rhfgf,rmuf: ", rhfgf, rmuf
     'rHo = SQR(rCo ^ 2 + 1.0/16.0*(rkf ^ 2 +
rrhof ^ 2 + rhfgf ^ 2 + rmuf ^ 2 + rDTwo ^ 2))
     ' Rewrite Ho in terms of properties and
Qf, eliminating DTwo from
```

```
                    ' the equation. Then the uncertaqinty is
as follows:
                    'PRINT "rQf, rCo", rQf, rCo
                    rHo = SQR((4! / 3! * rCo) ^ 2 + 1! / 9! *
(rkf ^ 2 + rrhof ^ 2 + rhfgf ^ 2 + rmuf ^ 2 + rQf ^ 2))
                    uHoZ(j) = rHo * HoZ(j)
                    'PRINT "HoZ, rHo: ", HoZ(j), rHo
                    '
                    'New DTwo
                    '
                    DTwo!(j) = Qflux(j) / HoZ(j)
                    Two = Tstm(j) - DTwo(j)
                    rDTwo! = SQR(rQf ^ 2 + rHo ^ 2)
                    'PRINT "DTwo, rDTwo: ", DTwo(j), rDTwo
                    uDTwo(j) = rDTwo * DTwo(j)
                    'INPUT "Press ENTER to Continue..", Ok
               LOOP WHILE ABS(1 - Two / Twop) > .0001
               PRINT " Data# & No. of Iter: ", j, iter

               'PRINT #6, USING frmres$; j; Vcw(j); DTQ(j);
Qflux(j) * .001; LMTD(j); Tstm(j); DTwo(j); Uo(j) * .001;
Hi(j) * .001; Ho(j) * .001; HoZ(j) * .001
               PRINT #6, USING frmres$; j; Vcw(j); DTQ(j);
Qflux(j) * .001; LMTD(j); Tstm(j); DTwo(j); Uo(j) * .001;
Hi(j) * .001; HoZ(j) * .001
               PRINT #7, USING frmhqt$; DTwo(j); Ho(j) *
.001; Qflux(j) * .000001; HoNu * .001
               PRINT #1, USING frmunc$; j; uVcw(j) / Vcw(j) *
100; uQflux(j) / Qflux(j) * 100; uDTwo(j) / DTwo(j) * 100;
uUo(j) / Uo(j) * 100; uHi(j) / Hi(j) * 100; uHoZ(j) / HoZ(j)
* 100
               '
               ' Compute X and Y Wilson data points
               '
               x!(j) = Dr * Z * L / (Omega(j) * kc(j) * (L! +
L1! * eff1! + L2! * eff2!))
               y!(j) = Z * (1! / Uo(j) - Rw * pi# * Dr * L)
               '
               'Compute averages....
               '
               DTwoAvg = DTwoAvg + DTwo(j)
               HoAvg = HoAvg + Ho(j)
               QfluxAvg = QfluxAvg + Qflux(j)
          NEXT j
          DTwoAvg = DTwoAvg / Nrun
          HoAvg = HoAvg / Nrun
          QfluxAvg = QfluxAvg / Nrun
          DTwAvg2 = QfluxAvg / HoAvg
          PRINT #1,
          PRINT #1,
          PRINT #1, "     Data  uVcw    uQflux     uDTwo
```

```
uUo       uHi        uHo"
          PRINT #1, "     #     (m/s)   (kW/m^2)      (C)        --
-----(kW/m^2K)------- "
          PRINT #1,
          frmunc$ = "     ##     #.###   #####.##    ###.##
###.##    ###.##     ###.##"
          FOR j = 1 TO Nrun
               PRINT #1, USING frmunc$; j; uVcw(j); uQflux(j)
* .001; uDTwo(j); uUo(j) * .001; uHi(j) * .001; uHoZ(j) *
.001
          NEXT j

          'PRINT
          'PRINT "HoAvg, QfluxAvg: ", HoAvg, QfluxAvg
          'PRINT "DTwAvg, DTwAvg2: ", DTwoAvg, DTwAvg2
          'PRINT
          PRINT #6, USING frmavg$; QfluxAvg * .001; DTwoAvg;
HoAvg * .001
          PRINT #6,
          PRINT #6, "   Wilson Plot X-Y data points..."
          PRINT #6,
          PRINT #6, "          X         Y              X
Y"
          PRINT #6,
          formXY$ = "        ##.##     ##.##          ##.##
##.##"
          Nrun2 = Nrun / 2
          FOR j = 1 TO Nrun2
               PRINT #6, USING formXY$; x(j); y(j); x(j +
Nrun2); y(j + Nrun2)
          NEXT j

          PRINT #9, "   X       Y"
          PRINT #9,
          frmwxy$ = " ##.##    ##.##"

          FOR j = 1 TO Nrun
               PRINT #9, USING frmwxy$; x(j); y(j)
          NEXT j

          CLOSE    'Close ALL input and output files...

          PRINT
          PRINT "The PROCESSED data were written to the file
", nameres$
          PRINT "Delta Two vs Ho & Q were written to the file
", namehqt$
          PRINT "Wilson Plot X,Y data are stored in the file
", namewxy$
          PRINT "Uncertainty data   were written to the file
", nameunc$
```

```
        PRINT
        PRINT " To get a hard copy of these files, do one
of the following:"
        PRINT "       1. Print the file from the DOS
prompt, OR"
        PRINT "       2. Load the file into QBasic, and
select FILE/PRINT."
        PRINT
        INPUT "Press ENTER to continue.", Ok
END SUB

FUNCTION psw (temp)
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'      VariX    VariY     R^2    RegDOF  RgSmSq  ErrDOF   ErSmSq
'    791.667    0.093   100.00    6.00    1.67  0.12e+02  0.12e-
09
'
        DIM poly(10)
        poly(6) = .0060209213#
        poly(5) = .00046443261#
        poly(4) = .00001262479#
        poly(3) = .00000033316902#
        poly(2) = .0000000015146197#
        poly(1) = 3.8793438D-11
        poly(0) = -3.8075649D-14
'
        ps = poly(0)
'
'     pressure in bar = 0.1MPa
'
        FOR i = 1 TO 6
            ps = ps * temp + poly(i)
        NEXT i
'
'     pressure in kPa
'
        psw = ps * 100!
END FUNCTION

SUB RawData
        CLS
        PRINT
        INPUT " Give the NAME of the Data File (NO
extensions)"; name$
        PRINT
        INPUT " Enter the number of data points in this
file"; Nrun
        PRINT
```

```
        namedat$ = name$ + ".dat"
        nameraw$ = name$ + ".raw"
        OPEN namedat$ FOR INPUT AS #5
        OPEN nameraw$ FOR OUTPUT AS #6
        INPUT #5, Itb, kt!, Ipc
        INPUT #5, Di, Dr
        frmdat$ = " ##   ##.##   ##.##   ##.##   ##.##   ###.##
###.##   ###.##   ###.##   ###.##"

        PRINT #6, "        Program Name:
DRPSRI.BAS"
        PRINT #6, "        Data File:
"; namedat$
        PRINT #6, "        Raw Data File:
"; nameraw$
        PRINT #6, "        Tube Number:
"; Itb
        SELECT CASE Ipc
             CASE 1
                  PRINT #6, "        Pressure Condition:
Vacuum"
             CASE 2
                  PRINT #6, "        Pressure Condition:
Atmospheric"
        END SELECT
        PRINT #6,
        PRINT #6, USING "        Thermal Conductivity (W/m-
K):  ####.#"; kt!
        PRINT #6, USING "        Tube Inside Diameter (mm):
###.##"; Di
        PRINT #6, USING "        Tube Outside Diameter (mm):
###.##"; Dr
        PRINT #6,
        PRINT #6, "Data  Flow   Room   CW In  CW Out  CW
Temp.  Steam   Gage    Xducer   Volts  Curnt"
        PRINT #6, "  #   Meter  Temp.  Temp.   Temp.
Diff.    Temp.   Press    Press"
        PRINT #6, "        (%)    (C)     (C)      (C)      (C)
(C)     (kPa)   (kPa)      (V)    (Amp)"
        PRINT #6,
        frmraw$ = " ##     ##     ##.##  ##.##    ##.##
##.##    ###.##    ###.##   ###.##   ###.##   ##.##"

        FOR j = 1 TO Nrun  'Loop for reading and writing
Nrun data runs
             INPUT #5, Fm, Trm, TQ1, TQ2, DTQ, Tstm, Pgage,
Pxdcr, Volts, Amps
             PRINT #6, USING frmraw$; j; Fm; Trm; TQ1; TQ2;
DTQ; Tstm; Pgage; Pxdcr; Volts; Amps
        NEXT j
```

```
          CLOSE    'Close ALL input and output files...

          PRINT
          PRINT " The RAW data were written on the file ",
nameraw$
          PRINT
          PRINT " To get a hard copy of the saved RAW data,
do one of these:"
          PRINT "        1. Print the file from the DOS
prompt, OR"
          PRINT "        2. Load the file into QBasic, and
select file/print."
          PRINT
          INPUT " Press ENTER to continue.", Ok
END SUB

FUNCTION rhofw (temp)
'
'     rhof in kg/m^3
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'   VariX   VariY    R^2   RegDOF  RgSmSq  ErrDOF  ErSmSq
'  791.667 178.092  100.00   6.00 3205.66   12.00 0.10e-03
'
          DIM poly(10)
          poly(6) = 999.81032#
          poly(5) = .070640968#
          poly(4) = -9.073794200000001D-03
          poly(3) = .000088129446#
          poly(2) = -7.631863099999999D-07
          poly(1) = .0000000039067797#
          poly(0) = -8.624459699999999D-12
          rhof = poly(0)
          FOR i = 1 TO 6
               rhof = rhof * temp + poly(i)
          NEXT i
          rhofw = rhof
END FUNCTION

FUNCTION rhogw (temp)
'
'     rhog in kg/m^3
'
'     data obtained by curve fitting between 10 and 100 C
from NIST databook
'
'   VariX   VariY    R^2   RegDOF  RgSmSq  ErrDOF  ErSmSq
' 791.667   0.032  100.00   5.00    0.58   13.00  0.12e-08
'
```

```
        DIM poly(10)
        poly(5) = .0049353625#
        poly(4) = .00031822098#
        poly(3) = .000011268464#
        poly(2) = .00000013911252#
        poly(1) = .0000000022447156#
        poly(0) = 8.446448600000001D-12
'
        rhog = poly(0)
        FOR i = 1 TO 5
             rhog = rhog * temp + poly(i)
        NEXT i
        rhogw = rhog
END FUNCTION

SUB SENSOR
     '
     ' Subroutine for data acquisition using National
Instruments PC2A
     ' IEEE-488 BOARD TO HP-3497 AND 2804A
     ' WRITTEN BY Ashok Das 4/11/95
     '              (Data Acqisition commands by TomC 4/15/94)
     ' This uses the Universal Language Interface
     ' ULI.COM must be run prior to running the program
     ' This is usally done in the AUTOEXEC.BAT
     ' -------------------------------------------------------
----------
     DIM Emf(5)
     ' Prepare interface between program and PC2A board
     'CLOSE
     OPEN "GPIB0" FOR OUTPUT AS #1
     OPEN "GPIB0" FOR INPUT AS #2

     'Initialize the bus and reset to default parameters

     PRINT #1, "ABORT"
     PRINT #1, "RESET"
     PRINT #1, "GPIBEOS CR LF"         'SET TERMINATOR
     '
     PRINT #1, "CLEAR "                'CLEAR ALL INSTRUMENTS ON
THE BUS
     PRINT #1, "REMOTE"                'PLACE ALL INSTRUMENTS IN
REMOTE MODE
     PRINT #1, "OUTPUT 13;T3R2EX"      'Set Quartz Thermometer
to T1-T2
     '
     ' Initialize ...
     '
     FOR i = 0 TO 4
     Emf(i) = 0
     NEXT i
```

```
     TC1 = 0
     TC2 = 0
     TQ1 = 0
     TQ2 = 0
     DTQ = 0
     Trm = 0
     Tstm1 = 0
     Tstm2 = 0
     Exdcr = 0
     Volts = 0
     Amps = 0
     '
     'PREPARE 3497
     'CHANNELS 61 THRU 62 : FOR VOLTAGE AN CURRENT
     PRINT #1, "OUTPUT 9; AR AF61 AL61 VR5"
     PRINT #1, "OUTPUT 9; ASSA"      'ANALOG STEP AND BEEP
     PRINT
     BEEP
     INPUT "Connect Voltage Line.", Ok
     'BEGIN TO TAKE DATA
     PRINT #1, "OUTPUT 9; AR AF61 AL61 VR5" 'CH 61 for
voltage
     PRINT #1, "OUTPUT 9; ASSA"          'ANALOG STEP AND
BEEP
     FOR j = 1 TO 5
          CALL FWAIT(2)
          PRINT #1, "ENTER 9"
          INPUT #2, DAT$
          Volts = Volts + VAL(DAT$)          'CONVERT STRING
TO NUMBER
     NEXT j
     Volts = Volts / 5!             'Take the average..
     Volts = Volts * 100!            'Scaling factor for data
acquisition
     BEEP
     INPUT "Disconnect Voltage Line.", Ok
     PRINT #1, "OUTPUT 9; AR AF62 AL62 VR5"
     PRINT #1, "OUTPUT 9; ASSA"          'ANALOG STEP AND
BEEP
     FOR j = 1 TO 5
          PRINT #1, "ENTER 9"
          INPUT #2, DAT$
          Amps = Amps + VAL(DAT$)          'CONVERT STRING
TO NUMBER
     NEXT j
     Amps = Amps / 5!
     PRINT #1, "OUTPUT 9; AR AF24 AL24 VR5"     'Reset the HP
display to CH 24 Thermocouple
     PRINT #1, "OUTPUT 9; ASSA"
     '-------------------
     'Take 5 sets of data for temperatures and pressure
```

```
'-------------------
PRINT
FOR j = 1 TO 5
        PRINT "Getting data set number", j
        '
        'TAKE DATA FROM 2804A Q. Thermometer
        '
        PRINT #1, "OUTPUT 13;T1R2EX"      'MESSAGE TO SELECT
SENSOR 1
        CALL FWAIT(8)                      'WAIT FOR READING
        PRINT #1, "ENTER 13"
        INPUT #2, DAT$
        TQ1 = TQ1 + VAL(DAT$)
        PRINT #1, "OUTPUT 13;T2R2EX"      'MESSAGE TO SELECT
SENSOR 2
        CALL FWAIT(8)                      'WAIT FOR READING
        PRINT #1, "ENTER 13"
        INPUT #2, DAT$
        TQ2 = TQ2 + VAL(DAT$)
        PRINT #1, "OUTPUT 13;T3R2EX"      'MESSAGE TO SELECT
DIFFERENTIAL
        CALL FWAIT(8)                      'WAIT FOR READING
        PRINT #1, "ENTER 13"
        INPUT #2, DAT$
        DTQ = DTQ + ABS(VAL(DAT$))
        'CHANNELS 64 : FOR Pressure Transducer EMF Reading
        PRINT #1, "OUTPUT 9; AR AF64 AL64 VR5"
        PRINT #1, "OUTPUT 9; ASSA"        'ANALOG STEP AND
BEEP
        PRINT #1, "ENTER 9"
        INPUT #2, DAT$
        Exdcr = Exdcr + VAL(DAT$)         'CONVERT STRING TO
NUMBER
        '
        'Take Data from the Thermocouples...
        '
        'CHANNELS 20 THRU 24 : FOR Thermocouple Temperature
EMFs
        PRINT #1, "OUTPUT 9; AR AF20 AL24 VR5"
        FOR i = 0 TO 4
            'ANALOG STEP AND BEEP
            PRINT #1, "OUTPUT 9; ASSA"
            PRINT #1, "ENTER 9"
            INPUT #2, DAT$
            'CONVERT STRING TO NUMBER  and Volts to
Millivolts
            Emf(i) = Emf(i) + VAL(DAT$) * 1000
        NEXT i
    NEXT j
    'PRINT #1, "CLEAR "                   'CLEAR ALL INSTRUMENTS
ON BUS
```

```
    'PRINT #1, "LOCAL "                    'PLACE ALL INSTRUMENTS
IN LOCAL MODE
    CLOSE #1
    CLOSE #2
    'Compute Average values...
    TQ1 = TQ1 / 5! + .013
    TQ2 = TQ2 / 5! + .013
    DTQ = DTQ / 5!
    Exdcr = Exdcr / 5!
    FOR i = 0 TO 4
         Emf(i) = ABS(Emf(i)) / 5!
    NEXT i
    Pxdcr = Patm - 2.94 * Exdcr                'Emf to Psi
    Pxdcr = Pxdcr * 6.89473                    'PSI to kPa
    '
    SELECT CASE Ipc
         CASE 0                                         '16-25 deg
C range
              Tstm1 = .44389 + 24.9487 * Emf(0)
              Tstm2 = .4926 + 24.8951 * Emf(4)

         CASE 1                                         '48-51 deg
C range
              Tstm1 = 2.222 + 23.563 * Emf(0)
              Tstm2 = 2.6287 + 23.3333 * Emf(4)

         CASE 2                                         '98-102
deg C range
              Tstm1 = 8.1396 + 21.5278 * Emf(0)
              Tstm2 = 7.8057 + 21.59 * Emf(4)

         CASE 3                                         'All other
temp range
              Tstm1 = FTCgen(Emf(0))
              Tstm2 = FTCgen(Emf(4))
    END SELECT
    '
    DTstm = Tstm1 - Tstm2
    IF ABS(DTstm) > .1 THEN
         BEEP
         PRINT
         PRINT USING " Steamside thermocouples differ by
###.##  deg C"; DTstm
    END IF
    TC1 = .56612 + 24.8415 * Emf(1)
    TC2 = .41666 + 25.0108 * Emf(2)
    DTC = TC2 - TC1 - DTQ
    IF ABS(DTC) > .05 THEN
         PRINT USING " TC and Quartz Delta-T differ by
###.##  deg C"; DTC
    END IF
```

```
     Trm = FTCgen(Emf(3))
END SUB

FUNCTION sigmaw (temp)
'
' ASME/NIST surface tension in N/m (Kg-m/s^2/m = Kg/s^2)
'
          tempK = (273.15# + temp) / 647.15#
          sigmaw = .2358# * (1 - tempK) ^ 1.256 * (1 - .625#
* (1 - tempK))
END FUNCTION

SUB TakeData
     DIM Fmv(20), timev(20), Trmv(20), TQ1v(20), TQ2v(20),
DTQv(20), Tstmv(20), Pxdcrv(20), Pgagev(20), Psatv(20),
Voltsv(20), Ampsv(20), mfngv(20)
          CLS
          BEEP
          INPUT "Today's Date"; today$
          PRINT
          DO
               PRINT " Enter Pressure Condition"
               BEEP
               INPUT "    1 for Vacuum, 2 for Atmospheric";
Ipc
               IF Ipc < 1 OR Ipc > 2 THEN
                    PRINT " Invalid Pressure Option."
                    PRINT
               END IF
          LOOP WHILE Ipc < 1 OR Ipc > 2
          BEEP
          INPUT " Enter Tube Number"; Itb
          INPUT " Enter Thermal Conductivity (W/m-K)"; kt!
          INPUT " Enter Tube ID, OD (mm)"; Di, Dr
          PRINT
          BEEP
          INPUT " Give a FILE NAME for the Data File (NO
extensions)"; name$
          namedat$ = name$ + ".dat"
          nameraw$ = name$ + ".raw"
          OPEN namedat$ FOR OUTPUT AS #5
          OPEN nameraw$ FOR OUTPUT AS #6
          PRINT #5, Itb, kt!, Ipc
          PRINT #5, Di, Dr
          frmdat$ = " ##  ##.##  ##.##  ##.##  ##.##  ###.##
###.##  ###.##  ###.##  ###.##"

          LPRINT "       Test Date:                          ";
today$
          LPRINT "       Program Name:
DRPSRI.BAS"
```

```
          LPRINT "       Data File:                       ";
namedat$
          LPRINT "       Raw Data File:                   ";
nameraw$
          LPRINT "       Tube Number:                     ";
Itb
          SELECT CASE Ipc
               CASE 1
                    LPRINT "       Pressure Condition:
Vacuum"
               CASE 2
                    LPRINT "       Pressure Condition:
Atmospheric"
          END SELECT
          LPRINT
          LPRINT USING "       Thermal Conductivity (W/m-K):
####.#"; kt!
          LPRINT USING "       Tube Inside Diameter (mm):
###.##"; Di
          LPRINT USING "       Tube Outside Diameter (mm):
###.##"; Dr
          LPRINT
          LPRINT " Flow  Room   CW In CW Out CW Temp. Steam
Gage   Xducer  Volts Curnt  MfNG"
          LPRINT " Meter Temp.  Temp.  Temp.  Diff.   Temp.
Press  Press"
          LPRINT "  (%)  (C)    (C)     (C)     (C)      (C)
(kPa)  (kPa)      (V)   (Amp)"
          LPRINT
          frmlpr$ = "  ##    ##.##  ##.##  ##.##   ##.##
###.##  ###.##  ###.##  ###.## ##.## ###.##"
          frmprn$ = "  ##     ###  ##.#  ##.##  ##.##  ###.##
##.##  ##.##  ###.## ###.##"

          PRINT #6, "       Test Date:
"; today$
          PRINT #6, "       Program Name:
DRPSRI.BAS"
          PRINT #6, "       Data File:
"; namedat$
          PRINT #6, "       Raw Data File:
"; nameraw$
          PRINT #6, "       Tube Number:
"; Itb
          SELECT CASE Ipc
               CASE 1
                    PRINT #6, "       Pressure Condition:
Vacuum"
               CASE 2
                    PRINT #6, "       Pressure Condition:
Atmospheric"
```

```
        END SELECT
        PRINT #6,
        PRINT #6, USING "      Thermal Conductivity (W/m-
K):  ####.#"; kt!
        PRINT #6, USING "      Tube Inside Diameter (mm):
###.##"; Di
        PRINT #6, USING "      Tube Outside Diameter (mm):
###.##"; Dr
        PRINT #6,
        PRINT #6, "Data  Flow   Room   CW In  CW Out  CW
Temp.  Steam   Gage    Xducer   Volts  Curnt"
        PRINT #6, "  #   Meter  Temp.  Temp.   Temp.
Diff.    Temp.   Press   Press"
        PRINT #6, "       (%)    (C)     (C)      (C)      (C)
(C)    (kPa)   (kPa)     (V)    (Amp)"
        PRINT #6,
        frmraw$ = " ##     ##     ##.##   ##.##    ##.##
##.##    ###.##  ###.##   ###.##  ###.##  ##.##"

        MWstm = 18.016
        MWair = 28.97
        Nrun = 0
        Fmp = 0
        TIMER ON
        timestart = TIMER
        DO     'Loop for taking Nrun data runs
             DO     'Loop for flowmeter reading input
                  BEEP
                  PRINT
                  INPUT " Enter Flowmeter Reading"; Fm
                  WHILE Fm < 20 OR Fm > 80
                       BEEP
                       INPUT " Incorrect Flowmeter Reading.
Please Re-enter"; Fm
                  WEND
                  PRINT " You Entered Flowmeter = ", Fm
                  BEEP
                  INPUT " Is it Correct? Yes (y) or No
(n)"; Iflg$
                  IF Fm = Fmp THEN
                       PRINT "New FM reading is same as the
last one."
                       BEEP: BEEP
                       INPUT "Is it Okay? Yes (y) or No
(n)"; Iflg$
                  END IF
             LOOP WHILE Iflg$ = "N" OR Iflg$ = "n"
             i = 0
             CLS
             DO     'Loop for data acquisition for "one"
flowrate
```

```
                    BEEP
                    PRINT USING "Taking data for ##% flow
rate."; Fm
                    INPUT "Press ENTER to begin data
acquisition.", Ok

                    CALL SENSOR

                    PRINT
                    timenow = TIMER - timestart
                    BEEP
                    INPUT " Enter Pressure Gage Reading
(psi)"; Pgage

                    i = i + 1
                    Pgage = Pgage * 6.8947        'convert to
kPa
                    Tstm = (Tstm1 + Tstm2) / 2!
                    Psat = psw(Tstm)
                    vfng = (Pxdcr - Psat) / Pxdcr
                    mfng = 100! / (1! + (1! / vfng - 1!) *
MWstm / MWair)
                    timev(i) = timenow
                    Fmv(i) = Fm
                    Trmv(i) = Trm
                    TQ1v(i) = TQ1
                    TQ2v(i) = TQ2
                    DTQv(i) = DTQ
                    Tstmv(i) = Tstm
                    Pxdcrv(i) = Pxdcr
                    Pgagev(i) = Pgage
                    Psatv(i) = Psat
                    Voltsv(i) = Volts
                    Ampsv(i) = Amps
                    mfngv(i) = mfng
                    PRINT
                    PRINT USING "Summary of last ## data
taken for this flow rate.."; i
                    PRINT
                    PRINT " Data  Time Flow  CW In  CW Temp.
Steam  Xducr  Sat.  Volts  MfNG"
                    PRINT "   #        Meter  Temp.  Diff.
Temp.  Pres.  Pres. "
                    PRINT "          (m)  (%)    (C)    (C)
(C)   (Psi)  (Psi)   (V)    (%)"
                    PRINT
                    FOR j = 1 TO i
                         PRINT USING frmprn$; j; timev(j) /
60; Fmv(j); TQ1v(j); DTQv(j); Tstmv(j); Pxdcrv(j) / 6.8947;
Psatv(j) / 6.8947; Voltsv(j); mfngv(j)
```

```
                    NEXT j
                    PRINT
                    BEEP

INPUT "OK to accept one of these data? Yes (y) or No (n)";
Ok$
                    PRINT


IF Ok$ = "Y" OR Ok$ = "y" THEN
                         Okd$ = "n"

WHILE Okd$ = "n" OR Okd$ = "N"
                              BEEP

INPUT "Which data set do you want to accept"; k
                              PRINT

PRINT USING "You chose to accept data set no. ##"; k
                              BEEP

INPUT "Is it Okay? Yes (y) or No (n)"; Okd$
                              PRINT
                         END
                    END IF

LOOP WHILE Ok$ = "N" OR Ok$ = "n"
               Nrun = Nrun + 1

LPRINT USING frmlpr$; Fmv(k); Trmv(k); TQ1v(k); TQ2v(k);
DTQv(k); Tstmv(k); Pgage; Pxdcrv(k); Voltsv(k); Ampsv(k);
mfngv(k)

PRINT #5, USING frmdat$; Fmv(k); Trmv(k); TQ1v(k); TQ2v(k);
DTQv(k); Tstmv(k); Pgagev(k); Pxdcrv(k); Voltsv(k); Ampsv(k)

PRINT #6, USING frmraw$; Nrun; Fmv(k); Trmv(k); TQ1v(k);
TQ2v(k); DTQv(k); Tstmv(k); Pgagev(k); Pxdcrv(k); Voltsv(k);
Ampsv(k)
               Fmp = Fm
               CLS

PRINT USING "Last data was taken for ##% flow rate"; Fm


               BEEP
```

```
INPUT "Will there be another data run (Y or N)"; Nflg$

WHILE Nflg$ <> "Y" AND Nflg$ <> "y" AND Nflg$ <> "N" AND
Nflg$ <> "n"
                    BEEP
                    INPUT "Will there be another data run (Y
or N)"; Nflg$
               WEND
               IF Nflg$ = "N" OR Nflg$ = "n" THEN
                    BEEP
                    INPUT "Once Again, will there be another
data run (Y or N)"; Nflg$
               END IF
          LOOP WHILE Nflg$ = "Y" OR Nflg$ = "y"


PRINT #5,
          PRINT #5, "No. of DATA sets :", Nrun

          CLOSE       'Close all output files..


PRINT USING " ## Data sets were stored in the file &"; Nrun;
namedat$
          PRINT " The RAW data were written on the file ",
nameraw$
          PRINT
          BEEP

INPUT "Press ENTER to continue.", Ok
END SUB
```

```
FUNCTION uCpw (T, uT)
          DIM poly(10)
'
' By curve fit between 10 and 100 C
'
' Cp in J/kg-K
'
          poly(0) = -.000000048411511#
          poly(1) = 1.529196E-06
          poly(2) = -.0018467209#
          poly(3) = .1145064#
          poly(4) = -3.431451
          poly(5) = 4216.853
          dCp = 5 * poly(0)
          FOR i = 1 TO 4
               dCp = dCp * T + (5 - i) * poly(i)
```

```
          NEXT i
'       RETURN Cp
          uCpw = ABS(dCp) * uT + 1!

END FUNCTION


FUNCTION uFTfric (Vcw, uVcw)

uFTfric = uVcw * (2 * .0024669874# * Vcw - .00066467689#)
END FUNCTION
```

FUNCTION uhfgw (T, uT)

```
'
'     uhfg in kJ/kg = 1000 J/kg = 1000 N-m/kg
'

'Data obtained by curve fitting between 10 and 100 C from
NIST databook
'
'   VariX    VariY    R^2    RegDOF  RgSmSq   ErrDOF  ErSmSq
' 791.667 4709.589  100.00   5.00  84772.60  13.00 0.72e-02
'          DIM poly(10)
'

          poly(5) = 2500.5197#
          poly(4) = -2.3700473#
          poly(3) = .0010148364#
          poly(2) = -.000030487402#
          poly(1) = .00000023213696#
          poly(0) = -9.6917486D-10
'
          dhfg = 5 * poly(0)

FOR i = 1 TO 4

     hfg = (5 - i) * poly(i) + dhfg * T
          NEXT i
'
'     hfg in J/kg = N-m/kg, uncertainty is 1kJ/kg
'
          uhfgw = (dhfg * uT + 1) * 1000#

END FUNCTION
```

FUNCTION ukfw (T, uT)

```
'
'NIST Conductivity in Watt/m-K for liquid water at saturation
pressure
'
```

```
'Data obtained by curve fitting between 10 and 100 C from
NIST databook
'

'   VariX    VariY      R^2    RegDOF  RgSmSq     ErrDOF  ErSmSq
' 916.667 1160.223  100.00    5.00  10442.00  0.40e+01 0.65e-
03
'

          DIM poly(10)
          poly(5) = 561.03333#
          poly(4) = 1.8883438#
          poly(3) = .0030282634#
          poly(2) = -.00023712121#
          poly(1) = .0000018735431#
          poly(0) = -.0000000051282051#
'
'

conductivity in mWatt/m-K
'
          dkf = 5 * poly(0)
          FOR i = 1 TO 5
               dkf = dkf * T + (5 - i) * poly(i)
          NEXT i
'
'
 convert to Watt/m-K
'
          ukfw = (ABS(dkf) * uT + .1) * .001#

END FUNCTION
```

FUNCTION umufw (T, uT)

```
'
' NIST Viscosity for liquid water at saturation pressure
'
'Data obtained by curve fitting between 10 and 100 C from
NIST databook NBS/NRC Steam Table, pp. 263 & 267
'
'    R^2       ErrDOF    ErSmSq
'  100.00    0.10e+01  0.14e-01
'
```

```
        DIM poly(10)
        poly(8) = 1800.19#
        poly(7) = -63.745948#
        poly(6) = 1.8275094#
        poly(5) = -.04512923#
        poly(4) = .0008736755#
        poly(3) = -.000011878223#
        poly(2) = .00000010329146#
        poly(1) = -5.0954132D-10
        poly(0) = 1.078869D-12
'
'
' viscosity in 1d-6 kg/m-s
'
        dmuf = 8 * poly(0)
        FOR i = 1 TO 7
             dmuf = dmuf * T + (8 - i) * poly(i)
        NEXT i
'
'
' convert to kg/m-s
'

umufw = (ABS(dmuf) * uT + .1) * .000001#

END FUNCTION
```

FUNCTION urhofw (T, uT)

```
'
'     rhof in kg/m^3
'
'

Data obtained by curve fitting between 10 and 100 C from NIST
databook
'

'   VariX    VariY     R^2    RegDOF  RgSmSq   ErrDOF  ErSmSq
'  791.667 178.092  100.00    6.00  3205.66    12.00  0.10e-03
'
        DIM poly(10)
        poly(6) = 999.81032#
        poly(5) = .070640968#
        poly(4) = -9.073794200000001D-03
        poly(3) = .000088129446#
        poly(2) = -7.631863099999999D-07
        poly(1) = .0000000039067797#
        poly(0) = -8.624459699999999D-12
        drhof = 6 * poly(0)
```

```
        FOR i = 1 TO 5
             drhof = drhof * T + (6 - i) * poly(i)
        NEXT i
        urhofw = ABS(drhof) * uT + .01

END FUNCTION
```

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