LAMINAR FLOW HEAT TRANSFER DOWNSTREAM FROM U-BENDS

By

AMANIE NASSIF ABDELMESSIH

Bachelor of Science in Chemical Engineering
Alexandria University
Alexandria, Egypt
1972

Master of Science in Chemical Engineering
Alexandria University
Alexandria, Egypt
1979

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Thesis Approved:

Kenneth J Bell
Thesis Advisor

Billy L. Crynes

Mayis Seapan

Jerald D Parker

Norman N. Durham
Dean of Graduate College

ABSTRACT

The use of horizontal U-tubes is common in several types of heat exchange equipment. However, the present understanding of laminar flow heat transfer downstream from the U-bend is limited. Consequently, the laminar flow heat transfer downstream from the unheated, vertical bends in horizontal U-tubes with electrically heated straight tube sections was investigated. Four U-tubes with curvature ratios of 4.84, 7.66, 12.35 and 25.36 were studied. Distilled water and almost pure ethylene glycol solutions (water content 1 to 5 %) were the test fluids. For each test section, local axial and peripheral wall temperatures were measured and the local peripheral heat transfer coefficients at the various locations were calculated. The experiments covered the local bulk Reynolds number range of 120 to 2500. The local bulk Prandtl number varied between 4 and 110, while the Grashof number ranged from 2,500 to 1,130,000. The uniform wall heat flux ranged from 900 to 4230 Btu/hr.sq.ft (3.12 to 13.33 kW/sq.m.).

This investigation permitted a better understanding of the interaction of the primary, secondary and tertiary flow patterns; i.e. the combination of forced and natural convection with the centrifugal effects. Also, the following correlation was developed:

$$Nu = \{4.364 + 0.3271 Gr^{0.25} Pr^{0.25} + 1.955 \times 10^{-6} Re^{1.6} De^{0.8} e^{-0.0725(X/d_i)}\} (\mu_b / \mu_w)^{0.14}$$

This correlation predicts the heat transfer coefficient downstream from unheated U-bends as well as the heat transfer coefficient in straight tubes.

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A = area, sq.ft or sq.m

C_p = specific heat of the liquid at the bulk temperature, Btu/(lbm.F) or J/(kg.K)

d_i = inside tube diameter, ft or m

F = conversion factor, 3.412 Btu/(hr.amp.V)

g = gravitational acceleration, ft/sq.hr or m/sq.hr

h = heat transfer coefficient, Btu/(hr.sq.ft.F) or W/(sq.m.K)

I = current of the test section, amperes

k = thermal conductivity, Btu/(hr.ft.F) or W/(m.K)

$\dot{m}$ = mass flow rate of the liquid flowing through the test section, lbm/hr or kg/hr

Qinput = rate of heat input to the test section, Btu/hr or W

Qloss = rate of heat lost from the test section, Btu/hr or W

Qoutput= heat gained by the test fluid, Btu/hr or W

q = heat flux, Btu/(hr.sq.ft) or W/(sq.m)

R_c = bend radius measured to centerline of tube, ft or m

r_i = tube inside radius, ft or m

T = temperature, F or K

T_i = bulk liquid temperature at the inlet of the test section, F or K

T_o = bulk liquid temperature at the exit of the test section, F or K

t = tube wall thickness, ft or m

u = flow velocity in the test section, ft/hr or m/hr

V = voltage drop across the test section, volts

W = velocity component in the axial direction (used in Figure 3)

X = distance along a test tube, usually from the beginning of heating of a straight section, except if otherwise mentioned, ft or m

Dimensionless Parameters

De = Dean number, $Re\sqrt{r_i/R_c}$

Gr = Grashof number, $g\beta\rho^2 d_i^3 (T_{wi}-T_b)/\mu^2$

Gz = Graetz number, $PrRed_i/X$

Nu = local average peripheral Nusselt number, hd_i/k

Pr = local bulk Prandtl number, $C_p\mu/k$

Pw = tube wall parameter, $(\bar{h}\, d_i/k\,)/(d_i/t)$

Ra = Rayleigh number, PrGr

Re = local bulk Reynolds number, $ud\rho/\mu$

Greek Letters

β = coefficient of volume expansion of a fluid, 1/F or 1/C

θ = time of fall between the viscometer marks, s

μ = fluid viscosity, lbm/(hr.ft) or Ns/(sq.m)

ρ = fluid density, lbm/cu.ft or kg/cu.m

Subscripts

b = at the bulk of the fluid

f = at the fluid film where $(T_{wi}+T_b)/2$

i = peripheral position (1 to 8)

ij = local peripheral

j = station number (1 to 11)

w = property of the tube wall

wi = property at the inside tube surface

wo = property at the outside surface of the tube

CHAPTER I

INTRODUCTION

The petrochemical and chemical process industries use U-tubes extensively in double pipe heat exchangers, kettle reboilers, other types of shell and tube exchangers, and a few air cooled exchangers. These tubes are bent 180 degrees at the middle.

In the laminar flow regime (for Newtonian, constant property fluids), the fully developed, steady state velocity profile is parabolic inside straight circular tubes. This flow is referred to as primary. Application of heat to the tube wall produces a tertiary flow due to natural convection, that affects the flow pattern. Figure 1 shows the tertiary flow pattern.

At the bend of a U-tube the fluid is subjected to a centrifugal force, which moves the more rapidly flowing fluid towards the outer wall and the slower moving fluid at the wall toward the bend axis. This superimposes a secondary flow pattern on the primary and tertiary flows in the downstream section of the tube. Figure 2 shows the secondary flow pattern.

Due to the complexity of the flow patterns (a combination of primary, secondary and tertiary) downstream from the U-bend and the limited knowledge of their heat

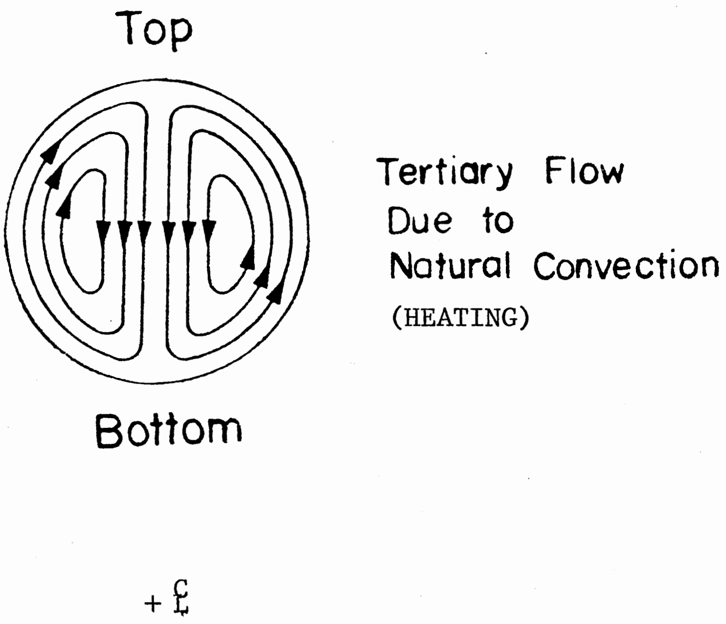


Figure 1: Sketch of the Tertiary Flow Pattern in a Straight Tube (adapted from ref. (25)).

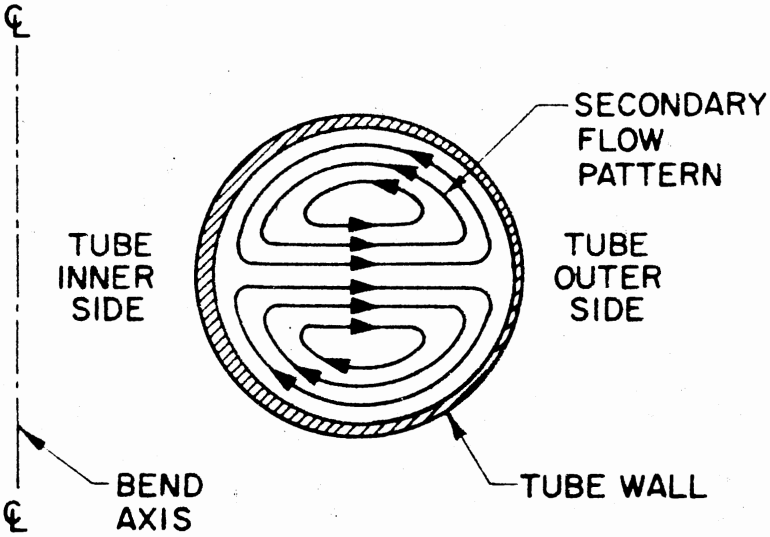


Figure 2: Sketch of the Secondary Flow Pattern in a Curved Tube (adapted from ref. (25)).

transfer characteristics, the existence of these bends is usually ignored in heat transfer calculations, though they may influence considerably the performance of heat exchangers. Consequently, in this thesis, we investigated the laminar flow heat transfer downstream from unheated, vertical bends in circular, horizontal U-tubes with electrically heated straight tube sections. Four U-tubes with curvature ratios of 4.84, 7.66, 12.35 and 25.36 were used. The curvature ratio is the ratio of the bend diameter (from the bend centerline to the tube axis) to the inside tube diameter. The test fluids were distilled water and ethylene glycol water solutions (water content 1 to 5 %).

Local wall temperatures were measured and the local peripheral heat transfer coefficients at various stations were calculated. The experiments included 84 runs. Water was used as the test fluid in 4 runs , over a local bulk Reynolds number range of 1040 to 2170, a local bulk Prandtl number of 3.9 to 5.3 and a Grashof number range from 120,000 to 1,130,000. The rest of the experimental runs were performed with ethylene glycol over a local bulk Reynolds number range of 120 to 2500, a Grashof number range of 2,500 to 45,100, while the local bulk Prandtl number varied between 44 and 110.

These experiments permitted a better understanding of the interaction of the primary, secondary and tertiary flow patterns and the development of a fully developed velocity and temperature profile. Also, a new correlation, which predicts the local average peripheral heat transfer coefficient downstream from an unheated U-bend, is introduced. The correlation is also valid for the prediction of the local average peripheral heat transfer coefficient for a fully developed laminar velocity profile in a straight tube.

CHAPTER II

LITERATURE SURVEY

Laminar Heat Transfer Downstream from U-bends in Horizontal U-Tubes

Although U-tubes are used widely in the petrochemical and chemical process industries, there is a scarcity of literature on laminar heat transfer downstream from U-bends in horizontal U-tubes.

Ede (6) investigated the effect of a horizontal 180 degree bend on the heat transfer between a U-tube and water flowing through it. He attached three bends of curvature ratios 4, 8 and 22, interchangeably, to two straight parallel tubes in a horizontal plane. Heat was generated by passing direct current through the tube wall. The heat flux varied from 570 Btu/hr.sq.ft. (1800 W/sq.m.) to 29,700 Btu/hr.sq.ft. (94,100 W/sq.m.) with a maximum tube to water temperature difference of 20.5 F (11.4 C). The Prandtl number ranged from 4.2 to 10.9.

Ede found that the effect of the heated bend on the local heat transfer coefficient was quite large for laminar flow and may extend to 40 diameters downstream. Immediately following the start of the bend, the local heat transfer coefficients are abruptly increased, due to the secondary circulation. Once the bend is passed, the coefficients decline slowly as the secondary motion decays. The Nusselt number at the exit of the tube was 10, whereas the theoretical fully developed value, assuming no free convection, is 4.36 (13).

Moshfeghian (25) studied the heat transfer in horizontal U-tubes, with the bends in the vertical plane. The U-tubes, including the bends were heated electrically by passing DC current through the tube walls. He used four U-tubes with curvature ratios of 4.84, 7.66, 12.32 and 25.62. The fluids tested were distilled water, ethylene glycol and Dowtherm G. The Prandtl numbers varied between 4 and 270 and the Reynolds numbers covered the range from 55 to 31000.

For the laminar flow downstream from the heated bend, Moshfeghian proposed the following correlation for the local mean heat transfer coefficient:

$$Nu=0.00275(\mu_b/\mu_w)^{0.14}(Pr)^{0.4}\left(Re^{\left[0.733+14.333(R_c/r_i)^{-0.593}(X/d_i)^{-1.619}\right]}\right)\left(1.0+8.5(Gr/Re^2)^{0.429}\right)\left(1.0+4.79e^{\left[-2.11(X/d_i)^{-0.237}\right]}\right) \tag{II.1}$$

for $\pi R_c/(2r_i) \le X/d_i \le 160$

where X is the distance from the inlet of the bend.

Moshfeghian found that, downstream from the heated U-bend for the laminar regime, the secondary flow tends to be counteracted by natural convection (tertiary flow), which results in a net decrease in the peripheral mean heat transfer coefficient as compared to a straight tube not preceded by a U-bend, under similar flow conditions.

Mehta (19) experimented with a single horizontal U-tube, with the bend in the vertical plane. The straight sections of the tube were heated electrically, and the bend was unheated. The U-tube had a curvature ratio of 7.66. He used ethylene glycol with Prandtl numbers of 75 to 132 and average Reynolds numbers ranging from 62 to 528.

In the straight section downstream of the bend, Mehta found that there is little enhancement of the local heat transfer coefficient by secondary flow at low local Reynolds numbers (85 -98), even immediately downstream from the bend, though the natural convection effect develops quickly. At higher local Reynolds numbers (496 - 555) immediately after the bend, the secondary flow increases the local heat transfer coefficient, but decays with distance.

Laminar Flow Heat Transfer in Straight Circular Tubes

McComas and Eckert (18) investigated experimentally the effect of free convection on laminar forced flow heat transfer in a horizontal uniformly heated tube. The Grashof number varied from 1 to 1000 and the Reynolds number ranged from 100 to 900. They found that the tertiary flow created by natural convection increased as the ratio of Grashof number to Reynolds number increased. They recommended more experimentation.

Mori et al. (22)(23) performed visual experiments and a theoretical analysis on the effect of the tertiary motion on forced convective laminar heat transfer for a fully developed flow in a horizontal tube with constant heat flux at the wall. From visual experiments, they confirmed that the center of the vortex of the tertiary flow, due to free convection, comes nearer to the tube wall with increasing values of ReRa. They assumed a boundary layer along the tube wall. By use of the boundary-layer integral method they obtained the following relationships for the Nusselt number

$$Nu = 0.09385(Nu_o)(ReRa)^{1/5} \qquad (II.2)$$

for $Pr = 0.72$

$$Nu = 0.1108(Nu_o)(ReRa)^{1/5} \qquad (II.3)$$

for $Pr = 1$

Nu = local average peripheral Nusselt number at the wall.

Nu_o = Nusselt number for forced convective heat transfer under the assumption of Poiseuille flow in a uniformly heated tube (4.364).

Shannon and Depew (32)(33) reported the results of a test program involving laminar flow of water and ethylene glycol in a horizontal tube with uniform wall heat flux. They measured the axial temperatures at 10 stations along the tube wall. They did not attempt to measure the possible existence of any temperature differences around the tube periphery. For water (32) the Reynolds numbers ranged from

120 to 2300, Grashof numbers went up to 250,000 and Graetz numbers varied from 1.5 to 1000. They found large deviations from the analytical solution for invariant properties, which they suspected to be due to natural convection. For ethylene glycol (33), the Reynolds numbers ranged from 6 to 300, Grashof numbers went up to 2800 and Prandtl numbers covered the range 26 to 500, while the Graetz numbers varied between 3 and 4800. For ethylene glycol, their results confirmed the presence of natural convection.

Hussain and McComas (10) investigated experimentally the effect of natural convection on forced flow in a horizontal circular tube, which was heated uniformly. They tested air at Reynolds numbers between 670 and 3800 and Grashof numbers between 10,000 and 1,000,000. They found that, far from the thermal entrance and at Reynolds numbers below 1200, the local Nusselt number was below the constant property pure forced flow prediction. At Reynolds numbers above 1200 the local Nusselt number increased above the forced flow prediction. Also, they observed significant peripheral variation, as much as 13 F (7 C) between the top and bottom of the tube, for the upper range of Grashof numbers investigated. They attributed these phenomena to natural convection.

Faris and Viskanta (8) theoretically analyzed the combined forced and free convection heat transfer of a quasi-incompressible fluid flowing laminarly in a horizontal tube. They considered the heat flux to be uniform along the tube and around the circumference. Also, they assumed the physical properties were independent of temperature except for the density, which is dependent on the temperature only in the buoyancy term. They included the buoyancy effect in the velocity term. They solved the resulting partial differential equations for the fully developed conditions. They presented graphically approximate analytical solutions of the peripheral Nusselt numbers.

Siegwarth et al. (34) analyzed the effect of the tertiary flow on the temperature field and the primary flow at the outlet of a long electrically heated horizontal tube. They developed a model for the flow field by dimensional reasoning and found that the tertiary flow controls the rate of heat transfer. For constant viscosity at almost infinite Prandtl numbers

$$Nu = 0.471(Gr.Pr)^{1/4} \tag{II.4}$$

Hwang and Cheng (11) presented a finite difference solution using an iterative method for fully developed combined free and forced laminar convection in uniformly heated horizontal tubes. They developed a boundary vorticity method for the solution of the Navier Stokes equation with biharmonic functions. Figure 3 shows a comparison between Mori et al. (22) experimental and theoretical results and Hwang and Cheng numerical method.

Hong, Morcos and Bergles (9) presented experimental and analytical results for laminar flow in horizontal circular tubes with nominally constant wall heat flux. They carried

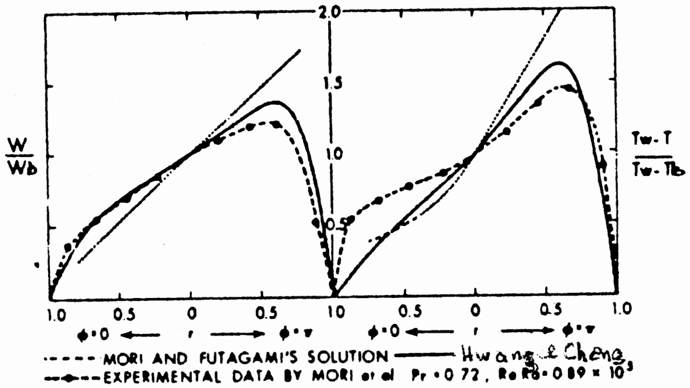


Figure 3: Comparison of Velocity and Temperature Distributions Along Central Vertical Line from Hwang and Cheng Work and Experimental and Theoretical Results from Mori et al. (adapted from ref.(11))

out a finite difference solution of the governing equations for the thermally developing region. They correlated the data with an accuracy of 10 per cent as follows

$$Nu_f = 0.378 Gr_f^{0.28} Pr_f^{0.33} / Pw^{0.12} \qquad (II.5)$$

where

$$Pw = (\bar{h} d_i / kw)(d_i / t)$$

All of the dimensionless groups are calculated at the film temperature, which is defined as:

$$T_f = (T_{wi} + T_b)/2$$

Newel and Bergles (26) investigated analytically the effects of free convection on fully developed laminar flow in horizontal circular tubes with uniform tube-wall conditions: low thermal conductivity (glass tube), and infinite thermal conductivity.

Siegwarth and Hanratty (35) measured the fully developed temperature field and axial velocity profile for a fluid with a Prandtl number of 80 at the outlet of a long horizontal tube. The tube was heated by wrapping an electrical tape around it. They solved the defining partial differential equations by finite difference techniques to obtain the tertiary flow patterns, temperature field and axial velocity field. They found large temperature gradients near the wall, horizontal isotherms in the core and a significant temperature variation in the vertical direction as shown in Figure 4. Although the tertiary flow had a large effect on the temperature field, it had little effect on the axial velocity distribution. They reported that the thickness of the velocity and temperature boundary layers are approximately equal.

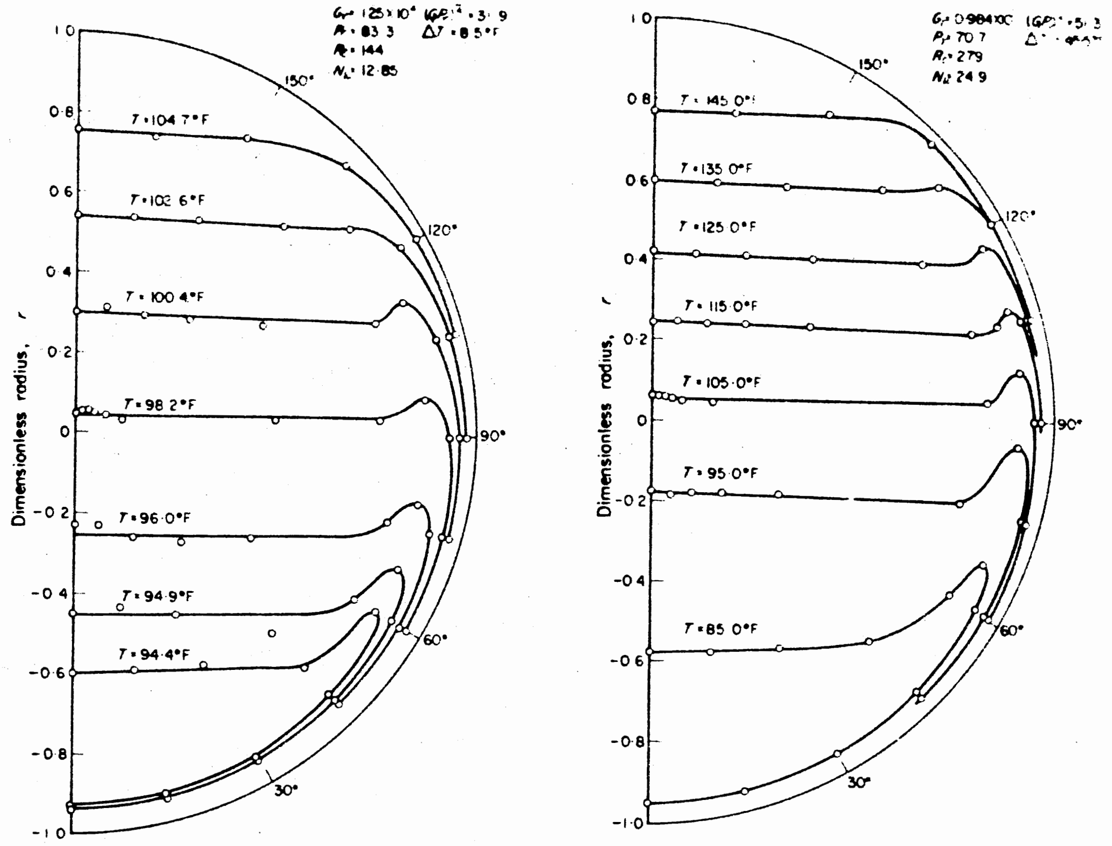
Bergles and Simons (1) studied visually and experimentally the effects of free convection on laminar flow of water in horizontal circular tubes with constant heat flux. The tubes were glass and were heated electrically.

Morcos and Bergles (20) considered fluid property variations in their heat transfer correlation for fully developed laminar flow in a straight tube:

$$Nu_f = \left[(4.36)^2 + \left(0.055 \left(Gr_f Pr_f^{1.35} / Pw^{0.25} \right)^{0.4} \right)^2 \right]^{1/2} \qquad (II.6)$$

The range of parameters tested is

$30{,}000 \le Ra \le 1{,}000{,}000$



(a)

(b)

Figure 4: Experimental Temperature Distribution from Siegwarth and Hanratty (a) Small Temperature Difference (b) Large Temperature Difference.

$4 \leq Pr \leq 175$

$2 \leq Pw \leq 66$

Mehta's (19) experimental data agreed well with this correlation except for Pw less than 2.0. He suggested modifying the constant 0.055 to 0.05 for Pw in the range 1.8 to 2.0.

El-Hawary (7) investigated the effect of wall heating on the stability of low Reynolds number (up to 3500) flow in a horizontal tube. He experimented with water in a tube with length to diameter ratio of 300. Instabilities were detected by examining signals of a thermocouple probe and a hot-film annemometer probe placed in the flow of the test section outlet. Results revealed regions of laminar flows, turbulent flows, and flows intermediate in behavior. He presented a stability map showing regions of different flows on nondimensional co-ordinates representing forced and natural convection effects.

Kato et al. (12) obtained an empirical equation, for a gas, for the overall heat transfer coefficient in a horizontal circular tube with uniform wall temperature.

In summary, a few investigators have studied experimentally and theoretically the laminar mixed (free and forced) convective heat transfer in horizontal circular tubes. For the fully developed flow, two experimental correlations (9)(21) were developed but no exact solutions exist. No research is reported for the entry region mixed convective heat transfer.

CHAPTER III

EXPERIMENTAL APPARATUS

Laminar heat transfer was studied in four horizontal U-tubes using distilled water (only four runs with test section A) and almost pure ethylene glycol solutions (water content 1 - 5%) as test fluids. Figure 5 shows the experimental loop. The experimental set-up and equipment are basically similar to those used by Moshfeghian (24)(25) and Mehta (19) in their theses.

Description of the Various Equipment

Test Sections

Four U-tubes with different bend diameters were used. Specifications of the test sections are given in Table I and in Figures 6, 7, 8 and 9.

Each test section was thermally insulated by wrapping it with woven fiberglass tape, followed by bonded fiberglass tape and pipe insulation (which was sometimes wrapped with bonded fiberglass tape), and finally secured with vapor seal tape. The total thickness was approximately 1 in.

Four pressure taps with 1/16 in. (1.59 mm) holes were silver-soldered to each test section.

Four 1/4 in. (6.35 mm) thick copper bars were silver

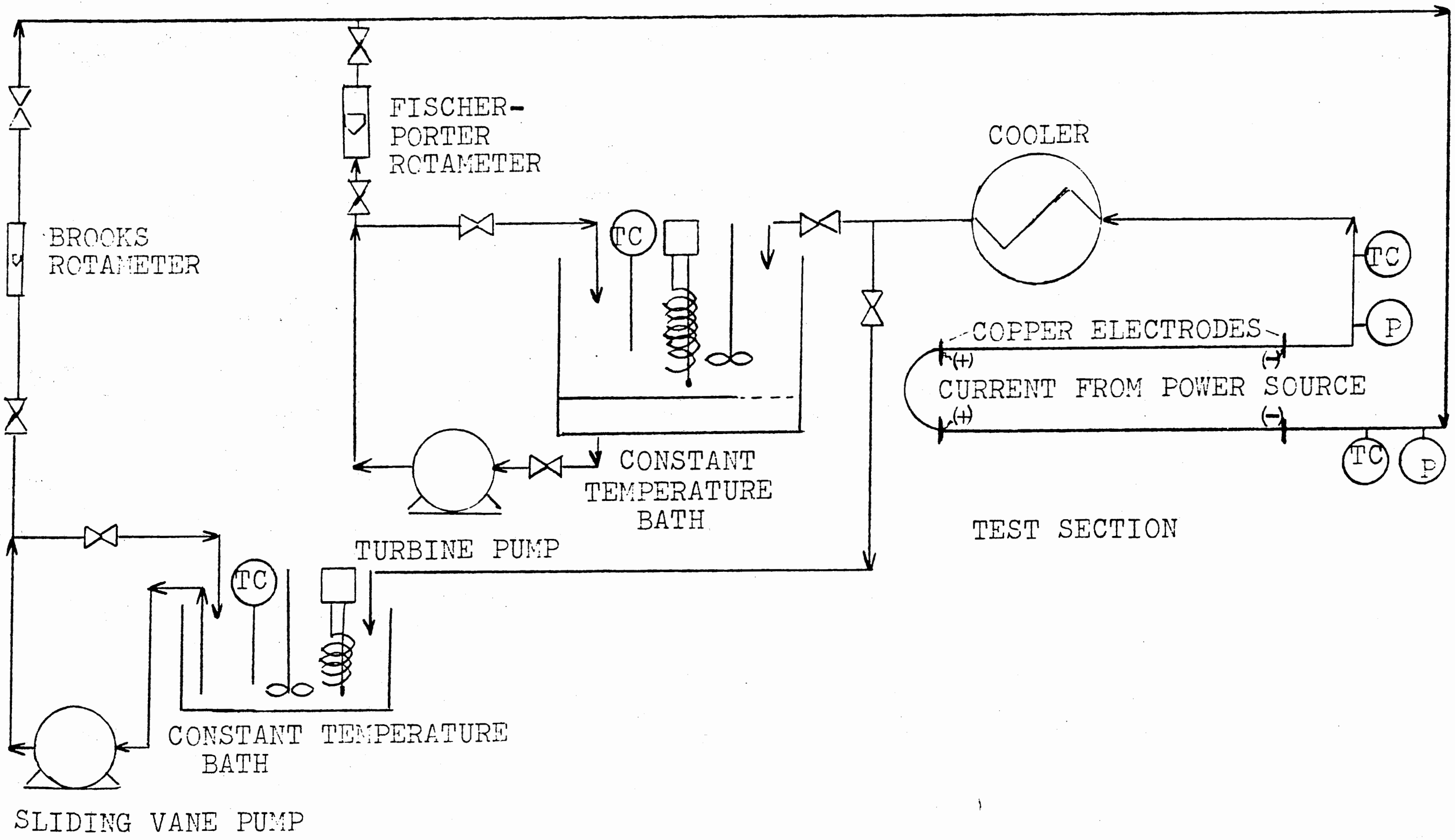
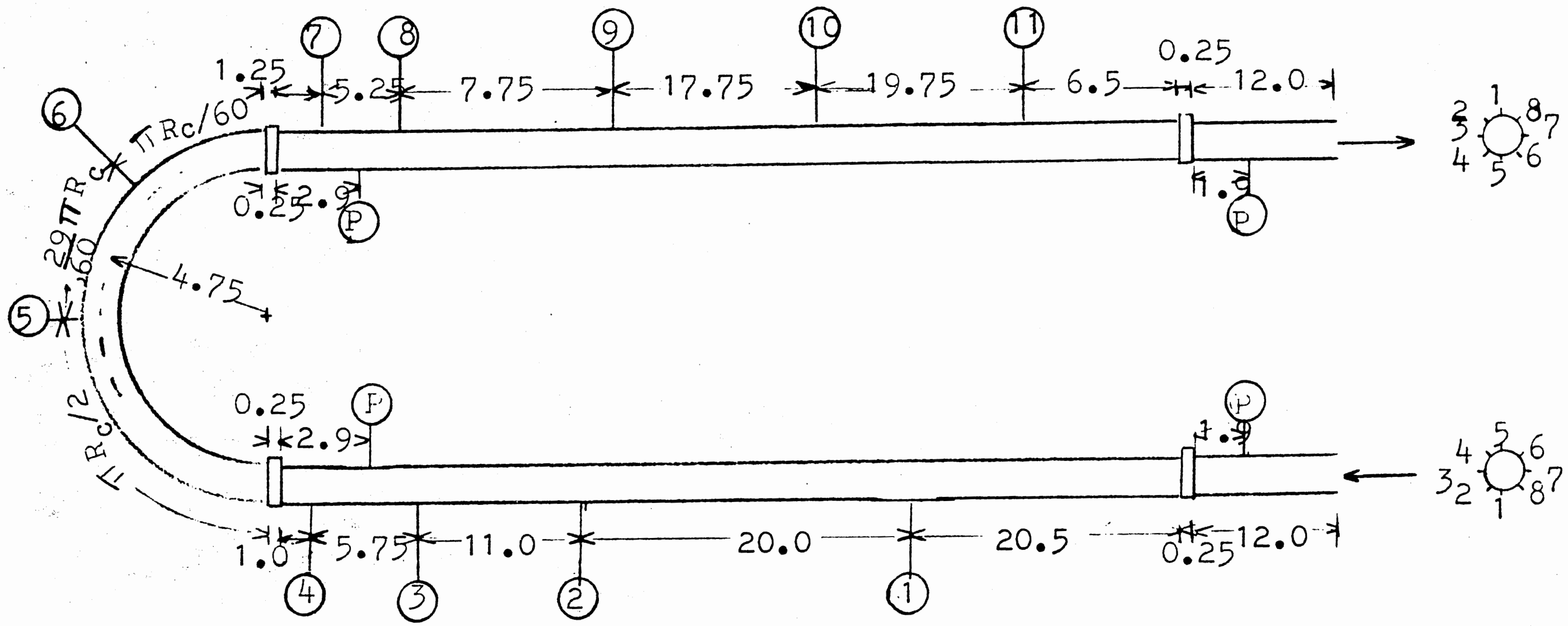


Figure 5: Heat Transfer Test Apparatus.

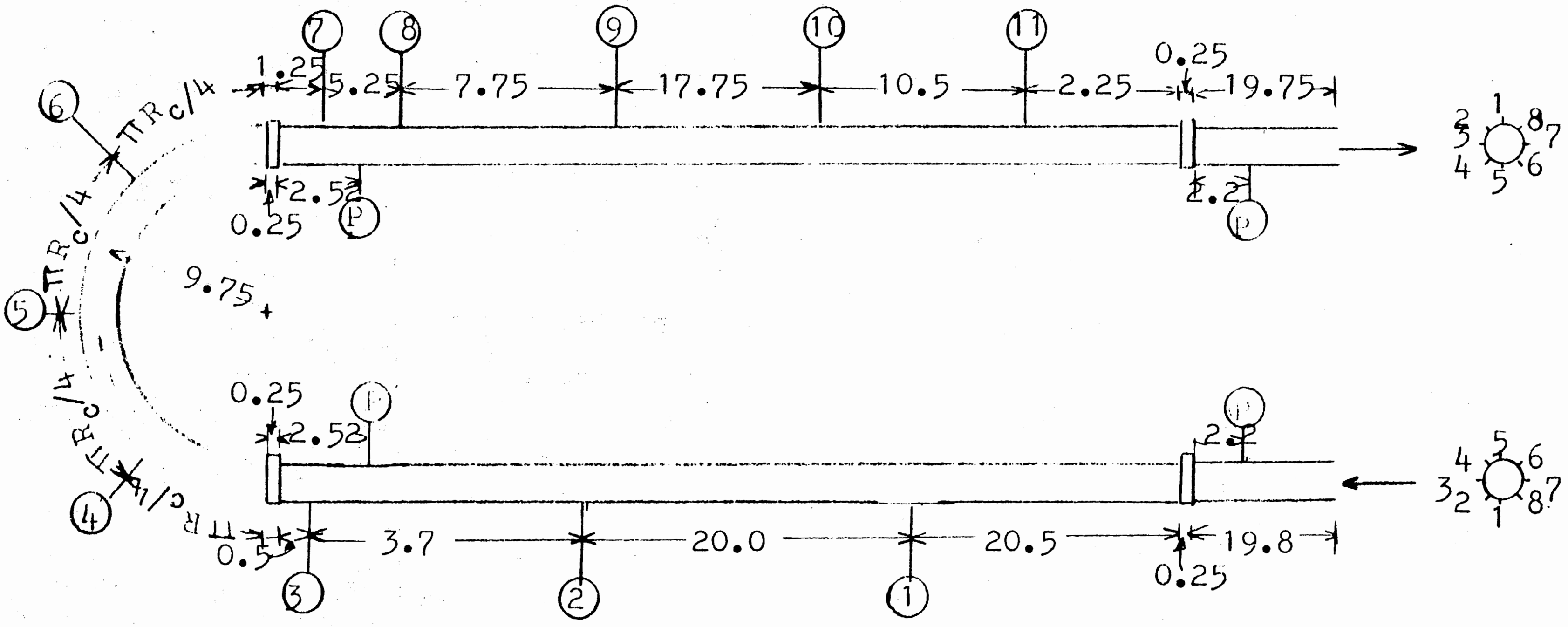


ALL DIMENSIONS IN INCHES

Ⓟ PRESSURE TAP

○ THERMOCOUPLE STATION

Figure 6: Location of Thermocouple Stations and Pressure Taps on Test Section A.



ALL DIMENSIONS IN INCHES

Ⓟ PRESSURE TAP

○ THERMOCOUPLE STATION

Figure 7: Location of Thermocouple Stations and Pressure Taps on Test Section B.

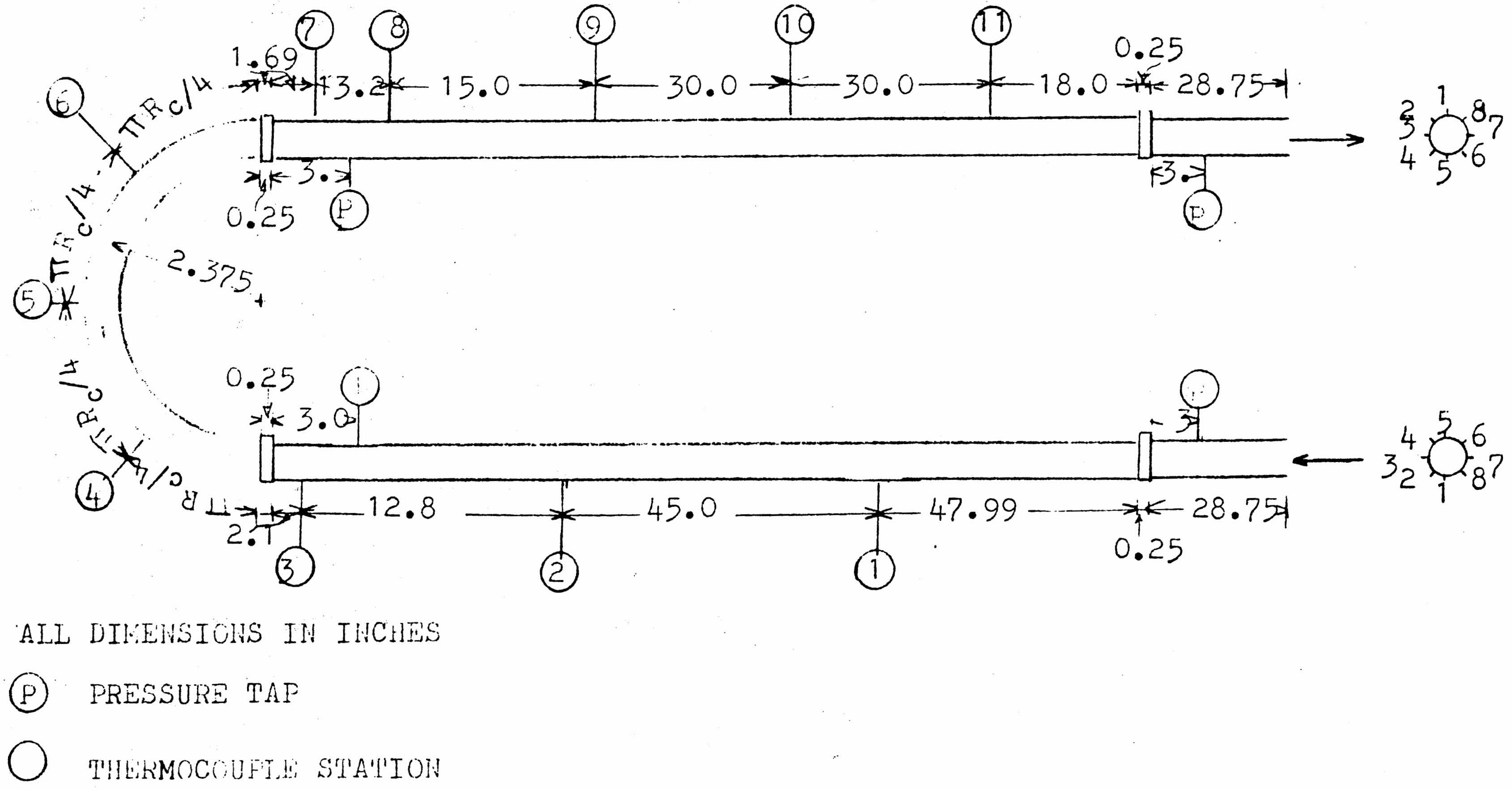


Figure 8: Location of Thermocouple Stations and Pressure Taps on Test Section C.

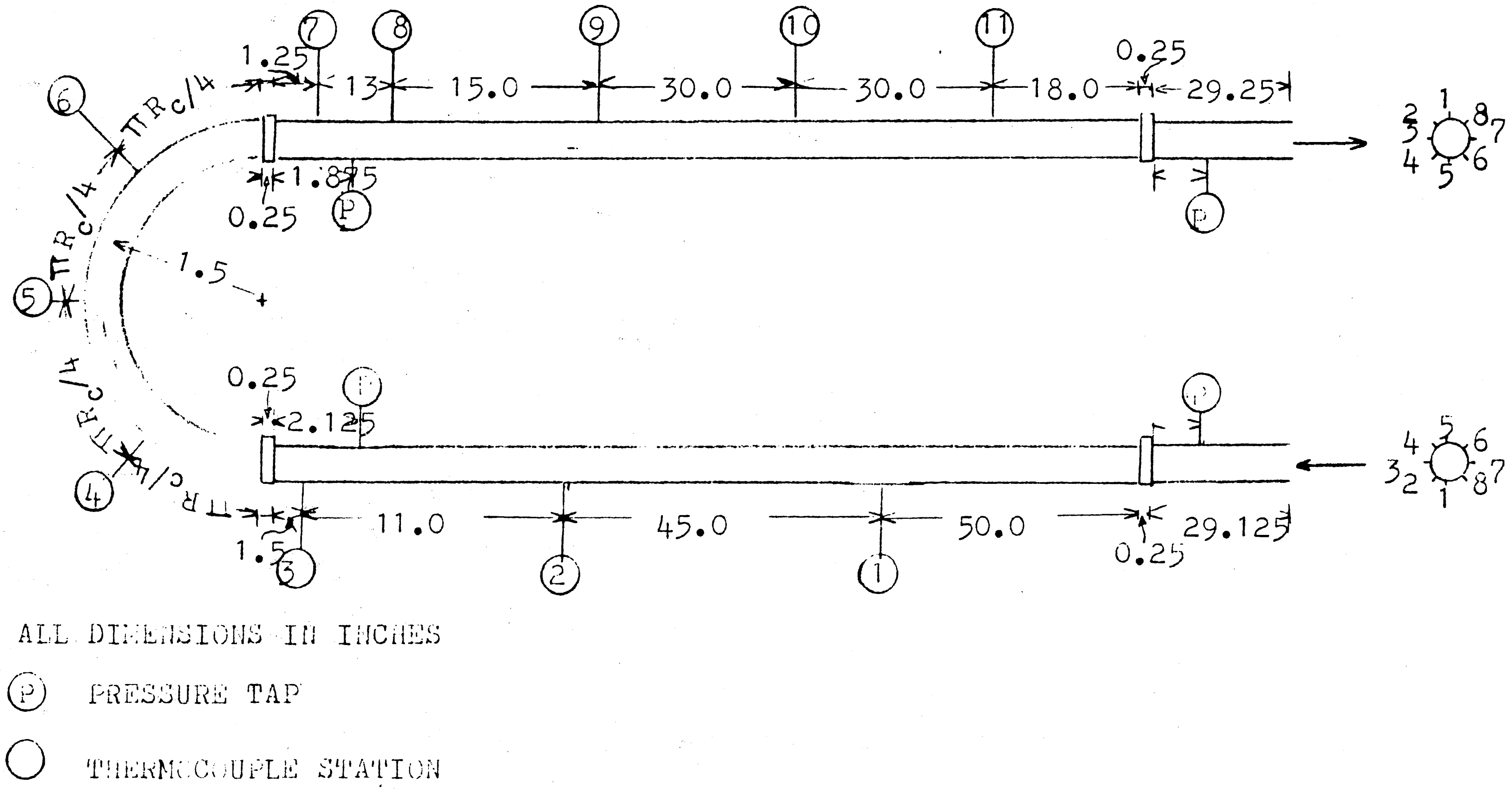


Figure 9: Location of Thermocouple Stations and Pressure Taps on Test Section D.

TABLE I

SPECIFICATIONS OF THE U-TUBES

Tube	A	B	C	D
Bend radius, in. (m)	4.75 (0.121)	9.75 (0.251)	2.375 (0.060)	1.50 (0.036)
Outside tube diameter, in.(m)	0.875 (0.022)	0.875 (0.022)	0.75 (0.019)	0.75 (0.019)
Inside tube diameter, in. (m)	0.769 (0.020)	0.769 (0.020)	0.62 (0.016)	0.62 (0.016)
Length of each straight, section, in.(m)	70.75 (1.797)	65.0 (1.651)	137.14 (3.483)	137.0 (3.48)
Length of each heated, section, in.(m)	58.75 (1.492)	46.25 (1.175)	108.39 (2.753)	108.0 (2.74)
Material of construction (seamless tube)	Inconel 600		Stainless steel 304	

soldered to each test section. Figures 6, 7, 8 and 9 illustrate the positions of these electrodes for test sections A, B, C and D, respectively. These copper bars serve as electrodes for passing the DC current through the wall of the test section. Each test section was electrically isolated from the rest of the loop with a short piece of neoprene tubing at each end. The pressure taps were isolated electrically by connecting them with Tygon tubing.

All experiments were performed on horizontal U-tubes with the U-bend in the vertical plane. The test fluid entered at the bottom and exited at the top for the four test sections.

Thermocouples

Copper constantan thermocouples (NN-T-30) were used to measure the bath temperature, room temperature and fluid bulk temperatures at the inlet and exit of the test section, as well as the outside wall temperatures of the test tubes. The inlet and exit thermocouple wires were overbraided with stainless steel for shielding. All thermocouple beads (approximately 0.5 mm diameter) were fabricated with a thermocouple welder in the laboratory.

Eighty-eight thermocouples were placed at eleven stations on the outside tube wall of each test section. Figures 7, 8, 9 and 10 show the locations of these stations for test sections A, B, C and D, respectively. At each station, eight thermocouples were placed 45 degrees apart around the tube periphery.

Each thermocouple carries two numbers. The first number (1 to 11) specifies the station number, while the second number (1 to 8) indicates the location of the thermocouple around the periphery of the tube. The thermocouples at each station were numbered such that number 1 was always at the outside of the bend, or the bottom of the lower straight section, or the top of the upper straight section. Thermocouple 5 was always on the inside of the bend or the top of the lower straight section or the bottom of the upper straight section, see Figures 6 through 9.

The thermocouple beads were fixed on the outside surface of the test sections A and C with Sauereisen cement, and on the surfaces of test sections B and D with Omegabond 101. The Omegabond 101 (27) is an epoxy adhesive which cures at room temperature and can endure continuous temperatures up to 275 F (135 C). This adhesive has a high thermal conductivity (86.4 Btu/(hr.ft)) and very high electrical resistivity (10^{15} Ohm-cm). At the point of thermocouple attachment, the surface of the test section was roughened with sand paper, then cleaned with acetone. A thin layer (approximately 1 mm) of the adhesive was placed at the intended thermocouple location and allowed to set, thus insulating the thermocouple beads from the surface and electrical current. The thermocouples were then held in place with metal hose clamps; the latter were electrically insulated from the test section with fiberglass. Another layer of adhesive was placed on the thermocouple beads, and left to set.

Before insulating the test sections, all the thermocouples attached to it were checked with a digital multimeter. Whenever necessary, immediate corrective action was taken such as rewelding the thermocouple bead or insulating any bead in direct contact with the tube wall.

The thermocouple lead wires from each station were connected to a barrier strip at the instrument panel, which in turn was connected by welding the wires to a rotary switch. The output leads from the rotary switches were welded to a master rotary switch, which was connected to a Doric thermocouple digital indicator.

Digital Thermocouple Indicator

A Doric digital thermocouple indicator, type T model DS 350, displayed the thermocouple outputs in degrees Fahrenheit. It has an accuracy of ± 0.3 F (5).

DC Power Source

A Lincolnweld SA-750 electric welder generated flat DC current, which was passed through the straight sections of each test tube between the copper bars, thus creating resistance heating. The DC power generator has a maximum output power of 30 KW. The duty cycle rating of the SA-750 is 750 amperes at 40 volts, continuous duty (17).

Voltmeter

The voltage drop through the straight sections of the test tube was measured by a Numatron. The Numatron is Leeds and Northrup Company's trade name for the voltmeter with a digital readout (16). The research engineer in the Electronics Laboratory calibrated the Numatron. The readings of the voltmeter agreed with the calibration.

DC Ammeter

The current, passing through the walls of the test section, was measured with a Weston 931 ammeter. It has a range of 0 to 750 amperes DC. It was placed in parallel with a 50 millivolt shunt. The Electrical School Laboratory Manager calibrated the ammeter. It is accurate within one per cent of its full range, i.e. ± 7.5 amperes.

Heat Exchanger

A 1-4 heat exchanger, manufactured by Kewanee-Ross Corporation, cooled the fluid from the test section. Water passing through the tubes was the cooling fluid.

Fluid Bath

The fluid bath was manufactured by Precision Scientific Co. The micro-set thermoregulator has a maximum rated temperature of 210 F (100 C), with a control sensitivity of ± 0.02 F (0.01 C) over the entire range (29). A T-type thermocouple measured the bath temperature. The pump at the bottom of the agitator was removed because it introduced air into the system. Two insulated tanks were used as the fluid bath. The original fluid bath tank holds 2.5 gallons and was used with the vane pump. The second insulated tank holds 14.7 gallons and was used with the turbine pump to eliminate the air entrainment problem (the probem is mentioned in chapter IV).

Pumps

A sliding vane pump was used to pump the fluids through the experimental loop. It is a positive displacement pump, manufactured by Eastern Industries, Inc. (Model VW-5-A). It has a maximum capacity of 1.2 gpm of water.

A turbine pump, manufactured by Roy E. Roth Co., was used for higher flow rates. The pump has a rated capacity of 10 gpm of water.

Rotameters

Two full-view rotameters measured the fluid flow rate after the pumps. Table II shows the rotameter specifications.

TABLE II

ROTAMETER SPECIFICATIONS

Item	Brooks rotameter	Fischer-Porter rotameter
Rotameter model number	1110-08H2B1A	10A3567A
Rotameter tube number	R-8M-25-4	FP-1-35
Float number	8-RV-14	6806A2725A7
Maximum water flow rate, gpm	1.45	6.0
Accuracy (% of full scale)	|2|	|2|

Pressure Gauges

To check the operation of the heat transfer apparatus, two pressure gauges were inserted on the fluid line after the pumps. The Ashcraft gauge ranged from 0 to 60 psig, with 0.25 psi divisions. The Norgren ranged from 0 to 60 psig, with 2 psi divisions.

Manometer

The six pressure taps, shown in Figure 5, were connected to a manifold by a series of Whitey valves. The switching system was arranged in such a manner that differential pressures between any two taps on different sides of the bend could be read on a U-tube manometer. The Meriam Instrument Co. supplied the manometer.

Test Fluids

Distilled water and an ethylene glycol solution (1 to 5 %) were tested. Fisher Scientific Co. supplied the ethylene glycol (E 178). Due to the hygroscopic nature of this glycol, the composition of the ethylene glycol solution was checked frequently. The supplied ethylene glycol had a water content of 0.2 %, but after opening the bottle and while handling (due to its hygroscopic nature), the water content increased (1 to 5 %).

Calibration Equipment

Auxiliary equipment was used for the calibration of the measuring instruments. The temperature and flow calibration equipment are included in Appendices A and C, respectively. The apparatus for the determination of the viscosity is described in Appendix D.

CHAPTER IV

EXPERIMENTAL PROCEDURE

Calibration Procedures

The thermocouples that measured the inlet bulk, exit bulk, bath and room temperatures were calibrated against a platinum thermometer. The calibration procedure and data for these thermocouples are given in Appendix A. Appendix B includes the surface temperature calibration data and a listing of a program to correct the outside wall temperature. The flow rate calibration procedure is presented in Appendix C. The procedure for evaluating the composition of ethylene glycol is given in Appendix D.

Start-Up and Operating Procedure

Before any experiment was performed, the fluid flow loop was tested for possible leaks by flowing water at the maximum possible flow rate. Any leaks detected were eliminated. The fluid flow loop was then insulated with woven fiberglass tape, bonded fiberglass tape, fiberglass pipe insulation and topped with aluminum foil or vapor seal tape.

Four test sections were tested, one at a time. After mounting a test section, the thermocouple wires were attached to the barrier strips on the switchboard box, and the electrodes connected to the generator.

The following procedure was followed for each run:

1. The agitator and the heater in the fluid bath were put on and set to the operating temperature (80 - 100 F), respectively.
2. The pump was started and the fluid flow rate was adjusted to the desired value by means of the flow control valves.
3. Since the capacity of the motor of the turbine pump was higher than required for pumping ethylene glycol (due to changes in the design of the line) the temperature of the ethylene glycol kept rising. Hence, as soon as the bath set temperature was reached, water was passed through the second cooling coil in the bath to keep the temperature of the circulating fluid constant.
4. After the test fluid had circulated at constant temperature for one hour the room, bath, inlet bulk, and exit bulk temperatures were recorded.
5. The Numatron was turned on.
6. The DC generator was started, with the polarity switch in the off position, and allowed to warm up for 30 minutes.
7. The polarity switch was switched to the electropositive position and the DC current was adjusted to the desired value by varying the output control switch on

the control box of the generator.

8. The cooling water was started to the heat exchanger located downstream of the test section. The cooling water flow rate was adjusted so that the bath fluid temperature remained constant.
9. The fan located near the door was turned on to keep the laboratory temperature constant during the run.
10. After at least two hours of steady state operation the following data were taken:
    a. the inlet and exit bulk fluid temperatures
    b. fluid flow rate (rotameter reading)
    c. the room and bath temperatures
    d. the DC current flowing through the wall of the test section and the voltage drop across the test section
    e. the output readings of the 88 thermocouples attached to the surface of the test section
    f. the differential pressures across the test section.
11. The data collected in step 9 were gathered again after half to one hour to ascertain that steady state was achieved. If the data did not agree, then step 10 was repeated until the data agreed within a maximum of ± 0.3 F (0.2 C), except for the transitional flow regime where temperatures could fluctuate ± 1 F (0.6 C).
12. The DC generator, Numatron and cooling water to the heat exchanger were shut off.
13. To calculate the heat loss at the exit of the test

section, the bath temperature was set to slightly higher than the exist bulk temperature. After circulating the test fluid at that set temperature for at least an hour, the inlet bulk, exit bulk and bath temperatures were recorded.

Some of the Problems Encountered

The voltage produced from the DC power source fluctuated slightly (± 0.01 Volts). Consequently, the temperature reading of the surface thermocouples fluctuated within ± 0.2 F (0.1 C). Accordingly, the heat generated in the tube had a maximum error of 3.3 % (see Appendix K for the error analysis).

Unstable surface thermocouple readings were obtained due to overheating (over 90 F) of the laboratory atmosphere. The problem was minimized when the laboratory door was kept open, a fan was installed infront of the door and behind the DC source to exhaust the warm air, and a higher flow rate of conditioned air was supplied to the laboratory.

Bubbles were noticed in the constant temperature tank and dispersed air was observed in the Fischer-Porter rotameter, when ethylene glycol was passed through the turbine pump. The air was eliminated from the system by installing a bigger (14.7 gallon) constant temperature tank. The higher capacity tank allowed a longer setting time for the bubbles.

Two of the pressure taps leaked due to unnoticed breaks. The thermocouples close to the leak became wet.

Suspiciously low temperature readings increasing slowly (within one hour) to reasonable readings revealed the problem. These and similar runs were omitted.

CHAPTER V

DATA REDUCTION

Four test sections were tested with nearly pure ethylene glycol solutions (water content 1 to 5 %), and one test section tested with distilled water. The test sections and the locations of the thermocouples on each test section are described in chapter III. The raw experimental data are included in Appendix G. The physical quantities measured for each run are listed in the second section of chapter IV. The computer program used by Moshfeghian (24) was modified to reduce the experimental data using the IBM 3081K. The listing for the modified computer program used to analyze the data is presented in Appendix H.

The outside wall temperatures were measured along the U-bend at 11 stations, with 8 peripheral positions at each station. For the calculation of the average local dimensionless groups, the bulk fluid temperature was assumed to increase linearly with the axial distance through the heated portion of the U-tube. The average bulk fluid temperature for each test section is assumed to be the arithmetic average of the inlet and exit bulk fluid temperatures. The average bulk fluid temperature was used in calculating an average bulk Reynolds and an average bulk Prandtl numbers for each run.

The physical properties of the test fluids and the tube walls are evaluated as functions of temperature as given in Appendix E. These correlations are incorporated into the computer program for reducing the data.

The following steps are followed in reducing the data:

1. Calculation of the overall heat balance.
2. Calculation of the local inside wall temperature and the local inside wall radial heat flux.
3. Calculation of the local heat transfer coefficient

Details of these procedures follows, and a sample calculation is presented in Appendix I.

Calculation of the Overall Heat Balance

The overall heat balance for each run is calculated as follows:

1. The rate of heat input to the fluid is calculated from the power input to the test section and the heat loss from the test section. The heat loss from the test section is the arithmetic mean between:
   a. the heat loss when the test fluid is run at constant temperature equal to the inlet bulk temperature, and
   b. the heat loss when the test fluid is circulated at a constant temperature equivalent to the exit bulk temperature (during a run).

$$Qinput=(F)(I)(V)-Qloss \qquad (V.1)$$

where Qinput = rate of heat input to the test section, Btu/hr.

F = conversion factor.

I = current to the test section, amperes.

V = voltage drop across the test section, volts.

Qloss = rate of heat loss from the test section, Btu/hr.

2. The heat absorbed by the fluid is calculated from the mass flow rate, inlet and outlet temperatures, and the specific heat evaluated at the average bulk temperature:

$$\text{Qoutput}=(\dot{m})(C_p)(T_o-T_i) \qquad (V.2)$$

where Qoutput = heat gained by the test fluid, Btu/hr.

$\dot{m}$ = mass flow rate of the liquid flowing through the test section, lbm/hr.

C_p = specific heat of the liquid at the average bulk temperature in the test section, Btu/(lbm.F).

T_o = bulk liquid temperature at the exit of the test section, F.

T_i = bulk liquid temperature at the inlet of the test section, F.

3. The error in the heat balance is calculated as follows:

$$\text{per cent error}=(100)(\text{Qinput}-\text{Qoutput})/\text{Qinput} \qquad (V.3)$$

Calculation of the Local Inside Wall Temperature and the Local Inside Wall Heat Flux

The computer program in Appendix H corrects the measured outside wall temperature according to the calibration in Appendix B. Then the inside wall temperature and the inside heat flux corresponding to each thermocouple location are computed using a two-dimensional relaxation calculation. In the numerical solution it is assumed that peripheral and radial wall conduction are significant, while axial conduction is negligible. Also, the solution accounts for the heat losses to the surroundings and the variation of the physical properties of the tube wall with the temperature. The derivation of the numerical solution is given in Appendix F.

Calculation of the Local Heat Transfer Coefficient

From the local inside wall temperature, the local inside heat flux and the bulk fluid temperature, the local heat transfer coefficient can be calculated as follows:

$$h_{ji}=q_{ji}/(T_{wi}-T_{b}) \tag{V.4}$$

where h_{ji} = local heat transfer cofficient.
q_{ji} = local inside heat flux.
T_{wi} = local inside wall temperature.
T_{b} = bulk temperature at station j.

The subscript 'j' denotes the station number and 'i' denotes the peripheral position.

The average peripheral heat transfer coefficient at a thermocouple station is calculated by two different methods

$$h_j = (1/8) \sum_{i=1}^{8} \{(Q/A)_i / (T_{wi} - T_b)\} \qquad (V.5)$$

$$h_j = \{(\sum_{i=1}^{8} q_i)/8\} / \{(\sum_{i=1}^{8} T_{wi})/8 - T_b\} \qquad (V.6)$$

The average peripheral heat transfer coefficients obtained from equations (V.5) and (V.6) were then used to determine the average peripheral Nusselt number for the thermocouple station. The Nusselt number based on equation (V.6) was used in the rest of thesis except if otherwise indicated. Equation (V.6) resembles practical cases where an average heat flux and an average temperature may be available. The physical properties of the test fluid, used in determining the dimensionless groups, were evaluated at the bulk temperature.

CHAPTER VI

RESULTS AND DISCUSSION OF RESULTS

Experimental data were gathered for four U-tubes for local bulk Reynolds numbers ranging from 120 to 2500, local bulk Prandtl numbers from 4 to 110, local Grashof numbers from 2500 to 1,130,000 and curvature ratios from 4.84 to 25.36. The test fluids were distilled water and almost pure ethylene glycol solutions (water content 1 to 5 %). The experiments were performed with nominally constant wall heat flux. The average heat fluxes ranged from 990 to 4230 Btu/hr.sq.ft (3.12 to 13.33 kW/sq.m.).

Effect of Various Parameters on the Heat Transfer Coefficient

Straight Section Upstream of the Bend

The peripheral temperature distribution upstream of the bend (begining from station 1) is shown at the left side of Figures 10 through 12 for runs 304, 312 and 354, respectively. As the fluid enters the straight section upstream of the bend ($X/d = 0$), the temperature is uniform and equal to the bulk temperature. However, as the fluid moves along this straight section there is considerable variation in the temperature between the top and bottom and

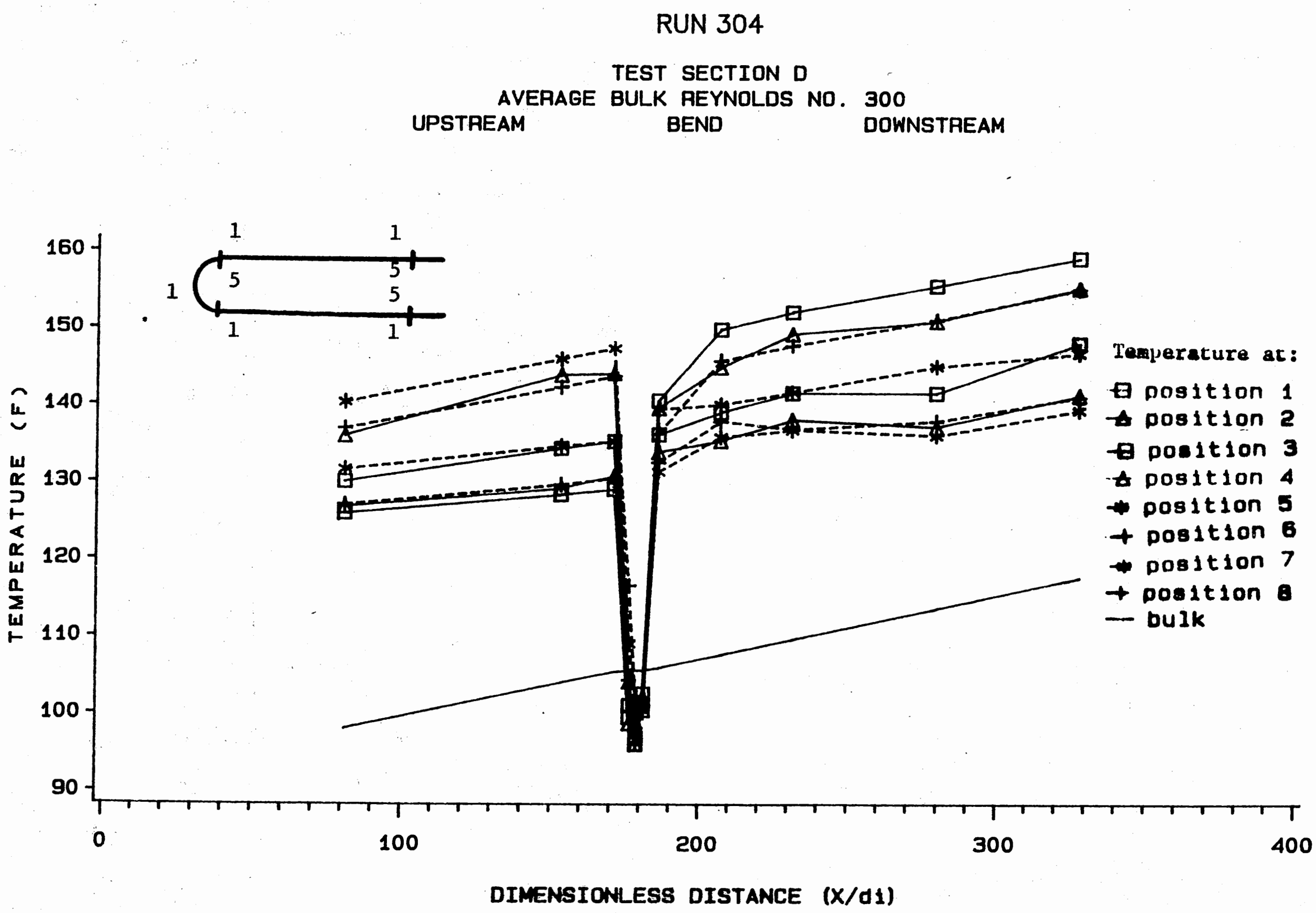


Figure 10: Variation of Local Temperature through the Test Section at Low Reynolds Numbers for Ethylene Glycol.

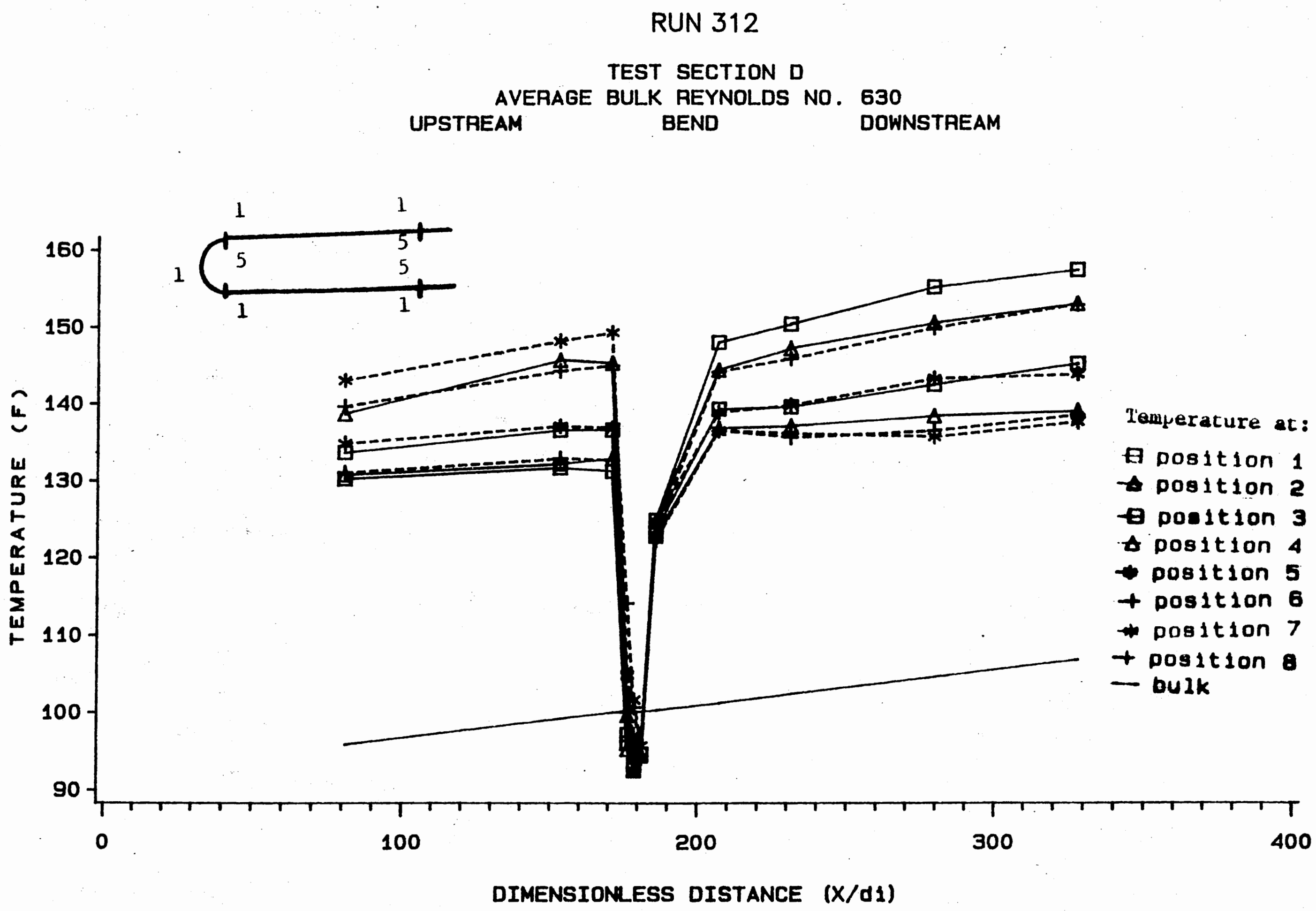


Figure 11: Variation of Local Temperature through the Test Section at Intermediate-Low Reynolds Numbers for Ethylene Glycol.

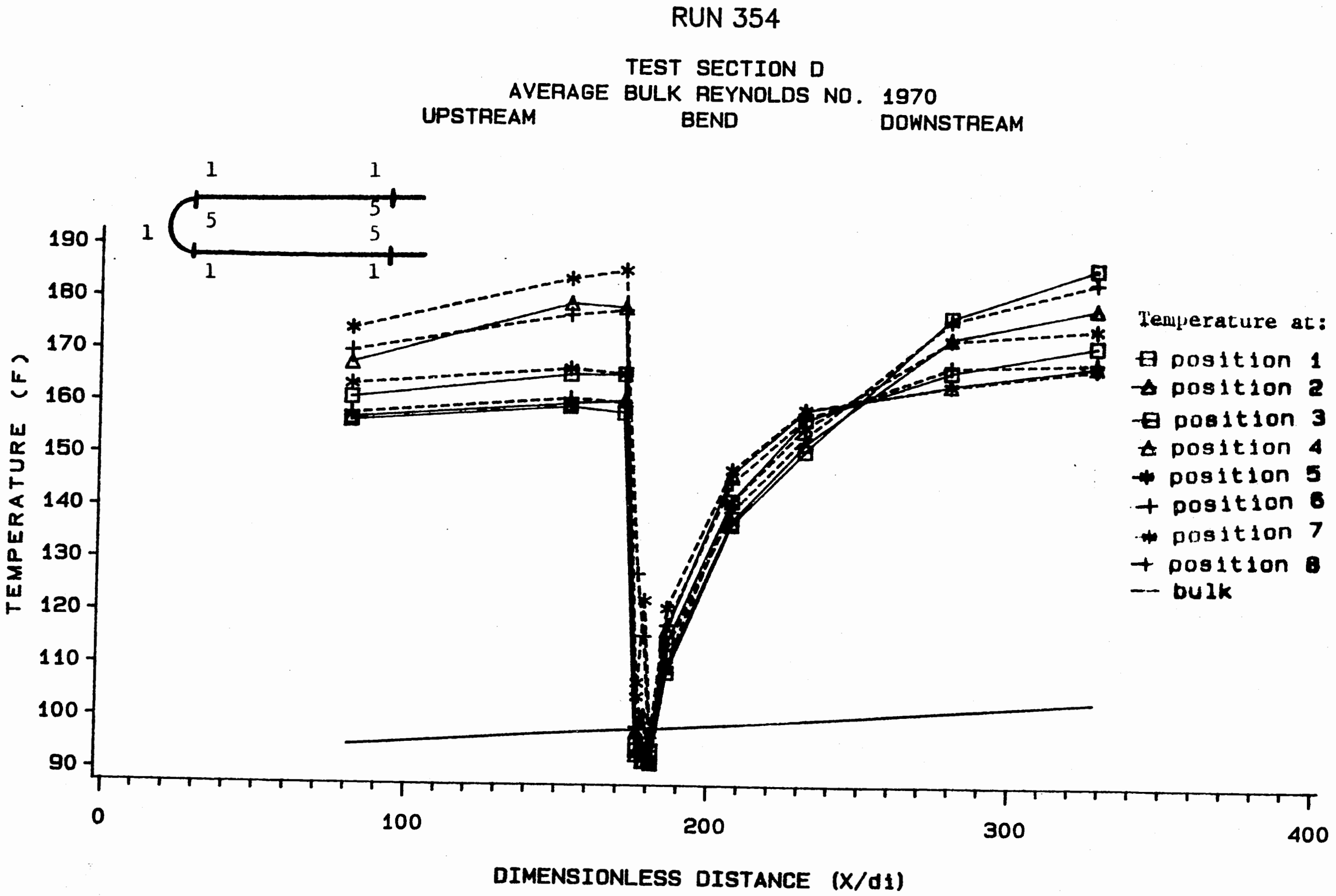


Figure 12: Variation of Local Temperature through the Test Section at High Reynolds Numbers for Ethylene Glycol.

around the tube periphery. This behavior was also observed by other researchers (1), (9), (19), (24) and (25). This phenomenon is due to natural convection. Due to heating, the fluid closer to the tube wall is warmer and consequently less dense than the bulk fluid in the core. Thus, the lighter fluid flows along the tube wall to the top and the heavier fluid at the core flows to the bottom, as shown in Figure 1 (page 2). Hence, the temperature is highest at the top of the tube and lowest at the bottom. Consequently the apparent heat transfer coefficient is maximum at the bottom of the tube and minimum at the top.

The experimental Nusselt numbers calculated by equations (V.5) and (V.6) are compared in Figure 13. For ethylene glycol both methods give very close results, though equation (V.6) gives slightly lower values. Water data (scattered points) showed great deviations between the two methods of calculation, though as with ethylene glycol equation (V.6) was always lower. Thus, equation (V.6) will be used in calculating the Nusselt number through the rest of thesis except if otherwise stated.

Figures 14 through 16 show the local average peripheral Nusselt number as a function of the local bulk Reynolds number with the dimensionless distance (X/d_i) as a parameter upstream of the bend. These graphs indicate that for water the average peripheral heat transfer coefficient calculated by equation (V.5) decreases with the increase in Reynolds number and increases with the distance down the tube (Figure 14). But when the average peripheral heat transfer

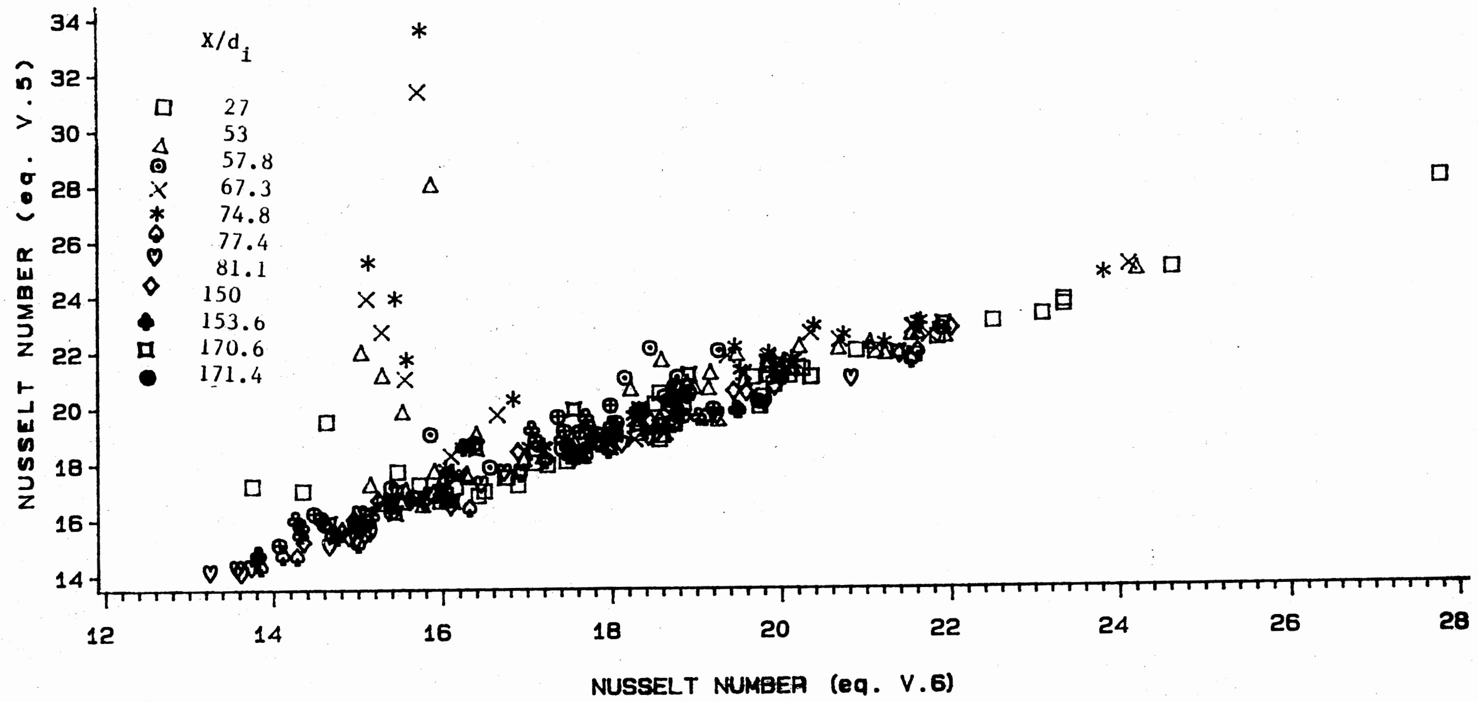


Figure 13: Comparison between the Experimental Nusselt Numbers Calculated by Equations (V.5) and (V.6) Upstream of the Bend.

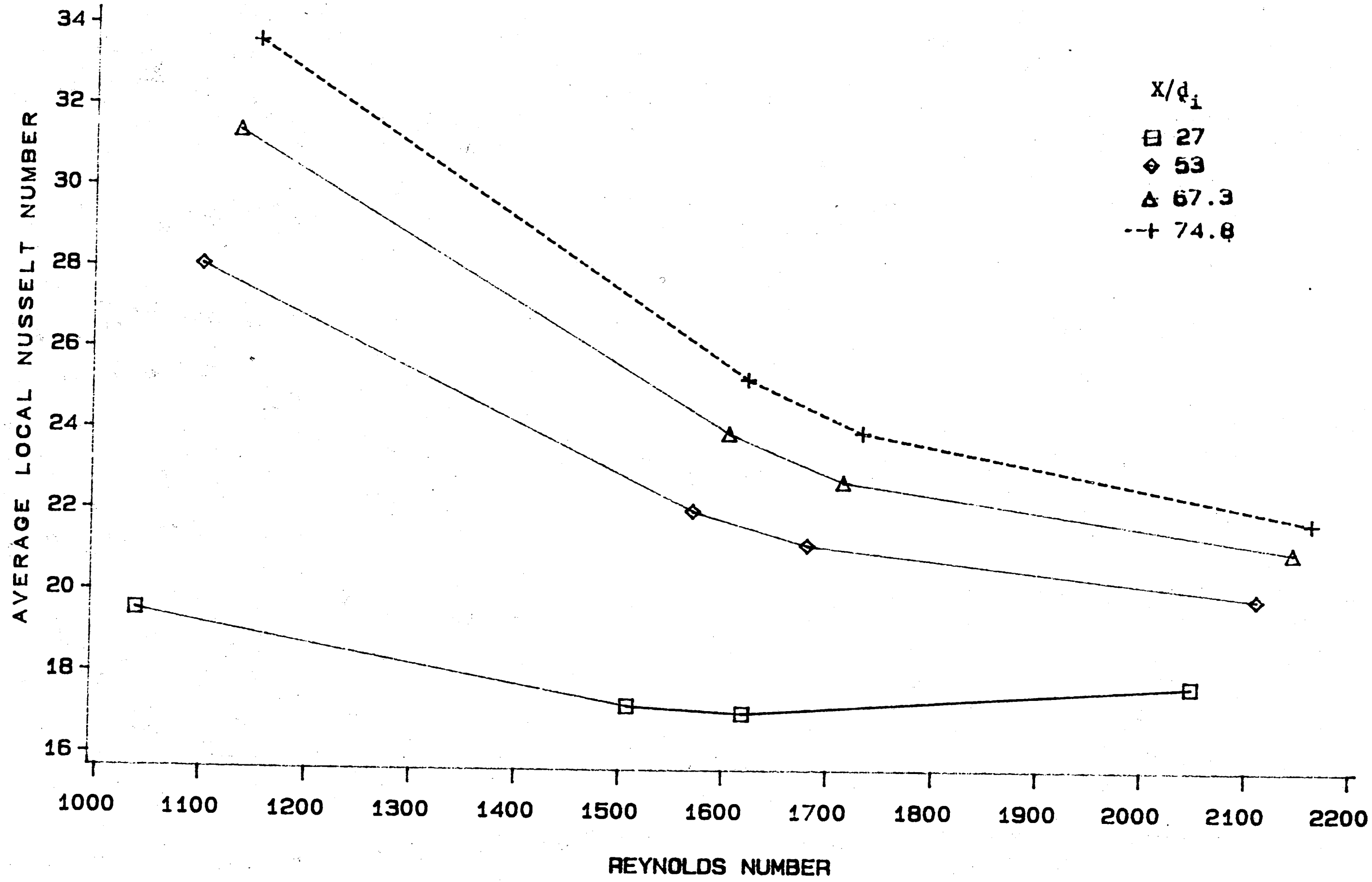


Figure 14: Effect of Reynolds Number on the Average Local Heat Transfer Coefficients (eq. V.5) Upstream of the U-Bend for Test Section A Using Water.

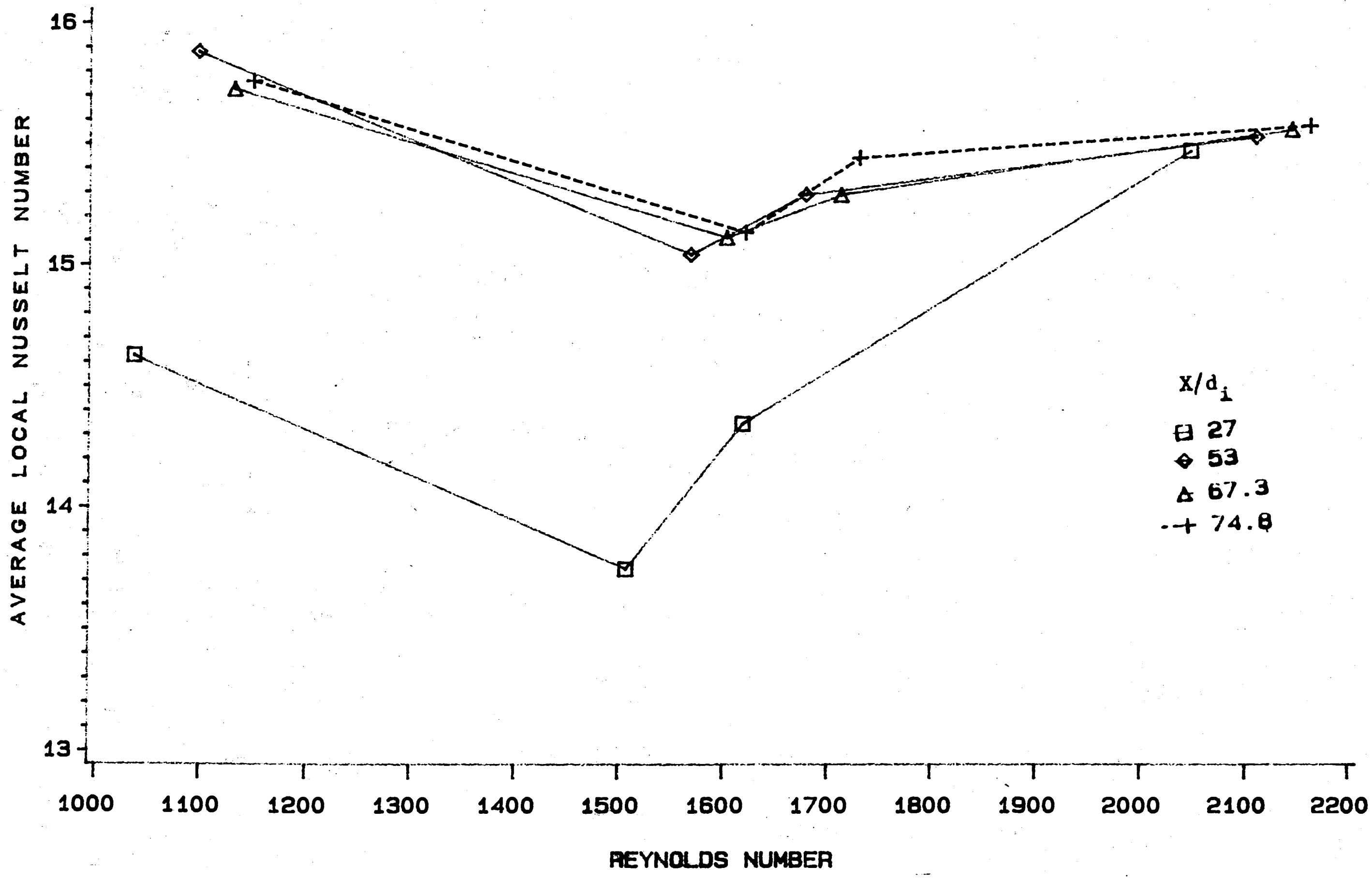


Figure 15: Effect of Reynolds Number on the Average Local Heat Transfer Coefficient (eq. V.6) Upstream of the U-Bend for Test Section A Using Water.

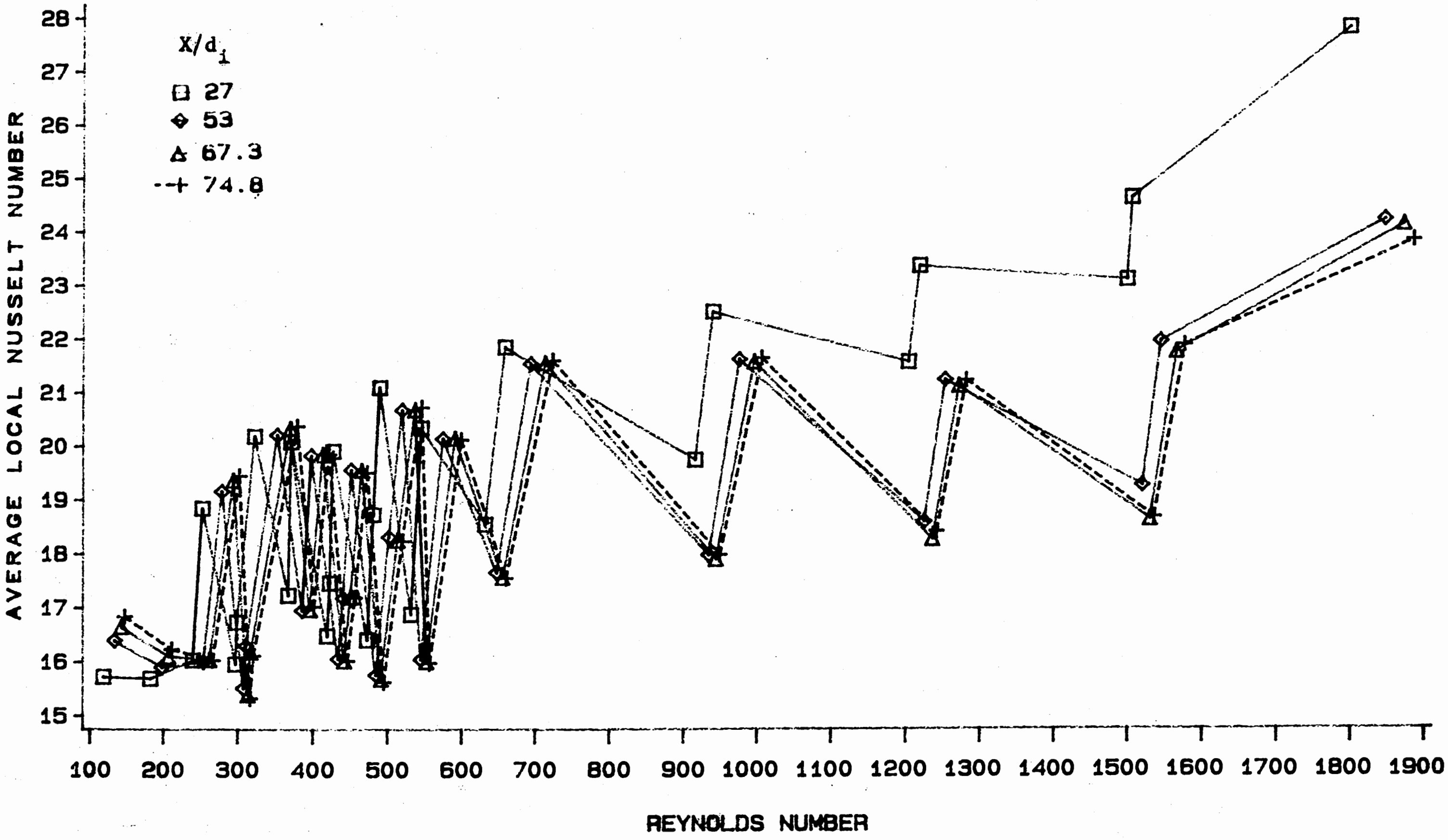


Figure 16: Effect of Reynolds Number on the Average Peripheral Heat Transfer Coefficient Upstream from the U-Bend for Ethylene Glycol.

coefficient was calculated by equation (V.6), the Reynolds number did not seem to have any effect (Figure 15). For ethylene glycol (figure 16) the heat transfer coefficient (equations (V.5,6)) increases with distance down the tube at low Reynolds numbers (when the tertiary flow is predominant) and decreases with distance at high Reynolds numbers (when the primary flow is predominant). The variation in the Reynolds number has no effect on the heat transfer coefficient for ethylene glycol. The irregularities in the curves are due to the variations in the Grashof and Prandtl numbers.

Upstream of the U-bend, the local average peripheral Nusselt number was plotted against the local Grashof number with the dimensionless distance as a parameter. These graphs are shown in Figures 17 and 18 for test section A with water and ethylene glycol as test fluids. Test sections B, C and D have similar plots. Studying these plots reveals that the local average peripheral heat transfer coefficients increase with the increase in the Grashof number. The irregularities in the curves are due to the variations in the Prandtl numbers for the different runs. The Nusselt numbers are higher than predicted for forced convection due to the presence of natural convection.

The Bend

The U-bend was unheated. At station 4, the first quarter of the bend, the temperature at the outside of the bend is lower than the temperature at the inside of the

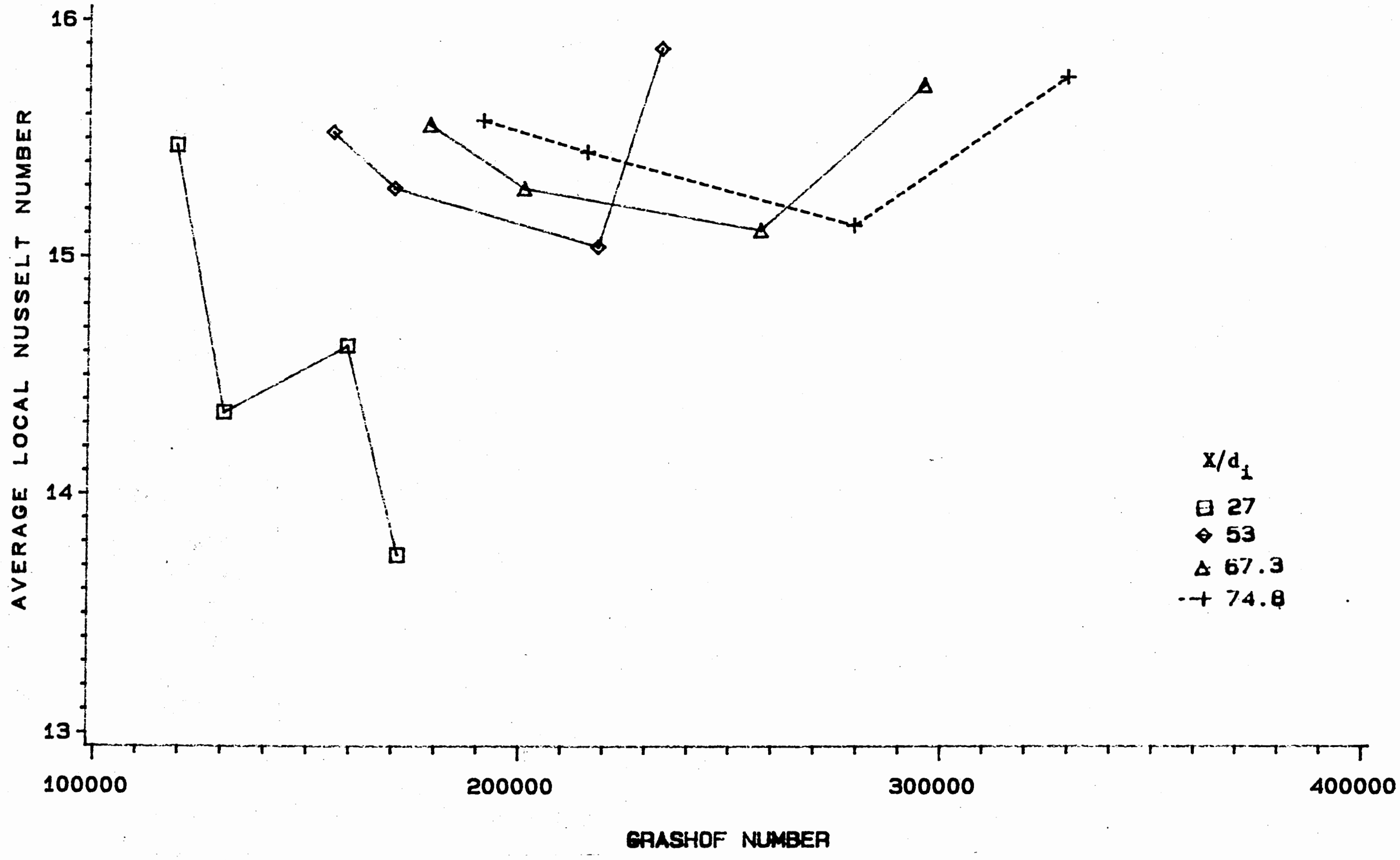


Figure 17: Effect of Grashof Number on the Average Peripheral Heat Transfer Coefficient Upstream of the Bend Using Water.

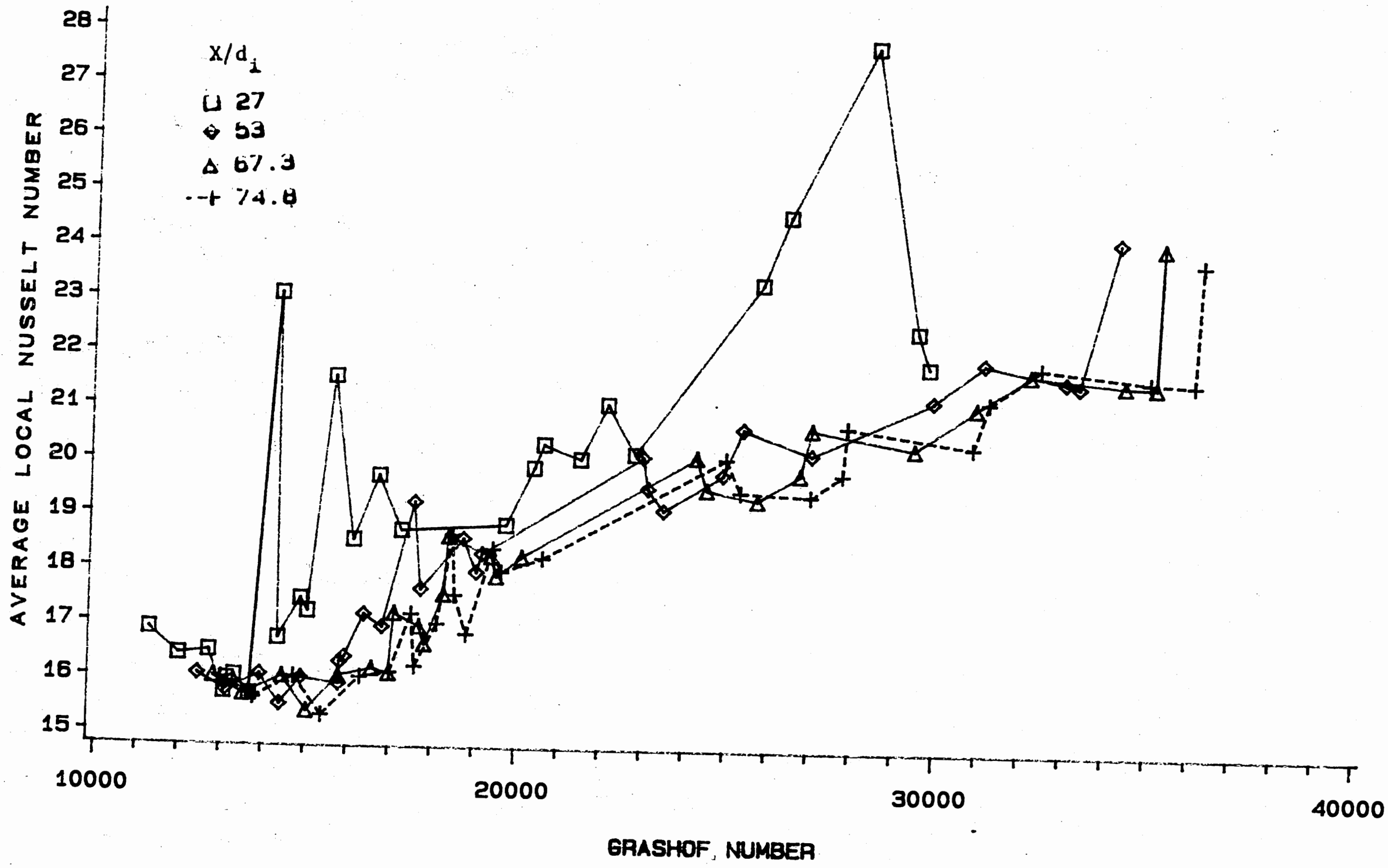


Figure 18: Effect of Grashof Number on the Average Peripheral Heat Transfer Coefficient Upstream of the Bend Using Ethylene Glycol.

bend. This behavior is explained by the fact that immediately before the bend natural convection exists, where the temperature is maximum at the top of the tube and minimum at the bottom. These temperatures of the test fluid in contact with these surfaces persist for some distance in the bend.

At station 5, which is at the middle of the bend, the temperature at the outside of the bend is always lower than the temperature at the inside of the bend, though the temperatures around the periphery are nearly uniform.

At station 6, the third quarter of the bend, for high Dean numbers using ethylene glycol, the temperature at the outside of the bend is lower than the temperature at the inside of the bend. This behavior is due to the centrifugal action, which causes the faster moving, cooler fluid at the tube centerline to move toward the outer wall of the bend and the slower moving fluid near the tube wall to move toward the inner wall of the bend, as shown in Figure 19. This secondary flow pattern is not observed at high curvature ratios and very low Reynolds numbers (Re = 200), i.e. at low Dean numbers. As seen in Figure 20, higher temperatures were noticed at the outside of the bend and lower temperatures at the inside of the bend. This behavior might be due to one or both of the following reasons: (1) heat conduction in the tube wall at the bend from the heated straight sections, which results in natural convection effects. (2) The fluid enters the bend with a nonuniform temperature. At low Dean numbers there is slight mixing and

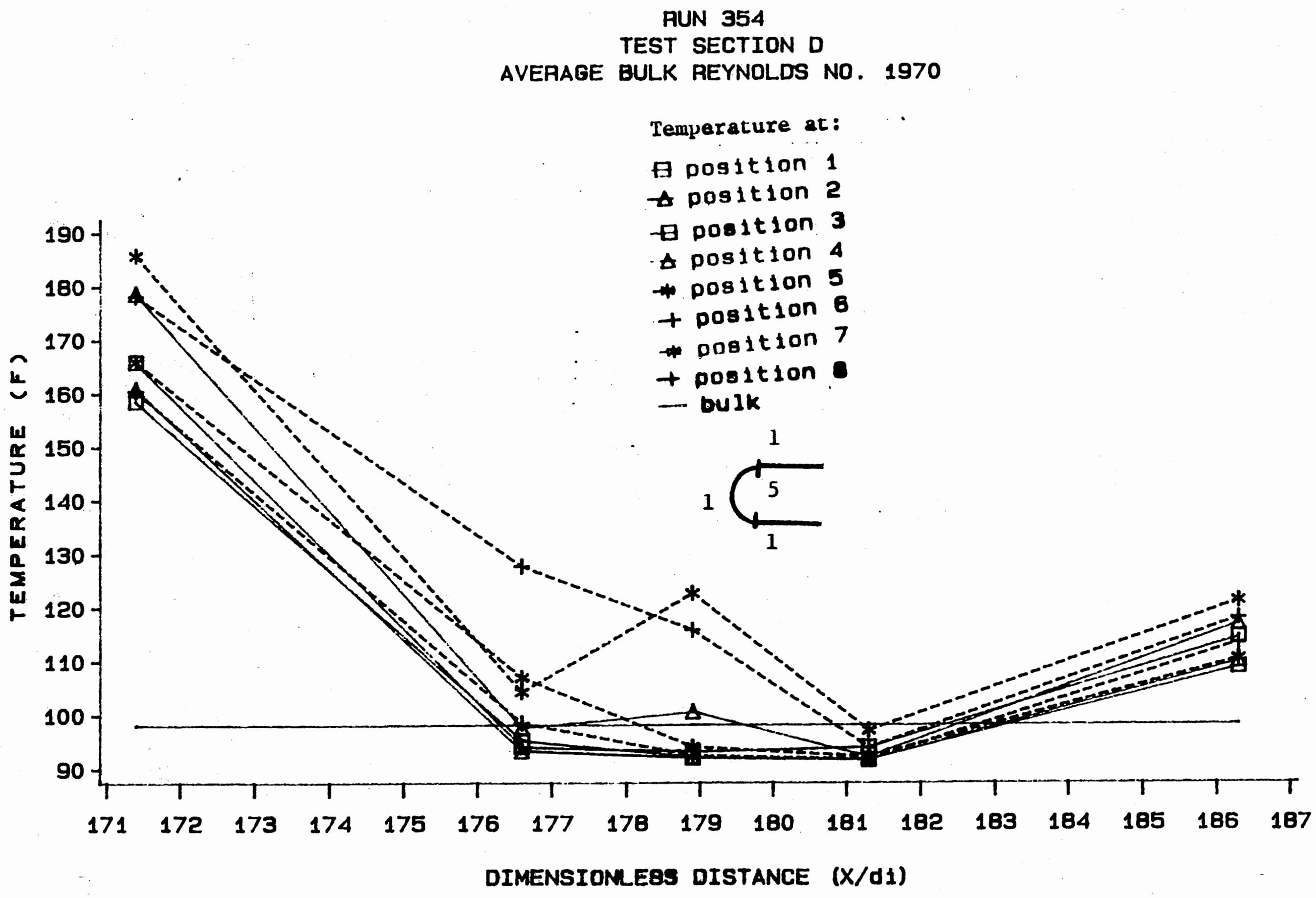


Figure 19: Variation of Local Temperature with Distance in the Unheated Bend at High Dean Numbers.

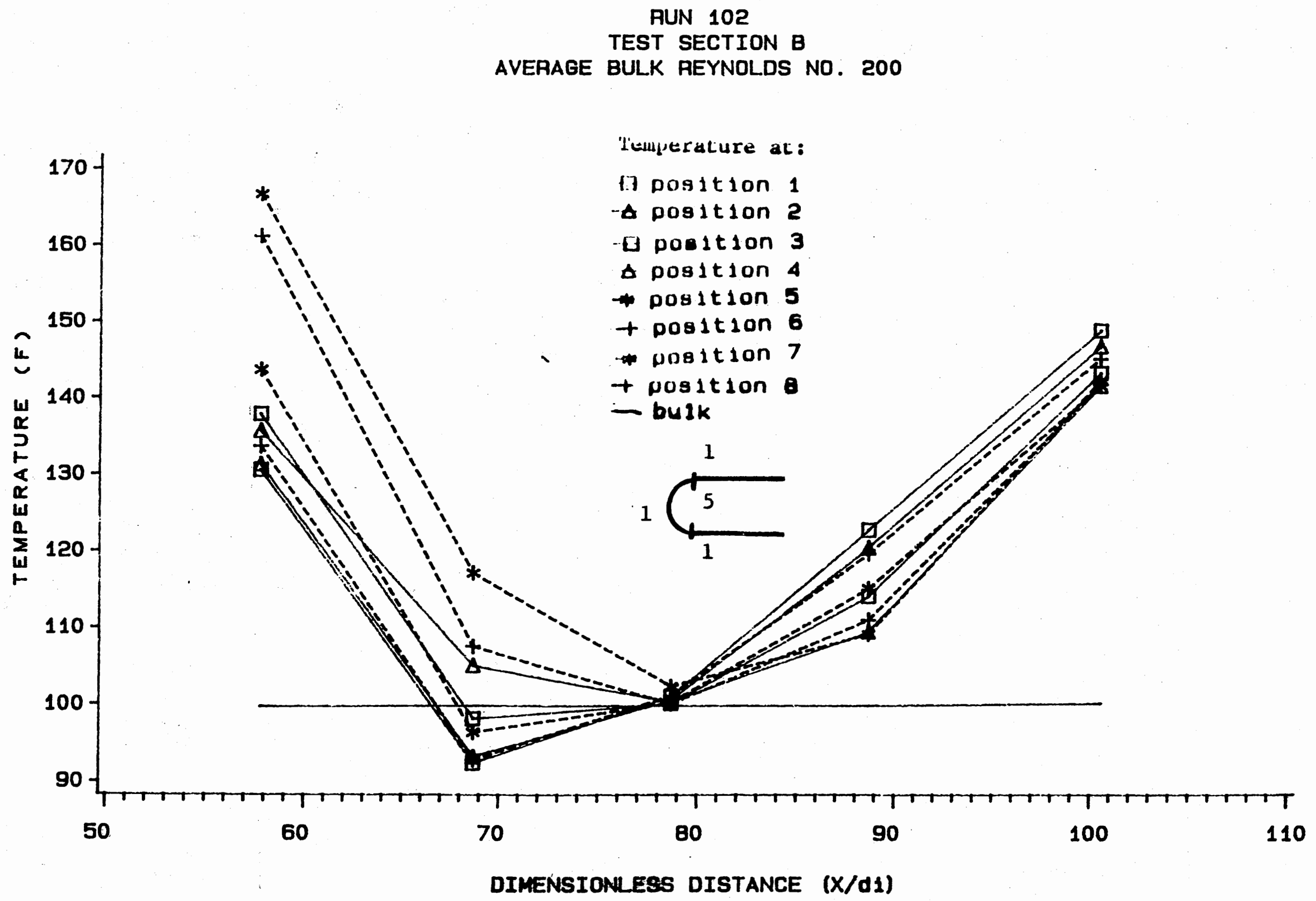


Figure 20: Variation of Local Temperature with Distance in the Unheated Bend at Low Dean Numbers.

consequently the effect of buoyancy is observed after station 5. The buoyancy effect causes the warmer, lower density fluid to move toward the higher locations (bend outside), while the cooler fluid moves downwards and towards the bend inside. This behavior might be the reason for the relatively low temperatures at the inside of the bend at station 5. Visual studies of the flow behavior at low Dean numbers are required to validate this hypothesis.

Straight Section Downstream from the U-Bend

From studying 84 runs for four U-tubes, it is concluded that after the bend at low Reynolds numbers the primary and tertiary flow patterns predominate. As the Reynolds number increases the secondary flow pattern becomes predominant for a short distance that also increases with the intensity of the secondary flow (higher Dean numbers). These effects can be seen from the peripheral temperature distribution downstream from the bend for runs 304, 312 and 354 in Figures 10, 11 and 12, respectively.

The experimental heat transfer coefficient downstream from the U-bend was calculated by both equations (V.5) and (V.6). Figure 21 shows the comparison between both methods. Both methods of calculation gave similar results for the ethylene glycol and different results for water.

When the ratio of the Grashof number to the square of the Reynolds number is close to unity mixed convection exists, but when the ratio is far below unity forced convection alone prevails (13). Figures 22 through 26

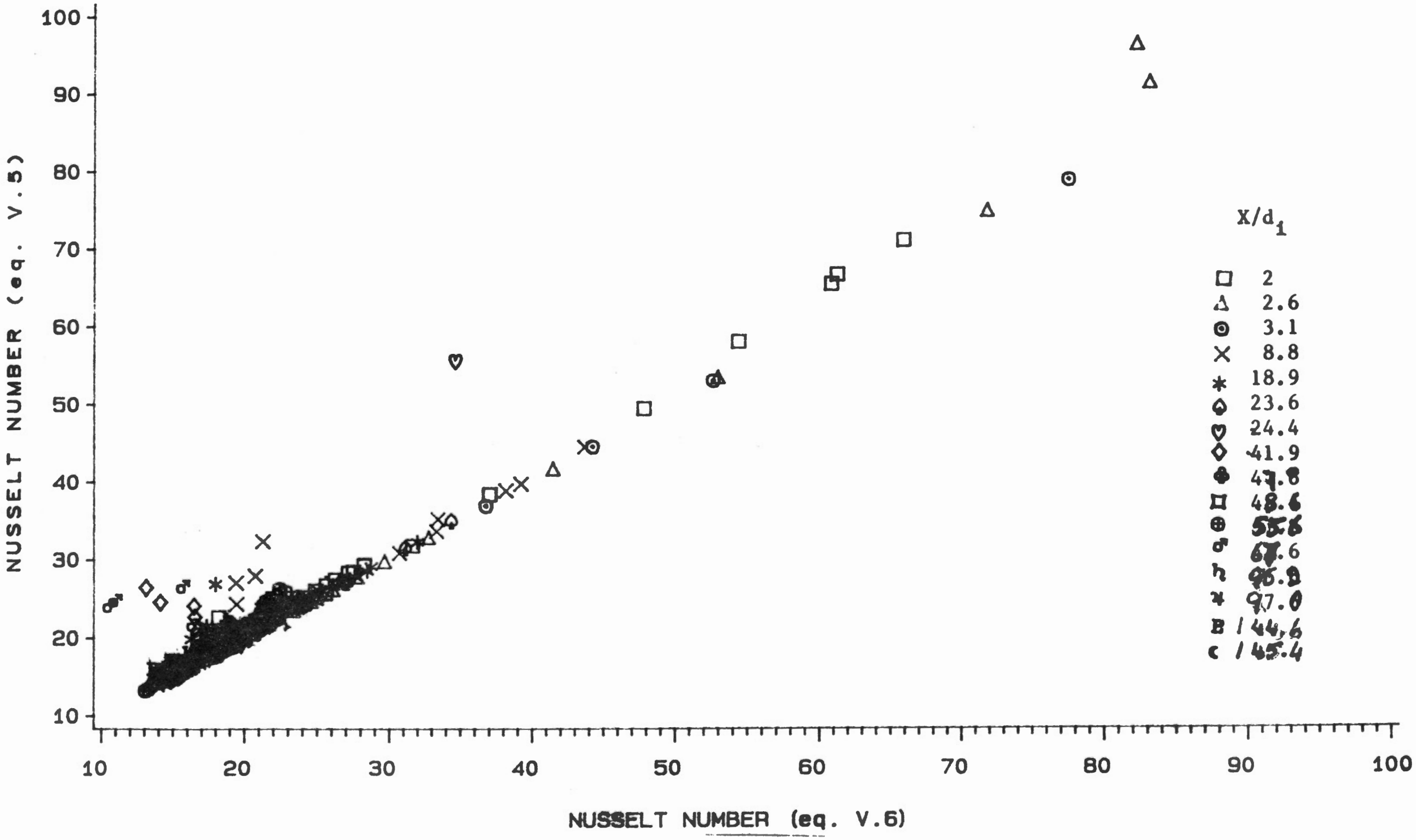


Figure 21: Comparison between the Nusselt Numbers Calculated by Equations (V.5) and (v.6) Downstream from the U-Bend.

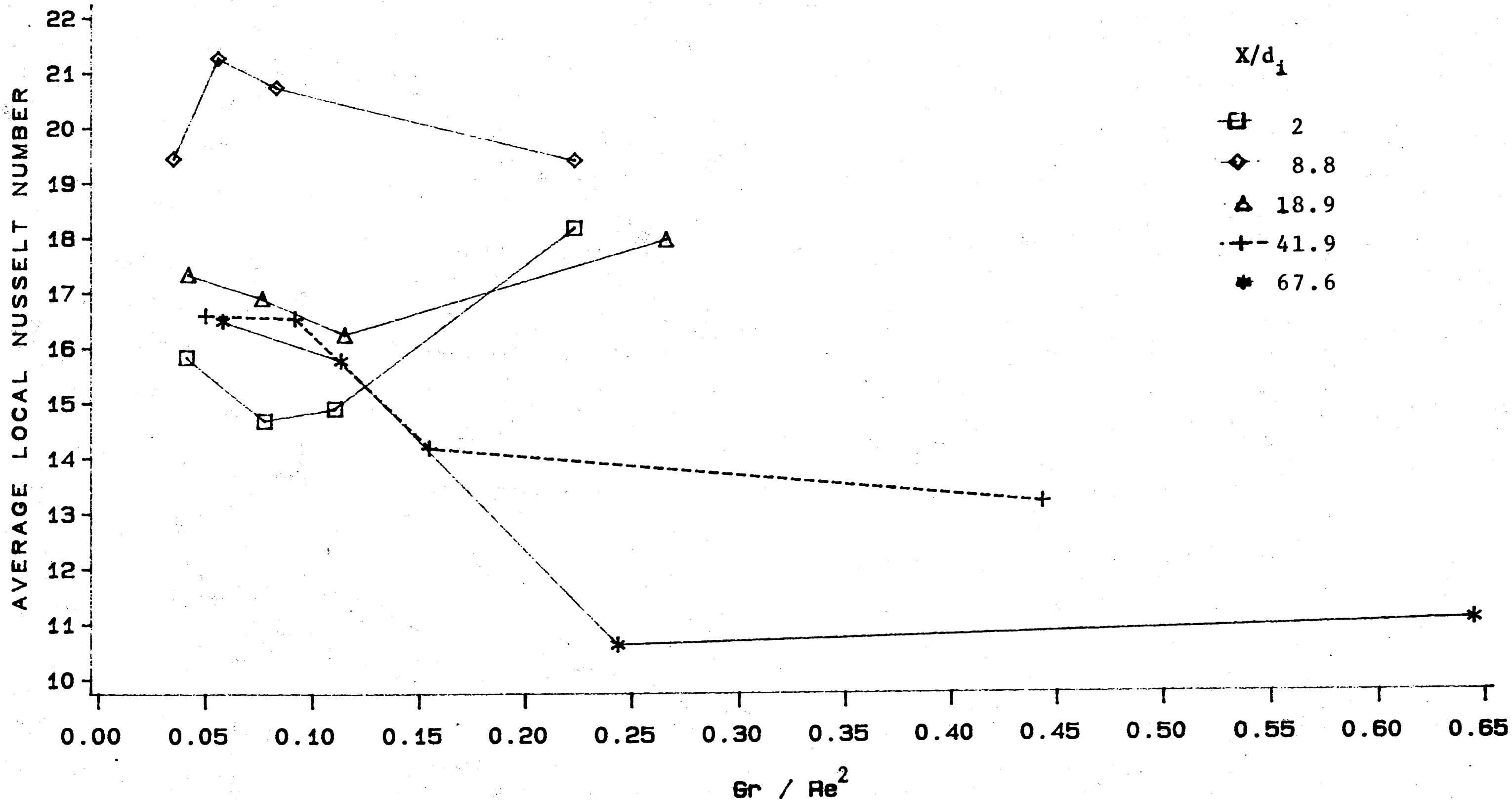


Figure 22: Effect of the Type of Convection on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section A Using Water.

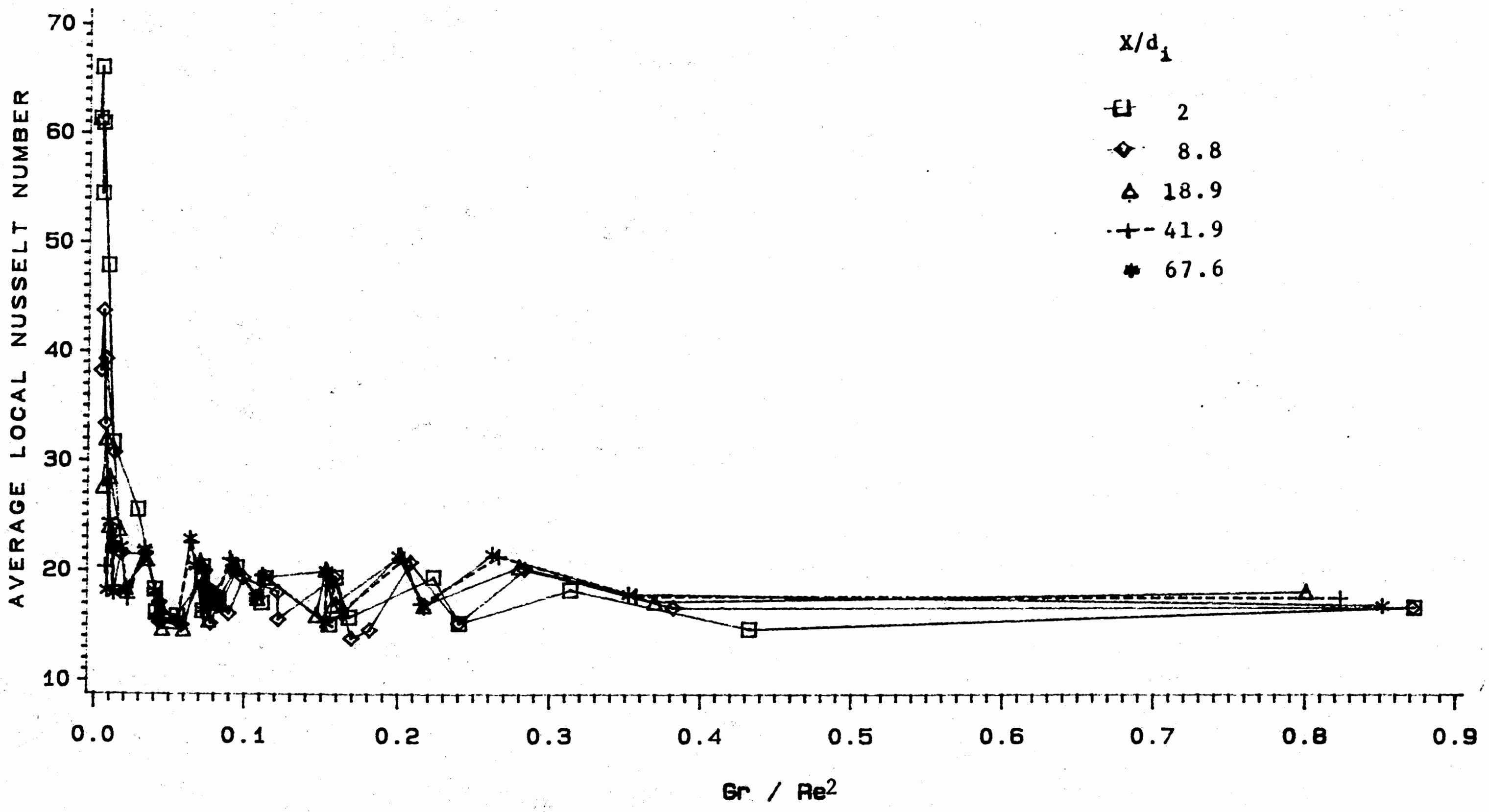


Figure 23: Effect of the Type of Convection on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section A Using Ethylene Glycol.

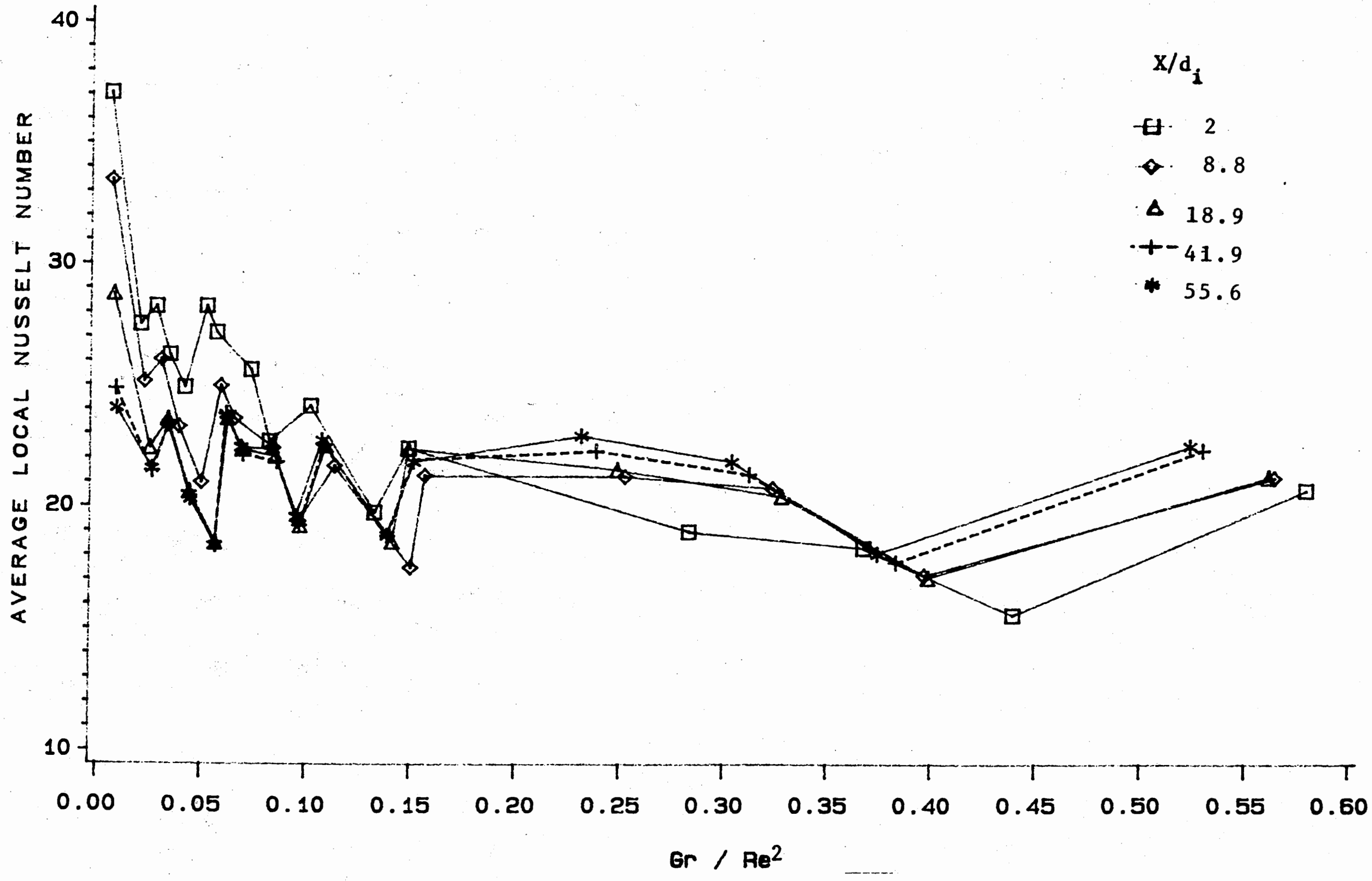


Figure 24: Effect of the Type of Convection on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section B Using Ethylene Glycol.

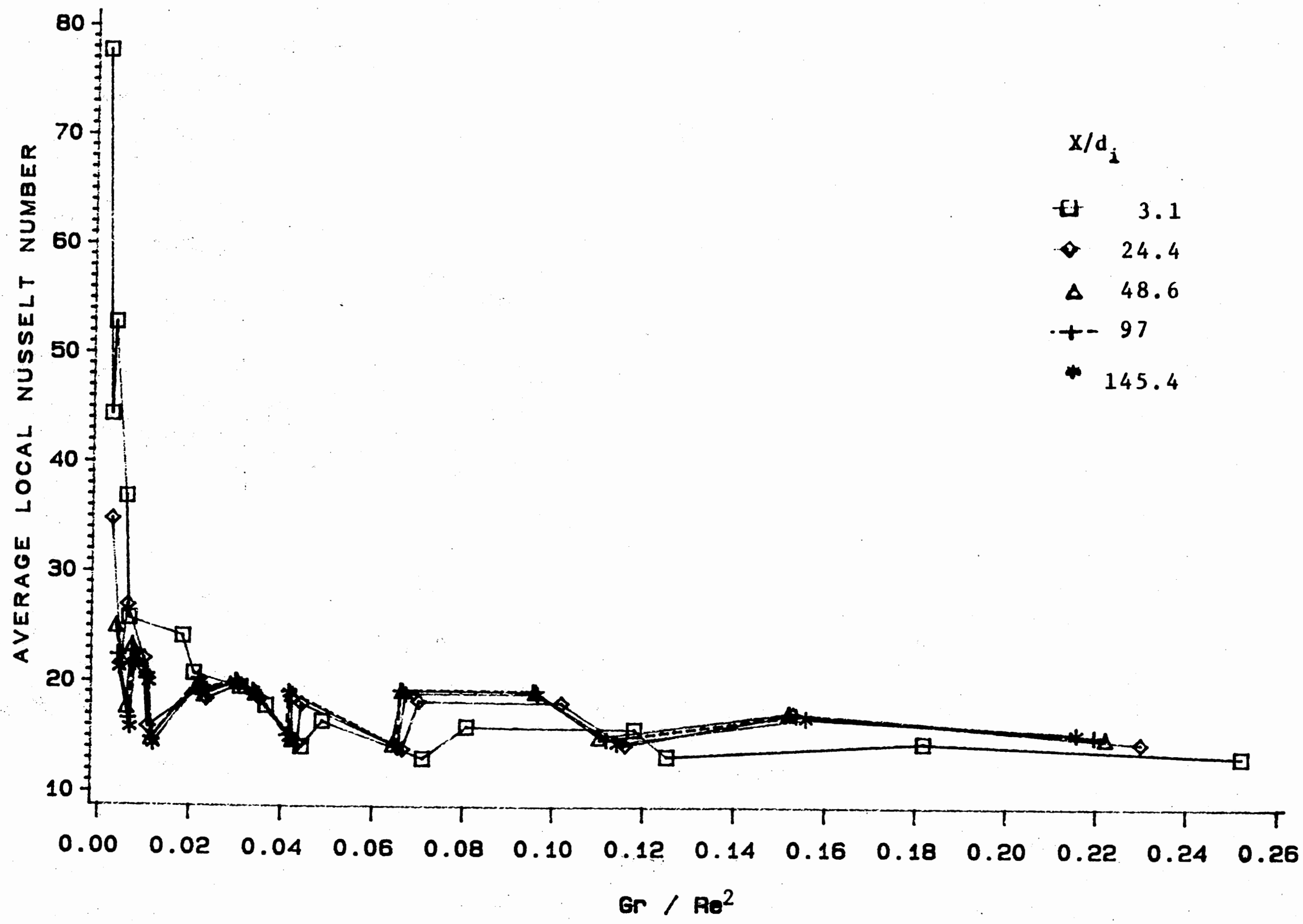


Figure 25: Effect of the Type of Convection on the Heat Transfer Coefficient Downstream From the U-Bend for Test Section C Using Ethylene Glycol.

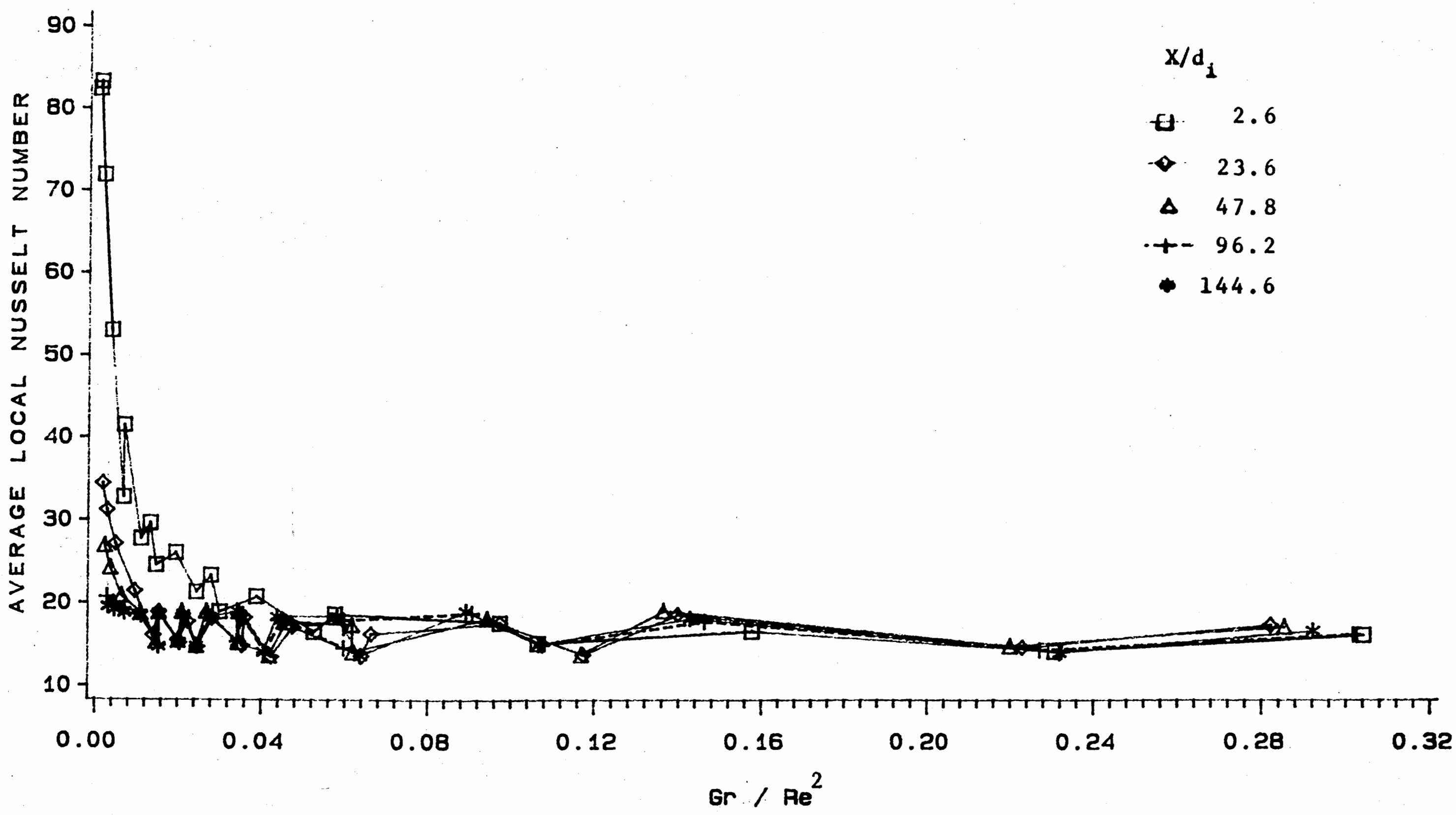


Figure 26: Effect of the Type of Convection on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section D Using Ethylene Glycol.

indicate that, immediately after the bend, secondary flow prevails, especially for high Reynolds and Prandtl numbers, and as the distance down the tube increases natural convection (tertiary flow) becomes more important. Secondary flow contributes to high heat transfer coefficients, which decrease with distance from the bend; see Figures 27 through 31. With small curvature ratios (tight bends), the heat transfer coefficient immediately after the bend is higher than for high curvature ratio tubes. Compare Figures 29 and 31 for test section B with curvature ratio of 25.36 and test section D with curvature ratio of 4.84, respectively. This behavior is attributed to the centrifugal force, which is inversely proportional to the curvature ratio. In conclusion, with increasing Reynolds numbers and small curvature ratios, the secondary flow becomes relatively stronger and causes higher heat transfer coefficients immediately after the bend.

For low Reynolds numbers, the heat transfer coefficient immediately after the bend is relatively low, because the secondary flow has little effect. Then the heat transfer coefficient increases slightly with distance down the tube, due to the increase in the Grashof number.

Approximately one-third of the runs attempted were repeated under the same conditions except for the heat flux, e.g. runs 317 and 318. Immediately after the U-bend (station 7) run 317 had a lower heat flux (Gr=4310) than run 318 (Gr=10370). Unexpectedly at station 7, run 317 had a higher heat transfer coefficient (Nu=32.8) than run 318

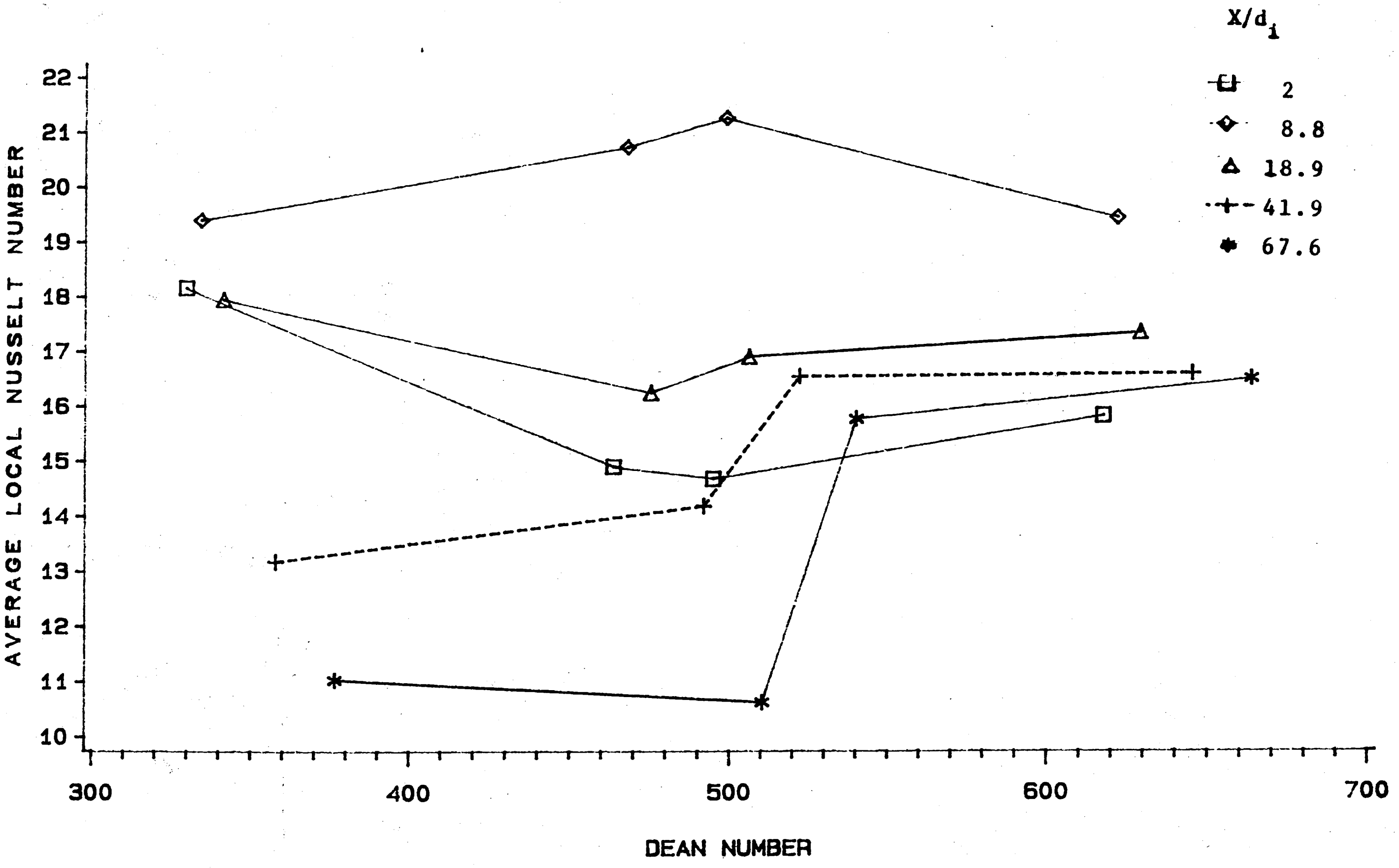


Figure 27: Effect of the Dean Number on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section A Using Water.

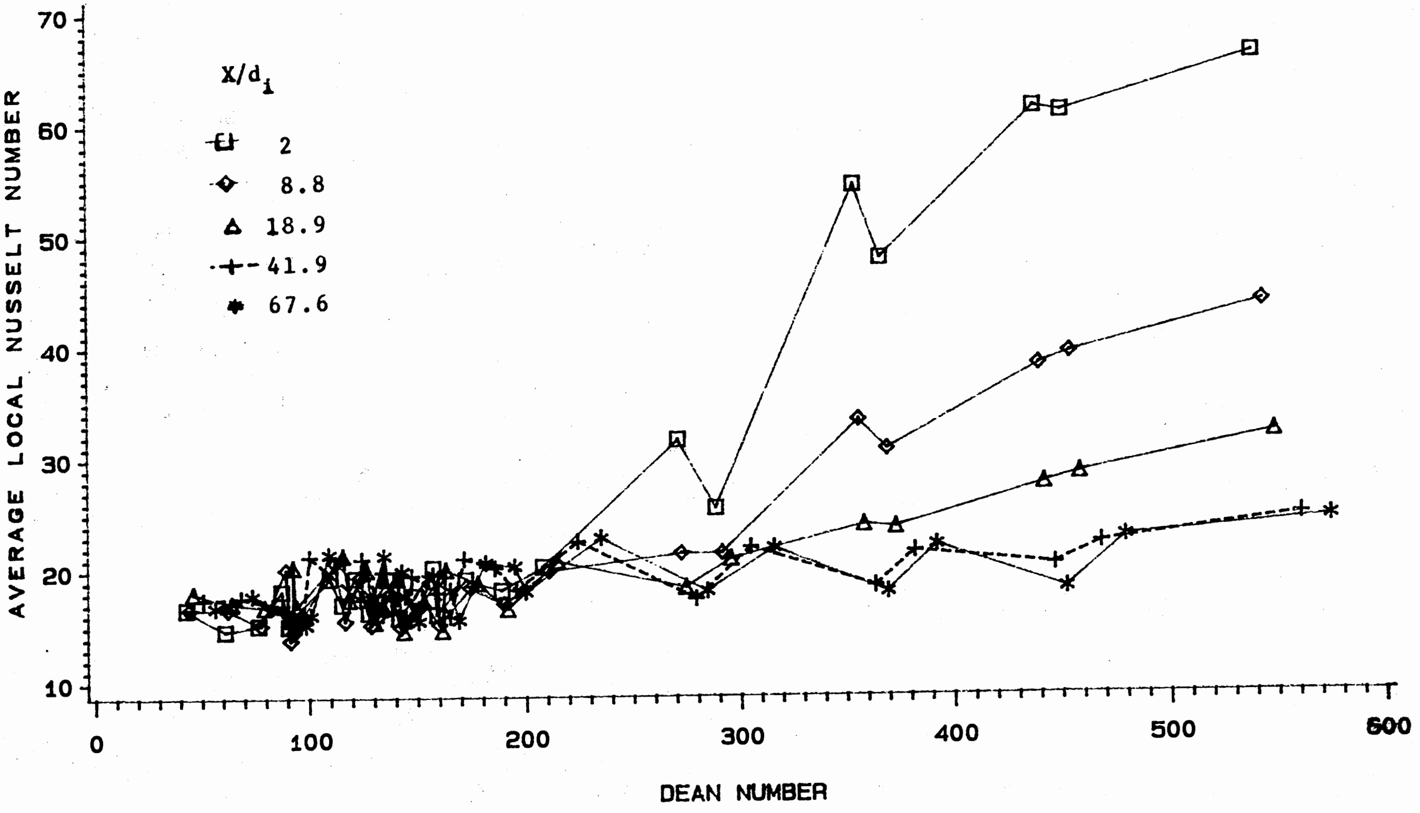


Figure 28: Effect of the Dean Number on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section A Using Ethylene Glycol.

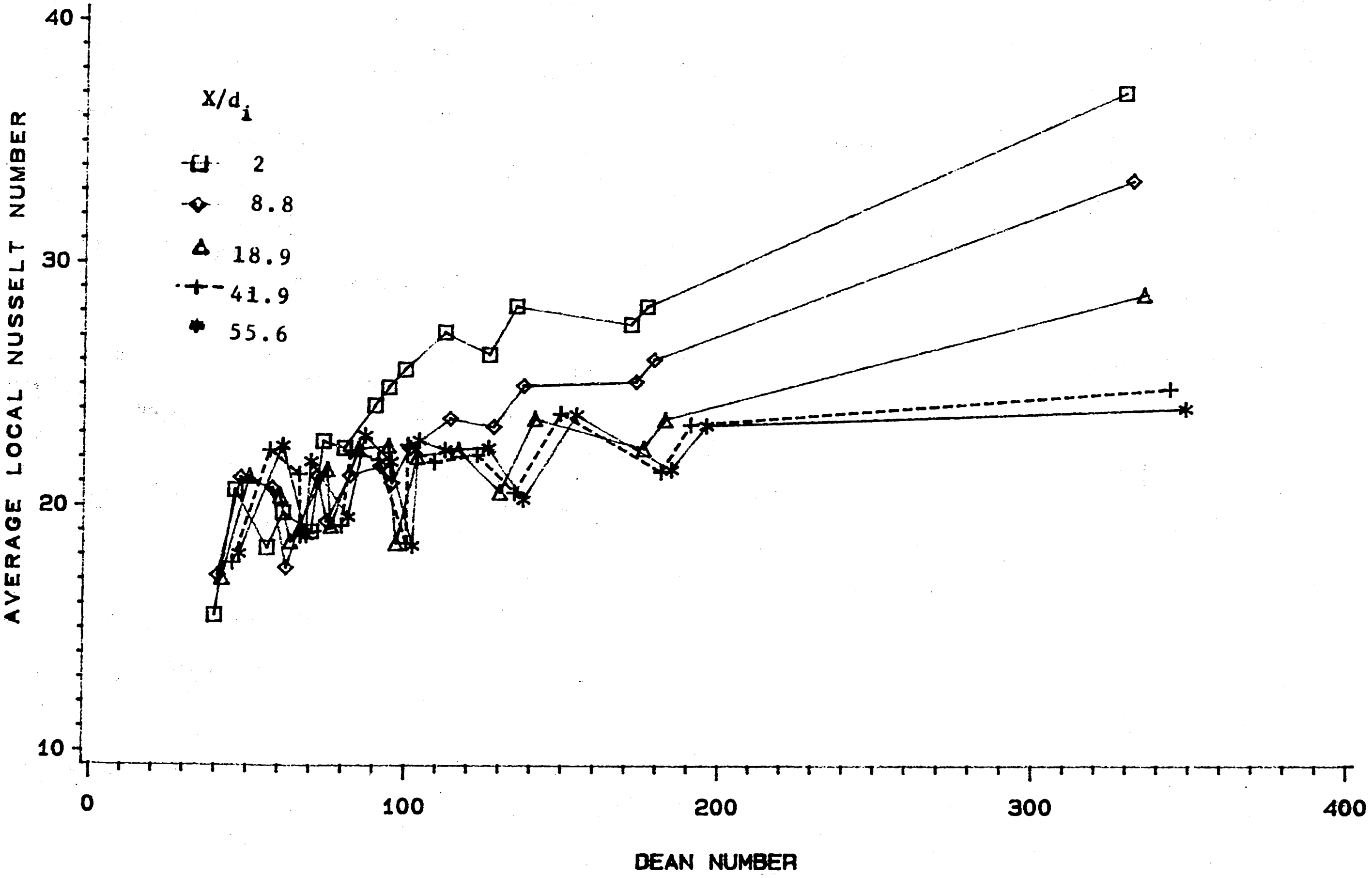


Figure 29: Effect of the Dean Number on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section B Using Ethylene Glycol.

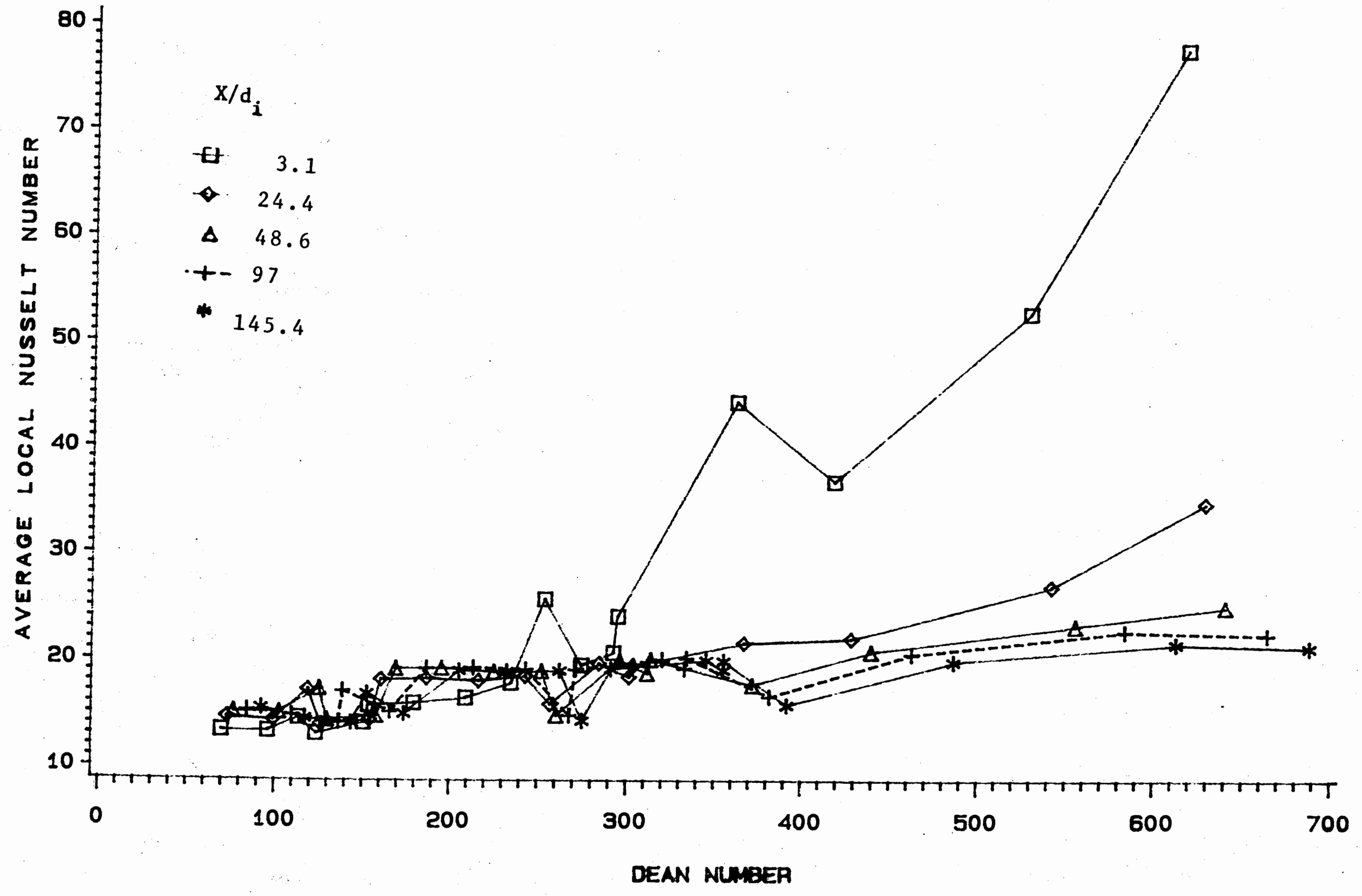


Figure 30: Effect of the Dean Number on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section C Using Ethylene Glycol.

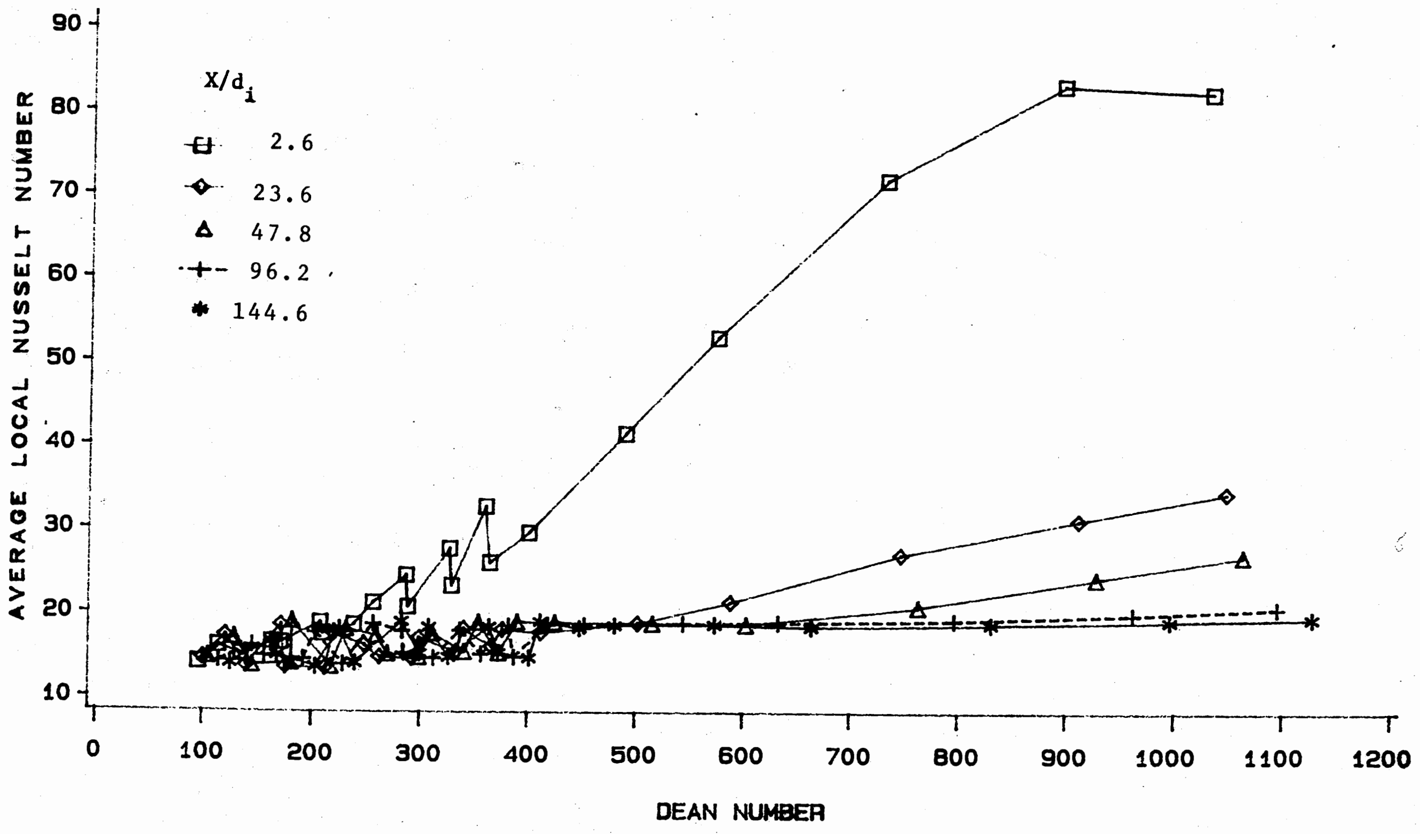


Figure 31: Effect of the Dean Number on the Heat Transfer Coefficient Downstream from the U-Bend for Test Section D Using Ethylene Glycol.

(Nu=29.7). All the runs that were replicated under different uniform heat fluxes, showed the same conduct displayed by runs 317 and 318. This behavior implies that, immediately downstream from the U-bend, the tertiary flow pattern counteracts the effect of the secondary flow pattern (for the case of heating).

Three of the four runs with water (runs 22, 23 and 25) showed negative heat transfer coefficients at the top of the last station. Those three runs had Reynolds numbers less than the run that did have any negative heat transfer coefficients.

Comparison With Literature

Colburn Correlation

Colburn (4) recognized the importance of natural convection in straight horizontal tubes. He correlated his data for the laminar flow as follows:

$$Nu=1.5(RePrd_i/X)^{1/3}(\mu_b/\mu_w)^{1/3}(1+0.015Gr^{1/3}) \qquad (VI.1)$$

Equation (VI.1) overpredicted the heat transfer coefficients at short distances from the entrance of the straight tube upstream of the bend; see Figures 32 and 33. Also, equation (VI.1) underpredicted the heat transfer coefficients downstream far away from the entrance.

Sieder and Tate Correlation

Sieder and Tate (31) correlated their experimental data

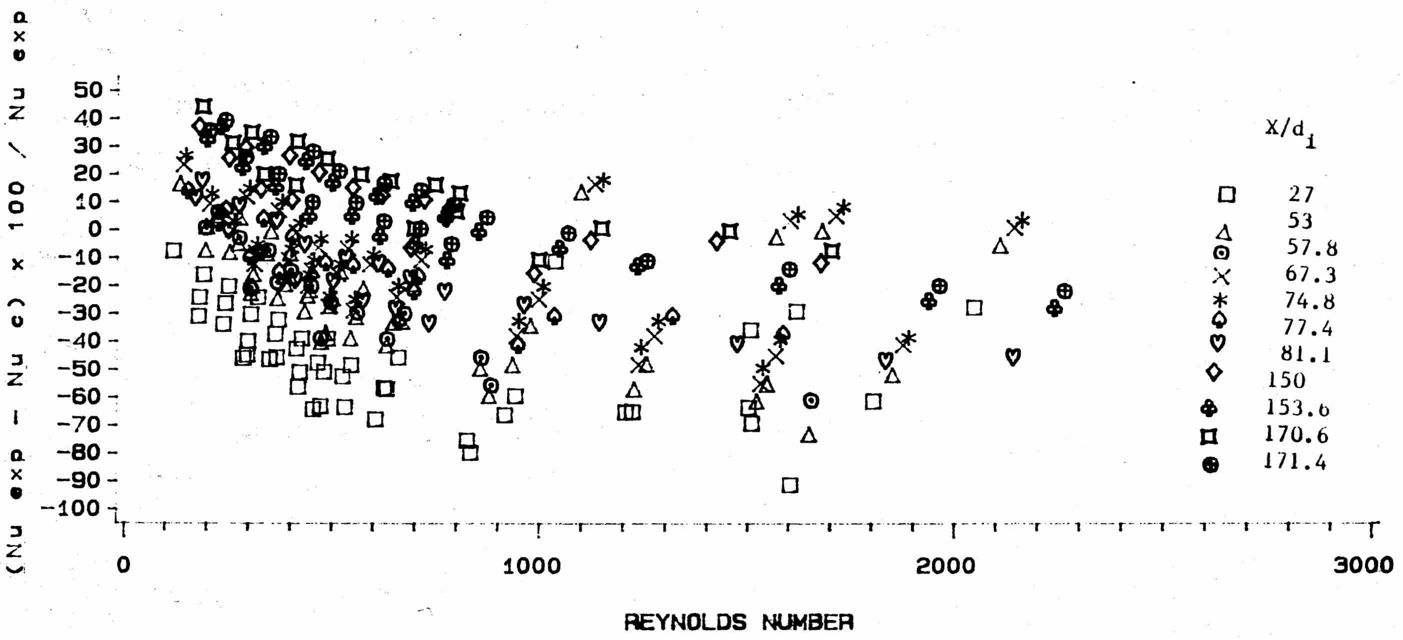


Figure 32: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Colburn (4) Upstream of the Bend.

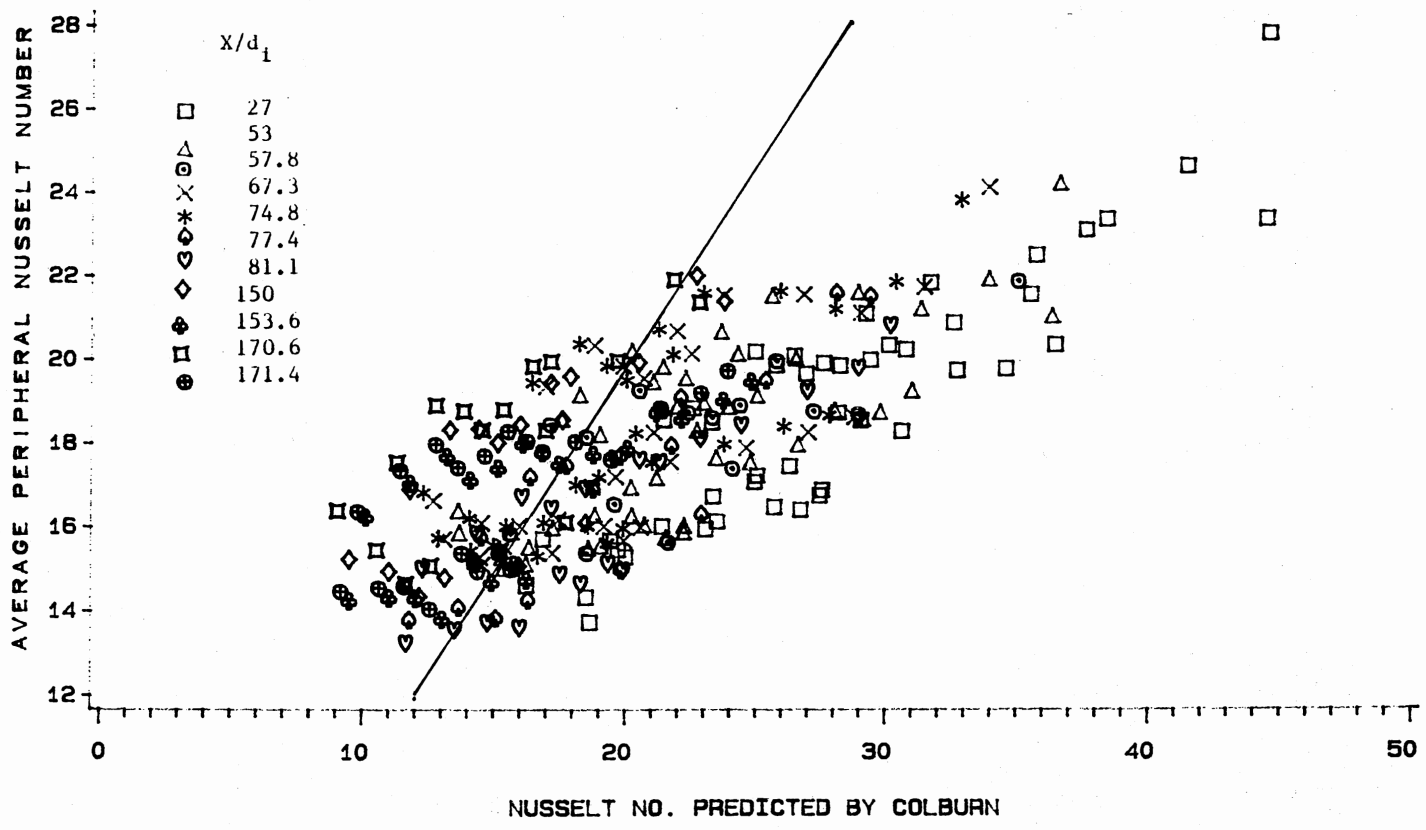


Figure 33: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Colburn (4) Upstream of the Bend.

for the flow inside straight tubes by the equation

$$Nu = 1.86(RePrd_i/X)^{1/3}(\mu_b/\mu_w)^{0.14} \qquad (VI.2)$$

When equation (VI.2) was applied upstream of the bend it had an accuracy within ± 70 %, as shown in Figures 34 and 35.

Immediately after the U-bend, station 7, equation (VI.2) overpredicts the heat transfer coefficient (more than 200 %), as indicated in Figures 36 and 37.

The Sieder and Tate equation does not take in consideration the effect of natural convection. Also, for extremely long tubes the Nusselt number predicted by Sieder and Tate is zero, which is contradictory to the 4.364 (13) for the theoretical solution for fully developed laminar forced flow for uniform heat flux.

Hausen Correlation

The Hausen equation (28) is valid for the fully developed velocity profile and constant wall temperature

$$Nu = \{3.66+0.0668Gz/(1+0.04Gz^{2/3})\}(\mu_b/\mu_w)^{0.14} \qquad (VI.3)$$

where Gz is the Graetz number. This equation does not consider the effects of natural convection. For purposes of comparison and because the experimental data are for constant wall heat flux, the first term 3.66, for the constant wall temperature, was substituted with 4.364, which is theoretically valid for constant wall heat flux (13).

The Hausen equation is an improvement over the Sieder and Tate equation, because it considers the fully developed

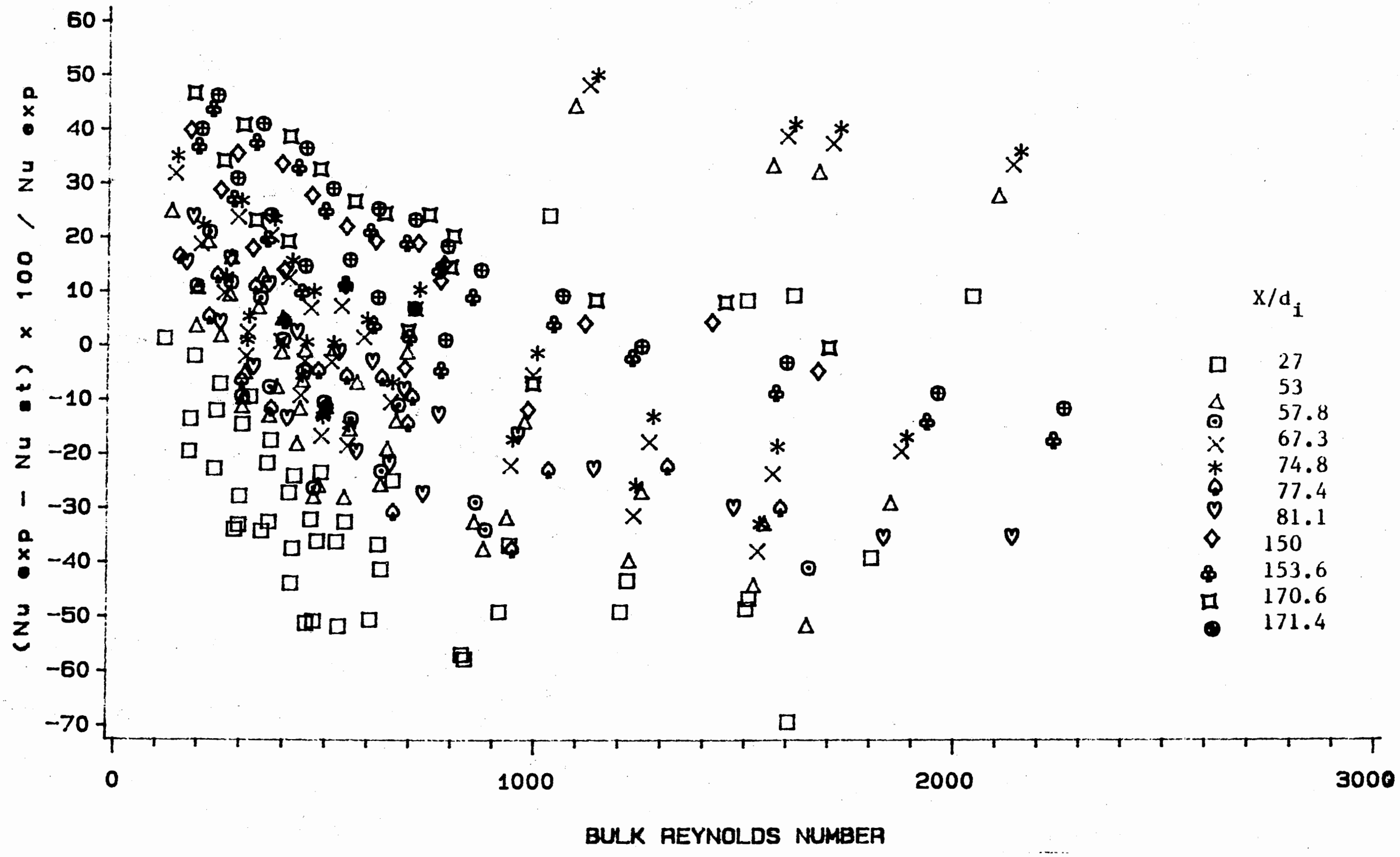


Figure 34: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Sieder and Tate (31) Upstream of the Bend.

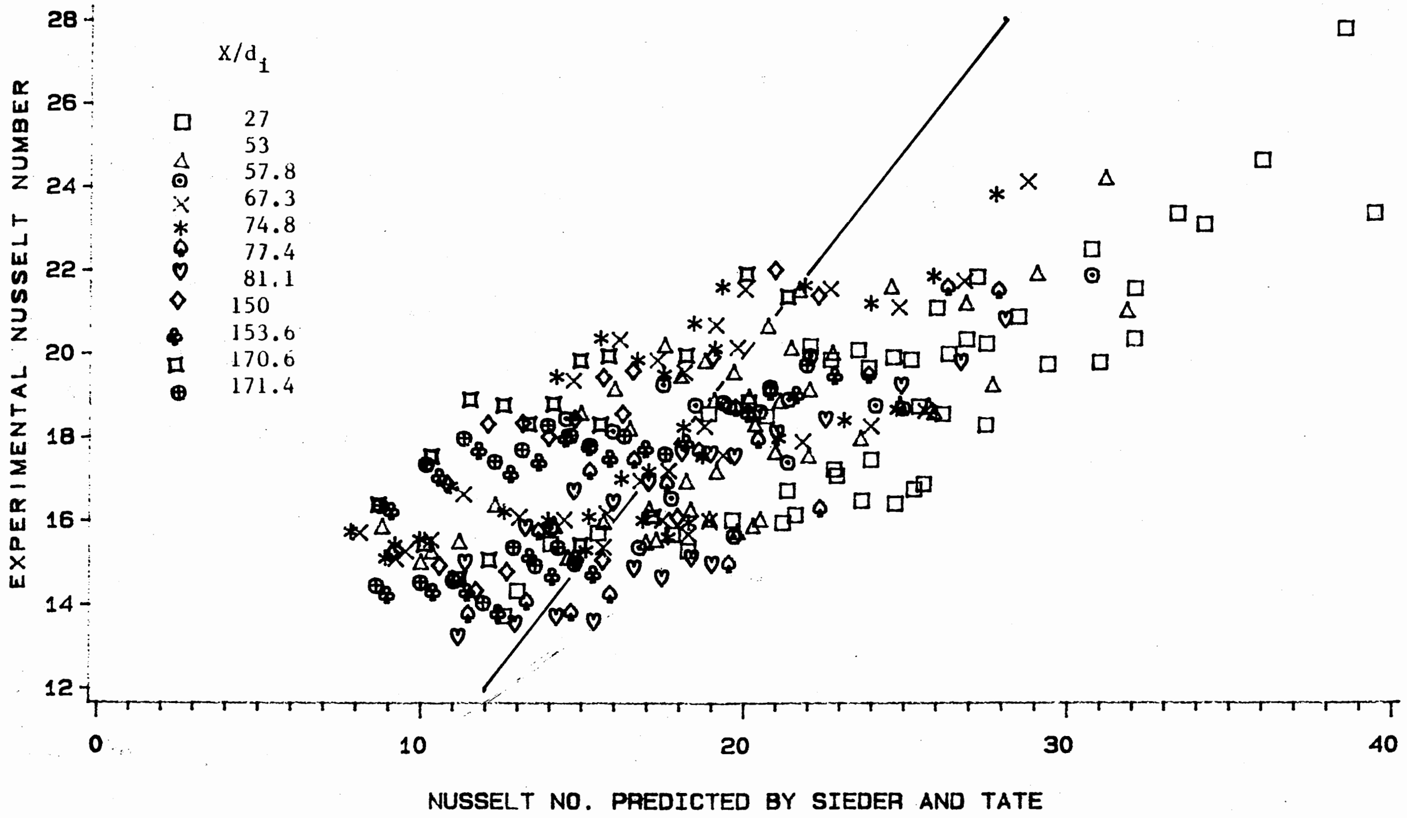


Figure 35: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Sieder and Tate (31) Upstream of the Bend.

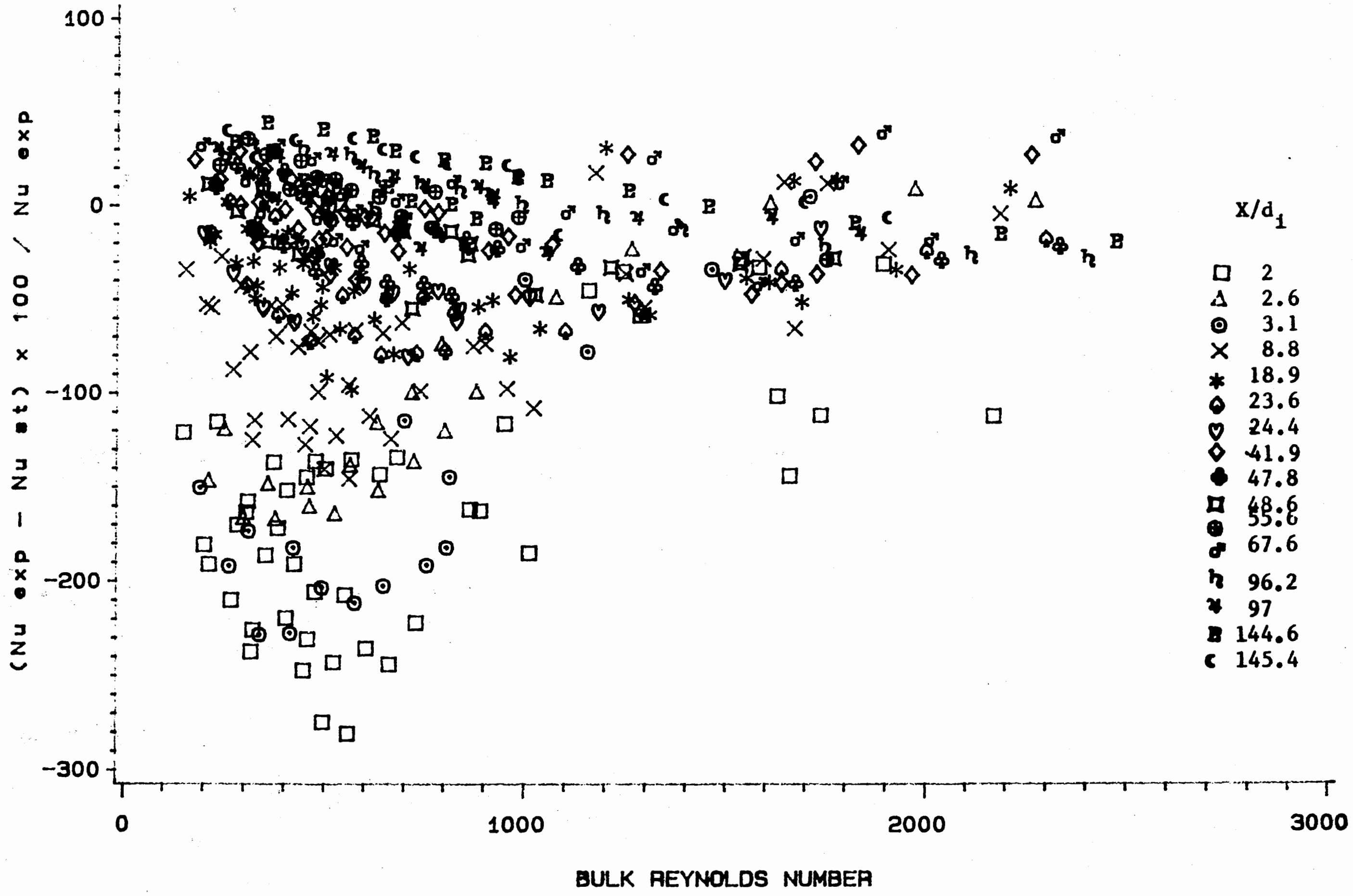


Figure 36: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Sieder and Tate (31) Downstream from the U-Bend.

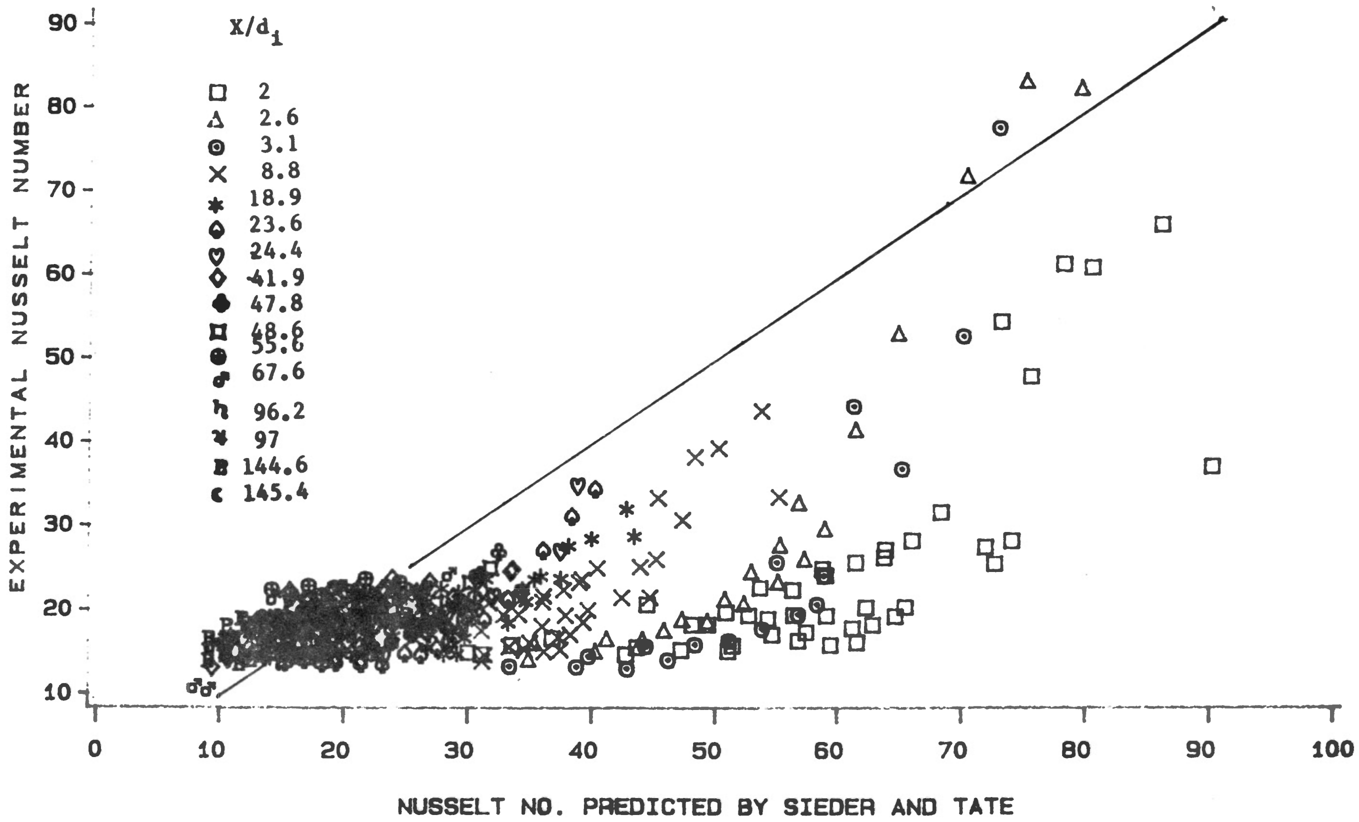


Figure 37: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficient Predicted by Sieder and Tate (31) Downstream from the U-Bend.

constant property prediction of the heat transfer coefficient. Also, in the range of experimantal data, either upstream to or downstream from the U-bend, it predicted the heat transfer coefficients better than the Sieder and Tate correlation (compare Figures 38 to 41 with 34 to 37, respectively).

Eubank and Proctor Correlation

For the laminar flow heat transfer in circular horizontal tubes, Eubank and Proctor (14) introduced the following correlation:

$$Nu=1.75\{Gz+0.04(GrPrd_i/X)^{0.75}\}^{1/3}(\mu_b/\mu_w)^{0.14} \qquad (VI.4)$$

Even though equation (VI.4) considers the effect of natural convection, it does not reduce properly to the constant property, fully developed heat transfer coefficient. Figures 42 and 43 show the deviation between the experimental data, upstream of the bend, and equation (VI.4).

Siegwarth Correlation

The Siegwarth equation (II.4) for the fully developed laminar flow in a straight tube was compared with the experimental data at each station. Upstream of the bend, equation (II.4) predicted the heat transfer coefficient better than equations (V.1), (V.2) and (VI.4), as seen from figures 44 and 45. Far from the entrance the Siegwarth predictions agreed well with the experimental data (Figure

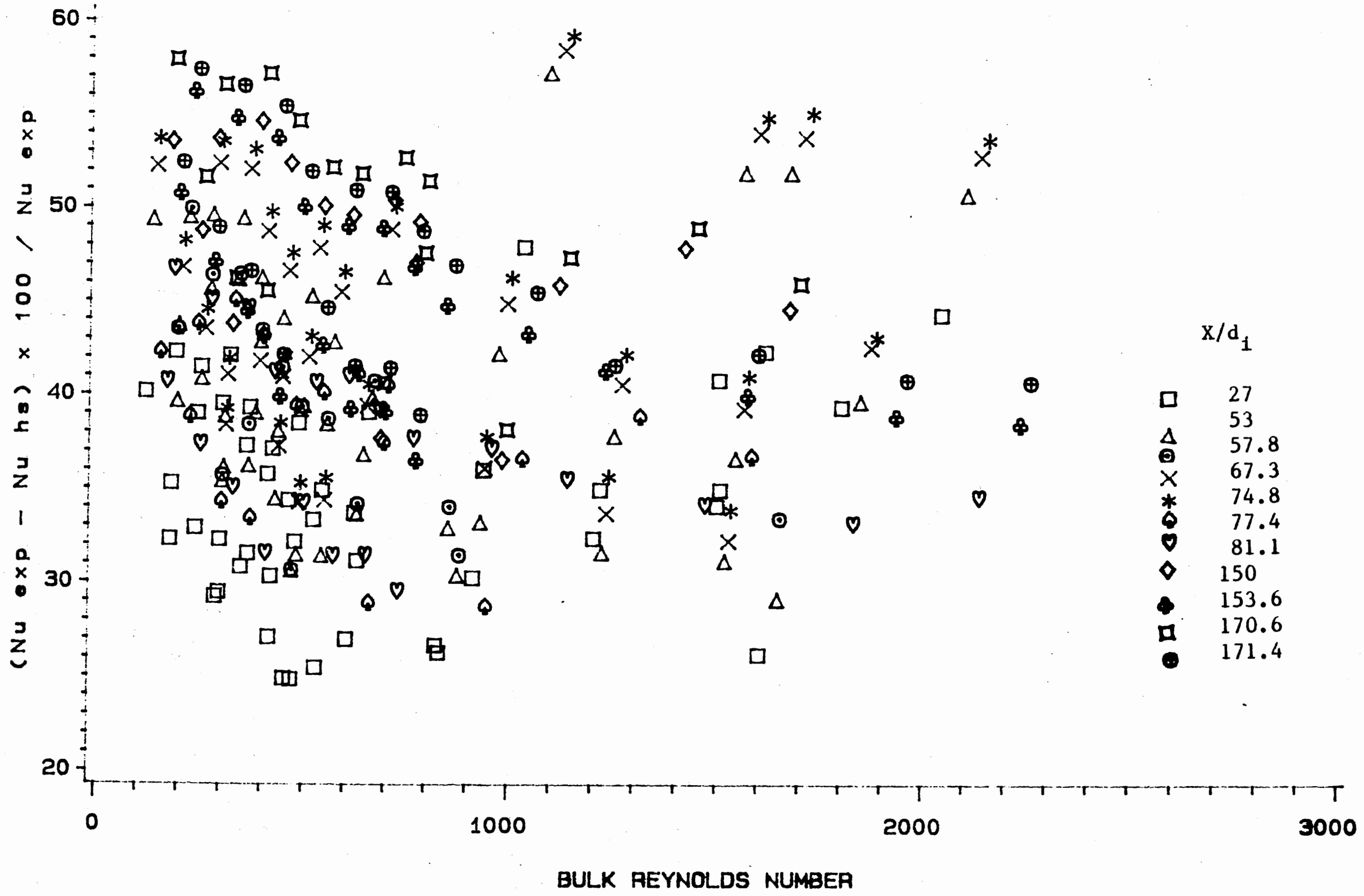


Figure 38: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Hausen (28) Upstream of the Bend.

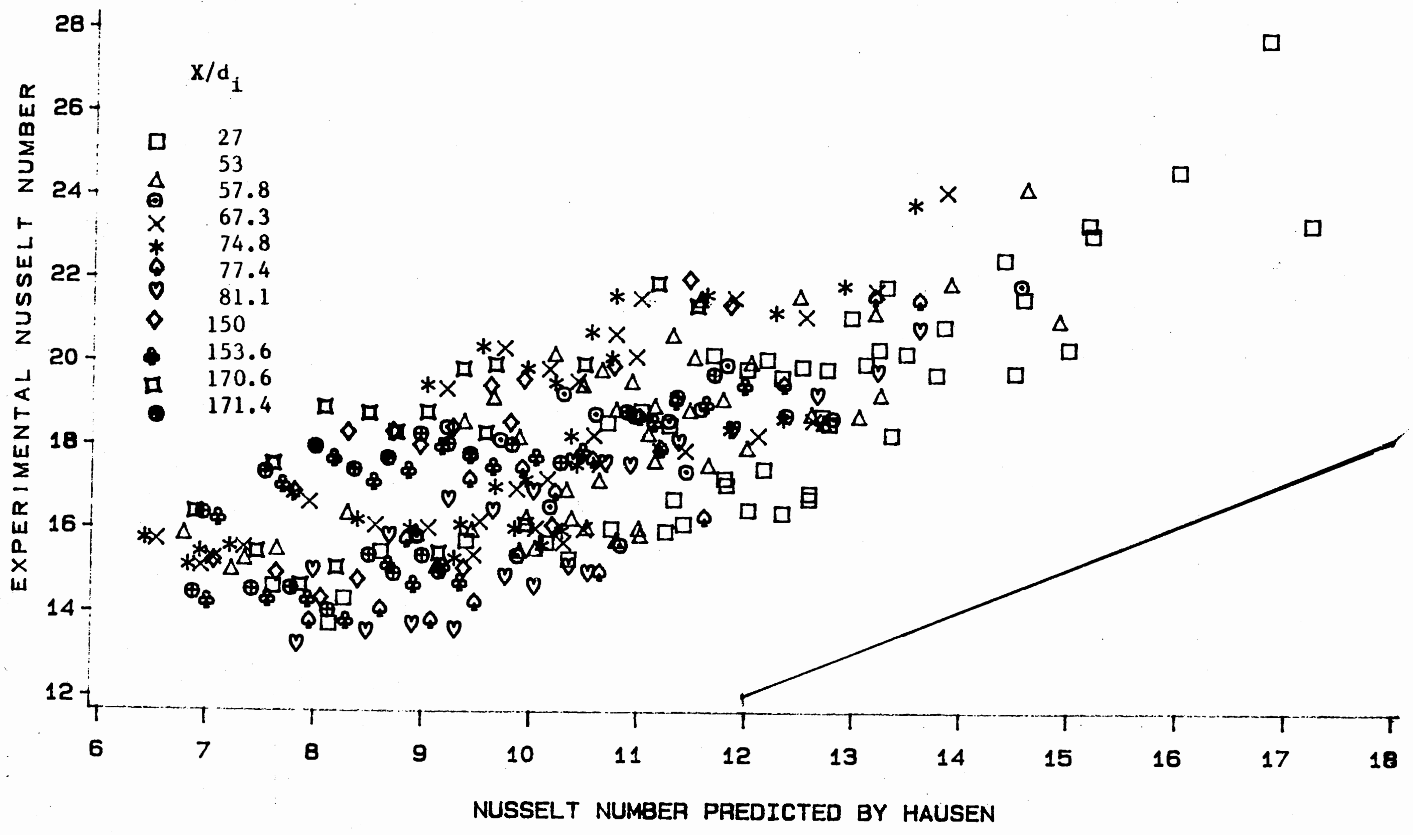


Figure 39: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Hausen (28) Upstream of the Bend.

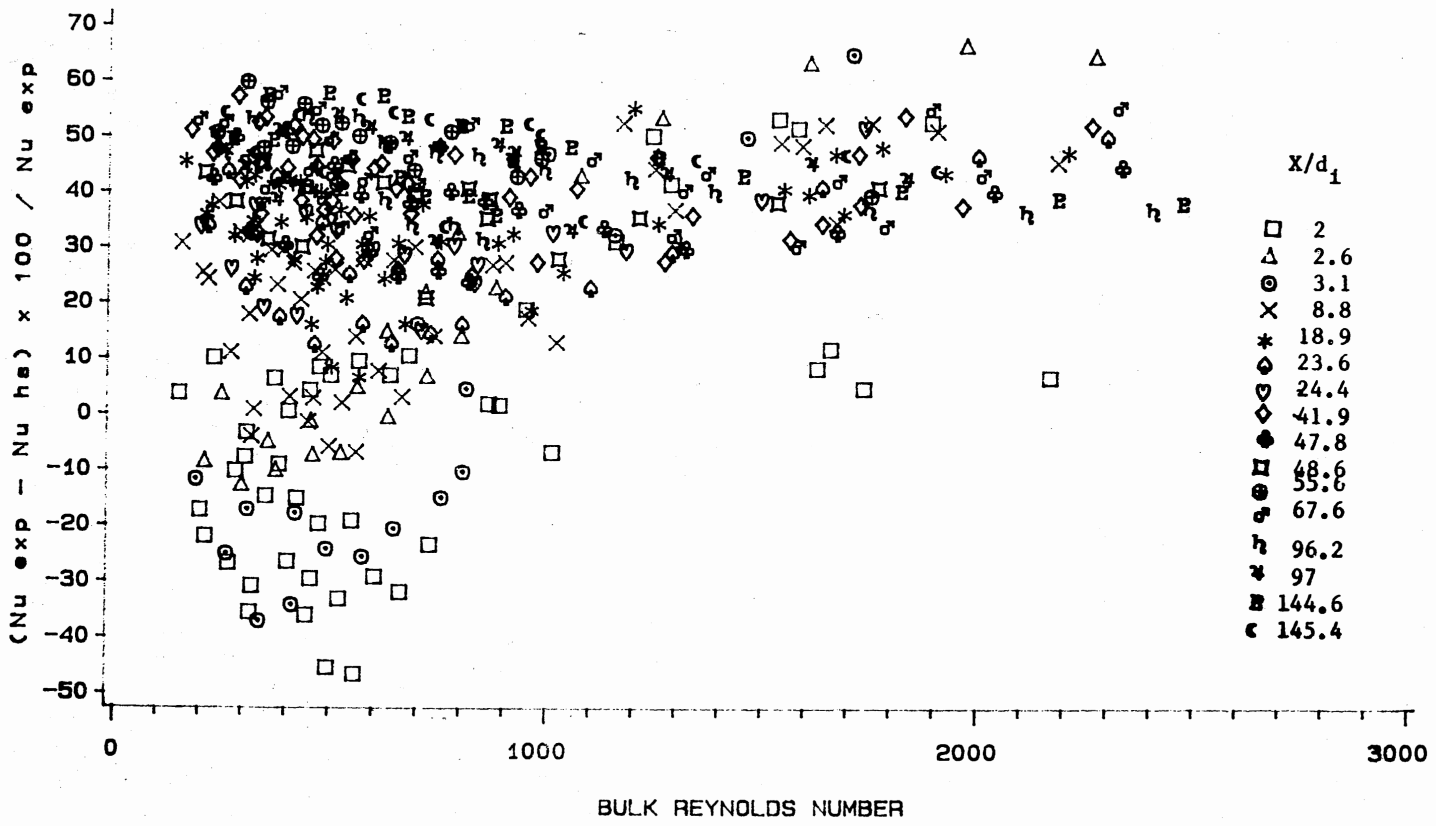


Figure 40: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted by Hausen (28) Downstream from the U-Bend.

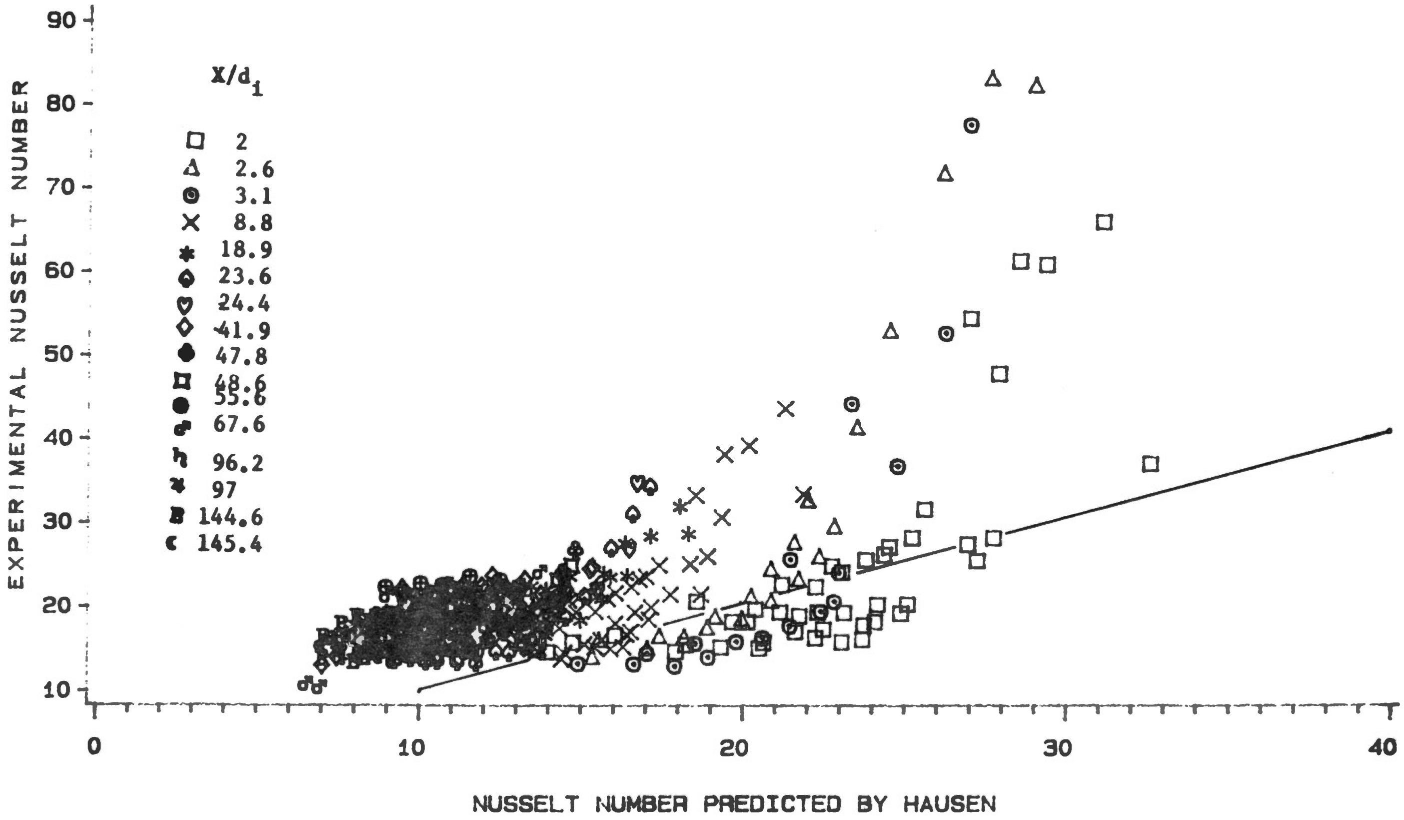


Figure 41: Comparison between the Experimental Heat Transfer Coefficients and the Heat Transfer Coefficients Predicted By Hausen (28) Downstream from the U-Bend.

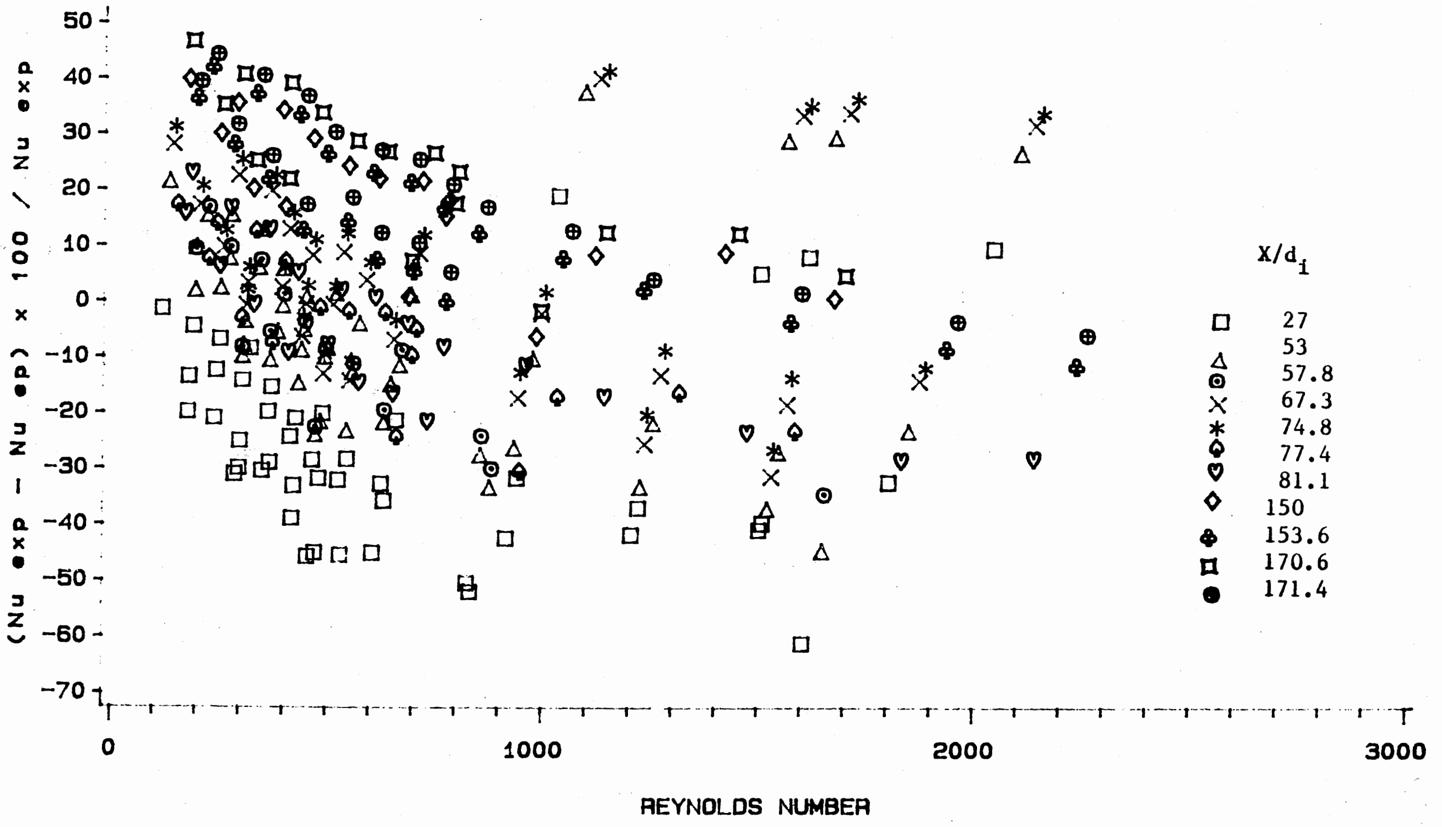


Figure 42: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Eubank and Proctor Upstream of the Bend.

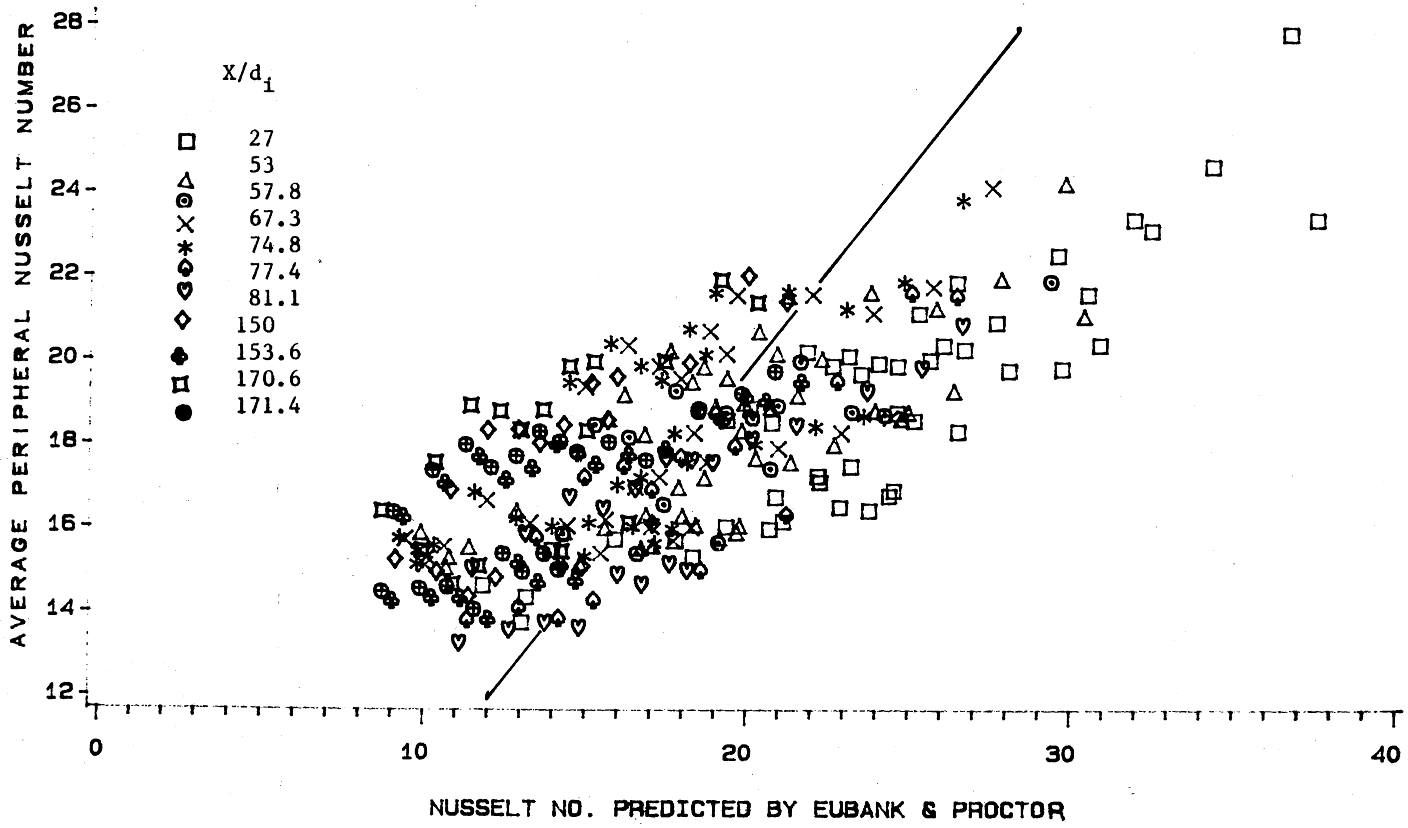


Figure 43: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Eubank and Proctor Upstream of the Bend.

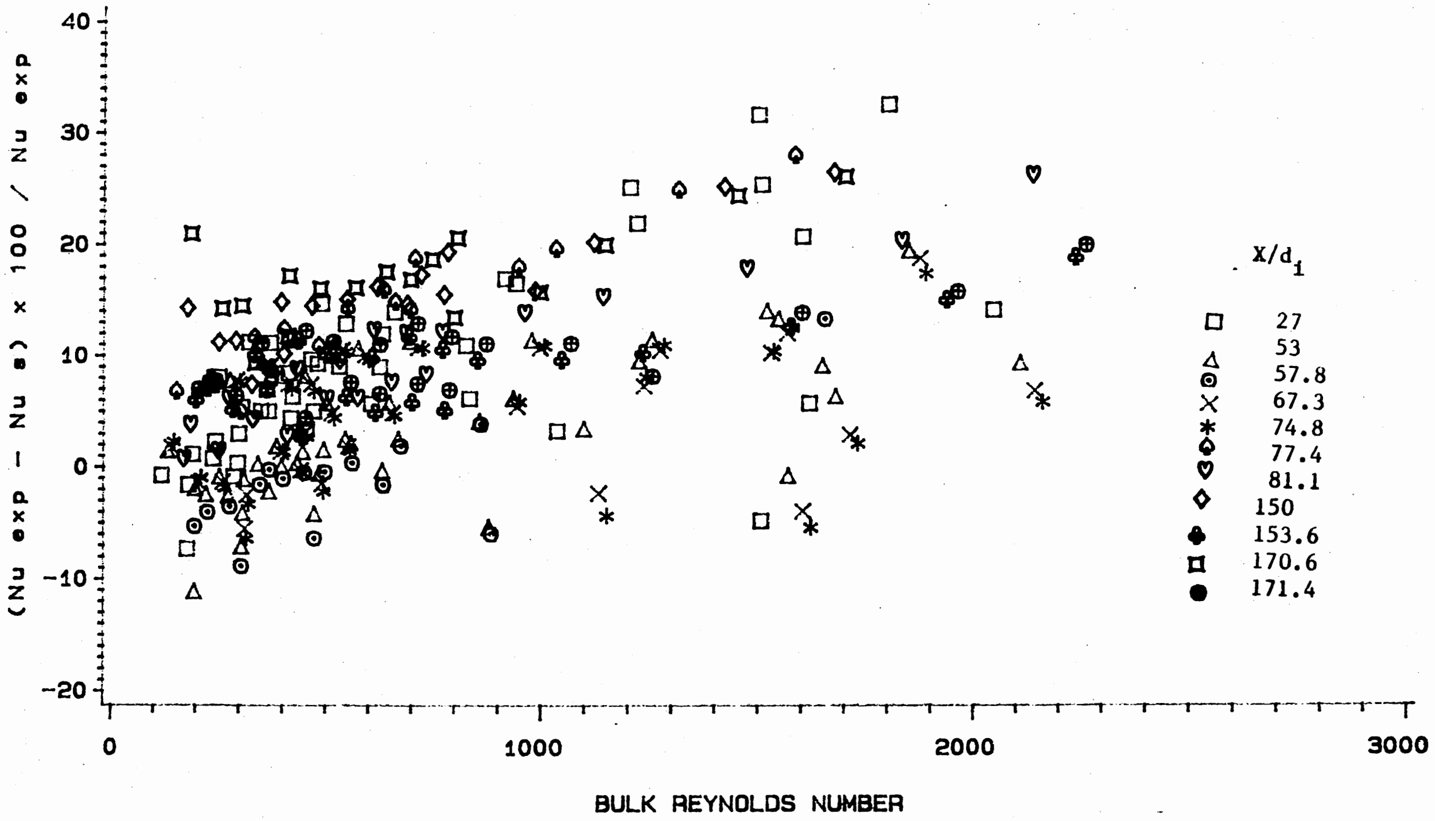


Figure 44: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Siegwarth et al. Upstream of the Bend.

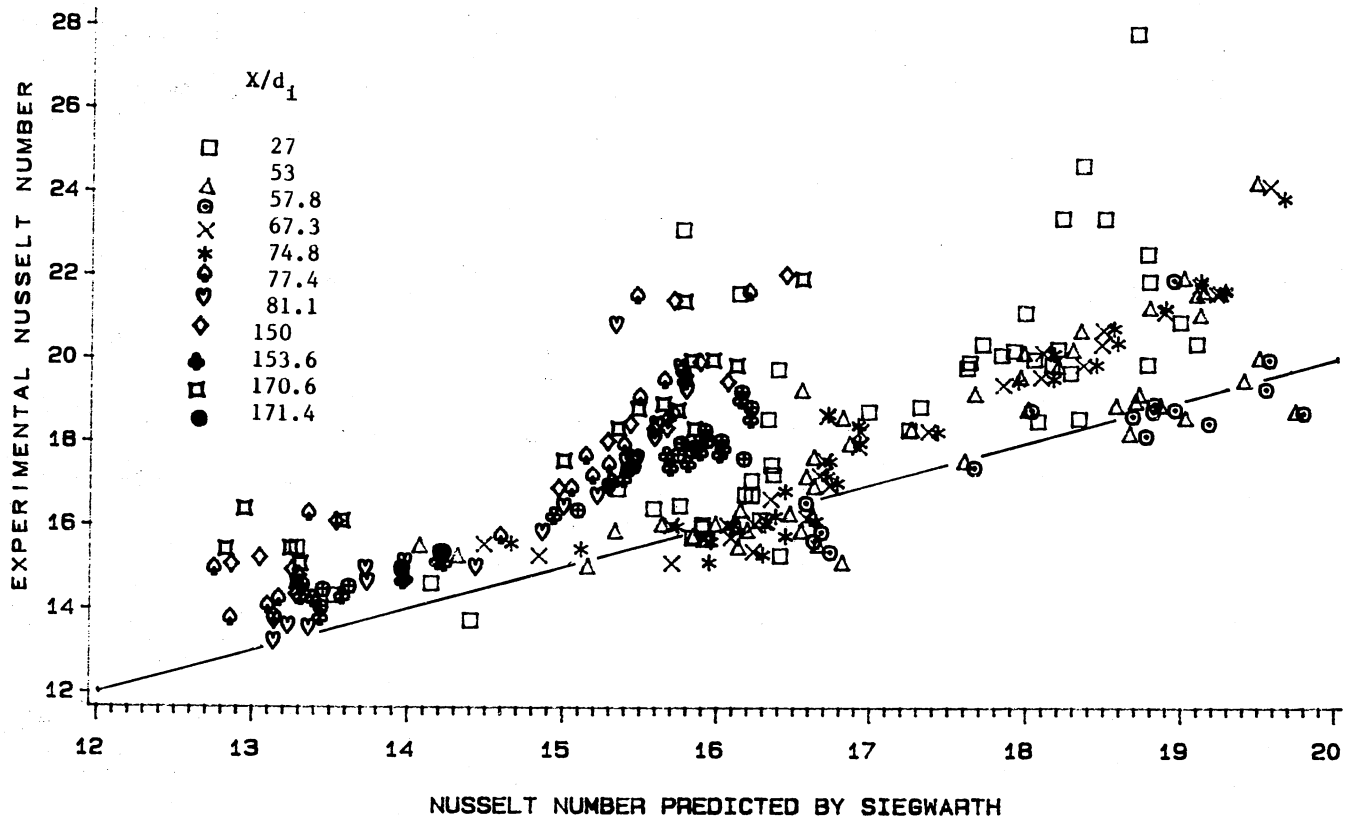


Figure 45: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Siegwarth et al. Upstream of the Bend.

44).

As expected downstream from the bend, due to the secondary flow pattern, the Siegwarth predictions deviated strongly as shown in Figure 46.

Though the Siegwarth equation predicted the heat transfer coefficient better than Colburn, Sieder and Tate and Eubank and Proctor equations, it did not consider the effect of the fully-developed forced convection term; i.e. when the natural convection term is very small the heat transfer coefficient is almost zero.

Hong, Morcos and Bergles Correlation

The Hong, Morcos and Bergles equation (II.5) for the fully developed laminar flow in a straight tube was compared with the experimental results at each station. The dimensionless groups in equation (II.5) were calculated at the film temperature.

Hong, Morcos and Bergles (9) reported that equation (II.5) represented 92 per cent of their data within 10 per cent.

Upstream of the bend, far from the entrance, equation (II.5) agreed well with the experimental data, as indicated in Figures 47 and 48. Downstream from the bend equation (II.5) was too conservative, because it does not consider the effect of the secondary flow pattern. Figures 49 and 50 show the deviation between the experimental and predicted heat transfer coefficients.

Similar to the Siegwarth correlation the Hong, Morcos

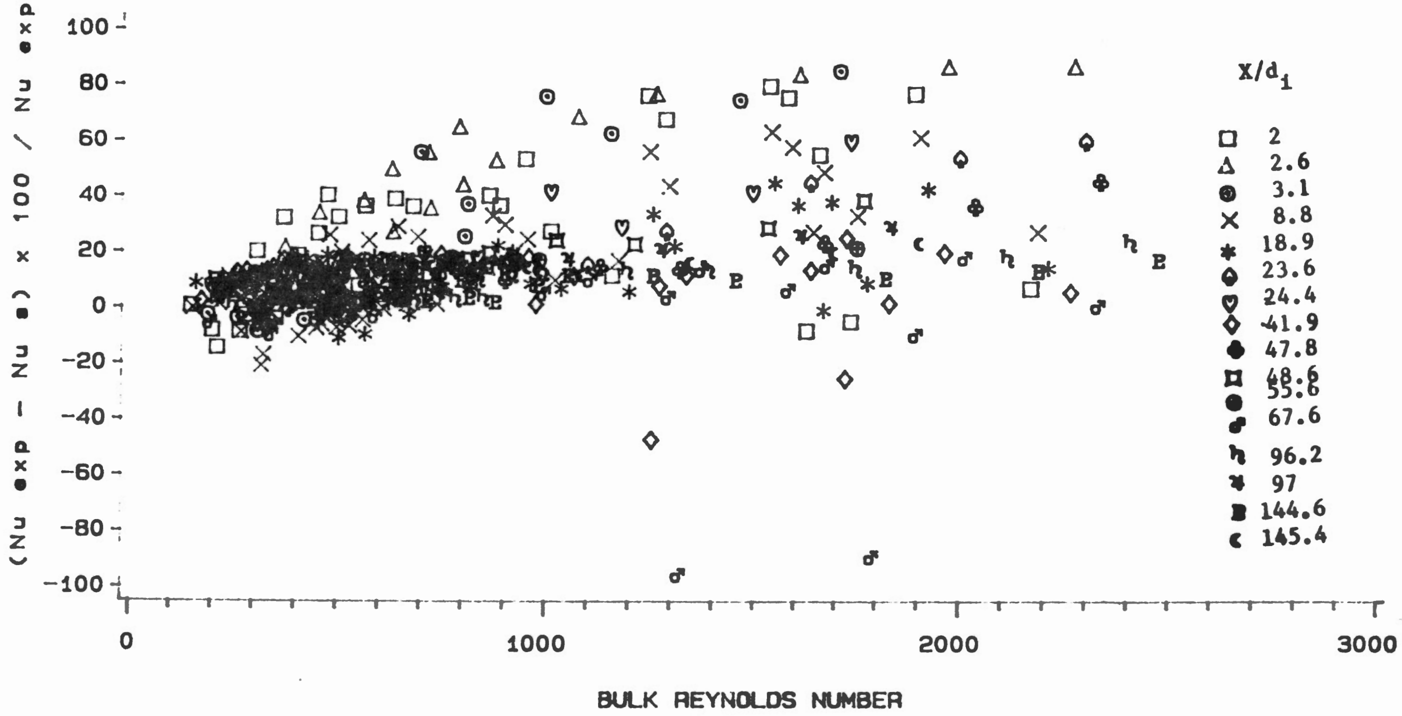


Figure 46: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Siegwarth et al. Downstream from the U-Bend.

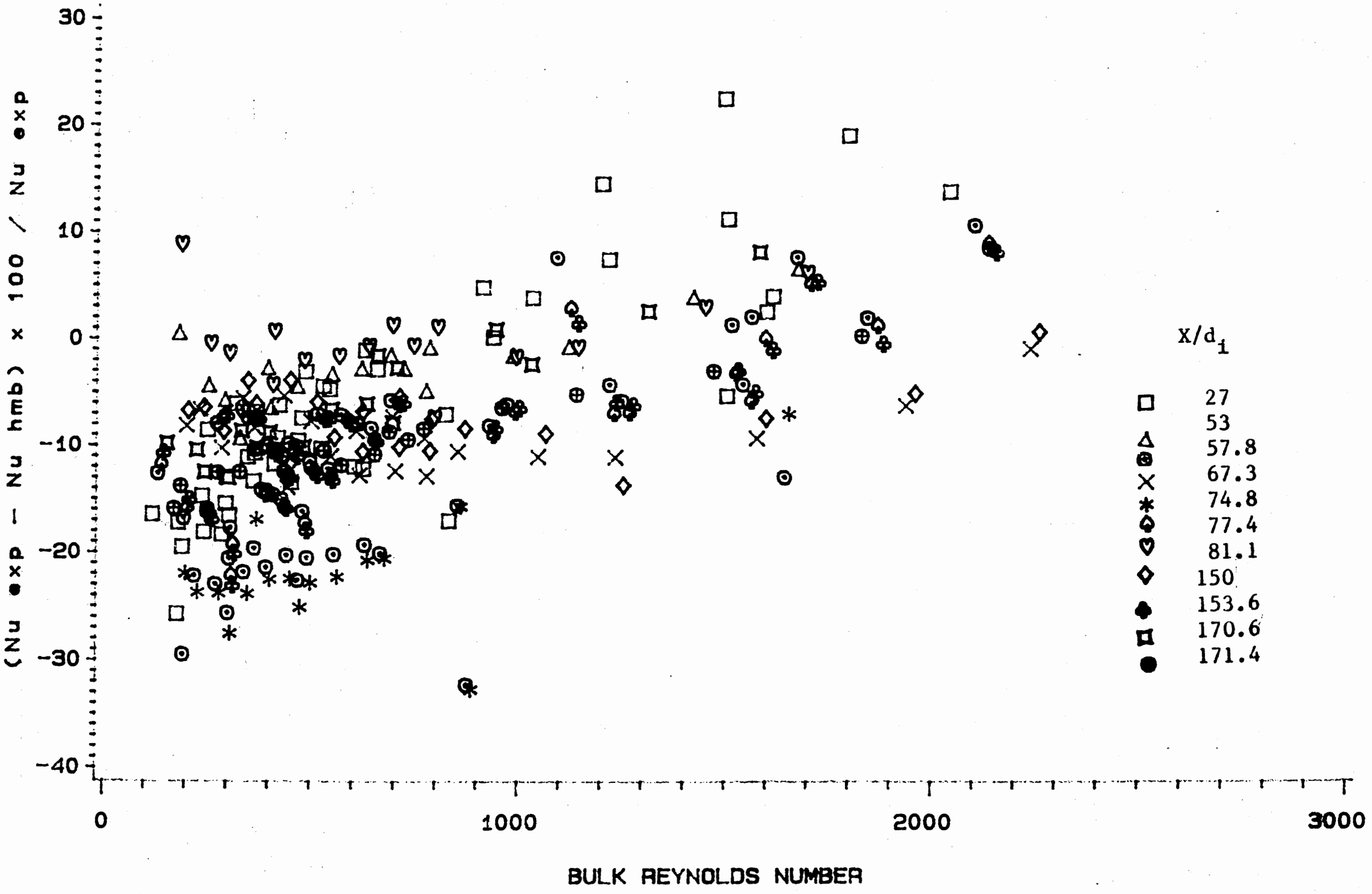


Figure 47: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Hong et al. Upstream of the Bend.

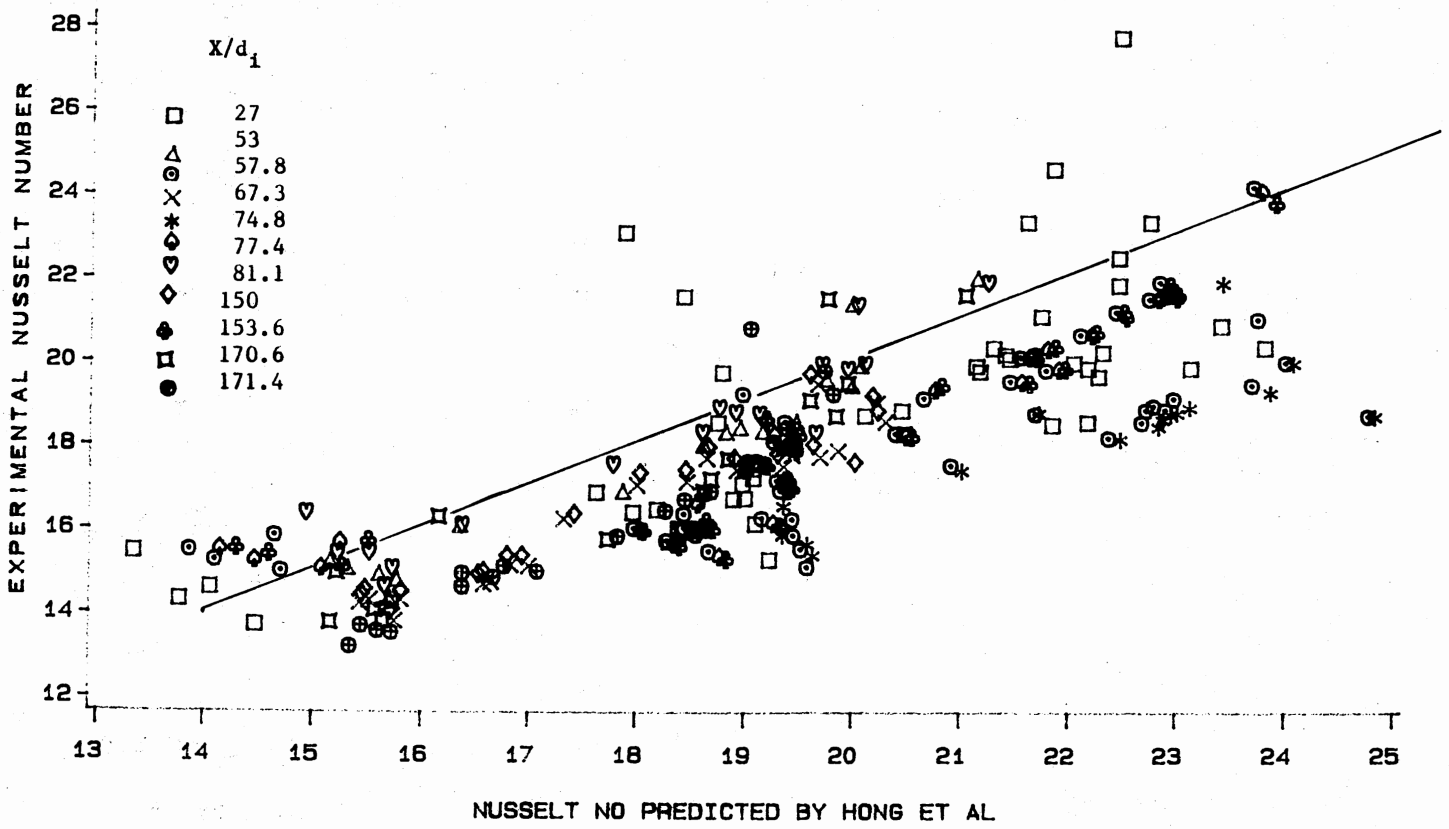


Figure 48: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Hong et al. Upstream of the Bend.

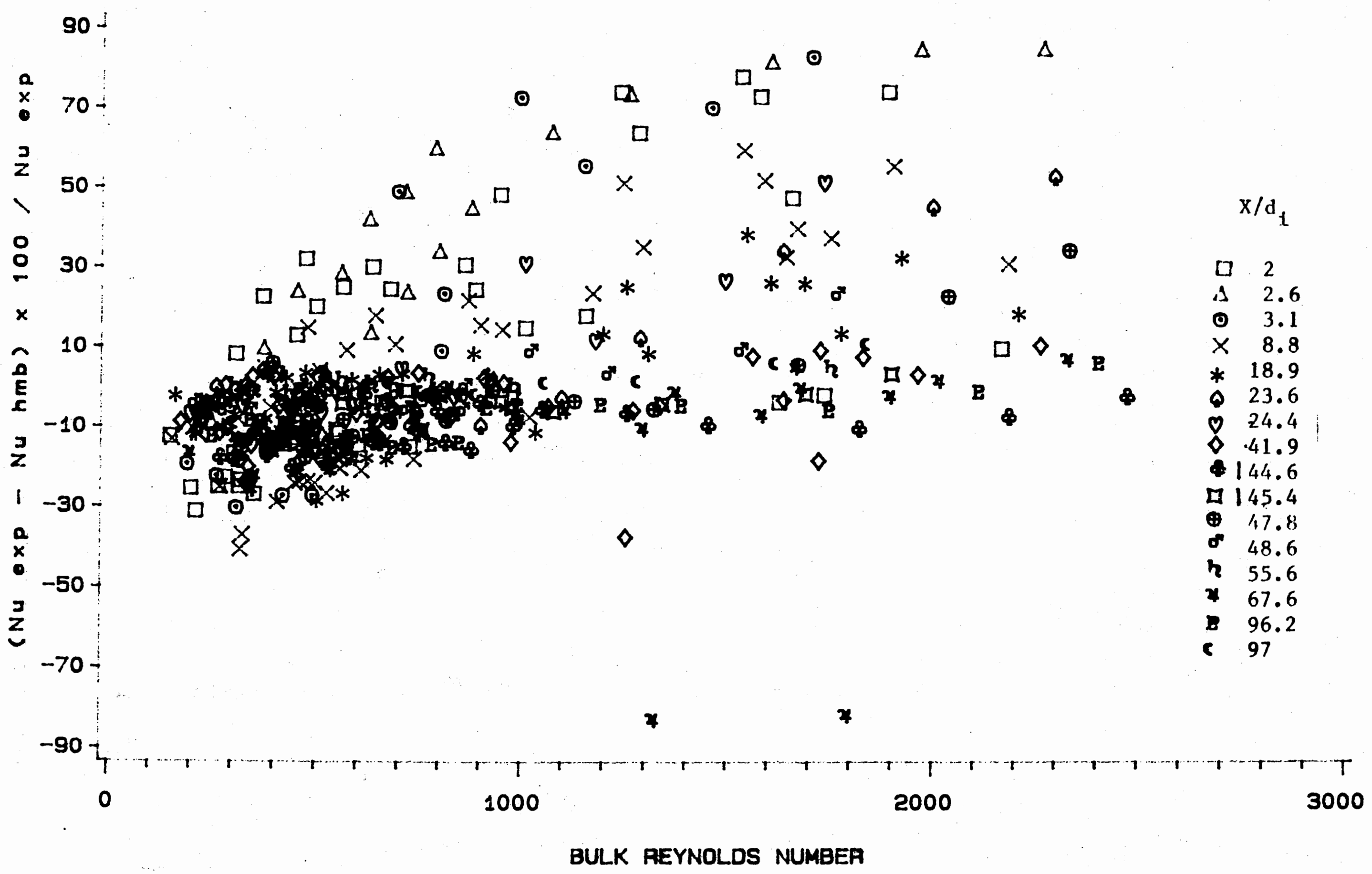


Figure 49: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Hong et al. Downstream from the U-Bend.

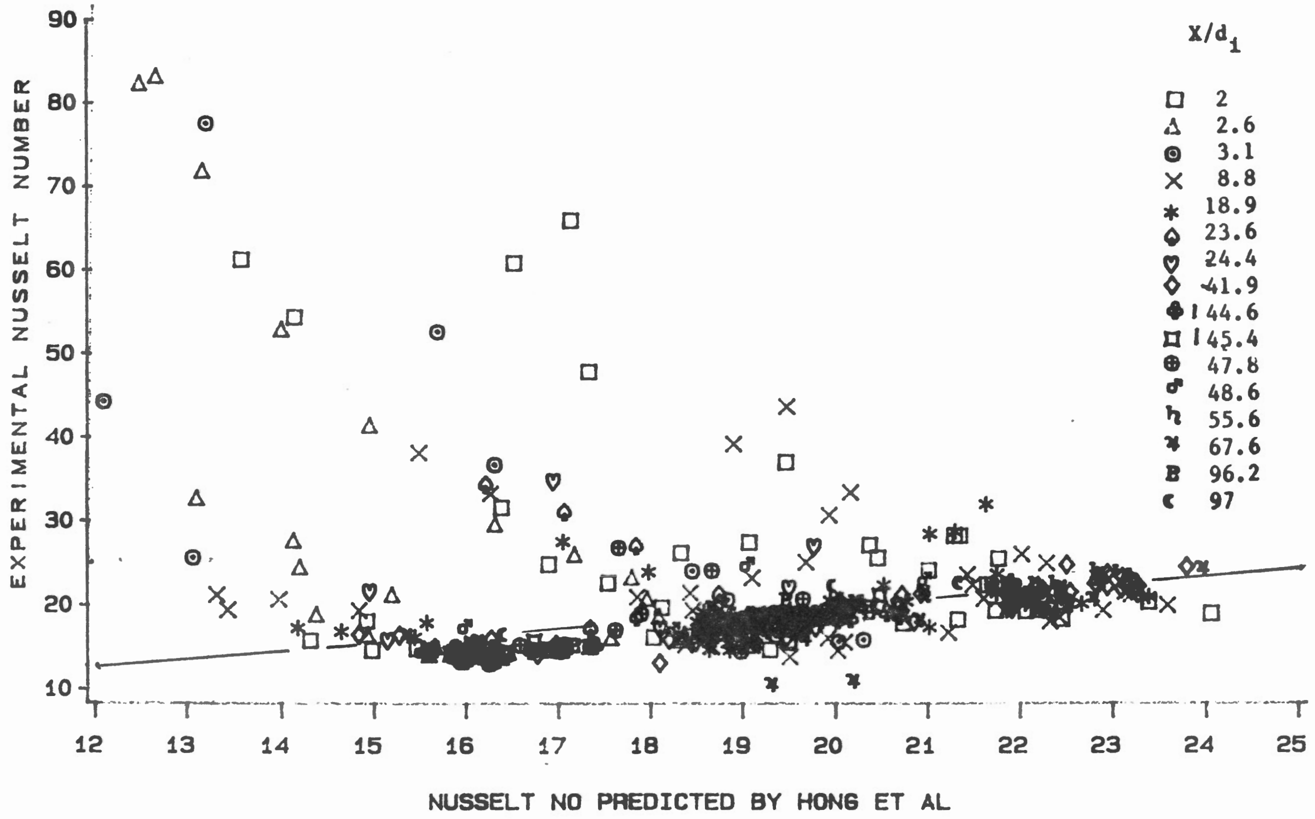


Figure 50: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Hong et al. Downstream from the U-Bend.

and Bergles correlation does not take in consideration the effect of the fully developed forced convection term.

Morcos and Bergles Correlation

The Morcos and Bergles equation (II.6) for the fully developed laminar flow in a straight tube was compared with the experimental results at each station. The dimensionless groups in equation (II.6) were calculated at the film temperature. Upstream of the bend, similar to the Hong, et al. correlation, the Morcos and Bergles predictions agreed well with the experimental data, especially far from the entrance (station 3), as shown in Figures 51 and 52.

As expected and similar to equation (II.5) the Morcos and Bergles correlation was too conservative when applied to station 7, downstream form the U-bend, see Figures 53 and 54.

The Morcos and Bergles correlation (II.6) is better than the Hong et al correlation (II.5), because it (II.6) considers the fully developed forced convection term for constant wall heat flux.

Moshfeghian Correlation

In the straight section upstream of the bend the heat transfer coefficients predicted by The Moshfegian correlation (II.1) agreed well with the experimental data, though his correlation was slightly conservative. Figures 55 and 56 show this agreement between the experimental and predicted (II.1).

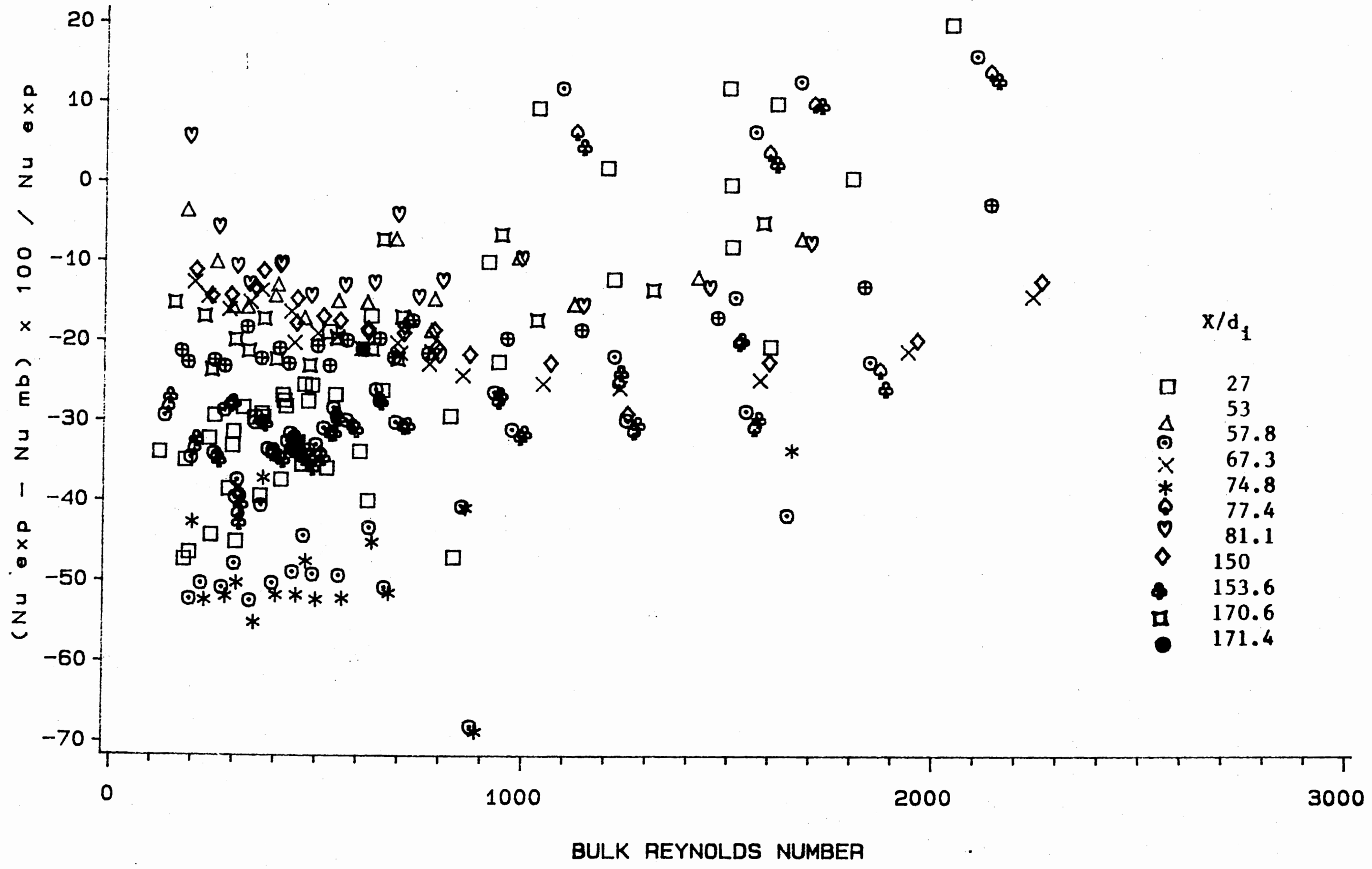


Figure 51: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Morcos and Bergles Upstream of the Bend.

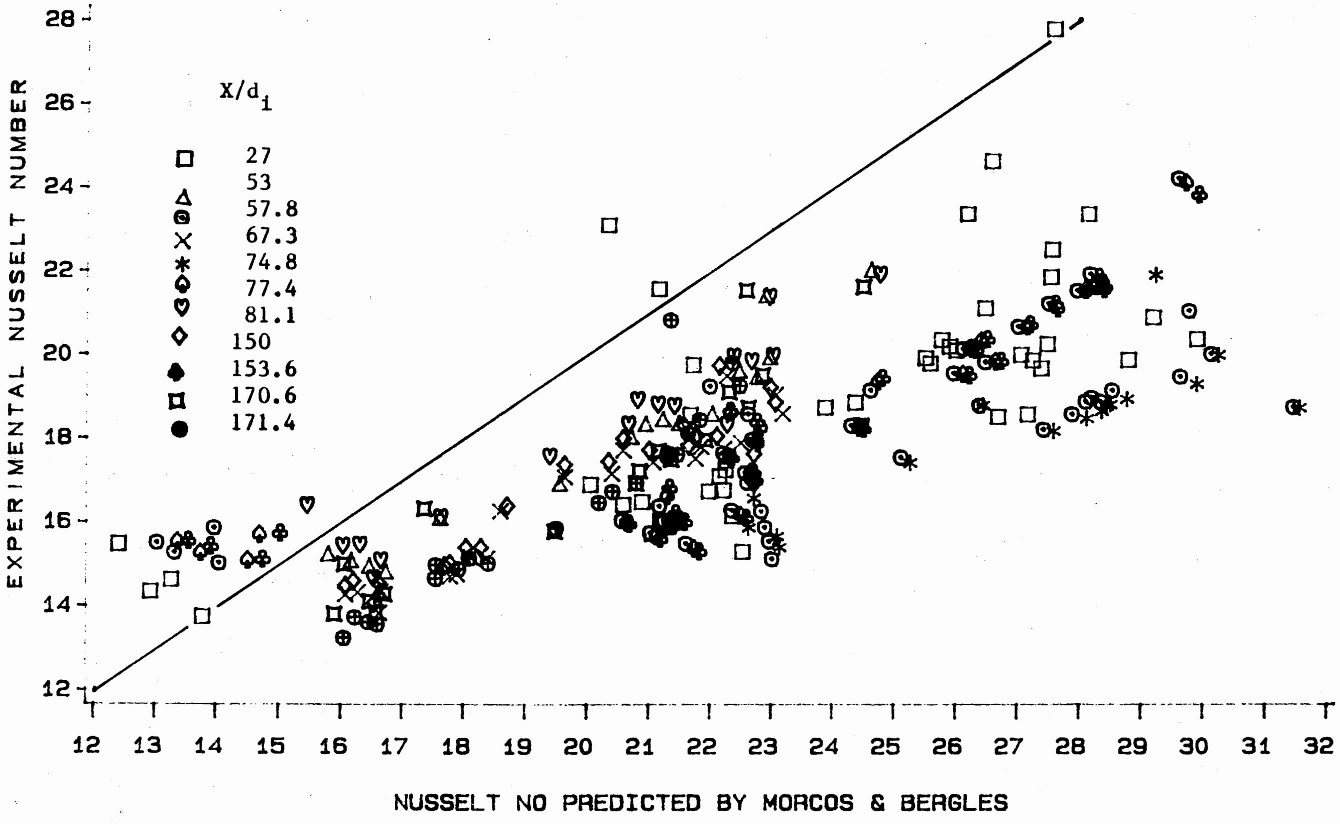


Figure 52: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Morcos and Bergles Upstream of the Bend.

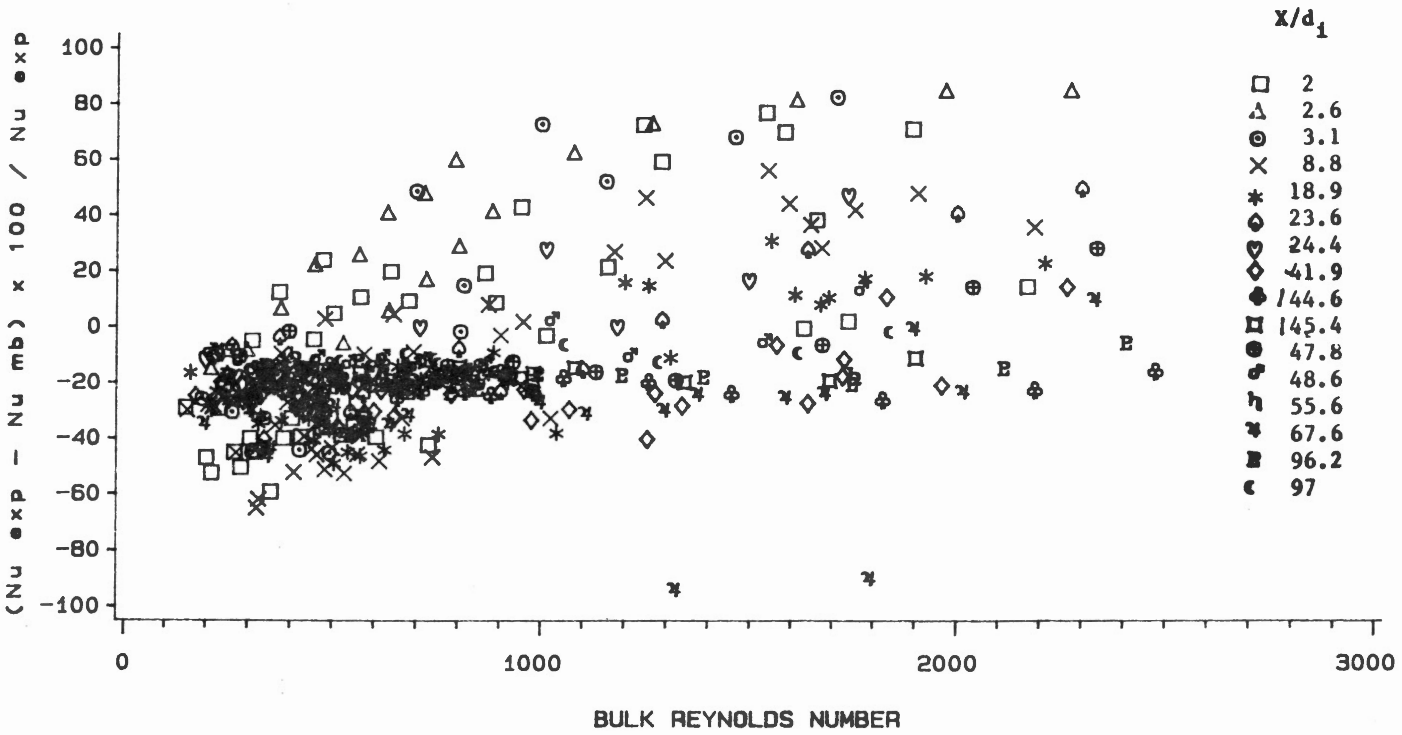


Figure 53: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Morcos and Bergles Downstream from the U-Bend.

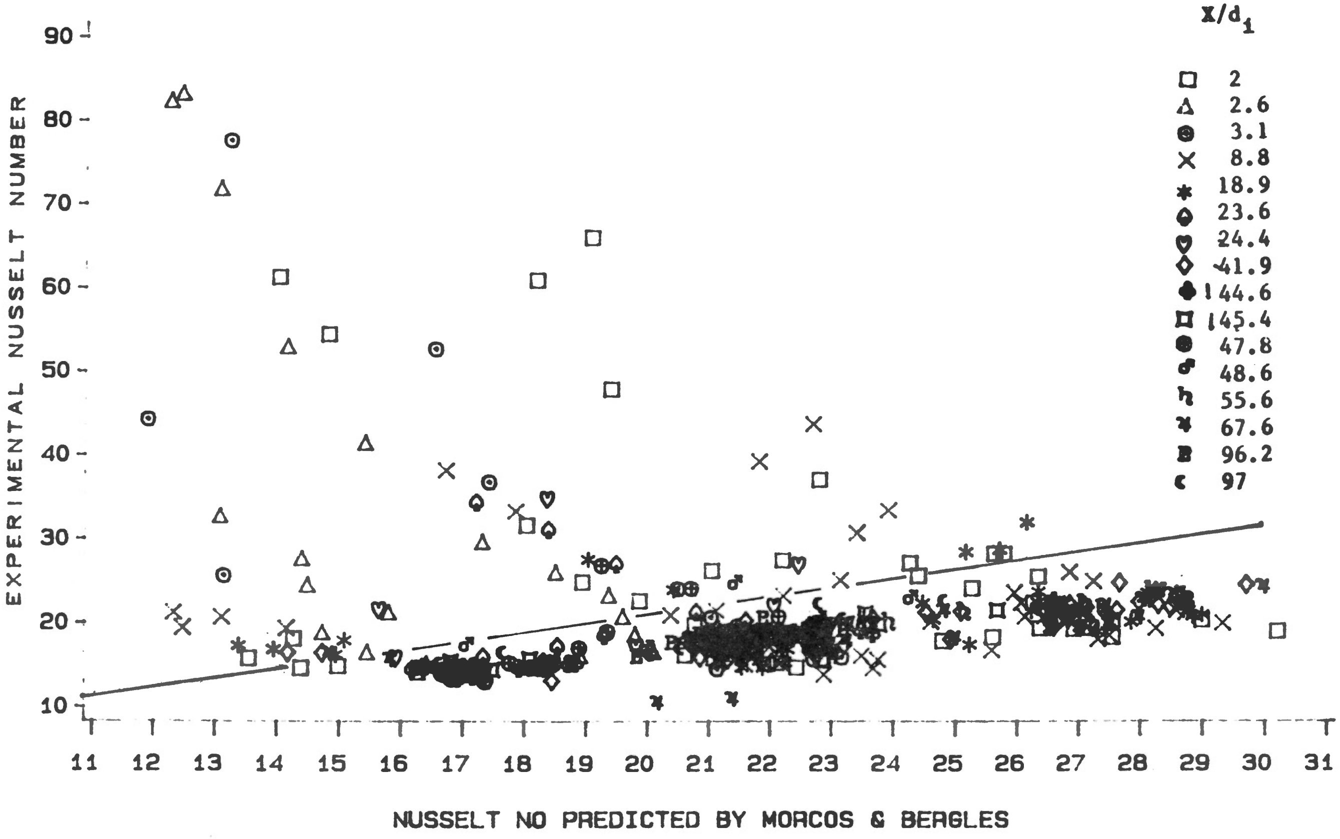


Figure 54: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Morcos and Bergles Downstream from the U-Bend.

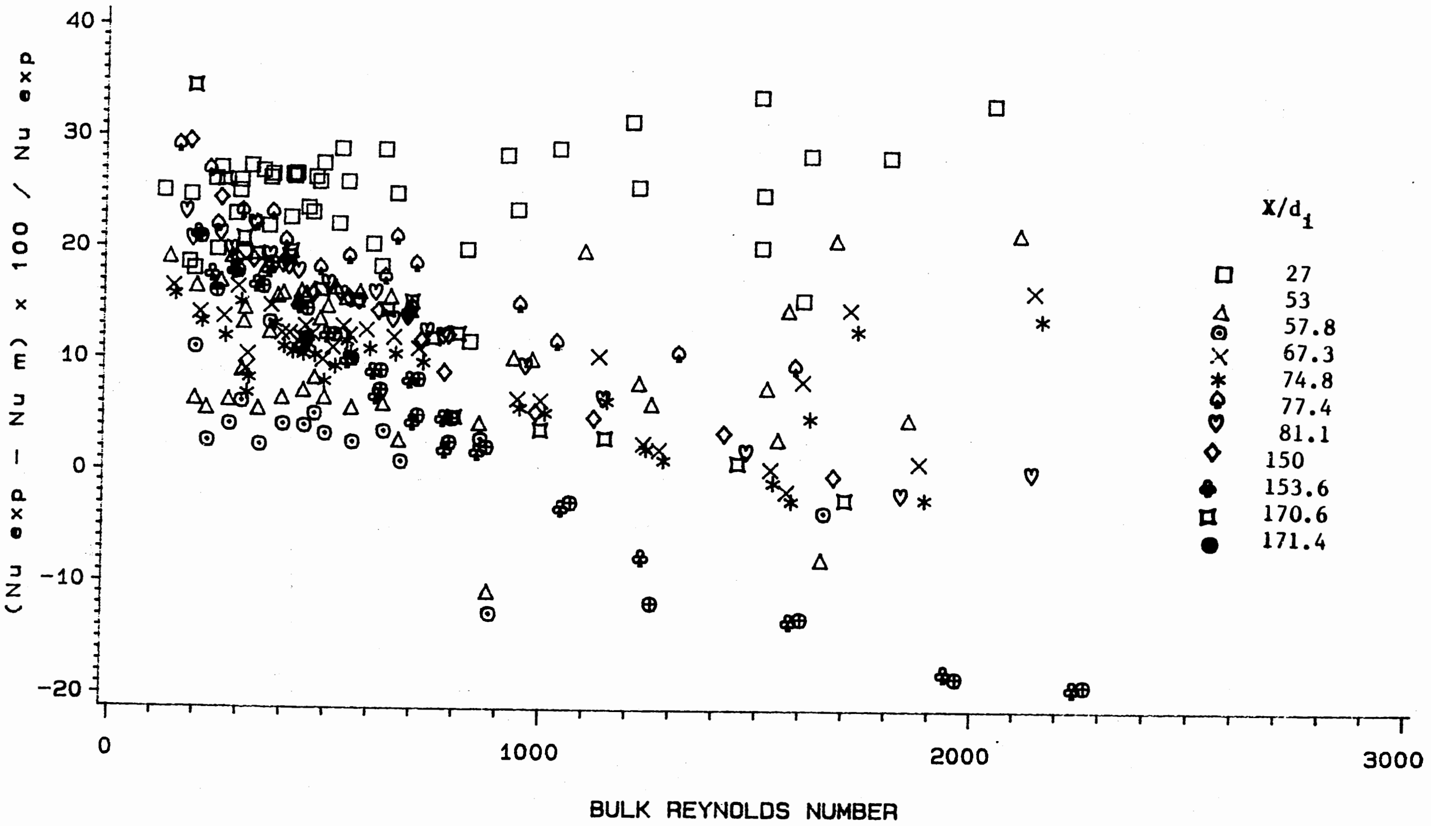


Figure 55: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Moshfeghian Upstream of the Bend.

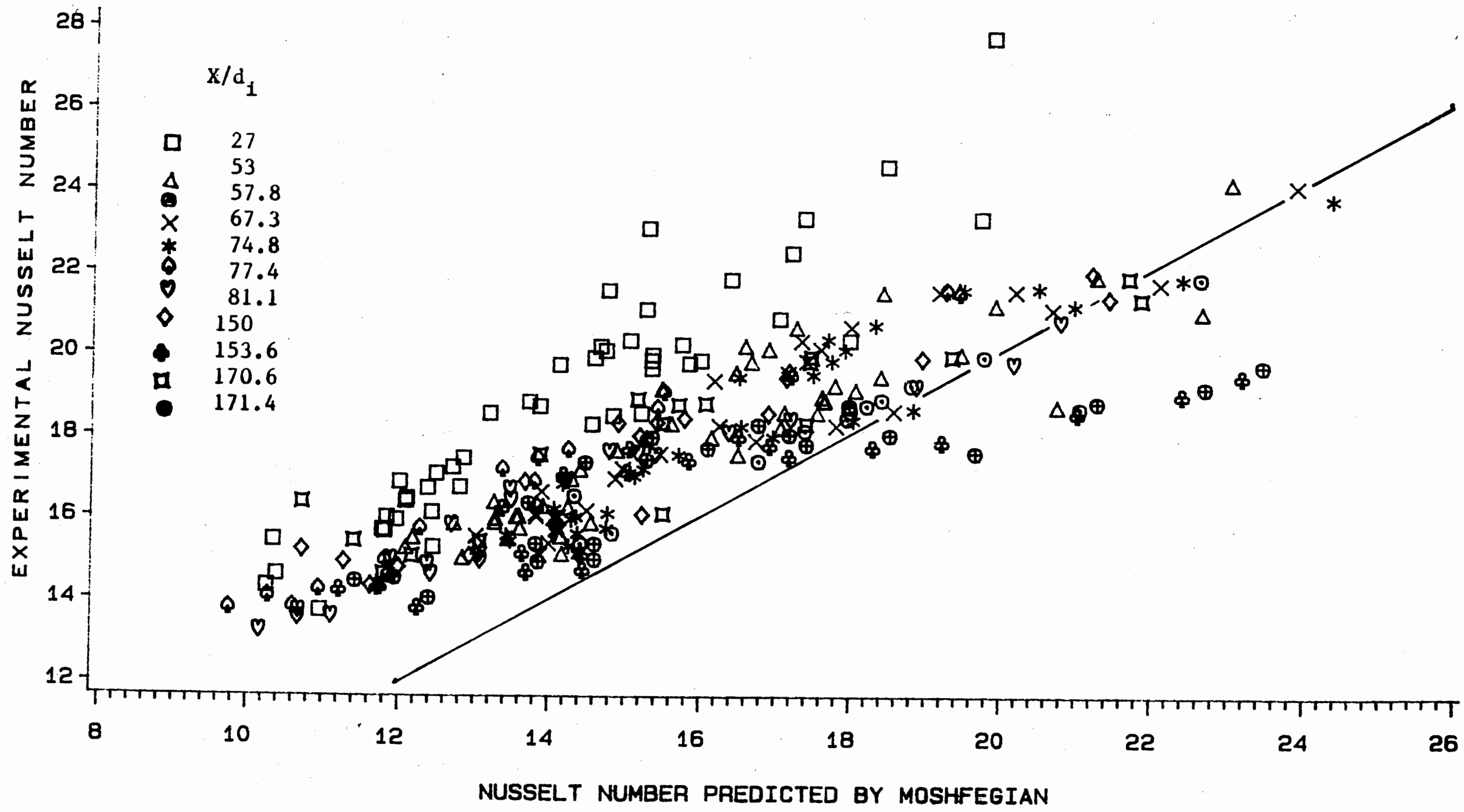


Figure 56: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Moshfeghian Upstream of the Bend.

After the U-bend, attempts were made to use 'X' as the start of heating in the straight section. These attempts failed because of the infinitly high predictions (II.1). But when the entrance to the U-bend was used (as indicated in equation II.1) as the starting point for the length dependence, even though there was no heating in the bend), the Moshfeghian correlation was too conservative. Figures 57 and 58 show the comparison between the experimental and predicted (II.1) heat transfer coefficients. Even though the Moshfeghian correlation, when applied to the experimental data downstream from the U-bend, was too conservative, it predicted the heat transfer coefficient better than any of the previous correlations.

Appendix J includes the comparison between the experimental heat transfer coefficients and those predicted by the previous correlations.

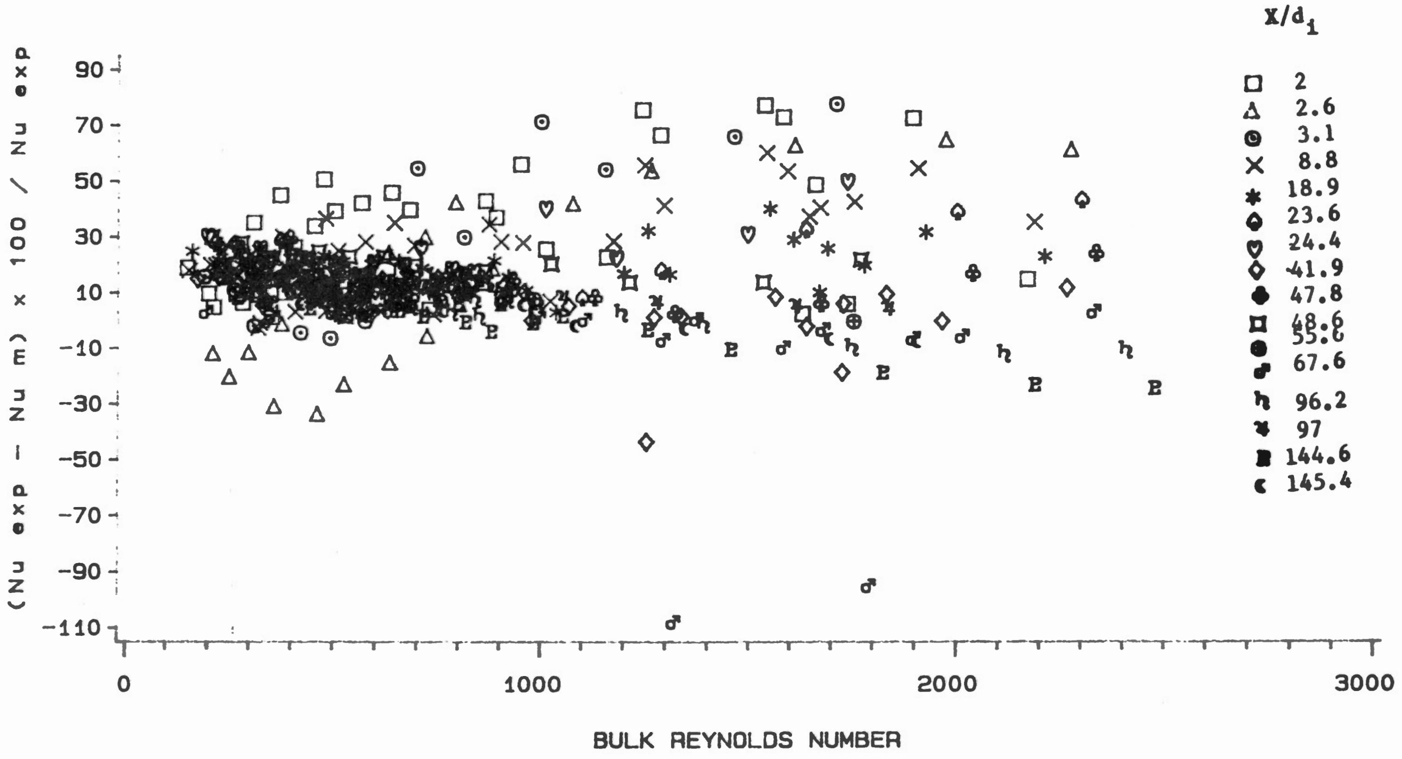


Figure 57: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Moshfeghian Downstream from the U-Bend.

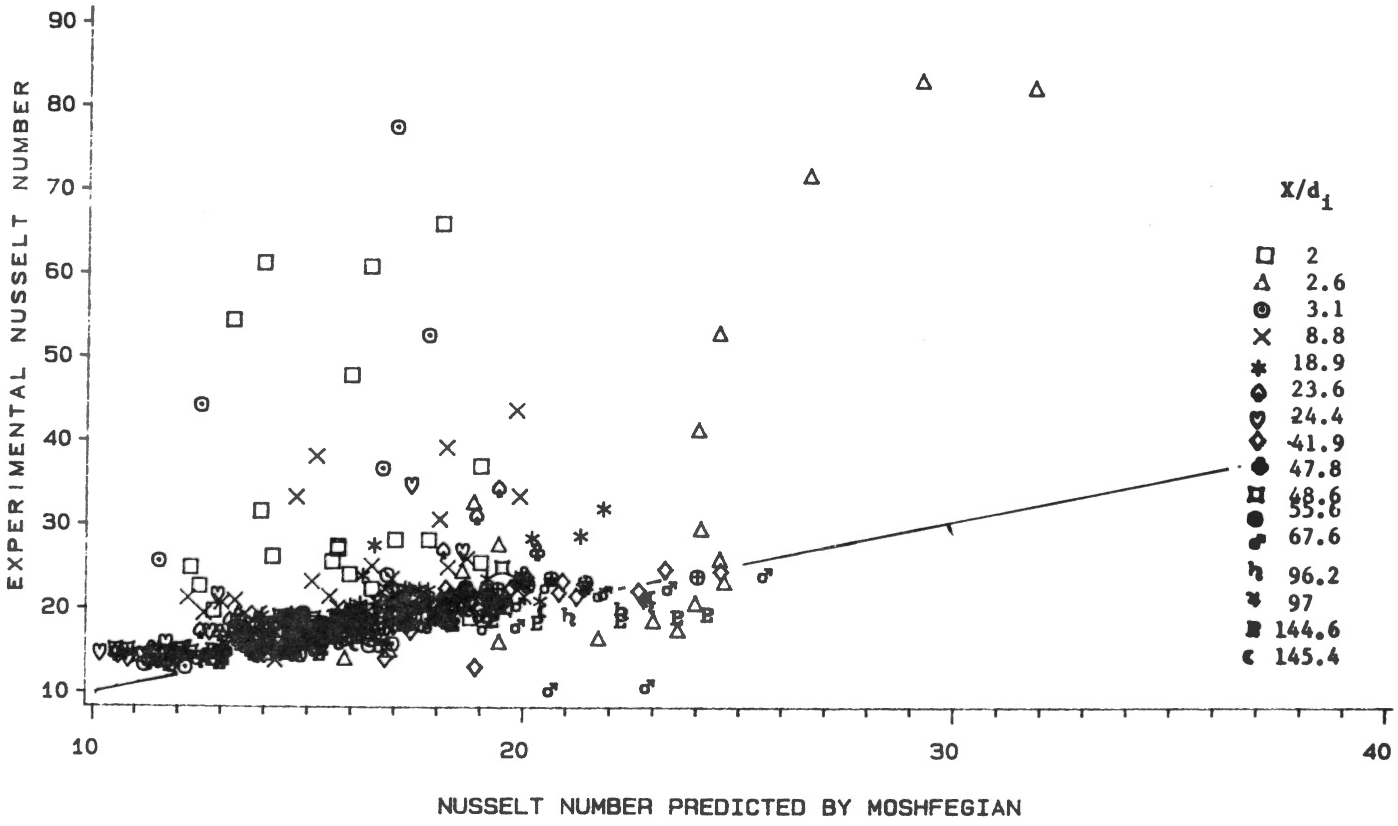


Figure 58: Comparison between the Experimental Heat Transfer Coefficient and the Heat Transfer Coefficient Predicted by Moshfeghian Downstream from the U-Bend.

CHAPTER VII

DEVELOPMENT OF THE CORRELATION

Experimental data in the laminar flow regime were gathered for 84 runs. For each run, data were collected at 11 stations. Each station has 8 peripheral positions. The heat transfer coefficients at each station were averaged, from the heat transfer data, by equation (V.6).

From the discussion of results in the previous chapter it is concluded that in the laminar flow regime:

1. For a fully developed velocity profile in a straight tube, upstream of the U-bend, the heat transfer coefficient increases with the increase in natural convection.
2. Downstream from the bend, the heat transfer coefficient increases with the increase in intensity of both the secondary and tertiary flow. The intensity of the secondary flow increases with tight bends and high Reynolds numbers (i.e. high Dean numbers) and decreases with distance down the tube.

Most of the literature correlations were developed for straight tubes. The Hausen equation (VI.3) and the Sieder and Tate equation (VI.2) do not consider the effects of natural convection (tertiary flow). Though the Hong, Morcos and Bergles equation (II.5) and the Morcos and Bergles equation (II.6) account for natural convection, these equations are applicable only to the fully developed flow in a straight tube. The Moshfeghian equation (II.1) for the flow in and downstream from heated U-bends as well as the previously mentioned equations poorly predicted the heat transfer coefficients downstream from the unheated U-bends (for more details refer to Chapter VI). This necessitated the development of a correlation that predicts more accurately the heat transfer coefficients downstream from the unheated U-bend.

Upstream of the Bend

For the fully developed velocity profile in a straight tube, there are two phenomena that contribute towards the heat transfer process; these phenomena are forced convection (primary flow) and natural convection (tertiary flow). Assuming that the two phenomena do not interact and that they are additive, the heat transfer coefficient could be expressed as follows:

$$Nu = (\text{forced convection term}) + (\text{natural convection term})$$

The heated length had no significant effect on the heat transfer coefficient. Also, the Graetz solution did not apply, possibly because the first station was far distant downstream ($X/d_i > 26$). Hence, for the forced convection term, the fully developed velocity and temperature contribution (4.364) is used. The natural convection term is expected to be a function of Grashof and Prandtl numbers, probably as a product of the numbers.

Experimental data in the straight section upstream to the bend (stations 1 to 3) were correlated for 282 points, where each point represents the dimensionless groups at one of the stations for each of the 84 runs. The resulting correlation, in light of the previous considerations is:

$$Nu = 4.364 + 0.3271 Gr^{0.25} Pr^{0.25} (\mu_b/\mu_w)^{0.14} \qquad (VII.1)$$

Equation (VII.1) is valid for:

$120 \le Re \le 2,500$

$3.9 \le Pr \le 110$

$2,500 \le Gr \le 1,130,000$

The traditional viscosity factor was used in correlationg the data. The dimensionless groups are calculated at the local bulk temperature. A computer program written by Chandler (3) was used to fit the experimental data to equation (VII.1), with two different methods. The two methods, modified Gauss-Newton and Marquardt-S, gave the same values for the constants in equation (VII.1). The first term in equation (VII.1) represents the fully developed flow, for the constant wall heat flux, in the absence of natural convection. The second group accounts for the effect of natural convection.

Equation (VII.1) agreed well with the experimental heat transfer coefficient, especially at large distances down the tube as indicated in Figures 59 and 60. Equation (VII.1) has an absolute average per cent deviation (AAPD) of 5.9 per cent. Equation (VII.1) agreed better (AAPD 5.9 %) with the mean coefficient calculated using equation (V.6) than those

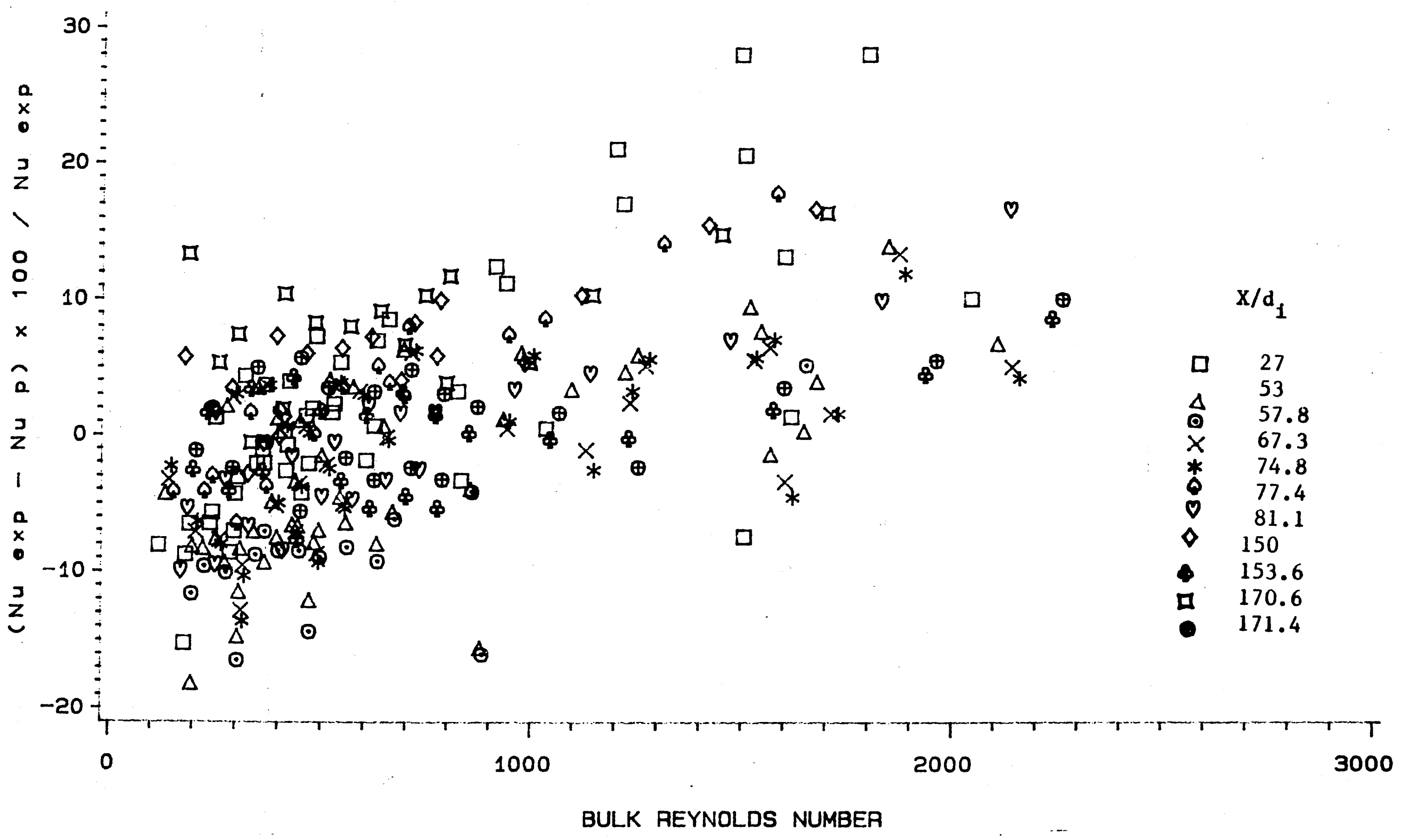


Figure 59: Comparison between the Experimental (eq. V.6) and the Predicted Heat Transfer Coefficients (eq. VII.1) Upstream of the Bend.

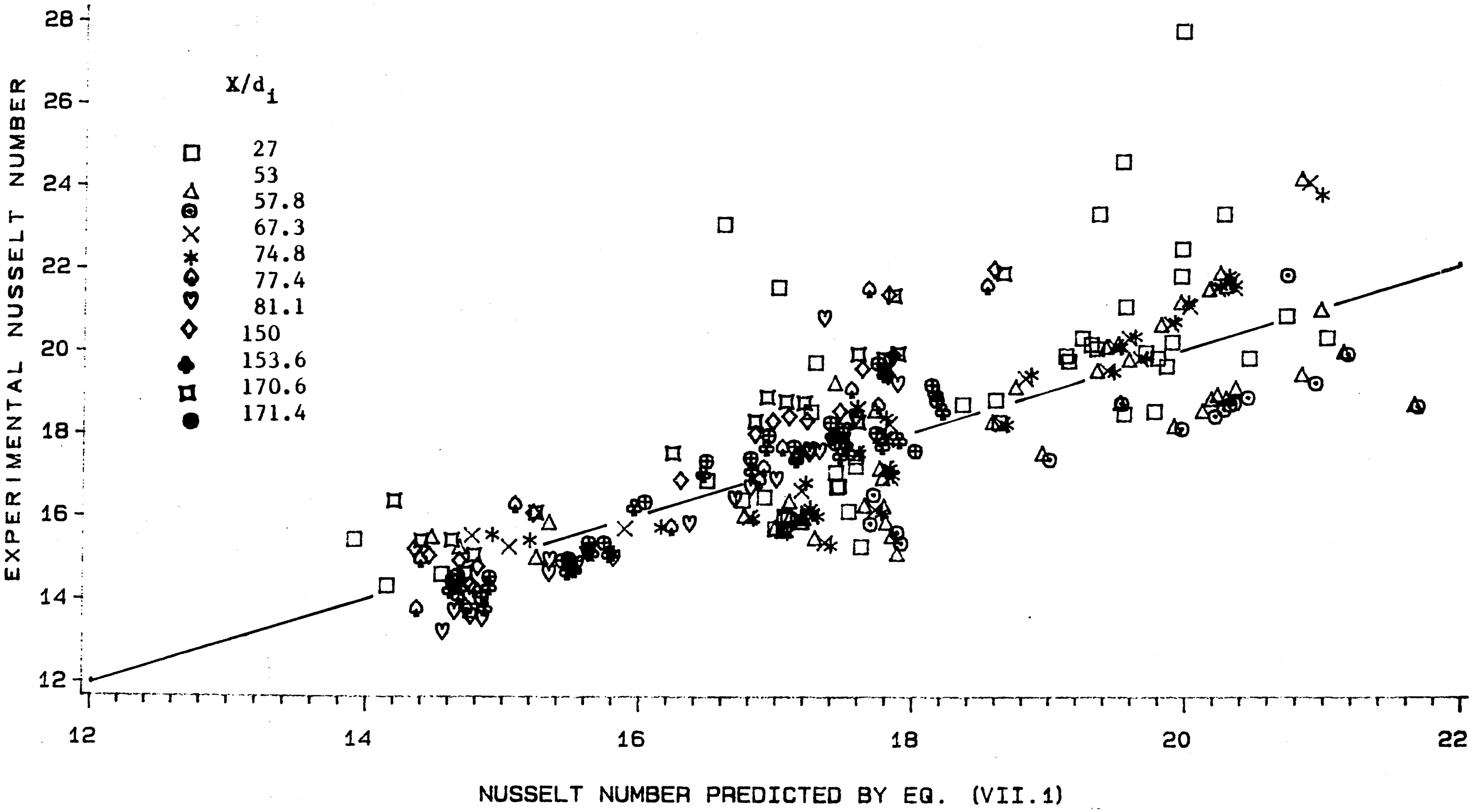


Figure 60: Comparison between the Experimental (eq. V.6) and the Predicted Heat Transfer Coefficients (eq. VII.1) Upstream of the Bend.

calculated by equation (V.5) (AAPD 8.9 %). When the predicted Nusselt number (VII.1) was compared with the experimental Nusselt number (V.5), the predictions were conservative.

Downstream from the U-Bend

Downstream from the U-bend, in addition to the forced and natural convection contributions, there is the secondary flow contribution. To evaluate the contribution of the secondary flow, equation (VII.1) was subtracted from the experimental Nusselt number and plotted against the Dean number (Figure 61). Figure 61 and Figures 27 to 31 indicate that, immediately after the U-bend, the heat transfer coefficient is a function of the Dean number and the Reynolds number and the coefficient decays exponentially with distance down the tube. Fitting procedures and hand calculations affirmed that the effect of the secondary flow on heat transfer decays exponentially with distance down the tube.

After fixing the forced and natural convection contributions, the experimental data downstream from the unheated bend (stations 7 to 11) were used to evaluate the exponential distance term for 400 points (ethylene glycol only). The water experimental runs (4 runs with test section A) were excluded because the secondary flow pattern did not seem to affect them. The evaluated exponential distance term was also fixed. Then the powers of the Reynolds number and the curvature ratio were evaluated

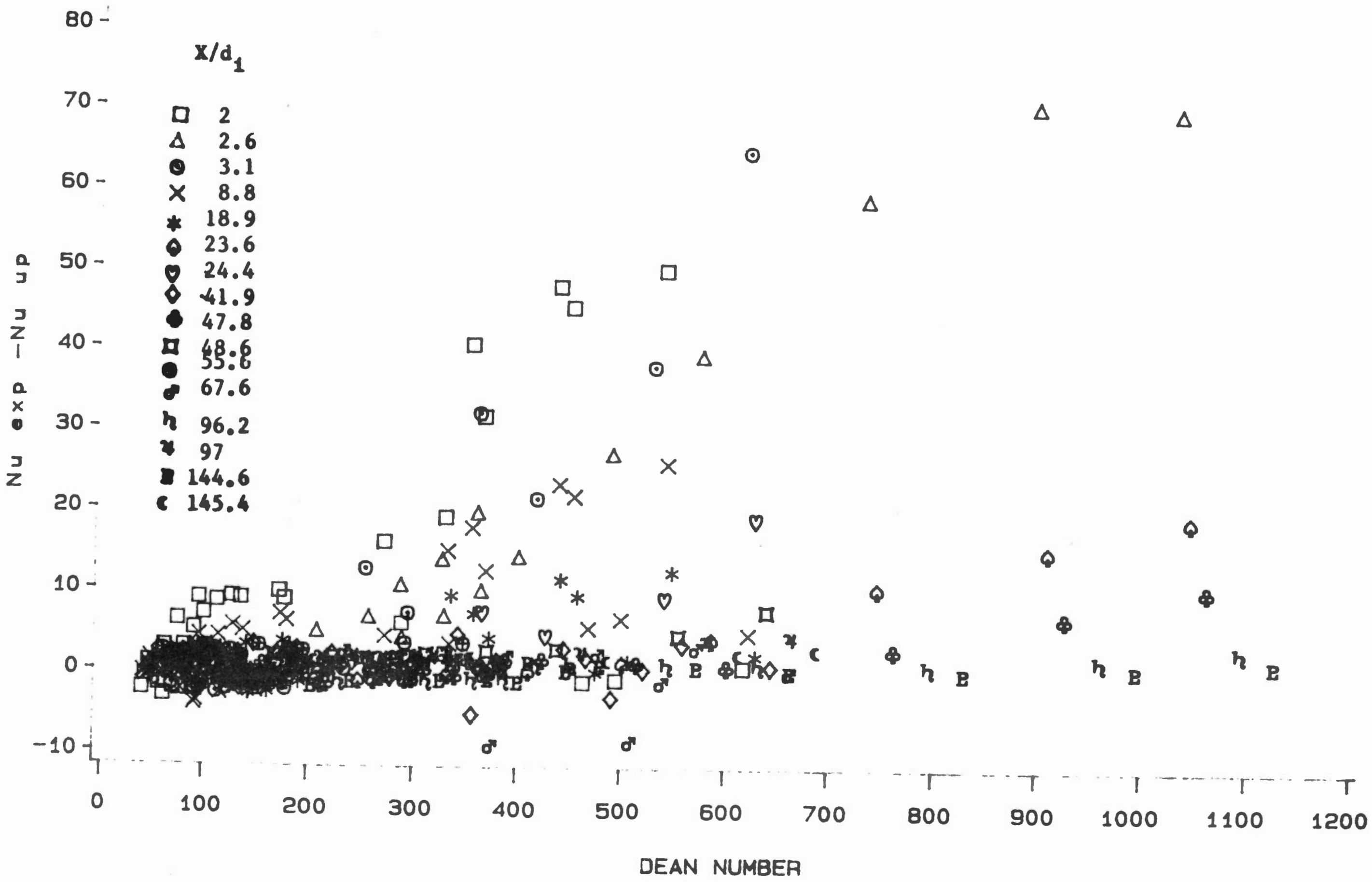


Figure 61: Effect of the Secondary Flow Pattern Downstream from the U-Bend.

immediately downstream from the bend (station 7). Finally, the experimental data (400 points) were fitted for the 400 points. Hence, the final correlation to predict the average peripheral Nusselt number downstream from an unheated U-bend in the laminar flow regime is:

$$Nu = \{4.364 + 0.3271 Gr^{0.25} Pr^{0.25} + 1.955x10^{-6} Re^{1.6} De^{0.8} e^{-0.0725(X/d_i)}\} (\mu_b/\mu_w)^{0.14} \qquad (VII.2)$$

Equation (VII.2) is valid for:

$$120 \leq Re \leq 2,500$$

$$44 \leq Pr \leq 110$$

$$2,500 \leq Gr \leq 45,100$$

The physical properties of the fluid used in equation (VII.2) were evaluated at the bulk temperature, except the viscosity at the wall, which was evaluated at the inside wall temperature. For the ethylene glycol data, the viscosity factor is approximately 1.01 to 1.15

Equation (VII.2) was compared with the experimental data for the ethylene glycol as shown in Figures 62 and 63. Equation (VII.2) has an absolute average per cent deviation of 9.9 %.

Equation (VII.2) has three limiting cases. The first case, when the curvature ratio tends to zero, the Dean number tends to zero and equation (VII.2) reduces to equation (VII.1) for the fully developed velocity profile in a straight tube. The second case is for the absence of natural convection, i.e. the Grashof number reduces to zero,

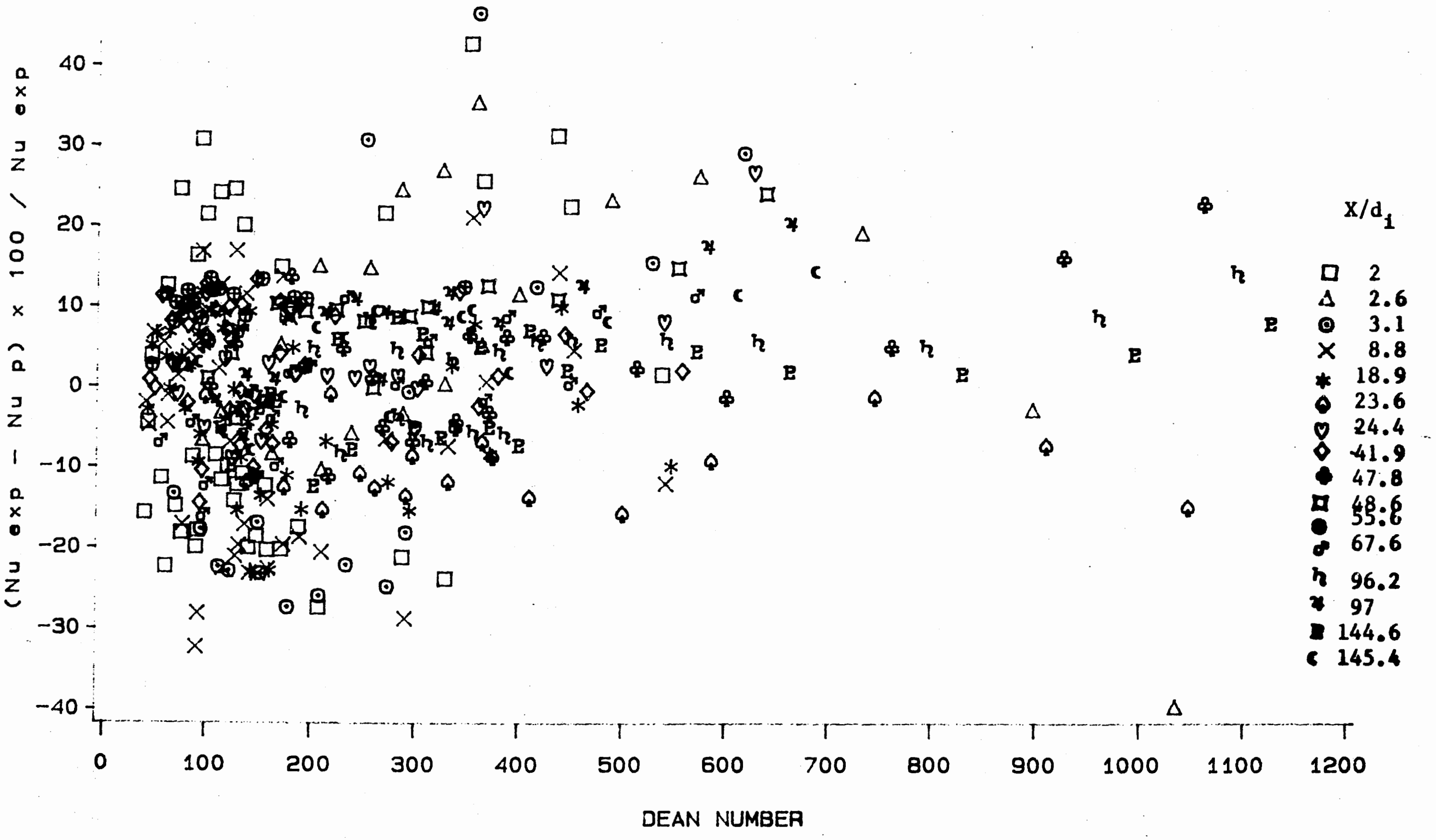


Figure 62: Comparison between the Experimental Heat Transfer Coefficient (eq.V.6) and the Heat Transfer Coefficient Predicted (eq. VII.2) Downstream from the U-Bend.

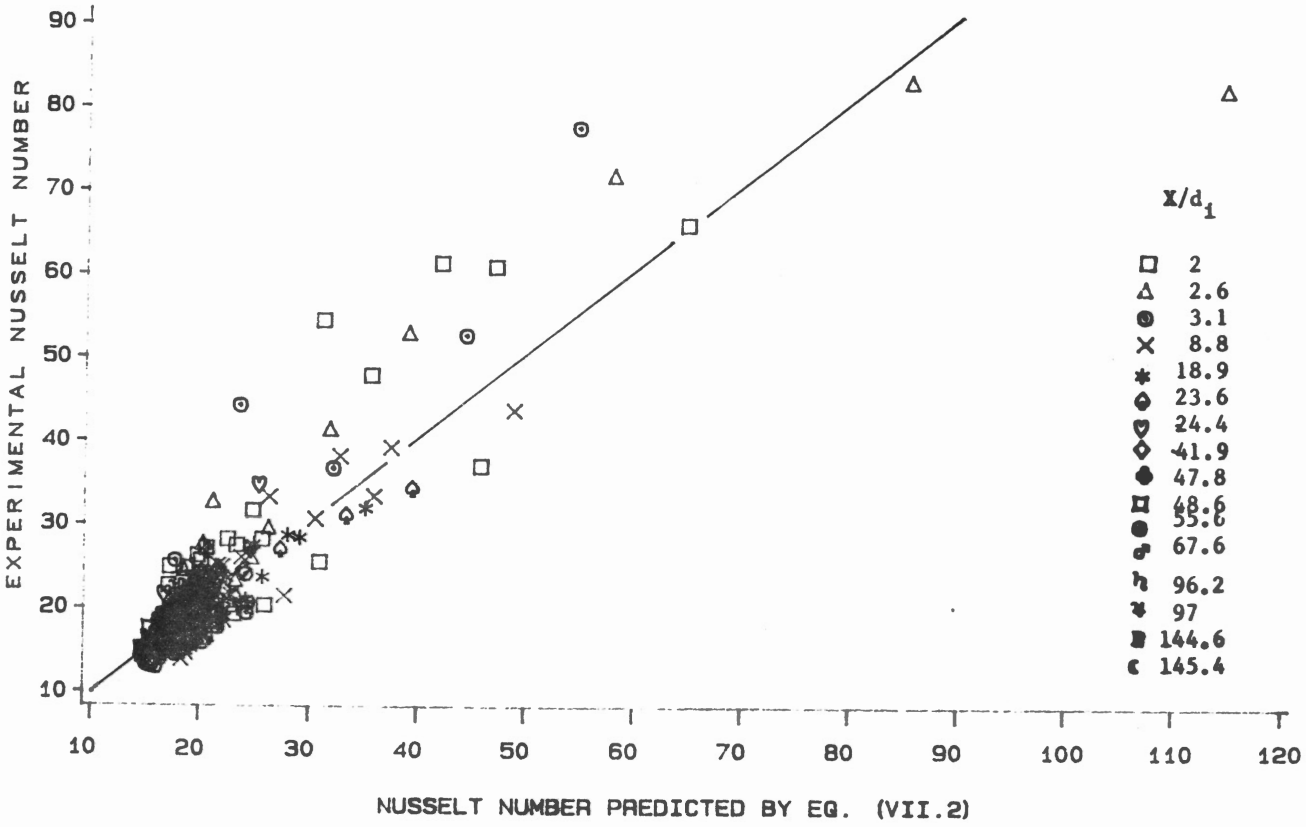


Figure 63: Comparison between the Experimental Heat Transfer Coefficient (eq. V.6) and the Heat Transfer Coefficient Predicted (eq. VII.2) Downstream from the U-Bend.

and equation (VII.2) reduces to:

$$Nu = \{4.364+1.955\times10^{-6} Re^{1.6} De^{0.8} e^{-0.0725(X/d_i)}\}(\mu_b/\mu_w)^{0.14} \qquad (VII.3)$$

The third case case is for the fully developed velocity and temperature profiles in a straight tube and the absence of natural convection, i.e. both the Dean number and the Grashof number tend to zero, and equation (VII.2) reduces to:

$$Nu=4.364(\mu_b/\mu_w)^{0.14} \qquad (VII.4)$$

Attempts to correlate the peripheral variation in the heat flux, upstream to and downstream from the U-bend, by the correlation introduced by Kays and Crawford (13)

$$q(\phi)=q(1+b\cos\phi) \qquad (VII.5)$$

failed.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

The effects of forced and natural convection, curvature ratios and distance along horizontal U-tubes were investigated for the laminar flow regime. The U-bends, in the vertical plane, were unheated. The straight sections were heated electrically with nominally constant heat fluxes.

In the laminar flow regime, when there is a temperature difference between the tube wall and bulk fluid, natural convection (tertiary flow) occurs in addition to forced convection. The tertiary flow enhances the mixing of the test fluid by the formation of two vortices and consequently causes a decrease in temperature of the tube wall, in the case of heating. Hence, higher, non-uniform heat transfer coefficients are observed around the tube periphery.

At the unheated bend, the flow seems to follow the same streamlines, upstream of the bend, till the middle of the bend. At low Reynolds numbers and high curvature ratios, the flow continues to follow the streamlines until the end of the U-bend. At higher Reynolds numbers and low curvature ratios, the secondary flow causes mixing of the flow in the bend and downstream from the bend.

Downstream from the U-bend, for low Reynolds and high

Grashof numbers the heat transfer coefficient increases slightly with distance down the tube, due to the increase in the Grashof number with distance. At higher Reynolds and lower Grashof numbers, the heat transfer coefficient immediately after the bend is high and decreases along the tube. The high heat transfer coefficient is due to the centrifugal action at the bend causing a secondary flow.

A correlation (VII.2) to predict the local average peripheral heat transfer coefficient downstream from the unheated U-bend has been proposed. This equation is also valid for the straight tube upstream of the bend, where $r / R = 0$ and equation (VII.2) becomes equation (VII.1).

Experiments should be conducted with the unheated U-bend in the horizontal plane in order to check the validity of the proposed mechanism and the equation.

Also, the validity of equation (VII.2) should be checked experimentally at different ranges of Reynolds (0.1 to 120), Prandtl and Grashof numbers.

If the first term in equation (VII.2) is changed to 3.66, the correlation might be valid for the case of constant wall temperature. Experimental data are required to justify this assumption.

It seems that natural convection increases with increase in length of heating. Experiments should be conducted to study the effect of heating length on natural convection.

In the straight sections upstream of the bends the first thermocouple stations were located at dimensionless distances greater than 26. More thermocouple stations should be located at the entrance section to study the entrance effects with mixed convection for the fully developed velocity profile.

After the middle of the U-bend at low Dean numbers, the secondary flow pattern did not seem to prevail. Two hypotheses were introduced in Chapter VI. Visual experiments are required to prove one or both hypotheses.

Immediately downstream from the U-bend, the tertiary flow pattern counteracts the effect of the secondary flow pattern. In the range of experimental runs included in this thesis, these effects were not very significant. A run at a high Reynolds number (2,000) should be repeated under very low and very high heat fluxes, to evaluate the maximum possible significance of this counteraction.

In the design of heat exchangers, use equations (VII.1) and (VII.2) for the prediction of the heat transfer coefficients upstream to and downstream from the U-bend, respectively. For quick, approximate calculations, use equation (VII.1) for the straight section downstream from the bend, as well as the straight section upstream to the bend. Immediately downstream from the U-bend, equation (VII.1) predicts conservative heat transfer coefficients, but after a short distance the predictions improve, because the coefficient decreases; see Appendix M for the behavior of equation (VII.2). For calculating the heat transfer area, given the outside heat transfer coefficient and stream temperatures, the inside heat transfer coefficient can be calculated by a trial and error procedure; this is illustrated in Appendix L.

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APPENDIX A

CALIBRATION OF THE UNATTACHED THERMOCOUPLES

Calibration Equipment

A thermometer (installed in the laboratory), the thermocouples in the room and the constant temperature bath, and the thermocouples at the inlet and exit of the test section were calibrated against a platinum resistance thermometer (S7928P120S), which was manufactured by Minco Products, Inc. (20). The thermocouple temperatures were read on the Doric DS-350 thermocouple indicator. The platinum resistance thermometer was connected to a Leeds and Northrup resistance bridge, Model 8069-B (15). A Leeds and Northrup galvanometer (Model 9834-2) was used as a null detector. A variable temperature bath (Model 910AD), which was regulated by a temperature controller (Model 910-53), maintained constant temperature. Both the bath and controller (30) were supplied by Rosemount Inc.

Temperature Calibration Procedure

The thermometer and the thermocouples that were not attached to the test sections were calibrated against a platinum resistance thermometer from 32 to 195 F (0 - 90.7 C). Water was used as the bath fluid. For calibration at 32 F (0 C), a mixture of ice and distilled water formed the bath medium.

The resistance bridge was adjusted and checked for the zero correction, as described in the instruction manual (15), before connecting the platinum resistance thermometer. The thermocouple beads at the inlet and exit of the test section were shielded with teflon tape, which was kept on during the calibration and the experimental runs. All thermocouples that were calibrated were deeply immersed in the calibrating bath.

The temperature controller was set to a constant temperature and eight readings were taken in sets of two, with fifteen minute intervals between the four sets, thus totaling an hour for each temperature. The bath temperature was increased in steps of approximately 10 F (5.6 C) between each setting. Table III shows the calibration data.

The difference between the readings of the platinum thermometer and the thermocouple indicatior were calculated over the working temperature range for each thermocouple. These correction factors were incorporated into the computer programs to correct the output readings of the temperature indicator.

TABLE III

CALIBRATION DATA OF THE UNATTACHED THERMOCOUPLES

Platinum thermometer (F)	Thermocouple			
	Bath (F)	Exit bulk (F)	Inlet bulk (F)	Room (F)
32.02	31.45	31.45	31.5	31.5
32.02	31.4	31.4	31.5	31.4
32.02	31.6	31.45	31.55	31.35
32.02	31.55	31.4	31.55	31.4
32.02	31.65	31.6	31.6	31.4
32.02	31.6	31.45	31.5	31.4
32.03	31.65	31.7	31.6	31.5
32.03	31.65	31.45	31.5	31.35
92.11	91.95	92.0	91.95	91.9
92.11	92.05	92.0	91.95	91.85
92.11	91.95	91.95	91.95	91.85
92.11	92.0	91.8	91.9	91.85
92.11	91.95	91.95	91.9	91.85
92.11	92.0	91.9	91.9	91.95
92.11	91.95	91.95	91.95	91.8
92.11	92.0	91.9	92.0	91.75
102.47	102.55	102.55	102.45	102.2
102.47	102.4	102.3	102.3	102.2
102.47	102.35	102.25	102.25	102.15
102.47	102.35	102.2	102.15	102.2
102.47	102.3	102.35	102.25	102.1
102.47	102.5	102.35	102.4	102.15
102.47	102.45	102.3	102.1	102.2
102.47	102.45	102.25	102.15	102.1
112.80	112.8	112.75	112.55	112.65
112.80	112.75	112.6	112.65	112.75
112.80	112.75	112.7	112.7	112.85
112.80	112.8	112.65	112.6	112.85
112.80	112.95	112.75	112.7	112.95
112.80	112.95	112.75	112.7	112.95
112.81	112.9	112.8	112.75	112.85
112.81	112.95	112.85	112.85	112.85
125.18	125.15	125.25	125.2	125.35
125.18	125.4	125.25	125.2	125.35
125.18	125.15	125.25	125.25	125.3
125.18	125.35	125.25	125.05	125.25

Continued

TABLE III (Continued)

125.19	125.25	125.2	125.25	125.35
125.18	125.25	125.1	125.1	125.25
125.18	125.35	125.25	125.05	125.25
125.18	125.25	125.15	125.15	125.25
136.08	136.1	136.2	136.05	136.2
136.08	136.25	136.15	136.05	136.25
136.08	136.1	136.1	136.05	136.3
136.08	136.35	136.15	136.1	136.35
136.08	136.35	136.3	136.1	136.35
136.08	136.15	136.15	136.05	136.25
136.08	136.25	136.35	136.15	136.25
136.08	136.15	136.3	136.2	136.35
147.99	148.05	148.05	147.9	147.9
147.96	148.0	147.95	147.85	147.9
147.98	148.05	148.05	147.75	147.9
147.98	147.95	147.9	147.75	147.95
147.97	147.9	147.85	147.8	1478.0
147.97	147.9	147.8	147.7	148.0
147.96	147.95	147.95	147.8	147.95
147.96	147.95	147.8	147.7	147.9
159.05	158.9	158.95	158.75	159.05
159.05	158.95	158.8	158.7	159.1
159.05	159.1	159.05	158.8	159.0
159.05	159.0	158.85	158.7	159.05
159.04	158.9	159.0	158.8	159.1
159.04	159.0	158.9	158.8	159.05
159.02	159.05	158.85	158.7	1589.0
159.02	159.05	158.8	158.8	159.1
159.02	158.95	158.9	158.8	158.9
159.02	159.05	158.9	158.8	158.95
170.33	170.05	170.1	169.8	170.0
170.33	170.25	170.15	170.1	170.05
170.33	170.15	170.1	170.0	170.4
170.33	170.1	170.0	169.85	170.15
170.31	169.95	169.95	169.8	170.2
170.31	170.05	170.05	169.75	170.1
170.31	170.05	170.05	169.85	170.3
170.31	169.9	170.05	169.9	170.3
182.26	181.85	181.75	181.5	182.05
182.26	181.85	181.85	181.65	182.05
182.25	181.85	181.85	181.7	181.9
182.25	182.05	181.95	181.6	182.05
182.25	181.85	181.8	181.6	182.05
182.25	181.85	181.85	181.65	182.05
182.24	181.9	181.85	181.6	182.05
182.24	181.9	181.8	181.55	181.95

Continued

TABLE III (Continued)

195.24	195.05	195.05	194.8	195.1
195.24	195.0	194.9	194.75	195.15
195.24	194.85	194.9	194.7	195.1
195.24	195.0	194.9	194.7	195.1
195.22	195.0	194.9	194.7	195.0
195.22	195.0	194.8	194.7	195.0
195.22	195.05	194.95	194.75	195.1
195.22	194.95	194.85	194.7	195.1
Correction over the working temperature range:				
	0.0	0.1	0.2	0.1

APPENDIX B

CALIBRATION OF THE THERMOCOUPLES ATTACHED TO THE SURFACE OF THE TEST SECTION

Calibration Procedure

All surface thermocouples were calibrated in situ by running distilled water or ethylene glycol in the test section at constant temperature and comparing their readings with the calibrated thermocouples measuring the inlet and exit fluid bulk temperatures.

A SAS (Statistical Analysis Systems) program was written to correct the attached thermocouple temperatures by the method of least squares according to the following correlation:

$$T_{correct}=T_{read}+A+B(T_{read}-T_{room}) \qquad (B.1)$$

Where A and B are constants calculated from the program. The second term A accounts for the thermocouple error and the third term accounts for the accuracy of the temperature measured due to heat loss to the laboratory.

A listing of the program follows. The calibration data are available as indicated in Appendices G and J.

```
$JOB
C  A PROGRAM TO CALCULATE THE ERROR IN THE TEMPERATURE READING OF THE
C    THERMOCOUPLES ATTATCHED TO THE SURFACE OF THE TEST SECTION.
C  AUTHOR      : AMANIE N. ABDELMESSIH
C  INSTALLATION: OKLAHOMA STATE UNIVERSITY.
C  DATE        : MARCH 3, 1985.
C  LANGUAGE    : WATFIV.
C  METHOD      : LEAST SQUARES FOR A STRAIGHT LINE.
C
C  INPUT QUANTITIES
C    J = NUMBER OF CALIBRATION SET.
C    TIN(J) = THE BULK INLET TEMPERATURE FOR THE JTH CALIBRATION.
C    TOUT(J) = THE BULK EXIT TEMPERATURE FOR THE JTH CALIBRATION.
C    TROOM(J) = THE LABORATORY TEMPERATURE DURING THE JTH CALIBRATION.
C    T(J,K,L) = THE OUTSIDE SURFACE TEMPERATURE AT STATION K AND
C                 POSITION L.
C    ALL TEMPERATURES IN DEGREE F.
C  OUTPUT QUANTITIES
C    X = OUTSIDE SURFACE READING - LABORATORY TEMPERATURE.
C    Y = BULK TEMPERATURE - OUTSIDE SURFACE READING.
C    SUMX = SUM OF X.
C    SUMX2 = SUM OF SQ. X.
C    SUMY = SUM OF Y.
C    SUMXY = SUM OF PRODUCT OF X Y.
C    A, B = CONSTANTS IN EQUATION (B.1)
      DIMENSION T(20,11,8), TIN(20), TOUT(20), TAVG(20), Y(20,11,8),
     /SX(11,8), SX2(11,8), SY(11,8), SXY(11,8),B(11,8),A(11,8),TROOM(20)
C  READER UNIT 8, PRINTER UNIT 6, AND FILE 9.
      M=8
      N=6
      NN=9
      JJ=0
      DO 80 J=1,20
        READ(M,20) TIN(J),TOUT(J),TROOM(J)
        IF(TIN(J).EQ.0.0)GO TO 85
C  CORRECTION FOR INLET AND EXIT BULK TEMPERATURES.
       TIN(J)=TIN(J)+0.2
       TOUT(J)=TOUT(J)+0.1
        JJ=JJ+1
        WRITE(N,10)
   10   FORMAT(1H1, 51HCALIBRATION OF SURFACE THERMOCOUPLES ORIGINAL DAT
     /A )
   20   FORMAT(3F6.0)
         TAVG(J)=(TIN(J)+TOUT(J))/2.0
         WRITE(N,30) TIN(J), TOUT(J), TAVG(J),TROOM(J)
   30  FORMAT(1H0, 24HBULK INLET TEMPERATURE =,F5.1, 2X, 'BULK EXIT
     1TEMPERATURE =',F5.1/20X,27H AVERAGE BULK TEMPERATURE= ,F6.2,
     2/30X,'ROOM TEMPERATURE = ',F5.1)
        WRITE(N,40)
   40   FORMAT(1H0,20X,27HTEMPERATURE (F) AT POSITION  )
        WRITE(N,50)
   50   FORMAT(1H0,8HSTATION ,4X,1H1,8X,1H2,8X,1H3,8X,1H4,8X,1H5,
     1  8X,1H6,8X,1H7,8X,1H8)
        DO 80 K=1,11
          READ(M,60)(T(J,K,L),L=1,8)
```

```
   60     FORMAT(8F6.0)
          WRITE(N,70)K,(T(J,K,L),L=1,8)
   70     FORMAT(1X,I6,8F9.1)
   80 CONTINUE
C  CALCULATION AND PRINTING THE DEVIATION IN TEMPERATURE.
   85 DO 120 J=1,JJ
C       WRITE(N,90)
C  90   FORMAT(1H1, 'TEMPERATURE DIFFERENCE BETWEEN AVERAGE BULK AND SUR
C    1FACE THERMOCOUPLE READING IN F')
C      WRITE(N,95)TAVG(J)
C  95  FORMAT(1H0, 20X,'AT AN AVERAGE TEMPERATURE OF ',F6.1,' F')
C      WRITE(N,100)
C 100   FORMAT(1H0, 30X,8HPOSITION )
C       WRITE(N,50)
          DO 120 K=1,11
            DO 110 L=1,8
              Y(J,K,L)=TAVG(J)-T(J,K,L)
  110       CONTINUE
C           WRITE(N,70)K,(Y(J,K,L),L=1,8)
  120 CONTINUE
C  METHOD OF LEAST SQUARES.
      DO 140 K=1,11
        DO 140 L=1,8
          SUMX=0.0
          SUMSQX=0.0
          SUMXY=0.0
          SUMY=0.0
          DO 130 J=1,JJ
            SUMX=SUMX+T(J,K,L)-TROOM(J)
            SUMSQX=SUMSQX+(T(J,K,L)-TROOM(J))**2
            SUMY=SUMY+TAVG(J)-T(J,K,L)
            SUMXY=SUMXY+(T(J,K,L)-TROOM(J))*(TAVG(J)-T(J,K,L))
  130     CONTINUE
          SX(K,L)=SUMX
          SX2(K,L)=SUMSQX
          SY(K,L)=SUMY
          SXY(K,L)=SUMXY
  140 CONTINUE
      WRITE(N,150)
  150 FORMAT(1H1,'METHOD OF LEAST SQUARES FOR THE ERROR IN SURFACE THERM
     1OCOUPLE READING .')
      WRITE(N,160)
  160 FORMAT(1H0,3X,8HPROPERTY,20X,8HPOSITION)
      WRITE(N,50)
      DO 180 K=1,11
      WRITE(N,170)K,(SX(K,L),L=1,8),(SX2(K,L),L=1,8),(SY(K,L),L=1,8),
     1         (SXY(K,L),L=1,8)
  170 FORMAT(1H0,I2,4HSUMX,8F9.1/2X,5HSUMX2,8F9.1/2X,5H SUMY,8F9.1/2X,
     1 5HSUMXY,8F9.1)
  180 CONTINUE
C     WRITE(N,190)JJ
C 190 FORMAT(1H0,26H NUMBER OF CALIBRATIONS =  ,I2)
      AJ=JJ
      WRITE(N,200)
  200 FORMAT(1H1,'CONSTANTS FOR THE CORRELATION CORRECTING THE SURFACE
```

```
     1THERMOCOUPLE READINGS')
      WRITE(N,160)
      WRITE(N,50)
      DO 210 K=1,11
        DO 210 L=1,8
       B(K,L)=(SXY(K,L)/SX(K,L)-SY(K,L)/AJ)/(SX2(K,L)/SX(K,L)-SX(K,L)/AJ
     1  )
        A(K,L)=SY(K,L)/AJ-B(K,L)*SX(K,L)/AJ
  210 CONTINUE
C  PRINTING AND SAVING THE CONSTANTS A AND B.
      DO 240 K=1,11
      WRITE(N,220)K,(B(K,L),L=1,8),(A(K,L),L=1,8)
  220 FORMAT(1H0,2X,I2,2X,1HB,8F9.6/7X,1HA,8F9.6)
C     WRITE(NN,230)(B(K,L),L=1,8),(A(K,L),L=1,8)
C 230 FORMAT(1H0,7F9.6,F8.5)
  240 CONTINUE
      STOP
      END
$ENTRY
```

APPENDIX C

FLOW RATE CALIBRATION

Calibration Equipment

A stop watch, manufactured by Fisher Scientific Company, was used to time the fluid flow rate. It has a precision of 0.01 seconds. A five gallon tank was used to collect the liquid. The collected liquid was weighed on a 50 kg analytical balance. A set of calibrated weights was used in conjunction with the balance. The accuracy of the final weight is within one gram.

Calibration Procedure

The fluid flow rate was adjusted to the desired float setting on the rotameter. After operating for approximately half an hour at the desired float setting, the fluid flowing in the system was collected in a previously weighed vessel and the time interval determined. The level of the liquid in the constant temperature bath was kept constant during the calibration. The bath fluid temperature was recorded and assumed to be the temperature of the fluid in the rotameter. The vessel containing the fluid was then weighed to determine the weight of the fluid collected. The weight was then converted into gpm, with a SAS program that calculates the density of the fluid at the bath temperature. A listing of the flow calibration program is given latter in this Appendix.

During the flow rate calibrations with ethylene glycol, great care was taken to minimize the exposure to air by closing the opening at the top of the weighing vessel as soon as it was filled. The composition of the ethylene glycol was determined before, during and after the flow calibration. Any change in the composition was accounted for in the flow calculations. All flow calibrations were performed twice.

By the method of least squares for a straight line, the data were correlated as follows:

$$\text{Volumetric flow rate} = B(\%\ \text{setting}) + A \qquad (C.1)$$

where for the Brooks rotameter using water

$B = 0.01402$

$A = 0.009849$

ethylene glycol $B = 0.01342$

$A = -0.009061$

For Fischer-Porter rotameter using ethylene glycol

$B = 0.05666$

$A = 0.07651$

A curve fit was attempted for all flow calibrations of the form:

$$\text{Volumetric flow} = A1 + A2(\%\ \text{set}) + A3(\%\ \text{set})^2 + \ldots \qquad (C.2)$$

where A1, A2, ... are constants

At low flow setting the curve fit gives better accuracy, as

TABLE IV

CONSTANTS OF EQUATION (C.2)

Rotameter	A1	A2	A3	A4
Brooks using				
water	0.0	0.017	-1.028×10^{-4}	8.314×10^{-7}
ethylene glycol	0.0011	0.00704	4.082×10^{-4}	7.84×10^{-7}
Fischer-Porter				
ethylene glycol	0.0314	0.06682	-3.317×10^{-4}	2.637×10^{-7}

shown in Figures 64 through 66, but at higher setting the linear fit is more accurate. Thus, for water runs the curve fit was used because the maximum rotameter setting was 26 %. But for ethylene glycol the minimum setting used for any run was 20 %; thus the linear fit was used.

Tables V, VI and VII show the comparison between the experimental and calculated flow data. The accuracy of the flow determinations was less than 2 % setting for either Brooks or Fischer-Porter rotameters

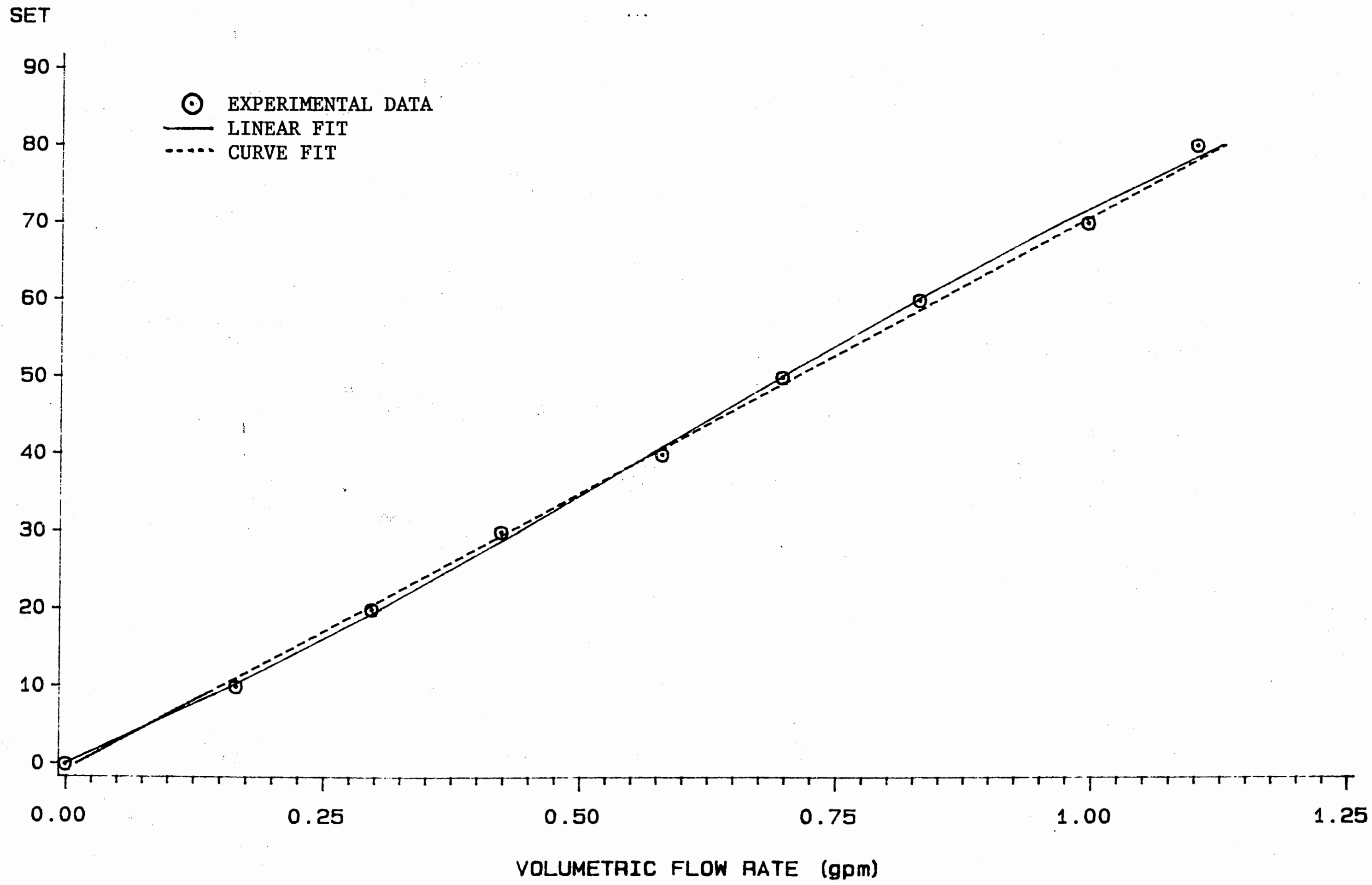

Figure 64: Flow Calibration Curve for Brooks Rotameter Using Water.

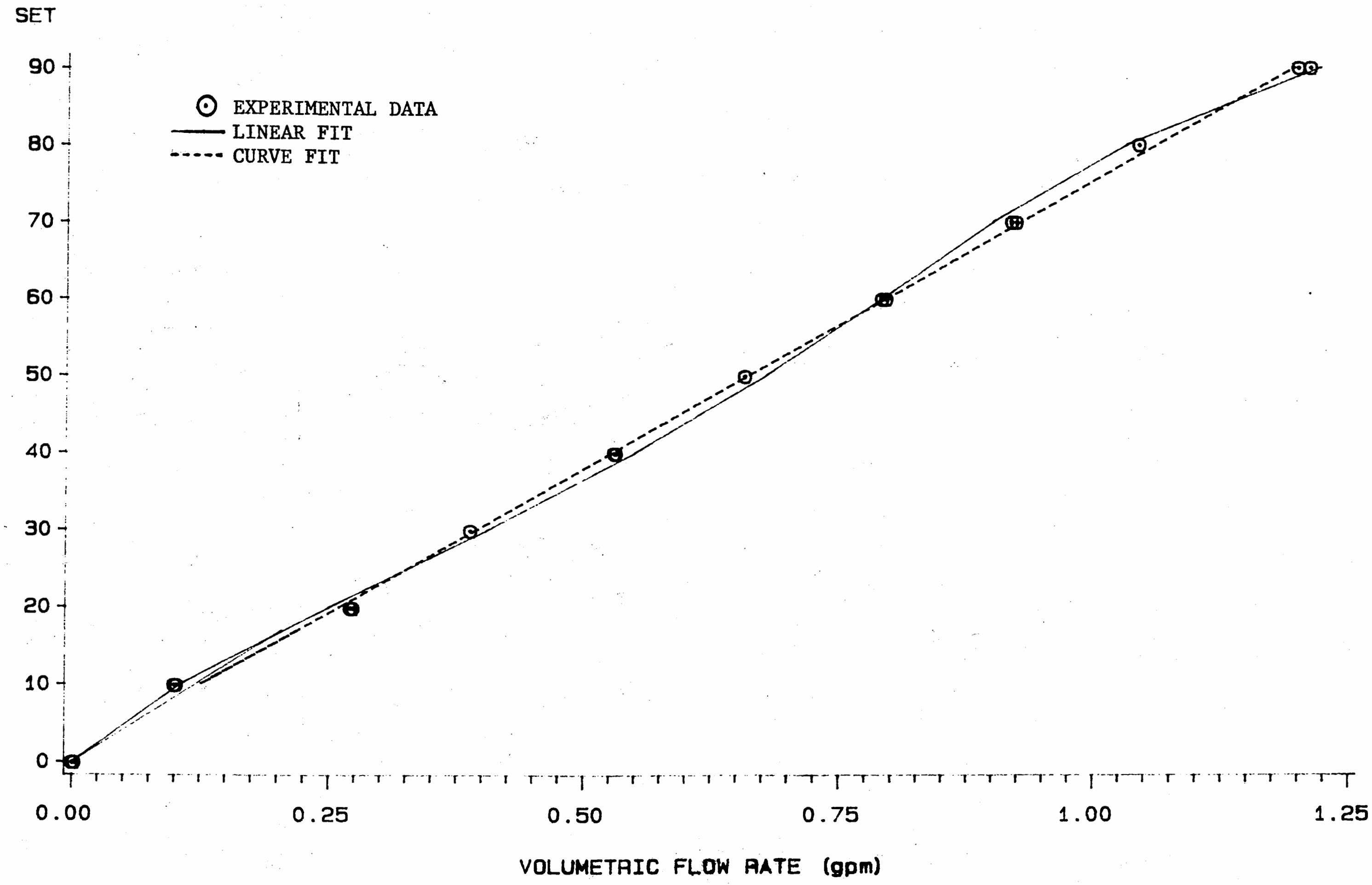

Figure 65: Flow Calibration Curve for Brooks Rotameter Using Ethylene Glycol.

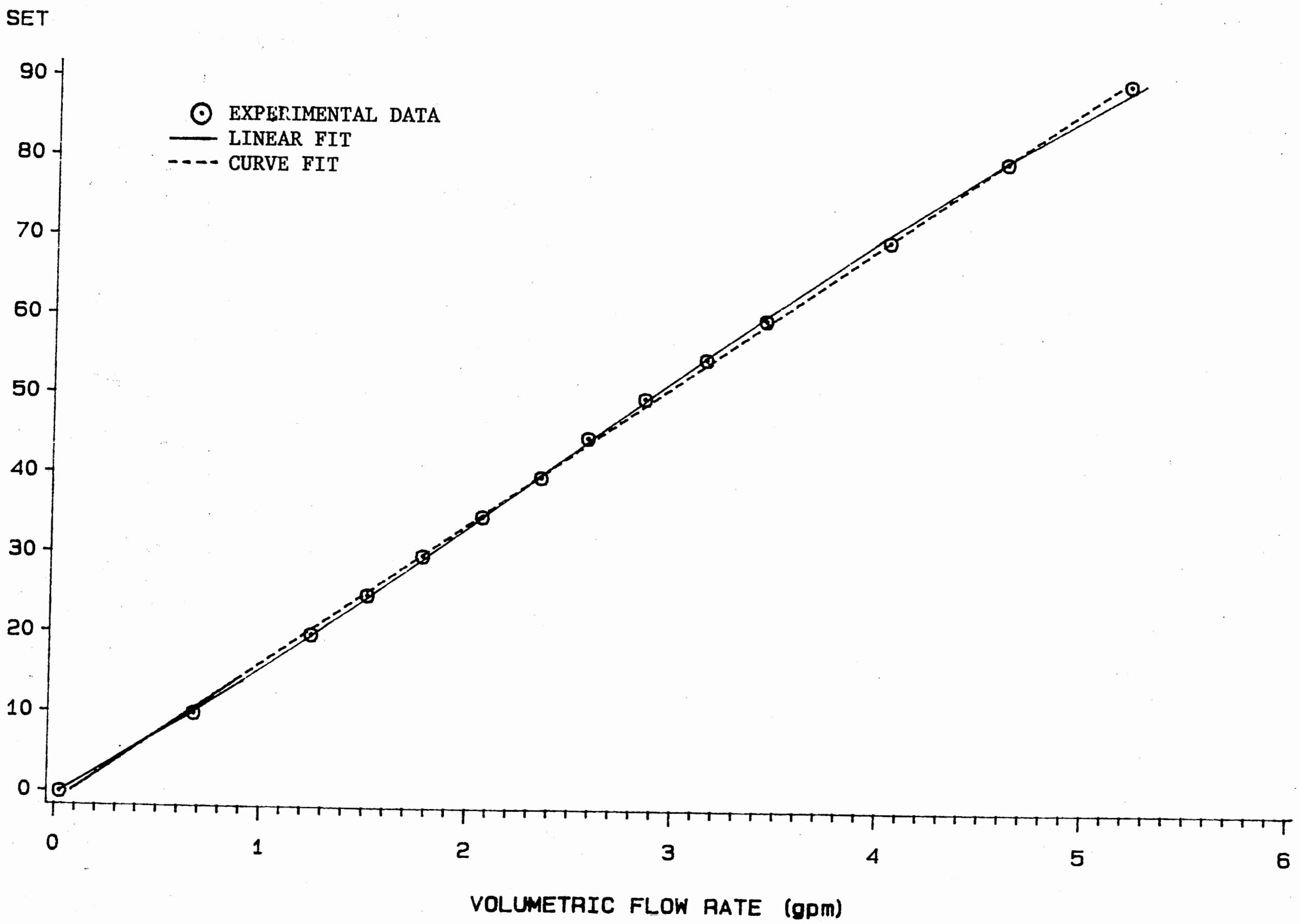

Figure 66: Flow Calibration Curve for Fischer-Porter Rotameter Using Ethylene Glycol.

TABLE V

CALIBRATION OF BROOKS ROTAMETER USING WATER.

Rotameter setting %	Flow rate (gpm)		Absolute Error exp-calc (gpm)
	Experimental	Calculated (curve fit)	
0	0.0	0.0	0.0
10	0.1661	0.1606	0.0055
20	0.2979	0.3056	-0.0077
30	0.4246	0.4401	-0.0155
40	0.5817	0.5689	0.0128
50	0.6994	0.6972	0.0022
60	0.8329	0.8298	0.0031
70	0.9992	0.9718	0.0274
80	1.1055	1.1128	-0.0227
90	1.3014	1.3039	-0.0025

TABLE VI

CALIBRATION OF BROOKS ROTAMETER USING ETHYLENE GLYCOL

Rotameter setting %	Flow rate (gpm) Experimental	Calculated (linear fit)	Absolute error exp-cal (gpm)
0	0.0009	-0.00906	0.00996
0	0.00316	-0.00906	0.01222
10	0.10084	0.12516	-0.02432
10	0.10303	0.12516	-0.02213
20	0.27221	0.25938	0.01283
20	0.27484	0.25938	0.01546
30	0.39019	0.39360	0.00341
40	0.53161	0.52782	0.00379
40	0.53344	0.52782	0.00562
50	0.66035	0.66204	-0.00169
60	0.79723	0.79572	0.00151
60	0.79326	0.79572	-0.00246
70	0.92234	0.93048	-0.00814
70	0.92687	0.93048	-0.00361
80	1.04829	1.06470	-0.01641
90	1.20398	1.19892	0.00506
90	1.21570	1.19892	0.01678

TABLE VII

CALIBRATION OF FISHER ROTAMETER USING ETHYLENE GLYCOL

Rotameter setting %	Flow rate (gpm) Experimental	Flow rate (gpm) Calculated (linear fit)	Absolute error exp-cal (gpm)
0	0.03142	0.07651	-0.0451
10	0.68163	0.6431	0.0385
20	1.24981	1.20969	0.0401
25	1.52064	1.492985	0.0277
30	1.78601	1.77628	0.0098
35	2.07399	2.059575	0.0144
40	2.35923	2.34287	0.0164
45	2.58589	2.626165	-0.0403
50	2.86007	2.90946	-0.0494
55	3.15621	3.192755	-0.0365
60	3.44411	3.47605	-0.0319
70	4.04691	4.04264	0.0043
80	4.62014	4.60923	0.0109
90	5.21699	5.17582	0.0412

```
*  CALIBRATION OF A ROTAMETER
   AUTHOR       :AMANIE NASSIF ABDELMESSIH
   INSTALLATION : OKLAHOMA STATE UNIVERSITY
   LANGUAGE     : SAS;
*
   INPUT QUANTITIES
     SETTING = ROTAMETER SETTING, %
     WT = WEIGHT OF ETHYLENE GLYCOL AND CONTAINING VESSEL, KG
     TIMEM = TIME IN MINUTES
     TIMES = FRACTION OF TIME IN SECONDS
     TEMP =TEMPERATURE DURING CALIBRATION, F
     WTB = WEIGHT OF EMPTY VESSEL, KG
     X = FRACTION OF ETHYLENE GLYCOL;
DATA;
OPTIONS NODATE;
INFILE FT08F001;
INPUT SETTING 1-3  WT 5-10  TIMEM 12-14  TIMES 15-19  TEMP 21-24
     WTB 26-31  X 33-38;
LABEL SETTING=SETTING (%)
      SIFLOW=FLOWRATE (KG.PER.SEC)
      TEMPC=TEMPERATURE (C)
      DENSTYSI=DENSITY (KG.PER.CU.M)
      USFLOW=FLOW RATE (GAL.PER.MIN)
      TEMP=TEMPERATURE (F)
      DENSTYUS=DENSITY (LBM.PER.CU.FT);
LIST;
WTG=WT-WTB;
TIME=TIMEM+TIMES/60.;
TEMPC=(TEMP-32.0)/1.8;
A=1.0004-1.2379E-04*TEMPC-2.9837E-06*TEMPC**2;
B=1.7659E-01*X-9.9189E-04*X*TEMPC+2.4614E-06*X*TEMPC**2;
C=4.9214E-02*X**2-4.1024E-04*X**2*TEMPC+9.5278E-08*X**2*TEMPC**2;
DENS=A+B-C;
DENSTYSI=DENS*1000.0;
DENSTYUS=DENS*62.428;
SIFLOW=WTG/(TIME*DENSTYSI*60.0);
USFLOW=SIFLOW*15859.0;
PROC PRINT LABEL LABEL;
PROC SORT; BY SETTING;
PROC PRINT LABEL; VAR SETTING SIFLOW TEMPC DENSTYSI;
TITLE3 CALIBRATION OF BROOKS ROTAMETER;
TITLE5 FOR ETHYLENE GLYCOL;
PROC PRINT LABEL;
PROC SORT; BY SETTING;
PROC PRINT LABEL; VAR SETTING USFLOW TEMP DENSTYUS;
TITLE3 CALIBRATION OF BROOKS ROTAMETER;
TITLE5 FOR ETHLENE GLYCOL;
PROC PLOT;
 PLOT SETTING*USFLOW='+';
```

APPENDIX D

EVALUATION OF THE COMPOSITION OF ETHYLENE GLYCOL

Apparatus

In determining the viscosity of ethylene glycol the following instruments and materials were used: a constant temperature bath, an Ostwald viscometer, pipettes and viscosity standard oil. The Ostwald viscometer (S-83305) is manufactured by Sargent-Welch Scientific Co. It has a delivery time of approximately 80 to 100 seconds when used with distilled water. The samples of ethylene glycol and viscosity standard oil were taken with 3 ml pipettes. The viscosity standard oil was obtained from Cannon Instruments Co. The properties of the viscosity standard oil are given in Table VII.

Procedure

With a pipette, 6 ml of ethylene glycol were introduced into the wide arm of the Ostwald viscometer. The viscometer was immersed in a constant temperature bath. The liquid was then sucked through the capillary into the bulb until the meniscus was above the top mark. The liquid then flowed down under its own weight. A stop watch measured the time

TABLE VIII

PROPERTIES OF THE VISCOSITY STANDARD OIL

Temperature (F)	Viscosity (cp)	Density (gm/c.c)
68.00	38.20	0.8589
77.00	29.72	0.8557
100.00	16.93	0.8476

of fall of the meniscus between the two marks. A thermocouple, immersed at the bottom of the wide arm, measured the temperature during the fall of the liquid between the marks. The process was then repeated with the viscosity standard. The viscosity of ethylene glycol was calculated from:

$$\mu_g = \mu_s \rho_g \theta_g / \rho_s \theta_s \qquad \text{(D.1)}$$

where μ_g and μ_s are the viscosities of the ethylene glycol and the viscosity standard, respectively. θ_g and θ_s are the time of fall of the meniscus of the ethylene glycol and the viscosity standard between the marks of the Ostwald viscometer. ρ_g and ρ_s are the densities of the ethylene glycol and the viscosity standard. As a check, distilled water was used as a second viscosity standard. The viscosities determined by both viscosity standards were comparable.

Immediately after use, the viscometer was cleaned, thoroughly rinsed with distilled water, and dried well with a stream of laboratory air.

Based on equation (E.7) for evaluating the viscosity of ethylene glycol, a SAS program was written to calculate the viscosities for various compositions at any set temperature (bath temperature). The experimental viscosity was compared with the calculated viscosity and the composition was thus known. A listing of the program follows.

```
*  A PROGRAM TO CALCULATE THE VISCOSITY
   AUTHOR       : AMANIE NASSIF ABDELMESSIH
   INSTALLATION : OKLAHOMA STATE UNIVERSITY
   LANGUAGE     : SAS;
*  INPUT QUANTITIES
     TEMP = TEMPERATURE, F
     X    = FRACTION OF ETHYLENE GLYCOL;
DATA;
OPTIONS NODATE;
INFILE FT08F001;
INPUT TEMP 1-6  X 8-12;
LABEL TEMP=TEMPERATURE (F)
      X=FRACTION OF ETHYLENE GLYCOL
      VISCOSTY=VISCOSITY (LBM.PER(HR.FT));
T=(TEMP-32.0)/1.8;
LIST;
A1=5.5164E-1+2.6492*X+8.2935E-1*X**2;
A2=(4.8136E-3*X**2-3.1496E-2*X-2.7633E-2)*T;
A3=(6.0629E-17+2.2389E-15*X+5.879E-16*X**2)**0.25*T**2;
VISCOSTY=2.718282**(A1+A2+A3)*2.419;
PROC SORT; BY X;
PROC PRINT LABEL; VAR TEMP X VISCOSTY;
TITLE3 VISCOSITY OF ETHYLENE GLYCOL;
TITLE5 (LBM PER (HR.FT));
PROC PLOT;
  PLOT VISCOSTY * X='*';
TITLE VISCOSITY OF ETHYLENE GLYCOL;
```

APPENDIX E

PHYSICAL PROPERTIES

Water

The correlation of thermal conductivity was reported in ref.(2), while the rest of the correlations were those used by Moshfeghian (25).

Density

$$\rho = 999.986 + 0.01890(T) - 0.005886(T^2) + (0.01548 \times 10^{-7})(T^3) \qquad (E.1)$$

where ρ = density, kg/m^3

T = temperature, C

1 K = 1 C + 273.2

This equation is valid for the temperature range 0 to 100 C. It has an accuracy within 2 %.

Viscosity

$$\log(\mu_T/\mu_{20}) = \{1.3272(20-T) - 0.001053(20-T^2)\}/(T+105) \qquad (E.2)$$

μ_{20} = viscosity of water at 20 C, Ns/m

T = temperature, C

This equation is applicable within the temperature range of 10 to 100 C. It has an accuracy within 1 %.

Specific Heat

$$C_p = 1.01881 - 0.4802\times10^{-3}(T) + 0.3274\times10^{-5}(T^2) - 0.604\times10^{-8}(T^3) \tag{E.3}$$

where C_p = specific heat, Btu/lbm F

T = temperature, F

1 Btu/lbm F = 4186.8 J/kg K

This equation has an accuracy within 1 %.

Thermal Conductivity

$$k' = 0.56276 + 1.874\times10^{-3}(T) - 6.8\times10^{-6}(T^2) \tag{E.4}$$

where k' = thermal conductivity of water, W/m.K

T = temperature, C

This equation is applied in temperature range 0 to 100 C.

It has an accuracy within 1 %.

Coefficient of Thermal Expansion

for this equation at $T = 23 \sim 23.5°C$. $\beta = 0$. which is not correct.

for $T \leq 23°C$ $\beta < 0$.

$$\beta = (1/\rho)\{0.0189 - 0.011772(T) + 0.4644\times10^{-3}(T^2)\} \tag{E.5}$$

where β = coefficient of thermal expansion, ~~W/m.K~~ 1/°C.

ρ = density, kg/m^3

T = temperature, C

This equation is applied in the temperature range 0 to 100 C.

Ethylene Glycol

Most of the properties in this section were available from reference (2) except for the specific heat and the coefficient of thermal expansion (25).

Density

$$\rho = \sum_{i=1}^{3} \sum_{j=1}^{3} A_{ij} . X^{(j-1)} . T^{(i-1)} \qquad (E.6)$$

where

Values of A_{ij}

	j=1	j=2	j=3
i=1	1.0004	0.17659	0.049214
i=2	-1.2379×10^{-4}	-9.9189×10^{-4}	4.1024×10^{-4}
i=3	-2.9837×10^{-6}	2.4614×10^{-6}	-9.5278×10^{-8}

ρ = density, kg/m^3

X = mass fraction of ethylene glycol

T = temperature, C

This equation has an accuracy within 0.25 %. It is applied over the temperature range -10 to 150 C.

Viscosity

$$\ln \mu = \sum_{i=1}^{2} \sum_{j=1}^{3} A_{ij} . X^{(j-1)} T^{(i-1)} + \left\{ \sum_{j=1}^{3} A_{ij} X^{(j-1)} \right\}^{1/4} T^{2} \qquad (E.7)$$

where

Values of A_{ij}

	j=1	j=2	j=3
i=1	0.5164	2.6492	0.82935
i=2	-2.7633×10^{-2}	-3.1496×10^{-2}	4.8136×10^{-3}
i=3	6.0629×10^{-17}	2.2389×10^{-15}	5.8790×10^{-16}

μ = viscosity, m.Pa.s

T = temperature, C

This equation is applied in the range -10 to 100 C. It has an accuracy within 5 %.

Specific Heat

$$C_p=0.518956+6.2290\times10^{-4}(T) \tag{E.8}$$

Where C_p = specific heat, Btu/lbm F

T = temperature, F

1 Btu/lbm F = 4186.8 J/kg K

This equation is applicable between 6 and 350 F. It has an accuracy within 1 %.

Thermal Conductivity

$$kpure=0.24511+1.755\times10^{-4}(T)-8.52\times10^{-7}(T^2) \tag{E.9}$$

$$k=(1-X).k'+X.kpure-F(k'-kpure)(1-X)X \tag{E.10}$$

where

$$F=0.6635-0.3698X-8.85\times10^{-4}T \tag{E.11}$$

kpure = thermal conductivity of 100 % ethylene glycol, W/m.K

T = temperature, C

This equation is applied in the range -20 C to 180 C. This equation has an accuracy within 1 %.

Coefficient of Thermal Expansion

$$\beta=\rho\{0.62796+18.4888\times10^{-4}(T-65)+9.171\times10^{-6}(T-65)^{2}\}\times10^{-6} \quad (E.12)$$

where ρ = density, kg/m^3

β = coefficient of thermal expansion, 1/C.

T = temperature, C

Inconel 600

The physical properties of inconel 600 were computed from the following correlations (25)

Electrical Resistivity

$$\rho=(10^{-6})\{40.4029+2.51538(T)\} \quad (E.13)$$

where ρ = electrical resistivity, Ohm.in

T =temperature, F

1 Ohm.in = 0.0254 Ohm.m

Thermal Conductivity

$$k=0.8313769+0.003846154(T) \quad (E.14)$$

where k = thermal conductivity, Btu/(hr.ft.F)

T = temperature, F.

1 Btu/(hr.ft.F) = 1.73 W/(m.K)

Stainless Steel

The following physical correlations (25) were used in calculating the physical properties of the stainlless steel.

Electrical Resistivity

$$\rho=2.601\mathrm{x}10^{-5}+1.37904\mathrm{x}10^{-8}(T)+8.5158\mathrm{x}10^{-12}(T^{2})$$
$$-10.11924\mathrm{x}10^{-17}(T^{3}) \qquad (E.15)$$

where ρ = electrical resistivity, ohm.in

T = temperature, F

1 Ohm.in = 0.0254 Ohm.m

Thermal Conductivity

$$k=7.8034+0.51691\mathrm{x}10^{-2}(T)-0.88501\mathrm{x}10^{-6}(T^{2}) \qquad (E.16)$$

where k = thermal conductivity, Btu/(hr.ft.F)

T =temperature, F.

1 Btu/hr.ft.F = 1.73 W/m.K

APPENDIX F

NUMERICAL SOLUTION OF THE WALL TEMPERATURE GRADIENT

The numerical solution is based on the following assumptions:

1. Peripheral and radial wall conduction are significant.
2. Axial conduction is negligible.
3. Steady state conditions prevail.
4. The electrical resistivity and thermal conductivity of the tube wall are functions of temperature.
5. There are heat losses from the test section to the surroundings.

The tube wall thickness of the straight sections was sliced into ten concentric equal thickness circles, while the tube cross section was divided into octants about the tube axis.

At the bend there are variations in the wall thickness. The thickness at the outside of the bend is less than the inside thickness. In solving for the bend, conservation of the volume of the tube inside diameter material is assumed. Also, it is assumed that the tube is still circular. The bend wall was sliced similar to the straight tube.

An energy balance on an interior element (Figure 67) gives:

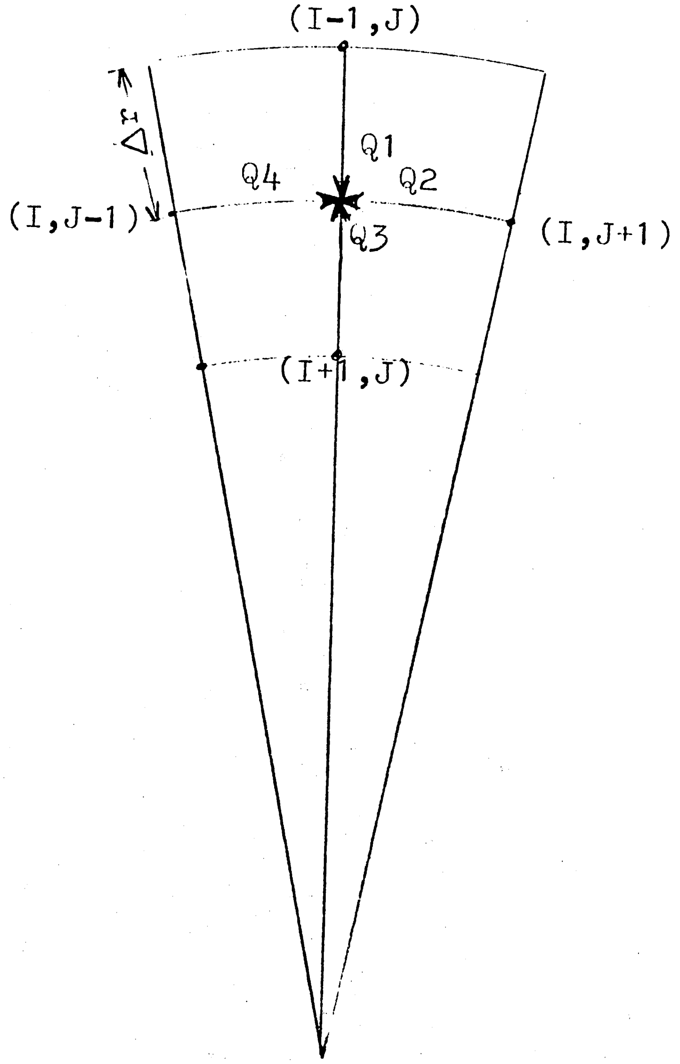

Figure 67: Interior Node.

$$Q_1+Q_2+Q_3+Q_4= 0 \tag{F.1}$$

From Fourier's law

$$Q =-k.A.dT/dX \tag{F.2}$$

Substituting in Fourier's law for the radial (I) and peripheral (J) directions for each of the four sides we obtain:

$$Q_1=(1/2)(K_{I-1,J}+K_{I,J})(\pi/4)(r_{I-1} - r/2)dZ(T_{I-1,J}-T_{I,J})/\Delta r \tag{F.3}$$

$$Q_2=(1/2)(K_{I,J+1}+K_{I,J})(\Delta r)(dZ)(T_{I,J-1}-T_{I,J})(4/\pi r_I) \tag{F.4}$$

$$Q_3=(1/2)(K_{I+1,J}+K_{I,J})(\pi/4)(r_{I+1} + r/2)(dZ)(T_{I+1,J}-T_{I,J})/\Delta r \tag{F.5}$$

$$Q_4=(1/2)(K_{I,J-1}+K_{I,J})(\Delta r)(dZ)(T_{I,J-1}-T_{I,J})(4/\pi r_I) \tag{F.6}$$

The heat generation is calculated as follows:

$$Q =I^2.R \tag{F.7}$$

where $R = (3.412).\rho.dZ/ A$ (F.8)

ρ= electrical resistivity at node (I,J), ohm-in

$A=(\pi/4)(r_I\Delta r)$ (F.9)

Subsituting equations (F.3), (F.4), (F.5), (F.6), (F.7), (F.8) and (F.9) into equation (F.1) and rearranging:

$$\begin{aligned} T_{I+1} = T_I \; -\{ & (3.412\,\rho.I^2/\Delta A) \\ & +(\pi/8\ r)(k_{I-1,J}+k_{I,J})(r_{I-1}-r/2)(T_{I-1,J}-T_{I,J}) \\ & +(2.\ r/\pi)(k_{I,J-1}+k_{I,J})(T_{I,J-1}-T_{I,J})/r_I \\ & +(2\ r/\pi)(k_{I,J+1}+k_{I,J})(T_{I,J+1}-T_{I,J})/r_I\}/ \\ & \{(\pi/8\,\Delta r)(k_{I+1}+k_{I,J})(r_{I+1}+\Delta r/2)\} \end{aligned} \qquad (F.10)$$

Equation (F.10) is used for all the interior nodes. For the exterior nodes where there is heat loss to the surroundings, equation (F.3) is substituted with:

$$\begin{aligned} Q & = Q_{loss}/8 \\ & = \{(Q_{loss1}-Q_{loss2}).dZ/Z+Q_{loss1}\}/(8Z) \end{aligned} \qquad (F.11)$$

where Z = length of U-tube from electrode 1 to electrode 4, i.e. total length of the heated portions of the test section and the length of the U-bend.

APPENDIX G

EXPERIMENTAL DATA

Run Number	Test Fluid	Test Section
1- 25	water	A
26-100	ethylene glycol	A
101-200	ethylene glycol	B
201-300	ethylene glycol	C
301-400	ethylene glycol	D

Only those experimental data which were referred to are presented here. Reduced data for these runs are given in Appendix J. The rest of the experimental data are available from

Professor Kenneth J. Bell
School of Chemical
Engineering

or Edmon Low Library
or Amanie N. Abdelmessih

Oklahoma State University
Stillwater, Oklahoma 74078

```
                          ---------------
                          RUN NUMBER   22
                          ---------------

             ROTAMETER SETTING                =     20.  PERCENT
             CURRENT TO TUBE                  =    305.  AMPS
             VOLTAGE DROP IN TUBE             =   2.810  VOLTS
             ROOM TEMPERATURE                 =    79.6  F (     26.4  C)
             UNCORRECTED INLET TEMPERATURE    =    85.2  F (     29.6  C)
             UNCORRECTED OUTLET TEMPERATURE   =   104.2  F (     40.1  C)
             BATH TEMPERATURE    =     85.5  F (     29.7  C)
             INLET TEMP. EQ TO EXIT HEATED    =   104.5  F (     40.3  C)
             OUTLET TEMP.BEFORE HEATING  =    85.0  F (     29.4  C)
             TEST FLUID IS WATER


                  UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1      2      3      4      5      6      7      8      9     10     11

  1   100.3  100.2  100.8  101.3   89.1  105.6  115.6  119.5  123.6  129.5  139.0
  2   101.0  101.3  102.5  103.0   89.2  104.7  116.7  113.2  117.0  122.5  131.0
  3   103.7  105.1  107.3  107.5   88.9  102.0  113.0  105.5  109.6  112.6  114.4
  4   110.1  115.2  116.5  117.0   88.8   98.2  107.8  102.0  106.6  107.9  110.0
  5   118.6  124.3  127.7  127.7   89.1   95.1  106.1  101.1  105.3  106.0  108.1
  6   114.5  117.2  119.8  122.6   88.9   98.1  107.6  100.6  106.6  107.4  111.4
  7   103.5  105.2  106.3  107.7   88.7  102.3  114.4  105.6  109.9  112.6  114.6
  8   100.7  100.8  101.9  102.1   89.0  104.5  116.0  115.2  117.7  121.9  122.4


                  UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

          1      2      3      4      5      6      7      8      9     10     11

  1    37.9   37.9   38.2   38.5   31.7   40.9   46.4   48.6   50.9   54.2   59.4
  2    38.3   38.5   39.2   39.4   31.8   40.4   47.1   45.1   47.2   50.3   55.0
  3    39.8   40.6   41.8   41.9   31.6   38.9   45.0   40.8   43.1   44.8   45.8
  4    43.4   46.2   46.9   47.2   31.5   36.8   42.1   38.9   41.4   42.1   43.3
  5    48.1   51.3   53.2   53.2   31.7   35.1   41.2   38.4   40.7   41.1   42.3
  6    45.8   47.3   48.8   50.3   31.6   36.7   42.0   38.1   41.4   41.9   44.1
  7    39.7   40.7   41.3   42.1   31.5   39.1   45.8   40.9   43.3   44.8   45.9
  8    38.2   38.2   38.8   39.0   31.7   40.3   46.7   46.2   47.6   49.9   50.2
```

```
                          ---------------
                          RUN NUMBER   23
                          ---------------

         ROTAMETER SETTING                  =      12.  PERCENT
         CURRENT TO TUBE                    =     302.  AMPS
         VOLTAGE DROP IN TUBE               =    2.775  VOLTS
         ROOM TEMPERATURE                   =     80.0  F (     26.7  C)
         UNCORRECTED INLET TEMPERATURE      =     85.5  F (     29.7  C)
         UNCORRECTED OUTLET TEMPERATURE     =    115.7  F (     46.5  C)
         BATH TEMPERATURE    =     86.0  F (     30.0  C)
         INLET TEMP. EQ TO EXIT HEATED      =    115.0  F (     46.1  C)
         OUTLET TEMP.BEFORE HEATING   =     85.1  F (     29.5  C)
         TEST FLUID IS WATER

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10      11

1     100.2   101.3   102.9   104.1    97.8   113.2   121.6   126.6   131.8   150.8   164.8
2     100.9   102.8   105.2   106.6    97.4   112.4   120.1   120.4   124.4   138.6   156.9
3     104.6   107.9   111.6   112.4    96.1   108.2   112.7   112.4   115.1   122.7   125.9
4     112.6   120.2   122.4   123.6    95.0   101.5   109.1   109.4   111.0   115.8   121.4
5     123.0   129.7   134.3   134.7    95.1    99.6   108.1   108.4   109.9   113.3   119.6
6     118.2   122.4   126.1   129.6    95.1   100.7   108.9   108.8   110.9   115.8   121.9
7     104.5   108.2   110.5   112.7    96.2   109.2   114.6   112.9   115.8   122.9   126.7
8     100.7   102.1   104.6   105.4    97.7   113.4   120.9   122.2   125.3   137.6   147.6

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

        1       2       3       4       5       6       7       8       9      10      11

1      37.9    38.5    39.4    40.1    36.6    45.1    49.7    52.6    55.4    66.0    73.8
2      38.3    39.3    40.7    41.4    36.3    44.7    48.9    49.1    51.3    59.2    69.4
3      40.3    42.2    44.2    44.7    35.6    42.3    44.8    44.7    46.2    50.4    52.1
4      44.8    49.0    50.2    50.9    35.0    38.6    42.9    43.0    43.9    46.5    49.7
5      50.6    54.3    56.8    57.1    35.0    37.6    42.3    42.4    43.3    45.2    48.7
6      47.9    50.2    52.2    54.2    35.1    38.2    42.7    42.6    43.9    46.6    50.0
7      40.3    42.3    43.6    44.8    35.7    42.9    45.9    44.9    46.6    50.5    52.6
8      38.2    39.0    40.3    40.8    36.5    45.2    49.4    50.1    51.8    58.7    64.2
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                         ---------------
                         RUN NUMBER   24
                         ---------------

            ROTAMETER SETTING                =     26.  PERCENT
            CURRENT TO TUBE                  =    305.  AMPS
            VOLTAGE DROP IN TUBE             =   2.805  VOLTS
            ROOM TEMPERATURE                 =    81.6  F (     27.6  C)
            UNCORRECTED INLET TEMPERATURE    =    85.7  F (     29.8  C)
            UNCORRECTED OUTLET TEMPERATURE   =   101.1  F (     38.4  C)
            BATH TEMPERATURE   =    85.9  F (    29.9  C)
            INLET TEMP. EQ TO EXIT HEATED    =   101.4  F (     38.6  C)
            OUTLET TEMP.BEFORE HEATING  =    85.6  F (     29.8  C)
            TEST FLUID IS WATER

                 UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10      11

 1     100.2   100.7   101.0   101.4    87.9    99.5   112.7   117.5   121.3   126.2   131.6
 2     100.8   101.6   102.4   102.6    87.9    99.0   112.0   111.0   115.0   120.0   123.5
 3     102.7   104.5   106.1   106.3    87.8    96.4   110.4   105.5   107.1   110.5   111.8
 4     107.3   113.2   114.0   114.5    87.9    94.0   108.5   102.4   104.5   106.2   109.0
 5     115.7   121.5   124.6   124.7    88.7    92.6   105.6   100.9   103.5   104.8   108.7
 6     111.6   114.8   117.1   119.9    88.3    93.9   108.1   103.3   104.9   105.5   110.3
 7     102.3   104.4   105.2   106.7    87.9    96.2   109.2   106.2   108.0   110.2   112.0
 8     100.5   100.7   101.8   101.9    88.0    98.2   110.5   113.0   115.5   119.0   116.1

                 UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

          1       2       3       4       5       6       7       8       9      10      11

 1      37.9    38.2    38.3    38.6    31.0    37.5    44.8    47.5    49.6    52.3    55.3
 2      38.2    38.7    39.1    39.2    31.1    37.2    44.4    43.9    46.1    48.9    50.8
 3      39.3    40.3    41.2    41.3    31.0    35.8    43.6    40.8    41.7    43.6    44.3
 4      41.8    45.1    45.6    45.8    31.1    34.4    42.5    39.1    40.3    41.2    42.8
 5      46.5    49.7    51.4    51.5    31.5    33.6    40.9    38.3    39.7    40.4    42.6
 6      44.2    46.0    47.3    48.8    31.3    34.4    42.3    39.6    40.5    40.8    43.5
 7      39.1    40.2    40.7    41.5    31.1    35.7    42.9    41.2    42.2    43.4    44.4
 8      38.1    38.2    38.7    38.8    31.1    36.8    43.6    45.0    46.4    48.3    46.7
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                         RUN NUMBER   25
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          ROTAMETER SETTING                 =      18.   PERCENT
          CURRENT TO TUBE                   =     305.   AMPS
          VOLTAGE DROP IN TUBE              =    2.820   VOLTS
          ROOM TEMPERATURE                  =     78.7   F (     25.9  C)
          UNCORRECTED INLET TEMPERATURE     =     87.0   F (     30.6  C)
          UNCORRECTED OUTLET TEMPERATURE    =    108.1   F (     42.3  C)
          BATH TEMPERATURE    =    87.3  F (    30.7   C)
          INLET TEMP. EQ TO EXIT HEATED     =    108.5   F (     42.5  C)
          OUTLET TEMP.BEFORE HEATING  =     86.8  F (     30.4  C)
          TEST FLUID IS WATER

               UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10      11

 1    102.1   102.1   102.8   103.4    91.9   110.2   120.9   120.3   127.6   143.2   161.2
 2    102.8   103.4   104.7   105.4    92.0   108.9   120.5   116.4   120.6   130.3   152.8
 3    105.8   107.5   110.1   110.4    91.7   106.0   113.3   108.0   112.4   116.4   119.5
 4    113.6   118.7   119.9   120.8    91.4   101.4   109.3   106.3   110.1   110.9   114.7
 5    123.9   128.1   131.6   131.8    91.8    98.0   108.8   105.5   110.2   109.1   113.2
 6    119.0   120.8   123.4   126.8    91.6   101.5   108.8   105.1   110.0   110.6   115.4
 7    105.8   107.8   109.0   110.6    91.5   107.0   115.3   107.9   113 1   116.4   120.6
 8    102.6   102.8   104.1   104.5    91.8   109.4   120.5   118.8   121.4   129.8   143.1

               UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

        1       2       3       4       5       6       7       8       9      10      11

 1     38.9    39.0    39.3    39.7    33.3    43.4    49.4    49.1    53.1    61.8    71.8
 2     39.3    39.7    40.4    40.8    33.3    42.7    49.2    46.9    49.2    54.6    67.1
 3     41.0    41.9    43.4    43.6    33.2    41.1    45.2    42.2    44.7    46.9    48.6
 4     45.3    48.2    48.8    49.3    33.0    38.6    42.9    41.3    43.4    43.8    45.9
 5     51.0    53.4    55.3    55.4    33.2    36.7    42.7    40.8    43.4    42.8    45.1
 6     48.3    49.3    50.8    52.7    33.1    38.6    42.7    40.6    43.3    43.7    46.3
 7     41.0    42.1    42.8    43.7    33.1    41.7    46.3    42.2    45.1    46.9    49.2
 8     39.2    39.3    40.1    40.3    33.2    43.0    49.2    48.2    49.6    54.3    61.7
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                       RUN NUMBER  102
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         ROTAMETER SETTING                  =     31.  PERCENT
         CURRENT TO TUBE                    =    322.  AMPS
         VOLTAGE DROP IN TUBE               =   2.362  VOLTS
         ROOM TEMPERATURE                   =    81.8  F (     27.7  C)
         UNCORRECTED INLET TEMPERATURE      =    90.0  F (     32.2  C)
         UNCORRECTED OUTLET TEMPERATURE     =   109.5  F (     43.1  C)
         BATH TEMPERATURE    =    90.4  F (    32.4  C)
         INLET TEMP. EQ TO EXIT HEATED      =   111.0  F (     43.9  C)
         OUTLET TEMP.BEFORE HEATING   =    89.5  F (     31.9  C)
         MASS FRACTION OF ETHYLENE GLYCOL =  0.9883

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

       1       2       3       4       5       6       7       8       9      10      11

 1   128.8   130.3   130.2    92.1   100.8   121.7   147.6   151.3   155.7   162.6   162.1
 2   128.8   130.5   131.1    93.0   100.1   119.8   145.2   145.4   147.8   150.6   156.1
 3   131.7   136.0   137.0    97.7    99.8   113.3   141.4   134.4   138.2   141.5   141.6
 4   142.7   147.0   135.7   104.0   100.1   109.1   139.5   130.2   134.2   136.4   135.7
 5   155.7   162.5   165.0   115.6   102.0   108.6   139.2   131.0   132.9   133.3   134.2
 6   148.4   159.0   160.0   107.0    99.9   110.6   140.2   136.5   133.5   134.6   135.2
 7   137.1   141.2   143.1    96.1    99.9   114.6   140.1   137.8   139.0   140.3   140.1
 8   130.2   133.4   133.3    92.5   100.9   118.8   143.3   144.3   147.4   152.3   154.4

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

       1       2       3       4       5       6       7       8       9      10      11

 1    53.8    54.6    54.6    33.4    38.2    49.8    64.2    66.3    68.7    72.6    72.3
 2    53.8    54.7    55.1    33.9    37.8    48.8    62.9    63.0    64.3    65.9    68.9
 3    55.4    57.8    58.3    36.5    37.7    45.2    60.8    56.9    59.0    60.8    60.9
 4    61.5    63.9    57.6    40.0    37.8    42.8    59.7    54.6    56.8    58.0    57.6
 5    68.7    72.5    73.9    46.4    38.9    42.6    59.6    55.0    56.1    56.3    56.8
 6    64.7    70.6    71.1    41.7    37.7    43.7    60.1    58.1    56.4    57.0    57.3
 7    58.4    60.7    61.7    35.6    37.7    45.9    60.1    58.8    59.4    60.2    60.1
 8    54.6    56.3    56.3    33.6    38.3    48.2    61.8    62.4    64.1    66.8    68.0
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                        RUN NUMBER  304
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           ROTAMETER SETTING                =     30.  PERCENT
           CURRENT TO TUBE                  =    330.  AMPS
           VOLTAGE DROP IN TUBE             =   3.667  VOLTS
           ROOM TEMPERATURE                 =    85.3  F (     29.6  C)
           UNCORRECTED INLET TEMPERATURE    =    91.2  F (     32.9  C)
           UNCORRECTED OUTLET TEMPERATURE   =   120.0  F (     48.9  C)
           BATH TEMPERATURE    =    91.4  F (     33.0  C)
           INLET TEMP. EQ TO EXIT HEATED    =   121.6  F (     49.8  C)
           OUTLET TEMP.BEFORE HEATING  =    90.5  F (    32.5  C)
           MASS FRACTION OF ETHYLENE GLYCOL =  0.9635

                UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10      11

 1   125.5   127.6   129.2   100.6    95.4   102.4   139.9   149.2   151.0   154.9   158.5
 2   125.9   128.3   131.0    98.6    95.9   102.0   138.9   144.4   148.0   149.6   154.7
 3   129.0   133.9   135.6    99.4    96.5   100.4   135.4   138.4   141.3   141.7   147.0
 4   135.5   143.3   144.0   103.5    98.7   101.2   133.2   135.2   137.7   137.0   140.4
 5   139.8   144.9   147.2   108.7   101.6   100.6   130.8   135.4   136.3   135.7   139.0
 6   136.3   141.5   143.4   115.1   101.3   100.1   132.1   137.2   136.3   137.4   140.6
 7   130.5   134.4   135.1   108.7    97.1   100.8   138.6   139.9   141.0   144.7   146.3
 8   126.5   129.2   130.6   103.9    96.1   101.9   135.6   145.1   147.3   150.3   154.5

                UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

         1       2       3       4       5       6       7       8       9      10      11

 1    51.9    53.1    54.0    38.1    35.2    39.1    59.9    65.1    66.1    68.3    70.3
 2    52.2    53.5    55.0    37.0    35.5    38.9    59.4    62.4    64.4    65.3    68.2
 3    53.9    56.6    57.6    37.4    35.8    38.0    57.4    59.1    60.7    60.9    63.9
 4    57.5    61.8    62.2    39.7    37.1    38.4    56.2    57.3    58.7    58.3    60.2
 5    59.9    62.7    64.0    42.6    38.6    38.1    54.9    57.4    57.9    57.6    59.4
 6    57.9    60.8    61.9    46.2    38.5    37.8    55.6    58.4    57.9    58.6    60.3
 7    54.7    56.9    57.3    42.6    36.2    38.2    59.2    59.9    60.6    62.6    63.5
 8    52.5    54.0    54.8    39.9    35.6    38.8    57.6    62.8    64.1    65.7    68.1
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                         RUN NUMBER  305
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              ROTAMETER SETTING               =     30.  PERCENT
              CURRENT TO TUBE                 =    420.  AMPS
              VOLTAGE DROP IN TUBE            =   4.718  VOLTS
              ROOM TEMPERATURE                =    87.9  F (     31.1  C)
              UNCORRECTED INLET TEMPERATURE   =    91.2  F (     32.9  C)
              UNCORRECTED OUTLET TEMPERATURE  =   139.8  F (     59.9  C)
              BATH TEMPERATURE   =    91.4  F (    33.0  C)
              INLET TEMP. EQ TO EXIT HEATED   =   142.6  F (     61.4  C)
              OUTLET TEMP.BEFORE HEATING  =   90.5  F (    32.5  C)
              MASS FRACTION OF ETHYLENE GLYCOL =  0.9635

                   UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1      2      3      4      5      6      7      8      9     10     11

 1    140.3  143.9  146.1  105.6  100.1  114.2  169.0  175.9  177.0  187.0  193.3
 2    140.9  144.9  149.1  102.7  100.8  113.0  167.0  168.2  171.2  179.4  187.2
 3    145.8  153.6  156.1  103.6  101.5  108.9  160.5  156.4  157.7  168.7  175.4
 4    156.2  168.6  169.7  109.4  104.2  110.9  155.7  149.3  150.1  162.1  165.7
 5    163.3  171.5  175.2  117.0  107.8  108.9  150.7  147.9  149.0  158.9  163.9
 6    157.6  165.9  168.9  126.8  107.4  108.1  153.7  148.4  151.5  160.3  166.2
 7    148.3  154.3  155.6  117.1  102.1  110.0  166.4  156.0  160.4  170.8  174.5
 8    141.8  146.1  148.4  110.2  101.0  112.7  161.1  167.5  171.0  179.6  186.6

                   UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

         1      2      3      4      5      6      7      8      9     10     11

 1     60.2   62.2   63.4   40.9   37.8   45.7   76.1   79.9   80.6   86.1   89.6
 2     60.5   62.7   65.1   39.3   38.2   45.0   75.0   75.7   77.3   81.9   86.2
 3     63.2   67.6   68.9   39.8   38.6   42.7   71.4   69.1   69.8   75.9   79.7
 4     69.0   75.9   76.5   43.0   40.1   43.9   68.7   65.2   65.6   72.3   74.3
 5     72.9   77.5   79.6   47.2   42.1   42.7   65.9   64.4   65.0   70.5   73.3
 6     69.8   74.4   76.1   52.6   41.9   42.3   67.6   64.7   66.4   71.3   74.6
 7     64.6   67.9   68.7   47.3   38.9   43.3   74.7   68.9   71.3   77.1   79.2
 8     61.0   63.4   64.6   43.4   38.3   44.8   71.7   75.3   77.2   82.0   85.9
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                              RUN NUMBER  312
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                  ROTAMETER SETTING                =     70.  PERCENT
                  CURRENT TO TUBE           .      =    370.  AMPS
                  VOLTAGE DROP IN TUBE             =   4.084  VOLTS
                  ROOM TEMPERATURE                 =    88.2  F (     31.2  C)
                  UNCORRECTED INLET TEMPERATURE    =    92.0  F (     33.3  C)
                  UNCORRECTED OUTLET TEMPERATURE   =   108.2  F (     42.3  C)
                  BATH TEMPERATURE    =    92.5  F (    33.6  C)
                  INLET TEMP. EQ TO EXIT HEATED    =   108.4  F (     42.4  C)
                  OUTLET TEMP.BEFORE HEATING  =    91.8  F (     33.2  C)
                  MASS FRACTION OF ETHYLENE GLYCOL =  0.9635

                     UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

              1       2       3       4       5       6       7       8       9      10      11

      1   129.9   131.0   131.5    96.9    92.3    94.6   124.7   147.6   149.5   154.7   156.9
      2   130.1   131.5   133.2    95.1    92.4    94.4   124.5   144.1   146.2   149.4   152.6
      3   132.8   136.3   137.1    95.9    93.1    94.6   123.0   138.9   139.5   142.7   144.4
      4   138.5   145.4   145.4    99.2    96.2    94.3   122.5   136.8   136.9   138.3   138.4
      5   142.7   147.3   149.2   104.4   101.1    95.6   122.2   136.2   135.8   135.6   137.4
      6   139.2   143.7   144.9   112.7   100.1    94.5   122.1   136.1   135.3   136.2   138.2
      7   133.9   137.0   136.8   104.8    93.9    94.1   124.4   138.9   139.4   143.1   143.6
      8   130.7   132.5   132.9    99.7    92.7    94.3   123.0   143.8   145.7   149.3   152.4

                     UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

              1       2       3       4       5       6       7       8       9      10      11

      1    54.4    55.0    55.3    36.1    33.5    34.8    51.5    64.2    65.3    68.2    69.4
      2    54.5    55.3    56.2    35.1    33.6    34.7    51.4    62.3    63.4    65.2    67.0
      3    56.0    57.9    58.4    35.5    34.0    34.8    50.6    59.4    59.7    61.5    62.4
      4    59.2    63.0    63.0    37.3    35.7    34.6    50.3    58.2    58.3    59.1    59.1
      5    61.5    64.1    65.1    40.2    38.4    35.4    50.1    57.9    57.7    57.6    58.6
      6    59.6    62.1    62.7    44.8    37.8    34.7    50.1    57.8    57.4    57.9    59.0
      7    56.6    58.3    58.2    40.4    34.4    34.5    51.3    59.4    59.7    61.7    62.0
      8    54.8    55.8    56.1    37.6    33.7    34.6    50.6    62.1    63.2    65.2    66.9
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                    RUN NUMBER  317
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         ROTAMETER SETTING                =     90.  PERCENT
         CURRENT TO TUBE                  =    375.  AMPS
         VOLTAGE DROP IN TUBE             =   4.134  VOLTS
         ROOM TEMPERATURE                 =    84.5  F (     29.2  C)
         UNCORRECTED INLET TEMPERATURE    =    92.3  F (     33.5  C)
         UNCORRECTED OUTLET TEMPERATURE   =   105.6  F (     40.9  C)
         BATH TEMPERATURE    =    92.6  F (    33.7  C)
         INLET TEMP. EQ TO EXIT HEATED    =   105.7  F (     40.9  C)
         OUTLET TEMP.BEFORE HEATING  =    92.1  F (     33.4  C)
         MASS FRACTION OF ETHYLENE GLYCOL =  0.9635

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1        2        3        4        5        6        7        8        9       10       11

 1   130.1    131.5    131.8     96.3     92.4     93.2    117.4    140.9    146.7    152.4    155.2
 2   130.3    131.9    133.3     94.7     92.6     93.2    117.3    139.3    143.5    146.9    150.7
 3   132.7    136.3    137.1     95.4     93.4     94.3    116.2    135.8    137.2    140.1    143.0
 4   138.0    144.8    144.6     98.3     96.8     93.5    116.4    134.0    134.7    136.9    137.2
 5   141.9    146.7    148.5    103.4    103.1     95.6    117.0    133.6    134.3    136.1    136.8
 6   138.6    143.2    144.3    112.3    101.4     94.3    116.4    133.7    134.5    136.4    138.4
 7   133.7    137.0    136.7    103.9     94.1     93.4    117.1    135.9    138.2    142.5    143.1
 8   130.9    132.7    133.0     98.9     92.9     93.2    116.3    138.8    143.8    147.9    151.1

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

        1        2        3        4        5        6        7        8        9       10       11

 1    54.5     55.3     55.4     35.7     33.6     34.0     47.5     60.5     63.7     66.9     68.4
 2    54.6     55.5     56.3     34.8     33.7     34.0     47.4     59.6     61.9     63.8     65.9
 3    55.9     57.9     58.4     35.2     34.1     34.6     46.8     57.7     58.4     60.1     61.7
 4    58.9     62.7     62.6     36.8     36.0     34.2     46.9     56.7     57.1     58.3     58.4
 5    61.1     63.7     64.7     39.7     39.5     35.3     47.2     56.4     56.8     57.8     58.2
 6    59.2     61.8     62.4     44.6     38.6     34.6     46.9     56.5     56.9     58.0     59.1
 7    56.5     58.3     58.2     39.9     34.5     34.1     47.3     57.7     59.0     61.4     61.7
 8    54.9     55.9     56.1     37.2     33.8     34.0     46.8     59.3     62.1     64.4     66.2
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                        ---------------
                        RUN NUMBER  318
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       ROTAMETER SETTING                =     90.  PERCENT
       CURRENT TO TUBE                  =    496.  AMPS
       VOLTAGE DROP IN TUBE             =   5.565  VOLTS
       ROOM TEMPERATURE                 =    87.0  F (     30.6  C)
       UNCORRECTED INLET TEMPERATURE    =    92.3  F (     33.5  C)
       UNCORRECTED OUTLET TEMPERATURE   =   116.1  F (     46.7  C)
       BATH TEMPERATURE    =     92.6  F (    33.7  C)
       INLET TEMP. EQ TO EXIT HEATED    =   116.4  F (     46.9  C)
       OUTLET TEMP.BEFORE HEATING   =     92.1  F (     33.4  C)
       MASS FRACTION OF ETHYLENE GLYCOL =  0.9635

            UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1        2        3        4        5        6        7        8        9       10       11

 1    149.4    151.3    151.9     98.9     92.8     95.8    141.7    178.1    179.7    186.0    190.1
 2    149.7    152.0    154.3     96.3     92.8     95.6    141.1    170.9    172.7    175.7    182.0
 3    154.0    159.3    160.4     97.4     94.1     96.2    138.3    161.8    158.5    162.0    167.8
 4    163.3    174.5    174.2    102.2     99.3     95.7    138.2    158.7    152.1    156.6    158.0
 5    171.2    178.3    181.2    110.1    108.9     98.0    139.1    158.6    151.0    155.1    156.7
 6    164.7    171.7    173.5    124.6    106.6     96.0    138.1    158.1    153.0    156.7    158.8
 7    155.9    160.4    160.0    110.9     95.2     95.1    140.1    162.6    161.3    167.4    167.4
 8    150.7    153.4    153.8    103.0     93.4     95.6    138.3    171.2    172.6    177.8    182.3

            UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

          1        2        3        4        5        6        7        8        9       10       11

 1     65.2     66.3     66.6     37.2     33.8     35.4     60.9     81.2     82.1     85.6     87.8
 2     65.4     66.7     67.9     35.7     33.8     35.3     60.6     77.2     78.2     79.8     83.3
 3     67.8     70.7     71.3     36.3     34.5     35.7     59.1     72.1     70.3     72.2     75.4
 4     72.9     79.2     79.0     39.0     37.4     35.4     59.0     70.4     66.7     69.2     70.0
 5     77.3     81.3     82.9     43.4     42.7     36.7     59.5     70.3     66.1     68.4     69.3
 6     73.7     77.6     78.6     51.4     41.4     35.6     58.9     70.1     67.2     69.3     70.4
 7     68.8     71.3     71.1     43.8     35.1     35.1     60.1     72.6     71.8     75.2     75.2
 8     65.9     67.4     67.7     39.4     34.1     35.3     59.1     77.3     78.1     81.0     83.5
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                    ---------------
                    RUN NUMBER  354
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         ROTAMETER SETTING                =     50.  PERCENT
         CURRENT TO TUBE                  =    570.  AMPS
         VOLTAGE DROP IN TUBE             =   6.351  VOLTS
         ROOM TEMPERATURE                 =    91.4  F (     33.0  C)
         UNCORRECTED INLET TEMPERATURE    =    91.6  F (     33.1  C)
         UNCORRECTED OUTLET TEMPERATURE   =   104.6  F (     40.3  C)
         BATH TEMPERATURE   =    91.7  F (    33.2  C)
         INLET TEMP. EQ TO EXIT HEATED    =   104.5  F (     40.3  C)
         OUTLET TEMP.BEFORE HEATING  =    91.7  F (     33.2  C)
         MASS FRACTION OF ETHYLENE GLYCOL =  0.9509

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1      2      3      4      5      6      7      8      9     10     11

 1    156.9  159.2  159.5   95.1   91.9   91.7  109.9  137.9  151.5  177.3  186.6
 2    156.8  159.7  161.8   93.4   91.9   91.7  110.9  138.4  152.6  172.3  179.1
 3    160.4  166.0  167.2   94.1   93.2   93.9  114.8  142.0  157.7  167.6  171.3
 4    168.0  179.5  179.4   97.3  100.9   92.4  117.6  147.2  159.3  164.6  167.5
 5    174.4  183.3  186.2  104.5  121.2   96.8  121.4  147.9  159.4  164.3  167.6
 6    170.0  177.0  178.5  125.4  114.8   93.9  118.4  145.3  157.7  167.4  168.7
 7    162.8  167.3  166.5  107.0   94.4   92.3  111.4  142.3  155.9  173.1  175.0
 8    158.1  161.2  161.3   98.4   92.3   91.7  113.7  140.1  154.4  176.2  183.7

              UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES C

        1      2      3      4      5      6      7      8      9     10     11

 1     69.4   70.7   70.8   35.1   33.2   33.2   43.3   58.8   66.4   80.7   85.9
 2     69.3   70.9   72.1   34.1   33.3   33.2   43.8   59.1   67.0   77.9   81.7
 3     71.3   74.4   75.1   34.5   34.0   34.4   46.0   61.1   69.8   75.3   77.4
 4     75.6   81.9   81.9   36.3   38.3   33.5   47.5   64.0   70.7   73.7   75.3
 5     79.1   84.1   85.7   40.3   49.6   36.0   49.6   64.4   70.8   73.5   75.3
 6     76.7   80.6   81.4   51.9   46.0   34.4   48.0   62.9   69.8   75.2   75.9
 7     72.7   75.2   74.7   41.7   34.7   33.5   44.1   61.3   68.9   78.4   79.4
 8     70.1   71.8   71.8   36.9   33.5   33.2   45.4   60.1   68.0   80.1   84.3
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APPENDIX H

COMPUTER LISTING OF THE MAIN PROGRAM

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$JOB
C  A PROGRAM FOR THE LAMINAR FLOW HEAT TRANSFER DOWNSTREAM FROM U-BENDS.
C  AUTHOR          : ALI OWHADI.
C  MODIFIED BY     : MAHMOOD MOSHFEGHIAN.
C  REMODIFIED BY   : AMANIE N. ABDELMESSIH.
C  INSTALLATION    : OKLAHOMA STATE UNIVERSITY.
C  DATE MODIFIED   : MARCH 17, 1985.
C  LANGUAGE        : WATFIV.
C
C
C  INPUT QUANTITIES
C    NRUN   = RUN NUMBER
C    MFLUID = TEST FLUID 1 WATER
C                        2 ETHYLENE GLYCOL USING VANE PUMP
C                        3 ETHYLEND GLYCOL USING TURBINE PUMP
C    X2     = MASS FRACTION OF TEST FLUID
C    SET    = VOLUMETRIC SETTING OF FLOW METER, %
C    TAMPS  = TOTAL CURRENT TO THE TEST SECTION, AMP.
C    VOLTS  = VOLTAGE DROP IN A STRAIGHT SECTION OF THE U-TUBE, V
C    TBATH  = BATH TEMPERATURE, F
C    TIN    = INLET BULK TEMPERATURE, F
C    TOUT   = EXIT BULK TEMPPERATURE DURING HEAT GENERATION, F
C    TIN2  = INLET BULK TEMPERATURE FOR FLUID CIRCULATING AT CONS. TEMP
C    TOUT1  = OUTLET TEMPERATURE BEFORE HEAT GENERATION, F
C    TROOM  = LABORATORY TEMPERATURE DURING RUN, F
C    TOSURF = OUTSIDE SURFACE TEMPERATURE OF THE TUBE WALL, F
C    IST    = STATION NUMBER
C    IPR    = PERIPHERAL POSITION OF THERMOCOUPLE
C  OUTPUT QUANTITIES
C    H1     = (1/8).SUM(Q/A)/(TISURF(IST,IPR)-TBULK(IST))
C    H2     = (SUM(Q/A)/8)/(SUM(TISURF(IST,IPR))/8-TBULK(IST))
C    Q/A    = LOCAL PERIPHERAL HEAT FLUX, BTU/HR.SQ.FT.
C    TISURF(IST,IPR) = INSIDE WALL TEMPERATURE AT STATION IST AND
C                        POSITION IPR
C    TBULK(IPR) = BULK FLUID TEMPERATURE AT STATION IST, F
C    BR/TR  = CURVATURE RATIO (BEND DIAMETER / TUBE DIAMETER)
C    LIT(1) =(H1 - HEAT TRANSFER COEF. CALC. BY MORCOS AND BERGLES)/H1
C    LIT(2) =(H2 - HEAT TRANSFER COEF. CALC. BY MORCOS AND BERGLES)/H2
C    LIT(3) =(H1 - HEAT TRANSFER COEF. CALC. BY HONG,MORCOS &BERGLES)/H1
C    LIT(4) =(H2 - HEAT TRANSFER COEF. CALC. BY HONG,MORCOS &BERGLES)/H2
C    LIT(5) =(H1 - HEAT TRANSFER COEF. CALC. BY HAUSEN)/H1
C    LIT(6) =(H2 - HEAT TRANSFER COEF. CALC. BY HAUSEN)/H2
C    LIT(7) =(H1 - HEAT TRANSFER COEF. CALC. BY MOSHFEGIAN)/H1
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C     LIT(8) =(H2 - HEAT TRANSFER COEF. CALC. BY MOSHFEGIAN)/H2
C     LIT(9) =(H1 - HEAT TRANSFER COEF. CALC. BY SEIDER &TATE)/H1
C     LIT(10)=(H2 - HEAT TRANSFER COEF. CALC. BY SEIDER & TATE)/H2
C     COR(1) =(H1- HEAT TRANSFER COEF. PREDICTED)/H1
C     COR(2) =(H2- HEAT TRANSFER COEF. PREDICTED)/H2
C     X/D    = DIMENSIONLESS DISTANCE FROM BEGINING OF HEATING AT EACH
C               STRAIGHT SECTION
C     TB     = LOCAL BULK TEMPERATURE, F
C     RE.NO. = LOCAL BULK REYNOLDS NUMBER
C     PR.NO. = LOCAL BULK PRANDTL NUMBER
C     GR.NO. = GRASHOF NUMBER
C     HT/HB  = RATIO OF THE TOP TO THE BOTTOM HEAT TRANSFER COEFFICIENTS
C     DE.NO. = LOCAL BULK DEAN NUMBER
C     GR/RE2 = RATIO OF THE GRASHOF NUMBER TO THE SQUARE OF THE REYNOLDS
C                NUMBER
C     NU1    = LOCAL AVERAGE PERIPHERAL NUSSELT NUMBER BASED ON H1
C     NU2    = LOCAL AVERAGE PERIPHERAL NUSSELT NUMBER BASED ON H2
C
C      MAIN PROGRAM
       DIMENSION TSAVE1(11,8),TSAVE2(11,8),SITOC(11,8),REN(11,8)
      1 , TCHCK1(8),TCHCK2(8)
       COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
       COMMON/READ2/TIN,TOUT,TIN2,TOUT1
       COMMON/READ3/TOSURF(11,8),TISURF(11,8)
       COMMON M,N
       COMMON/TCOND/CONDK(11,9)
       COMMON /TEMP1/ TWALL(11,8),AMPS(11,8),RESIS(11,8),POWERS(13)
      1,TPOWER
       COMMON /THERM1/TSAT(13),TSTART,TEND,QLOSS1(4),QLOSS2(4)
       COMMON/ERESIS/RSVTY(11,8)
       COMMON/MAIN1/IST,KOUNT
       COMMON /MAIN2/ AMP,OHMS,OHMS12,OHMS13
       COMMON /GEOM1/ XAREA(11,8),R(11  ),L(13,8),LTC(11),LEND(4),DELTAR(
      18),R456(11,8),LIN(4),LOUT(4),LTOTAL(4),ITSECT
       COMMON/GEOM2/RBEND(4),DOUT(4),DIN(4),PHI,DPHI,DELR,NODES,NSLICE
       COMMON/OUTT/INO,IRNO(300),ROR(300),IRENO(300),PRDNO(300),IQFLUX(30
      *0),QGEN(300),QGAIN(300),QL(300),QER(300)
       REAL*4 L,LEND,LTC,LIN,LOUT,LTOTAL
C   INPUT DEVICE 8 AND OUTPUT DEVICE 6
       M=8
       N=6
       INO=0
     1 READ(M,1010) NRUN
       IF (NRUN.EQ.0) GO TO 3333
  1010 FORMAT(I3)
       INO=INO+1
       CALL READS
       CALL GEOM
       CALL CORECT
       WRITE(N,100)
       WRITE(N,170)NRUN
       WRITE(N,4321)
   100 FORMAT(1H1)
   170  FORMAT(1H0,32X,15('-')/33X,'RUN NUMBER  ',I3/33X,15('-'))
  4321 FORMAT(1H0,20X,'CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F'
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     1//9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',6X,'9',6
     2X,'10',5X,'11'//)
      WRITE(N,556)(IPR,(TOSURF(IST,IPR),IST=1,11),IPR=1,8)
  556 FORMAT(3X,I1,F8.1,10F7.1)
       DO 921 IPR=1,8
       DO 921 IST=1,11
       SITOC(IST,IPR)=(TOSURF(IST,IPR)-32.0)/1.8
  921  CONTINUE
       WRITE(N,4322)
 4322 FORMAT(1H0,20X,'CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C'
     1//9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',6X,'9',6
     2X,'10',5X,'11'//)
      WRITE(N,556)(IPR,(SITOC(IST,IPR),IST=1,11),IPR=1,8)
      SIRMFL=RMFL*1.259979E-04
      WRITE(N,67)RMFL,SIRMFL
   67 FORMAT(1H0,15X,'MASS FLOW RATE         =',F8.1,2X,'LBM/HR  (',F8.5
     1,2X,'KG.PER.S)')
      IRNO(INO)=NRUN
      ROR(INO)=RBEND(ITSECT)/DIN(ITSECT)*2.0
      NNODE=NODES-1
C  START SOLUTION WITH STATION 1
      DO 9999 IST=1,11
      DO 9 IPR=1,8
    9 TCHCK1(IPR) =0.0
C  SET ALL RADIAL TEMPERATURES EQUAL TO THE OUTSIDE SURFACE TEMPERATURES
      DO 10 ISL=1,NODES
      DO 10 IPR=1,8
   10 TWALL(ISL,IPR)=TOSURF(IST,IPR)
C  CALCULATE THERMAL CONDUCTIVITY FOR EACH NODE
      KOUNT=1
   19 CONTINUE
      CALL THCOND
C  CALCULATE ELECTRICAL CONDUCTIVITY FOR EACH NODE
      CALL ERSTVT
C  CALCULATE RESISTANCE & CURRENT FOR EACH SEGMENT
C  CALCULATE EQUIVALENT RESISTANCE FOR PARALLEL CIRCUITS
      IF(ITSECT.EQ.1) GO TO 4334
      IF(IST.LT.4.OR.IST.GT.6) CALL GEOMST
      IF(IST.EQ.4.OR.IST.EQ.5.OR.IST.EQ.6) CALL GEOMBT
      GO TO 4335
 4334 IF(IST.LT.5.OR.IST.GT.6) CALL GEOMST
      IF(IST.EQ.5.OR.IST.EQ.6) CALL GEOMBT
 4335 RINV = 0.0
      DO 11 ISL=1,NODES
      DO 11 IPR=1,8
      RESIS(ISL,IPR) = RSVTY(ISL,IPR)*L(IST,IPR)/XAREA(ISL,IPR)
      RINV = RINV +1.0/RESIS(ISL,IPR)
   11 CONTINUE
      OHMS = 1.0/RINV
C  CALCULATE CURRENT FOR EACH SEGMENT
      AMP=0.0
      DO 12 ISL=1,NODES
      DO 12 IPR=1,8
      AMPS(ISL,IPR) = TAMPS*OHMS/(RESIS(ISL,IPR)*2.0)
      AMP=AMP+AMPS(ISL,IPR)
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```
   12 CONTINUE
C  CALCULATE TEMPERATURES AT NODE 2
      ISL=1
      DO 13 IPR=1,8
      IMINS=IPR-1
      IPLUS=IPR+1
      NMINS = ISL - 1
      NPLUS = ISL + 1
      IF(IMINS.EQ.0) IMINS=8
      IF(IPLUS.EQ.9) IPLUS=1
      A= AMPS(ISL,IPR)*AMPS(ISL,IPR)*3.41214/XAREA(ISL,IPR)
C     B=((QLOSS2(ITSECT)-QLOSS1(ITSECT))/LEND(ITSECT)*LTC(IST)+QLOSS1(IT
C    1SECT))/(LEND(ITSECT)*8.0)
      B=((QLOSS2(ITSECT)-QLOSS1(ITSECT))/LEND(ITSECT)+QLOSS1(ITSECT)
     1 /LTC(IST))/(LEND(ITSECT)*8.0)
      IF(ITSECT.EQ.1) GO TO 987
      IF(IST.EQ.4.OR.IST.EQ.5.OR.IST.EQ.6) GO TO 101
      GO TO 988
  987  IF(IST.EQ.5.OR.IST.EQ.6) GO TO 101
  988 C=DELR/(2.0*24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IPLUS))/R(ISL)
      D= DELR/(2.0*24.0*DPHI)* (CONDK(ISL,IPR)+CONDK(ISL,IMINS))/R(ISL)
      X= DPHI/(24.0*DELR)*(CONDK(ISL,IPR)+CONDK(NPLUS,IPR))*(R( NPLUS)+
     1DELR/2.0)
      GO TO 102
  101 CONTINUE
      A=0.0
      C = DELTAR(IPR)/(2.0*24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IPLUS))/
     1R456(ISL,IPR)
      D = DELTAR(IPR)/(2.0*24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IMINS))/
     1R456(ISL,IPR)
      X =DPHI/(24.0*DELTAR(IPR))*(CONDK(ISL,IPR)+CONDK(NPLUS,IPR))*(R456
     1(NPLUS,IPR)+DELTAR(IPR)/2.0)
  102 CONTINUE
      TWALL(NPLUS,IPR) = TWALL(ISL,IPR)-  (A*RSVTY(ISL,IPR)+B
     1+ C*(TWALL(ISL,IPLUS)-TWALL(ISL,IPR))+D*(TWALL(ISL,IMIN
     2S)-TWALL(ISL,IPR)))/X
   13 CONTINUE
C  CALCULATE REMAINING NODAL TEMPERATURES
      DO 14 ISL=2,NNODE
      DO 14 IPR=1,8
      IMINS=IPR-1
      IPLUS=IPR+1
      NMINS=ISL-1
      NPLUS=ISL+1
      IF(IMINS.EQ.0) IMINS= 8
      IF(IPLUS.EQ.9) IPLUS = 1
      A = 3.41214*AMPS (ISL,IPR)*AMPS(ISL,IPR)/ XAREA(ISL,IPR)
      IF(ITSECT.EQ.1) GO TO 911
      IF (IST.EQ.4.OR.IST.EQ.5.OR.IST.EQ.6) GO TO 103
      GO TO 912
  911 IF(IST.EQ.5.OR.IST.EQ.6) GO TO 103
  912 B = DPHI/(24.0*DELR)*(CONDK(ISL,IPR)+CONDK(NMINS,IPR))*(R(NMINS)
     1-DELR/2.0)
       C = DELR/(24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IPLUS))/ R(ISL)
      D = DELR/(24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IMINS))/ R(ISL)
```

```
      X = DPHI/(24.0*DELR)*(CONDK(ISL,IPR)+CONDK(NPLUS,IPR))*(R(NPLUS)
     1+DELR/2.0)
      GO TO 104
  103 CONTINUE
      A=0.0
      B =DPHI/(24.0*DELTAR(IPR))*(CONDK(ISL,IPR)+CONDK(NMINS,IPR))*(R456
     1(NMINS,IPR)-DELTAR(IPR)/2.0)
      C =DELTAR(IPR)/(24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IPLUS))/R456(
     1ISL,IPR)
      D =DELTAR(IPR)/(24.0*DPHI)*(CONDK(ISL,IPR)+CONDK(ISL,IMINS))/R456(
     1ISL,IPR)
      X =DPHI/(24.0*DELTAR(IPR))*(CONDK(ISL,IPR)+CONDK(NPLUS,IPR))*(R456
     1(NPLUS,IPR)+DELTAR(IPR)/2.0)
  104 CONTINUE
      TWALL(NPLUS,IPR)= TWALL(ISL,IPR) - (A*RSVTY(ISL,IPR)+B*(TWALL(NMIN
     1S,IPR)-TWALL(ISL,IPR)) +C* (TWALL(ISL,IPLUS)-TWALL(ISL,IPR))+ D*(T
     2WALL(ISL,IMINS)-TWALL(ISL,IPR)))/X
C   CHECK FOR THE CONVERGENCE OF THE WALL TEMPERATURE.
   14 CONTINUE
      DO 15 IPR=1,8
      TCHCK2(IPR)=TWALL(NODES,IPR)
   15 CONTINUE
      DO 16 IPR =1,8
      IF (ABS(TCHCK2(IPR)-TCHCK1(IPR)).GT.0.005) GO TO 17
   16 CONTINUE
      GO TO 20
   17 DO 18 IPR=1,8
   18 TCHCK1(IPR) = TCHCK2(IPR)
      KOUNT = KOUNT+1
      GO TO 19
   20 DO 21 IPR=1,8
      TISURF( IST ,IPR)=TWALL(NODES,IPR)
   21 CONTINUE
C   CALCULATE POWER GENERATED IN EACH SEGMENT IN BTU/HOUR
      POWER =0.0
      DO 22 ISL=1,NODES
      DO 22 IPR=1,8
      POWER=POWER+AMPS(ISL,IPR)*AMPS(ISL,IPR)*RESIS(ISL,IPR)
  22  CONTINUE
      POWERS(IST)=POWER*3.41214
C   CALCULATE POWER GENERATED IN SEGMENTS 12 & 13 BY SAVING VARIABLES FOR
C   STATIONS 1,2,10,AND 11
      IF(IST.GT.2) GO TO 23
      IF(IST.EQ.2) GO TO 24
      DO 25 ISL=1,NODES
      DO 25 IPR=1,8
   25 TSAVE1(ISL,IPR)=TWALL(ISL,IPR)
      GO TO 23
   24 DO 26 ISL=1,NODES
      DO 26 IPR=1,8
   26 TSAVE2(ISL,IPR)=TWALL(ISL,IPR)
      DO 27 ISL=1,NODES
      DO 27 IPR=1,8
   27 TWALL(ISL,IPR)=(TSAVE1(ISL,IPR)+TSAVE2(ISL,IPR))/2.0
      CALL ERSTVT
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```
      RINV=0.0
      DO 28 ISL=1,NODES
      DO 28 IPR=1,8
      RESIS(ISL,IPR) = RSVTY(ISL,IPR)*L( 12,IPR)/XAREA(ISL,IPR)
      RINV=RINV+1.0/RESIS(ISL,IPR)
C  REDEFINE WALL TEMPERATURES AT STATION 2
      TWALL(ISL,IPR) = TSAVE2(ISL,IPR)
   28 CONTINUE
      OHMS12=1.0/RINV
      DO 29 IPR=1,8
      POWER=0.0
      DO 29 ISL=1,NODES
      AMPS(ISL,IPR)= TAMPS*OHMS12/(RESIS(ISL,IPR)*2.0)
   29 POWER=POWER +AMPS(ISL,IPR)*AMPS(ISL,IPR)*RESIS(ISL,IPR)
      POWERS(12)=POWER*3.41214
   23 IF(IST.LT.10) GO TO 40
      IF(IST.EQ.11) GO TO 30
      DO 31 ISL=1,NODES
      DO 31 IPR=1,8
   31 TSAVE1(ISL,IPR)=TWALL(ISL,IPR)
      GO TO 40
   30 DO 32 ISL=1,NODES
      DO 32 IPR=1,8
   32 TSAVE2(ISL,IPR)=TWALL(ISL,IPR)
      DO 33 ISL=1,NODES
      DO 33 IPR=1,8
   33 TWALL(ISL,IPR)=(TSAVE1(ISL,IPR)+TSAVE2(ISL,IPR))/2.0
      CALL ERSTVT
      RINV=0.0
      DO 34 ISL=1,NODES
      DO 34 IPR=1,8
      RESIS(ISL,IPR) = RSVTY(ISL,IPR)*L( 13,IPR)/XAREA(ISL,IPR)
      RINV=RINV+1.0/RESIS(ISL,IPR)
C  REDEFINE WALL TEMPERATURES AT STATION 10
      TWALL(ISL,IPR) = TSAVE2(ISL,IPR)
   34 CONTINUE
      OHMS13=1.0/RINV
      DO 35 IPR=1,8
      POWER=0.0
      DO 35 ISL=1,NODES
      AMPS(ISL,IPR)= TAMPS*OHMS13/(RESIS(ISL,IPR)*2.0)
   35 POWER=POWER + AMPS(ISL,IPR)*AMPS(ISL,IPR)*RESIS(ISL,IPR)
      POWERS(13)=POWER*3.41214
   40 CONTINUE
      CALL QFLUX
 9999 CONTINUE
C  CALCULATE RENOLDS NUMBERS AT THE INSIDE SURFACE OF THE TUBE.
C     WRITE(N,555)
C 555 FORMAT(1H1,10X,'REYNOLDS NUMBER AT THE INSIDE TUBE WALL'
C    1//9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',6X,
C    2'9',6X,'10',5X,'11'//)
      DO 69 IST=1,11
      DO 69 IPR=1,8
      TR=TISURF(IST,IPR)
      CALL MEW(TR,MFLUID,X2,VISS)
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```
      REN(IST,IPR)=RMFL*48.0/(3.1416*DIN(ITSECT)*VISS)
   69 CONTINUE
C     WRITE(N,556)(IPR,(REN(IST,IPR),IST=1,11),IPR=1,8)
C  CALCULATE TOTAL POWER GENERATED IN BTU/HOUR
      TPOWER=0.0
      DO 61 ISTAT=1,13
   61 TPOWER=TPOWER+POWERS(ISTAT)
      CALL TLIQD
      WRITE(N,3334)
 3334 FORMAT(1H1)
      WRITE(N,3336)
 3336 FORMAT(1H0,3X,'NO',3X,'RUN NO',2X,'BR/TR',6X,'RE',6X,'PR',
     * 4X,'AVG HEAT FLUX',3X,'HEAT GENERATED',3X,'HEAT GAINED',3X,'HEAT
     1 LOST',3X,'H.B.% ERROR',/)
      DO 200 I=1,INO
      WRITE(N,3335)I,IRNO(I),ROR(I),IRENO(I),PRDNO(I),IQFLUX(I),QGEN(I),
     1QGAIN(I),QL(I),QER(I)
  200 CONTINUE
 3335 FORMAT(1H ,I5,I8,F8.3,I8,F8.1,I12,10X,F10.1,5X,F10.1,F12.1,F14.2)
      WRITE(N,3334)
      GO TO 1
 3333 STOP
      END
C
      SUBROUTINE READS
      DIMENSION SITOS(11,8)
      COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
      COMMON/READ2/TIN,TOUT,TIN2,TOUT1
      COMMON/READ3/TOSURF(11,8),TISURF(11,8)
      COMMON M,N
C READ INPUT QUANTITIES
      WRITE(N,104)
  104 FORMAT(1H1)
      READ (M,1)MFLUID,X2,SET,TAMPS,VOLTS,TBATH,TIN,TOUT,TIN2,TOUT1,
     1TROOM
    1 FORMAT(I2,10F7.0)
C  UNCORRECTED TEMPERATURE READINGS OF THE SURFACE TEMPERATURES
      READ (M,2)((TOSURF(IST,IPR),IPR=1,8),IST=1,11)
    2  FORMAT(8F7.2)
      SITR=(TROOM-32.0)/1.8
      SITIN=(TIN-32.0)/1.8
      SITOUT=(TOUT-32.0)/1.8
      SITBA=(TBATH-32.0)/1.8
      SITIN2=(TIN2-32.0)/1.8
      SITO1=(TOUT1-32.0)/1.8
      WRITE(N,101)NRUN,SET,TAMPS,VOLTS,TROOM,SITR,TIN,SITIN,TOUT,SITOUT
     1,TBATH,SITBA,TIN2,SITIN2,TOUT1,SITO1
  101 FORMAT(33X,15('-')/33X,'RUN NUMBER  ',I3/33X,15('-')//
     1      15X,'ROTAMETER SETTING                =',F8.0,2X,'PERCENT'/
     2      15X,'CURRENT TO TUBE                  =',F8.0,2X,'AMPS'/
     3      15X,'VOLTAGE DROP IN TUBE             =',F8.3,2X,'VOLTS'/
     5      15X,'ROOM TEMPERATURE                 =',F8.1,2X,'F (',F8.1,2
     4X,'C)'/
     5      15X,'UNCORRECTED INLET TEMPERATURE    =',F8.1,2X,'F (',F8.1,2
     4X,'C)'/
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     6      15X,'UNCORRECTED OUTLET TEMPERATURE  =',F8.1,2X,'F (',F8.1,2
     4X,'C)'/
     5      15X,'BATH TEMPERATURE   =',F8.1,2X,'F (',F8.1,2
     4X,'C)'/
     5      15X,'INLET TEMP. EQ TO EXIT HEATED   =',F8.1,2X,'F (',F8.1,2
     4X,'C)'/
     6      15X,'OUTLET TEMP.BEFORE HEATING  =',F8.1,2X,'F (',F8.1,2
     4X,'C)'/)
      IF(MFLUID.GT.1)GO TO 106
      WRITE(N,105)
  105 FORMAT(15X,'TEST FLUID IS WATER')
      GO TO 108
  106 WRITE(N,107)X2
  107 FORMAT(15X,'MASS FRACTION OF ETHYLENE GLYCOL =',F8.4)
  108 WRITE(N,102)
  102  FORMAT(// 20X,'UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES
     1 F'//
     1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
     26X,'9',6X,'10',5X,'11'//)
      WRITE(N,103)(IPR,(TOSURF(IST,IPR),IST=1,11),IPR=1,8)
  103 FORMAT(3X,I1,F8.1,10F7.1 )
      WRITE(N,109)
  109  FORMAT(// 20X,'UNCORRECTED OUTSIDE SURFACE TEMPERATURES - DEGREES
     1 C'//
     1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
     26X,'9',6X,'10',5X,'11'//)
      DO 110 IPR=1,8
      DO 110 IST=1,11
      SITOS(IST,IPR)=(TOSURF(IST,IPR)-32.0)/1.8
  110 CONTINUE
      WRITE(N,103)(IPR,(SITOS(IST,IPR),IST=1,11),IPR=1,8)
      RETURN
      END
C
      SUBROUTINE QFLUX
      COMMON /MAIN1/ IST,KOUNT
      COMMON /GEOM1/ XAREA(11,8),R(11   ),L(13,8),LTC(11),LEND(4),DELTAR(
     18),R456(11,8),LIN(4),LOUT(4),LTOTAL(4),ITSECT
      COMMON/GEOM2/RBEND(4),DOUT(4),DIN(4),PHI,DPHI,DELR,NODES,NSLICE
      COMMON/TCOND/CONDK(11,9)
      COMMON /TEMP1/ TWALL(11,8),AMPS(11,8),RESIS(11,8),POWERS(13)
     1,TPOWER
      COMMON /QFLUX1/ QFLXID(11,8)
      COMMON/ERESIS/RSVTY(11,8)
      COMMON /QFLUX2/ Q1,Q2,Q4,QGEN
C  CALCULATE HEAT FLUX AT INSIDE SURFACE BY MAKING A HEAT BALANCE
      ISL=NODES
      DO 10 IPR=1,8
      IPLUS=IPR+1
      IMINS=IPR-1
      IF (IPLUS.EQ.9) IPLUS=1
      IF (IMINS.EQ.0) IMINS=8
      IF(ITSECT.EQ.1) GO TO 913
      IF (IST.EQ.4.OR.IST.EQ.5.OR.IST.EQ.6) GO TO 8
      GO TO 914
```

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 913 IF(IST.EQ.5.OR.IST.EQ.6) GO TO 8
 914 Q1 = DPHI/(24.0*DELR)*(CONDK(ISL-1,IPR)+CONDK(ISL,IPR))*(R(ISL-1)
    1-DELR/2.0)*(TWALL(ISL-1,IPR)-TWALL(ISL,IPR))
     Q2 = DELR/(2.0*24.0*DPHI)/R(ISL)*(CONDK(ISL,IPLUS)+CONDK(ISL,IPR))
    1*(TWALL(ISL,IPLUS)-TWALL(ISL,IPR))
     Q4 = DELR/(2.0*24.0*DPHI)/R(ISL)*(CONDK(ISL,IMINS)+CONDK(ISL,IPR))
    1*(TWALL(ISL,IMINS)-TWALL(ISL,IPR))
     QGEN =3.41214*AMPS(ISL,IPR)*AMPS(ISL,IPR)*RSVTY(ISL,IPR)/XAREA(ISL
    1,IPR)
     QFLXID(IST,IPR) =(Q1+Q2+Q4+QGEN)/(R(NODES)*DPHI)*144.0
     GO TO 9
   8 CONTINUE
     Q1 = DPHI/(24.0*DELTAR(IPR))*(CONDK(ISL-1,IPR)+CONDK(ISL,IPR))*
    1(R456(ISL-1,IPR)-DELTAR(IPR)/2.0)* (TWALL(ISL-1,IPR)-TWALL(ISL,IPR
    2))
     Q2 = DELTAR(IPR)/(2.0*24.0*DPHI)/R456(ISL,IPR)*(CONDK(ISL,IPLUS)+
    1CONDK(ISL,IPR))*(TWALL(ISL,IPLUS)-TWALL(ISL,IPR))
     Q4 = DELTAR(IPR)/(2.0*24.0*DPHI)/R456(ISL,IPR)*(CONDK(ISL,IMINS)+
    1CONDK(ISL,IPR))*(TWALL(ISL,IMINS)-TWALL(ISL,IPR))
     QGEN=0.0
     QFLXID(IST,IPR) =(Q1+Q2+Q4+QGEN)/(R456(NODES,IPR)*DPHI)*144.0
   9 CONTINUE
  10 CONTINUE
     RETURN
     END
C
      SUBROUTINE  TLIQD
      COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
      COMMON/READ2/TIN,TOUT,TIN2,TOUT1
      COMMON/READ3/TOSURF(11,8),TISURF(11,8)
      COMMON /TEMP1/ TWALL(11,8),AMPS(11,8),RESIS(11,8),POWERS(13)
     1,TPOWER
      COMMON /GEOM1/ XAREA(11,8),R(11  ),L(13,8),LTC(11),LEND(4),DELTAR(
     18),R456(11,8),LIN(4),LOUT(4),LTOTAL(4),ITSECT
      COMMON/GEOM2/RBEND(4),DOUT(4),DIN(4),PHI,DPHI,DELR,NODES,NSLICE
      COMMON /THERM1/TSAT(13),TSTART,TEND,QLOSS1(4),QLOSS2(4)
      COMMON /THERM2/HTCOFF(11,8),QUALTY(13),HSTART,HEND,XSTART,XEND,ENT
     1H(13)
      COMMON /QFLUX1/ QFLXID(11,8)
      COMMON/TCOND/CONDK(11,9)
      COMMON /TLIQ1/ TBULK(13),HLIQ(13)
      COMMON /TLIQ2/ HTDBL(11),HNUSLT(11),HSTATE(11)  ,HAVG(11)
      COMMON/OUTT/INO,IRNO(300),ROR(300),IRENO(300),PRDNO(300),IQFLUX(30
     *0),QGEN(300),QGAIN(300),QL(300),QER(300)
      COMMON M,N
      DIMENSION QAVG(11),TAVG(11),H(11),PWP(11),SIH(11),SIHP(11,8)
      DIMENSION GRNO(11),GRRE2(11),RENO(11),PR(11)  ,HJ(11),XD(11)
       DIMENSION XX(22),YY(22),QLOSS(4),SIHAV(11),SITIS(11,8),SITB(11)
      DIMENSION SIQIN(11,8),HTBRG1(11),HTBRG2(11),HTHAS1(11),HTHAS2(11)
       DIMENSION DIS(11),HTST1(11),HTST2(11),HTMOS1(11),HTMOS2(11),
     1 HTA1(11),HTA2(11)
       DIMENSION ERQ(11),ERH(11),RRR(11),VISB(11),VISW(11)
      DIMENSION AHMB(11),BHMB(11),AHHB(11),BHHB(11),HL2(13)
      REAL*4 LIN,LOUT,LTOTAL,L,LTC,LEND,MTOT
        RR=1.0/ROR(INO)
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      G=32.144866
      WRITE(N,100)
        WRITE(N,170)NRUN
 170  FORMAT(1H0,32X,15('-')/33X,'RUN NUMBER  ',I3/33X,15('-'))
     WRITE(N,202)
 202  FORMAT(// 20X,'   INSIDE SURFACE TEMPERATURES - DEGREES F'//
    1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
    26X,'9',6X,'10',5X,'11'//)
     WRITE(N,103)(IPR,(TISURF(IST,IPR),IST=1,11),IPR=1,8)
 103 FORMAT(3X,I1,F8.1,10F7.1 )
     DO 232 IPR=1,8
     DO 232 IST=1,11
     SITIS(IST,IPR)=(TISURF(IST,IPR)-32.0)/1.8
 232 CONTINUE
     WRITE(N,231)
 231  FORMAT(// 20X,'   INSIDE SURFACE TEMPERATURES - DEGREES C'//
    1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
    26X,'9',6X,'10',5X,'11'//)
     WRITE(N,103)(IPR,(SITIS(IST,IPR),IST=1,11),IPR=1,8)
     WRITE(N,205)
 205  FORMAT(1H1,// 20X,'  INSIDE SURFACES HEAT FLUXES BTU/HR.FT2'//
    1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
    26X,'9',6X,'10',5X,'11'//)
     WRITE(N,103)(IPR,(QFLXID(IST,IPR),IST=1,11),IPR=1,8)
     DO 234 IPR=1,8
     DO 234 IST=1,11
     SIQIN(IST,IPR)=QFLXID(IST,IPR)*3.15491
 234 CONTINUE
     WRITE(N,235)
 235  FORMAT(// 20X,'   INSIDE SURFACES HEAT FLUXES W PER SQ.M.'//
    1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
    26X,'9',6X,'10',5X,'11'//)
     WRITE(N,103)(IPR,(SIQIN(IST,IPR),IST=1,11),IPR=1,8)
C  CALCULATION OF INPUT AND OUTPUT HEAT TRANSFER RATES ,BTU/HR.
     QGCALC=TPOWER
     QGEXPT =TAMPS*VOLTS*3.41214
     QLOSS(ITSECT)=(QLOSS1(ITSECT)+QLOSS2(ITSECT))/(2.0*LEND(ITSECT))*L
    1TOTAL(ITSECT)
     QIN=QGEXPT-QLOSS(ITSECT)
      TOE=TOUT
     T=(TOUT+TIN)/2.0
     CALL SPHEAT(T,MFLUID,SPHT)
     QBALNC=RMFL*SPHT*(TOUT-TIN)
      QPCT=(QIN-QBALNC)/QIN
     QPCT=100.0*QPCT
C  CALCULATION OF FLUID BULK TEMPERATURE AT EACH STATION ,DEG.F
     STLT=(LEND(ITSECT)-3.1416*RBEND(ITSECT))/2.0
     IF(ITSECT.EQ.1) GO TO 931
     DO 1 IST=1,3
     TBULK(IST) = TIN+(T-TIN)*LTC( IST  )/STLT
   1 CONTINUE
     DO 7 IST=4,6
     TBULK(IST)=T
   7 CONTINUE
     GO TO 934
```

```
 931 DO 932 IST=1,4
     TBULK(IST) = TIN+(T-TIN)*LTC( IST  )/STLT
 932 CONTINUE
     DO 933 IST=5,6
     TBULK(IST)=T
 933 CONTINUE
 934 DO 8 IST=7,11
     TBULK(IST)=T+(TOUT-T)*(LTC(IST)-STLT-3.1416*RBEND(ITSECT))/STLT
   8 CONTINUE
     WRITE(N,204)
 204  FORMAT(// 20X,'   BULK FLUID TEMPERATURE      - DEGREES F'//
    1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
    26X,'9',6X,'10',5X,'11'//)
     WRITE(N,203)(TBULK(IST),IST=1,11)
2204  FORMAT(// 20X,'   BULK FLUID TEMPERATURE      - DEGREES C'//
    1 9X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
    26X,'9',6X,'10',5X,'11'//)
     WRITE(N,2204)
     DO 2205 IST=1,11
     SITB(IST)=(TBULK(IST)-32.0)/1.8
2205 CONTINUE
     WRITE(N,203)(SITB(IST),IST=1,11)
 203 FORMAT(4X,F8.1,10F7.1)
       WRITE(N,163)
 163  FORMAT(1H0,//)
     SITOUT=(TOUT-32.0)/1.8
     SITIN=(TIN-32.0)/1.8
     WRITE(N,208)TOUT,SITOUT,TIN,SITIN
 208 FORMAT(1H0,20X,'CORRECTED OUTLET TEMPERATURE =',F8.1,'DEG F (',
    1F8.1,'DEG C)'/
    121X,'CORRECTED INLET TEMPERATURE  =',F8.1,'DEG F (',F8.1,'DEG C)')
     AID=3.1416*DIN(ITSECT)*DIN(ITSECT)/4.0/144.0
     GW=RMFL/AID
C  CALCULATION OF PERIPHERAL HEAT TRANSFER COEFFICIENT FROM EXPERIMENTAL
C    DATA,BTU/(HR-SQ.FT-DEG.F)
     DO 2 IST=1,11
     DO 2 IPR=1,8
     HTCOFF(IST,IPR) =QFLXID(IST,IPR)/(TISURF(IST,IPR)-TBULK(IST))
   2 CONTINUE
     DO 207 I=1,11
     QQ=0.0
     TT=0.0
     DO 206 J=1,8
     TT=TT+TISURF(I,J)
     QQ=QQ+QFLXID(I,J)
 206 CONTINUE
     TAVG(I)=TT/8.0
     QAVG(I)=QQ/8.0
     H(I)=QAVG(I)/(TAVG(I)-TBULK(I))
 207 CONTINUE
     DO 3 IST=1,11
     ERQ(IST)=QPCT
     RRR(IST)=1.0/RR
     TIS=0.0
     HAV=0.0
```

```
      DO 4 IPR=1,8
      TIS=TIS+TISURF(IST,IPR)
    4 HAV      =HAV+HTCOFF(IST,IPR)
        T=TBULK(IST)
      CALL MEW(T,MFLUID,X2,VISC)
      CALL SPHEAT(T,MFLUID,SPHT)
      CALL CONDFL(T,MFLUID,X2,COND)
      CALL DENS(T,MFLUID,X2,ROW)
      CALL BET(T,MFLUID,ROW,BETA)
      VISB(IST)=VISC
      PRNO=VISC*SPHT/COND
      REYNO=GW*DIN(ITSECT)/12.0/VISC
       GRNO(IST)=G*BETA*ROW**2*DIN(ITSECT)**3*(TAVG(IST)-TBULK(IST))/VIS
     %C**2 *3600.0**2/12.0/12.0  /12.0
        GRRE2(IST)=GRNO(IST)/REYNO/REYNO
         PR(IST)=PRNO
        RENO(IST)=REYNO
         YY(IST)=RENO(IST)*SQRT(RR)
        XX(IST)=HTCOFF(IST,1)/HTCOFF(IST,5)
        IF(IST.LT.5)XX(IST)=HTCOFF(IST,5)/HTCOFF(IST,1)
C  AVERAGE HEAT TRANSFER COEFFICIENT AT EACH STATION FROM EXPERIMENTAL
C    DATA,BTU/HR-SQ.FT-DEG.F
      T=TIS/8.0
      CALL MEW(T,MFLUID,X2,VISWL)
      VISW(IST)=VISWL
      T=TBULK(IST)
      CALL MEW(T,MFLUID,X2,VISC)
      T=(TAVG(IST)+TBULK(IST))/2.0
      CALL MEW(T,MFLUID,X2,VISF)
      CALL DENS(T,MFLUID,X2,ROWF)
      CALL BET(T,MFLUID,ROWF,BETAF)
      CALL SPHEAT(T,MFLUID,SPHTF)
      CALL CONDFL(T,MFLUID,X2,CONDF)
      GRASH=G*BETAF*ROWF**2*DIN(ITSECT)**3*(T-TBULK(IST))
     1 /VISF**2*3600.0**2/12.0/12.0/12.0
      REYNO=GW*DIN(ITSECT)/12.0/VISWL
      PRNO=VISF*SPHTF/CONDF
      HAVG(IST)=HAV/8.0
        TH=(DOUT(ITSECT)-DIN(ITSECT))/2.0
        TWALL(IST,1)=TAVG(IST)
        CALL THCOND
       HMB=ABS(H(IST))
         IF(GRNO(IST).LT.0.0)GO TO 230
C  MORCOS AND BERGLES CORRELATION FOR THE FULLY DEVELOPED
C    LAMINAR FLOW.
        DO 10 I=1,5
        PW=HMB   *(DIN(ITSECT)/12.0)**2/(CONDK(IST,3)*TH/12.0)
      HMB=(4.36**2+(0.055*(GRASH*PRNO**1.35/PW**0.25)**0.4)
     1 **2)**0.5 *CONDF/DIN(ITSECT)*12.0
   10  CONTINUE
         PWP(IST)=PW
       AHMB(IST)=HMB*DIN(ITSECT)/(COND*12.0)
C HONG, MORCOS AND BERGLESS CORRELATION
      HBERG=ABS(H(IST))
      DO 225 I=1,5
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      AFW=HBERG*(DIN(ITSECT)/12.0)**2/CONDK(IST,3)/TH*12.0
      HBERG=0.378*GRASH**0.28*PRNO**0.33/AFW**0.12*CONDF/DIN(ITSECT)
     1*12.0
  225 CONTINUE
       AHHB(IST)=HBERG*DIN(ITSECT)/(COND*12.0)
C  CALCULATION OF THE RATIO OF THE HEATED LENGTH OF THE TUBE TO
C     ITS INSIDE DIAMETER.
      IF(IST.GT.6) GO TO 216
      DIS(IST)=LTC(IST)/DIN(ITSECT)
      GO TO 218
  216 IF(ITSECT.GT.1) GO TO 217
      DIS(IST)=(LTC(IST)-LTC(6)-3.1416*RBEND(ITSECT)/(30.0*2.0))/DIN(ITS
     1ECT)
      GO TO 218
  217 DIS(IST)=(LTC(IST)-LTC(6)-3.1416*RBEND(ITSECT)/4.0)/DIN(ITSECT)
      GO TO 218
C  HAUSEN APPROXIMATION.
  218 DIST=1.0/DIS(IST)
      HASN=(4.364+(0.0668*RENO(IST)*PR(IST)*DIST)/(1.0+0.04*(
     1RENO(IST)*PR(IST)*DIST)**(2./3.)))*(VISC/VISWL)**0.14*COND/
     1 DIN(ITSECT)*12.0
C  MOSHFEGHIAN CORRELATION.
       IF(IST.GT.6) GO TO 221
      HMOS=0.00275*RENO(IST)**0.733*PR(IST)**0.4*(1.0+8.5*(GRNO(IST)/REN
     1O(IST)**2)**0.429)*(1.0+4.79*2.71828**(-2.11*DIS(IST)**(-0.237)))*
     1COND/DIN(ITSECT)*12.0*(VISC/VISWL)**0.14
      GO TO 222
  221 DISTM=DIS(IST)+RBEND(ITSECT)/DIN(ITSECT)
      HMOS=0.00275*RENO(IST)**(0.733+14.33*(ROR(INO)**(-0.593))*(DISTM
     * **(-1.619)))*PR(IST)**0.4*(1.0+8.5*(GRNO(IST)/
     *RENO(IST)**2)**0.429)*(1.0+4.79*2.71828**(-2.11*DISTM**(-0.237
     1)))*COND/DIN(ITSECT)*12.0
C  SIEDER AND TATE CORRELATION
  222 HST=1.86*(RENO(IST)*PR(IST)*DIST)**(1./3.)*(VISC/VISWL)**0.14
C  BELL AND ABDELMESSIH CORRELATION
      IF(IST.GT.6) GO TO 210
      HANA=(4.364+0.3271*GRNO(IST)**0.25*PR(IST)**0.25
     1 )*COND/DIN(ITSECT)*12.0*(VISC/VISWL)**0.14
      GO TO 211
  210 HANA=(4.364+0.3271*GRNO(IST)**0.25*PR(IST)**0.25+
     1 0.1955E-05*RENO(IST)**1.6*YY(IST)**0.8*
     1 EXP((-0.0725)*DIS(IST)))*(VISC/VISWL)**0.14
     1 *COND/DIN(ITSECT)*12.0
  211 CONTINUE
        HSTATE(IST)=(HAVG(IST)-HMB)/HAVG(IST)*100.0
       HTDBL(IST)=(H(IST)-HMB)/H(IST)*100.0
      HTBRG1(IST)=(HAVG(IST)-HBERG)/HAVG(IST)*100.0
      HTBRG2(IST)=(H(IST)-HBERG)/H(IST)*100.0
      HTHAS1(IST)=(HAVG(IST)-HASN)/HAVG(IST)*100.0
      HTHAS2(IST)=(H(IST)-HASN)/H(IST)*100.0
      HTMOS1(IST)=(HAVG(IST)-HMOS)/HAVG(IST)*100.0
      HTMOS2(IST)=(H(IST)-HMOS)/H(IST)*100.0
      HTST1(IST)=(HAVG(IST)-HST)/HAVG(IST)*100.0
      HTST2(IST)=(H(IST)-HST)/H(IST)*100.0
      HTA1(IST)=(HAVG(IST)-HANA)/HAVG(IST)*100.0
```

```
      HTA2(IST)=(H(IST)-HANA)/H(IST)*100.0
      IF(IST.LT.4.OR.IST.GT.6) GO TO 220
      HTBRG1(IST)=0.0
      HTBRG2(IST)=0.0
      HTHAS1(IST)=0.0
      HTHAS2(IST)=0.0
      HTMOS1(IST)=0.0
      HTMOS2(IST)=0.0
      HTA1(IST)=0.0
      HTA2(IST)=0.0
      HTST1(IST)=0.0
      HTST2(IST)=0.0
      HSTATE(IST)=0.0
      HTDBL(IST)=0.0
         GO TO 220
 230   CONTINUE
         PWP(IST)=0.0
        HSTATE(IST)=0.0
       HTDBL(IST)=0.0
       HTBRG1(IST)=0.0
       HTBRG2(IST)=0.0
       HTHAS1(IST)=0.0
       HTHAS2(IST)=0.0
      HTMOS1(IST)=0.0
      HTMOS2(IST)=0.0
      HTST1(IST)=0.0
      HTST2(IST)=0.0
       HTA1(IST)=0.0
       HTA2(IST)=0.0
220   CONTINUE
        HJ(IST)=1.0/((VISC/VISWL)**0.14)
      IF(IST.GT.6) GO TO 81
          XD(IST)=(LTC(IST))/DIN(ITSECT)
      GO TO 3
  81  IF(ITSECT.GT.1) GO TO 82
      XD(IST)=(LTC(IST)-LTC(6)-3.1416*RBEND(ITSECT)/(30.0*2.0))/DIN(ITS
     1ECT)
      GO TO 3
  82  XD(IST)=(LTC(IST)-LTC(6)-3.1416*RBEND(ITSECT)/4.0)/DIN(ITSECT)
   3  CONTINUE
      WRITE (N,100)
 100  FORMAT(1H1)
      T=(TIN+TOUT)/2.0
      CALL CONDFL(T,MFLUID,X2,COND)
      CALL MEW(T,MFLUID,X2,VISC)
      CALL SPHEAT(T,MFLUID,SPHT)
      PRNO=VISC*SPHT/COND
      REYNO=GW*DIN(ITSECT)/12.0/VISC
      QFLXAV=QIN/(3.1416*DIN(ITSECT)/12.0*(LEND(ITSECT)-3.1416*RBEND(ITS
     1ECT))/12.0)
      IRENO(INO)=REYNO
      PRDNO(INO)=PRNO
      IQFLUX(INO)=QFLXAV
      SIGW=GW/737.33806
      SIQAV=QFLXAV*3.154591
```

```
      WRITE(N,112)NRUN,REYNO,PRNO,GW,SIGW,QFLXAV,SIQAV
  112 FORMAT(33X,15('-')/33X,'RUN NUMBER  ',I3/33X,15('-')//
     6      10X,'AVERAGE REYNOLDS NUMBER          =',E10.3/
     1      10X,'AVERAGE PRANDTL NUMBER           =',E10.3/
     2      10X,'MASS FLUX                        =',E10.3,2X,'LBM/(SQ.FT
     3-HR)',E10.3,2X,'KG.PER.(S.SQ.M.)'/
     4      10X,'AVERAGE HEAT FLUX                =',E10.3,2X,'BTU/(SQ.FT
     5-HR) (',E10.3,2X,'W PER SQ.M.)')
      SIQG=QGEXPT*0.2930711
      SIQBAL=QBALNC*0.2930711
      SIQLOS=QLOSS(ITSECT)*0.2930711
      WRITE(N,789)QGEXPT,SIQG,QBALNC,SIQBAL,QLOSS(ITSECT),SIQLOS,QPCT
  789 FORMAT(10X,'Q=AMP*VOLT                          =',E10.3,2X,'BTU/HR ('
     1,E10.3,'W)'/
     110X,'Q=M*C*(T2-T1)                   =',E10.3,2X,'BTU/HR (',E10.3,
     2'W)'/
     310X,'HEAT LOST                       =',E10.3,2X,'BTU/HR (',E10.3,
     2'W)'/
     510X,'HEAT BALANCE ERROR %            =',E10.3)
      WRITE(N,333)
  333 FORMAT(/,15X,'PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-D
     $EG.F)')
      QGEN(INO)=QGEXPT
      QGAIN(INO)=QBALNC
      QL(INO)=QLOSS(ITSECT)
      QER(INO)=QPCT
      WRITE(N,8888)
 8888 FORMAT(/,13X,'1',6X,'2',6X,'3',6X,'4',6X,'5',6X,'6',6X,'7',6X,'8',
     16X,'9',6X,'10',5X,'11')
      WRITE(N,12)(IPR,(HTCOFF(IST,IPR),IST=1,11),IPR=1,8)
   12 FORMAT(3X,I2,4X,11F7.1)
      WRITE(N,444)
  444 FORMAT(/,15X,'PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)')
      WRITE(N,8888)
      DO 445 IST=1,11
      DO 445 IPR=1,8
      SIHP(IST,IPR)=HTCOFF(IST,IPR)*5.678263
  445 CONTINUE
      WRITE(N,12)(IPR,(SIHP(IST,IPR),IST=1,11),IPR=1,8)
      WRITE(N,101)
  101 FORMAT(/,15X,'AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.
     2F)')
      WRITE(N,8888)
      WRITE(N,13)(HAVG(IST),IST=1,11)
   13 FORMAT(5X,'(H1)',11F7.1)
      WRITE(N,11)(H(I),I=1,11)
   11 FORMAT(5X,'(H2)',11F7.1)
      WRITE(N,8101)
 8101 FORMAT(/,15X,'AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)')
      WRITE(N,8888)
      DO 8102 IST=1,11
      SIHAV(IST)=HAVG(IST)*5.678263
 8102 CONTINUE
      DO 8103 I=1,11
      SIH(I)=H(I)*5.678263
```

```
 8103 CONTINUE
      WRITE(N,13)(SIHAV(IST),IST=1,11)
      WRITE(N,11)(SIH(I),I=1,11)
      DO 33 IST=1,11
      T=TBULK(IST)
      CALL CONDFL(T,MFLUID,X2,COND)
       HLIQ(IST)=HAVG(IST)*DIN(ITSECT)/(12.0*COND)
       HL2(IST)=H(IST)*DIN(ITSECT)/(12.0*COND)
       ERH(IST)=HLIQ(IST)*ERQ(IST)/100.0
        HJ(IST)=HLIQ(IST)*HJ(IST)
   33 CONTINUE
      WRITE(N,102)
  102 FORMAT(/6X,' PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDI
     *CTED HEAT TRANSFER COEFFICIENTS')
      WRITE(N,8888)
      WRITE(N,15)(HSTATE(IST),IST=1,11)
   15 FORMAT(3X,'LIT(1)',11F7.2)
      WRITE(N,14)(HTDBL(IST),IST=1,11)
   14 FORMAT(3X,'LIT(2)',11F7.2)
      WRITE(N,16)(HTBRG1(IST),IST=1,11)
      WRITE(N,227)(HTBRG2(IST),IST=1,11)
      WRITE(N,228)(HTHAS1(IST),IST=1,11)
      WRITE(N,229)(HTHAS2(IST),IST=1,11)
      WRITE(N,224)(HTMOS1(IST),IST=1,11)
      WRITE(N,226)(HTMOS2(IST),IST=1,11)
      WRITE(N,223)(HTST1(IST),IST=1,11)
      WRITE(N,241)(HTST2(IST),IST=1,11)
      WRITE(N,212)(HTA1(IST),IST=1,11)
      WRITE(N,213)(HTA2(IST),IST=1,11)
   16 FORMAT(3X,'LIT(3)',11F7.2)
  227 FORMAT(3X,'LIT(4)',11F7.2)
  228 FORMAT(3X,'LIT(5)',11F7.2)
  229 FORMAT(3X,'LIT(6)',11F7.2)
  224 FORMAT(3X,'LIT(7)',11F7.2)
  226 FORMAT(3X,'LIT(8)',11F7.2)
  223 FORMAT(3X,'LIT(9)',11F7.2)
  241 FORMAT(3X,'LIT(10)',11F7.2)
  212 FORMAT(3X,'COR(11)',11F7.2)
  213 FORMAT(3X,'COR(12)',11F7.2)
 8889 CONTINUE
        WRITE(N,100)
         WRITE(N,170)NRUN
        WRITE(N,162)
  162    FORMAT(1H0,13X,'1',9X,'2',9X,'3',9X,'4',9X,'5',9X,'6',9X,'7',9X
     1,'8',9X,'9',9X,'10',9X,'11')
         WRITE(N,171)(XD(IST),IST=1,11)
         WRITE(N,166)(TBULK(IST),IST=1,11)
         WRITE(N,180)(HJ(IST),IST=1,11)
        WRITE(N,140)(RENO(IST),IST=1,11)
        WRITE(N,150)(PR(IST),IST=1,11)
       WRITE(N,120)(GRNO(IST),IST=1,11)
          WRITE(N,165)(XX(IST),IST=1,11)
         WRITE(N,164)(YY(IST),IST=1,11)
       WRITE(N,130)(GRRE2(IST),IST=1,11)
      WRITE(N,18)(HLIQ(IST),IST=1,11)
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      WRITE(N,9)(HL2(IST),IST=1,11)
    9  FORMAT(1H0,3X,'NU.2  ',11E10.3)
   18  FORMAT(1H0,3X,'NU.1  ',11E10.3)
  120 FORMAT(1H0,3X,'GR.NO.',11E10.3)
  130 FORMAT(1H0,3X,'GR/RE2',11E10.3)
  171 FORMAT(1H0,3X,'X/D   ',11E10.3)
  180 FORMAT(1H0,3X,'JHC   ',11E10.3)
  140 FORMAT(1H0,3X,'RE.NO.',11E10.3)
  150 FORMAT(1H0,3X,'PR.NO.',11E10.3)
  164 FORMAT(1H0,3X,'DE.NO.',11E10.3)
  165 FORMAT(1H0,3X,'HT/HB ',11E10.3)
  166 FORMAT(1H0,3X,'TB,F  ',11E10.3)
      RETURN
      END
C
      SUBROUTINE CORECT
      COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
      COMMON/READ2/TIN,TOUT,TIN2,TOUT1
      COMMON/READ3/TOSURF(11,8),TISURF(11,8)
      COMMON /GEOM1/ XAREA(11,8),R(11  ),L(13,8),LTC(11),LEND(4),DELTAR(
     18),R456(11,8),LIN(4),LOUT(4),LTOTAL(4),ITSECT
      COMMON/OUTT/INO,IRNO(300),ROR(300),IRENO(300),PRDNO(300),IQFLUX(30
     *0),QGEN(300),QGAIN(300),QL(300),QER(300)
      COMMON /THERM1/TSAT(13),TSTART,TEND,QLOSS1(4),QLOSS2(4)
      DIMENSION B(11,8),B1(11,8),A(11,8),A4(11,8)
      REAL*4 LEND,LTOTAL
C  CORRECT INLET AND OUTLET MIXTURE TEMPERATURES
      TIN=TIN+0.2
      TOUT=TOUT+0.1
      TIN2=TIN2+0.2
      TOUT1=TOUT1+0.1
C  READ OUTSIDE SURFACE TEMPERATURES.
      IF(INO.GT.1) GO TO 93
      NN=9
      DO 14 IST=1,11
      READ(NN,13)(B(IST,IPR),IPR=1,8),(A(IST,IPR),IPR=1,8)
   13 FORMAT(7F9.6,F8.5)
   14 CONTINUE
      NN=10
      DO 91 IST=1,11
      READ(NN,13)(B1(IST,IPR),IPR=1,8),(A4(IST,IPR),IPR=1,8)
   91 CONTINUE
C  CORRECT OUTSIDE SURFACE TEMPERATURES.
   93 IF(MFLUID.GT.1) GO TO 92
      DO 15 IST=1,11
      DO 15 IPR=1,8
      TOSURF(IST,IPR)=TOSURF(IST,IPR)+A(IST,IPR)+B(IST,IPR)*(TOSURF(IST,
     1IPR)-TROOM)
   15 CONTINUE
      GO TO 94
   92 DO 95 IST=1,11
      DO 95 IPR=1,8
      TOSURF(IST,IPR)=TOSURF(IST,IPR)+A4(IST,IPR)+B1(IST,IPR)*
     1(TOSURF(IST,IPR)-TROOM)
   95 CONTINUE
```

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C  CALCULATION OF VOLUMETRIC FLOW RATE IN GPM.
   94 IF (MFLUID.GT.1)GO TO 16
      VFLOW=0.017*SET-0.1028E-03*SET**2+0.8314E-06*SET**3
      GO TO 17
   16 IF(MFLUID.EQ.3) GO TO 18
      VFLOW=SET*0.013422-0.009061
      GO TO 17
   18 VFLOW=SET*0.056659+0.07651
C  CALCULATION OF MASS FLOW RATE IN LBM/HR
   17 CALL DENS(TBATH,MFLUID,X2,ROW)
      RMFL=VFLOW*0.13368*60.0*ROW
C  CALCULATION OF HEAT LOSS FROM TEST SECTION IN BTU/HR.
C    BASED ON INLET TEMPERATURE.
      T1=(TIN+TOUT1)/2.0
      CALL SPHEAT(T1,MFLUID,SPHT)
      QLOST1=RMFL*SPHT*(TIN-TOUT1)
C    BASED ON EXIT TEMPERATURE.
      T2=(TIN2+TOUT)/2.0
      CALL SPHEAT(T2,MFLUID,SPHT)
      QLOST2=RMFL*SPHT*(TIN2-TOUT)
C  CALCULATION OF HEAT LOSS FROM HEAT TRANSFER LOOP IN BTU/HR.
   12 CONTINUE
      QLOSS1(ITSECT)=QLOST1*LEND(ITSECT)/LTOTAL(ITSECT)
      QLOSS2(ITSECT)=QLOST2*LEND(ITSECT)/LTOTAL(ITSECT)
      RETURN
      END
C
      SUBROUTINE ERSTVT
      COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
      COMMON/ERESIS/RSVTY(11,8)
      COMMON /TEMP1/ TWALL(11,8),AMPS(11,8),RESIS(11,8),POWERS(13)
     1,TPOWER
      COMMON/GEOM2/RBEND(4),DOUT(4),DIN(4),PHI,DPHI,DELR,NODES,NSLICE
      IF(NRUN.LT.200)GO TO 321
C  ELECTTRICAL RESISTIVITY OF STAINLESS STEEL IN OHMS-SQIN/IN
      DO 12 ISL=1,NODES
      DO 12 IPR=1,8
      RSVTY(ISL,IPR)=.21675E-5 + 0.11492E-8*TWALL(ISL,IPR)   +0.70965E-12
     @ *TWALL(ISL,IPR)*TWALL(ISL,IPR) -0.84327E-17*TWALL(ISL,IPR)**3
      RSVTY(ISL,IPR)=RSVTY(ISL,IPR)*12.0
   12 CONTINUE
      GO TO 323
C  ELECTRICAL RESISTIVITY OF INCONEL IN OHMS-SQIN/IN.
  321 DO 322 ISL=1,NODES
      DO 322 IPR=1,8
      RSVTY(ISL,IPR)=(40.40292+2.515385E-3*TWALL(ISL,IPR))*1.0E-6
  322 CONTINUE
  323 RETURN
      END
C
      SUBROUTINE THCOND
      COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
      COMMON/TCOND/CONDK(11,9)
      COMMON /TEMP1/ TWALL(11,8),AMPS(11,8),RESIS(11,8),POWERS(13)
     1,TPOWER
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      COMMON/GEOM2/RBEND(4),DOUT(4),DIN(4),PHI,DPHI,DELR,NODES,NSLICE
      IF(NRUN.LT.200)GO TO 313
C  THERMAL CONDUCTIVITY OF STAINLESS STEEL IN BTU/(HR-FT-DEGF)
      DO 12 ISL=1,NODES
      DO 12 IPR=1,8
      CONDK(ISL,IPR)=7.8034+0.51691E-2*TWALL(ISL,IPR)-0.88501E-6*
     @TWALL(ISL,IPR)*TWALL(ISL,IPR)
   12 CONTINUE
      GO TO 316
C  THERMAL CONDUCTIVITY OF INCONEL IN BTU/(HR-FT-DEGF).
  313 DO 315 ISL=1,NODES
      DO 315 IPR=1,8
      CONDK(ISL,IPR)=8.313769+3.846154E-3*TWALL(ISL,IPR)
  315 CONTINUE
  316 RETURN
      END
C
      SUBROUTINE GEOM
C  THE GEOMETRY OF THE 4 U-TUBES AND THE LOCATION OF THE THERMOCOUPLES
      COMMON/READ1/TBATH,TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,SET,NRUN
      COMMON /GEOM1/ XAREA(11,8),R(11  ),L(13,8),LTC(11),LEND(4),DELTAR(
     18),R456(11,8),LIN(4),LOUT(4),LTOTAL(4),ITSECT
      COMMON/GEOM2/RBEND(4),DOUT(4),DIN(4),PHI,DPHI,DELR,NODES,NSLICE
      COMMON /MAIN1/ IST,KOUNT
      DIMENSION THICK1(6),THICK2(6),THICK3(6),THICK4(6),THICK5(6)
     1,THICK6(6),THICK7(6),THICK8(6)
      REAL * 4 L,LTC,LEND,LIN,LOUT,LTOTAL
      NSLICE=10
      LIN(1)=12.0+11.5
      LIN(2)=19.8+11.5
      LIN(3)=28.75+11.5
      LIN(4)=29.125+11.5
      LOUT(1)=12.0+13.25
      LOUT(2)=19.75+5.5
      LOUT(3)=28.75+8.00
      LOUT(4)=29.25+8.00
C  RADII OF THE U-BENDS
      RBEND(4)=1.5
      RBEND(3)=2.375
      RBEND(2)=9.75
      RBEND(1)=4.75
C  OUTSIDE DIAMETERS OF THE U-TUBES
      DOUT(1)=0.875
      DOUT(2)=0.875
      DOUT(3)=0.75
      DOUT(4)=0.750
C  INSIDE DIAMETERS OF THE U-TUBES
      DIN(1)=0.769
      DIN(2)=0.769
      DIN(3)=0.62
      DIN(4)=0.62
      IF(NRUN.LT.200) GO TO 371
      THICK=0.065
      GO TO 372
  371 THICK=0.053
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  372 NODES= NSLICE + 1
      PHI = 2*3.1416
      DPHI=PHI/8.0
      PIE14 = 1.0/4.0*3.1416
      PIE38 = 3.0/8.0*3.1416
      IF(NRUN.LT.200)GO TO 781
      DO 11 IPR=1,8
      L(1,IPR )=8.0
      L(2,IPR )=8.0
      L(3,IPR) =8.0
      L(7,IPR) =8.0
      L(8,IPR )=8.0
      L(9,IPR )=8.0
      L(10,IPR)=8.0
      L(11,IPR)=8.0
   11 CONTINUE
      GO TO 788
  781 DO 782 IPR=1,8
      L(1,IPR)=8.0
      L(2,IPR)=6.0
      L(3,IPR)=3.0
      L(7,IPR)=3.0
      L(8,IPR)=6.0
      L(9,IPR)=6.0
      L(10,IPR)=6.0
      L(11,IPR)=8.0
  782 CONTINUE
C  VARIABLE TUBE WALL THICKNESS AT THE U-BEND DUE TO BENDING
  788 IF(NRUN.GT.100) GO TO 111
      ITSECT=1
      THICK5(5)=0.058
      THICK3(5)=0.053
      THICK1(5)=0.0488
      GO TO 10
  111 IF(NRUN.GT.200) GO TO 112
      ITSECT=2
      THICK5(5)=0.0553
      THICK3(5)=0.053
      THICK1(5)=0.0509
      GO TO 10
  112 IF (NRUN.GT.300) GO TO 101
      ITSECT=3
        THICK1(5)=0.0568
        THICK3(5)=0.065
        THICK5(5)=0.076
        GO TO 10
  101 ITSECT=4
      THICK1(5)=0.0529
      THICK3(5)=0.065
      THICK5(5)=0.0842
   10 CONTINUE
      THICK2(5)=(THICK1(5)+THICK3(5))/2.0
      THICK4(5)=(THICK5(5)+THICK3(5))/2.0
      THICK6(5) = THICK4(5)
      THICK7(5) = THICK3(5)
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      THICK8(5) = THICK2(5)
      IF(ITSECT.EQ.1) GO TO 785
      THICK1(4) =  (THICK1(5)+THICK)/2.0
      THICK2(4) =  (THICK2(5)+THICK)/2.0
      THICK3(4) =  (THICK3(5)+THICK)/2.0
      THICK4(4) =  (THICK4(5)+THICK)/2.0
      THICK5(4) =  (THICK5(5)+THICK)/2.0
      THICK6(4) =  (THICK6(5)+THICK)/2.0
      THICK7(4) =  (THICK7(5)+THICK)/2.0
      THICK8(4) =  (THICK8(5)+THICK)/2.0
      THICK1(6) =   THICK1(4)
      THICK2(6) =   THICK2(4)
      THICK3(6) =   THICK3(4)
      THICK4(6) =   THICK4(4)
      THICK5(6) =   THICK5(4)
      THICK6(6) =   THICK6(4)
      THICK7(6)=THICK7(4)
      THICK8(6) =   THICK8(4)
      L(4,1) = (RBEND(ITSECT)-DIN(ITSECT)/2.0-THICK1(4)/2.0)*PIE38
      L(4,3)=RBEND(ITSECT)*PIE38
      L(4,5) = (RBEND(ITSECT)+DIN(ITSECT)/2.0+THICK5(4)/2.0)*PIE38
      L(4,2)=(L(4,1)+L(4,3))/2.0
      L(4,4)=(L(4,3)+L(4,5))/2.0
      L(4,6)=L(4,4)
      L(4,7)=L(4,3)
      L(4,8)=L(4,2)
      IF(NRUN.LT.200)GO TO 783
          DO 20 IPR=1,8
          L(12,IPR)=84.0
      L(13,IPR)=68.0
   20 CONTINUE
      GO TO 787
  783 IF(NRUN.LT.100) GO TO 785
      DO 784 IPR=1,8
      L(12,IPR)=28.0
      L(13,IPR)=16.0
  784 CONTINUE
      GO TO 787
  785 L(5,1)=(RBEND(ITSECT)-DIN(ITSECT)/2.0-THICK1(5)/2.0)*PIE14*2.0
      L(5,3)=RBEND(ITSECT)*PIE14*2.0
      L(5,5)=(RBEND(ITSECT)+DIN(ITSECT)/2.0+THICK5(5)/2.0)*PIE14*2.0
      L(5,2)=(L(5,1)+L(5,3))/2.0
      L(5,4)=(L(5,3)+L(5,5))/2.0
      L(5,6)=L(5,4)
      L(5,7)=L(5,3)
      L(5,8)=L(5,2)
      THICK1(6)=0.053/15.0+THICK1(5)*14.0/15.0
      THICK2(6)=0.053/15.0+THICK2(5)*14.0/15.0
      THICK3(6)=0.053/15.0+THICK3(5)*14.0/15.0
      THICK4(6)=0.053/15.0+THICK4(5)*14.0/15.0
      THICK5(6)=0.053/15.0+THICK5(5)*14.0/15.0
      THICK6(6)=0.053/15.0+THICK6(5)*14.0/15.0
      THICK7(6)=0.053/15.0+THICK7(5)*14.0/15.0
      THICK8(6)=0.053/15.0+THICK8(5)*14.0/15.0
      DO 786 IPR=1,8
```

```
      L(4,IPR)=2.25
      L(6,IPR)=L(5,IPR)
      L(12,IPR)=39.0
      L(13,IPR)=29.25
  786 CONTINUE
       GO TO 25
  787 DO 21 IPR=1,8
      L(5,IPR)=L(4,IPR)/PIE38*PIE14
      L(6,IPR)=L(4,IPR)
   21 CONTINUE
C  THERMOCOUPLE LOCATIONS
      IF(NRUN.LT.200) GO TO 25
      IF(NRUN.GT.300) GO TO 36
      LTC(1)=47.99
      LTC(2)=LTC(1) + 45.0
      LTC(3)=LTC(2) +12.8
      GO TO 28
   25 LTC(1)=20.75
      LTC(2)=LTC(1)+20.0
      IF(NRUN.GT.100) GO TO 26
      LTC(3)=LTC(2)+11.0
      LTC(4)=LTC(3)+5.75
      LTC(5)=LTC(4)+1.25+3.1416*RBEND(ITSECT)/2.0
      LTC(6)=LTC(5)+3.1416*29.0/30.0*RBEND(ITSECT)/2.0
      LTC(7)=LTC(6)+1.5+3.1416*RBEND(ITSECT)/(30.0*2.0)
      GO TO 27
   26 LTC(3)=LTC(2)+3.7
      LTC(4)=LTC(3) +3.1416*RBEND(ITSECT)/4.0+0.75
      LTC(5)=LTC(4) +3.1416*RBEND(ITSECT)/4.0
      LTC(6)=LTC (5)+3.1416*RBEND(ITSECT)/4.0
      LTC(7)=LTC(6) +3.1416*RBEND(ITSECT)/4.0+1.5
   27 LTC(8)=LTC(7)+5.25
      LTC(9)=LTC(8)+7.75
      LTC(10)=LTC(9)+17.75
      IF(NRUN.GT.100) GO TO 29
      LTC(11)=LTC(10)+19.75
      LEND(ITSECT)=LTC(11)+6.75
      GO TO 33
   29 LTC(11)=LTC(10)+10.5
      LEND(ITSECT)=LTC(11)+2.5
      GO TO 33
   28 LTC(4)=LTC(3) +3.1416*RBEND(ITSECT)/4.0+2.35
      LTC(5)=LTC(4) +3.1416*RBEND(ITSECT)/4.0
      LTC(6)=LTC (5)+3.1416*RBEND(ITSECT)/4.0
      LTC(7)=LTC(6) +3.1416*RBEND(ITSECT)/4.0+1.94
      LTC(8)=LTC(7) +13.2
      LTC(9)=LTC(8) +15.0
      LTC(10)=LTC(9) +30.0
      LTC(11)=LTC(10)+30.0
      GO TO 32
   36 LTC(1)=50.25
      LTC(2)=LTC(1)+45.0
      LTC(3)=LTC(2)+11.0
      LTC(4)=LTC(3) +3.1416*RBEND(ITSECT)/4.0+1.75
      LTC(5)=LTC(4) +3.1416*RBEND(ITSECT)/4.0
```

```
      LTC(6)=LTC (5)+3.1416*RBEND(ITSECT)/4.0
      LTC(7)=LTC(6) +3.1416*RBEND(ITSECT)/4.0+1.625
      LTC(8)=LTC(7) +13.0
      LTC(9)=LTC(8) +15.0
      LTC(10)=LTC(9) +30.0
      LTC(11)=LTC(10)+30.0
   32 LEND(ITSECT) = LTC(11)+18.25
   33 LTOTAL(ITSECT)=LOUT(ITSECT)+LIN(ITSECT)+LEND(ITSECT)
      RETURN
C
      ENTRY GEOMST
      DELR = (DOUT(ITSECT)-DIN(ITSECT))/2.0/NSLICE
      R(1) = DOUT(ITSECT)/2.0
      DO 103  I=1,NSLICE
  103 R(I+1)=R(I)-DELR
      DO 104 IPR=1,8
      XAREA (1,IPR)=(R(1)-DELR/4.0)*DPHI*DELR/2.0
  104 XAREA(NODES,IPR)=(R(NODES)+DELR/4.0) *DPHI*DELR/2.0
          DO 105 I=2,NSLICE
      DO 105 IPR=1,8
  105 XAREA (I,IPR)= R(I)*DPHI*DELR
          RETURN
C
      ENTRY GEOMBT
      DELTAR(1) = THICK1(IST)/NSLICE
          DELTAR(2) = THICK2(IST)/NSLICE
          DELTAR(3) = THICK3(IST)/NSLICE
      DELTAR(4) = THICK4(IST)/NSLICE
      DELTAR(5) = THICK5(IST)/NSLICE
      DELTAR(6) = THICK6(IST)/NSLICE
      DELTAR(7) = THICK7(IST)/NSLICE
      DELTAR(8) = THICK8(IST)/NSLICE
          DO 202 IPR=1,8
  202 R456(NODES,IPR) = DIN(ITSECT)/2.0
      DO 203 ISL=1,NSLICE
          DO 203 IPR=1,8
  203 R456(NODES-ISL,IPR)=R456(NODES-ISL+1,IPR)+DELTAR(IPR)
      DO 204 IPR=1,8
      XAREA(1,IPR) = (R456(1,IPR)-DELTAR(IPR)/4.0)*DPHI*DELTAR(IPR)/2.0
  204 XAREA(NODES,IPR)=(R456(NODES,IPR)+DELTAR(IPR)/4.0)*DPHI*DELTAR(IPR
     1)/2.0
      DO 205 ISL=2,NSLICE
      DO 205 IPR=1,8
  205 XAREA(ISL,IPR)=R456(ISL,IPR)*DPHI*DELTAR(IPR)
      RETURN
      END
C
C  SPECIFIC HEAT IN BTU/(LBM-DEGF).
      SUBROUTINE SPHEAT(T,MFLUID,SPHT)
      IF(MFLUID.GT.1)GO TO 305
      SPHT=1.01881-0.4802E-3*T+0.3274E-5*T**2-0.604E-8*T**3
      GO TO 306
  305 SPHT=5.18956E-1 +6.2290E-4*T
  306 RETURN
      END
```

```
C
C  DENSITY IN LBM/CU.FT.
      SUBROUTINE DENS(TF,MFLUID,X,ROW)
      T=(TF-32.0)/1.8
      IF(MFLUID.GT.1) GO TO 301
      ROWSI=999.986+0.01890*T-0.005886*T**2+0.1548E-7*T**3
      ROW=ROWSI*0.062428
      GO TO 302
  301 A=1.0004-1.2379E-4*T-2.9837E-6*T**2
      B=1.7659E-1*X-9.9189E-4*X*T+2.4614E-6*X*T**2
      C=4.9214E-2*X**2-4.1024E-4*X**2*T+9.5278E-8*X**2*T**2
      ROW=(A+B+C)*62.428
  302 RETURN
      END
C
C  VISCOSITY IN LBM/(HR.FT.).
      SUBROUTINE MEW(TF,MFLUID,X,VISC)
      T=(TF-32.0)/1.8
      IF(MFLUID.GT.1) GO TO 331
      VISC=2.419*1.0019*10.0**((1.3272*(20.0-T)-0.001053*(20-T)
     1**2)/(T+105.0))
      GO TO 332
  331 A1=5.5164E-1+2.6492*X+8.2935E-1*X**2
      A2=(4.8136E-3*X**2-3.1496E-2*X-2.7633E-2)*T
      A3=(6.0629E-17+2.2389E-15*X+5.879E-16*X**2)**0.25*T**2
      VISC=2.718282**(A1+A2+A3)*2.419
  332 RETURN
      END
C
C THERMAL CONDUCTIVITY OF THE TEST FLUID IN BTU/(HR.FT.DEGF)
      SUBROUTINE CONDFL(TF,MFLUID,X,COND)
      T=(TF-32.0)/1.8
      CONW=0.56276+1.874E-3*T-6.8E-6*T**2
      IF(MFLUID.GT.1) GO TO 341
      COND=CONW/1.729577
      GO TO 342
  341 CN=0.6635-0.3698*X-8.85E-4*T
      CONEG=0.24511+1.755E-4*T-8.52E-7*T**2
      CONSI=(1.0-X)*CONW+X*CONEG-CN*(CONEG-CONW)*(1.0-X)*X
      COND=CONSI/1.729577
  342 RETURN
      END
C
C  COEFFICIENT OF THERMAL EXPANSION 1/DEGF.
      SUBROUTINE BET(TF,MFLUID,ROW,BETA)
      T=(TF-32.0)/1.8
      IF(MFLUID.GT.1)GO TO 351
      BETA=(0.0189-0.011772*T+0.4644E-3*T**2)*62.428E-3/(ROW*1.8)
      GO TO 352
  351  BETA=ROW*(6.2796E-4 +9.2444E-7*(T-65.)*2 +3.057E-9*(T-65.)**2*3.)
     % /62.428/1.8
  352  RETURN
      END
$ENTRY
```

APPENDIX I

SAMPLE CALCULATION

Run 24 is presented as a sample calculation. For run 24, the test fluid was water, the rotameter setting was 26 %, and the input current and voltage drop were 305 amperes and 2.805 volts, respectively. The experimental data for this run are given in appendix G. The sample calculations given below follow the procedure presented in Chapter V. All calculations in this section are performed in U.S. units and reported in both U.S. and SI units. All calculations are based on the following assumptions:

1. Peripheral and radial wall conduction exist.
2. Axial conduction is negligible.
3. Steady state exists.
4. There is heat loss from the test section to the surroundings.

Calculation of the Heat Balance

<u>Rate of Heat Input</u>

$$\begin{aligned}\text{Power input} &= (F)(I)(V)\\ &= (3.41214)(305\text{A})(2.805\text{V})\\ &= 2919\ \text{Btu/hr}\\ &= 856\ \text{W}\end{aligned}$$

Volumetric flow rate from Appendix C

$$= (0.017)(26)-(1.028\text{x}10^{-4})(26)^2 +$$

$$(8.314\text{x}10^{-7})(26)^3$$

= 0.3871 gpm

Density of water at bath temperature (85.9 F = 303.1 K) from Appendix E

$= 995.3 \text{ kg/m}^3$

$= 62.13 \text{ lbm/ft}^3$

Mass flow rate

= (volumetric flow rate)(density of water at bath temp.)

$= (0.3871\text{gpm})(62.13\text{lbm/ft}^3)(0.1337\text{ft}^3/\text{gal})(60\text{min/hr})$

= 192.9 lbm/hr

= 0.0243 kg/s

Correction for inlet and exit bulk temperatures according to the calibration in Appendix A:

When the test fluid is circulated at a constant temperature equal to the inlet temperature:

Inlet temperature

= 85.7+0.2

= 85.9 F

= 303.1 K

Exit temperature

= 85.6+0.1

= 85.7 F

= 303 K

When the test fluid is circulated at a constant bath temperature equal to the exit bulk temperature

Inlet temperature

= 101.4+0.2

= 101.6 F

= 311.8 K

Exit temperature

= 101.1+0.1

= 276.7 K

Specific heat of water at 85.8 F from Appendix E

= 0.9979 Btu/lbm.F

= 0.2378 kJ/kg.K

Specific heat of water at 101.4 F from Appendix E

= 0.9975 Btu/lbm.F

= 0.2383 kJ/kg.K

Heat loss when the fluid is circulated at a constant temperature equal to the inlet temperature

$= (\dot{m})(C_p)(T_i - T_o)$

= (192.9)(0.9979)(85.9-85.7)

= 38.5 Btu/hr

= 11.28 W

Heat loss when the fluid is circulated at a constant temperature equal to the exit temperature

= (192.9)(0.9975)(101.6-101.2)

= 76.97 Btu/hr

= 22.56 W

Heat lost from the test section

= (38.5+76.97)/2

= 57.74 Btu/hr

= 16.92 W

Rate of heat input

= power input - heat lost

= 2919-57

= 2862 Btu/hr

= 840 W

Rate of Heat Output

Specific heat of water at the arithmetic mean of the inlet and exit temperatures (93.6 F = 307.4 K) from Appendix E

= 0.9976 Btu/lbm.F

= 0.2383 kJ/kg.K

Rate of heat output

$= (\dot{m})(C_p)(T_o - T_i)$

= (192.9)(0.9976)(101.2-85.9)

= 2944 Btu/hr

= 863 W

Heat Balance

heat balance = (100)(heat input - heat output) / heat input

= (100)(2862-2944)/2862

= -2.9 %

Calculation of the Local Inside Wall Temperature and the Local Inside Wall Heat Flux

The computer program in Appendix H corrects the outside wall temperature according to the calibration given in Appendix B. For example, the temperature at station 1, position 1 is corrected as follows:

$$T_{correct}=T_{read}+A+B(T_{read}-T_{room})$$
$$= 100.2+0.156983+(0.00455)(100.2-81.6)$$
$$= 100.4\ F$$
$$= 311.2\ K$$

Then the computer program solves numerically for the local inside wall temperature and the local inside heat flux. The derivation of the equations used in the numerical solution is in Appendix F. Since the numerical solution is a converging trial-and-error solution and is very tedious, it will not be attempted here. Typical results of this run are given in Appendix J.

Calculation of the Local Heat Transfer Coefficient

For station 1, position 1 the local heat transfer coifficient is calculated according to equation (V.4)

$$h = 1474/(100.1-88.6)$$
$$= 128\ Btu/ft.^2\ hr.F$$
$$= 728\ W/m.^2\ K$$

Similarly, the local heat transfer coefficient is calculated for the rest of the thermocouple locations.

The average peripheral heat transfer coefficient at station 1 is given from equation (V.5)

$$h = (1/8)\{1474/(100.1-88.6)+1485.3/(100.8-88.6)+1583.2/(102.5-88.6)+1643/(107.1-88.6)+700.5/(115.7-88.6)+1127/(111.5-88.6)+1849/(102.1-88.6)+1507.7/(100.4-88.6)\}$$

$$= 99\ \text{Btu/hr.ft.}^2\ \text{F}$$

$$= 546\ \text{W/m.}^2\ \text{K}$$

The average peripheral heat transfer coefficient at station 1 is given from equation (V.6)

$$h = \{(1474+1485.3+1583.2+1643+700.5+1127+1849+1507.7)/8\}/\{(100.1+100.8+102.5+107.1+115.7+111.5+102.1+100.4)/8-88.6\}$$

$$= 87\ \text{Btu/hr.ft.}^2\ \text{F}$$

$$= 480\ \text{W/m.}^2\ \text{K}$$

APPENDIX J

CALCULATED RESULTS

Run Number	Test Fluid	Test Section
1- 25	water	A
26-100	ethylene glycol	A
101-200	ethylene glycol	B
201-300	ethylene glycol	C
301-400	ethylene glycol	D

Only those calculated results which were referred to are presented here. The rest of the experimental data are available from

Professor Kenneth J. Bell
School of Chemical
Engineering

or Edmon Low Library
or Amanie N. Abdelmessih

Oklahoma State University
Stillwater, Oklahoma 74078

RUN NUMBER 22

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	100.6	100.3	100.9	101.4	89.3	106.0	116.0	119.9	124.1	130.0	139.7
2	101.3	101.5	102.7	103.1	89.4	104.9	117.2	113.5	117.4	123.1	131.6
3	103.9	105.3	107.5	107.6	89.1	102.2	113.4	105.7	110.0	113.1	114.9
4	110.3	115.3	116.8	117.3	88.9	98.4	108.3	102.2	106.8	108.3	110.3
5	118.8	124.4	127.9	128.0	89.4	95.3	106.6	101.4	105.6	106.4	108.6
6	114.7	117.5	120.1	122.8	89.1	98.3	107.9	100.9	106.9	107.7	111.8
7	103.8	105.3	106.5	107.9	88.8	102.5	114.8	105.8	110.2	113.0	115.1
8	100.9	101.0	102.0	102.2	89.2	104.7	116.3	115.5	118.0	122.4	122.9

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	38.1	38.0	38.3	38.5	31.8	41.1	46.7	48.8	51.2	54.4	59.8
2	38.5	38.6	39.3	39.5	31.9	40.5	47.3	45.3	47.5	50.6	55.3
3	39.9	40.7	42.0	42.0	31.7	39.0	45.2	40.9	43.3	45.1	46.0
4	43.5	46.3	47.1	47.4	31.6	36.9	42.4	39.0	41.6	42.4	43.5
5	48.2	51.3	53.3	53.3	31.9	35.1	41.4	38.5	40.9	41.4	42.6
6	45.9	47.5	49.0	50.4	31.7	36.8	42.2	38.3	41.6	42.1	44.3
7	39.9	40.7	41.4	42.2	31.6	39.2	46.0	41.0	43.4	45.0	46.2
8	38.3	38.4	38.9	39.0	31.8	40.4	46.8	46.4	47.8	50.2	50.5

MASS FLOW RATE = 152.3 LBM/HR (0.01919 KG.PER.S)

RUN NUMBER 22

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	100.2	99.9	100.5	101.0	89.3	106.0	115.6	119.7	123.9	129.8	139.7
2	100.9	101.1	102.3	102.7	89.4	104.9	116.9	113.2	117.1	122.7	131.3
3	103.4	104.9	107.1	107.2	89.1	102.2	113.1	105.3	109.6	112.7	114.4
4	109.9	115.0	116.4	116.9	88.9	98.3	107.9	101.8	106.5	107.9	109.9
5	118.6	124.3	127.8	127.9	89.4	95.2	106.2	101.0	105.2	106.0	108.2
6	114.4	117.2	119.8	122.6	89.1	98.3	107.5	100.4	106.6	107.3	111.4
7	103.3	104.8	106.0	107.4	88.8	102.5	114.6	105.4	109.8	112.6	114.7
8	100.6	100.6	101.6	101.8	89.2	104.7	116.0	115.3	117.6	122.0	122.5

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	37.9	37.7	38.1	38.3	31.8	41.1	46.5	48.7	51.1	54.4	59.8
2	38.3	38.4	39.1	39.3	31.9	40.5	47.2	45.1	47.3	50.4	55.2
3	39.7	40.5	41.7	41.8	31.7	39.0	45.1	40.7	43.1	44.8	45.8
4	43.3	46.1	46.9	47.2	31.6	36.9	42.2	38.8	41.4	42.2	43.3
5	48.1	51.3	53.2	53.3	31.9	35.1	41.2	38.3	40.6	41.1	42.4
6	45.8	47.3	48.8	50.3	31.7	36.8	42.0	38.0	41.4	41.8	44.1
7	39.6	40.5	41.1	41.9	31.6	39.2	45.9	40.8	43.2	44.8	46.0
8	38.1	38.1	38.7	38.8	31.8	40.4	46.6	46.3	47.6	50.0	50.3

```
                    INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

       1       2       3       4       5       6       7       8       9      10      11

1   1472.3  1514.0  1572.7  1555.3     0.3  -124.7  1496.3   791.5   670.6   563.8   -42.7
2   1510.2  1560.8  1581.2  1565.2   -16.0   -87.5  1120.4  1324.4  1362.2  1238.0   919.1
3   1629.2  1765.0  1664.3  1702.0     3.1   -62.2  1326.5  1658.2  1657.9  1703.6  2110.1
4   1531.7  1357.4  1521.9  1478.3    41.6    43.9  1607.5  1560.1  1513.2  1579.0  1576.6
5    680.4   480.7   309.0   483.8   -45.3   380.0  1583.6  1423.1  1560.6  1585.2  1682.5
6   1015.3  1111.1  1074.4   849.4     3.9    72.1  1726.1  1719.8  1513.6  1642.8  1419.0
7   1875.5  1863.8  1943.1  1945.0    35.9  -114.8  1093.7  1685.6  1670.6  1639.2  1666.2
8   1546.0  1609.4  1594.7  1682.6   -11.7   -45.9  1306.7  1096.9  1312.3  1312.9  1935.5

                    INSIDE SURFACES HEAT FLUXES W PER SQ.M.

       1       2       3       4       5       6       7       8       9      10      11

1   4644.9  4776.5  4961.6  4906.9     0.9  -393.3  4720.7  2497.0  2115.8  1778.9  -134.7
2   4764.6  4924.1  4988.6  4938.0   -50.5  -276.2  3534.9  4178.3  4297.6  3905.8  2899.6
3   5140.1  5568.3  5250.6  5369.5     9.8  -196.3  4184.9  5231.6  5230.4  5374.8  6657.3
4   4832.4  4282.6  4801.3  4663.8   131.3   138.5  5071.5  4922.1  4774.1  4981.7  4974.1
5   2146.6  1516.4   975.0  1526.2  -142.8  1198.9  4996.1  4489.9  4923.5  5001.0  5308.1
6   3203.2  3505.4  3389.6  2679.7    12.3   227.4  5445.8  5425.8  4775.4  5182.9  4477.0
7   5916.9  5880.2  6130.3  6136.4   113.2  -362.2  3450.5  5317.9  5270.5  5171.4  5256.6
8   4877.5  5077.5  5031.1  5308.3   -37.0  -144.9  4122.4  3460.6  4140.1  4142.1  6106.4

                    BULK FLUID TEMPERATURE      - DEGREES F

       1       2       3       4       5       6       7       8       9      10      11

     88.7    92.0    93.7    94.6    94.8    94.8    95.1    95.9    97.2   100.0   103.2

                    BULK FLUID TEMPERATURE      - DEGREES C

       1       2       3       4       5       6       7       8       9      10      11

     31.5    33.3    34.3    34.8    34.9    34.9    35.1    35.5    36.2    37.8    39.6

                  CORRECTED OUTLET TEMPERATURE =   104.3DEG F (     40.2DEG C)
                  CORRECTED INLET TEMPERATURE  =    85.4DEG F (     29.7DEG C)
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                       ---------------
                       RUN NUMBER   22
                       ---------------

AVERAGE REYNOLDS NUMBER        = 0.174E 04
AVERAGE PRANDTL NUMBER         = 0.485E 01
MASS FLUX                      = 0.472E 05  LBM/(SQ.FT-HR) 0.640E 02  KG.PER.(S.SQ.M.)
AVERAGE HEAT FLUX              = 0.146E 04  BTU/(SQ.FT-HR) ( 0.459E 04  W PER SQ.M.)
Q=AMP*VOLT                     = 0.292E 04  BTU/HR ( 0.857E 03W)
Q=M*C*(T2-T1)                  = 0.287E 04  BTU/HR ( 0.841E 03W)
HEAT LOST                      = 0.532E 02  BTU/HR ( 0.156E 02W)
HEAT BALANCE ERROR %           = 0.794E-02

     PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

        1      2      3      4      5      6      7      8      9     10     11

1     128.6  189.6  231.0  244.7   -0.0  -11.2   72.9   33.4   25.1   18.9   -1.2
2     123.9  171.2  184.2  193.2    2.9   -8.7   51.3   76.8   68.4   54.5   32.7
3     110.7  136.7  124.4  135.3   -0.5   -8.5   73.6  177.9  133.9  134.5  189.2
4      72.4   58.9   67.1   66.5   -7.0   12.6  125.8  266.4  163.0  200.9  236.4
5      22.8   14.9    9.1   14.6    8.3 1199.4  143.0  280.4  195.5  263.8  335.4
6      39.5   44.1   41.1   30.4   -0.7   21.1  138.9  382.3  161.4  226.5  172.8
7     128.7  144.6  158.5  152.3   -5.9  -14.9   56.2  178.5  132.7  130.1  144.9
8     130.8  185.3  201.2  234.6    2.1   -4.7   62.6   56.7   64.1   59.7  100.5

     PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

        1      2      3      4      5      6      7      8      9     10     11

1     730.2 1076.9 1311.4 1389.7   -0.3  -63.4  413.8  189.4  142.5  107.4   -6.6
2     703.6  971.9 1046.1 1097.2   16.6  -49.4  291.4  436.1  388.1  309.5  185.7
3     628.8  776.4  706.4  768.3   -3.1  -48.0  417.8 1010.0  760.0  763.8 1074.3
4     411.2  334.7  381.0  377.3  -39.7   71.3  714.3 1512.4  925.8 1140.9 1342.3
5     129.4   84.5   51.4   82.6   46.9 6810.7  811.8 1592.1 1110.0 1497.7 1904.7
6     224.4  250.2  233.6  172.6   -3.8  119.8  788.7 2171.0  916.7 1286.2  981.1
7     731.0  821.0  900.2  864.8  -33.8  -84.9  319.0 1013.4  753.8  738.9  822.8
8     742.8 1052.2 1142.7 1332.3   11.7  -26.5  355.4  322.2  364.1  338.8  570.7
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           AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

         1       2       3       4       5       6       7       8       9      10      11

 (H1)   94.7   118.2   127.1   134.0    -0.1   148.1    90.5   181.5   118.0   136.1   151.3
 (H2)   79.6    85.2    85.4    86.4    -0.3     1.1    82.2   119.2    94.9    93.2    89.1

           AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

         1       2       3       4       5       6       7       8       9      10      11

 (H1)  537.7   670.9   721.6   760.6    -0.7   841.2   514.0  1030.8   670.1   772.9   859.4
 (H2)  452.1   483.9   484.9   490.4    -1.5     6.5   466.6   676.6   538.6   529.1   506.1

   PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

         1       2       3       4       5       6       7       8       9      10      11

LIT(1)  23.42   36.51   38.89     0.00    0.00    0.00   10.22   61.72   33.16   38.49   40.41
LIT(2)   8.92   11.97    9.07     0.00    0.00    0.00    1.11   41.68   16.84   10.13   -1.18
LIT(3)  18.40   32.75   35.72     0.00    0.00    0.00    6.50   58.68   29.83   36.23   39.24
LIT(4)   2.94    6.75    4.35     0.00    0.00    0.00   -2.99   37.05   12.69    6.84   -3.17
LIT(5)  29.33   55.24   61.51     0.00    0.00    0.00  -85.12   45.19   35.45   57.76   67.56
LIT(6)  15.95   37.93   42.73     0.00    0.00    0.00-103.91   16.49   19.69   38.29   44.92
LIT(7)  31.67   35.35   35.06     0.00    0.00    0.00  -52.39   53.95   28.47   32.98   32.42
LIT(8)  18.73   10.36    3.36     0.00    0.00    0.00  -67.85   29.85   11.00    2.09  -14.75
LIT(9)  86.27   91.25   92.49     0.00    0.00    0.00   65.70   89.72   87.70   91.84   93.75
LIT(10)   83.68   87.87   88.83   0.00    0.00    0.00   62.21   84.34   84.70   88.08   89.38
COR(11)   17.06   30.76   33.88   0.00    0.00    0.00-231.23  -17.60  -29.30   24.00   36.11
COR(12)    1.36    4.00    1.60   0.00    0.00    0.00-264.85  -79.17  -60.88  -11.03   -8.48
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                                 ---------------
                                 RUN NUMBER   22
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          1         2         3         4         5         6         7         8         9         10         11

X/D     0.270E 02 0.530E 02 0.673E 02 0.748E 02 0.861E 02 0.955E 02 0.195E 01 0.878E 01 0.189E 02 0.419E 02 0.676E 02
TB,F    0.887E 02 0.920E 02 0.937E 02 0.946E 02 0.948E 02 0.948E 02 0.951E 02 0.959E 02 0.972E 02 0.100E 03 0.103E 03
JHC     0.166E 02 0.207E 02 0.222E 02 0.234E 02-0.212E-01 0.262E 02 0.158E 02 0.319E 02 0.206E 02 0.237E 02 0.262E 02
RE.NO.  0.162E 04 0.168E 04 0.171E 04 0.173E 04 0.174E 04 0.174E 04 0.174E 04 0.176E 04 0.178E 04 0.184E 04 0.190E 04
PR.NO.  0.524E 01 0.503E 01 0.492E 01 0.486E 01 0.485E 01 0.485E 01 0.484E 01 0.479E 01 0.471E 01 0.455E 01 0.439E 01
GR.NO.  0.131E 06 0.171E 06 0.201E 06 0.216E 06-0.772E 05 0.901E 05 0.236E 06 0.175E 06 0.244E 06 0.312E 06 0.411E 06
HT/HB   0.177E 00 0.784E-01 0.392E-01 0.595E-01-0.593E-02-0.931E-02 0.510E 00 0.119E 00 0.128E 00 0.717E-01-0.349E-02
DE.NO.  0.461E 03 0.478E 03 0.488E 03 0.493E 03 0.494E 03 0.494E 03 0.495E 03 0.500E 03 0.507E 03 0.523E 03 0.541E 03
GR/RE2  0.498E-01 0.605E-01 0.685E-01 0.721E-01-0.256E-01 0.299E-01 0.780E-01 0.568E-01 0.770E-01 0.923E-01 0.114E 00
NU.1    0.171E 02 0.212E 02 0.228E 02 0.240E 02-0.211E-01 0.265E 02 0.162E 02 0.324E 02 0.210E 02 0.242E 02 0.268E 02
NU.2    0.143E 02 0.153E 02 0.153E 02 0.154E 02-0.460E-01 0.204E 00 0.147E 02 0.213E 02 0.169E 02 0.166E 02 0.158E 02

         RUN NO  BR/TR      RE      PR    AVG HEAT FLUX   HEAT GENERATED   HEAT GAINED   HEAT  LOST   H.B.% ERROR
            22  12.354    1735     4.9        1456              2924.4         2871.0        53.2          0.01
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                                    ---------------
                                    RUN NUMBER   23
                                    ---------------

                     CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

         1        2        3        4        5        6        7        8        9       10       11

  1    100.4    101.4    103.0    104.2     98.1    113.7    122.0    127.0    132.3    151.5    165.8
  2    101.2    103.0    105.4    106.7     97.6    112.6    120.6    120.7    124.9    139.3    157.7
  3    104.8    108.1    111.8    112.5     96.3    108.4    113.1    112.6    115.5    123.3    126.5
  4    112.8    120.3    122.7    123.8     95.2    101.7    109.6    109.6    111.3    116.3    121.8
  5    123.2    129.8    134.5    135.0     95.3     99.8    108.6    108.7    110.2    113.8    120.3
  6    118.4    122.6    126.4    129.8     95.3    100.9    109.3    109.1    111.3    116.2    122.4
  7    104.8    108.3    110.7    112.9     96.3    109.4    115.0    113.1    116.1    123.4    127.4
  8    100.9    102.4    104.7    105.5     97.9    113.6    121.3    122.6    125.6    138.2    148.4

                     CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

         1        2        3        4        5        6        7        8        9       10       11

  1     38.0     38.6     39.5     40.1     36.7     45.4     50.0     52.8     55.7     66.4     74.3
  2     38.4     39.4     40.8     41.5     36.5     44.8     49.2     49.3     51.6     59.6     69.8
  3     40.4     42.3     44.3     44.7     35.7     42.5     45.1     44.8     46.4     50.7     52.5
  4     44.9     49.1     50.4     51.0     35.1     38.7     43.1     43.1     44.0     46.8     49.9
  5     50.7     54.3     56.9     57.2     35.2     37.6     42.5     42.6     43.4     45.5     49.1
  6     48.0     50.3     52.4     54.3     35.2     38.3     42.9     42.8     44.1     46.8     50.2
  7     40.4     42.4     43.7     44.9     35.7     43.0     46.1     45.1     46.7     50.8     53.0
  8     38.3     39.1     40.4     40.9     36.6     45.3     49.6     50.3     52.0     59.0     64.7

              MASS FLOW RATE          =     95.0  LBM/HR  ( 0.01197  KG.PER.S)
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                               ---------------
                               RUN NUMBER   23
                               ---------------

                  INSIDE SURFACE TEMPERATURES - DEGREES F

         1        2        3        4        5        6        7        8        9       10       11

 1     100.1    101.0    102.6    103.8     98.1    113.7    121.7    126.8    132.1    151.5    165.8
 2     100.8    102.6    105.0    106.3     97.6    112.7    120.3    120.4    124.5    139.0    157.7
 3     104.3    107.7    111.4    112.1     96.3    108.5    112.7    112.2    115.1    122.8    125.8
 4     112.4    120.0    122.3    123.5     95.2    101.6    109.3    109.2    110.9    115.9    121.4
 5     123.0    129.7    134.4    134.9     95.3     99.7    108.2    108.4    109.8    113.4    119.9
 6     118.2    122.4    126.2    129.6     95.3    100.8    108.9    108.7    110.9    115.8    122.0
 7     104.3    107.8    110.2    112.4     96.3    109.5    114.7    112.7    115.7    123.0    126.9
 8     100.5    102.0    104.3    105.1     98.0    113.7    121.0    122.3    125.3    137.9    148.1


                  INSIDE SURFACE TEMPERATURES - DEGREES C

         1        2        3        4        5        6        7        8        9       10       11

 1      37.8     38.4     39.2     39.9     36.7     45.4     49.9     52.7     55.6     66.4     74.3
 2      38.2     39.2     40.6     41.3     36.5     44.8     49.1     49.1     51.4     59.5     69.8
 3      40.2     42.0     44.1     44.5     35.7     42.5     44.9     44.5     46.2     50.5     52.1
 4      44.7     48.9     50.2     50.8     35.1     38.7     42.9     42.9     43.8     46.6     49.6
 5      50.6     54.3     56.9     57.2     35.2     37.6     42.3     42.4     43.2     45.2     48.9
 6      47.9     50.2     52.3     54.2     35.2     38.2     42.7     42.6     43.8     46.6     50.0
 7      40.2     42.1     43.4     44.7     35.7     43.0     45.9     44.8     46.5     50.6     52.7
 8      38.1     38.9     40.2     40.6     36.6     45.4     49.4     50.2     51.8     58.8     64.5
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                  INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

       1       2       3       4       5       6       7       8       9      10      11

 1  1450.0  1524.1  1612.1  1600.4   -28.8   -56.2  1253.6   759.6   561.1  -106.0  -110.5
 2  1540.1  1584.8  1612.5  1572.3   -46.7  -173.6  1033.5  1278.5  1272.9  1163.3    31.8
 3  1639.4  1789.6  1638.1  1694.3    14.0  -144.1  1608.4  1673.9  1674.7  1908.9  2939.2
 4  1517.0  1226.1  1439.8  1381.3    73.1   291.4  1520.9  1506.3  1563.0  1642.0  1566.0
 5   504.6   415.1   225.5   427.1    -5.1   185.8  1481.2  1447.3  1507.1  1659.4  1583.6
 6   873.0   971.1   943.0   705.4    63.7   445.3  1668.2  1593.3  1589.5  1658.2  1549.4
 7  1947.4  1868.2  1950.2  1937.4    32.8  -248.9  1409.8  1692.9  1653.9  1821.1  2314.2
 8  1569.9  1661.8  1620.8  1724.4   -78.6  -225.8  1064.6  1090.5  1220.8  1303.4  1181.2

                  INSIDE SURFACES HEAT FLUXES W PER SQ.M.

       1       2       3       4       5       6       7       8       9      10      11

 1  4574.6  4808.6  5086.0  5049.1   -90.9  -177.3  3954.9  2396.4  1770.2  -334.3  -348.6
 2  4858.9  4999.8  5087.4  4960.6  -147.2  -547.8  3260.6  4033.4  4015.8  3670.3   100.3
 3  5172.0  5646.0  5168.1  5345.5    44.1  -454.5  5074.5  5280.9  5283.5  6022.5  9272.9
 4  4786.0  3868.2  4542.5  4357.8   230.8   919.5  4798.2  4752.2  4931.2  5180.5  4940.7
 5  1591.8  1309.5   711.4  1347.5   -16.2   586.3  4673.1  4566.2  4754.7  5235.2  4996.0
 6  2754.3  3063.6  2975.0  2225.6   200.9  1405.0  5263.0  5026.9  5014.6  5231.4  4888.1
 7  6143.7  5893.8  6152.8  6112.3   103.6  -785.3  4447.6  5341.1  5217.9  5745.3  7301.0
 8  4952.7  5242.8  5113.5  5440.2  -248.1  -712.5  3358.7  3440.6  3851.7  4112.0  3726.5

                  BULK FLUID TEMPERATURE      - DEGREES F

       1       2       3       4       5       6       7       8       9      10      11

     91.0    96.1    99.0   100.4   100.7   100.7   101.1   102.5   104.5   109.0   114.1

                  BULK FLUID TEMPERATURE      - DEGREES C

       1       2       3       4       5       6       7       8       9      10      11

     32.8    35.6    37.2    38.0    38.2    38.2    38.4    39.2    40.3    42.8    45.6

                CORRECTED OUTLET TEMPERATURE =   115.8DEG F (    46.6DEG C)
                CORRECTED INLET TEMPERATURE  =    85.7DEG F (    29.8DEG C)
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                              ---------------
                              RUN NUMBER   23
                              ---------------

   AVERAGE REYNOLDS NUMBER        = 0.115E 04
   AVERAGE PRANDTL NUMBER         = 0.452E 01
   MASS FLUX                      = 0.295E 05  LBM/(SQ.FT-HR) 0.399E 02  KG.PER.(S.SQ.M.)
   AVERAGE HEAT FLUX              = 0.145E 04  BTU/(SQ.FT-HR) ( 0.458E 04  W PER SQ.M.)
   Q=AMP*VOLT                     = 0.286E 04  BTU/HR ( 0.838E 03W)
   Q=M*C*(T2-T1)                  = 0.285E 04  BTU/HR ( 0.836E 03W)
   HEAT LOST                      =-0.473E 01  BTU/HR (-0.139E 01W)
   HEAT BALANCE ERROR %           = 0.416E 00

        PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

             1      2      3      4      5      6      7      8      9     10     11

  1      159.8  311.2  436.5  475.9   10.8   -4.3   60.9   31.2   20.3   -2.5   -2.1
  2      157.2  246.3  266.6  267.8   15.0  -14.6   53.9   71.4   63.4   38.7    0.7
  3      123.0  155.2  131.4  144.8   -3.1  -18.7  138.5  172.7  157.3  138.1  251.5
  4       70.8   51.3   61.6   59.9  -13.1  346.0  187.3  224.8  244.0  238.7  214.6
  5       15.8   12.4    6.4   12.4    0.9 -180.0  209.3  246.2  282.4  375.4  269.5
  6       32.2   37.0   34.7   24.1  -11.612880.0  215.0  257.2  246.1  243.4  194.5
  7      146.7  159.5  173.6  161.4   -7.4  -28.5  104.0  165.3  147.2  130.1  180.6
  8      164.7  284.4  300.6  368.1   28.2  -17.5   53.6   55.0   58.6   45.1   34.7

        PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

             1      2      3      4      5      6      7      8      9     10     11

  1      907.3 1767.1 2478.8 2702.4   61.2  -24.7  345.6  177.3  115.1  -14.2  -12.1
  2      892.4 1398.8 1513.7 1520.8   85.0  -82.7  305.8  405.6  359.9  220.0    4.1
  3      698.2  881.1  746.2  821.9  -17.8 -106.2  786.6  980.4  893.2  784.4 1428.2
  4      401.9  291.5  349.5  340.1  -74.5 1964.5 1063.7 1276.2 1385.7 1355.6 1218.5
  5       89.5   70.3   36.1   70.3    5.4-1021.9 1188.3 1397.7 1603.8 2131.8 1530.3
  6      182.6  210.1  196.8  137.1  -66.173135.9 1220.8 1460.7 1397.5 1382.3 1104.6
  7      832.8  905.9  985.9  916.4  -42.2 -161.7  590.7  938.8  836.0  739.0 1025.3
  8      935.1 1614.7 1707.0 2090.1  159.9  -99.3  304.3  312.2  332.7  256.3  196.9
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           AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

          1       2       3       4       5       6       7       8       9      10      11

   (H1)  108.7   157.2   176.4   189.3     2.4  1620.3   127.8   153.0   152.4   150.9   143.0
   (H2)   81.4    89.0    88.4    88.8    -0.7     1.4   102.4   109.6   101.6    75.0    63.2

           AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

          1       2       3       4       5       6       7       8       9      10      11

   (H1)  617.5   892.4  1001.8  1074.9    13.9  9200.5   725.7   868.6   865.5   856.9   812.0
   (H2)  462.3   505.2   502.0   504.0    -4.1     7.8   581.7   622.2   577.0   426.0   358.7

    PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

          1       2       3       4       5       6       7       8       9      10      11

 LIT(1)  31.43   49.72   52.70    0.00    0.00    0.00   36.62   47.41   43.62   29.71   13.45
 LIT(2)   8.40   11.18    5.61    0.00    0.00    0.00   20.93   26.59   15.43  -41.39  -95.93
 LIT(3)  27.28   47.25   50.94    0.00    0.00    0.00   33.72   44.88   41.77   31.03   18.29
 LIT(4)   2.87    6.82    2.10    0.00    0.00    0.00   17.31   23.05   12.66  -38.75  -84.98
 LIT(5)  47.86   71.10   76.00    0.00    0.00    0.00  -11.83   44.68   57.65   67.17   69.89
 LIT(6)  30.35   48.95   52.11    0.00    0.00    0.00  -39.52   22.78   36.47   33.96   31.84
 LIT(7)  39.72   48.72   49.34    0.00    0.00    0.00   -6.83   38.43   38.95   23.61    2.21
 LIT(8)  19.48    9.43   -1.09    0.00    0.00    0.00  -33.29   14.05    8.43  -53.66-121.36
 LIT(9)  89.81   94.40   95.40    0.00    0.00    0.00   79.41   89.60   91.91   93.72   94.33
 LIT(10)  86.39   90.11   90.82    0.00    0.00    0.00   74.31   85.48   87.86   87.36   87.18
 COR(11)  25.52   45.31   49.34    0.00    0.00    0.00  -32.90    8.26   22.08   27.44   19.79
 COR(12)   0.51    3.39   -1.09    0.00    0.00    0.00  -65.81  -28.07  -16.88  -45.97  -81.57
```

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                             ---------------
                             RUN NUMBER   23
                             ---------------

            1          2          3          4          5          6          7          8          9         10         11

X/D      0.270E 02 0.530E 02 0.673E 02 0.748E 02 0.861E 02 0.955E 02 0.195E 01 0.878E 01 0.189E 02 0.419E 02 0.676E 02
TB,F     0.910E 02 0.961E 02 0.990E 02 0.100E 03 0.101E 03 0.101E 03 0.101E 03 0.102E 03 0.104E 03 0.109E 03 0.114E 03
JHC      0.190E 02 0.274E 02 0.307E 02 0.329E 02 0.436E 00 0.285E 03 0.222E 02 0.266E 02 0.264E 02 0.259E 02 0.243E 02
RE.NO.   0.104E 04 0.110E 04 0.113E 04 0.115E 04 0.115E 04 0.115E 04 0.116E 04 0.118E 04 0.120E 04 0.126E 04 0.132E 04
PR.NO.   0.509E 01 0.477E 01 0.461E 01 0.453E 01 0.452E 01 0.452E 01 0.450E 01 0.442E 01 0.432E 01 0.411E 01 0.388E 01
GR.NO.   0.160E 06 0.234E 06 0.296E 06 0.330E 06-0.923E 05 0.147E 06 0.301E 06 0.311E 06 0.385E 06 0.702E 06 0.113E 07
HT/HB    0.986E-01 0.398E-01 0.146E-01 0.260E-01 0.114E 02 0.241E-01 0.291E 00 0.127E 00 0.718E-01-0.664E-02-0.793E-02
DE.NO.   0.295E 03 0.313E 03 0.322E 03 0.327E 03 0.329E 03 0.329E 03 0.330E 03 0.335E 03 0.342E 03 0.358E 03 0.376E 03
GR/RE2   0.148E 00 0.194E 00 0.231E 00 0.249E 00-0.692E-01 0.110E 00 0.224E 00 0.225E 00 0.267E 00 0.444E 00 0.645E 00
NU.1     0.195E 02 0.281E 02 0.314E 02 0.336E 02 0.433E 00 0.288E 03 0.227E 02 0.271E 02 0.269E 02 0.265E 02 0.250E 02
NU.2     0.146E 02 0.159E 02 0.157E 02 0.158E 02-0.127E 00 0.243E 00 0.182E 02 0.194E 02 0.180E 02 0.132E 02 0.110E 02

              RUN NO  BR/TR       RE       PR     AVG HEAT FLUX    HEAT GENERATED    HEAT GAINED    HEAT  LOST    H.B.% ERROR

                  23  12.354     1154      4.5        1452                2859.5          2852.4         -4.7          0.42
```

RUN NUMBER 24

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	100.4	100.8	101.1	101.5	88.0	99.8	113.1	117.8	121.7	126.6	132.2
2	101.1	101.8	102.5	102.7	88.0	99.2	112.4	111.3	115.4	120.5	124.0
3	102.9	104.7	106.3	106.4	87.9	96.6	110.8	105.7	107.4	110.9	112.2
4	107.5	113.3	114.3	114.7	88.0	94.1	108.9	102.6	104.7	106.6	109.2
5	115.9	121.6	124.8	125.0	88.9	92.7	106.0	101.1	103.7	105.2	109.2
6	111.8	115.0	117.4	120.1	88.5	94.1	108.5	103.6	105.2	105.8	110.7
7	102.6	104.5	105.3	106.9	88.0	96.4	109.5	106.4	108.3	110.6	112.5
8	100.7	100.9	101.9	102.0	88.2	98.4	110.7	113.3	115.8	119.4	116.5

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	38.0	38.2	38.4	38.6	31.1	37.7	45.1	47.7	49.9	52.6	55.7
2	38.4	38.8	39.2	39.3	31.1	37.3	44.7	44.0	46.3	49.2	51.1
3	39.4	40.4	41.3	41.4	31.1	35.9	43.8	40.9	41.9	43.8	44.6
4	41.9	45.2	45.7	46.0	31.1	34.5	42.7	39.2	40.4	41.4	42.9
5	46.6	49.8	51.6	51.7	31.6	33.7	41.1	38.4	39.9	40.7	42.9
6	44.3	46.1	47.4	48.9	31.4	34.5	42.5	39.8	40.7	41.0	43.7
7	39.2	40.3	40.7	41.6	31.1	35.8	43.1	41.4	42.4	43.7	44.7
8	38.2	38.3	38.8	38.9	31.2	36.9	43.7	45.2	46.5	48.6	47.0

MASS FLOW RATE = 192.9 LBM/HR (0.02431 KG.PER.S)

RUN NUMBER 24

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	100.1	100.4	100.7	101.1	88.0	99.8	112.8	117.6	121.6	126.5	132.2
2	100.7	101.4	102.2	102.4	88.0	99.2	112.1	110.9	115.1	120.2	123.7
3	102.5	104.3	105.9	106.0	87.9	96.6	110.5	105.3	107.0	110.5	111.8
4	107.1	113.0	113.9	114.4	88.0	94.1	108.6	102.2	104.3	106.2	108.9
5	115.7	121.5	124.7	124.9	88.9	92.7	105.6	100.7	103.3	104.8	108.9
6	111.5	114.7	117.1	119.9	88.5	94.0	108.1	103.2	104.8	105.4	110.3
7	102.1	104.1	104.9	106.4	88.0	96.4	109.2	106.0	107.9	110.2	112.1
8	100.4	100.5	101.5	101.6	88.2	98.4	110.4	113.0	115.4	119.1	116.0

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	37.8	38.0	38.2	38.4	31.1	37.7	44.9	47.6	49.8	52.5	55.7
2	38.2	38.5	39.0	39.1	31.1	37.3	44.5	43.8	46.2	49.0	50.9
3	39.1	40.1	41.1	41.1	31.1	35.9	43.6	40.7	41.7	43.6	44.3
4	41.7	45.0	45.5	45.8	31.1	34.5	42.6	39.0	40.2	41.2	42.7
5	46.5	49.7	51.5	51.6	31.6	33.7	40.9	38.2	39.6	40.5	42.7
6	44.2	46.0	47.3	48.8	31.4	34.5	42.3	39.6	40.5	40.8	43.5
7	38.9	40.1	40.5	41.3	31.1	35.8	42.9	41.1	42.1	43.4	44.5
8	38.0	38.1	38.6	38.7	31.2	36.9	43.5	45.0	46.3	48.4	46.7

```
                    INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

      1      2      3      4      5      6      7      8      9     10     11

1  1460.4 1467.6 1535.1 1505.8   12.3 -105.7 1233.2  767.1  695.5  634.3   18.2
2  1471.7 1520.1 1539.5 1548.3   -5.1 -108.0 1353.6 1464.0 1314.9 1211.4 1210.9
3  1569.9 1736.6 1648.6 1671.2   11.0   13.7 1395.0 1553.3 1711.2 1712.6 1915.5
4  1629.4 1390.7 1562.6 1525.2   48.6   59.4 1344.2 1502.4 1505.1 1575.6 1575.8
5   686.5  549.1  365.8  531.6  -79.6  173.5 1717.3 1628.6 1548.4 1521.8 1492.1
6  1113.7 1185.6 1145.6  929.7    0.6   58.5 1325.6 1432.2 1498.0 1646.9 1431.7
7  1834.7 1803.6 1903.0 1888.7   34.9  -16.7 1418.6 1639.0 1663.7 1642.8 1532.0
8  1494.3 1607.5 1558.8 1659.7  -14.4  -28.9 1472.8 1274.4 1323.2 1317.0 2087.4

                    INSIDE SURFACES HEAT FLUXES W PER SQ.M.

      1      2      3      4      5      6      7      8      9     10     11

1  4607.5 4630.2 4843.0 4750.8   38.9 -333.4 3890.7 2420.1 2194.1 2001.0   57.6
2  4643.1 4795.7 4857.0 4884.7  -16.0 -340.7 4270.4 4618.6 4148.4 3821.8 3820.2
3  4952.8 5478.9 5201.3 5272.5   34.8   43.1 4401.2 4900.5 5398.8 5403.0 6043.3
4  5140.5 4387.4 4929.9 4811.8  153.4  187.5 4240.9 4739.8 4748.4 4971.0 4971.4
5  2165.8 1732.4 1154.2 1677.0 -251.3  547.5 5417.9 5138.0 4885.2 4801.0 4707.5
6  3513.5 3740.3 3614.3 2933.2    1.9  184.7 4182.1 4518.5 4726.1 5196.0 4516.9
7  5788.4 5690.1 6003.9 5958.6  110.2  -52.8 4475.5 5170.8 5248.8 5182.9 4833.3
8  4714.5 5071.4 4917.8 5236.2  -45.4  -91.3 4646.5 4020.7 4174.5 4155.1 6585.4

                    BULK FLUID TEMPERATURE      - DEGREES F

      1      2      3      4      5      6      7      8      9     10     11

     88.6   91.2   92.6   93.4   93.5   93.5   93.7   94.4   95.4   97.7  100.3

                    BULK FLUID TEMPERATURE      - DEGREES C

      1      2      3      4      5      6      7      8      9     10     11

     31.4   32.9   33.7   34.1   34.2   34.2   34.3   34.7   35.2   36.5   38.0

                  CORRECTED OUTLET TEMPERATURE =   101.2DEG F (    38.4DEG C)
                  CORRECTED INLET TEMPERATURE  =    85.9DEG F (    29.9DEG C)
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                         ---------------
                         RUN NUMBER   24
                         ---------------

          AVERAGE REYNOLDS NUMBER        = 0.217E 04
          AVERAGE PRANDTL NUMBER         = 0.493E 01
          MASS FLUX                      = 0.598E 05  LBM/(SQ.FT-HR) 0.811E 02  KG.PER.(S.SQ.M.)
          AVERAGE HEAT FLUX              = 0.145E 04  BTU/(SQ.FT-HR) ( 0.458E 04  W PER SQ.M.)
          Q=AMP*VOLT                     = 0.292E 04  BTU/HR ( 0.856E 03W)
          Q=M*C*(T2-T1)                  = 0.294E 04  BTU/HR ( 0.863E 03W)
          HEAT LOST                      = 0.577E 02  BTU/HR ( 0.169E 02W)
          HEAT BALANCE ERROR %           =-0.291E 01

               PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

             1      2      3      4      5      6      7      8      9     10     11

  1        127.2  158.8  190.0  194.8   -2.2  -16.9   64.7   33.0   26.6   22.1    0.6
  2        121.5  149.4  161.7  172.7    0.9  -19.1   73.8   88.7   66.9   53.9   51.9
  3        113.2  133.1  124.4  132.2   -2.0    4.5   83.5  143.2  147.8  134.3  167.5
  4         88.3   63.9   73.6   72.7   -8.8  102.7   90.4  193.3  168.9  186.6  184.5
  5         25.3   18.2   11.4   16.9   17.2 -196.8  144.8  257.8  195.7  215.3  174.9
  6         48.6   50.4   46.8   35.1   -0.1  118.3   92.0  163.1  159.5  215.3  143.5
  7        135.9  139.8  155.4  144.9   -6.3   -5.9   92.0  141.2  134.0  132.1  129.8
  8        127.1  172.4  175.9  202.8    2.7   -6.0   88.5   68.6   66.2   61.7  132.8

               PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

             1      2      3      4      5      6      7      8      9     10     11

  1        722.5  901.7 1079.1 1106.2  -12.6  -95.9  367.6  187.7  151.2  125.4    3.3
  2        689.7  848.5  918.0  980.7    5.2 -108.6  418.9  503.9  380.0  306.3  294.6
  3        643.0  755.7  706.2  750.5  -11.2   25.8  474.1  813.0  839.3  762.8  950.9
  4        501.1  362.7  417.8  412.9  -49.9  583.1  513.3 1097.6  959.1 1059.4 1047.7
  5        143.9  103.1   64.8   95.9   97.6-1117.7  822.0 1463.8 1111.3 1222.8  993.3
  6        276.1  286.1  265.9  199.4   -0.7  671.7  522.6  926.4  905.5 1222.7  814.9
  7        771.8  793.8  882.5  822.6  -35.8  -33.6  522.2  802.0  761.1  750.2  736.8
  8        721.8  978.9  998.6 1151.3   15.1  -34.1  502.5  389.8  375.9  350.3  753.9
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          AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

         1       2       3       4       5       6       7       8       9      10      11

 (H1)   98.4   110.7   117.4   121.5     0.2    -2.4    91.2   136.1   120.7   127.7   123.2
 (H2)   85.9    86.5    86.8    87.0    -0.2     2.0    88.4   108.7    97.1    93.2    92.9

          AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

         1       2       3       4       5       6       7       8       9      10      11

 (H1)  558.7   628.8   666.6   689.9     1.0   -13.7   517.9   773.0   685.4   725.0   699.4
 (H2)  487.5   491.0   492.8   493.8    -1.1    11.4   502.2   617.2   551.4   529.1   527.6

   PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

         1       2       3       4       5       6       7       8       9      10      11

LIT(1)  29.34   33.79   35.79   0.00    0.00    0.00   16.28   48.38   37.46   37.05   31.61
LIT(2)  19.01   15.20   13.15   0.00    0.00    0.00   13.67   35.35   22.26   13.74    9.35
LIT(3)  24.02   29.54   32.04   0.00    0.00    0.00   11.60   44.46   33.74   34.18   29.20
LIT(4)  12.91    9.75    8.07   0.00    0.00    0.00    8.84   30.44   17.63    9.82    6.15
LIT(5)  26.14   48.25   54.98   0.00    0.00    0.00  -98.19   20.54   31.43   51.15   57.01
LIT(6)  15.34   33.71   39.10   0.00    0.00    0.00-104.37    0.48   14.76   33.06   43.01
LIT(7)  33.68   30.49   29.89   0.00    0.00    0.00  -50.76   36.50   31.14   30.21   21.01
LIT(8)  23.99   10.97    5.16   0.00    0.00    0.00  -55.46   20.47   14.39    4.38   -4.70
LIT(9)  85.73   89.90   91.21   0.00    0.00    0.00   63.19   85.13   86.98   90.58   91.68
LIT(10)   83.65   87.06   88.10   0.00    0.00    0.00   62.04   81.38   83.82   87.09   88.97
COR(11)   21.55   27.22   29.82   0.00    0.00    0.00-388.58-124.10  -61.72   14.11   23.60
COR(12)   10.08    6.78    5.06   0.00    0.00    0.00-403.82-180.66-101.05  -17.68   -1.27
```

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                        ---------------
                        RUN NUMBER   24
                        ---------------

                1         2         3         4         5         6         7         8         9        10        11

X/D     0.270E 02 0.530E 02 0.673E 02 0.748E 02 0.861E 02 0.955E 02 0.195E 01 0.878E 01 0.189E 02 0.419E 02 0.676E 02
TB,F    0.886E 02 0.912E 02 0.926E 02 0.934E 02 0.935E 02 0.935E 02 0.937E 02 0.944E 02 0.954E 02 0.977E 02 0.100E 03
JHC     0.173E 02 0.194E 02 0.205E 02 0.212E 02 0.313E-01-0.429E 00 0.159E 02 0.239E 02 0.211E 02 0.223E 02 0.214E 02
RE.NO.  0.205E 04 0.211E 04 0.215E 04 0.216E 04 0.217E 04 0.217E 04 0.217E 04 0.219E 04 0.221E 04 0.227E 04 0.233E 04
PR.NO.  0.525E 01 0.508E 01 0.499E 01 0.494E 01 0.493E 01 0.493E 01 0.492E 01 0.488E 01 0.482E 01 0.468E 01 0.454E 01
GR.NO.  0.119E 06 0.156E 06 0.179E 06 0.192E 06-0.644E 05 0.342E 05 0.195E 06 0.169E 06 0.206E 06 0.261E 06 0.319E 06
HT/HB   0.199E 00 0.114E 00 0.600E-01 0.867E-01-0.129E 00 0.858E-01 0.447E 00 0.128E 00 0.136E 00 0.103E 00 0.327E-02
DE.NO.  0.583E 03 0.601E 03 0.610E 03 0.616E 03 0.617E 03 0.617E 03 0.618E 03 0.623E 03 0.630E 03 0.646E 03 0.664E 03
GR/RE2  0.284E-01 0.351E-01 0.389E-01 0.409E-01-0.137E-01 0.727E-02 0.413E-01 0.352E-01 0.421E-01 0.505E-01 0.586E-01
NU.1    0.177E 02 0.199E 02 0.210E 02 0.218E 02 0.310E-01-0.431E 00 0.163E 02 0.244E 02 0.216E 02 0.227E 02 0.219E 02
NU.2    0.155E 02 0.155E 02 0.156E 02 0.156E 02-0.350E-01 0.361E 00 0.158E 02 0.194E 02 0.173E 02 0.166E 02 0.165E 02

          RUN NO  BR/TR      RE      PR    AVG HEAT FLUX   HEAT GENERATED   HEAT GAINED   HEAT  LOST   H.B.% ERROR
              24  12.354   2167     4.9        1451                2919.2        2944.6        57.7         -2.91
```

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                              ---------------
                              RUN NUMBER   25
                              ---------------

                       CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

         1       2       3       4       5       6       7       8       9      10      11

 1    102.4   102.3   103.0   103.5    92.1   110.7   121.4   120.7   128.1   143.8   162.1
 2    103.1   103.6   104.9   105.6    92.2   109.1   121.1   116.7   121.0   130.9   153.6
 3    105.9   107.7   110.3   110.5    91.9   106.2   113.8   108.2   112.8   116.9   120.0
 4    113.8   118.8   120.2   121.1    91.6   101.6   109.8   106.5   110.3   111.4   115.0
 5    124.0   128.2   131.8   132.1    92.0    98.2   109.3   105.8   110.5   109.6   113.8
 6    119.2   121.1   123.8   127.0    91.8   101.7   109.2   105.4   110.4   111.0   115.8
 7    106.0   107.9   109.2   110.8    91.6   107.2   115.7   108.2   113.4   116.9   121.3
 8    102.9   103.0   104.2   104.6    92.0   109.6   120.8   119.2   121.6   130.3   143.9

                       CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

         1       2       3       4       5       6       7       8       9      10      11

 1     39.1    39.0    39.4    39.7    33.4    43.7    49.7    49.3    53.4    62.1    72.3
 2     39.5    39.8    40.5    40.9    33.4    42.8    49.5    47.1    49.5    55.0    67.5
 3     41.1    42.1    43.5    43.6    33.3    41.2    45.4    42.3    44.9    47.2    48.9
 4     45.4    48.2    49.0    49.5    33.1    38.6    43.2    41.4    43.5    44.1    46.1
 5     51.1    53.5    55.5    55.6    33.3    36.8    42.9    41.0    43.6    43.1    45.5
 6     48.4    49.5    51.0    52.8    33.2    38.7    42.9    40.8    43.5    43.9    46.6
 7     41.1    42.1    42.9    43.8    33.1    41.8    46.5    42.3    45.2    47.2    49.6
 8     39.4    39.4    40.1    40.3    33.3    43.1    49.3    48.4    49.8    54.6    62.2

                 MASS FLOW RATE          =   138.3  LBM/HR  ( 0.01742  KG.PER.S)
```

RUN NUMBER 25

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	102.0	101.9	102.6	103.1	92.1	110.7	121.1	120.4	128.0	143.8	162.2
2	102.7	103.2	104.5	105.2	92.2	109.1	120.8	116.4	120.7	130.6	153.6
3	105.5	107.3	109.9	110.1	91.9	106.2	113.4	107.7	112.4	116.5	119.3
4	113.4	118.5	119.8	120.7	91.6	101.5	109.4	106.1	109.9	111.0	114.6
5	123.9	128.1	131.8	132.0	92.0	98.1	108.9	105.5	110.1	109.2	113.5
6	119.0	120.8	123.5	126.8	91.8	101.7	108.8	105.0	110.0	110.6	115.4
7	105.5	107.4	108.7	110.3	91.6	107.3	115.4	107.7	113.0	116.5	120.7
8	102.5	102.6	103.9	104.2	92.0	109.6	120.5	119.0	121.3	130.0	143.6

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	38.9	38.8	39.2	39.5	33.4	43.7	49.5	49.1	53.3	62.1	72.3
2	39.3	39.5	40.3	40.7	33.4	42.9	49.3	46.9	49.3	54.8	67.5
3	40.9	41.8	43.3	43.4	33.3	41.2	45.2	42.1	44.7	46.9	48.5
4	45.2	48.1	48.8	49.3	33.1	38.6	43.0	41.2	43.3	43.9	45.9
5	51.0	53.4	55.4	55.6	33.3	36.7	42.7	40.8	43.4	42.9	45.3
6	48.3	49.3	50.9	52.7	33.2	38.7	42.7	40.6	43.3	43.7	46.3
7	40.9	41.9	42.6	43.5	33.1	41.8	46.3	42.1	45.0	46.9	49.3
8	39.1	39.2	39.9	40.1	33.3	43.1	49.2	48.3	49.6	54.4	62.0

```
                  INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

      1      2      3      4      5      6      7      8      9     10     11

1  1478.6 1523.6 1592.3 1591.0    0.2 -138.4 1357.3 1095.8  622.0 -128.8 -162.8
2  1526.4 1569.3 1603.9 1571.3  -18.7  -73.0 1005.4 1141.4 1344.1 1349.6  -41.6
3  1695.2 1810.5 1671.1 1730.2    3.0  -98.0 1601.9 1805.6 1739.1 1901.4 3077.8
4  1552.8 1314.7 1513.5 1443.9   44.1   75.2 1607.5 1463.3 1561.3 1622.3 1625.8
5   535.5  446.2  265.8  470.4  -35.7  431.9 1428.8 1423.2 1390.4 1590.9 1589.7
6   929.9 1061.9 1031.5  768.4    4.2  119.4 1787.4 1587.9 1591.8 1669.6 1606.2
7  1985.8 1892.3 1972.1 1989.7   31.5 -181.8 1329.6 1885.9 1704.1 1841.1 2410.0
8  1560.4 1642.5 1614.5 1700.3  -12.1  -65.0 1144.9  858.1 1310.9 1421.2 1167.6

                   INSIDE SURFACES HEAT FLUXES W PER SQ.M.

      1      2      3      4      5      6      7      8      9     10     11

1  4664.8 4806.9 5023.6 5019.6    0.7 -436.8 4282.1 3457.0 1962.3 -406.3 -513.6
2  4815.7 4951.0 5060.2 4957.4  -59.0 -230.4 3171.9 3601.1 4240.4 4257.9 -131.1
3  5348.1 5712.1 5272.2 5458.5    9.5 -309.0 5053.8 5696.6 5486.6 5998.6 9710.2
4  4899.0 4147.8 4775.0 4555.4  139.1  237.2 5071.6 4616.5 4925.6 5118.1 5129.4
5  1689.5 1407.8  838.5 1484.2 -112.7 1362.6 4507.6 4490.0 4386.6 5019.0 5015.3
6  2933.7 3350.2 3254.4 2424.2   13.2  376.8 5639.2 5009.8 5022.0 5267.4 5067.3
7  6265.0 5970.0 6221.6 6277.3   99.3 -573.6 4194.9 5949.9 5376.4 5808.4 7603.4
8  4922.9 5182.0 5093.6 5364.3  -38.1 -205.0 3612.0 2707.1 4135.6 4483.8 3683.5

                   BULK FLUID TEMPERATURE      - DEGREES F

      1      2      3      4      5      6      7      8      9     10     11

     90.9   94.5   96.4   97.5   97.7   97.7   98.0   98.9  100.3  103.5  107.0

                   BULK FLUID TEMPERATURE      - DEGREES C

      1      2      3      4      5      6      7      8      9     10     11

     32.7   34.7   35.8   36.4   36.5   36.5   36.6   37.2   37.9   39.7   41.7

                 CORRECTED OUTLET TEMPERATURE =   108.2DEG F (     42.3DEG C)
                 CORRECTED INLET  TEMPERATURE =    87.2DEG F (     30.7DEG C)
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                         ---------------
                         RUN NUMBER   25
                         ---------------

AVERAGE REYNOLDS NUMBER        = 0.163E 04
AVERAGE PRANDTL NUMBER         = 0.468E 01
MASS FLUX                      = 0.429E 05  LBM/(SQ.FT-HR) 0.581E 02  KG.PER.(S.SQ.M.)
AVERAGE HEAT FLUX              = 0.146E 04  BTU/(SQ.FT-HR) ( 0.461E 04  W PER SQ.M.)
Q=AMP*VOLT                     = 0.293E 04  BTU/HR ( 0.860E 03W)
Q=M*C*(T2-T1)                  = 0.290E 04  BTU/HR ( 0.849E 03W)
HEAT LOST                      = 0.552E 02  BTU/HR ( 0.162E 02W)
HEAT BALANCE ERROR %           =-0.592E 00

     PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

         1      2      3      4      5      6      7      8      9     10     11

1      133.3  205.7  260.1  283.2   -0.0  -10.7   58.8   51.0   22.5   -3.2   -3.0
2      129.0  180.4  199.0  203.4    3.4   -6.4   44.0   65.1   65.8   49.7   -0.9
3      115.9  141.6  124.6  136.8   -0.5  -11.5  104.0  204.6  143.8  146.2  249.8
4       69.1   54.7   64.7   62.1   -7.2   19.5  140.6  202.4  162.1  215.5  213.4
5       16.2   13.3    7.5   13.6    6.3 1217.8  130.1  217.4  141.2  277.1  246.0
6       33.2   40.3   38.1   26.2   -0.7   30.1  165.4  260.3  164.4  234.7  190.5
7      135.7  146.6  161.2  154.9   -5.2  -19.0   76.4  214.4  133.8  141.3  175.9
8      135.0  202.4  218.1  254.0    2.1   -5.5   50.7   42.8   62.3   53.6   31.9

     PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

         1      2      3      4      5      6      7      8      9     10     11

1      757.1 1168.3 1476.7 1608.3   -0.2  -60.5  333.7  289.5  127.7  -18.1  -16.8
2      732.3 1024.4 1129.9 1155.2   19.3  -36.3  250.0  369.5  373.9  282.2   -5.1
3      658.2  803.9  707.4  776.7   -2.9  -65.2  590.7 1161.5  816.7  830.4 1418.7
4      392.2  310.8  367.7  352.7  -40.8  110.9  798.5 1149.5  920.6 1223.5 1211.6
5       92.2   75.3   42.7   77.3   35.5 6915.1  738.9 1234.6  802.0 1573.6 1396.8
6      188.3  229.1  216.3  148.7   -4.0  170.7  939.0 1478.3  933.5 1332.6 1081.6
7      770.3  832.3  915.4  879.7  -29.4 -107.9  433.8 1217.6  759.7  802.5  999.0
8      766.7 1149.5 1238.5 1442.5   12.0  -31.1  288.0  243.1  354.0  304.1  181.1
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            AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

              1      2      3      4      5      6      7      8      9     10     11
  (H1)   95.9  123.1  134.2  141.8   -0.2  151.8   96.3  157.3  112.0  139.4  138.0
  (H2)   76.5   84.1   84.7   84.9   -0.4    1.1   83.7  116.6   91.5   80.2   60.3

            AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

              1      2      3      4      5      6      7      8      9     10     11

  (H1)  544.7  699.2  761.8  805.1   -1.3  862.0  546.6  893.0  636.0  791.4  783.4
  (H2)  434.4  477.5  480.9  482.2   -2.0    6.4  475.4  662.2  519.6  455.5  342.5

    PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

              1      2      3      4      5      6      7      8      9     10     11

LIT(1)  19.11  35.49  38.75   0.00   0.00   0.00  11.75  52.83  24.27  31.68  15.97
LIT(2)  -1.43   5.55   2.98   0.00   0.00   0.00  -1.46  36.39   7.31 -18.71 -92.18
LIT(3)  15.00  32.47  36.33   0.00   0.00   0.00   8.92  49.73  21.72  31.26  19.54
LIT(4)  -6.57   1.12  -0.85   0.00   0.00   0.00  -4.71  32.20   4.19 -19.43 -84.01
LIT(5)  32.43  58.33  64.59   0.00   0.00   0.00 -68.84  38.70  34.12  59.87  65.08
LIT(6)  15.27  38.99  43.91   0.00   0.00   0.00 -94.11  17.33  19.37  30.28  20.14
LIT(7)  27.81  34.01  34.53   0.00   0.00   0.00 -50.45  43.43  18.91  26.50   9.00
LIT(8)   9.48   3.38  -3.70   0.00   0.00   0.00 -72.97  23.71   0.75 -27.71-108.12
LIT(9)  86.88  91.88  93.13   0.00   0.00   0.00  68.83  88.52  87.46  92.27  93.31
LIT(10)  83.55  88.11  89.11   0.00   0.00   0.00  64.16  84.52  84.66  86.57  84.69
COR(11)  14.32  30.77  34.75   0.00   0.00   0.00-183.35 -26.36 -31.95  22.16  20.90
COR(12)  -7.43  -1.36  -3.35   0.00   0.00   0.00-225.76 -70.40 -61.50 -35.25 -80.89
```

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                                        ---------------
                                        RUN NUMBER   25
                                        ---------------
           1          2          3          4          5          6          7          8          9          10          11

X/D    0.270E 02 0.530E 02 0.673E 02 0.748E 02 0.861E 02 0.955E 02 0.195E 01 0.878E 01 0.189E 02 0.419E 02 0.676E 02
TB,F   0.909E 02 0.945E 02 0.964E 02 0.975E 02 0.977E 02 0.977E 02 0.980E 02 0.989E 02 0.100E 03 0.103E 03 0.107E 03
JHC    0.168E 02 0.215E 02 0.234E 02 0.247E 02-0.418E-01 0.267E 02 0.167E 02 0.275E 02 0.195E 02 0.241E 02 0.236E 02
RE.NO. 0.151E 04 0.157E 04 0.160E 04 0.162E 04 0.163E 04 0.163E 04 0.163E 04 0.165E 04 0.167E 04 0.173E 04 0.179E 04
PR.NO. 0.510E 01 0.487E 01 0.476E 01 0.470E 01 0.468E 01 0.468E 01 0.467E 01 0.462E 01 0.454E 01 0.437E 01 0.420E 01
GR.NO. 0.171E 06 0.219E 06 0.258E 06 0.280E 06-0.997E 05 0.134E 06 0.295E 06 0.228E 06 0.323E 06 0.464E 06 0.784E 06
HT/HB  0.122E 00 0.645E-01 0.289E-01 0.481E-01-0.604E-02-0.875E-02 0.452E 00 0.235E 00 0.159E 00-0.115E-01-0.120E-01
DE.NO. 0.429E 03 0.447E 03 0.456E 03 0.462E 03 0.463E 03 0.463E 03 0.464E 03 0.469E 03 0.476E 03 0.492E 03 0.510E 03
GR/RE2 0.754E-01 0.888E-01 0.100E 00 0.106E 00-0.377E-01 0.508E-01 0.111E 00 0.840E-01 0.116E 00 0.155E 00 0.243E 00
NU.1   0.172E 02 0.220E 02 0.239E 02 0.253E 02-0.414E-01 0.270E 02 0.171E 02 0.280E 02 0.199E 02 0.247E 02 0.243E 02
NU.2   0.137E 02 0.150E 02 0.151E 02 0.151E 02-0.632E-01 0.200E 00 0.149E 02 0.207E 02 0.163E 02 0.142E 02 0.106E 02

          RUN NO  BR/TR       RE        PR     AVG HEAT FLUX     HEAT GENERATED     HEAT GAINED     HEAT  LOST     H.B.% ERROR
     4       25  12.354      1626       4.7        1460                 2934.8           2896.6          55.2           -0.59
```

RUN NUMBER 102

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	130.3	131.6	131.1	92.5	101.1	122.8	149.2	154.1	157.9	164.0	166.0
2	130.4	132.1	131.8	93.3	100.6	120.4	147.2	147.7	150.4	153.8	158.1
3	133.8	138.4	138.2	98.3	100.2	114.2	143.8	136.5	139.7	143.7	143.8
4	144.1	148.8	136.6	105.2	100.4	109.5	142.0	132.3	136.3	137.8	137.5
5	157.1	164.8	166.6	117.0	102.4	109.2	142.6	133.9	135.0	134.4	135.8
6	150.2	161.3	161.5	107.6	100.1	111.2	142.2	138.6	135.6	135.8	137.0
7	138.8	142.7	144.2	96.6	100.3	115.2	142.1	140.9	141.0	141.6	141.7
8	132.1	134.7	134.2	92.9	101.2	119.7	145.6	146.5	149.7	153.5	156.3

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	54.6	55.3	55.0	33.6	38.4	50.4	65.1	67.8	69.9	73.3	74.4
2	54.7	55.6	55.4	34.1	38.1	49.1	64.0	64.3	65.8	67.6	70.1
3	56.6	59.1	59.0	36.8	37.9	45.7	62.1	58.0	59.8	62.1	62.1
4	62.3	64.9	58.1	40.6	38.0	43.1	61.1	55.7	57.9	58.8	58.6
5	69.5	73.8	74.8	47.2	39.1	42.9	61.5	56.6	57.2	56.9	57.7
6	65.7	71.8	71.9	42.0	37.8	44.0	61.2	59.2	57.6	57.7	58.4
7	59.3	61.5	62.3	35.9	38.0	46.2	61.2	60.5	60.5	60.9	61.0
8	55.6	57.1	56.8	33.8	38.4	48.7	63.1	63.6	65.4	67.5	69.0

MASS FLOW RATE = 235.3 LBM/HR (0.02964 KG.PER.S)

RUN NUMBER 102

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	129.9	131.2	130.6	92.5	101.1	122.8	148.9	153.9	157.7	163.9	165.8
2	130.0	131.6	131.3	93.2	100.6	120.5	146.9	147.4	150.0	153.4	157.8
3	133.4	138.0	137.9	98.3	100.2	114.2	143.3	136.0	139.2	143.3	143.3
4	143.6	148.4	135.8	105.1	100.4	109.5	141.6	131.8	135.9	137.4	137.0
5	157.0	164.6	166.7	117.3	102.5	109.2	142.3	133.5	134.6	134.0	135.4
6	149.9	161.1	161.2	107.6	100.1	111.1	141.8	138.2	135.2	135.3	136.6
7	138.3	142.1	143.7	96.5	100.3	115.2	141.6	140.5	140.5	141.1	141.2
8	131.7	134.3	133.8	92.8	101.2	119.7	145.2	146.1	149.3	153.1	156.0

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	54.4	55.1	54.8	33.6	38.4	50.5	64.9	67.7	69.8	73.3	74.3
2	54.4	55.3	55.2	34.0	38.1	49.2	63.8	64.1	65.6	67.4	69.9
3	56.3	58.9	58.8	36.8	37.9	45.7	61.9	57.8	59.5	61.8	61.8
4	62.0	64.6	57.6	40.6	38.0	43.0	60.9	55.4	57.7	58.6	58.4
5	69.5	73.7	74.9	47.4	39.1	42.9	61.3	56.4	57.0	56.7	57.4
6	65.5	71.7	71.8	42.0	37.8	44.0	61.0	59.0	57.3	57.4	58.1
7	59.1	61.2	62.1	35.8	38.0	46.2	60.9	60.3	60.3	60.6	60.7
8	55.4	56.8	56.5	33.8	38.4	48.7	62.9	63.4	65.2	67.3	68.9

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                 INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

        1      2      3      4      5      6      7      8      9     10     11

 1 1687.4 1779.8 1796.2   68.0  -23.8 -302.6 1245.5  753.3  650.5  348.6  540.5
 2 1763.3 1915.5 1904.9  238.8    8.7 -218.5 1485.2 1292.9 1388.9 1592.6 1198.5
 3 1968.7 1805.0 1099.5  108.0   37.9   92.3 1673.9 1982.5 2001.0 1814.3 2042.7
 4 1747.2 1907.1 3440.1  295.2  106.2  255.7 1710.4 1910.8 1693.5 1719.4 1842.0
 5  396.4  431.5 -503.1-1243.2 -254.0  132.1 1509.1 1748.1 1680.6 1845.5 1741.9
 6 1314.8  684.8  871.1  -88.0  149.7  126.7 1589.6 1434.7 1847.8 1833.1 1770.7
 7 1855.7 2206.8 2004.1  423.4   38.5   24.3 1783.8 1760.4 1769.8 1930.2 2152.6
 8 1848.1 1851.0 1968.2  188.1  -47.8  -76.3 1581.0 1693.8 1544.9 1496.8 1291.5

                  INSIDE SURFACES HEAT FLUXES W PER SQ.M.

        1      2      3      4      5      6      7      8      9     10     11

 1 5323.6 5615.1 5666.9  214.4  -75.0 -954.7 3929.4 2376.5 2052.4 1099.7 1705.1
 2 5563.2 6043.4 6009.9  753.5   27.4 -689.4 4685.6 4078.9 4382.0 5024.6 3781.0
 3 6210.9 5694.6 3468.7  340.7  119.5  291.0 5280.9 6254.6 6312.9 5724.0 6444.6
 4 5512.2 6016.810853.2  931.4  335.1  806.6 5396.2 6028.4 5343.0 5424.5 5811.2
 5 1250.5 1361.4-1587.3-3922.3 -801.3  416.7 4761.1 5515.1 5302.2 5822.3 5495.7
 6 4148.0 2160.6 2748.4 -277.6  472.4  399.9 5015.1 4526.5 5829.6 5783.3 5586.3
 7 5854.4 6962.3 6322.7 1335.9  121.6   76.7 5627.7 5554.0 5583.4 6089.6 6791.4
 8 5830.7 5839.7 6209.6  593.3 -150.9 -240.6 4987.8 5343.9 4874.1 4722.3 4074.7

                  BULK FLUID TEMPERATURE       - DEGREES F

        1      2      3      4      5      6      7      8      9     10     11

     94.7   98.9   99.7   99.9   99.9   99.9  100.2  101.3  103.0  106.8  109.1

                  BULK FLUID TEMPERATURE       - DEGREES C

        1      2      3      4      5      6      7      8      9     10     11

     34.8   37.2   37.6   37.7   37.7   37.7   37.9   38.5   39.4   41.6   42.8

                 CORRECTED OUTLET TEMPERATURE =   109.6DEG F (    43.1DEG C)
                 CORRECTED INLET TEMPERATURE  =    90.2DEG F (    32.3DEG C)
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                       ---------------
                       RUN NUMBER  102
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        AVERAGE REYNOLDS NUMBER         = 0.200E 03
        AVERAGE PRANDTL NUMBER          = 0.919E 02
        MASS FLUX                       = 0.729E 05  LBM/(SQ.FT-HR) 0.989E 02  KG.PER.(S.SQ.M.)
        AVERAGE HEAT FLUX               = 0.161E 04  BTU/(SQ.FT-HR) ( 0.508E 04  W PER SQ.M.)
        Q=AMP*VOLT                      = 0.260E 04  BTU/HR ( 0.761E 03W)
        Q=M*C*(T2-T1)                   = 0.265E 04  BTU/HR ( 0.777E 03W)
        HEAT LOST                       = 0.151E 03  BTU/HR ( 0.443E 02W)
        HEAT BALANCE ERROR %            =-0.853E 01

             PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

              1       2       3       4       5       6       7       8       9      10      11

   1         47.9    55.2    58.1    -9.1   -19.2   -13.2    25.6    14.3    11.9     6.1     9.5
   2         49.9    58.6    60.3   -35.8    12.2   -10.6    31.8    28.1    29.5    34.2    24.6
   3         50.9    46.2    28.8   -66.2   126.9     6.5    38.8    57.2    55.3    49.7    59.6
   4         35.7    38.6    95.5    56.8   211.0    26.7    41.3    62.7    51.5    56.2    65.9
   5          6.4     6.6    -7.5   -71.6   -98.8    14.2    35.9    54.4    53.2    67.9    66.2
   6         23.8    11.0    14.2   -11.4   850.5    11.3    38.2    38.9    57.5    64.3    64.3
   7         42.5    51.1    45.5  -123.0    93.7     1.6    43.1    45.0    47.2    56.3    67.0
   8         49.9    52.4    57.8   -26.5   -37.3    -3.8    35.2    37.9    33.4    32.3    27.5

             PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

              1       2       3       4       5       6       7       8       9      10      11

   1        272.0   313.5   330.0   -51.8  -109.3   -74.9   145.3    81.4    67.5    34.7    54.1
   2        283.4   333.0   342.4  -203.5    69.5   -60.3   180.8   159.5   167.7   194.3   139.6
   3        288.8   262.3   163.6  -375.9   720.4    36.7   220.4   324.9   314.1   282.5   338.6
   4        202.6   219.1   542.2   322.4  1198.2   151.6   234.7   356.2   292.6   319.3   373.9
   5         36.1    37.3   -42.6  -406.7  -561.3    80.7   203.7   308.8   302.0   385.5   375.9
   6        135.2    62.5    80.4   -64.8  4829.5    64.1   216.9   220.8   326.2   365.1   364.9
   7        241.3   290.1   258.6  -698.6   531.9     9.0   244.5   255.3   267.8   319.4   380.2
   8        283.2   297.4   328.4  -150.7  -211.7   -21.8   199.7   215.0   189.5   183.5   156.4
```

```
          AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

          1       2       3       4       5       6       7       8       9      10      11

  (H1)   38.4    40.0    44.1   -35.9   142.4     4.1    36.2    42.3    42.4    45.9    48.1
  (H2)   35.3    35.0    36.7    -2.4     2.2     0.3    36.0    39.7    39.5    41.0    41.8

          AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

          1       2       3       4       5       6       7       8       9      10      11

  (H1)  217.8   226.9   250.4  -203.7   808.4    23.1   205.8   240.2   240.9   260.5   272.9
  (H2)  200.4   198.5   208.1   -13.8    12.2     1.6   204.1   225.6   224.3   232.7   237.6

   PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

          1       2       3       4       5       6       7       8       9      10      11

LIT(1) -36.27  -33.82  -19.16    0.00    0.00    0.00  -46.54  -20.69  -21.48  -12.37   -7.27
LIT(2) -48.15  -52.94  -43.34    0.00    0.00    0.00  -47.70  -28.54  -30.47  -25.83  -23.23
LIT(3) -16.30  -13.86   -1.88    0.00    0.00    0.00  -25.00   -4.04   -4.58    3.05    7.33
LIT(4) -26.44  -30.12  -22.56    0.00    0.00    0.00  -25.99  -10.80  -12.31   -8.56   -6.46
LIT(5)  -3.81   21.76   31.56    0.00    0.00    0.00-167.38  -37.65   -5.29   27.01   37.15
LIT(6) -12.86   10.58   17.67    0.00    0.00    0.00-169.49  -46.60  -13.08   18.27   27.79
LIT(7)  -4.71  -13.98   -2.77    0.00    0.00    0.00   -7.73   10.93    8.05    9.36   10.77
LIT(8) -13.84  -30.27  -23.62    0.00    0.00    0.00   -8.58    5.13    1.24   -1.49   -2.50
LIT(9)  52.38   63.57   68.07    0.00    0.00    0.00  -20.40   38.10   52.18   66.28   70.78
LIT(10)  48.23   58.36   61.59    0.00    0.00    0.00  -21.35   34.07   48.65   62.24   66.43
COR(11)  -5.98   -3.37    7.27    0.00    0.00    0.00  -14.70    4.32    4.26   11.49   15.44
COR(12) -15.22  -18.14  -11.55    0.00    0.00    0.00  -15.61   -1.90   -2.83    0.89    2.86
```

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                             ---------------
                             RUN NUMBER  102
                             ---------------

             1         2         3         4         5         6         7         8         9        10        11

X/D     0.270E 02 0.530E 02 0.578E 02 0.687E 02 0.787E 02 0.887E 02 0.195E 01 0.878E 01 0.189E 02 0.419E 02 0.556E 02
TB,F    0.947E 02 0.989E 02 0.997E 02 0.999E 02 0.999E 02 0.999E 02 0.100E 03 0.101E 03 0.103E 03 0.107E 03 0.109E 03
JHC     0.149E 02 0.155E 02 0.172E 02-0.155E 02 0.615E 02 0.169E 01 0.141E 02 0.166E 02 0.167E 02 0.181E 02 0.190E 02
RE.NO.  0.179E 03 0.196E 03 0.199E 03 0.200E 03 0.200E 03 0.200E 03 0.201E 03 0.206E 03 0.213E 03 0.229E 03 0.239E 03
PR.NO.  0.102E 03 0.936E 02 0.922E 02 0.919E 02 0.919E 02 0.919E 02 0.913E 02 0.893E 02 0.865E 02 0.805E 02 0.773E 02
GR.NO.  0.145E 05 0.174E 05 0.171E 05 0.201E 03 0.360E 03 0.617E 04 0.178E 05 0.168E 05 0.180E 05 0.201E 05 0.215E 05
HT/HB   0.133E 00 0.119E 00-0.129E 00 0.784E 01 0.195E 00-0.929E 00 0.713E 00 0.264E 00 0.224E 00 0.899E-01 0.144E 00
DE.NO.  0.356E 02 0.389E 02 0.395E 02 0.397E 02 0.397E 02 0.397E 02 0.399E 02 0.408E 02 0.422E 02 0.455E 02 0.475E 02
GR/RE2  0.450E 00 0.453E 00 0.431E 00 0.503E-02 0.903E-02 0.155E 00 0.440E 00 0.397E 00 0.399E 00 0.383E 00 0.375E 00
NU.1    0.166E 02 0.173E 02 0.191E 02-0.155E 02 0.616E 02 0.176E 01 0.157E 02 0.183E 02 0.184E 02 0.198E 02 0.208E 02
NU.2    0.153E 02 0.151E 02 0.159E 02-0.105E 01 0.932E 00 0.119E 00 0.156E 02 0.172E 02 0.171E 02 0.177E 02 0.181E 02

          RUN NO  BR/TR      RE      PR   AVG HEAT FLUX   HEAT GENERATED   HEAT GAINED   HEAT  LOST   H.B.% ERROR
             102  25.358     199    91.9      1610                2595.2        2652.5        151.2         -8.53
```

RUN NUMBER 304

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	126.5	129.0	129.6	101.1	96.1	102.6	140.9	150.1	152.4	155.8	159.4
2	127.3	129.8	131.4	98.9	96.2	102.2	140.0	145.3	149.6	151.3	155.7
3	130.6	135.0	135.9	99.7	96.9	100.6	136.7	139.6	142.2	142.2	148.6
4	136.4	144.1	144.4	104.3	99.0	101.6	134.3	135.9	138.6	137.8	141.9
5	140.6	146.2	147.7	109.2	102.0	100.8	132.0	136.4	137.3	136.6	139.9
6	137.4	142.6	144.1	116.2	101.8	100.3	133.2	138.4	137.4	138.6	141.7
7	132.2	135.2	135.9	109.2	97.5	101.0	139.7	140.6	142.2	145.5	147.3
8	127.6	130.3	131.0	104.5	96.4	102.1	136.9	146.2	148.2	151.6	155.5

CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	52.5	53.9	54.2	38.4	35.6	39.2	60.5	65.6	66.9	68.8	70.8
2	52.9	54.3	55.2	37.2	35.7	39.0	60.0	63.0	65.3	66.3	68.7
3	54.8	57.2	57.7	37.6	36.1	38.1	58.2	59.8	61.2	61.2	64.8
4	58.0	62.3	62.5	40.1	37.2	38.6	56.9	57.7	59.2	58.8	61.0
5	60.4	63.5	64.3	42.9	38.9	38.2	55.5	58.0	58.5	58.1	60.0
6	58.6	61.5	62.3	46.8	38.8	37.9	56.2	59.1	58.6	59.2	60.9
7	55.7	57.4	57.7	42.9	36.4	38.3	59.8	60.4	61.2	63.1	64.1
8	53.1	54.6	55.0	40.3	35.8	39.0	58.3	63.4	64.5	66.4	68.6

MASS FLOW RATE = 230.1 LBM/HR (0.02899 KG.PER.S)

RUN NUMBER 304

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	126.0	128.5	129.1	101.1	96.1	102.6	140.7	149.9	152.2	155.6	159.2
2	126.8	129.2	130.9	98.8	96.2	102.2	139.6	144.9	149.3	151.0	155.4
3	130.1	134.5	135.3	99.6	96.9	100.5	136.2	139.1	141.7	141.7	148.1
4	136.0	143.9	144.2	104.2	99.0	101.6	133.9	135.4	138.1	137.2	141.3
5	140.4	146.0	147.5	109.1	102.1	100.8	131.5	135.9	136.9	136.1	139.4
6	137.1	142.3	143.8	116.6	101.9	100.2	132.6	137.9	136.9	138.0	141.2
7	131.7	134.7	135.4	109.1	97.4	101.0	139.6	140.1	141.8	145.1	146.8
8	127.1	129.8	130.5	104.4	96.4	102.2	136.3	145.8	147.8	151.2	155.2

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	52.2	53.6	54.0	38.4	35.6	39.2	60.4	65.5	66.8	68.7	70.7
2	52.7	54.0	54.9	37.1	35.7	39.0	59.8	62.7	65.2	66.1	68.5
3	54.5	56.9	57.4	37.5	36.0	38.0	57.9	59.5	60.9	60.9	64.5
4	57.8	62.2	62.3	40.1	37.2	38.7	56.6	57.4	59.0	58.5	60.7
5	60.2	63.3	64.1	42.9	39.0	38.2	55.3	57.7	58.3	57.8	59.7
6	58.4	61.3	62.1	47.0	38.8	37.9	55.9	58.9	58.3	58.9	60.6
7	55.4	57.1	57.4	42.8	36.3	38.3	59.8	60.1	61.0	62.9	63.8
8	52.8	54.3	54.7	40.2	35.8	39.0	58.0	63.2	64.3	66.2	68.5

```
                INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

        1      2      3      4      5      6      7      8      9     10     11

 1 1573.4 1600.1 1703.4   98.2   37.5  -78.8  856.7  481.4  648.8  477.2  589.7
 2 1639.6 1832.1 1663.3  291.6   50.4 -113.0 1142.3 1281.7  911.3  907.6 1039.6
 3 1622.3 1785.8 1806.0  379.6  144.0  267.3 1479.3 1602.8 1780.7 1871.1 1431.7
 4 1228.0  656.5  826.9   41.3  102.5 -188.3 1375.1 1802.0 1622.9 1726.9 1888.7
 5  595.2  782.0  670.2  248.9 -401.5   21.7 1742.2 1546.6 1527.6 1704.9 1767.2
 6 1172.3  987.6  901.7-1524.3 -464.2  145.2 1940.4 1408.8 1869.0 1906.0 1792.1
 7 1446.8 1635.7 1732.3  253.7  331.4   38.2  403.9 1725.6 1507.3 1289.9 1659.1
 8 1727.6 1750.4 1732.1  132.2   67.3  -64.3 2091.5 1211.8 1207.3 1198.8  938.1

                 INSIDE SURFACES HEAT FLUXES W PER SQ.M.

        1      2      3      4      5      6      7      8      9     10     11

 1 4963.9 5048.1 5374.0  309.7  118.3 -248.6 2702.9 1518.6 2046.8 1505.5 1860.3
 2 5172.8 5780.1 5247.7  919.9  159.2 -356.4 3603.9 4043.5 2875.0 2863.5 3279.8
 3 5118.2 5634.1 5697.7 1197.7  454.3  843.4 4666.9 5056.8 5618.0 5903.3 4516.9
 4 3874.2 2071.0 2608.9  130.4  323.5 -594.1 4338.3 5685.0 5120.1 5448.3 5958.7
 5 1877.9 2467.3 2114.3  785.2-1266.6   68.4 5496.3 4879.3 4819.4 5379.0 5575.2
 6 3698.4 3115.8 2844.9-4808.9-1464.5  458.0 6121.7 4444.5 5896.6 6013.2 5654.0
 7 4564.6 5160.4 5465.4  800.3 1045.5  120.5 1274.4 5444.1 4755.4 4069.6 5234.2
 8 5450.4 5522.2 5464.6  416.9  212.4 -202.8 6598.5 3823.3 3809.0 3782.0 2959.7

                 BULK FLUID TEMPERATURE      - DEGREES F

        1      2      3      4      5      6      7      8      9     10     11

     98.1  104.1  105.5  105.7  105.7  105.7  106.0  107.7  109.7  113.7  117.7

                 BULK FLUID TEMPERATURE      - DEGREES C

        1      2      3      4      5      6      7      8      9     10     11

     36.7   40.0   40.8   41.0   41.0   41.0   41.1   42.1   43.2   45.4   47.6

               CORRECTED OUTLET TEMPERATURE =    120.1DEG F (    48.9DEG C)
               CORRECTED INLET TEMPERATURE  =     91.4DEG F (    33.0DEG C)
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                          ---------------
                          RUN NUMBER  304
                          ---------------

   AVERAGE REYNOLDS NUMBER        = 0.297E 03
   AVERAGE PRANDTL NUMBER         = 0.720E 02
   MASS FLUX                      = 0.110E 06  LBM/(SQ.FT-HR) 0.149E 03  KG.PER.(S.SQ.M.)
   AVERAGE HEAT FLUX              = 0.136E 04  BTU/(SQ.FT-HR) ( 0.428E 04  W PER SQ.M.)
   Q=AMP*VOLT                     = 0.413E 04  BTU/HR ( 0.121E 04W)
   Q=M*C*(T2-T1)                  = 0.386E 04  BTU/HR ( 0.113E 04W)
   HEAT LOST                      = 0.169E 03  BTU/HR ( 0.496E 02W)
   HEAT BALANCE ERROR %           = 0.247E 01

        PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

          1       2       3       4       5       6       7       8       9      10      11

1       56.3    65.6    72.2   -21.2    -3.9    25.2    24.7    11.4    15.3    11.4    14.2
2       57.1    72.8    65.6   -42.1    -5.3    31.8    34.0    34.4    23.0    24.3    27.6
3       50.6    58.8    60.6   -61.6   -16.2   -50.8    48.9    51.1    55.7    66.9    47.0
4       32.4    16.5    21.4   -27.3   -15.2    45.5    49.2    65.1    57.1    73.3    80.0
5       14.1    18.6    16.0    73.4   110.5    -4.4    68.4    54.9    56.2    76.0    81.3
6       30.1    25.8    23.6  -140.2   120.9   -26.2    72.9    46.6    68.8    78.3    76.3
7       43.0    53.3    58.1    76.2   -39.7    -8.1    12.0    53.2    47.0    41.0    56.9
8       59.5    68.1    69.3   -99.7    -7.2    17.9    68.9    31.8    31.7    31.9    25.0

        PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

          1       2       3       4       5       6       7       8       9      10      11

1      319.9   372.3   410.0  -120.2   -22.1   143.0   140.3    64.8    86.7    64.6    80.6
2      324.4   413.5   372.8  -238.8   -30.1   180.4   192.9   195.4   130.7   138.1   156.7
3      287.3   333.6   344.1  -349.6   -92.2  -288.2   277.7   290.0   316.2   379.8   267.0
4      183.9    93.6   121.5  -155.3   -86.2   258.2   279.5   369.4   324.2   416.2   454.2
5       79.8   105.9    90.8   416.5   627.4   -24.9   388.2   311.5   319.3   431.7   461.7
6      170.8   146.6   133.8  -796.1   686.4  -148.7   414.0   264.6   390.4   444.7   433.3
7      244.1   302.7   329.7   432.8  -225.2   -45.7    68.3   302.3   267.0   232.8   323.0
8      338.0   386.6   393.5  -566.2   -40.9   101.8   391.4   180.6   179.9   181.4   141.8
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              AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

             1       2       3       4       5       6       7       8       9      10      11

     (H1)   42.9    47.4    48.3   -30.3    18.0     3.9    47.4    43.6    44.3    50.4    51.0
     (H2)   40.7    43.0    43.7    26.5     2.2    -0.8    45.5    41.4    41.5    45.0    45.3

              AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

             1       2       3       4       5       6       7       8       9      10      11

     (H1)  243.5   269.4   274.5  -172.1   102.1    22.0   269.0   247.3   251.8   286.2   289.8
     (H2)  230.9   244.3   248.3   150.2    12.5    -4.6   258.3   234.8   235.6   255.2   257.1

     PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

             1       2       3       4       5       6       7       8       9      10      11

   LIT(1) -16.58   -5.74   -3.73    0.00    0.00    0.00   -4.35  -18.95  -17.68   -1.86   -1.92
   LIT(2) -22.95  -16.58  -14.69    0.00    0.00    0.00   -8.68  -25.29  -25.80  -14.19  -14.85
   LIT(3) -10.41   -0.47    1.35    0.00    0.00    0.00    0.40  -12.40  -11.14    3.18    3.21
   LIT(4) -16.44  -10.76   -9.07    0.00    0.00    0.00   -3.74  -18.39  -18.81   -8.54   -9.08
   LIT(5)  16.35   39.57   42.87    0.00    0.00    0.00-145.50  -27.70    2.50   33.45   42.89
   LIT(6)  11.79   33.38   36.83    0.00    0.00    0.00-155.70  -34.50   -4.23   25.39   35.64
   LIT(7)  -3.07   -1.97   -1.53    0.00    0.00    0.00-489.45   -0.30    1.72    9.38    5.00
   LIT(8)  -8.70  -12.42  -12.26    0.00    0.00    0.00-513.94   -5.64   -5.07   -1.60   -7.05
   LIT(9)  69.77   78.05   79.27    0.00    0.00    0.00   15.01   55.30   65.33   76.00   79.34
   LIT(10)  68.12   75.80   77.08    0.00    0.00    0.00   11.48   52.92   62.94   73.09   76.72
   COR(11)  -3.74    5.71    7.42    0.00    0.00    0.00    1.20   -6.18   -3.78    9.55    9.80
   COR(12)  -9.41   -3.95   -2.36    0.00    0.00    0.00   -2.91  -11.84  -10.95   -1.40   -1.64
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                              RUN NUMBER  304
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            1         2         3         4         5         6         7         8         9        10        11

X/D     0.810E 02 0.154E 03 0.171E 03 0.176E 03 0.178E 03 0.180E 03 0.262E 01 0.236E 02 0.478E 02 0.962E 02 0.145E 03
TB,F    0.981E 02 0.104E 03 0.106E 03 0.106E 03 0.106E 03 0.106E 03 0.106E 03 0.108E 03 0.110E 03 0.114E 03 0.118E 03
JHC     0.132E 02 0.146E 02 0.149E 02-0.101E 02 0.612E 01 0.131E 01 0.147E 02 0.134E 02 0.137E 02 0.156E 02 0.159E 02
RE.NO.  0.255E 03 0.287E 03 0.296E 03 0.297E 03 0.297E 03 0.297E 03 0.298E 03 0.308E 03 0.320E 03 0.344E 03 0.370E 03
PR.NO.  0.834E 02 0.743E 02 0.723E 02 0.720E 02 0.720E 02 0.720E 02 0.717E 02 0.695E 02 0.670E 02 0.625E 02 0.583E 02
GR.NO.  0.778E 04 0.931E 04 0.969E 04-0.115E 03-0.232E 04-0.135E 04 0.947E 04 0.111E 05 0.120E 05 0.128E 05 0.146E 05
HT/HB   0.249E 00 0.284E 00 0.221E 00-0.346E 01-0.352E-01-0.574E 01 0.361E 00 0.208E 00 0.272E 00 0.150E 00 0.175E 00
DE.NO.  0.116E 03 0.131E 03 0.134E 03 0.135E 03 0.135E 03 0.135E 03 0.136E 03 0.140E 03 0.145E 03 0.157E 03 0.168E 03
GR/RE2  0.120E 00 0.113E 00 0.111E 00-0.131E-02-0.263E-01-0.153E-01 0.107E 00 0.117E 00 0.117E 00 0.108E 00 0.107E 00
NU.1    0.143E 02 0.158E 02 0.161E 02-0.101E 02 0.599E 01 0.129E 01 0.158E 02 0.145E 02 0.148E 02 0.167E 02 0.169E 02
NU.2    0.136E 02 0.143E 02 0.146E 02 0.882E 01 0.736E 00-0.268E 00 0.152E 02 0.138E 02 0.138E 02 0.149E 02 0.150E 02

          RUN NO  BR/TR     RE      PR    AVG HEAT FLUX    HEAT GENERATED    HEAT GAINED    HEAT  LOST    H.B.% ERROR
           304    4.839     296    72.0       1356                4129.1        3861.9         169.2           2.47
```

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                     ---------------
                     RUN NUMBER  305
                     ---------------

              CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

        1      2      3      4      5      6      7      8      9      10     11

 1    141.4  145.6  146.6  106.1  100.9  114.5  170.4  177.0  178.8  188.1  194.5
 2    142.5  146.7  149.5  103.0  101.2  113.2  168.4  169.4  173.2  181.6  188.4
 3    147.7  154.9  156.4  104.0  102.0  109.1  162.1  157.8  158.8  169.3  177.4
 4    157.2  169.5  170.2  110.2  104.6  111.4  157.1  150.2  151.1  163.1  167.6
 5    164.3  173.2  175.7  117.6  108.2  109.0  152.1  149.0  150.2  160.1  165.1
 6    158.9  167.2  169.7  127.9  107.9  108.3  155.0  149.7  152.8  161.8  167.6
 7    150.3  155.3  156.5  117.6  102.5  110.3  167.9  156.9  161.9  171.8  175.8
 8    143.1  147.4  148.9  110.8  101.4  113.1  162.8  168.9  172.1  181.3  188.0

              CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

        1      2      3      4      5      6      7      8      9      10     11

 1     60.8   63.1   63.7   41.2   38.3   45.8   76.9   80.6   81.5   86.7   90.3
 2     61.4   63.7   65.3   39.5   38.4   45.1   75.8   76.3   78.4   83.1   86.9
 3     64.3   68.3   69.1   40.0   38.9   42.8   72.3   69.9   70.4   76.3   80.8
 4     69.6   76.4   76.8   43.5   40.3   44.1   69.5   65.6   66.2   72.8   75.3
 5     73.5   78.4   79.9   47.5   42.4   42.8   66.7   65.0   65.6   71.2   73.9
 6     70.5   75.1   76.5   53.3   42.2   42.4   68.3   65.4   67.1   72.1   75.3
 7     65.7   68.5   69.2   47.6   39.2   43.5   75.5   69.4   72.2   77.7   79.9
 8     61.7   64.1   64.9   43.8   38.6   45.0   72.7   76.0   77.8   82.9   86.6

         MASS FLOW RATE         =  230.1  LBM/HR  ( 0.02899  KG.PER.S)
```

RUN NUMBER 305

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	140.7	144.8	145.7	106.1	100.9	114.5	170.0	176.8	178.5	187.9	194.2
2	141.6	145.8	148.7	102.9	101.2	113.3	167.8	168.8	172.7	181.1	187.9
3	146.9	154.0	155.5	103.8	101.9	108.9	161.4	157.0	157.9	168.5	176.7
4	156.6	169.2	169.8	110.2	104.5	111.6	156.4	149.3	150.2	162.3	166.7
5	164.0	172.8	175.4	117.5	108.4	109.0	151.2	148.2	149.4	159.2	164.2
6	158.3	166.7	169.3	128.6	108.1	108.2	154.0	148.8	152.0	160.9	166.7
7	149.6	154.5	155.7	117.5	102.4	110.2	167.7	156.0	161.1	171.1	175.0
8	142.3	146.5	148.0	110.8	101.4	113.1	161.8	168.3	171.5	180.7	187.4

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	60.4	62.7	63.2	41.2	38.3	45.9	76.7	80.5	81.4	86.6	90.1
2	60.9	63.2	64.8	39.4	38.4	45.2	75.4	76.0	78.2	82.8	86.6
3	63.8	67.8	68.6	39.9	38.8	42.7	71.9	69.5	69.9	75.8	80.4
4	69.2	76.2	76.5	43.4	40.3	44.2	69.1	65.2	65.7	72.4	74.8
5	73.3	78.2	79.7	47.5	42.5	42.8	66.2	64.6	65.2	70.7	73.5
6	70.2	74.9	76.3	53.7	42.3	42.3	67.8	64.9	66.6	71.6	74.8
7	65.3	68.1	68.7	47.5	39.1	43.5	75.4	68.9	71.7	77.3	79.5
8	61.3	63.6	64.4	43.8	38.6	45.1	72.1	75.7	77.5	82.6	86.4

```
                   INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

      1      2      3      4      5      6      7      8      9      10     11

 1  2535.7 2570.9 2808.9  143.7   71.4 -239.3 1240.4  579.3  953.8  841.1  936.0
 2  2696.4 2996.8 2675.8  389.8   44.4 -287.6 1819.5 1851.7 1337.2 1669.0 1757.5
 3  2692.8 2950.1 3002.6  536.8  184.3  674.9 2399.9 2678.2 2989.2 2926.8 2414.0
 4  2005.4 1094.9 1388.5  113.6  132.9 -520.3 2268.9 2948.1 2967.5 2620.5 3073.1
 5   933.4 1246.4 1033.3  382.2 -508.2  189.8 3091.2 2460.9 2649.5 2783.4 2815.3
 6  1914.8 1627.4 1502.1-2271.1 -589.5  297.7 3336.5 2943.1 2939.1 3157.7 2901.0
 7  2399.0 2687.9 2852.5  381.8  447.2   85.3  352.6 2775.0 2391.7 2222.0 2703.3
 8  2831.0 2900.3 2830.3  206.3   48.9 -135.9 3615.6 1865.1 1899.6 2010.4 1691.5

                    INSIDE SURFACES HEAT FLUXES W PER SQ.M.

      1      2      3      4      5      6      7      8      9      10     11

 1  7999.9 8111.1 8861.8  453.5  225.4 -755.0 3913.2 1827.6 3009.1 2653.5 2953.1
 2  8507.0 9454.6 8441.8 1229.8  140.1 -907.5 5740.4 5841.8 4218.8 5265.5 5544.9
 3  8495.4 9307.3 9472.8 1693.7  581.5 2129.3 7571.3 8449.5 9430.7 9233.9 7615.8
 4  6326.9 3454.4 4380.5  358.5  419.2-1641.5 7158.2 9301.1 9362.3 8267.5 9695.4
 5  2944.9 3932.4 3260.0 1205.9-1603.5  598.8 9752.5 7763.9 8358.8 8781.3 8882.1
 6  6041.1 5134.2 4739.1-7165.1-1859.9  939.310526.4 9285.3 9272.7 9962.4 9152.5
 7  7568.7 8480.2 8999.3 1204.4 1410.8  269.1 1112.5 8754.8 7545.5 7010.3 8528.6
 8  8931.7 9150.2 8929.3  650.9  154.1 -428.911406.9 5884.2 5993.1 6342.7 5336.6

                    BULK FLUID TEMPERATURE      - DEGREES F

      1      2      3      4      5      6      7      8      9      10     11

     102.7  112.8  115.3  115.6  115.6  115.6  116.0  118.9  122.3  129.1  135.8

                    BULK FLUID TEMPERATURE      - DEGREES C

      1      2      3      4      5      6      7      8      9      10     11

      39.3   44.9   46.3   46.5   46.5   46.5   46.7   48.3   50.2   53.9   57.7

                  CORRECTED OUTLET TEMPERATURE =   139.9DEG F (    59.9DEG C)
                  CORRECTED INLET TEMPERATURE  =    91.4DEG F (    33.0DEG C)
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                        RUN NUMBER  305
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AVERAGE REYNOLDS NUMBER         = 0.357E 03
AVERAGE PRANDTL NUMBER          = 0.604E 02
MASS FLUX                       = 0.110E 06  LBM/(SQ.FT-HR) 0.149E 03  KG.PER.(S.SQ.M.)
AVERAGE HEAT FLUX               = 0.223E 04  BTU/(SQ.FT-HR) ( 0.703E 04  W PER SQ.M.)
Q=AMP*VOLT                      = 0.676E 04  BTU/HR ( 0.198E 04W)
Q=M*C*(T2-T1)                   = 0.660E 04  BTU/HR ( 0.193E 04W)
HEAT LOST                       = 0.255E 03  BTU/HR ( 0.749E 02W)
HEAT BALANCE ERROR %            =-0.137E 01

     PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

         1       2       3       4       5       6       7       8       9      10      11

 1     66.8    80.3    92.2   -15.0    -4.8   214.9    23.0    10.0    17.0    14.3    16.0
 2     69.2    90.7    80.0   -30.6    -3.1   122.8    35.1    37.1    26.5    32.1    33.7
 3     60.9    71.5    74.7   -45.3   -13.4   -99.3    52.9    70.4    84.1    74.3    59.0
 4     37.2    19.4    25.5   -20.8   -11.9   127.2    56.2    97.2   106.3    78.8    99.6
 5     15.2    20.8    17.2   212.1    70.4   -28.5    88.0    84.0    98.0    92.2    99.0
 6     34.4    30.2    27.8  -175.1    78.5   -39.9    87.9    98.6    99.2    99.2    93.9
 7     51.2    64.4    70.6   202.5   -33.7   -15.8     6.8    74.8    61.6    52.8    68.9
 8     71.5    85.9    86.5   -42.2    -3.4    53.8    79.1    37.8    38.6    39.0    32.8

     PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

         1       2       3       4       5       6       7       8       9      10      11

 1    379.2   456.0   523.4   -85.4   -27.4  1220.1   130.6    56.8    96.5    81.2    91.1
 2    393.0   515.0   454.4  -173.7   -17.4   697.1   199.5   210.8   150.6   182.1   191.5
 3    345.6   406.2   423.9  -257.4   -76.2  -564.1   300.5   399.5   477.5   421.7   335.1
 4    211.2   110.2   144.7  -118.1   -67.8   722.3   319.3   552.1   603.6   447.6   565.5
 5     86.5   118.0    97.6  1204.5   399.6  -161.6   499.7   477.2   556.4   523.7   562.2
 6    195.4   171.3   158.0  -994.4   445.5  -226.6   499.3   559.6   563.1   563.5   532.9
 7    290.4   365.9   400.8  1149.6  -191.5   -89.5    38.7   424.9   349.8   299.8   391.2
 8    406.2   488.0   491.0  -239.8   -19.5   305.5   448.9   214.7   219.4   221.2   186.0
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            AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

         1       2       3       4       5       6       7       8       9      10      11

 (H1)   50.8    57.9    59.3    10.7     9.8    41.9    53.6    63.7    66.4    60.3    62.9
 (H2)   47.6    51.3    52.3     4.2     1.8    -1.8    50.1    56.3    57.6    53.7    55.0

            AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

         1       2       3       4       5       6       7       8       9      10      11

 (H1)  288.5   328.8   336.7    60.6    55.7   237.9   304.6   362.0   377.1   342.6   356.9
 (H2)  270.2   291.5   297.0    23.8     9.9   -10.1   284.4   319.5   327.1   305.2   312.4

   PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

         1       2       3       4       5       6       7       8       9      10      11

LIT(1) -16.01   -2.58   -0.34    0.00    0.00    0.00 -13.43    8.25   11.68   -2.63    0.19
LIT(2) -23.86  -15.72  -13.75    0.00    0.00    0.00 -21.48   -3.94   -1.82  -15.21  -14.03
LIT(3)  -6.04    5.89    7.86    0.00    0.00    0.00  -3.63   15.22   18.31    6.04    8.65
LIT(4) -13.21   -6.16   -4.45    0.00    0.00    0.00 -10.98    3.96    5.82   -5.47   -4.36
LIT(5)  27.52   49.46   52.48    0.00    0.00    0.00-122.46   11.83   34.34   43.49   53.01
LIT(6)  22.61   42.98   46.14    0.00    0.00    0.00-138.25    0.12   24.30   36.57   46.31
LIT(7)  -3.01   -0.03    0.54    0.00    0.00    0.00-586.02   21.21   24.79    7.58    5.22
LIT(8)  -9.98  -12.84  -12.75    0.00    0.00    0.00-634.71   10.74   13.29   -3.75   -8.28
LIT(9)  73.85   81.69   82.81    0.00    0.00    0.00  23.21   69.24   76.74   79.71   83.08
LIT(10)  72.08   79.35   80.51    0.00    0.00    0.00  17.76   65.16   73.19   77.22   80.67
COR(11)   3.33   14.41   16.25    0.00    0.00    0.00  -1.03   21.25   25.31   15.24   17.81
COR(12)  -3.21    3.45    5.06    0.00    0.00    0.00  -8.21   10.78   13.89    4.85    6.10
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                        ---------------
                        RUN NUMBER  305
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            1         2         3         4         5         6         7         8         9        10        11

X/D     0.810E 02 0.154E 03 0.171E 03 0.176E 03 0.178E 03 0.180E 03 0.262E 01 0.236E 02 0.478E 02 0.962E 02 0.145E 03
TB,F    0.103E 03 0.113E 03 0.115E 03 0.116E 03 0.116E 03 0.116E 03 0.116E 03 0.119E 03 0.122E 03 0.129E 03 0.136E 03
JHC     0.152E 02 0.175E 02 0.180E 02 0.358E 01 0.336E 01 0.141E 02 0.162E 02 0.195E 02 0.204E 02 0.185E 02 0.194E 02
RE.NO.  0.280E 03 0.339E 03 0.354E 03 0.357E 03 0.357E 03 0.357E 03 0.359E 03 0.378E 03 0.401E 03 0.448E 03 0.497E 03
PR.NO.  0.763E 02 0.634E 02 0.608E 02 0.604E 02 0.604E 02 0.604E 02 0.600E 02 0.571E 02 0.540E 02 0.486E 02 0.440E 02
GR.NO.  0.130E 05 0.177E 05 0.189E 05-0.154E 04-0.535E 04-0.202E 04 0.203E 05 0.200E 05 0.219E 05 0.293E 05 0.353E 05
HT/HB   0.228E 00 0.259E 00 0.186E 00-0.141E 02-0.686E-01-0.755E 01 0.261E 00 0.119E 00 0.173E 00 0.155E 00 0.162E 00
DE.NO.  0.127E 03 0.154E 03 0.161E 03 0.162E 03 0.162E 03 0.162E 03 0.163E 03 0.172E 03 0.182E 03 0.204E 03 0.226E 03
GR/RE2  0.167E 00 0.154E 00 0.151E 00-0.121E-01-0.420E-01-0.159E-01 0.158E 00 0.140E 00 0.136E 00 0.146E 00 0.143E 00
NU.1    0.169E 02 0.193E 02 0.197E 02 0.355E 01 0.326E 01 0.139E 02 0.178E 02 0.212E 02 0.220E 02 0.200E 02 0.208E 02
NU.2    0.159E 02 0.171E 02 0.174E 02 0.139E 01 0.581E 00-0.589E 00 0.166E 02 0.187E 02 0.191E 02 0.178E 02 0.182E 02

         RUN NO  BR/TR      RE      PR    AVG HEAT FLUX    HEAT GENERATED    HEAT GAINED    HEAT  LOST    H.B.% ERROR
          305    4.839     356    60.4        2228                6761.4         6595.1        255.5          -1.37
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                                ----------------
                                RUN NUMBER  312
                                ----------------

                   CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

          1       2       3       4       5       6       7       8       9      10      11

 1     131.0   132.4   131.9    97.3    92.9    94.7   125.5   148.4   150.8   155.5   157.8
 2     131.5   133.0   133.6    95.4    92.7    94.5   125.3   145.0   147.7   151.0   153.5
 3     134.5   137.4   137.4    96.2    93.5    94.7   124.1   140.0   140.4   143.2   145.9
 4     139.4   146.2   145.8    99.8    96.5    94.5   123.5   137.5   137.8   139.1   139.8
 5     143.5   148.6   149.7   104.9   101.5    95.8   123.3   137.1   136.8   136.5   138.3
 6     140.3   144.8   145.6   113.7   100.5    94.6   123.0   137.2   136.4   137.3   139.2
 7     135.6   137.8   137.5   105.1    94.2    94.2   125.3   139.6   140.5   143.9   144.6
 8     131.9   133.6   133.3   100.1    93.0    94.5   124.1   144.8   146.5   150.5   153.4

                   CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

          1       2       3       4       5       6       7       8       9      10      11

 1      55.0    55.8    55.5    36.3    33.8    34.8    51.9    64.7    66.0    68.6    69.9
 2      55.3    56.1    56.4    35.2    33.7    34.7    51.9    62.8    64.3    66.1    67.5
 3      56.9    58.6    58.5    35.6    34.2    34.8    51.1    60.0    60.2    61.8    63.3
 4      59.7    63.4    63.2    37.7    35.8    34.7    50.8    58.6    58.8    59.5    59.9
 5      62.0    64.8    65.4    40.5    38.6    35.4    50.7    58.4    58.2    58.1    59.1
 6      60.2    62.7    63.1    45.4    38.1    34.8    50.6    58.4    58.0    58.5    59.6
 7      57.6    58.8    58.6    40.6    34.6    34.6    51.8    59.8    60.3    62.2    62.5
 8      55.5    56.4    56.3    37.9    33.9    34.7    51.2    62.7    63.6    65.8    67.4

            MASS FLOW RATE          =    544.3  LBM/HR  ( 0.06858  KG.PER.S)
```

RUN NUMBER 312

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	130.4	131.8	131.3	97.3	92.9	94.7	125.0	148.1	150.5	155.3	157.5
2	130.9	132.3	133.0	95.3	92.6	94.5	124.8	144.5	147.3	150.6	153.1
3	133.9	136.7	136.7	96.1	93.4	94.7	123.5	139.4	139.7	142.6	145.3
4	138.9	145.8	145.4	99.7	96.4	94.5	122.9	136.9	137.2	138.5	139.1
5	143.2	148.3	149.4	104.8	101.8	95.9	122.7	136.6	136.2	135.9	137.7
6	139.8	144.4	145.2	114.3	100.7	94.6	122.4	136.6	135.7	136.6	138.6
7	135.0	137.2	136.9	105.0	94.1	94.2	124.8	139.0	140.0	143.4	143.9
8	131.2	133.0	132.7	100.1	93.0	94.5	123.5	144.3	146.0	150.0	153.0

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	54.7	55.4	55.2	36.3	33.8	34.8	51.7	64.5	65.8	68.5	69.7
2	54.9	55.7	56.1	35.2	33.7	34.7	51.6	62.5	64.0	65.9	67.3
3	56.6	58.2	58.2	35.6	34.1	34.8	50.8	59.7	59.8	61.4	62.9
4	59.4	63.2	63.0	37.6	35.8	34.7	50.5	58.3	58.4	59.2	59.5
5	61.8	64.6	65.2	40.4	38.8	35.5	50.4	58.1	57.9	57.7	58.7
6	59.9	62.4	62.9	45.7	38.2	34.8	50.2	58.1	57.6	58.1	59.2
7	57.2	58.5	58.3	40.6	34.5	34.5	51.6	59.4	60.0	61.9	62.2
8	55.1	56.1	56.0	37.8	33.9	34.7	50.8	62.4	63.4	65.6	67.2

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                    INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

        1       2       3       4       5       6       7       8       9      10      11

 1  1880.3  1927.5  2052.1    86.3    -5.5   -41.4  1556.6  1003.4   961.4   739.7   834.9
 2  1981.0  2127.4  1957.5   258.6    92.1    46.1  1603.3  1579.5  1301.1  1396.7  1389.0
 3  1936.5  2196.7  2223.9   284.4   217.9   -41.4  1795.6  1993.6  2235.5  2126.4  1908.0
 4  1658.6  1073.1  1255.9   155.1   246.0   161.3  1756.9  1956.3  1902.9  1905.6  2225.8
 5   959.2  1082.9   906.6   448.5  -771.3  -281.7  1718.9  1785.1  1798.1  2093.1  1991.7
 6  1579.8  1405.9  1324.4-1892.4  -605.0    86.5  1975.1  1979.4  2213.8  2339.7  2200.8
 7  1834.4  2023.8  2141.4   380.0   518.9    71.3  1366.2  2032.8  1927.1  1745.6  2108.2
 8  2028.3  2045.3  2020.6   204.6    99.0    -5.1  1991.5  1568.7  1565.0  1578.9  1281.6

                     INSIDE SURFACES HEAT FLUXES W PER SQ.M.

        1       2       3       4       5       6       7       8       9      10      11

 1  5932.1  6081.1  6474.1   272.4   -17.2  -130.7  4910.8  3165.5  3033.1  2333.8  2634.2
 2  6249.9  6711.9  6175.8   815.8   290.6   145.6  5058.3  4983.1  4104.7  4406.6  4382.2
 3  6109.6  6930.2  7016.2   897.1   687.6  -130.5  5665.1  6289.5  7052.7  6708.6  6019.4
 4  5232.7  3385.4  3962.4   489.2   776.1   508.9  5543.0  6171.8  6003.4  6012.0  7022.1
 5  3026.3  3416.6  2860.3  1415.1-2433.3  -888.8  5422.8  5631.9  5672.9  6603.5  6283.5
 6  4984.1  4435.4  4178.4-5970.3-1908.8   273.0  6231.3  6244.9  6984.2  7381.4  6943.2
 7  5787.4  6385.0  6755.9  1199.0  1637.2   225.1  4310.3  6413.4  6079.9  5507.4  6651.2
 8  6399.0  6452.9  6374.7   645.4   312.2   -16.1  6283.1  4949.1  4937.5  4981.3  4043.3

                    BULK FLUID TEMPERATURE      - DEGREES F

        1       2       3       4       5       6       7       8       9      10      11

      95.9    99.3   100.1   100.2   100.2   100.2   100.4   101.3   102.5   104.7   106.9

                    BULK FLUID TEMPERATURE      - DEGREES C

        1       2       3       4       5       6       7       8       9      10      11

      35.5    37.4    37.8    37.9    37.9    37.9    38.0    38.5    39.1    40.4    41.6

                  CORRECTED OUTLET TEMPERATURE =   108.3DEG F (     42.4DEG C)
                  CORRECTED INLET TEMPERATURE  =    92.2DEG F (     33.4DEG C)
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                          ---------------
                          RUN NUMBER  312
                          ---------------

AVERAGE REYNOLDS NUMBER        = 0.630E 03
AVERAGE PRANDTL NUMBER         = 0.799E 02
MASS FLUX                      = 0.260E 06  LBM/(SQ.FT-HR) 0.352E 03  KG.PER.(S.SQ.M.)
AVERAGE HEAT FLUX              = 0.173E 04  BTU/(SQ.FT-HR) ( 0.547E 04  W PER SQ.M.)
Q=AMP*VOLT                     = 0.516E 04  BTU/HR ( 0.151E 04W)
Q=M*C*(T2-T1)                  = 0.509E 04  BTU/HR ( 0.149E 04W)
HEAT LOST                      = 0.949E 02  BTU/HR ( 0.278E 02W)
HEAT BALANCE ERROR %           =-0.668E 00

     PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

         1      2      3      4      5      6      7      8      9     10     11

 1      54.6   59.4   65.8  -28.8    0.7    7.5   63.2   21.5   20.0   14.6   16.5
 2      56.7   64.4   59.6  -52.2  -12.1   -8.0   65.5   36.6   29.0   30.4   30.1
 3      51.1   58.7   60.8  -68.2  -31.9    7.5   77.7   52.3   60.1   56.1   49.8
 4      38.7   23.1   27.7 -306.5  -63.6  -27.9   77.9   55.0   54.8   56.4   69.2
 5      20.3   22.1   18.4   99.4 -503.6   64.3   76.9   50.6   53.2   67.2   64.8
 6      36.0   31.2   29.4 -135.0-1301.2  -15.2   89.5   56.1   66.6   73.3   69.6
 7      46.9   53.4   58.3   79.3  -83.9  -11.7   55.9   54.0   51.4   45.1   57.0
 8      57.5   60.7   62.0-1256.2  -13.6    0.9   86.2   36.5   35.9   34.8   27.8

     PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

         1      2      3      4      5      6      7      8      9     10     11

 1     310.1  337.1  373.7 -163.5    4.2   42.6  358.8  121.9  113.6   83.0   93.8
 2     321.9  365.7  338.4 -296.5  -68.7  -45.3  372.1  207.8  164.9  172.8  170.9
 3     290.0  333.3  345.3 -387.1 -181.0   42.4  441.0  297.2  341.0  318.8  282.5
 4     219.5  130.9  157.4-1740.3 -361.3 -158.3  442.2  312.1  311.1  320.4  393.1
 5     115.2  125.5  104.5  564.2-2859.7  365.2  436.7  287.6  302.4  381.5  367.8
 6     204.4  177.1  167.0 -766.7-7388.7  -86.6  508.4  318.8  378.1  416.2  395.1
 7     266.5  303.1  330.9  450.4 -476.6  -66.7  317.3  306.7  291.9  256.4  323.5
 8     326.4  344.8  351.9-7133.2  -77.0    5.0  489.6  207.1  203.9  197.7  158.0
```

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                AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

              1       2       3       4       5       6       7       8       9      10      11

   (H1)     45.2    46.6    47.7 -208.5  -251.1     2.2    74.1    45.3    46.4    47.3    48.1
   (H2)     43.9    44.1    44.8    -7.1     5.6     0.1    73.7    44.2    44.4    44.2    44.6

                AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

              1       2       3       4       5       6       7       8       9      10      11

   (H1)    256.8   264.7   271.1-1184.1-1426.1    12.3   420.7   257.4   263.4   268.3   273.1
   (H2)    249.2   250.1   254.7   -40.4    31.7     0.6   418.5   250.7   252.3   250.8   253.2

     PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

              1       2       3       4       5       6       7       8       9      10      11

LIT(1)  -16.91  -14.96  -11.75    0.00    0.00    0.00   41.22  -19.16  -16.71  -15.97  -14.59
LIT(2)  -20.44  -21.64  -18.98    0.00    0.00    0.00   40.90  -22.32  -21.81  -24.06  -23.61
LIT(3)   -9.13   -7.19   -4.36    0.00    0.00    0.00   42.45  -11.04   -8.78   -7.92   -6.63
LIT(4)  -12.43  -13.43  -11.12    0.00    0.00    0.00   42.14  -13.99  -13.53  -15.44  -15.02
LIT(5)   -9.25   15.76   21.03    0.00    0.00    0.00-104.39  -67.56  -28.19    1.84   16.73
LIT(6)  -12.55   10.86   15.92    0.00    0.00    0.00-105.48  -72.00  -33.79   -5.01   10.18
LIT(7)  -13.96  -21.54  -19.91    0.00    0.00    0.00-420.88  -10.42   -5.50   -9.91  -13.33
LIT(8)  -17.40  -28.60  -27.67    0.00    0.00    0.00-423.65  -13.35  -10.10  -17.58  -22.25
LIT(9)   61.29   69.72   71.55    0.00    0.00    0.00   28.59   41.92   55.18   65.18   70.19
LIT(10)    60.12   67.96   69.71    0.00    0.00    0.00   28.21   40.38   53.22   62.75   67.84
COR(11)    -1.59    0.49    3.05    0.00    0.00    0.00   25.05  -10.46   -2.12    0.22    1.56
COR(12)    -4.66   -5.30   -3.22    0.00    0.00    0.00   24.65  -13.39   -6.58   -6.74   -6.18
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                              ---------------
                              RUN NUMBER  312
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             1          2          3          4          5          6          7          8          9          10          11

X/D     0.810E 02 0.154E 03 0.171E 03 0.176E 03 0.178E 03 0.180E 03 0.262E 01 0.236E 02 0.478E 02 0.962E 02 0.145E 03
TB,F    0.959E 02 0.993E 02 0.100E 03 0.100E 03 0.100E 03 0.100E 03 0.100E 03 0.101E 03 0.102E 03 0.105E 03 0.107E 03
JHC     0.137E 02 0.141E 02 0.145E 02-0.693E 02-0.849E 02 0.734E 00 0.233E 02 0.138E 02 0.141E 02 0.144E 02 0.146E 02
RE.NO.  0.577E 03 0.618E 03 0.629E 03 0.630E 03 0.630E 03 0.630E 03 0.632E 03 0.644E 03 0.659E 03 0.688E 03 0.718E 03
PR.NO.  0.870E 02 0.814E 02 0.801E 02 0.799E 02 0.799E 02 0.799E 02 0.797E 02 0.783E 02 0.766E 02 0.735E 02 0.705E 02
GR.NO.  0.833E 04 0.951E 04 0.965E 04 0.330E 03-0.117E 04-0.139E 04 0.588E 04 0.103E 05 0.107E 05 0.117E 05 0.127E 05
HT/HB   0.371E 00 0.372E 00 0.280E 00-0.345E 01-0.147E-02 0.117E 00 0.822E 00 0.424E 00 0.376E 00 0.218E 00 0.255E 00
DE.NO.  0.262E 03 0.281E 03 0.286E 03 0.286E 03 0.286E 03 0.286E 03 0.287E 03 0.293E 03 0.299E 03 0.313E 03 0.327E 03
GR/RE2  0.250E-01 0.249E-01 0.244E-01 0.831E-03-0.293E-02-0.351E-02 0.147E-01 0.248E-01 0.246E-01 0.248E-01 0.245E-01
NU.1    0.151E 02 0.156E 02 0.159E 02-0.696E 02-0.838E 02 0.723E 00 0.247E 02 0.151E 02 0.155E 02 0.157E 02 0.160E 02
NU.2    0.147E 02 0.147E 02 0.150E 02-0.237E 01 0.186E 01 0.323E-01 0.246E 02 0.147E 02 0.148E 02 0.147E 02 0.148E 02

          RUN NO  BR/TR      RE       PR    AVG HEAT FLUX    HEAT GENERATED    HEAT GAINED    HEAT  LOST    H.B.% ERROR

            312   4.839     630     79.9        1733                5156.0         5094.9        94.9          -0.67
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                         ----------------
                         RUN NUMBER  317
                         ----------------

             CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

         1       2       3       4       5       6       7       8       9      10      11

1     131.2   133.0   132.3    96.7    93.1    93.3   118.2   141.7   148.0   153.3   156.1
2     131.8   133.5   133.7    95.0    92.9    93.3   118.1   140.2   145.0   148.6   151.6
3     134.4   137.4   137.4    95.7    93.7    94.4   117.2   136.9   138.1   140.6   144.5
4     138.9   145.6   145.0    99.0    97.1    93.8   117.4   134.7   135.6   137.7   138.6
5     142.8   148.1   149.0   103.9   103.5    95.7   118.0   134.6   135.3   137.0   137.7
6     139.7   144.4   145.0   113.3   102.0    94.4   117.3   134.8   135.6   137.6   139.5
7     135.5   137.9   137.5   104.3    94.5    93.6   117.9   136.6   139.4   143.3   144.1
8     132.1   133.9   133.5    99.4    93.2    93.4   117.3   139.8   144.6   149.2   152.1

             CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

         1       2       3       4       5       6       7       8       9      10      11

1      55.1    56.1    55.7    36.0    33.9    34.1    47.9    60.9    64.5    67.4    68.9
2      55.4    56.4    56.5    35.0    33.8    34.1    47.8    60.1    62.8    64.8    66.5
3      56.9    58.6    58.5    35.4    34.3    34.7    47.3    58.3    58.9    60.3    62.5
4      59.4    63.1    62.8    37.2    36.2    34.3    47.4    57.1    57.6    58.7    59.2
5      61.5    64.5    65.0    39.9    39.7    35.4    47.8    57.0    57.4    58.4    58.7
6      59.9    62.4    62.8    45.2    38.9    34.7    47.4    57.1    57.6    58.7    59.7
7      57.5    58.8    58.6    40.2    34.7    34.2    47.7    58.1    59.7    61.9    62.3
8      55.6    56.6    56.4    37.4    34.0    34.1    47.4    59.9    62.6    65.1    66.7

          MASS FLOW RATE          =   700.3  LBM/HR  ( 0.08823  KG.PER.S)
```

RUN NUMBER 317

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	130.6	132.4	131.6	96.7	93.1	93.3	117.7	141.2	147.7	153.0	155.8
2	131.2	132.8	133.1	94.9	92.9	93.3	117.6	139.7	144.6	148.1	151.2
3	133.8	136.8	136.7	95.6	93.7	94.5	116.6	136.4	137.4	139.9	143.9
4	138.4	145.2	144.6	98.9	97.0	93.7	116.8	134.1	135.0	137.1	137.9
5	142.4	147.7	148.7	103.7	103.9	95.9	117.5	134.0	134.7	136.5	137.1
6	139.2	143.9	144.6	113.9	102.2	94.4	116.7	134.2	135.0	136.9	138.8
7	134.9	137.3	136.8	104.2	94.3	93.5	117.4	136.0	138.8	142.8	143.5
8	131.5	133.2	132.8	99.3	93.2	93.4	116.7	139.3	144.2	148.7	151.7

INSIDE SURFACE TEMPERATURES - DEGREES C

.SK 1

	1	2	3	4	5	6	7	8	9	10	11
1	54.8	55.8	55.3	35.9	33.9	34.1	47.6	60.7	64.3	67.2	68.8
2	55.1	56.0	56.1	34.9	33.8	34.0	47.5	59.8	62.5	64.5	66.2
3	56.6	58.2	58.2	35.3	34.3	34.7	47.0	58.0	58.6	60.0	62.2
4	59.1	62.9	62.6	37.2	36.1	34.3	47.1	56.7	57.2	58.4	58.8
5	61.3	64.3	64.8	39.8	40.0	35.5	47.5	56.7	57.1	58.0	58.4
6	59.6	62.2	62.5	45.5	39.0	34.7	47.1	56.8	57.2	58.3	59.4
7	57.2	58.5	58.2	40.1	34.6	34.2	47.4	57.8	59.3	61.5	61.9
8	55.3	56.2	56.0	37.4	34.0	34.1	47.1	59.6	62.3	64.8	66.5

```
                    INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

       1       2       3       4       5       6       7       8       9      10      11

 1  1943.3  1930.9  2057.0    80.0     3.1     5.3  1654.9  1428.9  1112.8   863.7   902.9
 2  1989.7  2138.8  2015.5   241.0    88.0   115.1  1678.9  1601.2  1377.2  1449.7  1511.3
 3  1966.9  2224.8  2198.8   251.2   254.1  -183.4  1867.8  1887.7  2249.0  2311.0  1919.4
 4  1720.4  1187.8  1396.3   175.2   364.7   294.7  1817.3  1990.1  2011.6  2025.2  2311.5
 5  1060.0  1136.6   954.0   549.1-1027.3  -383.6  1613.8  1828.3  1844.0  1908.1  2062.6
 6  1650.8  1495.5  1413.3-2017.6  -674.7    55.4  1897.6  1937.6  2141.8  2330.0  2087.8
 7  1874.4  2041.2  2154.5   436.8   643.9    71.6  1634.0  1928.4  1940.3  1794.8  2144.5
 8  2029.0  2104.2  2069.6   217.3    90.9     7.4  1921.1  1643.1  1590.2  1611.1  1370.5

                     INSIDE SURFACES HEAT FLUXES W PER SQ.M.

       1       2       3       4       5       6       7       8       9      10      11

 1  6131.0  6091.9  6489.5   252.3     9.9    16.6  5220.9  4508.0  3510.8  2725.0  2848.6
 2  6277.2  6747.7  6358.8   760.3   277.5   363.0  5296.9  5051.6  4344.9  4573.6  4768.1
 3  6205.5  7018.9  6937.0   792.6   801.8  -578.6  5892.8  5955.6  7095.3  7291.1  6055.6
 4  5427.7  3747.5  4405.2   552.8  1150.5   929.6  5733.5  6278.5  6346.4  6389.2  7292.4
 5  3344.3  3585.9  3009.9  1732.2-3240.9-1210.2  5091.3  5768.2  5817.5  6019.9  6507.2
 6  5208.0  4718.3  4458.8-6365.2-2128.6   174.8  5986.8  6113.1  6757.3  7350.8  6586.8
 7  5913.7  6439.8  6797.2  1378.2  2031.4   225.9  5155.2  6083.8  6121.4  5662.3  6765.7
 8  6401.4  6638.7  6529.3   685.4   286.7    23.5  6060.9  5183.9  5017.0  5082.7  4323.8

                     BULK FLUID TEMPERATURE      - DEGREES F

       1       2       3       4       5       6       7       8       9      10      11

    95.6    98.3    99.0    99.1    99.1    99.1    99.2   100.0   100.9   102.7   104.6

                     BULK FLUID TEMPERATURE      - DEGREES C

       1       2       3       4       5       6       7       8       9      10      11

    35.3    36.8    37.2    37.3    37.3    37.3    37.3    37.8    38.3    39.3    40.3

                  CORRECTED OUTLET TEMPERATURE =   105.7DEG F (    40.9DEG C)
                  CORRECTED INLET TEMPERATURE  =    92.5DEG F (    33.6DEG C)
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                         ---------------
                         RUN NUMBER  317
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     AVERAGE REYNOLDS NUMBER        = 0.792E 03
     AVERAGE PRANDTL NUMBER         = 0.817E 02
     MASS FLUX                      = 0.334E 06  LBM/(SQ.FT-HR) 0.453E 03  KG.PER.(S.SQ.M.)
     AVERAGE HEAT FLUX              = 0.178E 04  BTU/(SQ.FT-HR) ( 0.560E 04  W PER SQ.M.)
     Q=AMP*VOLT                     = 0.529E 04  BTU/HR ( 0.155E 04W)
     Q=M*C*(T2-T1)                  = 0.537E 04  BTU/HR ( 0.157E 04W)
     HEAT LOST                      = 0.102E 03  BTU/HR ( 0.297E 02W)
     HEAT BALANCE ERROR %           =-0.346E 01

          PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

            1       2       3       4       5       6       7       8       9      10      11

 1        55.6    56.7    63.0   -33.4    -0.5    -0.9    89.5    34.6    23.8    17.2    17.6
 2        55.9    62.0    59.2   -57.3   -14.2   -19.7    91.4    40.3    31.5    32.0    32.4
 3        51.4    57.9    58.3   -72.4   -46.7    39.7   107.2    51.9    61.7    62.2    48.8
 4        40.2    25.3    30.6  -872.9  -173.2   -54.2   103.4    58.3    59.1    59.0    69.4
 5        22.6    23.0    19.2   119.2  -213.6   118.8    88.0    53.8    54.5    56.6    63.4
 6        37.8    32.8    31.0  -135.9  -218.3   -11.8   108.2    56.6    62.9    68.3    60.9
 7        47.7    52.4    57.0    85.7  -133.5   -12.9    89.8    53.5    51.2    44.8    55.2
 8        56.5    60.3    61.2   939.7   -15.4    -1.3   109.9    41.8    36.8    35.1    29.1

          PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

            1       2       3       4       5       6       7       8       9      10      11

 1       315.4   322.1   358.0  -189.8    -2.9    -5.2   508.4   196.7   135.1    97.6   100.1
 2       317.4   352.0   335.9  -325.2   -80.4  -112.0   518.9   229.1   179.1   181.5   184.2
 3       291.9   328.6   331.1  -411.1  -265.4   225.3   608.7   294.7   350.1   353.0   277.1
 4       228.3   143.8   173.9-4956.7  -983.7  -307.8   586.9   331.0   335.4   335.2   393.8
 5       128.5   130.6   109.1   677.1-1212.6   674.5   499.8   305.4   309.5   321.4   360.2
 6       214.7   186.3   176.2  -771.6-1239.8   -67.0   614.6   321.4   357.0   387.5   346.0
 7       270.7   297.7   323.6   486.8  -757.8   -73.2   510.0   304.0   290.9   254.6   313.2
 8       320.8   342.3   347.4  5336.0   -87.7    -7.4   623.8   237.4   208.8   199.2   165.2
```

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            AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

          1      2      3      4      5      6      7      8      9     10     11

  (H1)   46.0   46.3   47.4   -3.4 -101.9    7.2   98.4   48.9   47.7   46.9   47.1
  (H2)   44.9   44.2   45.0   -4.6   11.4    0.4   98.2   48.3   46.0   44.5   44.3

            AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

          1      2      3      4      5      6      7      8      9     10     11

  (H1)  261.0  262.9  269.4  -19.3 -578.8   40.9  558.9  277.5  270.7  266.3  267.5
  (H2)  254.7  250.9  255.5  -26.2   64.6    2.4  557.7  274.2  261.4  252.9  251.4

    PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

          1      2      3      4      5      6      7      8      9     10     11

LIT(1) -15.08 -16.40 -13.05   0.00   0.00   0.00  60.12  -6.94 -12.34 -16.82 -17.53
LIT(2) -17.92 -21.98 -19.19   0.00   0.00   0.00  60.04  -8.21 -16.38 -22.97 -25.05
LIT(3)  -7.39  -8.32  -5.37   0.00   0.00   0.00  60.09  -0.35  -4.86  -8.59  -9.09
LIT(4) -10.04 -13.51 -11.09   0.00   0.00   0.00  60.00  -1.54  -8.63 -14.30 -16.07
LIT(5) -17.63   7.01  12.86   0.00   0.00   0.00 -64.72 -68.51 -36.10  -8.44   6.67
LIT(6) -20.54   2.55   8.13   0.00   0.00   0.00 -65.07 -70.51 -40.99 -14.14   0.70
LIT(7) -18.11 -29.19 -27.36   0.00   0.00   0.00-329.76  -5.95  -7.02 -15.82 -21.13
LIT(8) -21.03 -35.38 -34.27   0.00   0.00   0.00-330.67  -7.21 -10.87 -21.92 -28.88
LIT(9)  58.55  66.77  68.78   0.00   0.00   0.00  42.28  41.65  52.58  61.74  66.77
LIT(10)  57.53  65.17  67.08   0.00   0.00   0.00  42.16  40.96  50.88  59.73  64.64
COR(11)   0.03  -0.48   2.18   0.00   0.00   0.00  35.65  -5.51   0.43  -0.47  -0.67
COR(12)  -2.44  -5.29  -3.13   0.00   0.00   0.00  35.51  -6.77  -3.15  -5.76  -7.11
```

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                               ---------------
                               RUN NUMBER  317
                               ---------------

             1         2         3         4         5         6         7         8         9         10         11

X/D     0.810E 02 0.154E 03 0.171E 03 0.176E 03 0.178E 03 0.180E 03 0.262E 01 0.236E 02 0.478E 02 0.962E 02 0.145E 03
TB,F    0.956E 02 0.983E 02 0.990E 02 0.991E 02 0.991E 02 0.991E 02 0.992E 02 0.100E 03 0.101E 03 0.103E 03 0.105E 03
JHC     0.139E 02 0.140E 02 0.144E 02-0.113E 01-0.343E 02 0.244E 01 0.313E 02 0.149E 02 0.145E 02 0.142E 02 0.143E 02
RE.NO.  0.737E 03 0.780E 03 0.790E 03 0.792E 03 0.792E 03 0.792E 03 0.794E 03 0.807E 03 0.822E 03 0.852E 03 0.883E 03
PR.NO.  0.876E 02 0.830E 02 0.819E 02 0.817E 02 0.817E 02 0.817E 02 0.816E 02 0.803E 02 0.789E 02 0.762E 02 0.736E 02
GR.NO.  0.825E 04 0.937E 04 0.945E 04 0.434E 03-0.677E 03-0.122E 04 0.431E 04 0.915E 04 0.997E 04 0.111E 05 0.120E 05
HT/HB   0.407E 00 0.406E 00 0.305E 00-0.357E 01 0.243E-02-0.767E-02 0.102E 01 0.644E 00 0.437E 00 0.304E 00 0.278E 00
DE.NO.  0.335E 03 0.354E 03 0.359E 03 0.360E 03 0.360E 03 0.360E 03 0.361E 03 0.367E 03 0.373E 03 0.387E 03 0.401E 03
GR/RE2  0.152E-01 0.154E-01 0.151E-01 0.692E-03-0.108E-02-0.195E-02 0.684E-02 0.141E-01 0.148E-01 0.153E-01 0.153E-01
NU.1    0.154E 02 0.155E 02 0.158E 02-0.114E 01-0.340E 02 0.240E 01 0.329E 02 0.163E 02 0.159E 02 0.156E 02 0.157E 02
NU.2    0.150E 02 0.148E 02 0.150E 02-0.154E 01 0.380E 01 0.144E 00 0.328E 02 0.161E 02 0.154E 02 0.149E 02 0.148E 02

   RUN NO  BR/TR      RE       PR    AVG HEAT FLUX   HEAT GENERATED   HEAT GAINED   HEAT  LOST    H.B.% ERROR

     317   4.839     792     81.7       1776               5289.7         5367.5        101.5          -3.46
```

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                               ---------------
                               RUN NUMBER  318
                               ---------------

                   CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

        1        2        3        4        5        6        7        8        9       10       11

 1    150.6    153.1    152.4     99.3     93.4     95.9    142.7    179.3    181.5    187.1    191.3
 2    151.5    154.0    154.7     96.5     93.1     95.7    142.2    172.1    174.7    177.9    183.2
 3    156.1    160.7    160.7     97.7     94.5     96.3    139.6    163.3    159.6    162.6    169.7
 4    164.4    175.5    174.7    102.9     99.6     96.0    139.4    159.7    153.2    157.5    159.7
 5    172.2    180.1    181.8    110.6    109.4     98.1    140.4    159.8    152.2    156.2    157.8
 6    166.1    173.2    174.4    125.8    107.1     96.1    139.2    159.6    154.4    158.2    160.1
 7    158.1    161.5    160.9    111.4     95.5     95.3    141.2    163.5    162.8    168.4    168.7
 8    152.2    154.8    154.3    103.5     93.7     95.8    139.7    172.6    173.7    179.5    183.6

                   CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

        1        2        3        4        5        6        7        8        9       10       11

 1     65.9     67.3     66.9     37.4     34.1     35.5     61.5     81.8     83.1     86.2     88.5
 2     66.4     67.8     68.2     35.9     33.9     35.4     61.2     77.9     79.3     81.0     84.0
 3     69.0     71.5     71.5     36.5     34.7     35.7     59.8     73.0     70.9     72.6     76.5
 4     73.5     79.7     79.3     39.4     37.6     35.5     59.7     70.9     67.3     69.7     71.0
 5     77.9     82.3     83.2     43.7     43.0     36.7     60.2     71.0     66.8     69.0     69.9
 6     74.5     78.4     79.1     52.1     41.7     35.6     59.6     70.9     68.0     70.1     71.2
 7     70.1     71.9     71.6     44.1     35.3     35.1     60.7     73.1     72.7     75.8     76.0
 8     66.8     68.2     68.0     39.7     34.3     35.5     59.8     78.1     78.7     81.9     84.2

            MASS FLOW RATE          =    700.3  LBM/HR  ( 0.08823  KG.PER.S)
```

RUN NUMBER 318

INSIDE SURFACE TEMPERATURES - DEGREES F

	1	2	3	4	5	6	7	8	9	10	11
1	149.6	152.1	151.3	99.3	93.4	95.9	141.9	178.7	181.0	186.7	190.8
2	150.4	152.8	153.7	96.4	93.0	95.7	141.3	171.2	174.0	177.1	182.4
3	155.1	159.5	159.5	97.6	94.3	96.3	138.6	162.2	158.4	161.3	168.6
4	163.4	174.8	174.0	102.8	99.4	95.9	138.4	158.6	152.0	156.5	158.5
5	171.7	179.5	181.3	110.3	109.9	98.3	139.5	158.9	151.1	155.2	156.7
6	165.2	172.4	173.6	126.8	107.5	96.1	138.2	158.5	153.2	157.0	158.9
7	157.1	160.4	159.8	111.2	95.3	95.2	140.3	162.4	161.8	167.5	167.6
8	151.1	153.7	153.2	103.4	93.7	95.8	138.6	171.7	172.8	178.6	182.9

INSIDE SURFACE TEMPERATURES - DEGREES C

	1	2	3	4	5	6	7	8	9	10	11
1	65.3	66.7	66.3	37.4	34.1	35.5	61.0	81.5	82.8	85.9	88.2
2	65.8	67.1	67.6	35.8	33.9	35.4	60.7	77.4	78.9	80.6	83.6
3	68.4	70.8	70.8	36.4	34.6	35.7	59.2	72.3	70.2	71.9	75.9
4	73.0	79.4	78.9	39.3	37.5	35.5	59.1	70.3	66.7	69.1	70.3
5	77.6	81.9	82.9	43.5	43.3	36.8	59.7	70.5	66.2	68.4	69.3
6	74.0	78.0	78.7	52.6	41.9	35.6	59.0	70.3	67.3	69.4	70.5
7	69.5	71.3	71.0	44.0	35.1	35.1	60.2	72.5	72.1	75.3	75.3
8	66.1	67.6	67.3	39.7	34.3	35.5	59.2	77.6	78.2	81.4	83.8

```
                     INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

        1      2      3      4      5      6      7      8      9     10     11

 1  3407.1 3441.2 3617.2  126.7   -1.6  -31.8 2735.1 1691.2 1587.6 1342.4 1481.9
 2  3556.3 3785.0 3549.7  376.7  154.1   85.6 2911.0 2987.5 2280.2 2536.7 2596.2
 3  3533.1 4025.8 4024.8  404.9  376.4 -101.9 3365.8 3714.0 4093.8 4260.9 3559.2
 4  3120.7 2074.0 2422.0  265.7  551.7  285.3 3246.2 3575.5 3741.7 3570.7 4035.3
 5  1653.2 1929.4 1611.4  906.0-1541.1 -489.0 2894.4 3125.5 3499.3 3520.2 3629.9
 6  2958.3 2654.4 2519.0-3250.7-1070.7  132.1 3452.1 3618.6 3829.2 4061.7 3854.3
 7  3370.0 3699.9 3895.5  709.5 1001.6  142.5 2745.4 3709.5 3426.5 3251.0 3853.7
 8  3625.1 3687.9 3660.8  349.5  133.2  -40.9 3606.1 2908.6 2839.2 2818.2 2400.1

                      INSIDE SURFACES HEAT FLUXES W PER SQ.M.

        1      2      3      4      5      6      7      8      9     10     11

 1 10749.110856.711412.1  399.7   -4.9 -100.4 8629.0 5335.5 5008.8 4235.0 4675.2
 2 11219.911941.211198.9 1188.3  486.2  269.9 9183.8 9425.4 7193.9 8003.0 8190.9
 3 11146.712701.012698.0 1277.3 1187.6 -321.610618.911717.212915.613442.711229.1
 4  9845.4 6543.3 7641.0  838.2 1740.7  900.010241.511280.311804.811265.412731.1
 5  5215.8 6087.2 5083.9 2858.5-4861.9-1542.7 9131.4 9860.711040.011106.011452.1
 6  9333.2 8374.3 7947.3*******-3378.1  416.810891.111416.412080.812814.412160.0
 7 10632.111672.912290.1 2238.4 3159.9  449.4 8661.511703.110810.310256.612158.1
 8 11436.911634.911549.4 1102.7  420.1 -129.011377.1 9176.3 8957.3 8891.1 7572.2

                      BULK FLUID TEMPERATURE      - DEGREES F

        1      2      3      4      5      6      7      8      9     10     11

     98.0  103.0  104.2  104.3  104.3  104.3  104.5  106.0  107.6  110.9  114.2

                      BULK FLUID TEMPERATURE      - DEGREES C

        1      2      3      4      5      6      7      8      9     10     11

     36.7   39.4   40.1   40.2   40.2   40.2   40.3   41.1   42.0   43.8   45.7

                    CORRECTED OUTLET TEMPERATURE =   116.2DEG F (    46.8DEG C)
                    CORRECTED INLET TEMPERATURE  =    92.5DEG F (    33.6DEG C)
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                         ---------------
                         RUN NUMBER  318
                         ---------------

AVERAGE REYNOLDS NUMBER          = 0.879E 03
AVERAGE PRANDTL NUMBER           = 0.739E 02
MASS FLUX                        = 0.334E 06  LBM/(SQ.FT-HR) 0.453E 03  KG.PER.(S.SQ.M.)
AVERAGE HEAT FLUX                = 0.318E 04  BTU/(SQ.FT-HR) ( 0.100E 05  W PER SQ.M.)
Q=AMP*VOLT                       = 0.942E 04  BTU/HR ( 0.276E 04W)
Q=M*C*(T2-T1)                    = 0.969E 04  BTU/HR ( 0.284E 04W)
HEAT LOST                        = 0.143E 03  BTU/HR ( 0.420E 02W)
HEAT BALANCE ERROR %             =-0.449E 01

    PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

        1      2      3      4      5      6      7      8      9     10     11

1     66.0   70.1   76.7  -25.1    0.1    3.8   73.2   23.2   21.6   17.7   19.4
2     67.9   75.9   71.7  -47.6  -13.6   -9.9   79.3   45.8   34.3   38.3   38.1
3     61.9   71.2   72.8  -59.8  -37.6   12.7   98.9   66.0   80.7   84.5   65.4
4     47.7   28.8   34.7 -171.6 -112.2  -33.6   95.9   68.0   84.2   78.4   91.0
5     22.4   25.2   20.9  151.6 -276.8   80.9   82.9   59.1   80.4   79.5   85.4
6     44.0   38.2   36.3 -145.1 -340.2  -16.0  102.7   68.9   83.9   88.2   86.1
7     57.0   64.4   70.1  104.3 -110.1  -15.6   76.7   65.7   63.3   57.5   72.2
8     68.3   72.6   74.6 -375.9  -12.5    4.8  106.0   44.2   43.5   41.6   34.9

    PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

        1      2      3      4      5      6      7      8      9     10     11

1    375.0  397.8  435.5 -142.4    0.8   21.5  415.8  132.0  122.8  100.6  109.9
2    385.3  430.9  407.2 -270.5  -77.4  -56.0  450.1  259.9  195.0  217.6  216.1
3    351.6  404.3  413.1 -339.5 -213.7   72.3  561.6  374.9  458.1  479.6  371.2
4    270.9  163.8  197.0 -974.1 -637.3 -190.9  544.6  385.9  478.3  445.0  516.7
5    127.4  143.2  118.7  860.7-1571.7  459.3  470.4  335.5  456.5  451.5  484.7
6    250.0  217.2  206.0 -824.0-1931.8  -90.7  582.9  391.3  476.7  500.8  489.1
7    323.9  365.8  397.9  592.3 -625.3  -88.6  435.3  373.1  359.3  326.4  410.0
8    388.0  412.4  423.7-2134.6  -70.8   27.2  601.7  251.1  247.2  236.3  198.4
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          AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

       1       2       3       4       5       6       7       8       9      10      11

 (H1)  54.4    55.8    57.2   -71.2 -112.9     3.4    89.4    55.1    61.5    60.7    61.6
 (H2)  52.6    52.5    53.5    -8.6    8.2     0.3    89.0    53.4    57.0    56.0    56.1

          AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

       1       2       3       4       5       6       7       8       9      10      11

 (H1) 309.0   316.9   324.9  -404.0  -640.9   19.3   507.8   313.0   349.2   344.7   349.5
 (H2) 298.7   298.3   303.8   -48.9    46.7    1.6   505.5   303.1   323.9   318.2   318.6

   PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

         1       2       3       4       5       6       7       8       9      10      11

LIT(1) -18.33  -17.89  -14.57   0.00    0.00    0.00   41.63  -19.94   -4.85   -8.52   -8.34
LIT(2) -22.42  -25.26  -22.54   0.00    0.00    0.00   41.36  -23.84  -13.04  -17.57  -18.87
LIT(3)  -5.59   -4.92   -2.12   0.00    0.00    0.00   45.03   -6.79    6.00    3.06    3.36
LIT(4)  -9.23  -11.48   -9.23   0.00    0.00    0.00   44.77  -10.26   -1.34   -5.02   -6.03
LIT(5)  -3.12   20.18   25.30   0.00    0.00    0.00  -88.45  -55.21   -8.47   14.11   26.90
LIT(6)  -6.68   15.19   20.11   0.00    0.00    0.00  -89.33  -60.26  -16.95    6.94   19.80
LIT(7) -17.16  -26.82  -25.22   0.00    0.00    0.00-498.29  -11.06    4.59   -3.38   -7.85
LIT(8) -21.20  -34.75  -33.94   0.00    0.00    0.00-501.08  -14.67   -2.87  -12.00  -18.33
LIT(9)  63.70   71.52   73.29   0.00    0.00    0.00   34.07   46.36   62.29   69.78   74.05
LIT(10)  62.44   69.74   71.43   0.00    0.00    0.00   33.77   44.61   59.34   67.26   71.53
COR(11)   5.05    6.07    8.54   0.00    0.00    0.00   12.00  -10.05   13.19   13.24   13.80
COR(12)   1.78    0.20    2.17   0.00    0.00    0.00   11.59  -13.63    6.41    6.00    5.42
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                                   ---------------
                                   RUN NUMBER  318
                                   ---------------

             1          2          3          4          5          6          7          8          9          10         11

X/D     0.810E 02 0.154E 03 0.171E 03 0.176E 03 0.178E 03 0.180E 03 0.262E 01 0.236E 02 0.478E 02 0.962E 02 0.145E 03
TB,F    0.980E 02 0.103E 03 0.104E 03 0.104E 03 0.104E 03 0.104E 03 0.105E 03 0.106E 03 0.108E 03 0.111E 03 0.114E 03
JHC     0.159E 02 0.163E 02 0.168E 02-0.236E 02-0.383E 02 0.116E 01 0.274E 02 0.162E 02 0.182E 02 0.180E 02 0.183E 02
RE.NO.  0.775E 03 0.855E 03 0.876E 03 0.879E 03 0.879E 03 0.879E 03 0.882E 03 0.907E 03 0.936E 03 0.996E 03 0.106E 04
PR.NO.  0.835E 02 0.759E 02 0.742E 02 0.739E 02 0.739E 02 0.739E 02 0.737E 02 0.718E 02 0.696E 02 0.656E 02 0.619E 02
GR.NO.  0.137E 05 0.168E 05 0.172E 05 0.476E 03-0.177E 04-0.241E 04 0.104E 05 0.185E 05 0.184E 05 0.212E 05 0.239E 05
HT/HB   0.340E 00 0.360E 00 0.273E 00-0.605E 01-0.512E-03 0.468E-01 0.884E 00 0.393E 00 0.269E 00 0.223E 00 0.227E 00
DE.NO.  0.352E 03 0.389E 03 0.398E 03 0.400E 03 0.400E 03 0.400E 03 0.401E 03 0.412E 03 0.426E 03 0.453E 03 0.481E 03
GR/RE2  0.229E-01 0.229E-01 0.225E-01 0.616E-03-0.229E-02-0.311E-02 0.133E-01 0.225E-01 0.210E-01 0.214E-01 0.213E-01
NU.1    0.182E 02 0.186E 02 0.191E 02-0.237E 02-0.376E 02 0.113E 01 0.298E 02 0.184E 02 0.205E 02 0.202E 02 0.205E 02
NU.2    0.176E 02 0.175E 02 0.178E 02-0.287E 01 0.274E 01 0.928E-01 0.297E 02 0.178E 02 0.190E 02 0.186E 02 0.186E 02

          RUN NO  BR/TR      RE      PR    AVG HEAT FLUX   HEAT GENERATED   HEAT GAINED   HEAT  LOST    H.B.% ERROR

           318    4.839     879     73.9       3176                9418.3        9691.4       143.4          -4.49
```

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                           ---------------
                           RUN NUMBER  354
                           ---------------

                    CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES F

         1      2      3      4      5      6      7      8      9     10     11

 1    158.2  161.1  160.0   95.4   92.3   91.8  110.5  138.6  152.8  178.3  187.7
 2    158.7  161.8  162.2   93.5   92.1   91.7  111.5  139.2  154.1  174.3  180.2
 3    162.6  167.4  167.5   94.3   93.5   94.0  115.7  143.1  158.7  168.2  173.2
 4    169.1  180.5  179.9   97.8  101.2   92.5  118.4  148.0  160.4  165.6  169.3
 5    175.4  185.1  186.8  104.9  121.7   96.9  122.4  149.0  160.7  165.5  168.8
 6    171.4  178.5  179.4  126.5  115.4   94.0  119.3  146.5  159.1  169.0  170.1
 7    165.1  168.4  167.4  107.4   94.7   92.4  112.1  143.0  157.3  174.2  176.3
 8    159.6  162.7  161.8   98.7   92.5   91.8  114.6  141.0  155.3  177.8  185.0

                    CORRECTED OUTSIDE SURFACE TEMPERATURES -DEGREES C

         1      2      3      4      5      6      7      8      9     10     11

 1     70.1   71.7   71.1   35.2   33.5   33.2   43.6   59.2   67.1   81.3   86.5
 2     70.4   72.1   72.4   34.2   33.4   33.2   44.2   59.5   67.9   79.1   82.4
 3     72.5   75.2   75.3   34.6   34.2   34.5   46.5   61.7   70.4   75.7   78.4
 4     76.2   82.5   82.2   36.5   38.4   33.6   48.0   64.4   71.3   74.2   76.3
 5     79.7   85.1   86.0   40.5   49.8   36.1   50.2   65.0   71.5   74.2   76.0
 6     77.5   81.4   81.9   52.5   46.3   34.5   48.5   63.6   70.6   76.1   76.7
 7     73.9   75.8   75.2   41.9   34.8   33.5   44.5   61.7   69.6   79.0   80.2
 8     70.9   72.6   72.1   37.1   33.6   33.2   45.9   60.6   68.5   81.0   85.0

            MASS FLOW RATE          =  1696.5  LBM/HR  ( 0.21376  KG.PER.S)
```

```
                         ---------------
                         RUN NUMBER  354
                         ---------------

                INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10      11

 1    156.8   159.7   158.6    95.4    92.3    91.8   109.0   137.2   151.4   177.2   186.7
 2    157.3   160.3   160.9    93.4    92.1    91.7   110.1   137.8   152.8   173.1   179.0
 3    161.2   165.9   166.0    94.2    93.3    94.1   114.5   141.8   157.5   166.8   171.8
 4    167.8   179.5   178.8    97.7   100.7    92.3   117.1   146.9   159.2   164.2   168.0
 5    174.5   184.2   185.9   104.4   123.0    97.2   121.3   147.8   159.4   164.1   167.5
 6    170.2   177.3   178.3   127.9   115.9    94.0   118.1   145.3   157.8   167.7   168.6
 7    163.8   167.0   166.0   107.1    94.1    92.3   110.5   141.7   156.0   172.9   175.0
 8    158.2   161.3   160.5    98.6    92.5    91.8   113.5   139.8   154.1   176.6   183.9

                INSIDE SURFACE TEMPERATURES - DEGREES C

        1       2       3       4       5       6       7       8       9      10      11

 1     69.4    71.0    70.4    35.2    33.5    33.2    42.8    58.5    66.3    80.7    86.0
 2     69.6    71.3    71.6    34.1    33.4    33.1    43.4    58.8    67.1    78.4    81.6
 3     71.8    74.4    74.5    34.6    34.1    34.5    45.8    61.0    69.7    74.9    77.7
 4     75.5    81.9    81.6    36.5    38.2    33.5    47.3    63.8    70.7    73.5    75.5
 5     79.2    84.5    85.5    40.2    50.5    36.2    49.6    64.4    70.8    73.4    75.3
 6     76.8    80.7    81.3    53.3    46.6    34.4    47.9    62.9    69.9    75.4    75.9
 7     73.2    75.0    74.4    41.7    34.5    33.5    43.6    60.9    68.9    78.3    79.4
 8     70.1    71.8    71.4    37.0    33.6    33.2    45.3    59.9    67.8    80.3    84.4
```

```
                      INSIDE SURFACES HEAT FLUXES BTU/HR.FT2

      1      2      3      4      5      6      7      8      9     10     11

1  4384.9 4442.5 4632.1  119.2    1.2    1.0 4598.7 4452.3 4572.0 3699.5 3102.6
2  4550.9 4731.5 4520.5  260.4  139.2  229.0 4390.3 4480.2 4504.6 3968.4 4248.9
3  4449.9 4985.6 4961.8  267.0  624.4 -392.7 3908.4 4223.9 3849.7 4567.7 4548.4
4  4165.3 3279.3 3592.6  377.0 1537.5  657.8 4183.7 3714.7 4008.2 4468.8 4564.3
5  3057.2 2977.3 2647.1 1736.0-3494.9 -848.6 3327.1 3755.1 3959.4 4579.8 4408.5
6  3926.1 3817.6 3703.1-4481.0-1628.9  140.9 3630.6 4017.6 4134.5 4378.8 4739.7
7  4272.2 4656.7 4871.8 1117.9 1901.1  114.4 5069.0 4287.9 4140.4 4024.9 4467.7
8  4612.0 4638.0 4600.9  513.9  163.2   45.6 3373.6 4076.6 4101.3 3860.2 3558.7

                       INSIDE SURFACES HEAT FLUXES W PER SQ.M.

      1      2      3      4      5      6      7      8      9     10     11

1 13834.014015.714613.7  376.2    3.7    3.214508.614046.714424.111671.6 9788.3
2 14357.814927.414261.9  821.5  439.1  722.513851.114134.614211.712520.113404.9
3 14039.115729.115654.0  842.4 1970.1-1238.912330.713325.912145.314410.514349.9
4 13141.210345.911334.4 1189.5 4850.8 2075.213199.311719.512645.514098.814399.8
5  9645.3 9393.1 8351.3 5477.0*******-2677.310496.811846.912491.514448.913908.4
6 12386.512044.311683.1*******-5139.0  444.411454.312675.213044.113814.614953.3
7 13478.414691.515370.1 3526.8 5997.9  360.915992.213528.013062.712698.114095.1
8 14550.514632.414515.5 1621.2  515.0  143.910643.312861.312939.112178.611227.4

                       BULK FLUID TEMPERATURE      - DEGREES F

      1      2      3      4      5      6      7      8      9     10     11

    94.8   97.5   98.1   98.3   98.3   98.3   98.4   99.1  100.0  101.8  103.6

                       BULK FLUID TEMPERATURE      - DEGREES C

      1      2      3      4      5      6      7      8      9     10     11

    34.9   36.4   36.7   36.8   36.8   36.8   36.9   37.3   37.8   38.8   39.8

                     CORRECTED OUTLET TEMPERATURE =    104.7DEG F (    40.4DEG C)
                     CORRECTED INLET TEMPERATURE  =     91.8DEG F (    33.2DEG C)
```

```
                         ---------------
                         RUN NUMBER  354
                         ---------------

AVERAGE REYNOLDS NUMBER        = 0.197E 04
AVERAGE PRANDTL NUMBER         = 0.778E 02
MASS FLUX                      = 0.809E 06  LBM/(SQ.FT-HR) 0.110E 04  KG.PER.(S.SQ.M.)
AVERAGE HEAT FLUX              = 0.423E 04  BTU/(SQ.FT-HR) ( 0.133E 05  W PER SQ.M.)
Q=AMP*VOLT                     = 0.124E 05  BTU/HR ( 0.362E 04W)
Q=M*C*(T2-T1)                  = 0.127E 05  BTU/HR ( 0.372E 04W)
HEAT LOST                      = 0.746E-02  BTU/HR ( 0.219E-02W)
HEAT BALANCE ERROR %           =-0.279E 01

     PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/(SQ.FT-HR-DEG.F)

        1      2      3      4      5      6      7      8      9     10     11

1      70.7   71.4   76.6  -42.0   -0.2   -0.2  430.1  116.9   89.0   49.1   37.3
2      72.8   75.3   72.1  -54.1  -22.5  -34.8  372.9  115.8   85.4   55.7   56.4
3      67.0   72.8   73.1  -66.2 -125.9   95.5  242.6   98.9   66.9   70.2   66.7
4      57.1   40.0   44.5 -639.1  632.5 -110.3  222.7   77.8   67.8   71.6   70.9
5      38.4   34.3   30.1  283.8 -141.4  805.2  144.9   77.1   66.6   73.5   69.1
6      52.0   47.8   46.2 -151.2  -92.2  -33.0  183.5   87.1   71.5   66.5   72.9
7      61.9   67.0   71.8  126.7 -461.6  -19.3  416.5  100.7   73.9   56.6   62.6
8      72.7   72.7   73.8 1583.3  -28.3   -7.1  222.6  100.3   75.9   51.6   44.3

     PERIPHERAL HEAT TRANSFER COEFFICIENT W/(SQ.M. K)

        1      2      3      4      5      6      7      8      9     10     11

1     401.3  405.2  434.8 -238.2   -1.1   -0.9 2442.3  663.7  505.2  278.7  211.9
2     413.6  427.6  409.2 -307.0 -127.9 -197.6 2117.6  657.6  484.9  316.0  320.2
3     380.3  413.6  415.2 -376.1 -715.0  542.2 1377.5  561.5  380.0  398.8  378.6
4     323.9  227.1  252.9-3629.1 3591.5 -626.6 1264.7  441.9  384.8  406.5  402.7
5     217.8  195.0  171.2 1611.7 -802.8 4571.9  822.6  437.7  378.3  417.4  392.1
6     295.5  271.5  262.5 -858.8 -523.4 -187.7 1042.1  494.5  406.2  377.6  413.8
7     351.7  380.3  407.8  719.5-2620.9 -109.6 2365.1  572.0  419.7  321.3  355.5
8     413.0  412.7  419.3 8990.5 -160.6  -40.2 1263.9  569.4  430.8  293.1  251.6
```

```
              AVERAGE HEAT TRANSFER COEFFICIENT-BTU/(SQ.FT.HR-DEG.F)

               1        2        3        4        5        6       7        8        9        10       11

      (H1)    61.6     60.2     61.0    130.2    -29.9     87.0   279.5     96.8     74.6     61.8     60.0
      (H2)    60.6     58.3     58.8     -2.7    -42.4      1.3   254.9     95.6     74.2     61.2     58.9

              AVERAGE HEAT TRANSFER COEFFICIENT-W/(SQ.M. K)

               1        2        3        4        5        6       7        8        9        10       11

      (H1)   349.7    341.6    346.6    739.1   -170.0    493.9  1587.0    549.8    423.7    351.2    340.8
      (H2)   344.1    330.9    334.1    -15.6   -240.9      7.3  1447.3    542.8    421.6    347.5    334.2

         PER CENT DEVIATION BETWEEN THE EXPERIMENTAL AND PREDICTED HEAT TRANSFER COEFFICIENTS

               1        2        3        4        5        6       7        8        9        10       11

    LIT(1) -12.33   -18.63   -16.66     0.00     0.00     0.00   86.34    41.40    14.23   -14.58   -21.28
    LIT(2) -14.14   -22.49   -21.01     0.00     0.00     0.00   85.02    40.64    13.80   -15.80   -23.69
    LIT(3)   0.89    -4.03    -2.39     0.00     0.00     0.00   86.15    45.67    22.70    -0.86    -6.16
    LIT(4)  -0.71    -7.41    -6.21     0.00     0.00     0.00   84.82    44.97    22.31    -1.93    -8.27
    LIT(5) -27.86    -5.05     0.53     0.00     0.00     0.00   22.12   -17.29   -23.20   -19.33    -6.98
    LIT(6) -29.93    -8.47    -3.19     0.00     0.00     0.00   14.60   -18.79   -23.83   -20.60    -9.10
    LIT(7) -38.42   -56.99   -56.69     0.00     0.00     0.00-210.32    23.70     0.73   -30.50   -41.96
    LIT(8) -40.66   -62.09   -62.54     0.00     0.00     0.00-240.26    22.72     0.22   -31.89   -44.78
    LIT(9)  56.50    63.97    65.82     0.00     0.00     0.00   73.04    60.24    58.29    59.43    63.43
    LIT(10)  55.79    62.80    64.55     0.00     0.00     0.00   70.44    59.73    58.08    59.00    62.71
    COR(11)  11.39     7.55     8.99     0.00     0.00     0.00    6.30    -5.84    16.66     9.77     6.06
    COR(12)   9.96     4.55     5.59     0.00     0.00     0.00   -2.74    -7.20    16.23     8.81     4.19
```

```
                          ---------------
                          RUN NUMBER  354
                          ---------------

          1          2          3          4          5          6          7          8          9          10         11

X/D     0.810E 02 0.154E 03 0.171E 03 0.176E 03 0.178E 03 0.180E 03 0.262E 01 0.236E 02 0.478E 02 0.962E 02 0.145E 03
TB,F    0.948E 02 0.975E 02 0.981E 02 0.983E 02 0.983E 02 0.983E 02 0.984E 02 0.991E 02 0.100E 03 0.102E 03 0.104E 03
JHC     0.173E 02 0.169E 02 0.171E 02 0.420E 02-0.972E 01 0.288E 02 0.875E 02 0.285E 02 0.215E 02 0.175E 02 0.169E 02
RE.NO.  0.184E 04 0.194E 04 0.197E 04 0.197E 04 0.197E 04 0.197E 04 0.198E 04 0.201E 04 0.204E 04 0.212E 04 0.219E 04
PR.NO.  0.833E 02 0.790E 02 0.779E 02 0.778E 02 0.778E 02 0.778E 02 0.776E 02 0.765E 02 0.752E 02 0.726E 02 0.702E 02
GR.NO.  0.151E 05 0.175E 05 0.178E 05 0.102E 04 0.561E 03-0.128E 04 0.402E 04 0.112E 05 0.151E 05 0.198E 05 0.221E 05
HT/HB   0.543E 00 0.481E 00 0.394E 00-0.677E 01 0.140E-02-0.196E-03 0.297E 01 0.152E 01 0.134E 01 0.668E 00 0.540E 00
DE.NO.  0.835E 03 0.883E 03 0.894E 03 0.896E 03 0.896E 03 0.896E 03 0.898E 03 0.912E 03 0.929E 03 0.962E 03 0.997E 03
GR/RE2  0.447E-02 0.465E-02 0.460E-02 0.263E-03 0.144E-03-0.330E-03 0.103E-02 0.279E-02 0.362E-02 0.442E-02 0.460E-02
NU.1    0.201E 02 0.197E 02 0.199E 02 0.425E 02-0.978E 01 0.284E 02 0.913E 02 0.316E 02 0.244E 02 0.202E 02 0.196E 02
NU.2    0.198E 02 0.190E 02 0.192E 02-0.897E 00-0.139E 02 0.421E 00 0.833E 02 0.312E 02 0.242E 02 0.200E 02 0.192E 02

        RUN NO  BR/TR      RE      PR    AVG HEAT FLUX   HEAT GENERATED   HEAT GAINED   HEAT  LOST    H.B.% ERROR

          354   4.839     1971    77.8       4230             12352.2        12696.6          0.0          -2.79
```

APPENDIX K

ERROR ANALYSIS

Correction of the Outside Wall Temperature

The main computer program in Appendix H did not take into account the thickness of the adhesive layer between the thermocouple bead and the outside surface of the test section. The adhesive layer is approximately 0.1 mm thick.

From Figure 68

$$T_o - T_{app} = (Q/A)_{adhes}\ X_{adhesive}/K_{adhesive} \qquad \text{(K.1)}$$

Maximum heat loss, $(Q/A)_{adhesive}$ for test sections B and D is 255.5 Btu/hr.sq.ft. for run 305

$$T_o - T_{app} = (255.5)(0.1/(10\text{x}2.54\text{x}12))/(0.6)$$

$$= 0.14 \text{ F}$$

From this equation the difference between the apparent outside temperature, T_{app}, and the actual outside temperature, T_o , is less than 0.2 F.

Error Analysis

To determine the error in the experimental heat transfer coefficient, an error analysis for all the experimental variables included in the calculation of the heat transfer coefficient is performed. Table IX presents

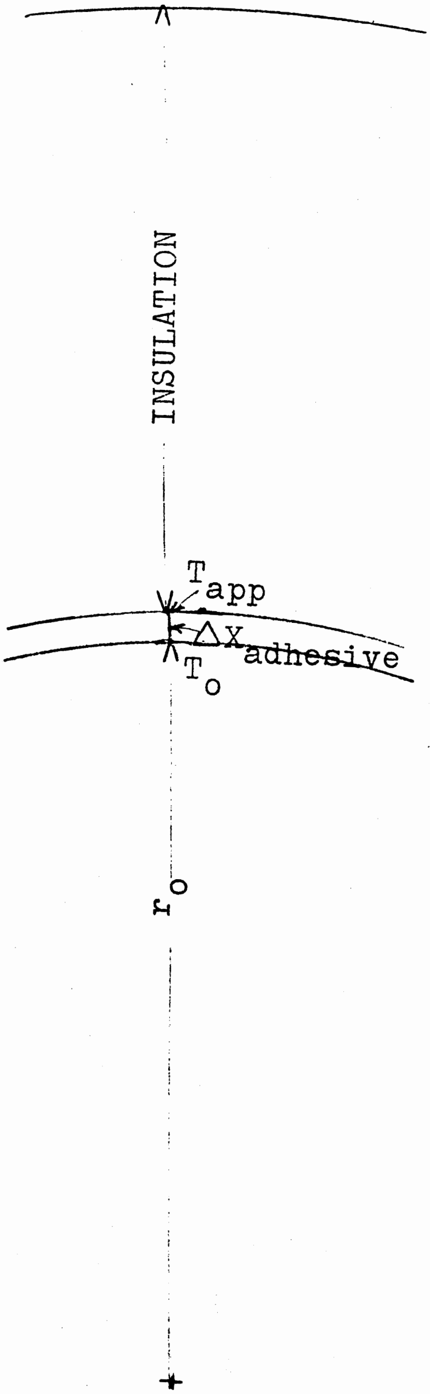


Figure 68: Adhsive Thickness.

the maximum and minimum values of the variables used in the experiments and their absolute accuracy. The absolute accuracies are based on calibrations reported elsewhere in the thesis.

As an example from Chapter V

The power input (P)

$=F.I.V$

$=f(I,V)$

$dP=F.V.dI+Fc.I.dV$

$dP/P=dI/I+dV/V$

Substituting from Table IX

Maximum possible error in power input for the lowest power

$=7.5/300 + 0.020/2.36$

$= 3.3\ \%$

For the highest power input, the maximum error

$=7.5/620 + 0.020/6.64$

$= 1.5\ \%$

The same reasoning is used for the rest of the properties and the values of the maximum error possible, assuming that all the maximum errors in all variables occur at the same time. The values for the maximum errors are given in Table X

All runs attempted had an error less than 20 % in the heat balance. 84 runs (90 % of the runs) had less than 10 % error in the heat balance. These 84 runs were the only runs used in any calculations in the thesis. Thus for the 84 runs included in the calculations, the maximum possible error in the heat transfer coefficient is ± 13 %.

TABLE IX

RANGE OF PROPERTIES MEASURED AND THEIR ACCURACY

Variable	Maximum value	Minimum value	Maximum absolute error
Current (amperes)	620	300	7.5
Voltage drop (volts)	6.640	2.360	0.020*
Rotameter reading (%)			
Brooks: water	26	12	2
ethylene glycol	90	20	2
Fischer: ethylene glycol	61	21	2
Thermocouples (F)			
bath	101.3	85.5	0.3
room	96.8	74.5	0.3
inlet to U-tube	101.0	85.0	0.3
exit from U-tube	146.5	97.8	0.3
attached to surface	200.0	85.0	0.5

* This value is the variation recorded during acceptable runs. This variation is due to the fluctuation of the power from the DC source.

TABLE X

MAXIMUM POSSIBLE ERRORS

Property	Range of Maximum Possible Error(%)	
Power	1.5	3.3
Volumetric flow rate		
water	4.3	8.8
ethylene glycol	2.2	10.0
Mass flow rate		
water	6.3	10.8
ethylene glycol	2.5	10.3
Heat lost to surroundings	6.0	16.6
Heat input	10.0	19.9
Heat output	4.5	12.8
Heat balance	10.0	20.0
Length of test section	0.0	0.5
Radius of test section	1.0	1.0
Area	1.5	1.5
Heat flux	9.0	21.5
Heat transfer coefficient	11.5	23.0

APPENDIX L

EXAMPLE PROBLEM

An ethylene glycol solution (water content 5 %) is flowing at a bulk temperature of 100 F (311 K) inside a 1 in. x 14 BWG stainless steel 304 tube (wall thickness = 0.083 in.). The glycol is running at a 1.2 ft/s (0.336 m/s). The U-tube has a bend diameter to tube inside diameter ratio of 8. The outside film heat transfer coefficient is 300 Btu/hr.sq.ft.F (1700 W/sq.m.K), based on the outside surface area. Assume there is no fouling.

Calculate the local heat fluxes for a fully develped flow and for a case near the entrance from the bend (X/d_i = 1.5). Assume that the outside fluid has a local bulk temperature of 140 F (333.2 K). Repeat the calculation for 170 F (349.9 K).

The physical properties for ethylene glycol are calculated at the bulk temperature from Appendix E:

ρ = 68.45 lbm/ft^3 = 1096 kg/m^3

μ = 20.41 lbm/hr.ft = 8.44 m.Pa.s

C_p = 0.5813 Btu/lbm.F = 2.43 kJ/kg.K

k = 0.1536 Btu/hr.ft.F = 0.2658 W/m.K

β = 0.003518 /F

Check for the type of flow inside the U-tube

$Re = \rho ud / \mu$

$=(68.45\text{lbm/ft}\ )(1.2\text{ft/s})(0.834\text{ft}/12)(3600\text{s/hr})$

$/(20.41\text{lbm/hr.ft})$

$= 1007$

Thus the flow is laminar.

Case 1

This case is for fully developed flow, where the outside fluid has a local bulk temperature of 140 F (333.2 K). As a first approximation, assume the tube inside wall temperature is the average of the inside and outside bulk temperatures.

$T_{wi} = (100+140)/2$

$= 120\text{ F}$

$= 322.1\text{ K}$

From Appendix E

μ_w @120 F = 14.08 lbm/hr.ft.

Calculate the dimensionless parameters

$\mu_b/\mu_w = (20.41\text{lbm/hr.ft})/(14.08\text{lbm/hr.ft})$

$= 1.45$

$$Gr = (32.17\text{ft/s}^2)(3.514\text{x}10^{-4}/\text{F})(68.45\text{lbm/ft}^3)^2$$

$$(0.834\text{ft}/12)^3(120\text{F}-100\text{F})(3600\text{s/hr})^2/(20.41\text{lbm/hr.ft})^2$$

$Pr = (0.5813\text{Btu/lbm.F})(20.41\text{lbm/hr.ft})/(0.1536\text{Btu/hr.ft.F})$

$= 77.24$

Since the flow is fully developed and laminar, then use equation (VII.1) to calculate the inside heat transfer coefficient

$$h_i = \{4.364+0.3271(11,100)^{0.25}(77.24)^{0.25}\}(1.45)^{0.14}$$

$$= 33.3 \text{ Btu/hr.ft}^2\text{.F}$$

$$= 190 \text{ W/m}^2$$

Check for the assumption of surface temperature from heat balances between the two bulk temperatures

$$h_i A_i (T_{wi} - T_{bi}) = kw(A_i + A_o)(T_{wo} - T_{wi})/2\Delta X \quad (L.1)$$

$$h_o A_o (T_{bo} - T_{wo}) = h_i A_i (T_{wi} - T_{bi}) \quad (L.2)$$

Where the thermal conductivity of the wall (8.41Btu/hr.ft.F) is calculated from equation (E.16). Substituting and solving equations (L.1) and (L.2) for the inside and outside wall surface temperatures:

T_{wi} = 135.8 F = 330.9 K

T_{wo} = 136.7 F = 331.4 K

For the new surface temperature (136 F) recalculate the Grashof number (Gr=19,940) and the viscosity ratio factor (1.092), resubstite in equation (VII.1)

$h_i = 38.3 \text{ Btu/hr.ft}^2\text{.F} = 218 \text{ W/m}^2$

Recheck the inside and outside surface temperatures from equations (L.1) and (L.2)

T_{wi} = 135.2 F = 330.5 K

T_{wo} = 136.2 F = 331.1 K

These temperatures are very close to the previous calculation (0.8 F difference).

Thus the heat flux based on the outside heat transfer surface is:

$$= (T_{bo} - T_{bi})/\{1/h_o + (d_o/d_i h_i) + d_o \ln(d_o/d_i)/2kw\}$$

$$=(140-100)/\{1/300+1/(0.834)(38.3)+\ln(1/0.834)/(2)(8.49)\}$$

$$= 882\ \mathrm{Btu/hr.ft}^{2}$$

$$= 5\ \mathrm{kW/m}^{2}$$

Case 2

This case is for the fully developed flow and where the outside fluid has a local bulk temperature of 170 F (349.9 K). Assume the surface temperature is 160 F (344.3 K). Calculate the inside heat transfer coefficient from equation (VII.1) which is 44 Btu/hr.sq.ft.F (250 W/sq.m.K). Recheck the surface temperature (160.6 F). Calculate the heat flux, which is 1700 Btu/hr.sq.ft (9.7 kW/sq.m).

Case 3

This case is for the entrance effect (X/d =1.5) downstream from the U-bend, and the outside fluid has a local bulk temperature of 140 F (333.2 K). Assume the surface temperature is 132 F (328.7 K). For this case calculate the inside heat transfer coefficient from equation (VII.2)

$$h_o =\{4.364+0.3271(17{,}700)^{0.25}(77.24)^{0.25}$$

$$+1.955\times10^{-6}(1007)^{1.6}(1007\ 0.125)^{0.8}e^{-0.0725(1.5)}\}$$

$$(20.14/11.6)^{0.14}(0.1536)/(0.834/12)$$

$$= 66.5\ \mathrm{Btu/hr.ft.}^{2}\mathrm{F} = 378\ \mathrm{W/m}^{2}\mathrm{C}$$

Check the inside surface temperature (132.4 F). Thus the heat flux based on the outside heat transfer area is 1250 Btu/hr.sq.ft (7 kW/sq.m)

Case 4

This case is for the entrance effect (X/d =1.5) downstream from the U-bend, and the outside fluid has a local bulk temperature of 170 F. Assume the surface temperature is 155 F (341.5 K). Then from equation (VII.2) the inside heat transfer coefficient is 73.6 Btu/hr.sq.ft.F (418 W/sq.m). Recheck the surface temperature (155.6 F). Thus the heat flux based on the outside heat transfer surface area is 2320 Btu/hr.sq.ft or (13 kW/sq.m).

APPENDIX M

BEHAVIOR OF THE DEVELOPED CORRELATION

The Nusselt number predicted by the developed equation (VII.2) is plotted as a function of the Reynolds number, curvature ratio and the product of Grashof and Prandtl numbers in Figures 69 through 72.

Equation (VII.2) is integrated over the length

$$\overline{Nu}=(1/L)\int_{0}^{L} Nu(X)dX \qquad (M.1)$$

$$Nu=\{4.364+0.3271Gr^{0.25}Pr^{0.25}+2.696x10^{-5}Re^{1.6}De^{0.8}$$

$$\{1-e^{-0.0725(L/d_i)}\}d_i/L\}(\mu_b/\mu_w)^{0.14} \qquad (M.2)$$

A correction factor due to the secondary flow is defined as the ratio of the integrated form (equation (M.2)) for the length-averaged Nusselt number downstream from the bend to the Nusselt number without the secondary flow effect (equation (VII.1)). This correction factor is plotted as a function of the tube length (L) to the inside diameter for a few typical cases of Reynolds numbers, curvature ratios and the product of Grashof and Prandtl numbers; see Figures 73 through 76.

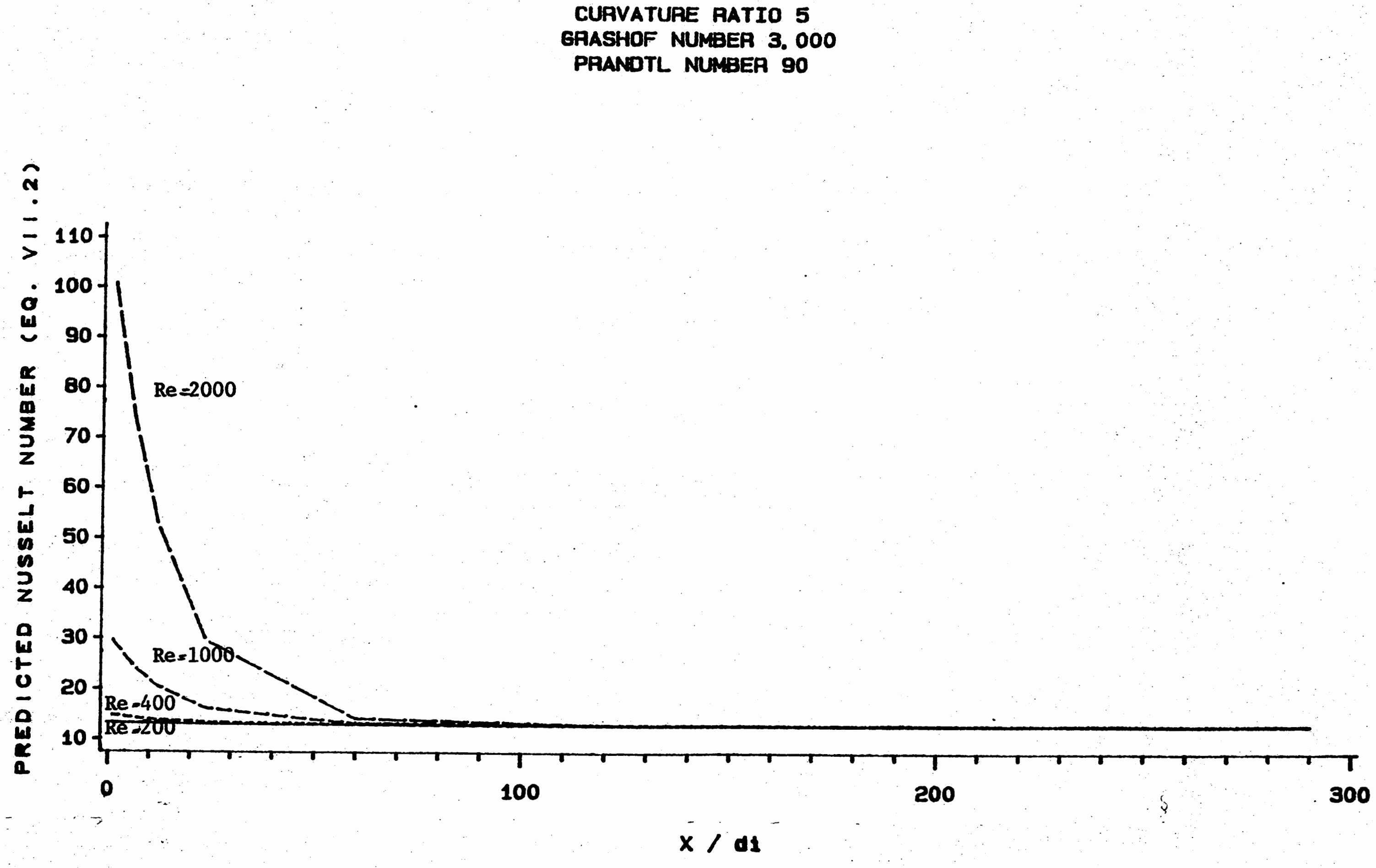


Figure 69: Prediction of the Heat Transfer Coefficient (eq. VII.2) at Low Curvature Ratio when the Natural Convection is Low.

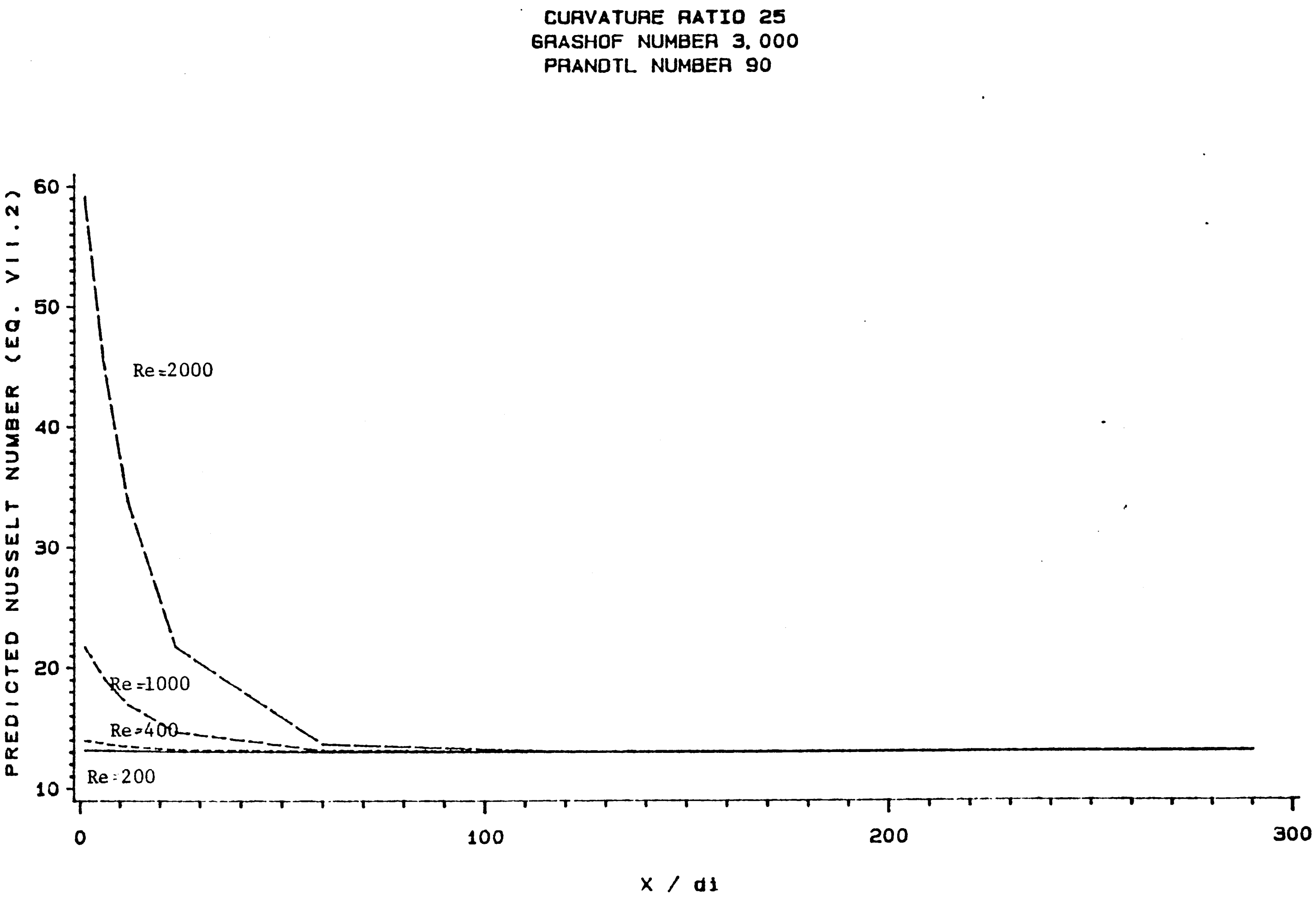


Figure 70: Prediction of the Heat Transfer Coefficient (eq. VII.2) at High Curvature Ratio when the Natural Convection is Low.

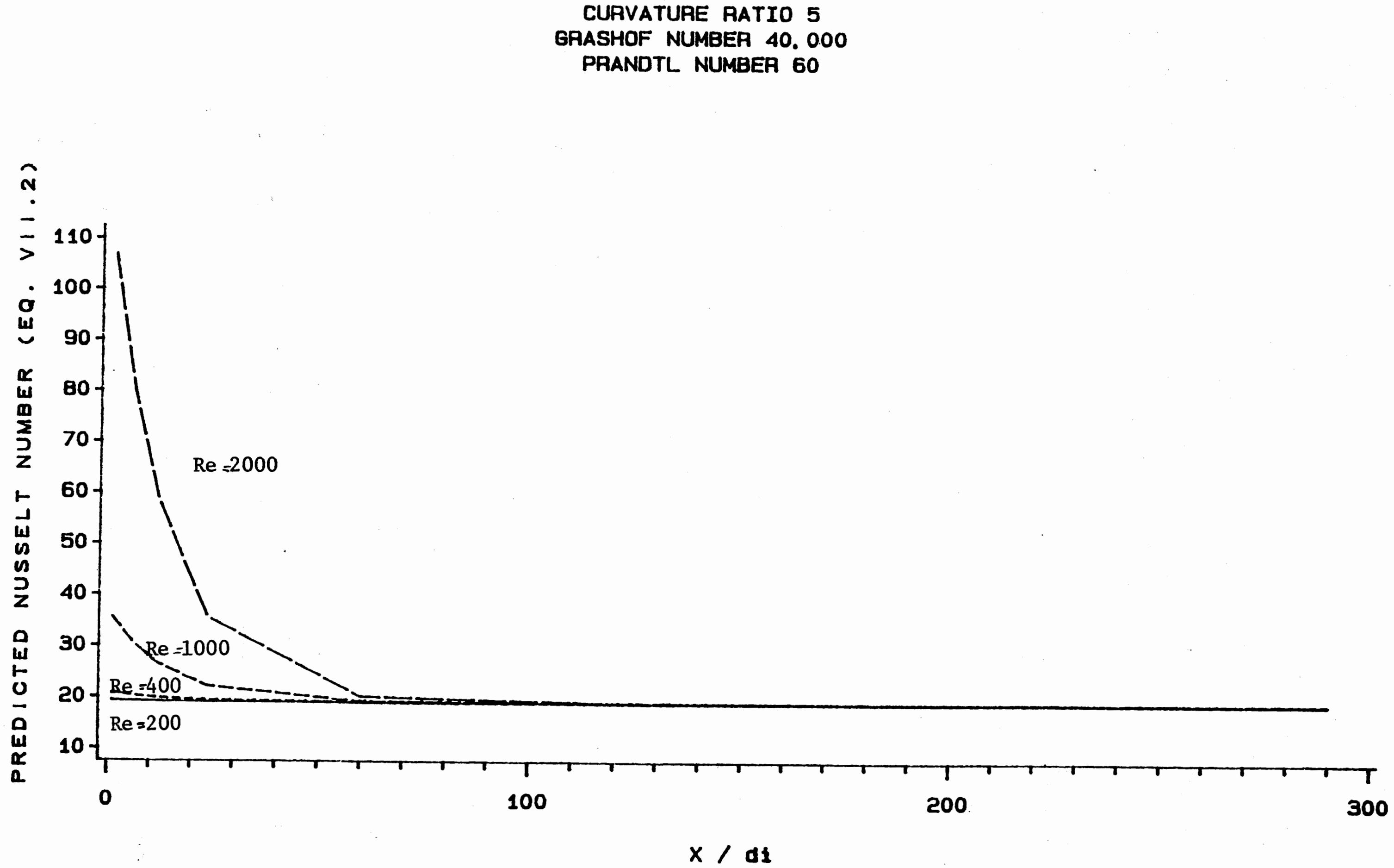


Figure 71: Prediction of the Heat Transfer Coefficient (eq. VII.2) at Low Curvature Ratio when the Natural Convection is High.

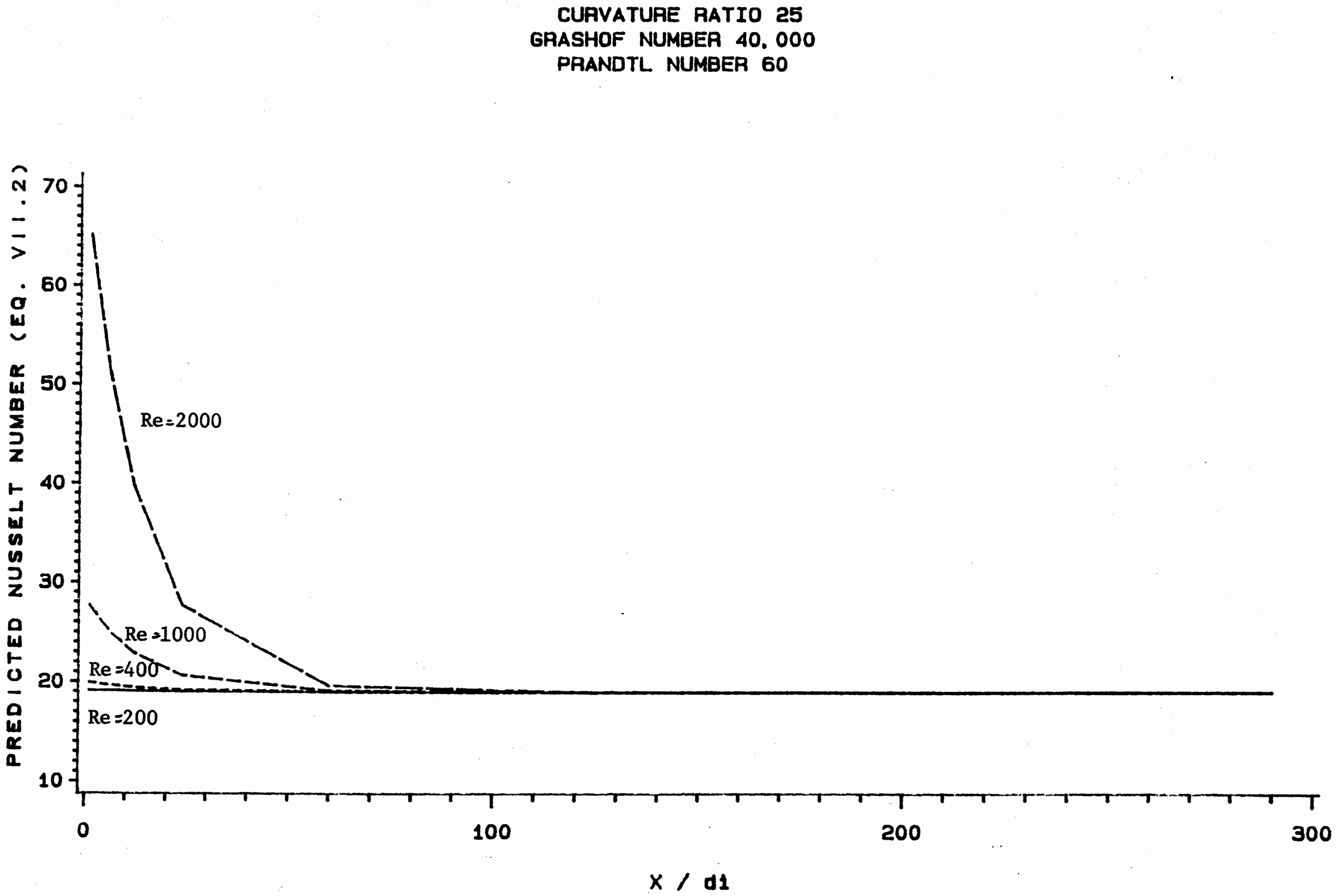
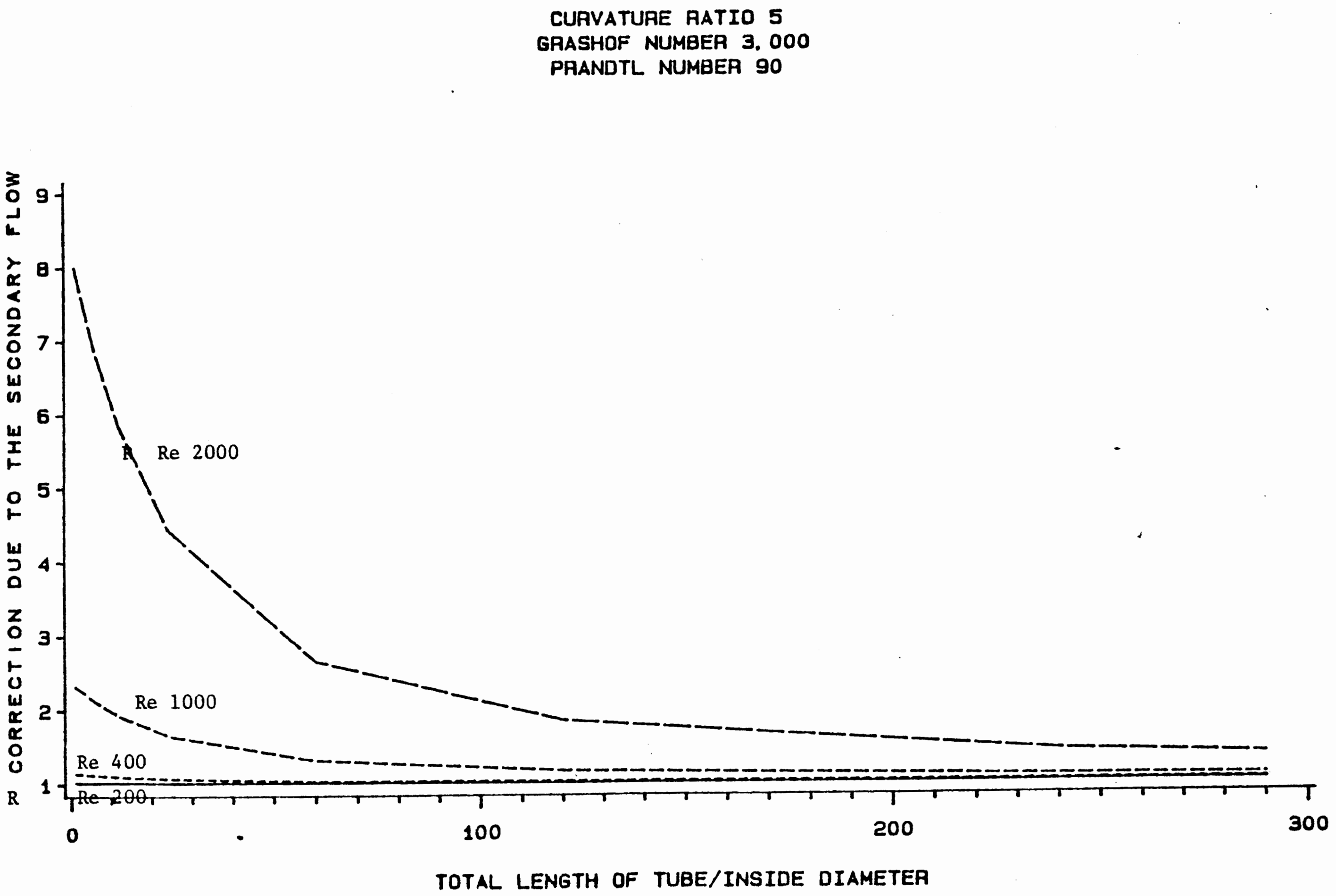


Figure 72: Prediction of the Heat Transfer Coefficient (eq. VII.2) at High Curvature Ratio when the Natural Convection is High.



CURVATURE RATIO 5
GRASHOF NUMBER 3,000
PRANDTL NUMBER 90

Figure 73: Ratio of Length-Averaged Nusselt Number to the Nusselt Number in a Straight Tube for Various Tube Lengths at Low Curvature Ratio when the Natural Convection is Low.

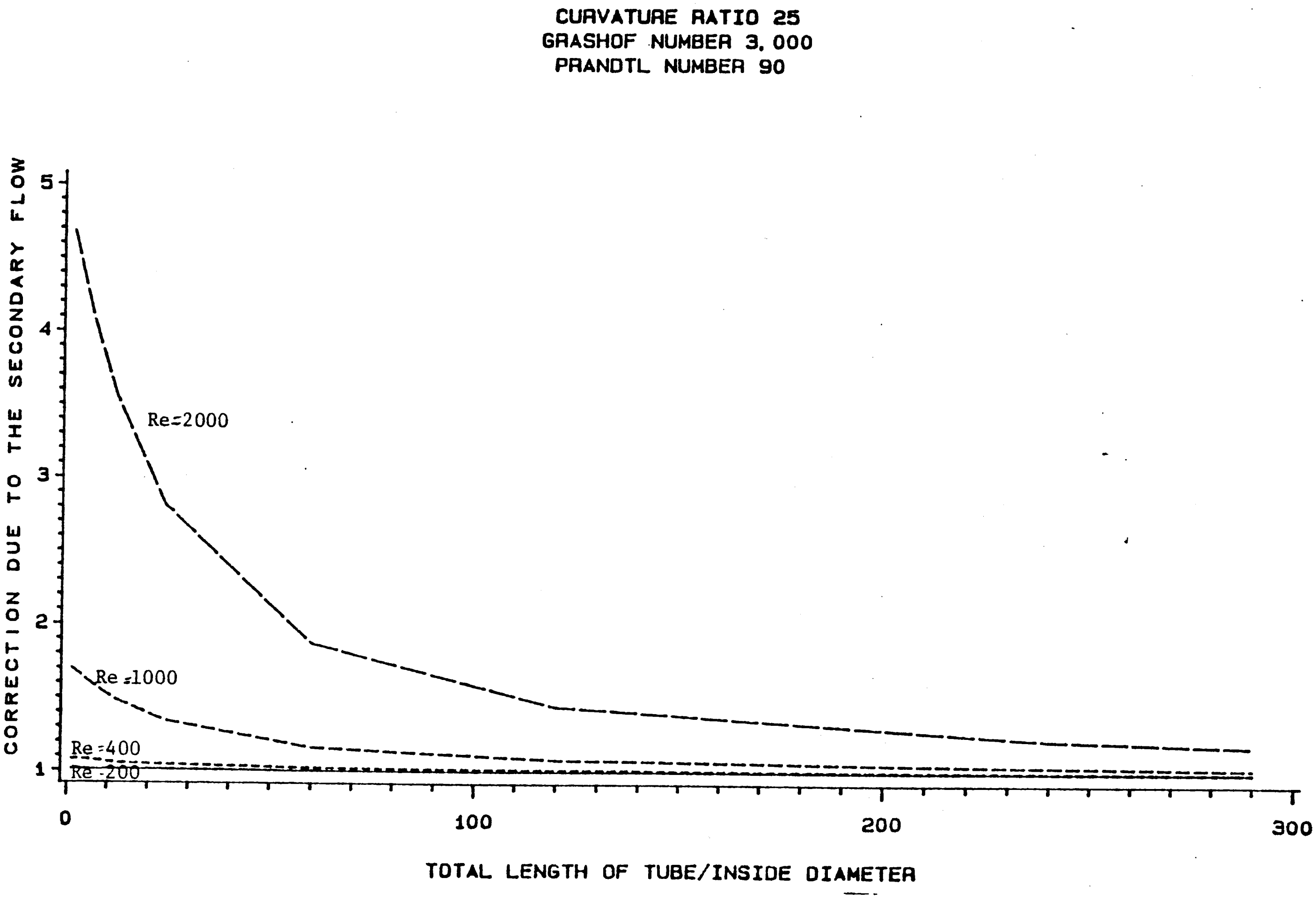


Figure 74: Ratio of Length-Averaged Nusselt Number to the Nusselt Number in a Straight Tube for Various Tube Lengths at High Curvature Ratio when the Natural Convection is Low.

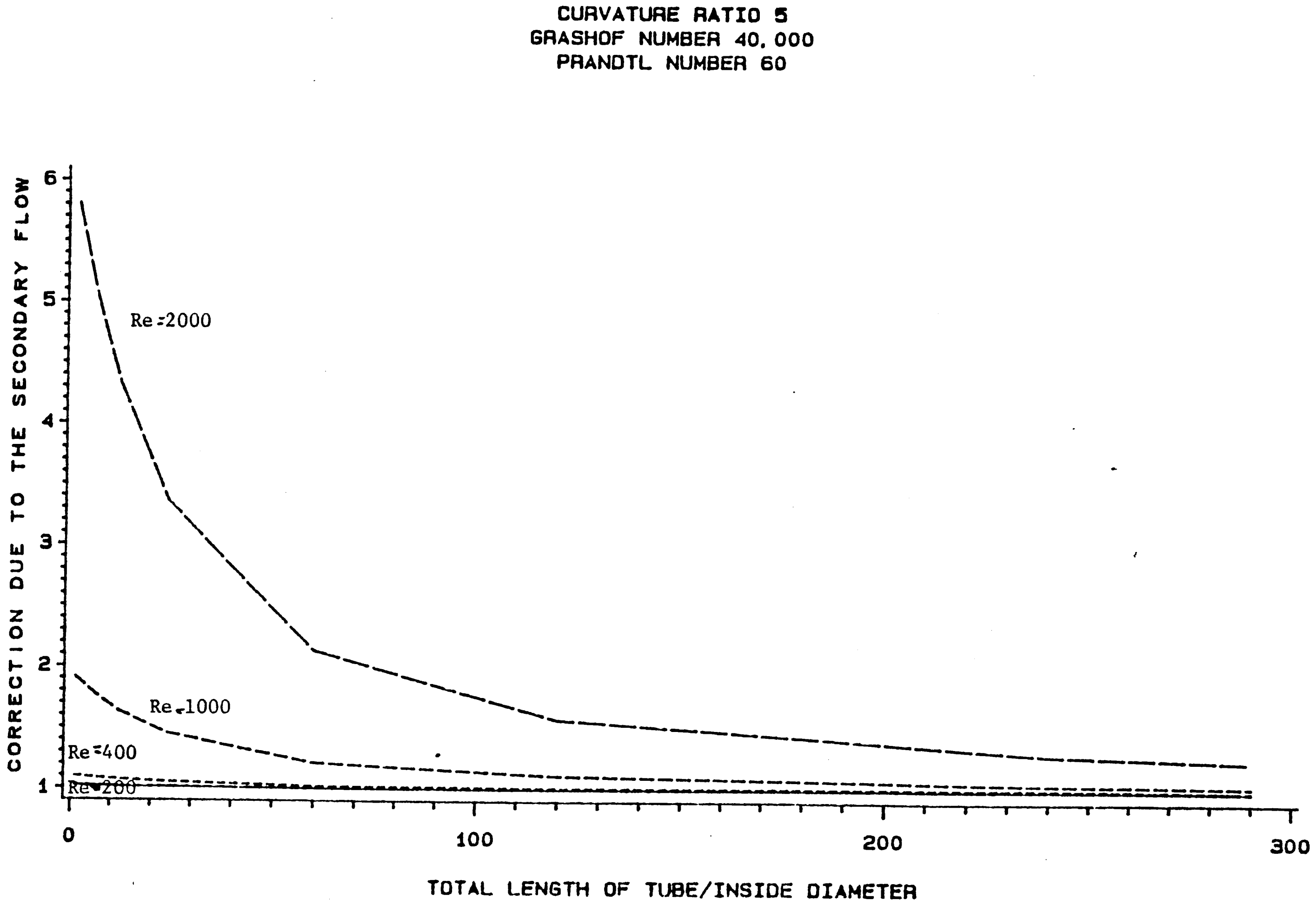


Figure 75: Ratio of Length-Averaged Nusselt Number to the Nusselt Number in a Straight Tube for Various Tube Lengths at Low Curvature Ratio when the Natural Convection is High.

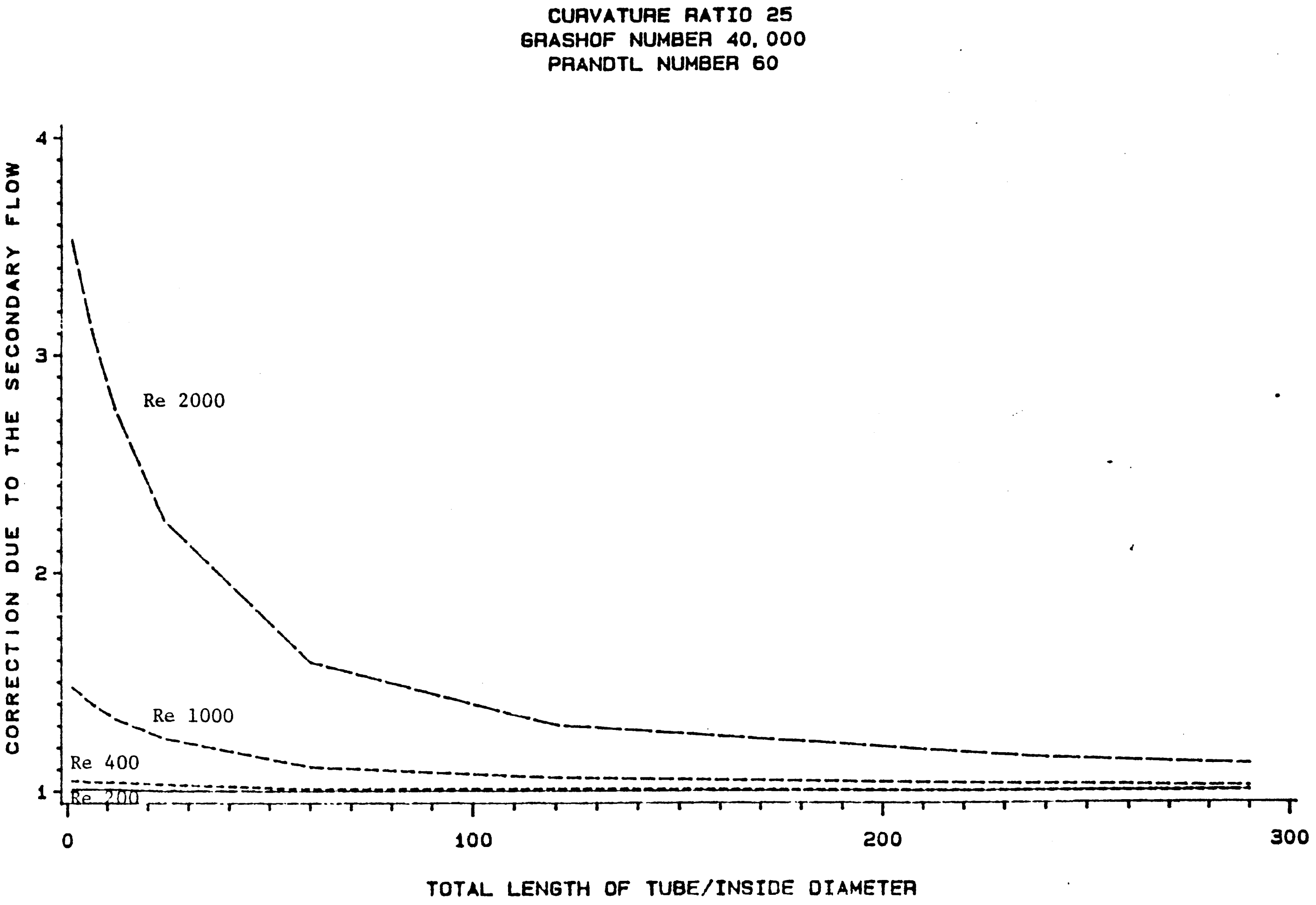


Figure 76: Ratio of Length-Averaged Nusselt Number to the Nusselt Number in a Straight Tube for Various Tube Lengths at High Curvature Ratio when the Natural Convection is High.

VITA

Amanie Nassif Abdelmessih

Candidate for the Degree of

Doctor of Philosophy

Thesis: LAMINAR FLOW HEAT TRANSFER DOWNSTREAM FROM U-BENDS

Major Field: Chemical Engineering

Biographical:

Education: Received the Bachelor of Science degree in Chemical Engineering (1972) and the Master of Science degree in Chemical Engineering (1979) from Alexandria University, Egypt. Completed requirements for the Doctor of Philosophy degree at Oklahoma State University in May, 1987.

Professional Experience: Teaching Assistant, School of Chemical Engineering, Oklahoma State University, January 1982 to May 1985; Research Assistant, School of Chemical Engineering, Oklahoma State University, August 1980 to December 1981 and September 1985 to May 1986. Chemical Engineer, February 1973 to August 1980, at the National Paper Company, Egypt.

Professional Membership and Honors: Associate Member, American Institute of Chemical Engineers; Student Member, National Society of Professional Engineers; Engineer-In-Training, October 1985; Student Member, Society of Women Engineers; Member, Omega Chi Epsilon; Member, Golden Key National Honor Society; Residence Hall Association, Award of Academic Merit, April 1983; Marcia Martin Award, for Outstanding Woman Engineer, 1985 - 1986.