DESIGN, CONSTRUCTION AND TESTING OF A SINGLE-PHASE AND TWO-PHASE FLUID FLOW SYSTEM IN A HORIZONTAL CIRCULAR TUBE WITH CONSTANT HEAT FLUX

By

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NOMENCLATURE

A	area, ft^2 or m^2
C_{PL}	specific heat of the liquid evaluated at the bulk temperature, Btu/lbm-°F or J/kg-K
C_{PG}	specific heat of the gas evaluated at the bulk temperature, Btu/lbm- °F or J/kg-K
d, D	inside diameter of the test section, 1.097 inches (2.7863 cm)
DeltaTB	difference in exit and inlet bulk temperatures, °F or °C
DeltaTBin	difference in inlet bulk temperatures for one minute, °F/min or °C/min
DeltaTBot	difference in exit bulk temperatures for one minute, °F/min or °C/min
f	friction factor coefficient
F.R.	flow rate, gpm or lpm
Frq	frequency, Hz
Gr	Grashof number
h, h_{TP}	heat transfer coefficient, Btu/hr^2- °F or W/m^2- °K
Hbal	heat balance error
Hin	heat input to the system, W or Btu/hr
Hout	heat carried by the water, W or Btu/hr
h_t/h_b	ratio of heat transfer coefficient at the top to the bottom of the test section
I	current carried by the test section, amperes
k_s	thermal conductivity of the stainless steel test section, Btu/hr-ft- °F or W/m-°K
k_L	thermal conductivity of the water, Btu/hr-ft- °F or W/m- °K

k_G	thermal conductivity of air, Btu/hr-ft- °F or W/m- °K
L	length of the stainless steel test section, ft or m
$\dot{m}_L$	mass flow rate of water, lbm/s or kg/s
$\dot{m}_G$	mass flow rate of air, lbm/s or kg/s
Nu	local circumferentially averaged Nusselt number, hd/k, dimensionless
Pr_L	Prandtl number of water, C_{PL} μ_L/k, dimensionless
Pr_G	Prandtl number of air, C_{PG} μ_G/k, dimensionless
q"	heat flux, Btu/hr-ft^2 or W/m^2
Q_L	volume flow rate of the water, gpm or m^3/s
Q_G	volume flow rate of the air, ft^3/min or m^3/s
R^2	regression coefficient
Ra	Rayleigh number, (Gr Pr), dimensionless
Re_{SL}	local Reynolds number of the water, $(\rho_L V_L d/\mu_L)$, dimensionless
Re_{SG}	local Reynolds number of the air, $(\rho_G V_G d/\mu_G)$, dimensionless
T	temperature, °F or °C
TBATH	temperature of the bath, °F or °C
TC	temperature reading of the thermocouple, °F or °C
Tbulkin	inlet bulk temperature, °F or °C
Tbulkout	exit bulk temperature, °F or °C
Ttank	temperature of the water in the storage tank, °F or °C
Tamb	ambient temperature in the experimental setup room, °F or °C
T_b	bulk temperature, °F or °C

T_w	tube outside wall temperature, °F or °C
Tw_A	inside wall temperature at station-A (top of the test section) thermocouple, °F or °C
Tw_C	inside wall temperature at station-C (bottom of the test section) thermocouple, °F or °C
T_{wi}	tube inside wall temperature, °F or °C
V	voltage drop across the test section, volts
V_G	actual flow velocity of the air, ft/hr or m/s
V_L	actual flow velocity of the water, ft/hr or m/s
V_{SG}	superficial flow velocity of the gas, ft/hr or m/s
V_{SL}	superficial flow velocity of the liquid, ft/hr or m/s
x	distance from the entrance of the test section, inches or cm
X	thermocouple reading in °C or °F
Y	temperature of the bath in °C or °F

GREEK SYMBOLS

α	void fraction ratio
β	coefficient of volume expansion, 1/°F or 1/°C
μ	viscosity, lbm/hr-ft or kg/m-sec
ρ	density, lbm/ft^3 or kg/ m^3

SUBSCRIPTS

avg	average
B	bulk
b	refers to bottom of tube

Cal	calculated
Exp	experimental
G	gas (air)
GX	theoretical local Nusselt number
L	liquid (water)
MIX	water-air mixture
SL	superficial liquid (water)
SG	superficial gas (air)
t	refers to top of tube
wall	refers to wall
W	wall

CHAPTER I

INTRODUCTION

This Chapter will discuss the background of the study of single-phase and two-phase flows in horizontal circular cross-section tubes. The basic necessity of the study and its applications were also presented in this chapter. Some experimental work done by previous investigators has been compared with this study. Much study has been done to estimate the heat transfer coefficient in two-phase flow. Limited success has been achieved in building a setup that can be used to produce all kinds of flow patterns and identify them. One of the major applications is to study the behavior of combined gas/liquid flow in oil and gas pipelines. Also two-phase flow occurs in many industrial applications, such as in chemical processing.

Whether laminar or turbulent, two-phase flows are dependent on the flow pattern. The ability to predict flow regimes is essential for proper flow modeling and correlation development, as well as for successful selection of heat transfer enhancement techniques. Depending upon the identified flow pattern, a certain correlation can be used to predict the heat transfer coefficient. Therefore identifying the flow pattern itself plays a major role in predicting heat transfer effects in two-phase flow. The main flow patterns that might exist in two-phase gas-liquid flow in horizontal tubes can be classified as bubbly, froth, stratified, annular, wavy, slug, and mist. The variety of flow patterns reflects the different ways that the gas and liquid phases are distributed within a pipe. This causes the heat transfer mechanism to be different for different flow patterns.

1.1 Background

The expression "two-phase" flow is used to describe the simultaneous flow, usually in a closed channel, pipe or conduit, of a gas and a liquid, a gas and a solid, or a liquid and a solid. All three of these types of two-phase flows occur in practical engineering systems.

The two phases may be formed from the same chemical species, as in the two-phase flows formed from water and steam or from water and ice, in which case the flow is a one-component two-phase flow; or, the two phases may be formed from several chemical species and be referred to as a multi-component flow. That is, each phase may be a solution (or mixture).

The system which was the subject of the present investigation was of the gas-liquid multi-component type formed with water and air. It is common in this situation to associate a single chemical identity to dry air and to refer to this system as a two-component system even though in the true chemical sense, the number of components is much greater. Numerous flow patterns can be observed in two-phase flows, and all authors do not agree on the names of these patterns. The major flow patterns encountered in water/air flow in horizontal tubes are: bubbly, froth, stratified, wavy, annular, mist, and slug flow.

1.2 Objectives

The main object of this study was to design and build a test loop that can handle two-phase flow. Initially the setup has been run and tested for single–phase flow, the fluid used in this case was distilled water. The long-range goal of this investigation was to study heat transfer to/from a two-phase flow in tubes under the constant wall heat flux condition. The test loop was very carefully designed to handle water-air fluids. The test flow was so designed that it can safely handle all types of flow patterns and flow regimes. Variations in temperature along the test section were carefully recorded via a data acquisition system. This test section can handle pressure up to 120 psi (84500 kg/m^2) and temperature up to 110 °F (43.05 °C). Calibration of the thermocouples, the flow rate measurement device (turbine meter), and thermocouple bulk temperature probes has been performed carefully and accurately. The last step is to find the efficiency of the test loop (heat balance error), and compare the Nusselt number from the experimental data with that of available correlations.

1.2.1 Prospects of the Work

This study details the preparation of a suitable experimental apparatus having the inherent versatility to fulfill all long-term objectives. This required the ability to handle all types of flow patterns and flow regimes, as well as having a quick reliable approximate method for measuring void fraction ratio without the necessity of taking the apparatus apart. To deliver this ability, a unique mixing chamber, a calming section, a mixing well, and a void fraction measurement section were designed, constructed and tested (detailed in Chapter II).

Special containment housings were constructed to suppress the noise and vibration produced by the pump and the welder (used to supply the electricity for the wall heat flux). Rubber damping materials were used to reduce the vibration from the pump. The welder was located near an external wall so that exhaust noise could be removed from the lab. Rubber hoses were used at some locations in order to reduce the vibration transmitted by the pump to the test section. The rubber hoses were designed to also help with any future modification on the test loop, since they could be easily removed and re-connected. These rubber hoses, along with damping materials, were used mainly on the return lines. The test section was supported on a wooden bridge, and it was fully insulated with fiberglass insulation material. A fluid filter was used in the return loop to remove particles above five microns in diameter. All of these components are described in detail in Chapter II.

Clear polyvinyl carbonate (PVC) tubes were used in some locations upstream and downstream of the test section in order to visualize the flow. A special support was constructed to hold the mixing chamber. The mixing chamber was made out of clear PVC, which will help to clearly visualize the type of flow pattern that the fluid will take in future two-phase testing. A clear calming section of 110 inches (279.40 cm) was placed just before the test section. This will help the fluids to mix thoroughly before they actually entered the test section. In order to help maintain consistent behavior of the flow, the entire test loop had a 1.097 inch (2.786 cm) internal diameter. A separator was placed at the end of the test section to separate water from air for two-phase flow.

Water will be re-circulated and the air will be returned to the atmosphere. The water was recycled through a heat exchanger in order to maintain a steady state.

To facilitate massive and accurate data accumulation, digital acquisition systems were employed with fast sampling capability. When used in tandem with a personal computer, labor and data collection periods were reduced and accuracy was increased. (See Chapter II for details on these systems.)

1.2.2 Database

This thesis discusses the design, construction, calibration, and testing for single-phase fluid flow in a circular horizontal electrically heated straight tube with constant heat flux. The fluid used for single-phase flow was distilled water. The heat transfer data was taken over a wide range of Reynolds (2800 to 17000), Prandtl (4.0 to 6.5), and Nusselt (15 to 115) numbers. About 120 shake down runs were conducted, after which 43 were performed in order to validate the proper working of the test loop.

1.2.3 Correlation Comparison

Using the results obtained from the data of the test runs, several correlations were used to predict the Nusselt number. A listing of all of the correlations used is given in Tables I and II. Of these correlations, only a few seem to accurately predict the single-phase data from this test setup. These correlation comparisons are reported in Chapter IV. Three correlations accurately predicted Nusselt number for this test setup. They were the correlations developed by Sieder and Tate (1936), Colburn (1933), and Gnielinski (1976). By modifying these pre-existing correlation, a good correlation equation was formulated which better matched the data presented in this thesis.

1.3 Literature Survey

Experimental investigation of two-phase flows in a horizontal circular tube under constant heat flux is limited, considering the wide range of conditions under which these flows may occur and be of engineering interest. In this section, a brief review of successful work related to horizontal, constant heat flux single-phase and two-phase pipe flow is given. At the end of this section, a table is provided for ease in comparing of the correlations.

Shannon and Depew (1968 and 1969) investigated natural convection effects for a resistance (DC current) heated stainless steel tube that also incorporated an unheated calming section. They used water and ethylene glycol to cover a Reynolds number range of 6 to 2300. Their results showed the influence of free convection and were correlated using the parameter $((GrPr)^{1/4}/Nu_{GX})$, where Nu_{GX} is the theoretical local Nusselt number found from Siegel et al. (1958). They concluded that when $((GrPr)^{1/4}/Nu_{GX})$ was less than 2, the free convection effect was unimportant.

Siegwarth et al. (1969) analyzed the effect of secondary flow on the temperature field and primary flow at the outlet of a long electrically heated tube. They developed a model for the flow field by dimensional reasoning and found that secondary flow controls the rate of heat transfer. Their model showed good agreement with the data measured by Readal (1969).

Petukov and Polyakov (1967) used distilled water in a tube, heated by electrical resistance (using AC current), to study local heat transfer coefficient. By measuring the temperature at both axial and radial locations, they plotted average Nusselt number versus the reduced parameter (x/D)/(RePr), and showed that the local Nusselt number was a strong function of Rayleigh number. They also observed that the thermal entry length decreased when Rayleigh number increased.

Using flow visualization techniques, Bergles and Simonds (1971) studied the effects of free convection on laminar water flow in horizontal circular tubes with constant heat flux. The tubes were Pyrex E-C coated tube with four thermocouples placed 90 degrees apart in the circumferential direction. A DC arc welder was used as a heat source for the test section. Heat was generated in the Pyrex E-C coating to provide constant heat flux with nearly zero radial conduction, and their results were similar to Petukhov and Polyakov (1967).

Ede (1961) used water and air under constant heat flux. He studied the free convection on fluid flow at Reynolds numbers from 300 to 100,000 in electrically heated aluminum-brass pipes with varying inside diameter and wall thickness for abruptly converging and diverging inlet geometries. He found that there was no consistent variation in Nusselt number with Grashof number (for Grashof number less than 100,000) in the laminar region (Re <2300). He presented no correlations for transition or turbulent flows, and his laminar equation for Re < 2300 in fact had no Reynolds number dependency.

Seigel et al. (1958) proposed an analytical solution for laminar heat transfer without natural convection. They developed an equation for local Nusselt number with a fully developed velocity profile and uniform heat flux boundary condition. Petukhov and Polyakov (1967), Bergles and Simonds (1971), and Hong and Bergles (1976) used the Seigel et al. (1958) correlation as a basic solution for laminar forced convection heat transfer. But their pure forced convection equation gave lower predictions for heat transfer coefficients than the experimental data showed, as found by Petukhov and Polyakov (1967). They observed that, with increased heat flux, higher deviations from the forced convection prediction and increased density variation (represented by Rayleigh number) occurred.

Ghajar and Tam (1994) studied the heat transfer effects in an electrically heated horizontal circular tube. The heat transfer section they used was an 316 stainless steel circular tube with an inside diameter of 0.624 inch (1.63 cm) and an outside diameter of 0.748 inch (1.89 cm). The total length of the test section was 20 feet (6.096 m) with an L/D equal to 385. The authors used finite difference formulations to find the local inside wall temperature, local peripheral heat transfer coefficient, and other pertinent information such as local outside-wall temperature at different axial locations along the test section. Ghajar and Zurigat (1991) developed an interactive computer program to calculate the local inside wall temperatures and local peripheral heat transfer coefficients from local outside wall temperatures. The program also calculated the pertinent fluid flow and heat transfer dimensionless parameters. One of the interesting results was the ratio of top to bottom peripheral heat transfer coefficients. If this ratio was close to 1.0, forced convection dominated and heat transfer was primarily dependent on the Reynolds and Prandtl numbers. However, if the ratio was less than 1.0, natural convection existed and heat transfer was by mixed convection. In this case, secondary flow caused by the difference between the fluid density at the wall and at the pipe center also affected the temperature profile. For mixed convection, the heat transfer was dependent on the Grashof number (which accounts for variation in the density of the test fluid) in addition to Reynolds and Prandtl numbers.

The design and experimental results on two-phase test loops by various researchers is briefly discussed herein.

Johnson (1955) investigated heat transfer and pressure drop in the horizontal flow of oil-air mixtures. This was an example of two-phase two-component system, which differs greatly from the air-water system with respect to heat transfer, due to the difference in properties of the fluids.

Aggour (1978) used a 0.46 inch (1.168 cm) diameter test section made of stainless steel, with an L/D (the test section length to inside diameter) equal to 52.1. He used this test loop to run four different sets of fluid combinations. They were air-water, helium-water, freon-12-water, and air-glycerin. He used 47 thermocouples at 16 positions along the test section, both axially and circumferentially. The orientation of the pipe was vertical. He used a by-pass line, made of 1.5 inch (3.81 cm) copper tubing, with a control valve to set the required flow rate. While applying a constant wall heat flux, he considered that the temperature difference between the tube wall and the bulk of the fluid should be small in order to minimize the circumferential variation in fluid properties. He made sure that this temperature difference would be large enough to accurately determine the heat transfer coefficients. An estimated temperature difference (T_W-T_B) of 15 ^{o}F was considered adequate to meet these requirements. Aggour (1978) proposed that the knowledge of the flow patterns is important in two-phase flow, as it might affect the heat transfer. The flow patterns were classified on the evidence provided by the naked eye and taking short exposure still photographs.

Pletcher (1966) used a horizontal circular pipe made of 15 feet (4.572 m) galvanized steel with 1 inch (2.54 cm) internal diameter. He used a water-air mixture to study the heat transfer effects. He passed air through a 2 inch (5.08 cm) pipe, and used a compressor capable of delivering air at the rate of 1 lb/sec (2.2 kg/sec) at 100 psig (7.045 kg/cm^2). The air he used had a relative humidity of 10%. The compressor was capable of operating at 0, 25, 50, 75 and 100% of rated capacity. Water was injected through the tube walls in a mixing section, which allowed the water to join the air stream in an annular pattern and with an axial velocity at the point of contact with the air stream. The heat transfer section was fabricated from a 60 inch (152.4 cm) length of type 304 stainless steel with an inside diameter of 1 inch (2.54 cm) and outside diameter of 2 inches (5.08 cm). Pletcher (1966) used pressure taps at seven different locations along the stainless steel pipe, and he placed 58 thermocouples at thirteen different locations (axially and circumferentially) along the pipe. He heated the test section with 13 gage Nichrome V heating wire. The wire was electrically insulated with a double wrapping on unimpregnated fiberglass. It could dissipate up to 25 kW with a maximum voltage drop of 250 V. Pletcher (1966) found that the pressure drop measurements for the heat transfer runs agreed well with those of other investigators, both isothermal and with heat transfer. In comparing the theory with data, 85% of the predictions fell within ± 60% (almost all high) of the data and 33% of the predictions came within ± 20% of the data. Pletcher (1966) covered $\dot{m}_L$ between 0.0694 and 0.3876 lbm/sec, $\dot{m}_G$ between 0.03 and 0.2568 lbm/sec, q" between 7372 and 11077

Btu/hr- ft^2, h between 433 and 1043.8 Btu/hr-ft^2 °F, mixture temperature between 64.9 and 99.4 °F, and wall temperature between 73.6 and 107.1 °F.

King (1952) used a horizontal copper pipe with an internal diameter of 0.7357 inches (1.872 cm) to study the heat transfer and pressure drop characteristics for two-phase, two-component, non-isothermal flow of an air-water mixture. He found that the two-phase heat transfer coefficient, when calculated for a given liquid rate, was found to increase greatly upon the addition of small amounts of gas until it reached a maximum, substantiating the results of Abou-Sabe (1951) investigation. He investigated flow patterns for various combinations of flow rates. King covered $\dot{m}_L$ between 1375 and 6410 lbm/hr, $\dot{m}_G$ between 0.82 and 43.7 lbm/sec, Re_{SL} between 22500 and 119000, Re_{SG} between 1570 and 84200, two-phase heat transfer coefficient between 1462 and 4415 Btu/hr-ft^2 °F, mixture temperature between 136.8 and 144.85 °F, wall temperature between 184.3 and 211.3 °F, mixture pressure between 15.8 and 55.0 lbf/in^2, V_{SG}/V_{SL} between 1.08 and 6.94, and pressure difference between 147.9 and 3226 lbf/ ft^2.

Davis (1960) studied heat transfer and pressure drop for steam-water mixture flowing in a rectangular, stainless steel, horizontal duct, with inside dimensions of 0.769 inches (1.953 cm), in height and 0.260 inches (0.66 cm) in width. The duct was heated electrically on one vertical face over a short distance so as to provide essentially point heat transfer coefficient. He investigated two-phase heat transfer mainly in the region of high vapor mass velocities, where forced convection-controlled heat transfer was found to occur. His setup pressures varied from 25 to 150 psia, heat fluxes ranged from 60,000 to 260,000 Btu/hr-ft2, and steam mass fractions from 0.50 to 0.90. The wall temperatures were measured by thermocouples inserted into a thick copper plate electroplated onto the thin-walled duct, and the inside wall temperature was determined from calculations of the temperature drop through the copper plate and duct wall. The bulk temperature of the stream was determined form measurement of the saturation pressure, and the heat input by electrical measurements. He found that the maximum heat transfer coefficients were found to occur at qualities from 80% to 90% steam, and at that point liquid deficiency was observed to occur at the wall.

The need for this experimental study is due to the fact that there have not been significant experimental studies of two-phase flows in a horizontal circular tube with uniform heat flux. Although other work may exist, only data of Pletcher (1966) and King (1952) have been found accessible in the open literature. So a horizontal tube of 1.097 inches (2.786 cm) internal diameter experimental setup was designed that could handle a wide range of flow regimes and a variety of flow patterns. A mixing chamber was uniquely designed to produce various flow patterns. A clear calming section of eight foot long was used to visualize the flow pattern. Void fraction measurement setup was designed to measure the accurate value of void-fraction ratio for the two-phase flows. These features are an added advantage in studying the two-phase flow for water/air combination, over previous researchers. This thesis discusses how the design and construction of every component of the setup was accomplished. While designing this setup, the experimental setups used by Pletcher (1966), Strickland (1990), and Tam (1995) have been carefully studied. Several ideas on the design of the mixing chamber have been borrowed from Pletcher (1966). Some of the test equipment used by Strickland (1990) and Tam (1995) were utilized for this experimental setup.

After the test setup was designed and constructed, calibrations of thermocouples, flow meter (turbine meter), and thermocouple probes were carefully done. To validate the proper working of the test setup, single-phase test runs were made using water as the fluid. From the data obtained from these test runs, comparisons with single-phase correlations were done (see Table I for single-phase correlations). A literature survey of twenty two-phase correlations using seven two-phase data sets was made [Kim et al. (1997), and Kim et al. (1999)] and a Fortran code (PHASEI program) was written to calculate the heat transfer coefficient, error in heat transfer coefficient prediction, Re_{SL}, Re_{SG}, and V_{SL}/V_{SG}. Kim et al. [(1997) and (1999)] briefly discuss the work of Davis and David, Hughmark, Martins and Sims, Oliver and Wright, and Shah in two-phase horizontal flow. The PHASEI program is briefly discussed in Appendix C. For the single-phase testing, Reynolds number range of 2800 to 17000, Prandtl number range of 4.0 to 6.5, and Nusselt number range of 15 to 115 were covered to validate the proper working of the test loop.

The correlations provided in the Tables's I and II were taken from Kakac et al. (1987) handbook, except for Ghajar and Tam (1994).

TABLE I

SINGLE-PHASE HEAT TRANSFER CORRELATIONS FOR LAMINAR PIPE FLOW

INVESTIGATOR	CORRELATION	CONDITIONS
Hausen (1943) [Horizontal]	$\overline{Nu} = 3.66 + \frac{0.668(D/L)\mathrm{Re}\,\mathrm{Pr}}{1+0.04[(D/L)\mathrm{Re}\,\mathrm{Pr}]^{2/3}}(\frac{\mu}{\mu_w})^{0.14}$	Uniform wall temperature
	$\overline{Nu} = 4.36 + \frac{[(0.045\mathrm{Re}\,\mathrm{Pr}\,D/l) + 0.00356(\mathrm{Re}\,\mathrm{Pr}\,D/L)^{5/3})]}{[1+0.04(\mathrm{Re}\,\mathrm{Pr}\,D/L)^{2/3}]^2}(\frac{\mu}{\mu})^{0.14}$	Local Nusselt value derived from average value and accounting for constant heat flux $0.48<\mathrm{Pr}<16700$ $0.0044 < (\mu/\mu_w) < 9.75$
Sieder & Tate (1936) [Horizontal]	$\overline{Nu} = 1.86(\mathrm{Re}\,\mathrm{Pr}\,D/L)^{1/3}(\frac{\mu}{\mu_w})^{0.14}$	Correlation recommended for Values of $(\mathrm{Re}\mathrm{Pr}D/L)^{1/3}(\frac{\mu}{\mu_w})^{0.14} \geq 2$
	$\overline{Nu} = 1.24(\mathrm{Re}\,\mathrm{Pr}\,D/L)^{1/3}(\frac{\mu}{\mu_w})^{0.14}$	Local Nusselt value derived from average value.
Mori et al. (1966) [Horizontal]	$\overline{Nu} = 0.6(Gr\,\mathrm{Pr}\,\mathrm{Re})^{0.2}[1 + \frac{1.8}{(Gr\,\mathrm{Pr}\,\mathrm{Re})^{0.2}}]$	Constant heat flux Re=100 to 13000

TABLE I (Cont'd)

SINGLE-PHASE HEAT TRANSFER CORRELATIONS FOR LAMINAR PIPE FLOW

INVESTIGATOR	CORRELATION	CONDITIONS
Colburn (1933) [Horizontal]	$\overline{Nu} = 1.5(\mathrm{Re}\,\mathrm{Pr}\,D/L)^{1/3}(\frac{\mu}{\mu_w})^{1/3}(1+0.015Gr^{1/3})$ $\overline{Nu} = (\mathrm{Re}\,\mathrm{Pr}\,D/L)^{1/3}(\frac{\mu}{\mu_w})^{1/3}(1+0.015Gr^{1/3})$	Local Nusselt value derived from average value.
Ghajar and Tam (1994) [Horizontal]	$Nu = 1.24[(\mathrm{Re}\,\mathrm{Pr}\,D/x) + 0.025(Gr\,\mathrm{Pr})^{0.75}]^{1/3}(\frac{\mu_b}{\mu_w})^{0.14}$	$3 \leq x/D \leq 192$ $280 \leq \mathrm{Re} \leq 3800$ $40 \leq \mathrm{Pr} \leq 160$ $1000 \leq \mathrm{Gr} \leq 2.8 \times 10^4$ $1.2 \leq \frac{\mu_b}{\mu_w} \leq 3.8$

TABLE II

SINGLE-PHASE HEAT TRANSFER CORRELATIONS FOR TURBULENT PIPE FLOW

INVESTIGATOR	CORRELATION	CONDITIONS
Sieder & Tate (1936) [Horizontal]	$\overline{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}(\frac{\mu}{\mu_w})^{0.14}$	$0.7 \le \mathrm{Pr} \le 16700$ $\mathrm{Re} \ge 10000$ $L/D \ge 60$
Colburn (1933) [Horizontal]	$\overline{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}$	$0.6 \le \mathrm{Pr} \le 160$ $\mathrm{Re} \ge 10000$ This relation can be used only in cases for small to moderate temperature differences.
Dittus-Boelter (1930) [Horizontal]	$\overline{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}$ $(heating)$ $\overline{Nu} = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3}$ $(cooling)$	$0.7 \le \mathrm{Pr} \le 120$ $\mathrm{Re} \ge 10000$ $L/D \ge 60$ To be used for small to moderate temperature differences.
Petukhov & Popov (1963) [Horizontal]	$\overline{Nu} = \frac{\mathrm{Re}\,\mathrm{Pr}}{a}(\frac{f}{8})(\frac{\mu}{\mu_w})^n$ $where\ a = 1.07 + 12.7(\mathrm{Pr}^{2/3} - 1)(f/8)^{0.5}$ $n = 0.11$ $for\ heating\ (T_{wall} > T_{bulk})$ $f = (1.82 \log \mathrm{Re} - 1.64)^{-2}$	$10^4 < \mathrm{Re} < 5 \times 10^6$ $0.5 < \mathrm{Pr} < 2000$ $0.08 < \frac{\mu}{\mu_w} < 40$

TABLE II (Cont'd)

SINGLE-PHASE HEAT TRANSFER CORRELATIONS FOR TURBULENT PIPE FLOW

INVESTIGATOR	CORRELATION	CONDITIONS
Gnielinski (1976) [Horizontal]	$a)\ \overline{Nu} = \dfrac{(f/2)(\mathrm{Re}-1000)\,\mathrm{Pr}}{1+12.7(f/2)^{1/2}(\mathrm{Pr}^{2/3}-1)}$	$2300<\mathrm{Re}<5\mathrm{x}10^6$ $0.5<\mathrm{Pr}<2000$
	$b)\ \overline{Nu} = 0.0214(\mathrm{Re}^{0.8}-100)\,\mathrm{Pr}^{0.4}$	$10000<\mathrm{Re}<5\mathrm{x}10^6$ $0.5<\mathrm{Pr}<1.5$
	$c)\ Nu = 0.012(\mathrm{Re}^{0.87}-280)\,\mathrm{Pr}^{0.4}$	$3000<\mathrm{Re}<1\mathrm{x}10^6$ $1.5<\mathrm{Pr}<500$
Ghajar and Tam (1994) [Horizontal]	$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.385}(x/D)^{-0.0054}(\dfrac{\mu_b}{\mu_w})^{0.14}$	$7000 \leq \mathrm{Re} \leq 49000$ $4 \leq \mathrm{Pr} \leq 34$ $3 \leq \mathrm{x/D} \leq 192$ $1.1 \leq \dfrac{\mu_b}{\mu_w} \leq 1.7$

CHAPTER II

EXPERIMENTAL SETUP

2.1 Description of the Apparatus

Presented in this chapter is a description of the experimental apparatus used, including the necessary instrumentation details. Following the apparatus description is an explanation of all necessary calibration procedures, which are designed to insure the accuracy of the apparatus and instrumentation elements. The design and machining of all of the experimental setup components explained in this chapter were a joint effort of Mr. Dongwoo Kim and this author. The DC arc welder, turbine meter, small motor pump and heat exchanger were borrowed from the Strickland (1990) and Tam (1995) experimental setup. A schematic diagram of the heat transfer experimental apparatus is shown in Fig. 2.1. Care has been taken while designing this setup in order to meet the foreseeable future needs. If any part is worn out or damaged, that part can be replaced without any problem, because, in this design, each section is easy to take out and replace without much difficulty. Every part of this apparatus has been carefully machined and assembled.

Several previous researchers' experimental setups (Chapter I) have been carefully studied to gain knowledge of the procedures they have employed while designing a test loop for single-phase and two-phase setups. Ideas have been borrowed from previous studies also. To achieve the required versatility, several unique features like the design of the mixing chamber, the length of the clear calming section, and installation of the separator, to name a few, were incorporated into the system. The

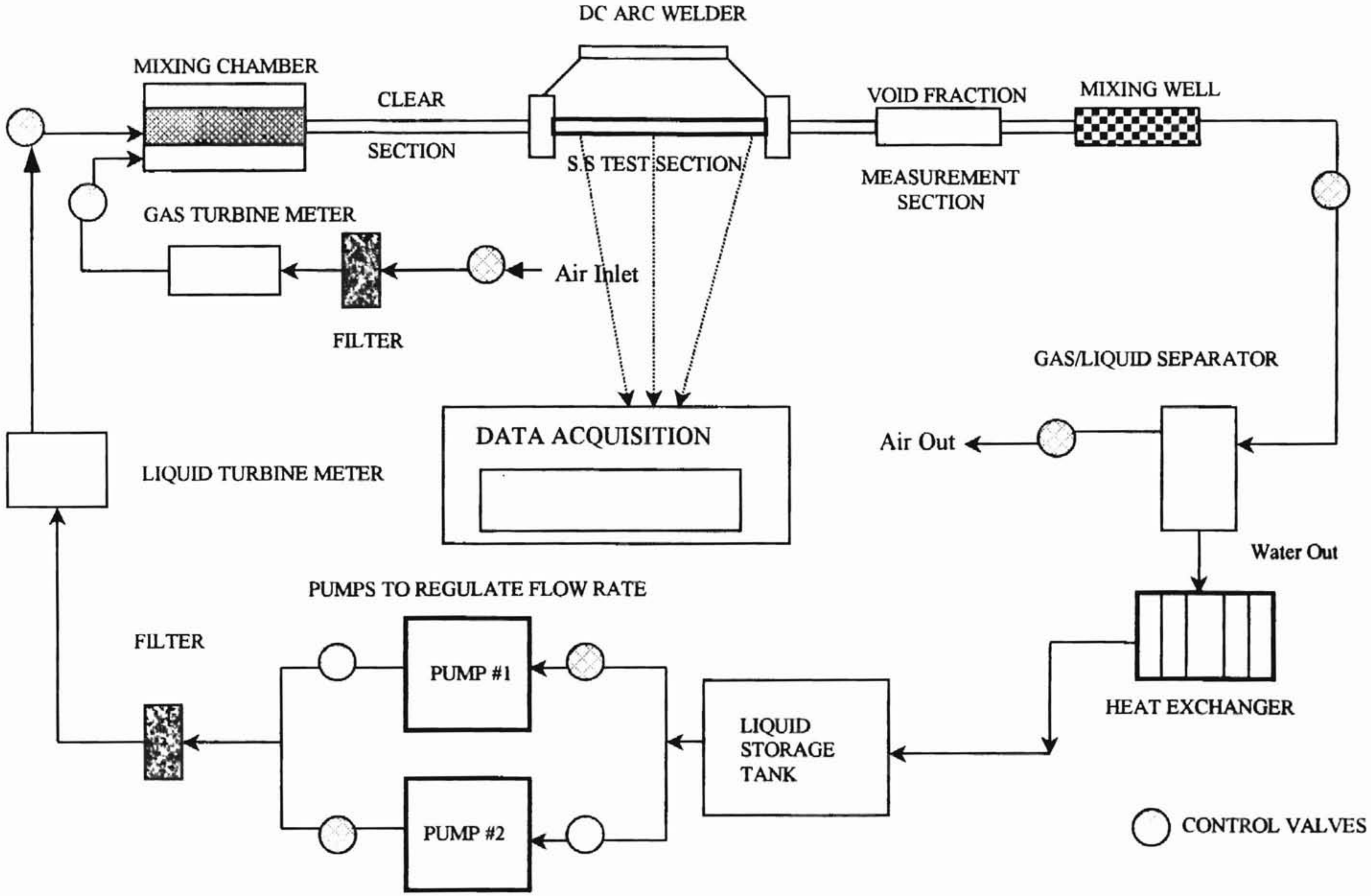


Figure 2.1: Schematic Diagram of the Experimental Setup

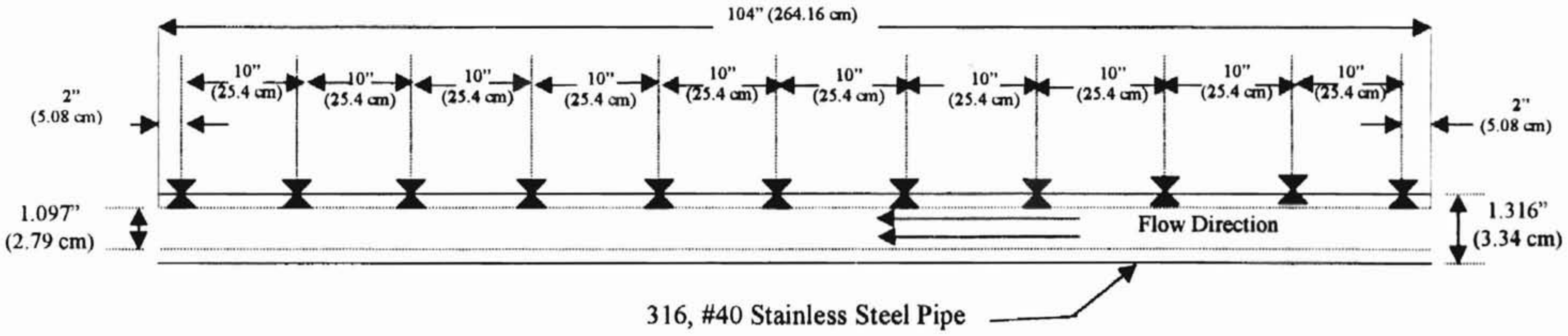
final coverage of this chapter will detail the data reduction techniques and the software assisting in this task. This section will introduce all of the equipment used to handle the heat transfer measurements. It will clearly explain all of the components, their design and function in detail. All equipment specifications are given in Appendix A.

2.1.1 Test Section

The test section was a horizontal seamless 316, #40 stainless steel circular tube with an average inside diameter of 1.097±0.001 inches (2.7863±0.00254 cm) and an average outside diameter of 1.316±0.001 inches (3.3426±0.00254 cm). The total length of the test section was 110 inches (279.40 cm), providing a maximum length to diameter ratio (L/D) of 94.804. The stainless steel tube was procured from Stillwater Steel and Supply, Stillwater, OK.

Eleven pressure tap holes were drilled along the test section (see Fig. 2.2). The tap diameter was 0.06811 inches (0.173 cm). These taps were drilled with an R18C cobalt bit. In order to ensure proper flow without any disturbance, the pressure tap holes were de-burred with a 1/16 inch (0.15875 cm) ridge reamer. Pressures were not measured in the shakedown runs presented herein.

A ¼ inch (0.635 cm) thick, 5 inch (12.7 cm) wide, 7 inch (17.78 cm) long copper plate was silver soldered to the two ends of the test section. Supporting copper material was bolted to the end plates such that bus bars (2 inch x 7 inch) could be dropped into position for attachment to welding cables for heat addition. These bus bars were then bolted to phenolic plates [5 inch (12.7 cm) x 7 inch (17.78 cm) x .5 inch (1.27 cm)]. The phenolic plates were used to insulate the electrodes and to



Tap Diameter = 0.06811 inch (0.0173 cm)

Figure 2.2: Pressure Tap Locations Along the Test Section

minimize heat loss beyond the electrode region (see Fig. 2.3) and also worked as supports for the electrode plates.

The entire test section was surrounded with fiberglass pipe wrap insulation (5 inch (12.7 cm) x 0.25 inch (0.635 cm)), followed by a thin polymer vapor seal to prevent moisture penetration. An approximate total thickness of the insulation materials was 2.5 inches (6.35 cm). When the test section was completed, it was leveled (within ±0.5°) using a level gauge.

Forty thermocouples were placed at ten axial locations along the test section. Four thermocouples were placed circumferentially at each section. Making and calibrating these thermocouples is explained briefly in Experimental Calibration (Chapter III). The position of these thermocouples is clearly shown in Fig. 2.4.

2.1.2 <u>DC Arc Welder</u>

The heat source was a Lincoln Idealarc DC-600 three-phase rectified electric welder, and was used with variable voltage to produce a DC electric current through the test section. The welder was rated for 100% duty cycle at 600 amps and 44 volts at either 50/60 Hz, giving a maximum power output of 24.6 kW. A General Electric dropping resistor was used when the experiments were conducted with the current below 150 amps. This resistor was placed in series with the electric welder. To ensure minimal room heating and vibrational effects from the motor, pump, and air conditioning system, the arc welder was located at an external wall where it exhausted hot air (outside the room) through a square duct, and took in cooler air through a duct protected by a steel grate. Much of these systems' noise was alleviated in this manner.

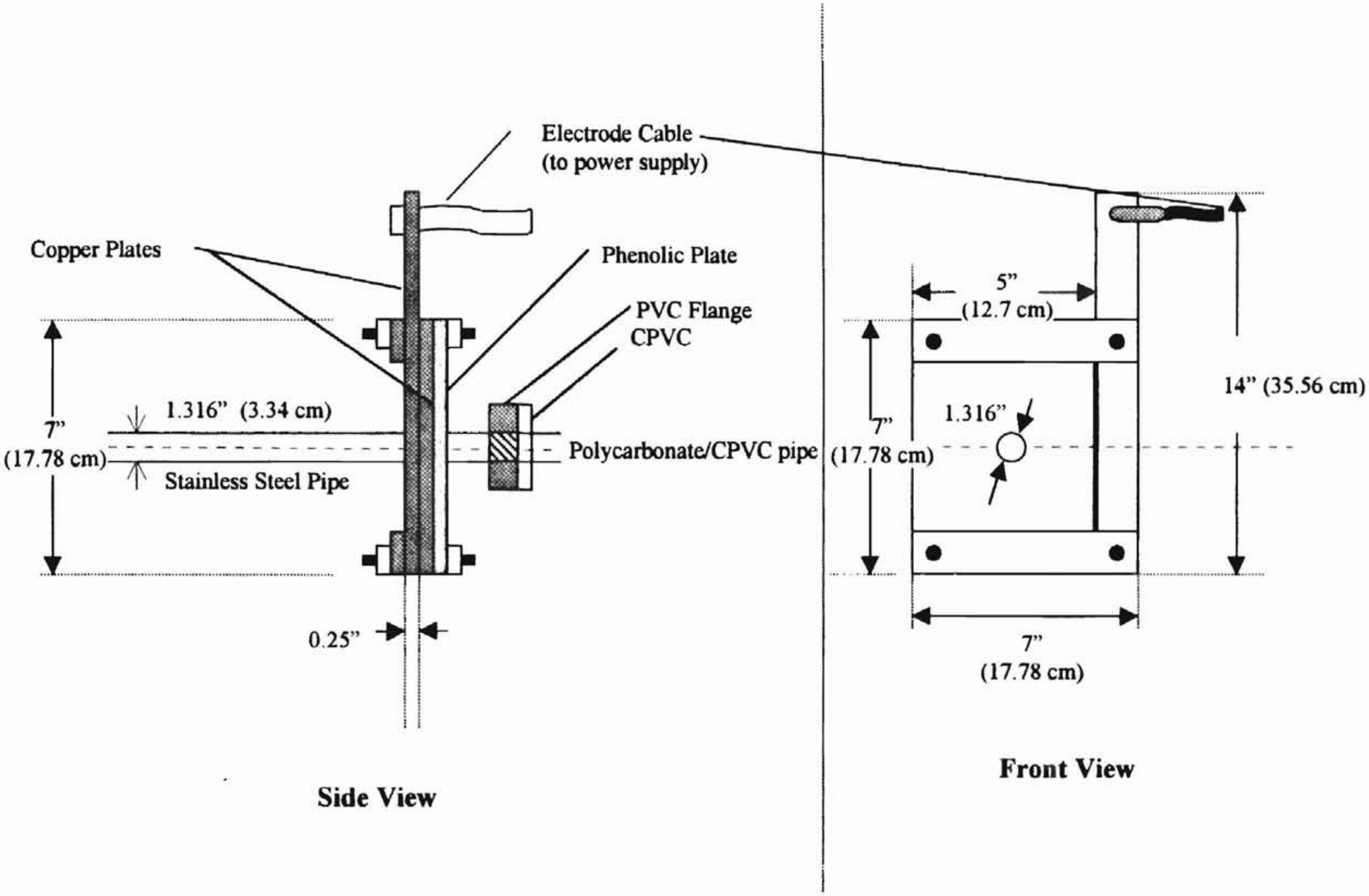
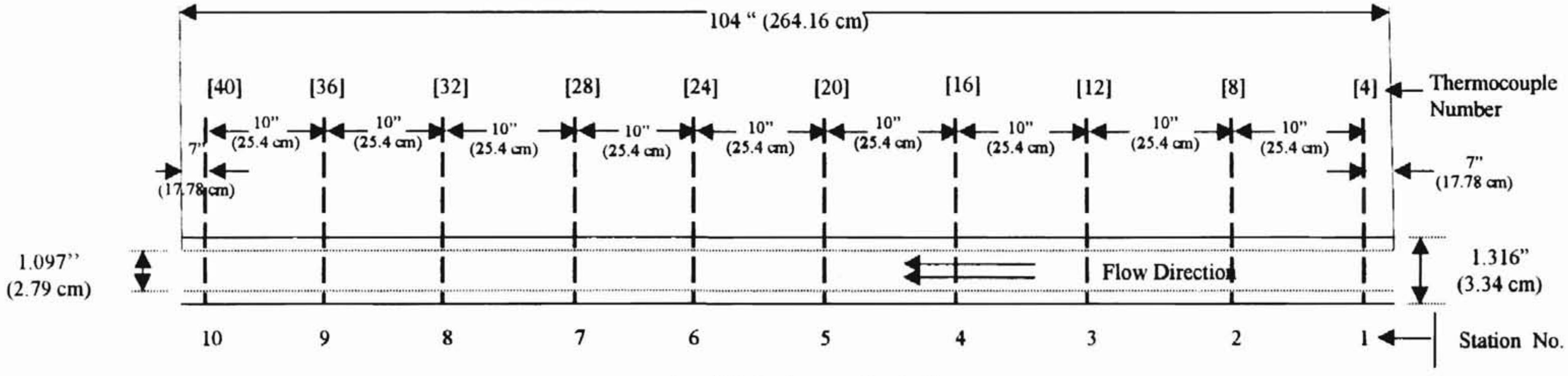
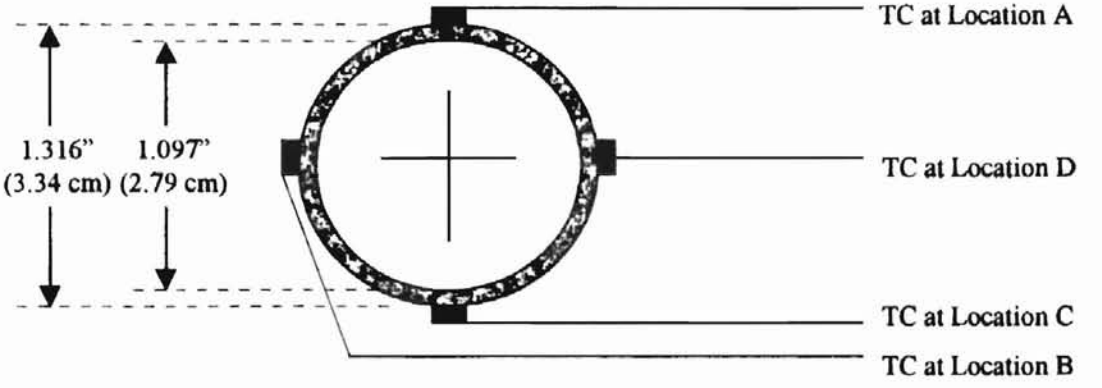


Figure 2.3: Copper Plate and Electrode Cables



316, #40 Stainless Steel Pipe



Cross Section of the Stainless Steel Pipe

Figure 2.4: Thermocouple Locations Along the Test Section

A plywood box fitting flush with the external wall and layered on all sides with duct insulation helped to eliminate the noise due to the welder's operation. To control transmission of vibration through the floor, the welder was placed on rubber damping pads.

2.1.3 Calming Inlet Section

The calming section served as a flow straightening and turbulence reduction device. The calming section was 8 feet (2.438 m) long, 1.0 inch (2.54 cm) internal diameter, and 1.25 inch (3.175 cm) outside diameter clear polycarbonate pipe (refer to Appendix A). One end of the calming section was connected to the test section with a PVC type flange, which is clearly shown in Fig. 2.5, the other end of the calming section was connected to the mixing chamber (see Fig. 2.6)

The CPVC flange was glued to the calming section with clear solvent cement from Weldon #3. This flange was 1/2 inch (12.7 mm) thick by 5 inches (12.7 cm) in diameter, with a 1.25 inch (3.175 cm) internal diameter hole carefully drilled so that the calming section was glued into it. After gluing the two, the resulting piece was left undisturbed for 24 hours so that the glue could harden completely.

Eight quarter inch (0.635 cm) holes were drilled in the CPVC flange, so that it could be easily bolted to the PVC flange, which was screwed to the test section. A small groove of 1/10 depth was cut in the CPVC flange, and a sealing gasket was placed in the groove (refer Fig. 2.6). This gasket seal helped to stop any leaks at the flange connection. The two flanges were bolted together very carefully so that the heated test section never touched the polycarbonate tube. This was done so that the polycarbonate tube wouldn't melt while applying heat to the test section.

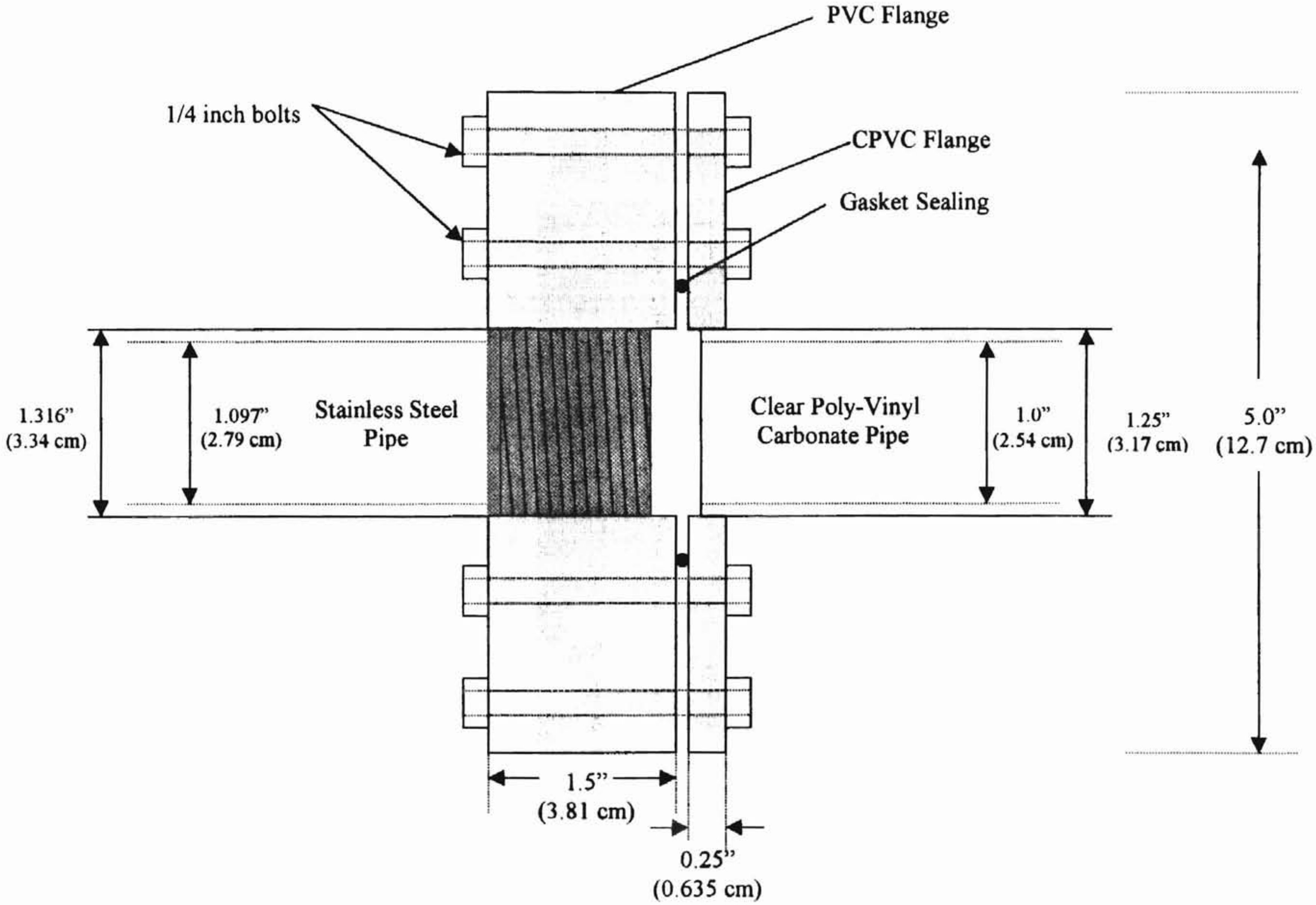


Figure 2.5: Stainless Steel Pipe and Calming Section

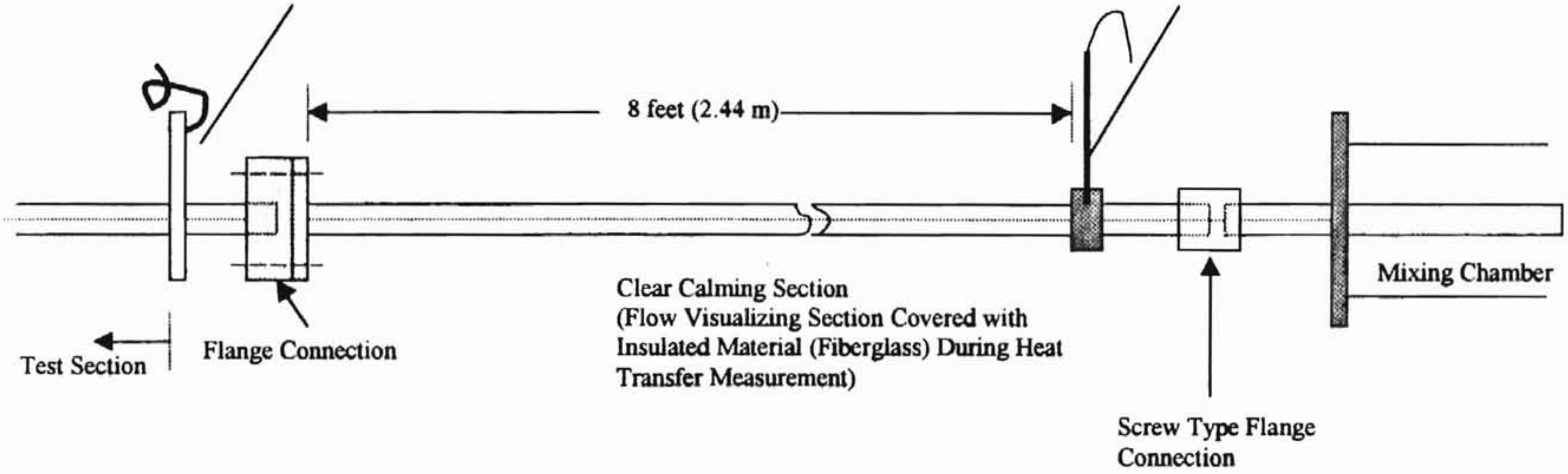


Figure 2.6: Flange Connection, Calming Section and Mixing Chamber

2.1.4 Thermocouples

The thermocouples were placed on the outer surface of the heat transfer test section. There were 40 thermocouples used, and they were placed at ten positions on the test section. Ten stations used four thermocouples per station. At each station, the four thermocouples were placed peripherally at 90 degree intervals. Starting from the top at a particular section, the top position was designated as 'A', the next position at the same section as 'B', and so on (see Fig. 2.4). This was done so that it was easy to identify the thermocouples while plotting graphs. Omega TT-T-30 Copper-Constantan insulated T-type thermocouple wire was used with Omega extension wire (see Appendix A) for relay to the data acquisition system. The thermocouple beads were fabricated using a Tigtech Inc. thermocouple welder. Fig. 2.4 shows the positioning of the thermocouples. Twenty extra thermocouples were made in case they were needed in the future due to breakage, malfunctioning, additional thermocouple stations needed, etc. All thermocouples were calibrated between 10° C (50.5° F) to 65° C (149.5° F) at intervals of 5° C using a constant temperature bath. (See Appendix A for name, company, and specifications.) The calibration procedure is carefully outlined in the next chapter, Experimental Calibration (Chapter III).

Each thermocouple was labeled (refer Fig. 2.4) with a two digit identification number (TC 01,TC 02, etc.). Two additional thermocouples were used to measure the room temperature (near the test section) and temperature of the water in the storage tank. Also, two thermocouple probes were used to measure the inlet bulk temperature and the outlet bulk temperature. These probes were procured from Omega (see Appendix A). The inlet thermocouple probe was placed just after the mixing chamber as shown in Fig. 2.6. The manner in which the probe was inserted into the fluid is clearly shown in Fig. 2.7. The thermocouple probe tip was positioned at the center of the pipe to take the bulk temperature at precisely that location. The temperature was measured only at the tip of the thermocouple probe.

The outlet bulk temperature probe was placed after the mixing well, this was to make sure that the fluid really mixes well before the bulk temperature reading was taken. The thermocouple probes were placed in a special housing, and were properly inserted into the flow pipe to get an accurate bulk temperature measurement (very similar to the inlet configuration of Fig. 2.7). All of the thermocouples were monitored with a Cole-Palmer MAC-14 data logger. The thermocouple readings were averaged over a user chosen length of time (typically 50 seconds) before the heat transfer measurements were actually recorded. The average system stabilization time period was from 30 to 60 minutes after the system attained steady-state. Calibration curves for all of the thermocouples were produced using an MS-Excel spreadsheet. (See Appendix E for calibration curve equations for all the thermocouples.) This is explained in section one of Chapter III (Section 3.1).

Thermocouple beads were attached to the outside of the tube wall using Omegabond 101 epoxy adhesive (see Appendix A), a two-part adhesive providing a high thermal conductivity (0.6 Btu/hr-ft-°F), and a very high electrical resistivity of 1×10^{15} ohm-m. An initial drop of epoxy (approximately 1 mm in radius), was placed at each thermocouple location and allowed to cure for twenty four hours. Each thermocouple was then placed on the hardened Omegabond surface (preventing direct contact with the tube surface and providing electrical insulation), held in place with a

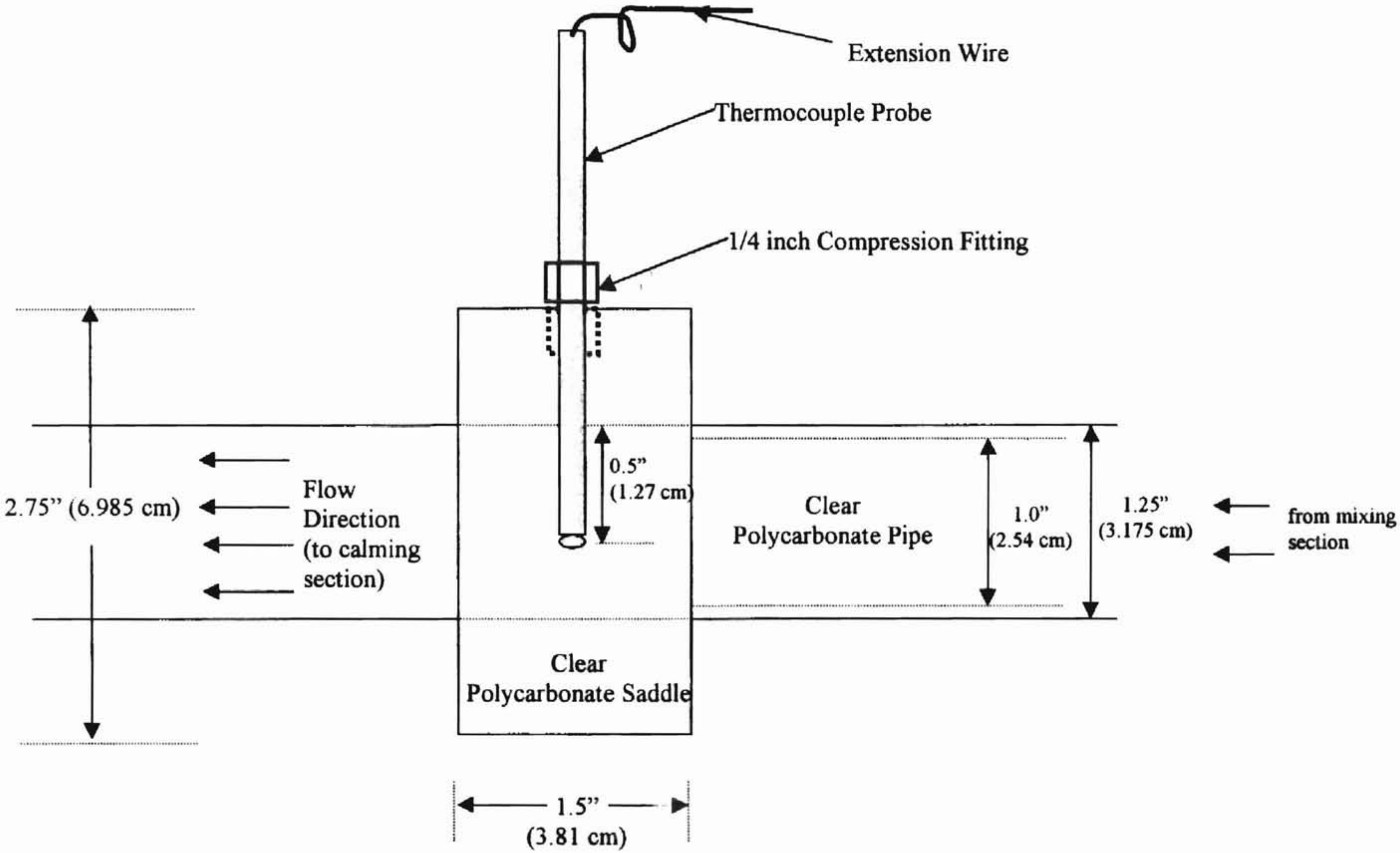


Figure 2.7: Inlet Thermocouple Probe Placement

strip of electrical tape such that the bead and hardened surface were exposed, and then coated with another drop of Omegabond to ensure permanent positioning. The thermocouple extension wires were then bundled in groups of four, fastened to the wood channels supporting the test section using wiring bundle rings, and connected to the data acquisition system.

2.1.5 Mixing Well

To ensure a uniform fluid bulk temperature at the exit of the test section, a mixing well was utilized. The mixing well (see Fig. 2.8) was a 22 inch (55.88 cm) long 1.0 inch (2.54 cm) internal diameter clear polycarbonate tube. The mixing well was placed after the void fraction measurement section. The purpose of the mixing well was to mix the fluid properly and obtain a good bulk temperature measurement.

The mixing well had four Omega static mixers (see Appendix A), each having a length of 5.3 inches (134.62 cm) and a diameter of 0.906 inches (2.30 cm). The outlet bulk temperature measurement was performed immediately after the mixing well section, as shown in Fig. 2.8.

2.1.6 Mixing Chamber

The mixing chamber was carefully designed to handle high pressures (150 psig) of both air and water. It was a clear section that was 17.5 inch (44.45 cm) long. The mixing chamber consisted of a 16 inch (40.64 cm) long, 6.5 inch (16.51 cm) inside diameter clear polycarbonate section, two porous bronze tubes, two circular steel plates of ¾ inch (1.905 cm) thickness and 11 inch (27.94 cm) diameter, and two CPVC circular plates of 11 inch (27.94 cm) outside diameter and 7 inch (17.78 cm) inside

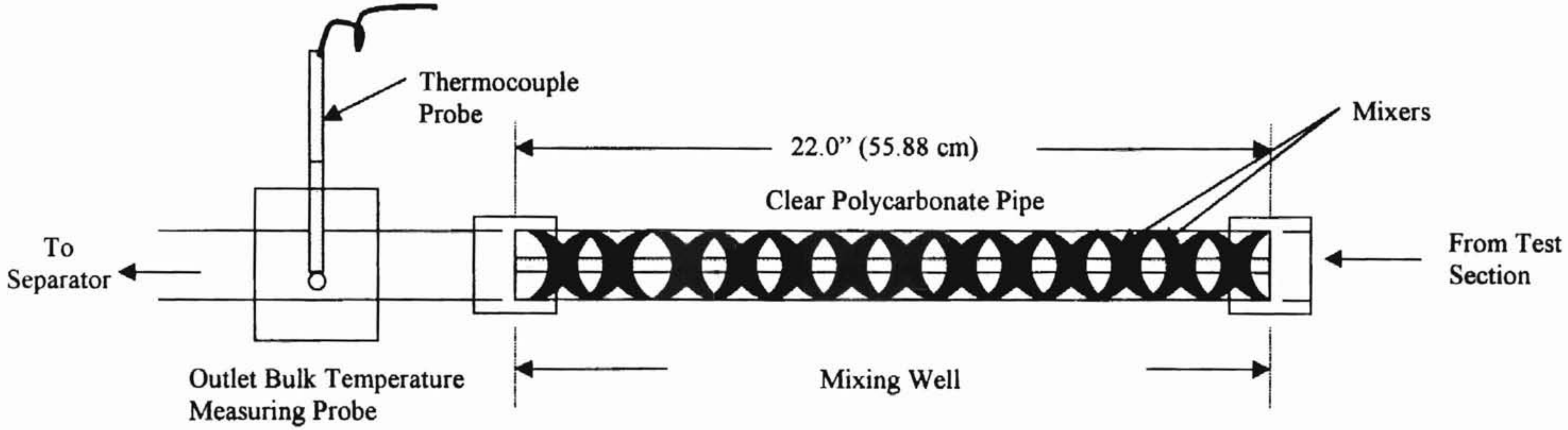


Figure 2.8: Mixing Well and Outlet Thermocouple Probe

diameter (see Fig. 2.9). The porous bronze tubes were procured from Capstone Permaflow (see Appendix A). They were 8 inches (20.32 cm) in length, had an inside diameter of 0.8 inches (2.03 cm), and an outside diameter of 1 inch (2.54 cm).

The two porous bronze tubes were welded into one longer tube with an arc welder. The arc welding was done by North Lab Manager, Mr. James Davis. The arc welding was carefully done without destroying the properties of the tubes. The steel plates and CPVC plates were drilled with 12 quarter inch (0.635 cm) holes. At the exit end of the steel plates, a central hole was drilled and tapped with internal threads at 1 ¼ inch diameter (12 NPT). This was done to connect a steel pipe (1ft long, this is not the test section), which in turn was joined to the inlet thermocouple probe measuring section. A collar that was 1 inch (2.54 cm) diameter and 1/10 inch (0.254 cm) thick was drilled on the inside of the two steel plates. This was done to hold the welded bronze tube. The inlet end of the mixing section had a 1 ¼ inch (3.18 cm) threaded (12 NPT) hole for the entry of the water. The water entered the test loop here. The water then flowed through the porous bronze tube. The inlet end of the test section also had 4 one-half inch (1.27 cm) threaded holes for the entry of air. In the mixing chamber, air entered through these four inlets, and, due to the porosity of the bronze tube, the air entered the tube and mixed well with the water. The four inlets for the air could be controlled with ½ inch (1.27 cm) ball valves.

2.1.7 Constant Heat Source

A variable voltage Lincoln Idealarc DC-600 three phase rectified type electric welder was used to produce DC current. The current was delivered to the test section through Radaflex AWG 4/0 welding cable attached to the copper bus bars located at the

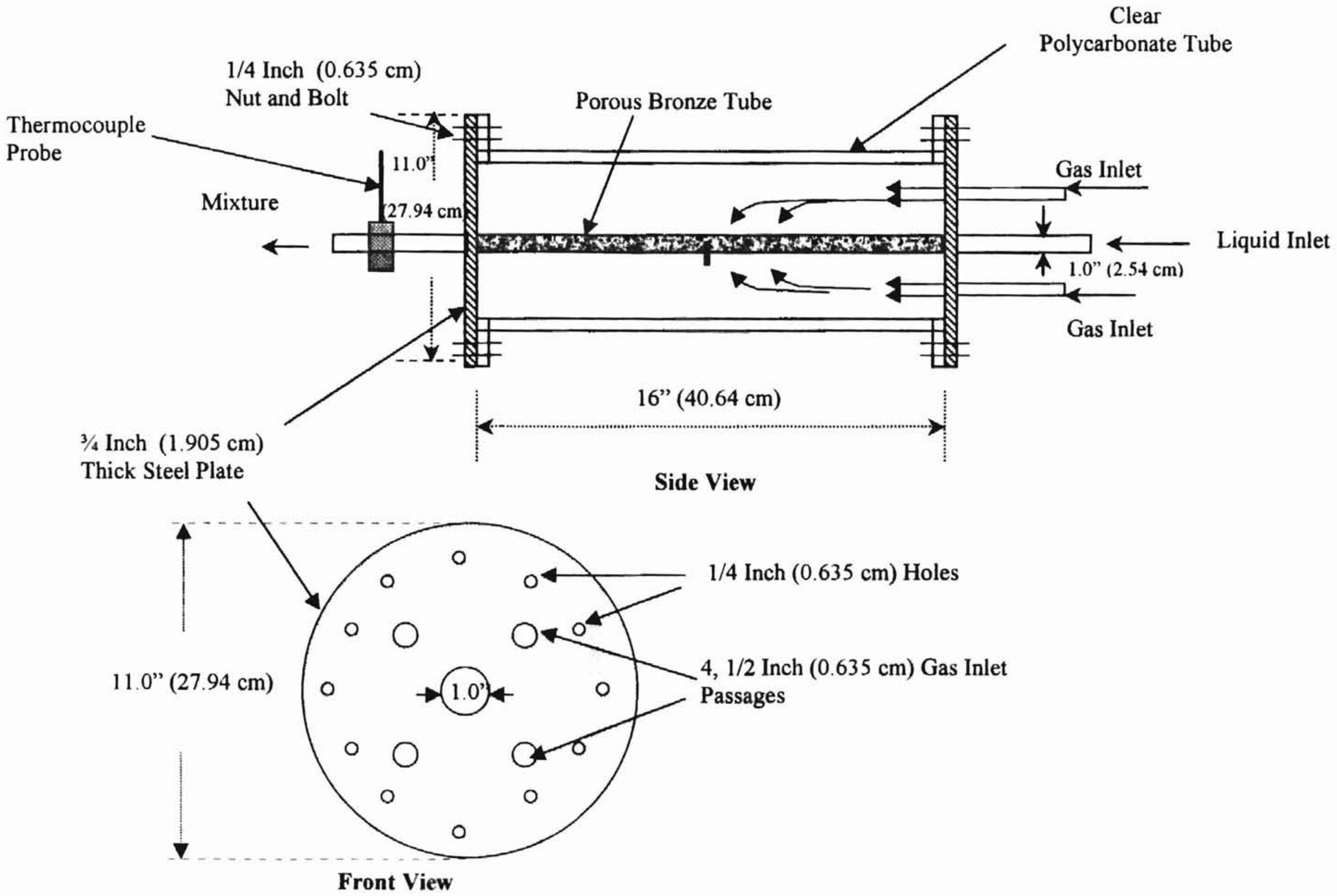


Figure 2.9: Mixing Chamber

inlet and exit flanges (see Fig. 2.3). Heat was generated internally in the steel tube wall due to its electrical resistivity. The DC-600 was rated for 100% duty cycle at 600 amperes and 44 volts for either 60 or 50 Hertz. But while actually applying the heat, the welder was not able to give 100% of the output it was supposed to give. This might have been due to the Radaflex 4/0 AWG being shortened to meet the required length; so we used a connector to increase its length. The place near the connector might have been losing heat, or the stainless steel pipe had a high resistance which might decrease the output.

To insure minimal room heating and vibrational effects from the welder, it was located at an external wall where it exhausted any hot air (outside the room). The hot air was exhausted through a custom made plenum to a 12.25 inch (31.11 cm) square duct, and cooler air was brought in through a 7.25 inch (18.42 cm) wide by 18.25 inch (46.36 cm) tall duct protected by a steel grate. Much of the exhaust noise was also rejected in this manner. A large 37 inch (94.0 cm) tall by 41 inch (104.14 cm) wide by 57 inch (144.78 cm) deep plywood box fitting flush with the external wall and layered on all internal sides with approximately 2 inches (5.08 cm) of duct insulation muffled the noise due to the welder's operation. To control transmission of vibration through the floor, the welder was placed on approximately 10 refrigerator type rubber damping pads.

2.1.8 Voltmeter

A Hewlett-Packard model 3468B digital multimeter (see Appendix A) was used to measure the actual voltage drop across the test section.

2.1.9 DC Ammeter

The current passing through the test section wall was measured with a Weston Instruments Division ammeter (see Appendix A) placed in parallel with a 50 millivolt shunt. It was calibrated by Mr. Gerald Stotts, manager of the Electronics Laboratory, Electrical and Computer Engineering at Oklahoma State University.

2.1.10 Heat Exchanger

An ITT standard one shell and two pass tube heat exchanger (see Appendix A) was used to cool the test fluid to an allowable and steady-state inlet bulk temperature. The shell had an effective surface area of 21.2 ft^2 (1.97 m^2) and a maximum duty of 67190 Btu/hr (19.7 kW). The cooling water was provided from a city water tap through an Omega FL-9028 rotameter. A Teek Water Systems double cartridge filter (see Appendix A) removed impurities, and 1.25 inch (3.175 cm) schedule 40 poly-vinyl-chloride (PVC) tubing carried the coolant to the heat exchanger, exiting to a waste water trough. The heat exchanger was 39.625 inches in length (1.0 m), and was mounted on a wooden saw horse for stability.

2.1.11 Void Fraction Measurement Section with Quick Closing Valves

For two-phase fluid flow, it was necessary to prepare for measuring the void fraction of the mixture in order to insure accurate experimental reporting and correlation calculation of the heat transfer coefficient. Calculation of the void fraction is always critical, since it is very hard to predict exactly (based on input flow rates for air and water) the ratio of volume of the liquid to volume of the gas in the mixture at any moment of time.

We have installed three quick-closing solenoid valves, two manually operated valves and a 24 inch (60.96 cm) long, 1 inch (2.54 cm) inside diameter clear polycarbonate tube to measure the void fraction ratio in two-phase fluid flow (see Figs. 2.10 and 2.1 for overall location of this section). The two quick-closing solenoid valves were procured from W&W International (see Appendix A). These two solenoid valves were in line with the test loop. They were designed to be always open except when measuring the void fraction. Another solenoid which was procured from Automatic Switch Co. (see Appendix A) was placed in the by-pass line.

Two manually operated Teflon-PFA type (see Appendix A), ¼ inch (0.635 cm) valves were procured from Omega Engineering, Inc. These valves can withstand pressures up to 40 psi, and temperatures up to 300 °F (148.6 °C). Two quarter inch (0.635 cm) clear tubes were connected to these valves to allow draining of the liquid trapped between the two quick-closing solenoid valves (see Fig. 2.11).

To measure the void fraction ratio, the two solenoid valves (A and B) could be closed instantaneously, and valve C opened simultaneously to by-pass the fluid. Then the two Teflon type valves could be opened to drain the fluid into a measuring container. The weight of the fluid could then be measured carefully using any accurate weighing device, and the density of the water at the measured room exit test section conditions could be used to compute the drained liquid volume. Knowing the total volume of the section of tube between two quick-closing valves would allow computation of void fraction. For the valves of Teflon, a saddle of 1.25 inch (3.175 cm) diameter and 2.0 inch (5.08 cm) external diameter was machined from a solid cylindrical clear piece of polycarbonate. A ¼ inch (0.635 cm) (NPT 12) threaded hole was drilled and tappped in

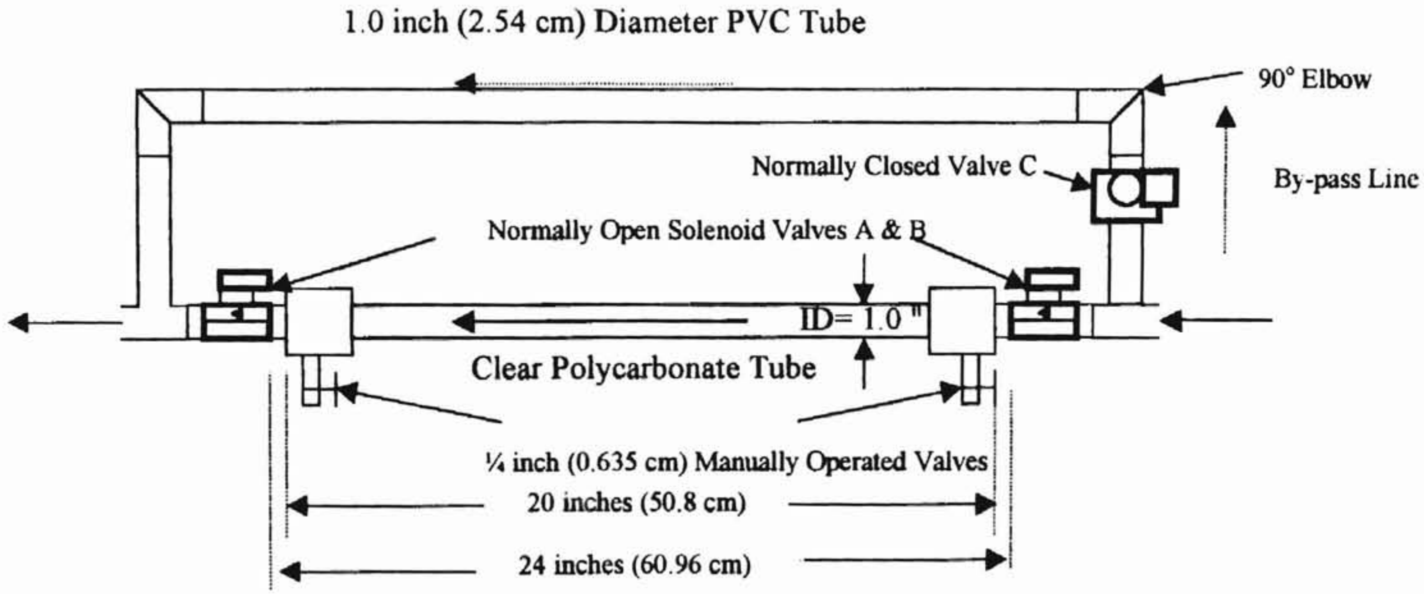


Figure 2.10: Void Fraction Measurement Setup

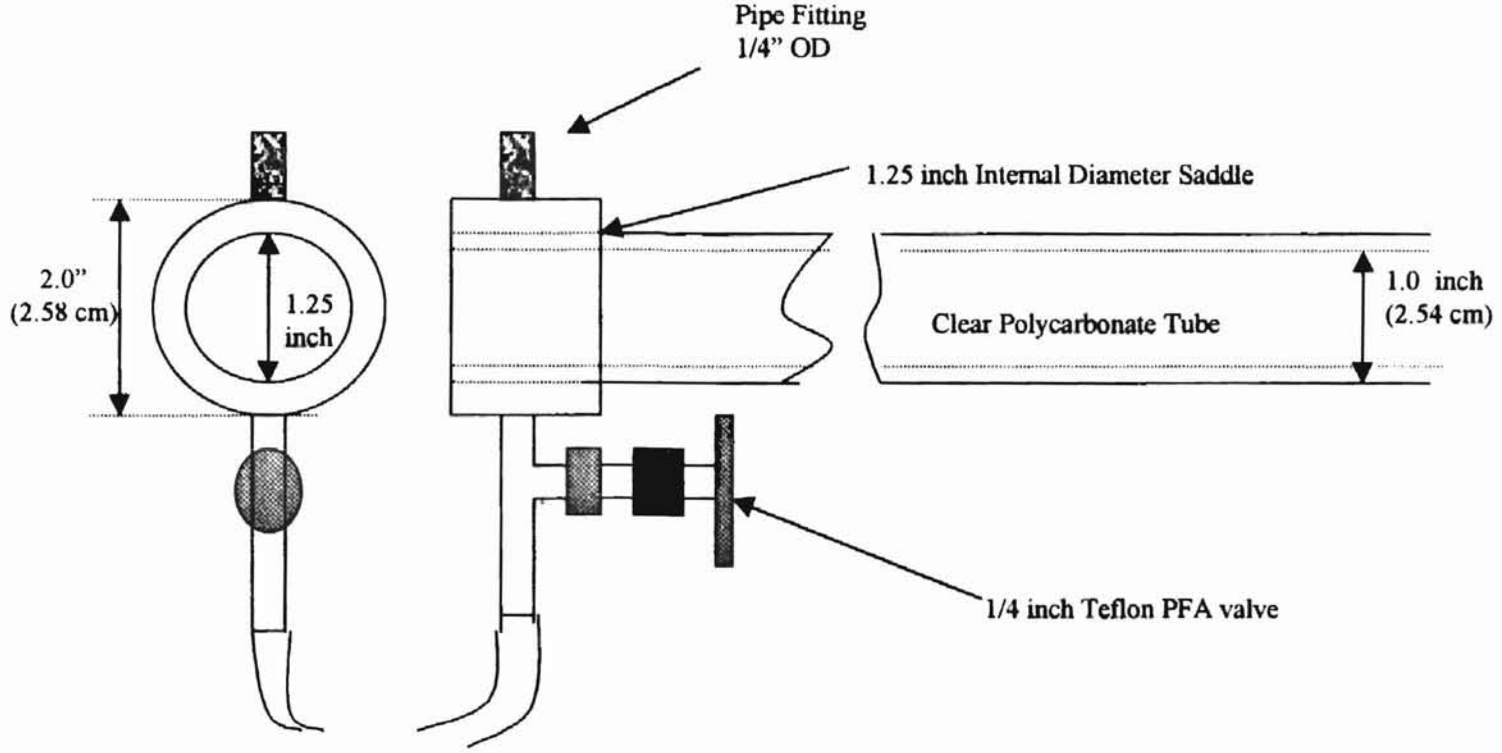


Figure 2.11: One Quarter Inch Teflon-PFA Type Drain

the top of each saddle. This was done in order to allow pressurization of the inside of the tube to drive the fluid out when measuring the void fraction ratio.

2.1.12 Water/Air Separator

A water/air separator was procured from Hayward Industrial Products Inc. (see Appendix A), and was designed to separate water and air from the fluid. This separator could handle a pressure of 160 psi at 450 °F.

The separator was placed in line with the test loop (see Fig. 2.1). This was made possible by mounting the separator on a specially constructed wooden stand. The inlet orifice was 1 ½ inches (3.81 cm) and the outlet was ¾ inch (1.905 cm) through which the water was driven out; and the air was exhausted to the room through a 1 ½ inch (3.81 cm) outlet orifice. The water was then sent to the heat exchanger and then to the storage tank.

The separator was made of cast iron, and some of the internal parts were rust proof stainless steel. To insure a rust free environment inside the separator, it was painted with rust proof paint. Water would be trapped inside the separator by the vortex motion of the fluid as it came inside. The trapped water would settle down and then drain out to the heat exchanger. The separator was not able to handle the designed flow rate range: 1.5 gpm to 4.5 gpm. In order to make it work over this range of flow rates, a ball valve inside the separator was removed. The approximate shape and dimensions of the separator are shown in Fig. 2.12.

2.1.13 Water Reservoir

A 35 gallon (132.44 liters) cylindrical polyethylene tank was used to store and supply water to the test section.

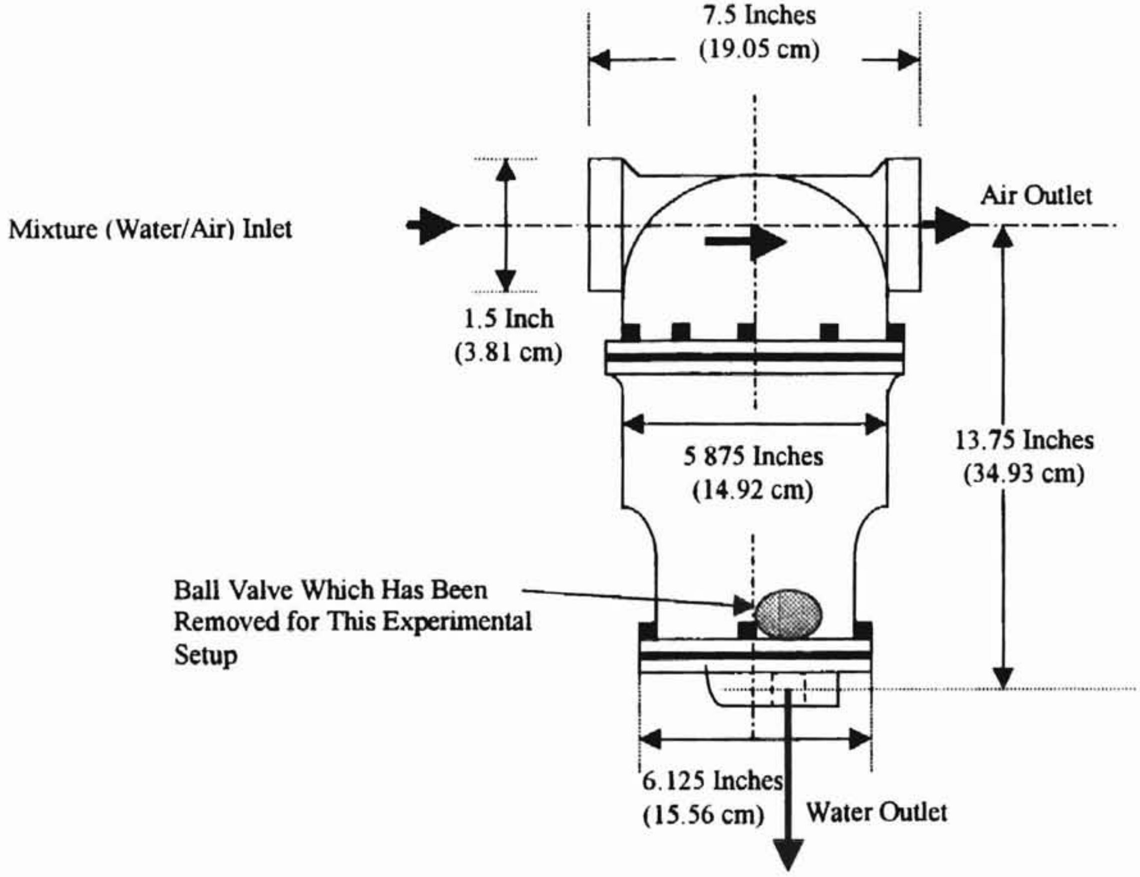


Figure 2.12: Water/Air Separator-Trap (Cast Iron)

2.1.14 Pumps

For low flow rates, a pump manufactured by Oberdorfer Pumps (see Appendix A) was used. It produced a flow rate of 4.8 gpm at 3450 rpm using a General Electric 1/3 hp (245.66 watts) motor.

For high flow rates, a Westinghouse pump (see Appendix A) was used. The motor was rated at 1.5 HP, which produced a flow rate of 35 gpm at 3535 rpm. To minimize the noise and vibrational effects of the large pump during operation, it was mounted inside a plywood box using rubber damping material approximately 3/8 inches (0.95 cm) thick. The box had dimensions of 57 inches (144.78 cm) wide, 30 inches (70.62) high, and 16 inches (40.64 cm) deep. On all interior walls of the box, approximately 1 inch (2.54 cm) of duct insulation material was placed, providing acoustic absorption. The whole pump containment box was isolated from the floor with 12 refrigerator type rubber dampers, in order to reduce vibration transmission. For the single-phase test runs, only the small pump was used.

In addition, to help prevent vibration transmission through the fluid return tubing, flexible hoses connected the pump box at both upstream and downstream locations. The pumps operated at a constant rpm. Therefore, to minimize cavitation and potential lack of water in the pumps at low flow rates, a separate by-pass line was placed just after the pumps and before the filter. To regulate the flow rate, the valve at the bypass line was opened or closed, and the pumps were always operated under full load. A schematic view of how these pumps were connected to the test loop is shown in Fig. 2.13.

2.1.15 Turbine Meter

For flow rates up to approximately 10.5 gpm (39.73 liters/min), a Halliburton 1 inch (2.54 cm) turbine meter (see Appendix A) was used over a frequency range from 50 to 150 Hertz. The turbine meter was calibrated on several occasions, and details of the procedure are outlined in Experimental Calibration (Chapter III).

2.1.16 Frequency Meter

A Hewlett-Packard universal counter (see Appendix A) was used to measure the frequency of the turbine meter during data collection. During operation of the turbine meters at low frequency, frequency instability problems were observed. To counter this problem, a variable amplifier was constructed by Mr. Pinit Ngamsom, an electrician for the School of Mechanical and Aerospace Engineering. It had a variable gain from 1 to 20, to produce a stable signal for the HP universal counter under the previously mentioned conditions.

2.1.17 Test Fluids

The liquid used was distilled water. Distilled water was obtained from the Chemical lab in room 311 of the Physical Science building at Oklahoma State University.

2.1.18 Fluid Return

After the liquid exited out of the mixing well (see Fig. 2.1), it flowed through high temperature 1.5 inch (3.81 cm) schedule 40 CPVC tubing. The return tubing began there and took the hot fluid to the heat exchanger. Exiting the heat exchanger, standard 1 inch (2.54 cm) schedule 40 PVC allowed the system to drain or return to the storage tank via 1 inch (2.54 cm) PVC ball valves. Leaving the storage tank, ½ inch

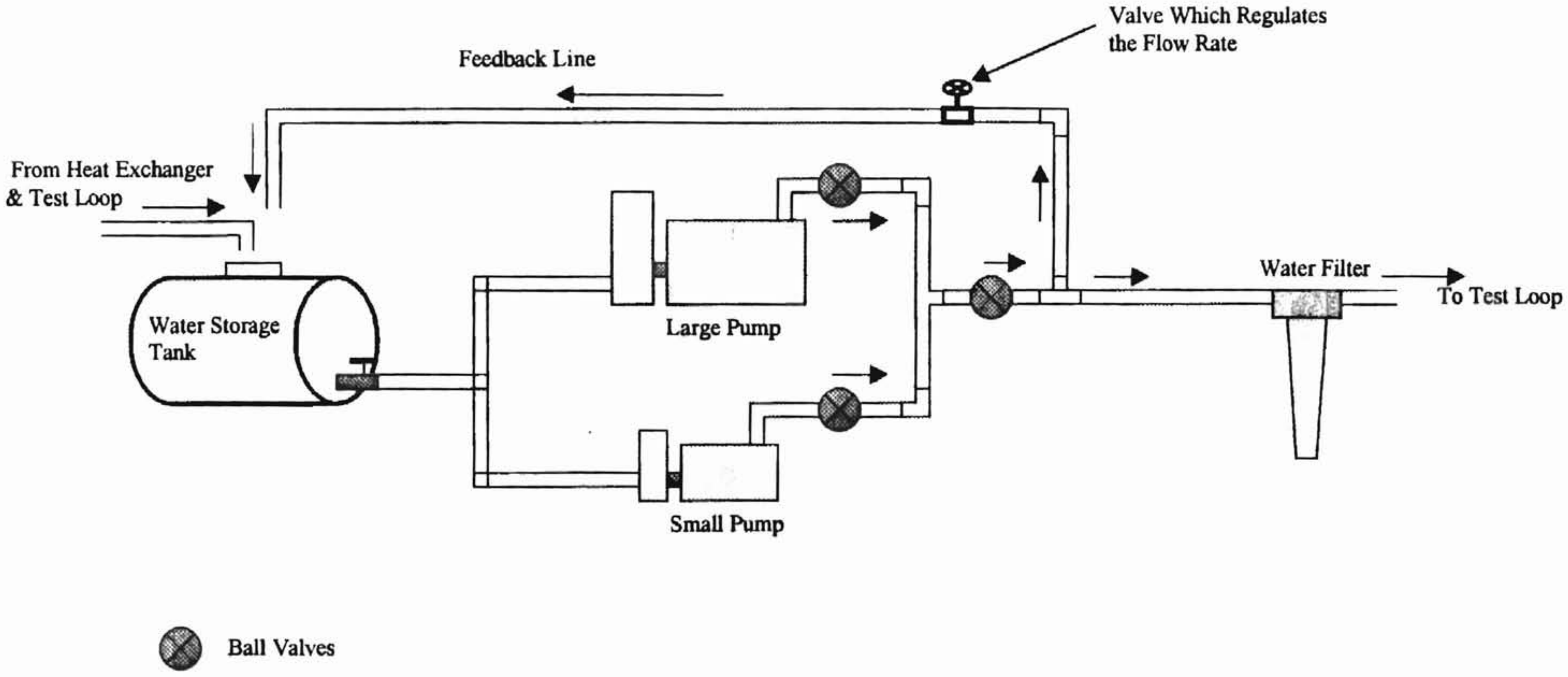


Figure 2.13: Pump and Feedback Line Design

(1.27 cm) schedule 40 PVC tubing carried the fluid to the pump box assembly described earlier (see Fig. 2.14). Upon exiting the pump assembly, a ½ inch (1.27 cm) stainless steel ball valve was used for flow control, and an Aqua-Pure Water filter model AP12T double cartridge filter system (see Appendix A) removed impurities as small as 5 microns in diameter from the flow. Next, the liquid traveled via 1.5 inch (3.81 cm) PVC schedule 40 tubing to the turbine meter assembly previously described (in section 2.1.14). The liquid then traveled through the mixing chamber, then through the flow visualizing section, and then to the test section (see Fig. 2.1). The flow visualizing section was a 1.25 inch (3.18 cm) internal diameter, clear polycarbonate tube as shown in Fig. 2.6.

2.1.19 Data Acquisition System

A Cole-Palmer ninety-six input MAC-14 data logger was interfaced with an AT (808386) personal computer to provide digital data acquisition for the temperature measurements. It accepted input voltages from 0.3 microvolts to 10 volts, had an accuracy of ± 0.02% of full scale range, and had 16 bit resolution. The operation manual had information regarding specific parameters associated with the MAC-14 data logger.

Connection to the computer was through a shielded cable to an RS232 port, and to the printer via the printer port. Menu-driven software (MS), was used in conjunction with signal conditioning (SC), real time graphics (RTG), and printer driver (PD) software to handle data input. The MS software allowed each channel to be tagged with the thermocouple identification labels and gave the user the ability to specify logging interval, disk storage, or screen only monitoring. The SC software provided

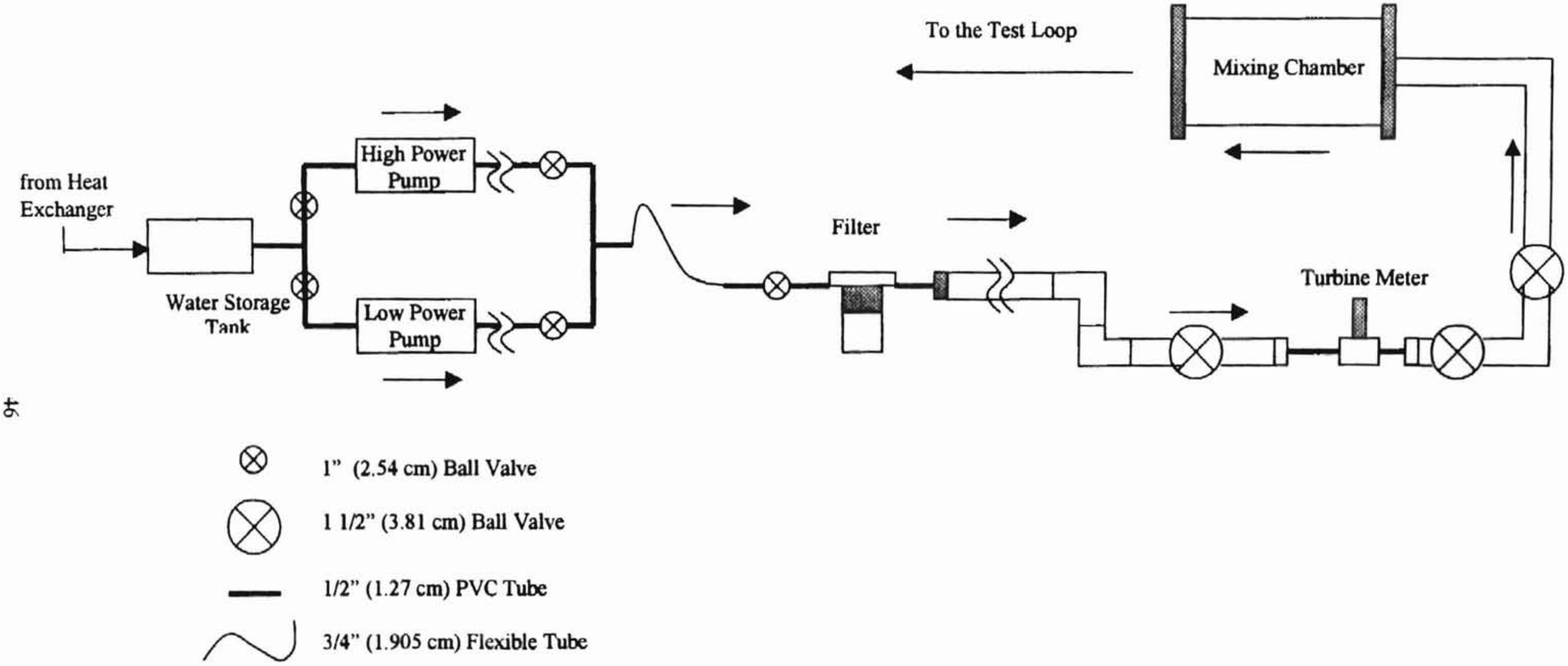


Figure 2.14: Return Line Configuration

additional columns on each channel for scale factors and units. It also performed the thermocouple conversions for all channels (volts to degrees). The RTG was a much expanded version of the MS which gave real time graphic display in scientific graph or industrial strip chart format. RTG required both MS and SC options for its use. The MAC-14 data logger was entirely self-contained requiring no special mounting. Additional software was required for post-experimental data reduction and was not available with the data logger (see Experimental Procedure in Chapter III for software discussion).

The IBM compatible AT (80386) personal computer had a 40 MB hard drive, dual floppy disk drives, EGA monitor, and an 80386 coprocessor. The computer was for data logging and data storage only. A Gateway 2000 computer with a Pentium II 266 MHz processor was used for data reduction and heat transfer calculations.

2.1.20 Supplemental Data Acquisition

An Electronic Controls Design (ECD) digital data logger (see Appendix A) with forty channel capacity was used to calibrate the thermocouples. The data logger was connected to the FTS system, which was a constant temperature bath, while calibrating the thermocouples. The model ECD had a resolution of 0.1 °F, over a temperature range from 158 to 752 °F and a ± 0.1 °F conformity error over a range from −105 to 400 °F. Using PC-TALK, the model ECD could interface with a personal computer through a shielded cable to a second RS232 port. The data logger memory was transferable to the computer hard disk or floppy diskette via PC-TALK, and it incorporated a strip chart recorder for instant data access.

CHAPTER III

EXPERIMENTAL CALIBRATION

Upon completing the experimental setup construction and acquiring the monitoring equipment, calibration of all equipment and much of the apparatus was required. The accompanying manuals gave instructions for calibration of the off-the-shelf equipment, while existing standard procedures were used for calibrating various components of the apparatus. The following sections outline the details of calibration.

3.1 Thermocouples

For the MAC–14 data acquisition system, no calibration was required. However the thermocouples connected to the system were calibrated by means of a constant temperature bath. The constant temperature bath system used was an FTS system, which uses HT-30 fluid to maintain a constant temperature. For this experiment, we made 56 thermocouples, out of which 44 were used during the actual experimental test. The 56 thermocouples were tested on the FTS system initially to check that they worked properly.

A Model 5100 data logger was used to take temperature readings while calibrating the thermocouples. The 56 thermocouples were tested for a temperature range from 10 °C to 65 °C at 5 °C intervals. Two sets of thermocouples were used while testing, since the maximum input for the 5100 data logger was only 40. The first set contained 32 thermocouples, and the second set contained 24 thermocouples. After collecting the data for the two sets of thermocouples for the temperature range from 10

°C to 65 °C, the data sets were then used to determine the maximum, minimum, and average temperatures for each thermocouple using a Fortran program called RED50.FOR. This program was written by Mahesh Rajagopalan. The program and sample input/output files are given in Appendix B. There has not been any change in temperature readings when the thermocouples were used with MAC-14 and Model 5100 data logger. Therefore the thermocouples were not re-calibrated with MAC-14.

It was observed that almost all thermocouples behaved well (within ±0.4 °C), before they were actually placed on the test section. Defective thermocouples were removed during the calibration runs. Two thermocouples (# 7 at station 2, and # 40 at station 10) were found to be operating defectively after they were placed on the test section. They were then replaced by well-behaved thermocouples. Calibration curves for each thermocouple were plotted using MS-Excel-97. A sample calibration curve for thermocouple 1 is shown in Fig. 3.1. (See Appendix D for calibration curves for all of the other thermocouples used for this test setup.)

To study the behavior of how the difference between the thermocouple readings and bath temperature changed as the temperature of the bath changed, Fig. 3.2 was plotted. From this graph, it is evident that, although there was a bias in the temperature calibration as temperature increased, the thermocouples were working well enough to carry out the experiment.

The calibration was performed with respect to the standard bath temperature. Although there are slight deviations in the standard bath temperatures (± .1 °C), the bath

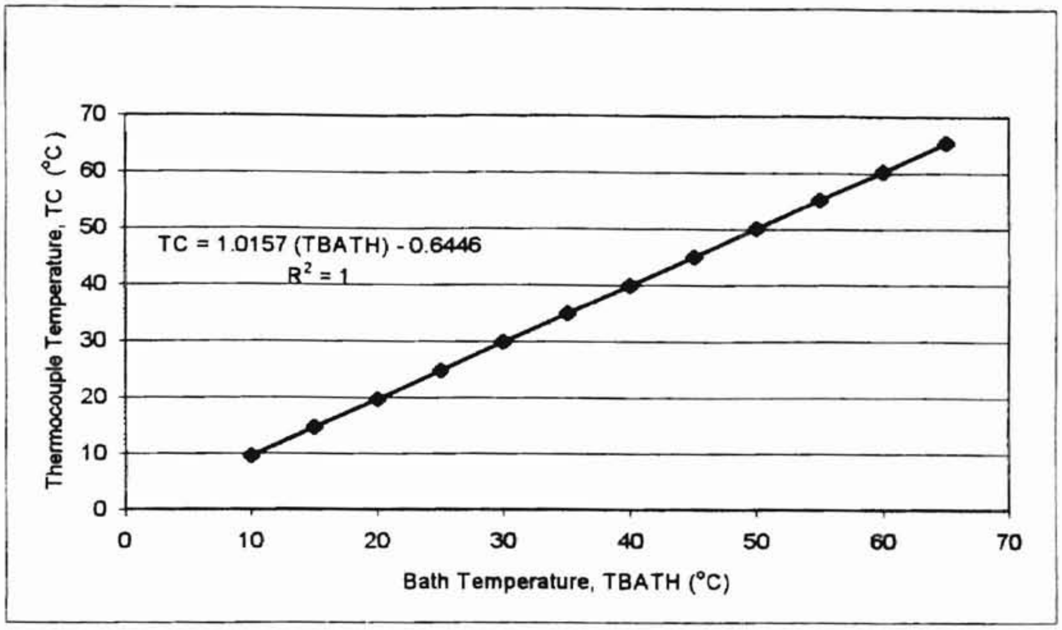


Figure 3.1: Calibration Equation for Thermocouple 1

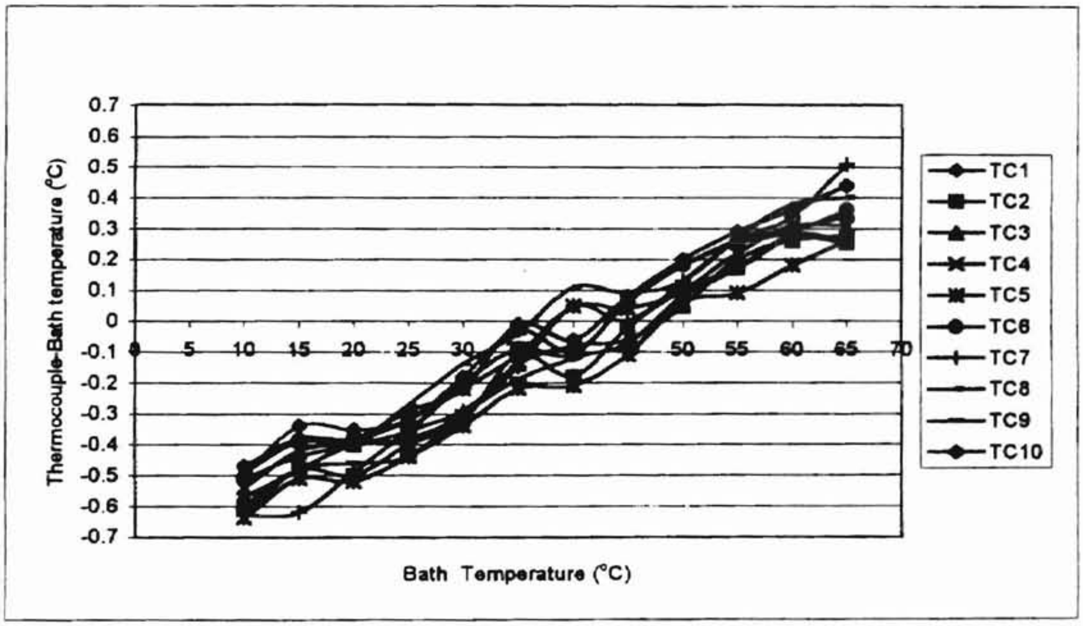


Figure 3.2: Trend of Difference Between Thermocouples and Bath Temperature vs. Bath Temperature

temperature was assumed to be accurate. The calibration was done at several values of temperature as explained above (10 °C to 65 °C). These calibration curves are straight lines, which clearly showed that the thermocouples behaved well at all of the temperatures ranging from 10 °C to 65 °C. Calibration curves, showing the deviation of the thermocouple vs. bath temperatures for the first 10 thermocouples are shown in Fig. 3.2. Similar plots like Fig. 3.2 for all of the other 30 thermocouples and the bulk temperature probes are given in Appendix D.

Similarly the probes measuring the bulk temperatures were also calibrated in the same way, with the help of the temperature bath. The calibration curves for both of the probes are shown in Fig. 3.3 (inlet bulk temperature probe) and Fig. 3.4 (outlet bulk temperature probe).

Fig. 3.5 shows the uncorrected and corrected (calibrated) temperatures for an isothermal run taken during the test runs. More than ten isothermal test runs were conducted to check the proper working of the thermocouples. These isothermal runs were made without any heat added to the test section, and at an average flow rate of 2.0 gpm. These test run temperatures were averaged over 50 minute run times. From each run, we learned how these thermocouples behaved and could see their relative accuracy. These test runs have been very informative and helped to remove the defective thermocouples in the initial stages of the test runs. From Fig. 3.5, it is possible to see that thermocouples 7 and 40 were defective, and they were replaced with new ones. Figure 3.6 shows an isothermal run (#8) with thermocouples 7 and 40 replaced. This figure also shows that the inlet bulk temperature and the outlet bulk temperature were approximately equal, which should be true for an isothermal case.

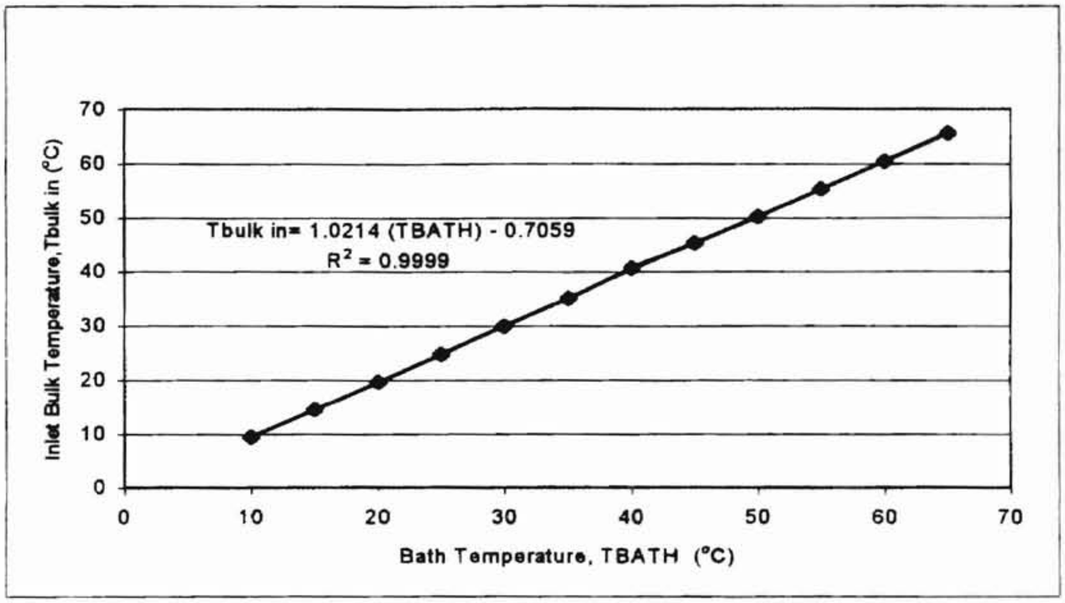


Figure 3.3: Calibration Equation for Bulk Inlet Thermocouple Probe

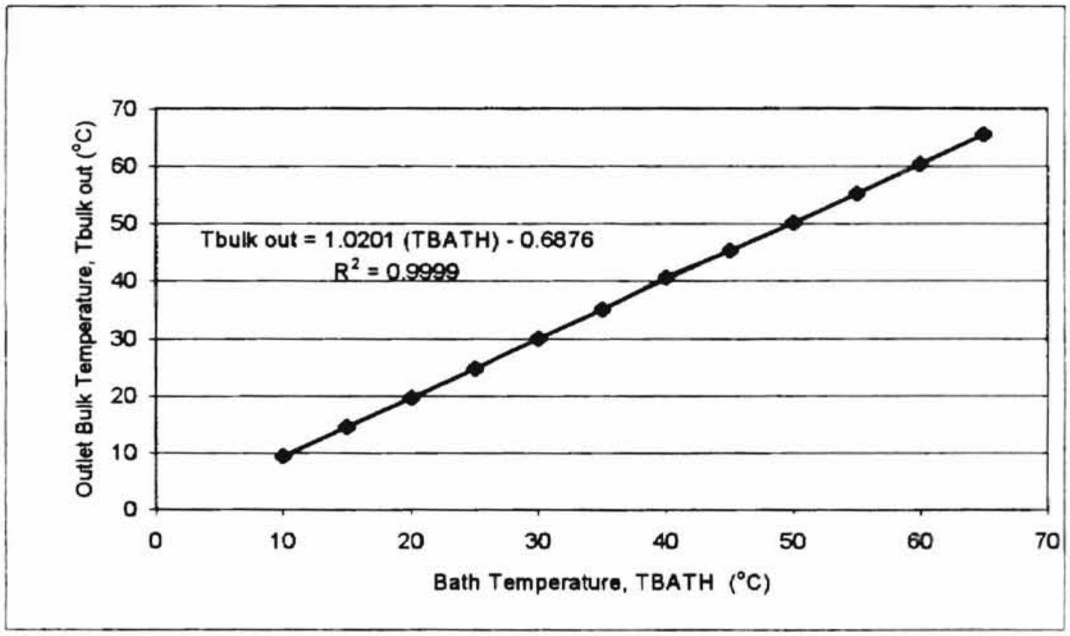


Figure 3.4: Calibration Equation for Bulk Outlet Thermocouple Probe

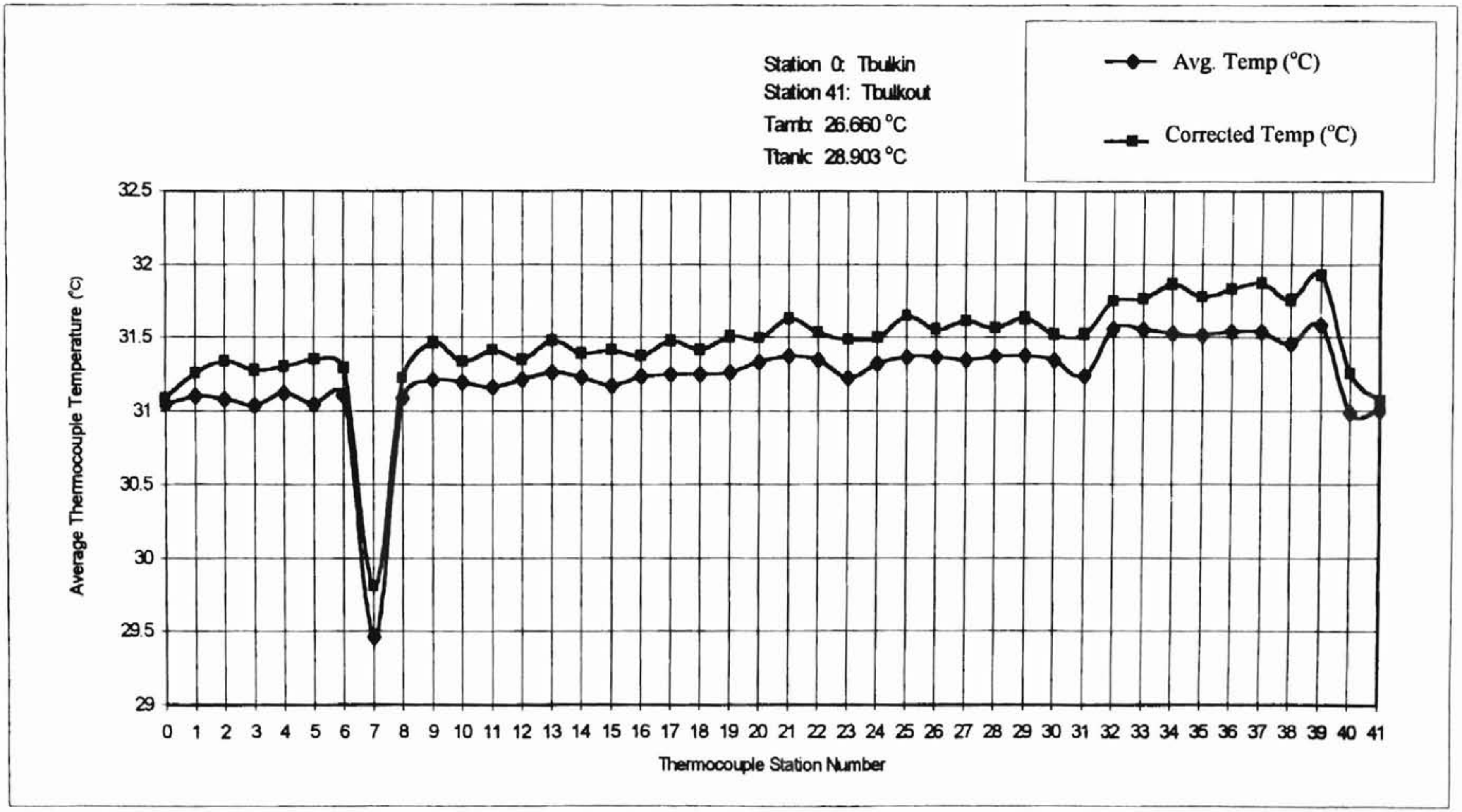


Figure 3.5: Corrected/Uncorrected Thermocouple Temperature Readings for an Isothermal Test Run (Medium Flow Rate)

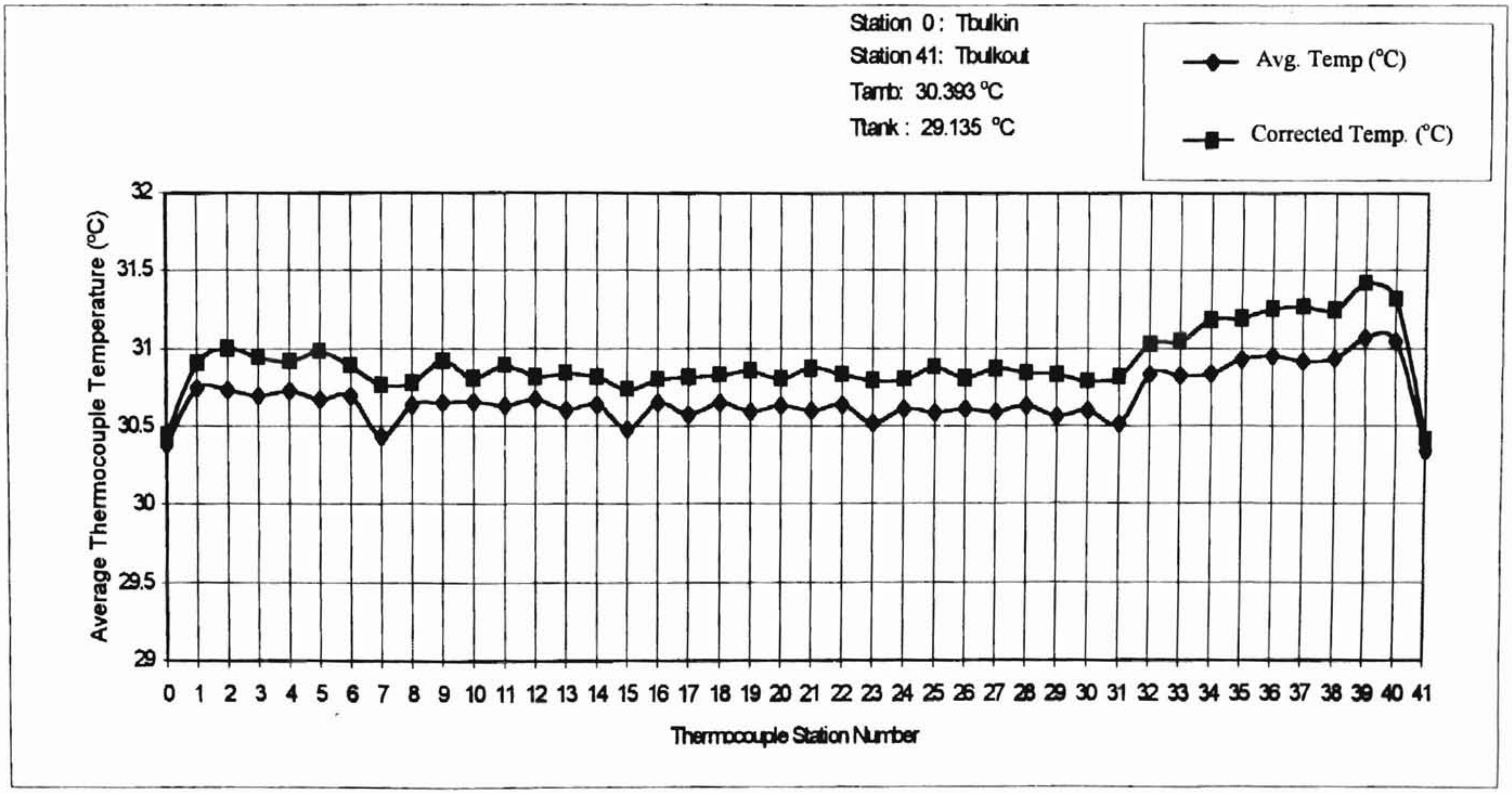


Figure 3.6: Corrected/Uncorrected Thermocouple Temperature Readings for an Isothermal Test Run (#8) [TC 7 and TC 40 Replaced] with Medium Flow Rate

After the isothermal runs, test runs were done with some uniform heat flux applied to the section. At least 50 such runs were done to see how the thermocouples responded with heat on the test section. Figure 3.7 (test run 138) shows how the thermocouples behaved with constant heat flux on the test section. Each thermocouple location on the test section was carefully studied during these test runs. It was found that the thermocouples needed no further calibration or replacements. Although the thermocouples worked well over 100 °C, it was made sure that the temperatures were not raised above 100 °C, since the water would start boiling. The test section pressure was not measured for single-phase flows, but the pressure information is needed in the future for two-phase flows.

Figure 3.8 shows the thermocouple readings at axial locations along the test section. The test section had ten stations with four thermocouples placed circumferentailly at each station. At uniform heat flux, the temperatures at the upper part of the test section may heat up more than the rest of the test section. Location A (top location), showed the maximum temperature reading over the rest of the locations, i.e., B, C, D, which should be true for a uniform heat flux over the test section (see Fig. 2.4 for circumferential thermocouple locations on the test section). Figure 3.7 also indicates the ambient temperature (Tamb), the temperature of the water in the water tank (Ttank), and the inlet and exit bulk temperatures (stations 0 and 41 on the x-axis). We see that the bulk temperatures read 6 to 7 °C low as compared to the thermocouple readings on the outside of the stainless steel test section. This was because the thermocouples were the temperatures on the outside of the test section, whereas the

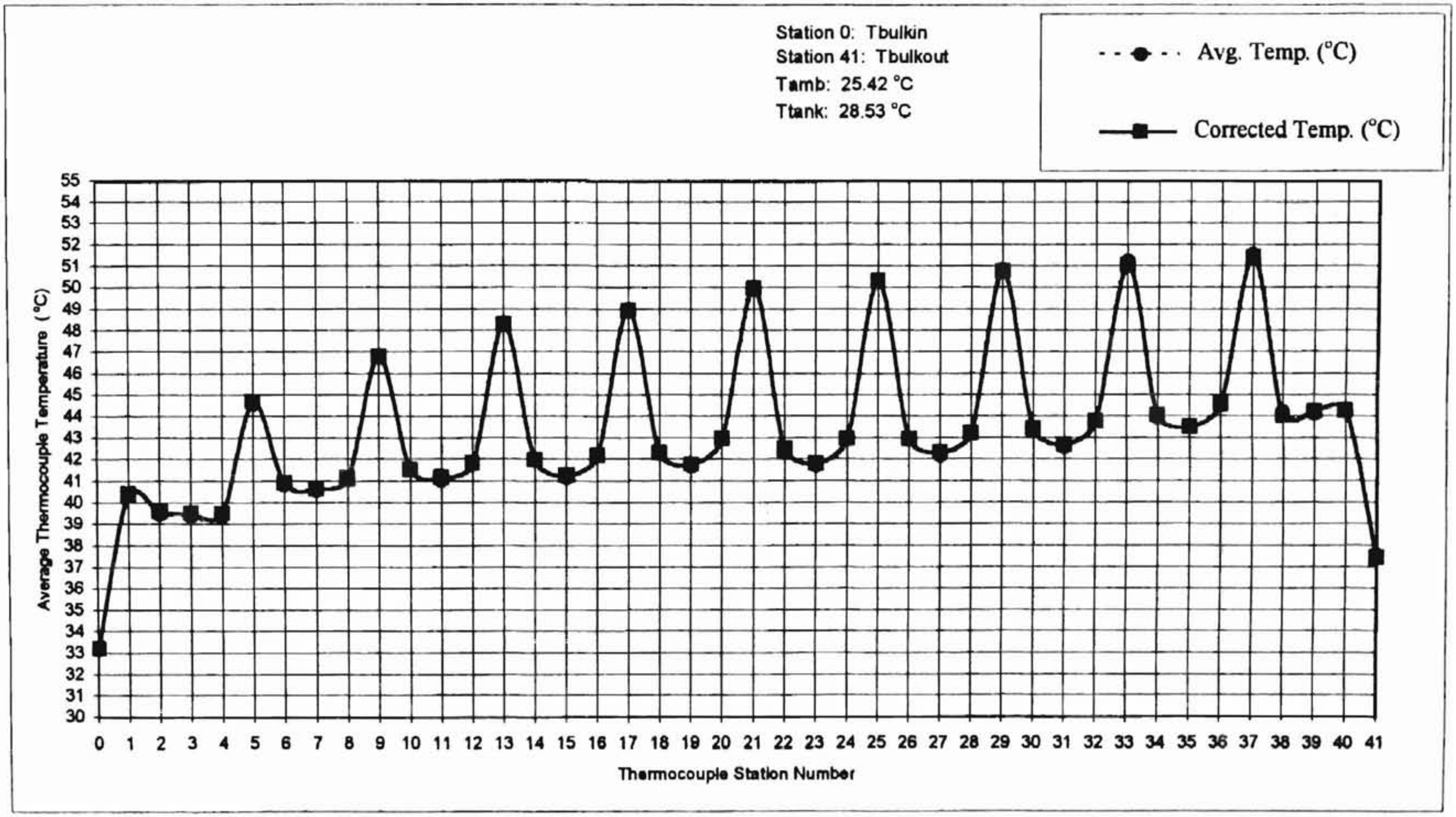


Figure 3.7: Corrected/Uncorrected Thermocouple Readings for Test Run 138 with a Uniform Heat Flux/2.0 gpm Flow Rate

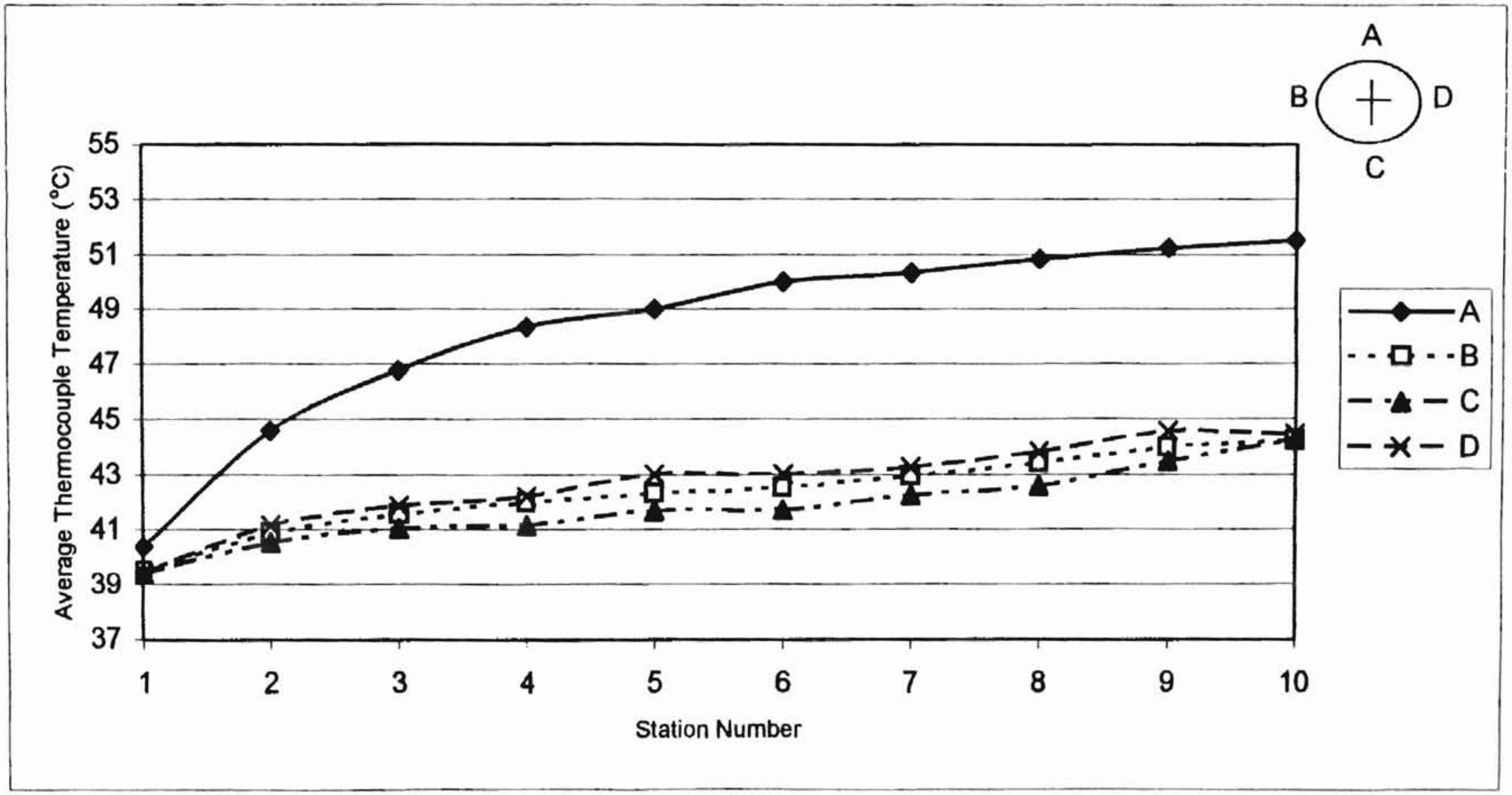


Figure 3.8: Average Thermocouple Readings vs. Test Station Number for Test Run 138 with Uniform Heat Flux/2.0 gpm Flow Rate

bulk temperatures were the temperatures of the water inside. During calculation of the physical properties of water, the bulk temperature of the water inside the test section was calculated using the inlet and exit bulk temperatures. For this calculation, the bulk temperature along the test section was assumed to vary linearly along the length of the test section

3.2 Turbine Meter

The flow rate through the turbine meters was calibrated against the frequency of impeller rotation. Correctly performing the calibration required a stopwatch, a frequency meter (HP 5314A), a calibrated cylinder, and at least two people. The calibration was done without any heat addition to the test section. The pump was switched on and allowed to run for a few seconds until normal pump operation occurred and to allow the water to reach steady-state flow conditions. At pre-selected time increments (typically 5 seconds) during the fluid collection, the frequency indicated by the meter was recorded. The flow was switched to the measuring cylinder [5 gallons (18.927 liters)], and time was recorded for it to fill. By operating the flow control valve, flow rate was measured with the help of the stop watch and measuring cylinder at various flow rates; and simultaneously the frequency on the meter was recorded at these various flow rates. For the temperature ranges of interest in this experimental setup, there should not be any significant change in the density of the water as temperature varies.

For the small motor, the maximum flow rate reached was 4.4 gpm, and the minimum was 0.72 gpm. The large pump hasn't been tested, since the small pump met the requirements (to achieve laminar/turbulent flow) to safely run the single-phase experiments. The flow rate obtained from the stop watch/graduated cylinder method was then plotted against the frequency indicated on the meter. This data was then correlated using a linear least squares curve fit (see Fig. 3.9). A total of 25 data points were taken at two different time intervals. Figure 3.9 illustrates the data collected and the curve fits for water (including the regression coefficients). Figure 3.10 shows the difference in actual and predicted (from calibration curve) flow rate versus the frequency. It shows that, at high flow rates (for frequency greater than 600 Hz), the flow measurement might be inaccurate to ±0.03 gpm.

3.3 Model 5100 Data Logger

The model 5100 data logger required a calibration procedure outlined in its operation manual. To perform the calibration, a DC voltage supply standard model MV116, made by Electronic Development Corporation was used (see Appendix A). It had an accuracy of ±1 microvolt. To begin the calibration, the setup procedure described in the manual was performed. With the data logger held on channel number one, a 2.0 volt ±10 microvolts standard signal was applied to the channel. On the accessory card, the R32 unit was adjusted until the main frame display indicated exactly 2.0 volts. This calibration was done for all the channels. The calibration of all of the thermocouples was performed only once. After they were placed on the test section, they were not replaced unless the thermocouples showed a faulty reading, which happened for thermocouples 7 and 40. All the other thermocouples behaved well after replacing thermocouples 7 and 40, so it was not required to re-calibrate them.

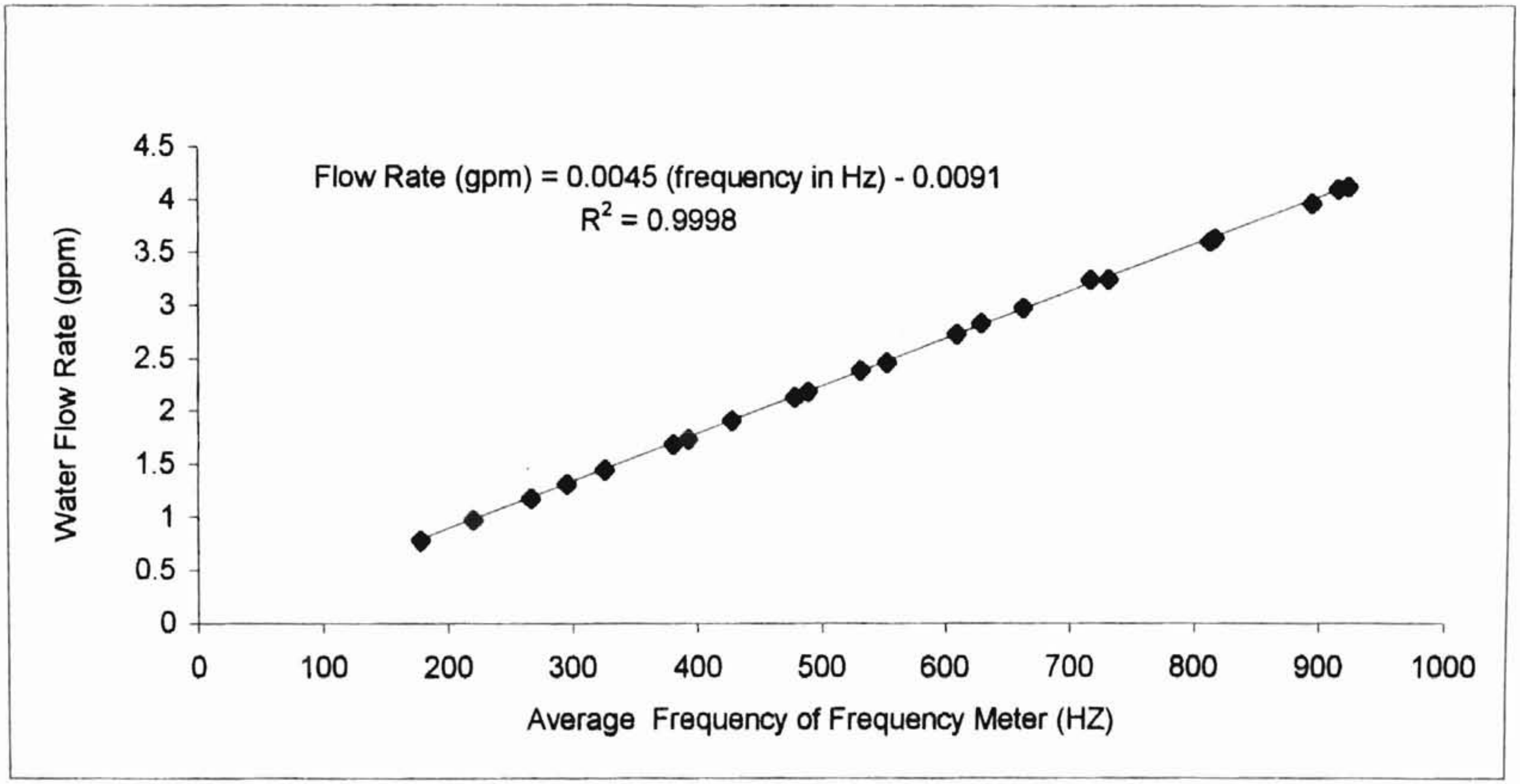


Figure 3.9: Small Turbine Meter Flow Rate Calibration Curve Using HP 5314A Meter

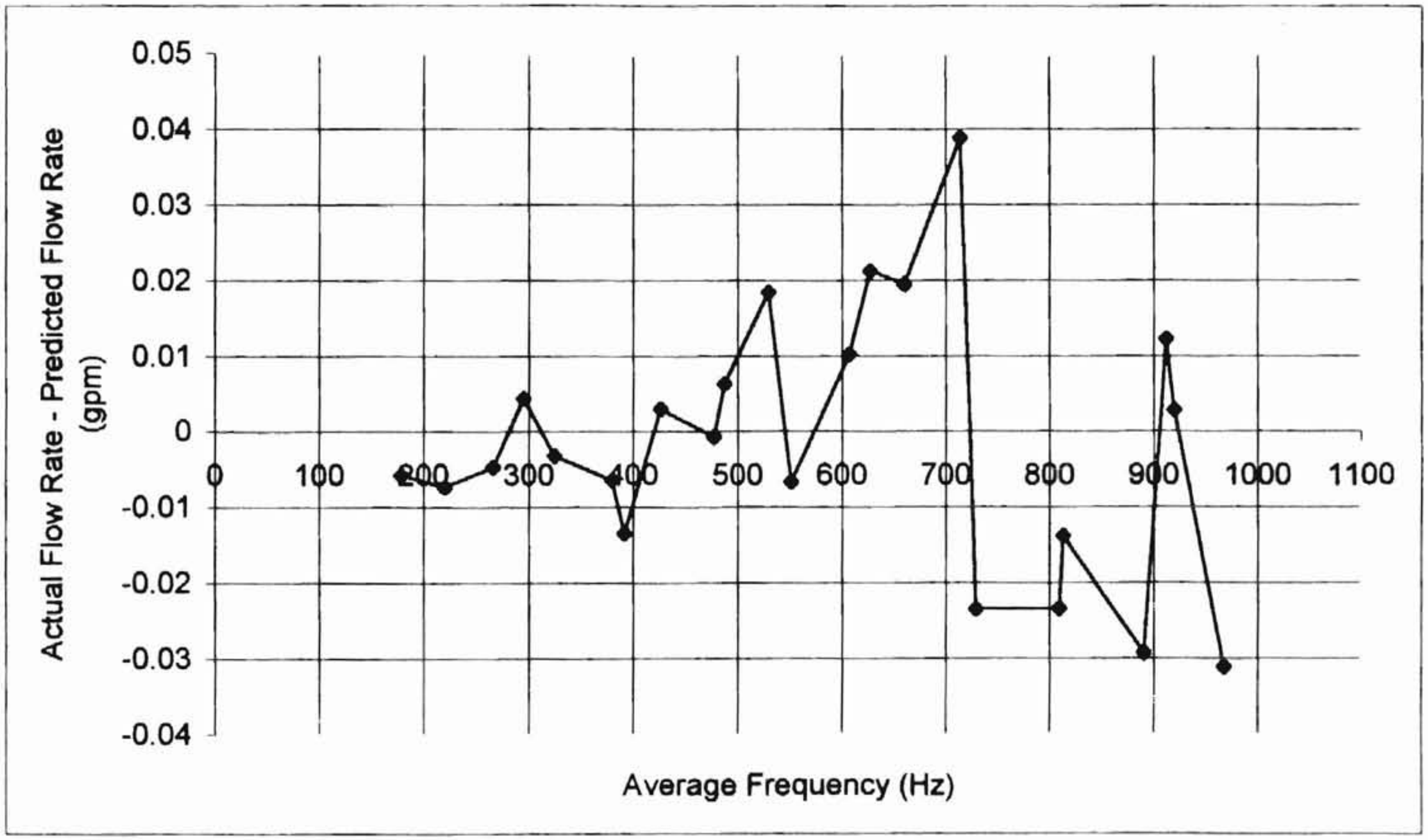


Figure 3.10: Calibration Flow Rate Difference vs. Average Frequency for the Small Turbine Meter

3.4 Experimental Procedure

The system warm up, data collection, and shut off procedures were conceived with consideration for accuracy, repeatability, safety, and ease of performance. Throughout the wide ranges of Reynolds number, Prandtl number, bulk temperature difference, etc. that were covered, the data collection procedures were consistent.

3.4.1 Testing the Loop

Before each data collection experiment occurred, a quick check of the apparatus and all equipment was performed to ensure that there were no leaks nor failed components present in the system. When a decision about the desired flow rate and heat input had been made, the warm up procedure was instituted.

3.4.2 Warm Up

The warm up procedure is as follows:

1. Set the inlet and exit control valves such that the desired flow is provided to the heat transfer test section.
2. Open the turbine meter assembly control valves.
3. Connect the shielded coaxial cable from the turbine meter to either the amplifier or the frequency meter depending upon the frequency of operation. For low flow rates (0.70 to 1.5 gpm), the frequency meter couldn't pick up the frequency, so it is advisable to use the amplifier along with the frequency meter.
4. Turn on the frequency meter.

5. Set the control valves of the pump box assembly in the correct position such that the correct pump will provide flow to the system. (For this thesis, the larger motor was never used, but I always made sure that small pump was open for the water.)
6. Open the flow control valves to the full open position; and provided that all valves are in the correct position, switch on the pump.
7. Determine the necessary frequency to attain the desired flow rate and adjust the flow accordingly with the flow control valve.
8. Check the welder cable and all connections to ensure their integrity and proper fitting. Turn on the voltmeter and the MAC-14 data logger.
9. Switch the welder on and adjust the current output near to the desired value on the welder ammeter. Check the DC ammeter in the test section circuit and re-adjust the welder current until this meter is reading the desired value. (Note: Do not turn on the welder with no flow in the system.)
10. After approximately 15 minutes of operation (depending on the type of heat input), switch on the reservoir mixer and the heat exchanger coolant. The coolant through the heat exchanger is set such that the inlet bulk temperature for steady-state operation is in the desired vicinity to carry out the experimental run.

3.4.3 Data Collection and Shut Down

When the test section reaches steady-state conditions, the initiation of data collection begins. A brief procedure on how to attain steady-state and how to regulate the inlet bulk temperature and the maximum difference in bulk temperature for all the nine cases of test runs is given in Appendix F. The data collection procedure and shutdown is common for all types of experimental test runs. By monitoring the inlet bulk temperature, exit bulk temperature, the first thermocouple station temperature, and the last thermocouple station temperature, a decision as to when steady-state conditions are reached can be made. The procedure is as follows:

1. On the AT computer, bring up the RTG software monitoring the MAC-14 data logger output. Set the data logger to print data on the screen every minute.
2. Readjust the heat exchanger coolant flow such that inlet bulk temperature is in the desired vicinity (within ± 0.5° F).
3. When the first thermocouple station, the last thermocouple station, and the inlet and the exit bulk temperatures all indicate less than 0.3° F deviation over one minute, assume that steady-state conditions are present.
4. Record the frequency of the flow meter (at least 50 readings for each run and then average them), the voltage at the digital voltmeter, and amperage on the ammeter.
5. Set a 10 second dwell on the MAC-14 data logger, and start taking the data.
6. Set the MAC-14 logging parameters through the RTG such that disk storage of data occurs for all of the channels. Monitor all equipment during

operation and discontinue data collection on the MAC-14 until the desired number of samples (75-100) is stored. The program RHt98F which reduces this data can take only 100 samples (explained in data reduction section of this chapter.)

7. When the data collection period is complete, repeat step 4 in order to obtain all final values. Disable all data recording devices.
8. Turn off the DC welder, voltmeter, amplifier, and/or frequency meter. When the inlet and exit bulk temperatures approach room temperature, shut off the coolant water to the heat exchanger and the reservoir mixer.
9. Turn off the pump, and close the flow control valve as well as the inlet and exit test section valves. Switch off the MAC-14, and the AT computer.
10. Inspect the test section apparatus and insure that no leaks have become evident.
11. It is always advisable not to take two runs sequentially, as it may built up considerable heat in the welder.
12. Provide at least a gap of 2 hours between any two consecutive test runs. This will also help to return the bulk temperatures to room temperature.

3.5 Data Reduction

A computer program called RHt98F (see Appendix C) was the major data reduction tool. Initially MS-Excel had been used to calculate the heat balance errors for the test runs. The RHt98F program calculates the heat transfer coefficient, Reynolds number, Prandtl number, Nusselt number, Grashof number, inside bulk temperatures, and several other heat transfer parameters (see Appendix B.2 for a sample input/output file for this program). In order to validate the proper working of this computer program, the heat transfer parameters were also calculated using the MS-Excel spread sheet. The results of heat transfer parameters were same from both of these methods. After the results obtained from the MS-Excel spreadsheet compared well with the results from the computer program RHt98F, the program RHt98F was used from there on.

A sample hand calculation was performed initially to see that the program RHt98F is giving accurate results, and this is given in Appendix E for test run 0172.

The program inputs include the fluid used (here water), the voltage drop across the tube, the current carried by the tube, the volume flow rate, the bulk temperatures at the inlet and exit, and the outside wall temperature data for all stations (a sample input file is included as Table XVII of Appendix B). The program then uses a finite-difference technique [Ghajar and Zurigat (1991)] to calculate the inside wall temperature taking into account heat conduction in both the longitudinal, peripheral and radial directions. Fluid bulk temperatures from inlet to exit were assumed to vary linearly along the axial direction and were used to calculate heat transfer parameters like Reynolds number, Prandtl number, Grashof number, viscosity ratios, density, etc. for water. The program automatically generates an output file, which has the extension HTI and gives a complete listing of all of the output calculations. A sample output file is given in Table XVIII of Appendix B. Outputs for all 41 good test runs are also provided in Appendix B. The following steps provide the data input and data reduction procedure:

1. Obtain the data of the thermocouple readings from the 96 channel data logger, through the MAC-14 software.
2. Input the voltage drop across the test section, current carried through the test section, and the volume flow rate, along with the thermocouple data obtained from the data 96 channel data logger to the program Datared98F. The program Datared98F creates a formatted output file (Table XVII of Appendix B), which is used as an input data file for program RHt98F.
3. Run the program RHt98F to get the output of all of the experimental calculations (Table XVIII of Appendix B). The program RHt98F calculates the inside local temperatures and heat transfer coefficients, mass flow rate of test fluid, local heat fluxes, heat balance error, local and average Reynolds, Prandtl, Nusselt, and Grashof numbers, local ratios of absolute viscosities (bulk to wall), heat transfer coefficients at top and bottom of the test section, and finally local bulk fluid temperatures. Other miscellaneous calculations are given by RHt98F but those listed above are of primary interest.
4. Use the output data files from RHt98F to generate further reduced data which is input to MS-Excel and Sigma Plot 4.0 graphics software to produce the figures to be analyzed and presented in this thesis.

3.6 Two-Phase Flow Patterns

In order to insure that the test setup was able to handle two-phase flow patterns, various combinations of water and air were used to produce some of the major flow patterns. The air was injected into the mixing chamber along with water (see Fig. 2.9). The flow rate (in liters per minute, lpm) of the air was monitored by a Cole-Parmer digital gas flow meter (see Appendix A). This section presents some flow patterns produced for different amounts of water and air flow rates. The pictures presented in this section were taken with a Pentax IQZoomEZY camera.

Several patterns may occur when gas and liquid flow cocurrently inside a horizontal tubular channel. Six general flow pattern descriptors are stratified, wavy, plug, slug, bubbly, and annular. In order to model the transport characteristics, flow patterns might be combined into basic regimes in which the mechanism are expected to be similar. The following four groups provide such classification:

1. shear controlled separated flows, such as the annular regime;
2. intermittent flows, such as plug and slug regimes (see Photos. 3.1 and 3.2);
3. gravity controlled separated flows, such as the stratified and wavy regimes (see Photos. 3.3, 3.4, 3.5, 3.6, and 3.7);
4. dispersed flows, such as the bubble regime (see Photos. 3.8 and 3.9 for slug/bubbly transitional.);

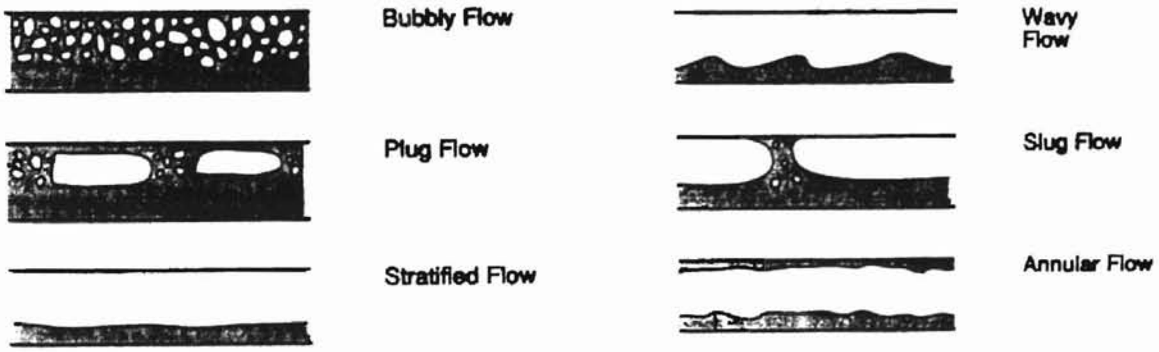
The various flow rates of water/air which produced these flow patterns are given below each picture. It is evident that the mixing chamber is producing identifiable flow patterns to carry out two-phase experiments. Table III shows the flow rate ranges for water and air and the corresponding flow patterns generated with these flow rates. The following flow measurements were taken at room temperature (24 °C). The pressure for air was not measured, but the air pressure is estimated to be between 25 and 100 psia.

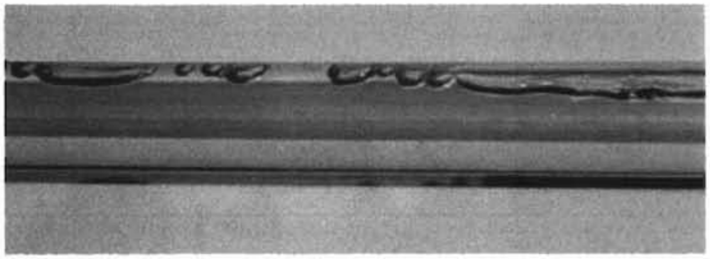
TABLE III

Identified Flow Patterns with their Flow Rates

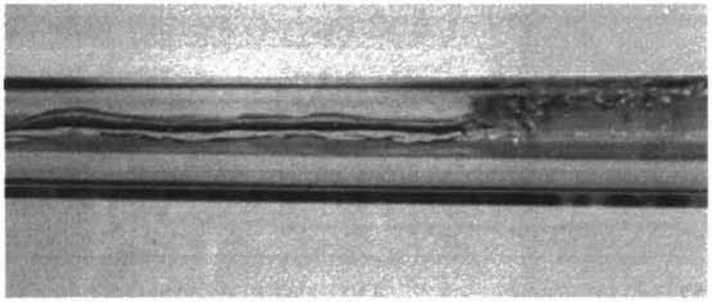
Flow Pattern	Flow Rate	
	Water (gpm)	Air (gpm)
Plug	4.00	0.793
Slug	3.78	3.17
Stratified/Slug Transition	3.43	10.8
Wavy	2.71	21.1
Stratified/Wavy Transition-1	2.05	2.11
Stratified/Wavy Transition-2	1.16	2.37
Stratified	0.63	1.58
Slug/Bubbly Transition	3.43	11.8

The schematic representation of flow patterns observed in horizontal, co-current water/air flows are shown below. The flow patterns observed in the experimental two-phase flows (see Photographs 3.1 to 3.9) fairly coincide with schematic flow representations given in Van (1992).

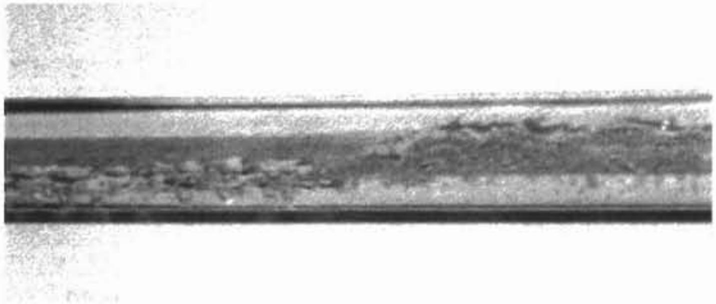




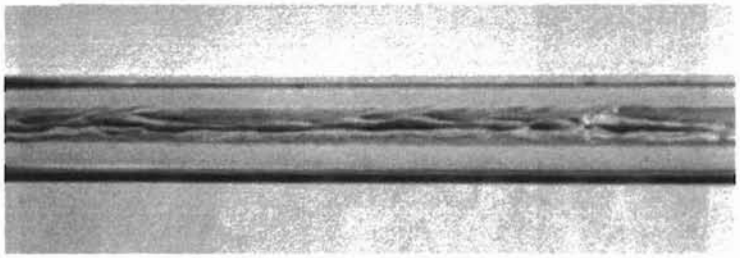
Photograph 3.1: Plug
Water: 4.00 gpm (15.14 lpm)/Air: 0.793 gpm (3.0 lpm)



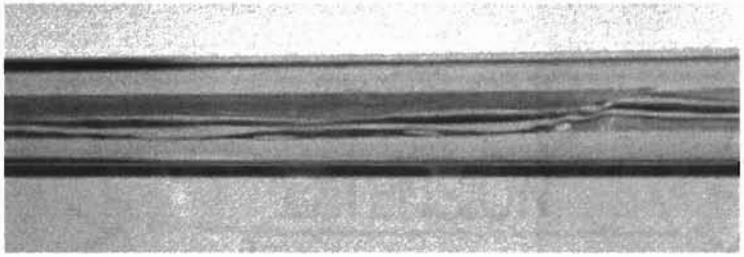
Photograph 3.2: Slug
Water: 3.78 gpm (14.3 lpm)/Air: 3.17 gpm (12.0 lpm)



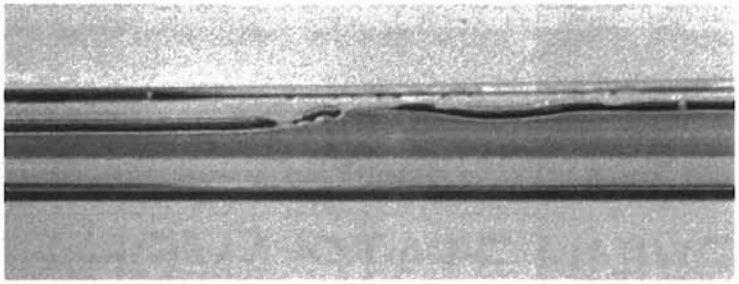
Photograph 3.3: Stratified/Slug Transition
Water: 3.43 gpm (12.99 lpm)/Air: 10.8 gpm (40.88 lpm)



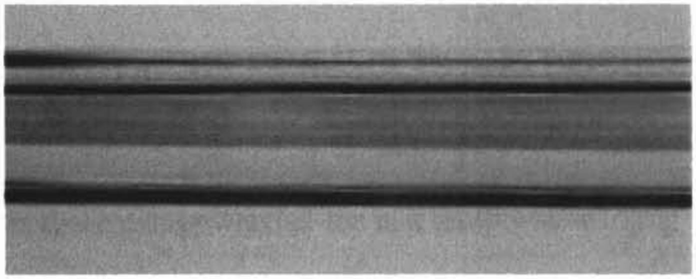
Photograph 3.4: Wavy
Water: 2.71 gpm (10.25 lpm)/Air: 21.1 gpm (80.0 lpm)



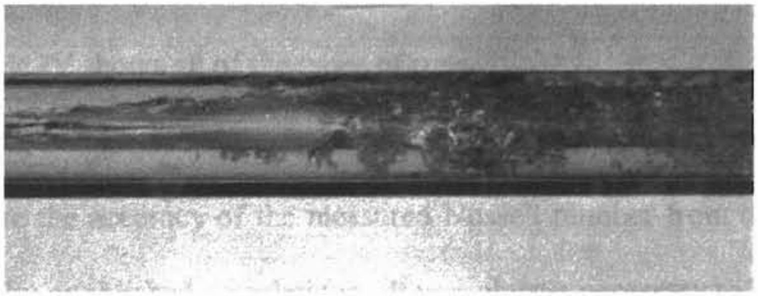
Photograph 3.5: Stratified/Wavy Transition-1
Water: 2.05 gpm (7.76 lpm)/Air: 2.11 gpm (8.0 lpm)



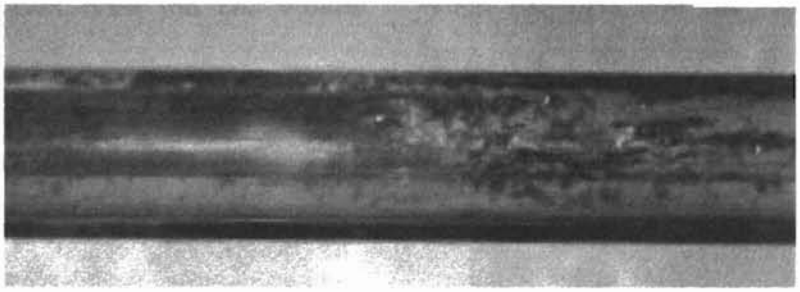
Photograph 3.6: Stratified/Wavy Transition-2
Water: 1.16 gpm (4.39 lpm)/Air: 2.37 gpm (9.0 lpm)



Photograph 3.7: Stratified
Water: 0.630 gpm (2.38 lpm)/Air: 1.58 gpm (6.0 lpm)



Photograph 3.8: Slug/Bubbly Transition
Water: 3.43 gpm (12.98 lpm)/Air: 11.8 gpm (45 lpm)



Photograph 3.9: Slug/Bubbly Transition
Water: 3.43 gpm (12.98 lpm)/Air: 11.8 gpm (45 lpm)

CHAPTER IV

HEAT TRANSFER RESULTS AND DISCUSSION

To help in determining whether the test setup was working well enough to carry out two-phase experiments in the future, single-phase heat transfer data was taken and compared with predictions of established correlations. The test section was operated at steady-state to carry out the experimental runs. Based on the heat input, flow rate, Reynolds number, and Prandtl number, the calibration runs were divided into 9 type of runs. The Table IV shows all of the types of runs.

Since we had identified the types of test runs that we had to make, the next step was to compare the accuracy of the measured Nusselt number from the test section to that predicted by established correlations. It was always necessary to bring the fluid to steady-state before taking any data. Heat addition was accomplished in the form of uniform heat flux with the DC welder. When the first and the last test section thermocouple stations, and the two bulk fluid temperatures no longer indicated temperature deviations (for 1 minute) greater than 0.25 °F, a steady-state condition was assumed to be present. Data collection was performed (see the Experimental Procedure section 3.4 of Chapter III), and the resulting Nusselt numbers were compared with those predicted by the accepted single-phase correlations outlined in the literature survey section of Chapter I. The fully turbulent forced convection uniform heat flux correlations of Sieder and Tate (1936), Gnielinski [Kakac et al. (1987)], Colburn (1933), and Ghajar and Tam (1994) were used to predict the validity of the experimental data. Only these correlations were compared with the experimental data.

TABLE IV

Classification of the Test Runs Based on Heat Input, Flow Rate, and Ranges Covered

Low Power Supply 818 Btu/hr- 857 Btu/hr (239.5 W – 251 W)	Low Flow Rate (0.78 gpm-1.2 gpm) CASE: 1	Medium Flow Rate (2.0 gpm-3.0 gpm) CASE: 2	High Flow Rate (3.5 gpm-4.5 gpm) CASE: 3
	2500<Re<3500 4.75<Pr<6.40 $1.80 < \Delta T < 2.2$ (°F)	8500<Re<10000 4.80<Pr<5.50 $0.65 < \Delta T < 0.80$ (°F)	14500<Re<17500 5.00<Pr<5.90 $0.35 < \Delta T < 0.45$ (°F)
Medium Power Supply 2851 Btu/hr-3196 Btu/hr (835 W – 936 W)	Low Flow Rate (0.78 gpm-1.2 gpm) CASE: 4	Medium Flow Rate (2.0 gpm-3.0 gpm) CASE: 5	High Flow Rate (3.5 gpm-4.5 gpm) CASE: 6
	2500<Re<3500 4.75<Pr<6.40 $6.5 < \Delta T < 8.0$ (°F)	8500<Re<10000 4.80<Pr<5.50 $2.2 < \Delta T < 3.0$ (°F)	14500<Re<17500 5.00<Pr<5.90 $1.2 < \Delta T < 1.75$ (°F)
High Power Supply 5968 Btu/hr-6560 Btu/hr (1748 W- 1921 W)	Low Flow Rate (0.78 gpm-1.2 gpm) CASE: 7	Medium Flow Rate (2.0 gpm-3.0 gpm) CASE: 8	High Flow Rate (3.5 gpm-4.5 gpm) CASE: 9
	2500<Re<3500 4.75<Pr<6.40 $10.0 < \Delta T < 15.0$ (°F)	8500<Re<10000 4.80<Pr<5.50 $5.0 < \Delta T < 5.7$ (°F)	14500<Re<17500 5.00<Pr<5.90 $5.5 < \Delta T < 6.0$ (°F)

The reason why the test runs were divided into the nine types was to check how the test setup responded to different levels of heat input and flow rate. After experimenting with the nine cases of test runs listed in Table IV, it was found that, for some cases, the test setup provided promising Nusselt number comparison with the correlations. From these nine types of test runs, it was found that the heat input and flow rate are inter-dependent in finding values that will produce a reasonable Nusselt number comparison (±30% error) with the correlations. For example, for medium power, the setup provided good Nusselt number comparison (±30% error) using low to medium flow rates; and for low power, the setup provided good Nusselt number comparison using low flow rates. For high power input, the setup provided good Nusselt number comparison with correlations. Using these nine test run cases, a suitable procedure was found to get a good Nusselt number comparison. This procedure is discussed in Section 4.2 of this chapter. Test runs 134 through 1184, in Table XV of Appendix B, were made based on this classification. After studying these test cases, runs 1186 through 4143 were conducted.

From forty-three test runs, which were mainly transitional and turbulent flow, heat transfer results will be discussed briefly in this chapter. There were several parameters which influenced the heat balance of the test setup. The major parameters include the difference between inlet and exit bulk temperatures, the flow rate, and the heat input. The difference between inlet and exit bulk temperature depended upon the heat input and the flow rate. These effects on the heat balance errors will be discussed briefly in this chapter, and finally comparison of heat transfer data with existing correlations will be presented. Then one existing equation will be modified to predict the Nusselt number data over all of the flow regimes represented by the data.

Heat balance errors were calculated for all experimental runs by taking a percent difference between two methods of calculating the heat addition. The product of voltage drop across the test section and the current carried by the tube was the primary method, while the fluid enthalpy rise from inlet to exit was the second method. The algorithm to calculate the heat balance error is given below:

Method 1:

$$\text{Hin} = \text{I (amps) V (Volts)} \tag{4.1}$$

Method 2:

$$\text{Hout} = \dot{m}\,(\,C_p\,)\,\Delta T \tag{4.2}$$

where: $\dot{m}$ is the mass flow rate of water

C_p is the specific heat capacity of water

ΔT is the difference in exit and inlet bulk temperature of water

Then:

$$\text{Hbal} = (\text{Hin}-\text{Hout})\text{x}100/\text{Hin} \tag{4.3}$$

The primary method (Method 1) was the one used in the RHt98F Program for all the heat flux and heat transfer coefficient calculations. The heat balance errors ranged from –5.30% to 12.50%. A complete listing of all of the experimental runs is given in Tables XIV, XV, and XVI of Appendix B. This data given in Appendix B is for all the runs taken for water, regardless of flow regime.

4.1 Factors Affecting the Heat Balance Errors

The heat balance errors directly depended on the difference in the inlet and exit bulk temperatures. Identifying the proper conditions, under which the bulk temperatures behaved properly to give a good heat balance error, increased the probability of getting a good heat balance error, and of good heat transfer measurements along the test section. This also helped to foresee the heat transfer effects even before the actual data was taken.

The inlet bulk temperature depended upon the tank temperature and the ambient temperature of the room, the heat input to the test section, and the exit temperature from the heat exchanger. Before the heat input was applied to the test section, the water was cycled in the system continuously until the inlet bulk temperature and the tank temperature were approximately the same. This was made possible with the help of the heat exchanger which maintained a constant tank temperature. Figure 4.1 shows the range of values of inlet bulk temperature for which the heat balance errors were reasonable (±5.0%) for some experimental runs, applying case 1 conditions (low power/low flow rate, see Table IV). From the experimental runs shown in Fig. 4.1, it is highly advisable to run the setup with inlet bulk temperature greater than 80° F. Figure 4.1 indicates that, if the inlet bulk temperature is below 80° F, the heat balance errors were not as good as for the runs with the inlet bulk temperature greater than 80° F. We cannot conclude from this graph how cases for runs with inlet bulk temperature greater than 90° F will perform with respect to the heat balance error. But maintaining the inlet bulk temperature below 90° F was good enough to carry out the runs.

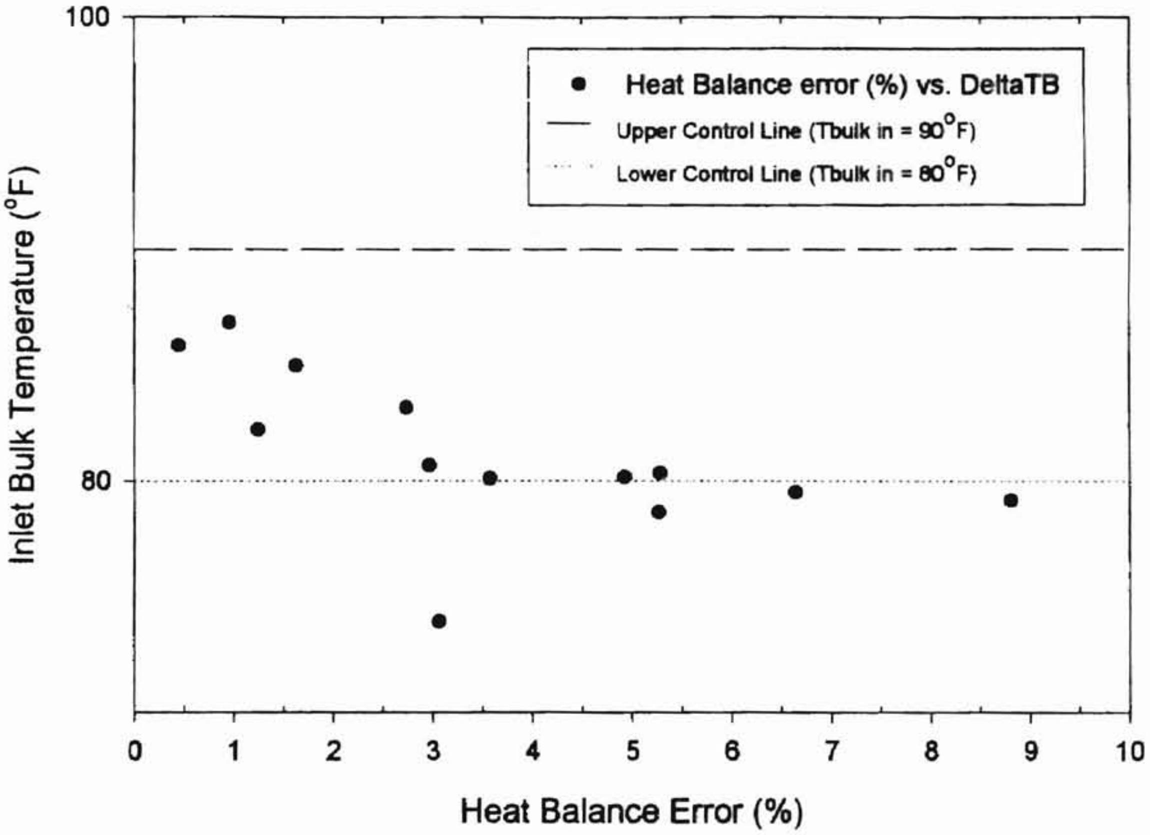


Figure 4.1: Trend of Inlet Bulk Temperature vs. Heat Balance Error

for Case 1 (Low Power/Low Flow Rate) Test Runs

Once the inlet bulk temperature was maintained within this range, then the water was run through the test section for additional time until the exit bulk temperature become equal to the inlet bulk temperature. Once the inlet and exit bulk temperatures showed approximately the same value, then heat was applied to the test section.

The difference between inlet and exit bulk temperatures had a much greater effect on the heat balance error. For case 1 conditions (low power/low flow rate, see Table II), Fig. 4.2 shows the effect of this difference on heat balance error. As we can see, the greater the difference in inlet and exit bulk temperatures, the better the heat balance errors.

Finally the flow rate under which a given run was made also affected the heat balance error. Figure 4.3 shows how the heat balance error was affected by the flow rate for case 1 (low power/low flow rate, see Table IV) types of runs. From this figure, we can conclude that the heat balance errors were agreeable for flow rates within the range of 0.8 gpm to 1.4 gpm.

4.2 Identifying Good Test Runs

Test runs were made for Reynolds number ranging from 2000 to 17000, Prandtl number range from 4.5 to 6.5, and for power input ranging from 818.0 Btu/hr (239.5 W) to 6560.0 Btu/hr (1921.0 W). The local bulk Nusselt number ranged from 12.0 to 100.0. The experimental numbers were achieved using a uniform wall heat flux ranging from 330.0 Btu/hr-ft^2 (1.071 kW/m^2) to 2647 Btu/hr-ft^2 (8.598 kW/m^2).

To avoid mixed convection, the heat input was increased, as the flow rate was increased. Runs 192, 196, 1116, 1117, 1118, 1119, 1124, 1132 in Appendix B are examples.

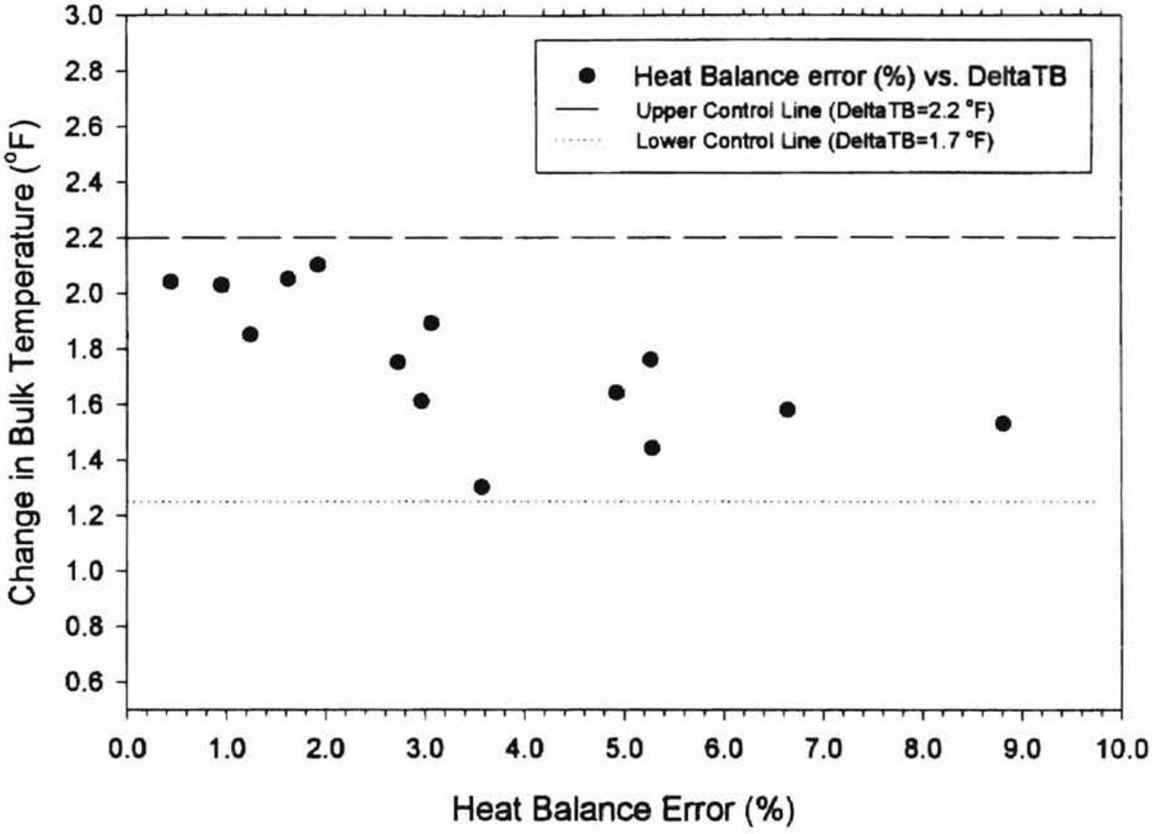


Figure 4.2: Effect of Bulk Temperature on Heat Balance Error for

Case 1 (Low Power/Low Flow Rate) Test Runs

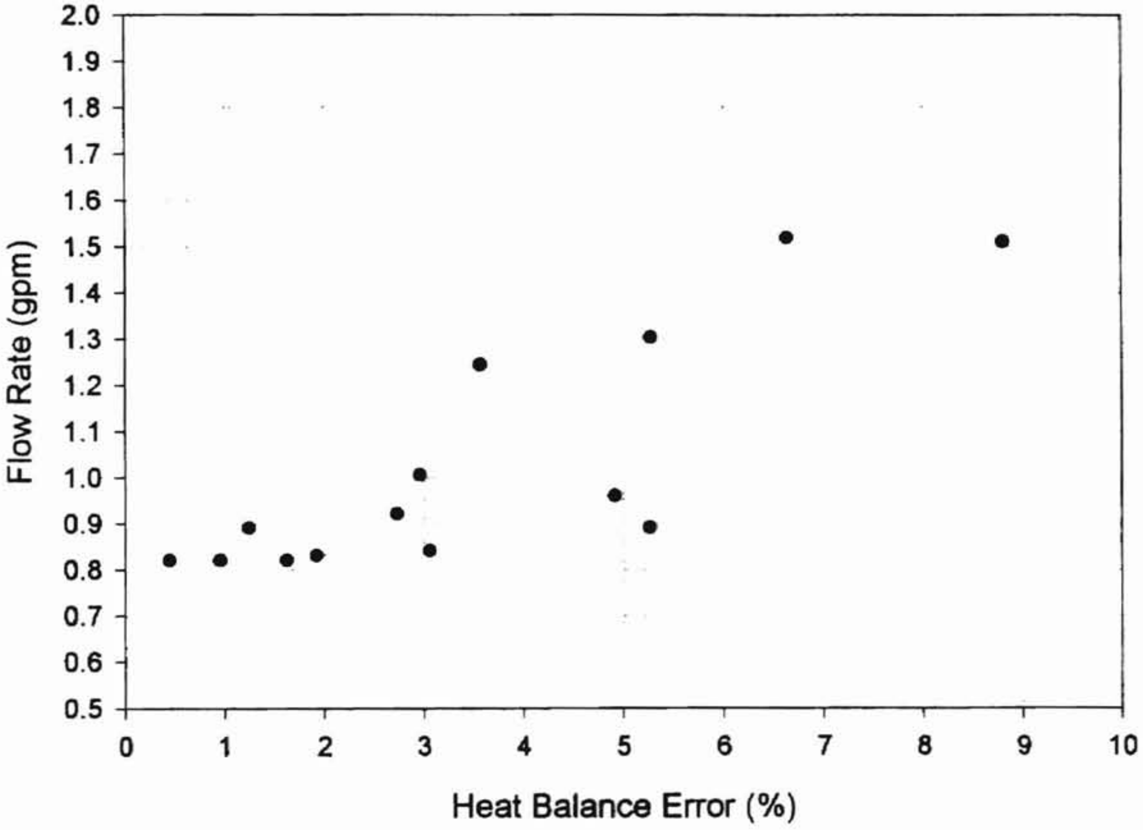


Figure 4.3: Effect of Flow Rate on the Heat Balance Error for Case 1 (Low Power/Low Flow Rate) Test Runs

These runs showed a ratio of temperature for top to the bottom thermocouples at section 6 to be much greater than 1.00 (see Tables IV and XV). This indicated that mixed convection effects were taking place for this kind of power input/flow rate. This type of the test run has been considered to be "bad," since only forced convection conditions were desired, in order to compare with established correlation predictions. Thus further test runs were not made in this range of power input/flow rate combination.

In addition to the low power/medium flow rate cases, test run case 3 (low power/high flow rate) results were never accurately predicted by Nusselt number correlations. This appeared to be due to non-uniform temperatures around the circumference (see runs 133 and 172 in Appendix B, Table XIV) at a specific location along the test section, which appeared to affect the Nusselt number calculation. The non-uniform temperatures could be due to partial filling of water in the test section and boiling of water at high power inputs. So test runs operating in this power input/flow rate range were also not advisable, if steady state laminar or turbulent fully developed heat transfer conditions were desired.

Test runs representing case 4 (see Table XIV) also showed poor heat balance errors, and also non-uniform temperature conditions throughout the test section (see runs 138, 194, 180, and 183 in Appendix B, Table XIV). Further test runs were not carried out in this power input/flow rate range. For low power input, it was observed that low flow rate test runs gave good heat transfer results as compared to those of medium and high flow rates for that particular heat input. This was found after a series of test runs (runs 2105 thru 4105 in Table XV) were made over a wide range of power and flow rates.

From the nine test cases (see Table IV) it was observed that the test section should be operated only in certain ranges of flow rate and power input. After a series of test runs were made over all of the flow rate ranges and power inputs, runs with good heat balance errors and Nusselt number prediction were studied further. They showed that the power input and flow rate are interdependent upon each other if good heat balance error and Nusselt number prediction are desired.

From these runs, a simple equation has been developed to estimate the power input needed for a particular flow rate. The equation was based on a linear curve fit applied to some of the very best test runs. That equation is:

$$\text{Hin (watts)} = (\text{F.R. (gpm)}+0.6686)/0.0068 \tag{4.4}$$

The use of this equation helped get a good heat balance error. It was also observed that a consistent difference in inlet and exit bulk temperature of 2.0 °F was maintained for all of the test runs carried out using this equation. Run 2103 and there on were performed based on this equation. For power input of 433.06 W (1478.5 Btu/hr^2) to 485.125 W (1656.2 Btu/hr^2), a flow rate range of 1.91 to 2.2 gpm yielded a good heat balance error (see Table XV for runs 2103 to 4105). We can see (from Appendix B) that the heat balance errors were brought to within ±2.0% for these runs. A data sheet has been provided in Appendix B.3, which gives the power input to be used for any flow rate. This data sheet also shows how much current should be supplied to attain that power. Therefore, with increased flow rate, the amount of heat addition could also be increased without the onset of mixed convection.

The heat transfer coefficient (h) is defined as:

$$h = q''/\,(T_{wi}-T_b) \tag{4.5}$$

The average wall heat flux, q", was obtained from the electric power input to the tube from the welder. The wall temperature (T_w) was measured on the outside of the tube, and, using a finite difference technique, the inside wall temperature T_{wi} was calculated. The bulk temperature was measured at the tube inlet and exit, and was assumed to vary in a linear fashion such that bulk fluid temperature (T_b) calculations at all locations could be made. The RHt98F program performed all of the bulk fluid temperature and heat transfer coefficient calculations.

To illustrate the different trends in heat transfer coefficient ratio for flows dominated by forced convection and mixed convection heat transfer, Fig. 4.4 is presented. The figure includes representative Reynolds number ranges from lower transitional (2612 to 7789) to fully turbulent (8790 and above) flow. As the figure demonstrates, the higher Reynolds number flows are dominated by forced convection heat transfer, because the heat transfer ratio (for top to bottom of the tube) does not fall below 0.90. The flows dominated by mixed convection heat transfer have heat transfer coefficient ratios beginning near 1.0 but dropping off rapidly as the length to diameter ratio increases. Beyond 30 diameters, the ratio tended to stabilize to an approximate value of 0.30, indicating a much less dominant heat transfer role for forced convection [Ghajar and Tam (1994)] and increased natural convection activity.

Since convection heat transfer depends upon temperature differences, the change in heat transfer coefficient can be related to temperature. For fluid heated by ideal forced convection, the peripheral inside wall temperatures are constant, resulting in uniform local heat transfer and near constant local heat transfer coefficient with respect to the periphery. As the flow rate is decreased for the heated case, the fluid encounters a longer contact residence time with the surface causing the fluid nearer the wall to become warmer and less dense than that near the center.

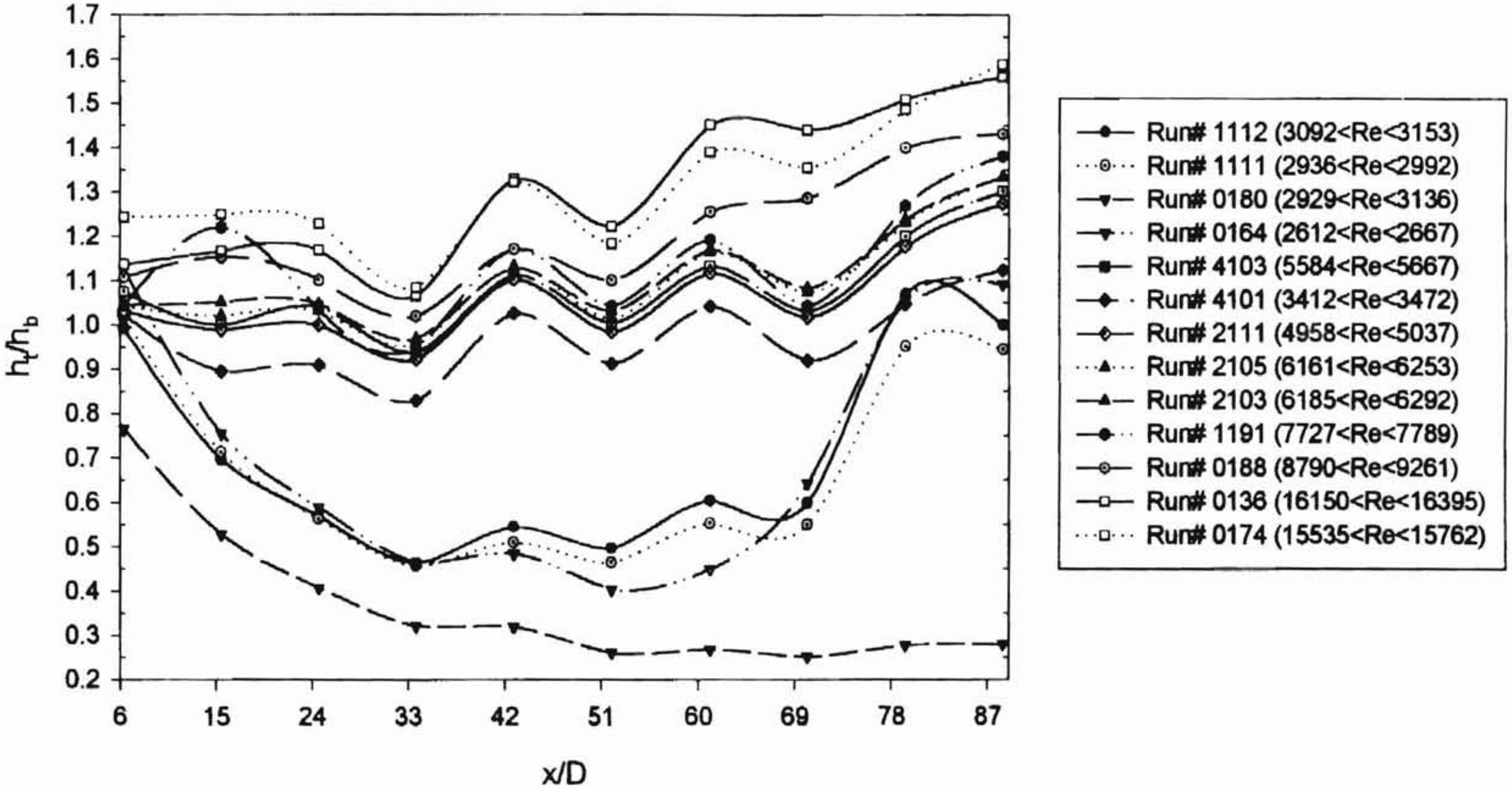
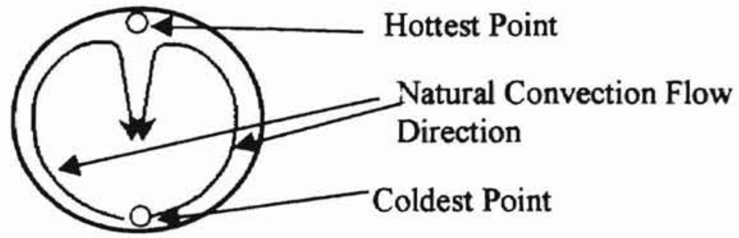


Figure 4.4: Trend of Heat Transfer Coefficient Ratio vs. Dimensionless Axial Distance

Due to buoyant forces the less dense fluid rises along the fluid wall and the denser fluid flows down near the center. This produces a temperature difference along the periphery of the tube wall as shown here:



Because of this effect there is a maximum temperature at the tube top and a minimum at the tube bottom. The temperature difference along the periphery drives a secondary flow pattern at right angles to the primary (forced flow) direction consisting of two vertically symmetrical vortices. These temperature differences also lead to free convection heat transfer occurring simultaneously with forced convection, resulting in a non-uniform heat transfer coefficient with respect to the peripheral location. Figure 4.5 demonstrates how these temperatures behaved for test run 1117, which was driven by both free and forced convection type of heat transfer. From this figure, it is evident that the test section is not uniformly heated, and that thermocouple location A (see Fig. 2.4) always showed a very high temperature when compared to the other three thermocouple temperatures at that station.

Figure 4.6 show the peripheral temperature distribution for steady-state run 4103. This figure demonstrates that all four peripheral thermocouple locations at each station yielded almost the same temperature reading. This shows that the test section was uniformly heated for that particular flow rate, and the system was in steady-state.

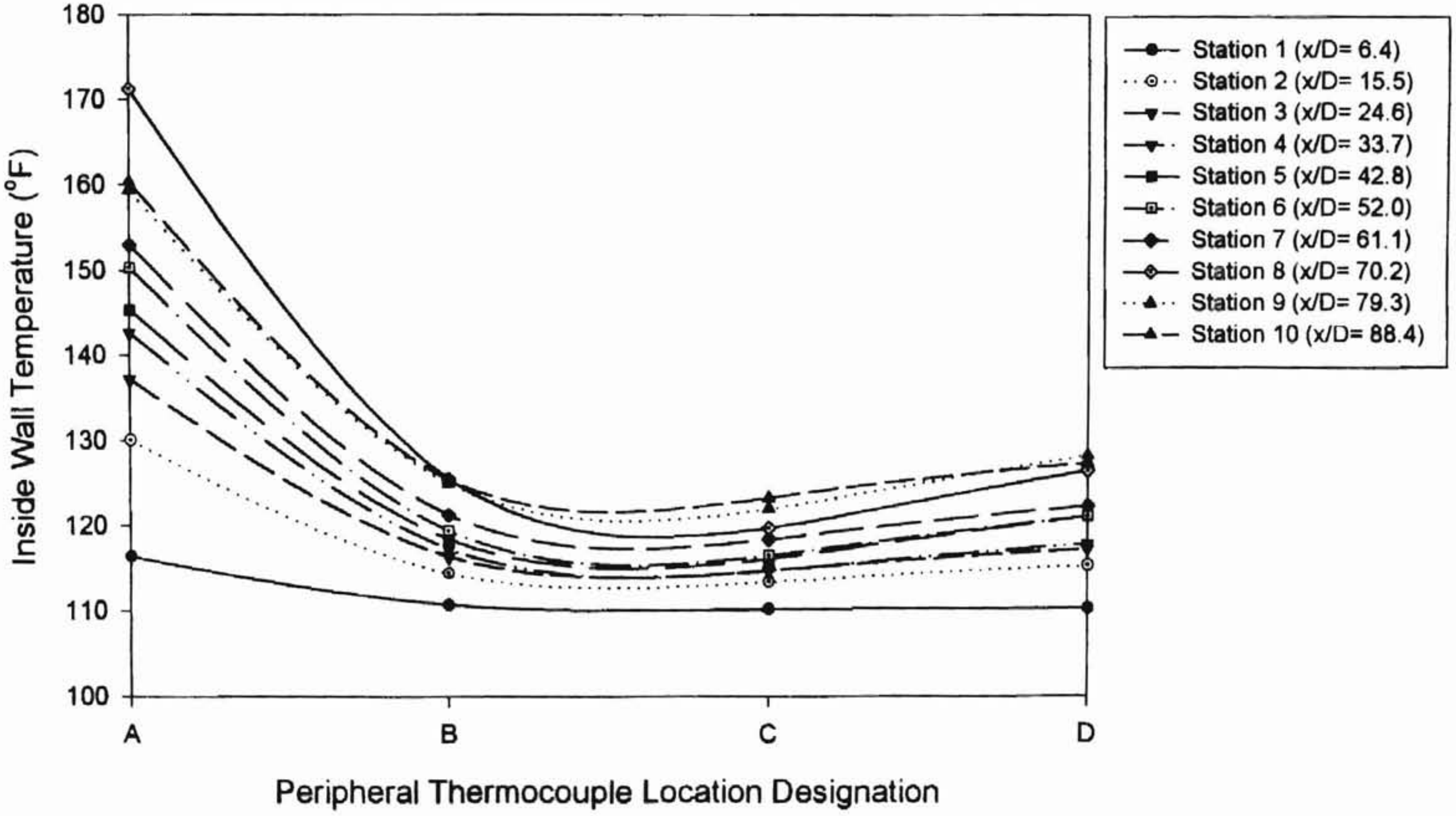


Figure 4.5: Peripheral Inside Wall Temperature Distribution for Mixed Convection in Run 1117

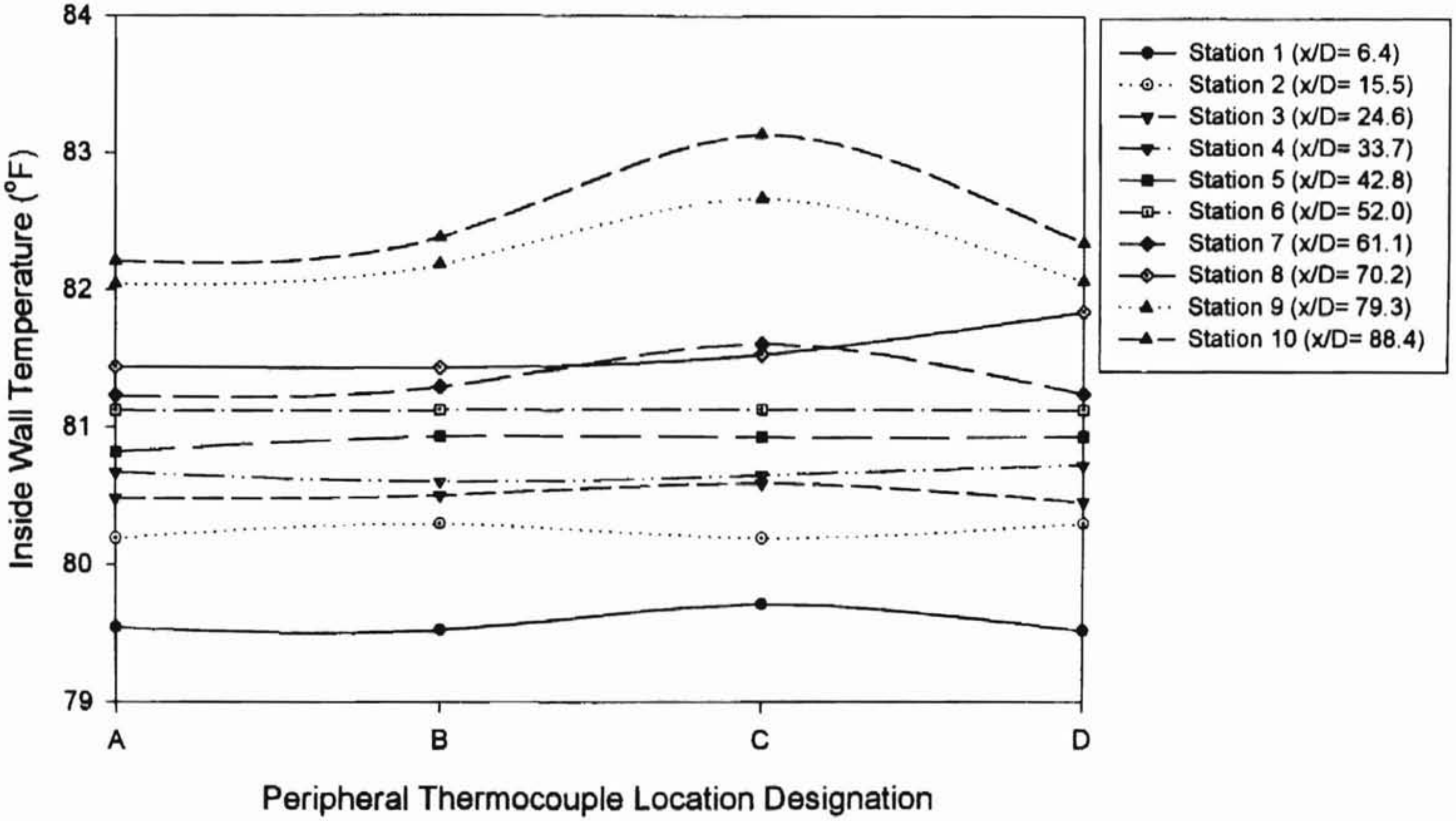


Figure 4.6: Peripheral Inside Wall Temperature Distribution for Forced Convection in Run 4103

4.3 Trend of Nusselt Number Along the Test Section

After the flow had traveled through the tube to a point far from the inlet, the velocity and thermal profiles became fully developed. The distance from the inlet to this fully developed point is known as the entrance length. Siegel et al. (1958) defined the thermal entrance region as the length required for the local heat transfer coefficient to approach to within a few percent of the fully developed value of the coefficient. Others such as Shah (1978) defined thermal entry length as it related to Nusselt number; and because the Nusselt number is a function of the heat transfer coefficient, the criteria for thermal entrance effect can be related to heat transfer coefficient [or the Nusselt number] deviation equally well. Figure 4.7 shows an example of Nusselt number variation with dimensionless axial distance for test runs which covered a wide range of Reynolds number. This figure demonstrates that the Nusselt number over all of the Reynolds number range (2600 to 16400) showed a steady decrease from the inlet of the test section, and gradually became constant after x/D was 40. This indicated that the fluid attained a fully developed flow after x/D equal to 40. Hence station 6 (x/D=52.0) was considered to be an ideal station where the fluid was said to be fully developed; and thus all of the Nusselt number comparison with selected correlations has been performed at this station.

4.4 Comparison of Available Correlations with Experimental Data

Using the data accumulated throughout this study, it was desirable to consider how accurately the data could be predicted by conventional correlations.

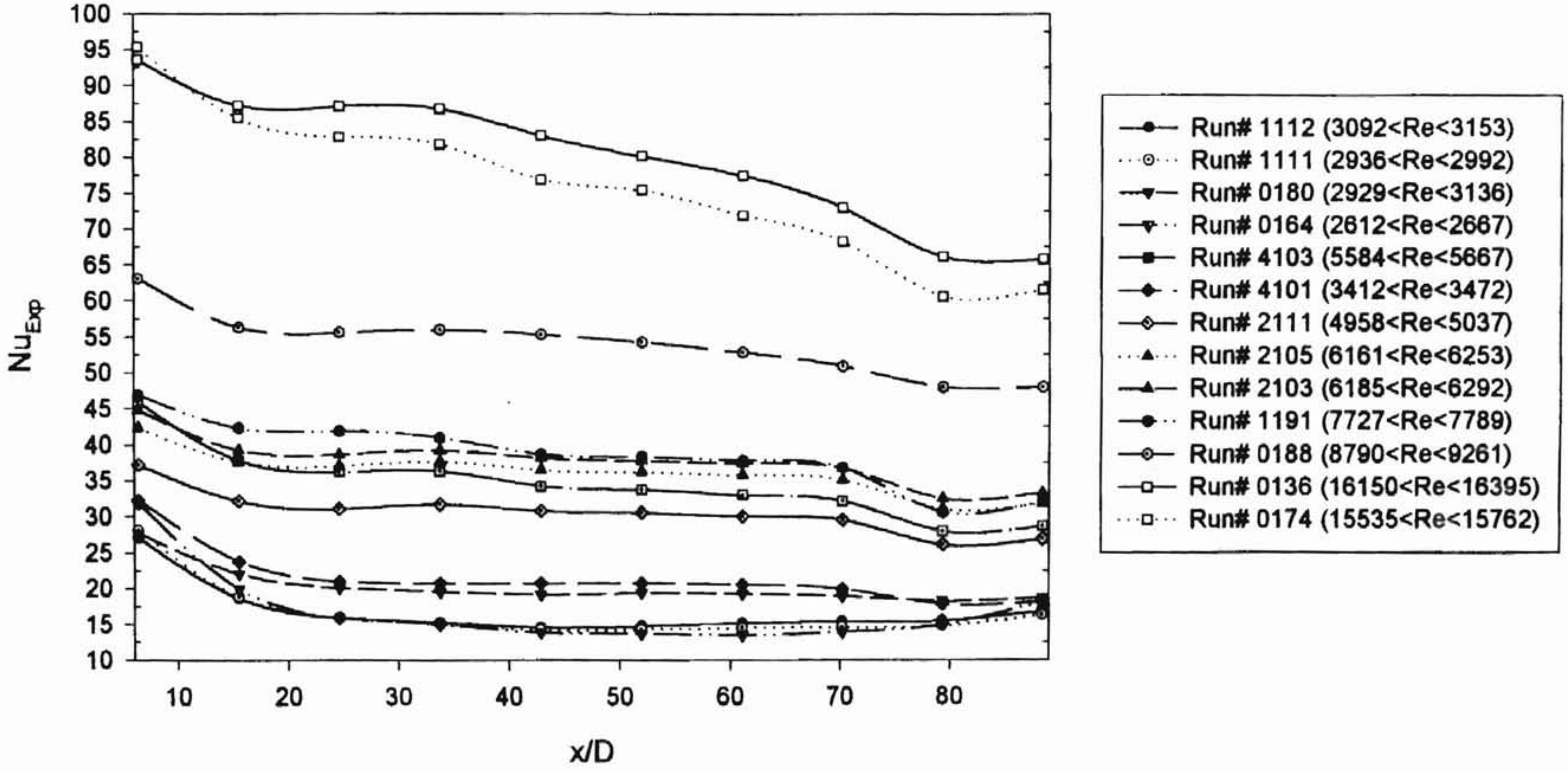


Figure 4.7 Experimental Nusselt Number vs. Dimensionless Axial Distance for All Types of Test Runs

To accomplish this goal, some of the correlations provided in Table II were compared with the data conforming to the respective correlation limitations (and sometimes outside of the ranges of those correlations in order to see the robustness of data vs. correlation). The Nusselt number was calculated using data at station 6, at which the flow was considered to be fully developed. From Figure 4.6, it is evident that the temperatures at station 6 were uniform among all peripheral locations. From Fig. 4.7, we observe that the Nusselt number at station 6 (x/D=52.0) appeared to be steady. An error of ±30 % between experimental and prediction was considered to be a good test run, and all of the following graphs have been drawn with ±30% reference lines.

The table given below shows the ranges, minimum and maximum values for Reynolds, Prandtl, and Grashof numbers, and viscosity ratio (ratio of viscosity at bulk temperature to viscosity at the wall temperature, μ_b/μ_w) at station 6. Determining the right correlation to be used for the test runs required attention to the ranges of Reynolds number, Prandtl number, and viscosity ratio. A total of 43 test runs were used to predict the Nusselt numbers (Nu_{CAL}).

TABLE V

Ranges of Reynolds Number, Prandtl Number, Grashof Number, Nusselt Number, and Viscosity Ratio for 43 Test Runs

	Reynolds Number	Prandtl Number	Grashof Number	Viscosity Ratio	Experimental Nusselt Number
Minimum	2954.5	4.91	115319.2	1.0231	17.48
Maximum	16286.4	6.3	1389900	1.3841	83.37
Average	7942.6	5.8105	325033.6	1.0863	45.29

A total of four different correlations were used to compare the data with the experimental Nusselt number. Sieder and Tate (1936), Colburn (1933), Gnielinski [Kakac et al. (1987)], and Ghajar and Tam (1994) were used. Gnielinski has given three correlations for different parameter ranges, and these were also compared with each other.

A total of 32 data sets were used to predict the Sieder and Tate (1936) turbulent correlation. The following table shows experimental ranges, comparison (experimental and prediction), their maximum and minimum values from Sieder and Tate (turbulent) correlation

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{1/3}\left({}^{\mu_b}\!/_{\mu_w}\right)^{0.14} \tag{4.6}$$

where

$\mathrm{Re} \geq 10000,\ 0.7 \leq \mathrm{Pr} \leq 16700$

TABLE VI

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Sieder and Tate (1936) Correlation

	Reynolds	Prandtl	Nusselt Number	Nusselt Number	% Error	% Error (Re> 10000)
	Number	Number	Experimental	Calculated	$(Nu_{Cal}/Nu_{Exp}-1)\times100$	$(Nu_{Cal}/Nu_{Exp}-1)\times100$
Minimum	5630.5	4.91	33.79	42.3	0.576	8.11
Maximum	16286.4	6.3	83.37	92.75	36.78	23.03
Mean	9370.89	5.8197	53.26	62.42	17.73	18.78

Figure 4.8 shows the Nusselt number comparison for this correlation. We see from the table and the graph, that, for higher Reynolds number (>8000 in this case), the Sieder and Tate correlation (turbulent) shows better results than for low Reynolds number. The recommended Reynolds number range for the Sieder and Tate turbulent correlation

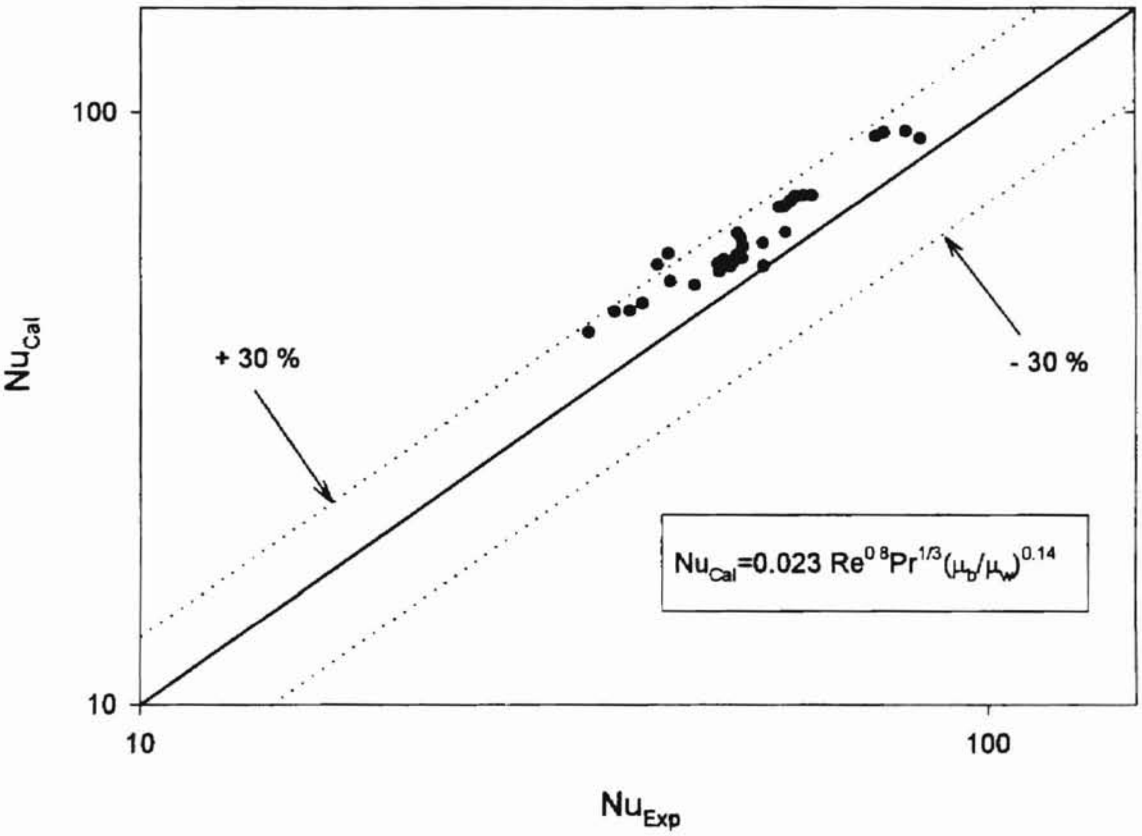


Figure 4.8: Comparison of Experimental Nusselt Number to Calculated Using Sieder and Tate (1936) Correlation

is 10000 and above. A maximum error of 36.78% and a minimum error of 0.576% is achieved by using the Sieder and Tate (1936) correlation. From the 32 test runs, 30 runs fall within the ±30% error band, which showed a good Nusselt number comparison.

The Colburn (1933) correlation for turbulent flow was used to compare 29 sets of data, since only 29 data sets reasonably met this correlation's parameter ranges. The table below shows the experimental ranges, Nusselts number comparison (experimental and correlation), and their maximum and minimum values. The correlation is:

$$Nu = 0.023 \mathrm{Re}^{0.8} \mathrm{Pr}^{1/3} \tag{4.7}$$

where

$\mathrm{Re} \geq 10000,\ 0.6 \leq \mathrm{Pr} \leq 160$

TABLE VII

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Colburn (1933) Correlation

	Reynolds	Prandtl	Nusselt Number	Nusselt Number	% Error	% Error (Re> 10000)
	Number	Number	Experimental	Calculated	$(Nu_{Cal}/Nu_{Exp}-1)\times100$	$(Nu_{Cal}/Nu_{Exp}-1)\times100$
Minimum	5630.5	4.91	33.79	42.04	-1.47	-1.47
Maximum	16286.4	6.3	83.37	92.2	36.35	22.13
Mean	9436.67	5.8069	53.26	61.72	16.22	16.11

Figure 4.9 shows the Nusselt number comparison for this correlation. The recommended Reynolds number range for the Colburn (1933) turbulent correlation is 10000 and above, and Prandtl number range is 0.6 to 160. We see from the table and the graph that, even for Reynolds number less than 10000, the Colburn (1933) correlation predicted results well for these 29 runs.

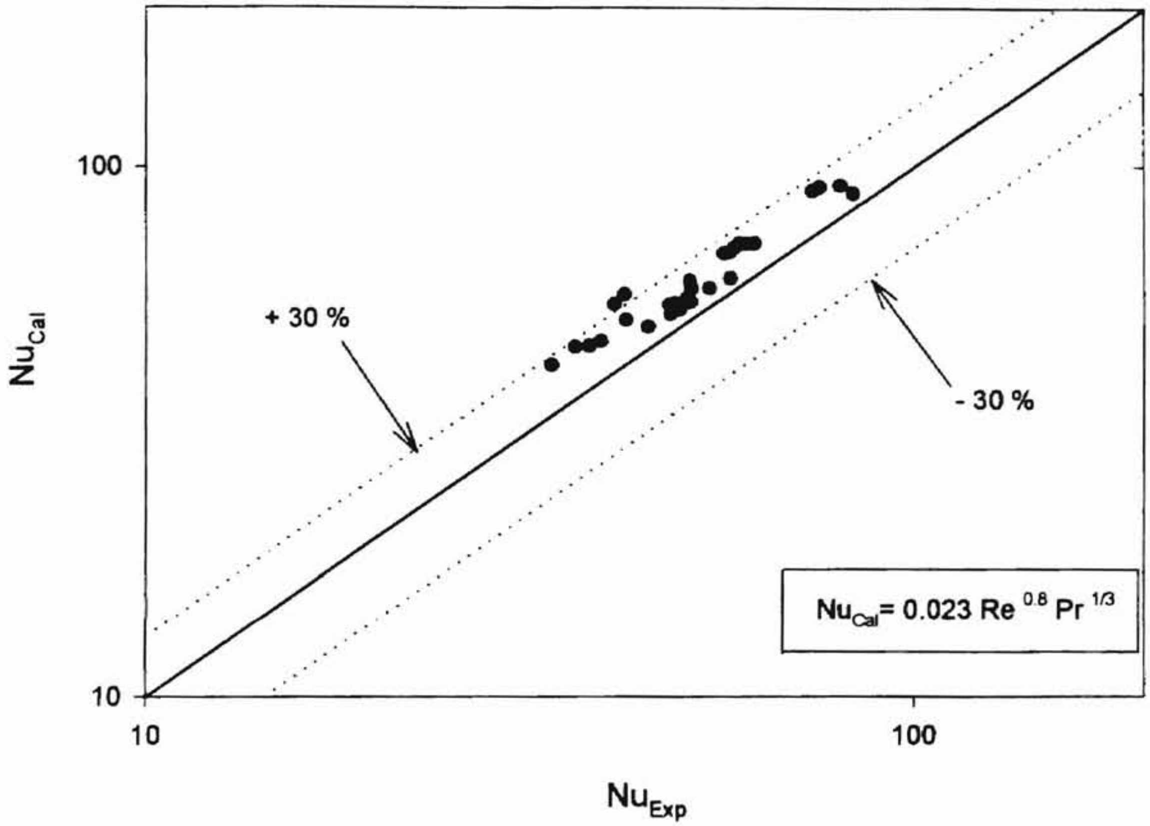


Figure 4.9: Comparison of Experimental Nusselt Number to Calculated Using Colburn (1933) Correlation

This Correlation showed a maximum error of 36.35% a minimum of –1.47%, and a mean error of 16.22, which were better than the results from the Sieder and Tate (1936) correlation. We see from the graph that almost all the test runs (except for 2) fell within the ±30% error band.

The Ghajar and Tam (1994) correlation was used for viscosity ratios (μ_b/μ_w) greater than 1.1. It became practically difficult to obtain such a high viscosity ratio, because this required high power input. But quite a few runs (24 data sets) were achieved which had viscosity ratios greater than 1.1. These runs and other runs which had viscosity ratios greater than 1.044 were employed to test the validity of the test setup and of the correlation. The table below shows some of these runs which were used to predict Nusselt number with the Ghajar and Tam (1994) correlation, which is:

$$Nu = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.385}(x/D)^{-0.0054}(\mu_b/\mu_w)^{0.14} \tag{4.8}$$

where

$3 \le x/D \le 192$, $7000 \le \mathrm{Re} \le 49{,}000$

$4 \le \mathrm{Pr} \le 34$, $1.1 \le (\mu_b/\mu_w) \le 1.7$

TABLE VIII

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Ghajar and Tam (1994) Correlation

	Reynolds	Prandtl	Nusselt Number	Nusselt Number	% Error	Viscosity	% Error (Re> 7000)
	Number	Number	Experimental	Calculated	$(Nu_{Cal}/Nu_{Exp} - 1)\times100$	Ratio	$(Nu_{Cal}/Nu_{Exp} - 1)\times100$
Min	6212.9	4.91	36.26	49.15	15.15	1.041	15.01
Max	16286.4	6.2	83.37	98.68	35.56	1.175	32.01
Mean	9547.5	5.765	54.44	67.65	24.52	1.097	23.46

Figure 4.10 shows the correlation comparison for Ghajar and Tam (1994) predictions. We see that, except for 2 runs (out of 24), the rest of the test data falls in the ±30% error band; and showed good Nusselt number comparison. It can be concluded that the current data is reasonably accurate since the proven Ghajar and Tam (1994) predictions agree reasonably well with the data presented herein.

Gnielinski proposed three correlations for different parameter ranges, these three correlations were taken from Kakac et al. (1987). The first correlation employs the friction factor (f) and is used for transitional and turbulent flows. The second and third correlations do not require friction factor. The second correlation is used for low Prandtl number and fully turbulent flows. The third correlation is used for transitional and turbulent flow. The first correlation and its parameter ranges are:

<u>Gnielinski [1]</u>

$$Nu = \frac{(f/2)(\mathrm{Re}-1000)\mathrm{Pr}}{1+12.7(f/2)^{1/2}(\mathrm{Pr}^{2/3}-1)} \tag{4.9}$$

$$\frac{1}{\sqrt{f}} = 1.58\ln \mathrm{Re} - 3.28 \qquad \text{Filonenko Correlation} \tag{4.10}$$

$0.5 \leq \mathrm{Pr} \leq 2000,\ 2300 \leq \mathrm{Re} \leq 5\mathrm{x}10^6$

TABLE IX

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Gnielinski [1] Correlation

	Reynolds Number	Prandtl Number	Nusselt Number Experimental	Nusselt Number Calculated	% Error $(Nu_{Cal}/Nu_{Exp} - 1)\times 100$
Minimum	2954.5	4.91	17.48	20.19	1.43
Maximum	16286.4	6.3	83.37	108.39	50.94
Mean	7948.4	5.8076	45.07	58.56	28.82

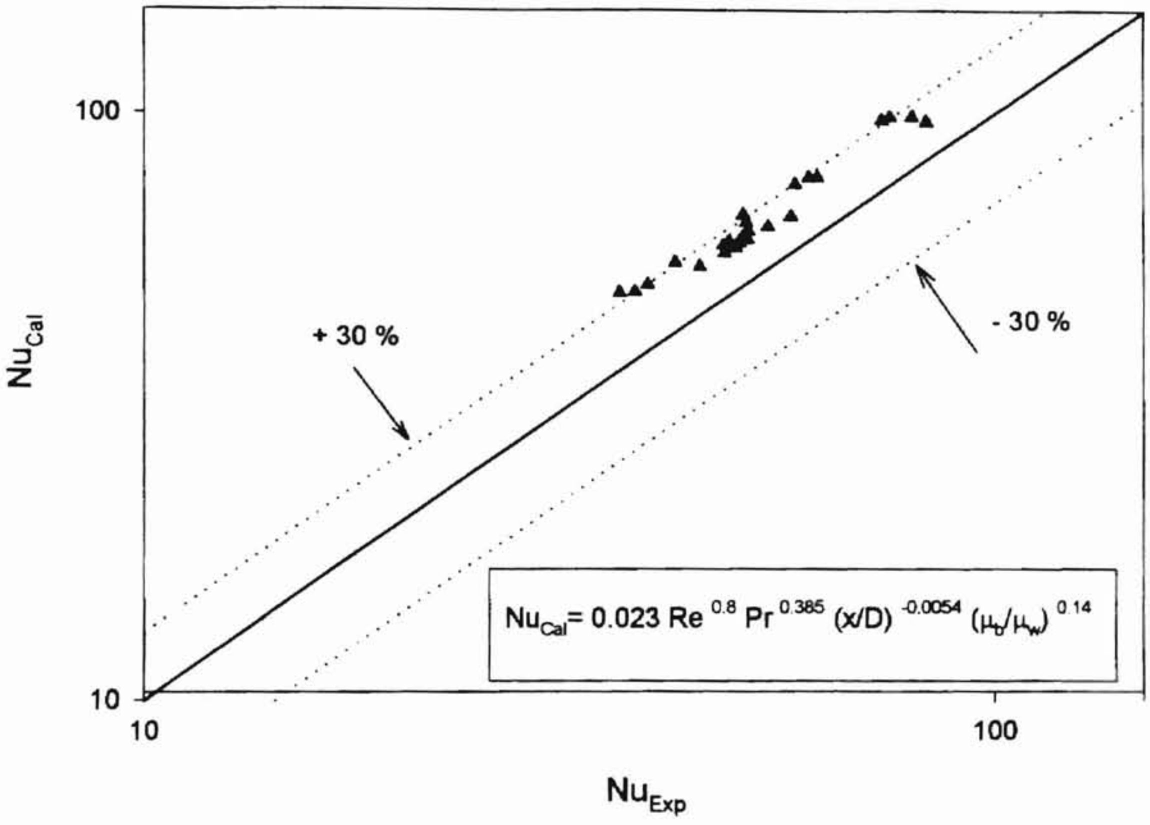


Figure 4.10: Comparison of Experimental Nusselt Number to Calculated Using Ghajar and Tam (1994) Correlation

Figure 4.11 shows the Nusselt number comparison with the Gnielinski [1] correlation. Figure 4.11 clearly shows that the Nusselt number comparison is not very good with the first Gnielinski correlation. This may be due to the fact that the friction factor in this correlation plays an important role in estimating the Nusselt number and that the friction factor correlation may have been inaccurate. Of the 43 test data points, only 22 fell within the ±30% error band.

The use of second Gnielinksi correlation showed a better comparison for the Nusselt number. The correlation is:

Gnielinski [2]

$$Nu = 0.0214\,(\mathrm{Re}^{0.8} - 100)\,\mathrm{Pr}^{0.4} \tag{4.11}$$

where

$0.5 \le \mathrm{Pr} \le 1.5,\ 10^4 \le \mathrm{Re} \le 5\mathrm{x}10^6$

TABLE X

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Gnielinski [2] Correlation

	Reynolds Number	Prandtl Number	Nusselt Number Experimental	Nusselt Number Calculated	% Error $(Nu_{Cal}/Nu_{Exp} - 1)\mathrm{x}100$	% Error (Re> 10000) $(Nu_{Cal}/Nu_{Exp} - 1)\mathrm{x}100$
Minimum	2954.5	4.91	17.48	20.95	3.11	6.47
Maximum	16286.4	6.3	83.37	91.45	34.09	22.03
Mean	7948.4	5.8076	45.07	58.56	16.12	16.79

This correlation has shown a very good Nusselt number comparison. Figure 4.12 shows the Nusselt number comparison with this correlation. Out of the 43 test data points, only 3 fell outside of the ±30% error band, and the average error was better

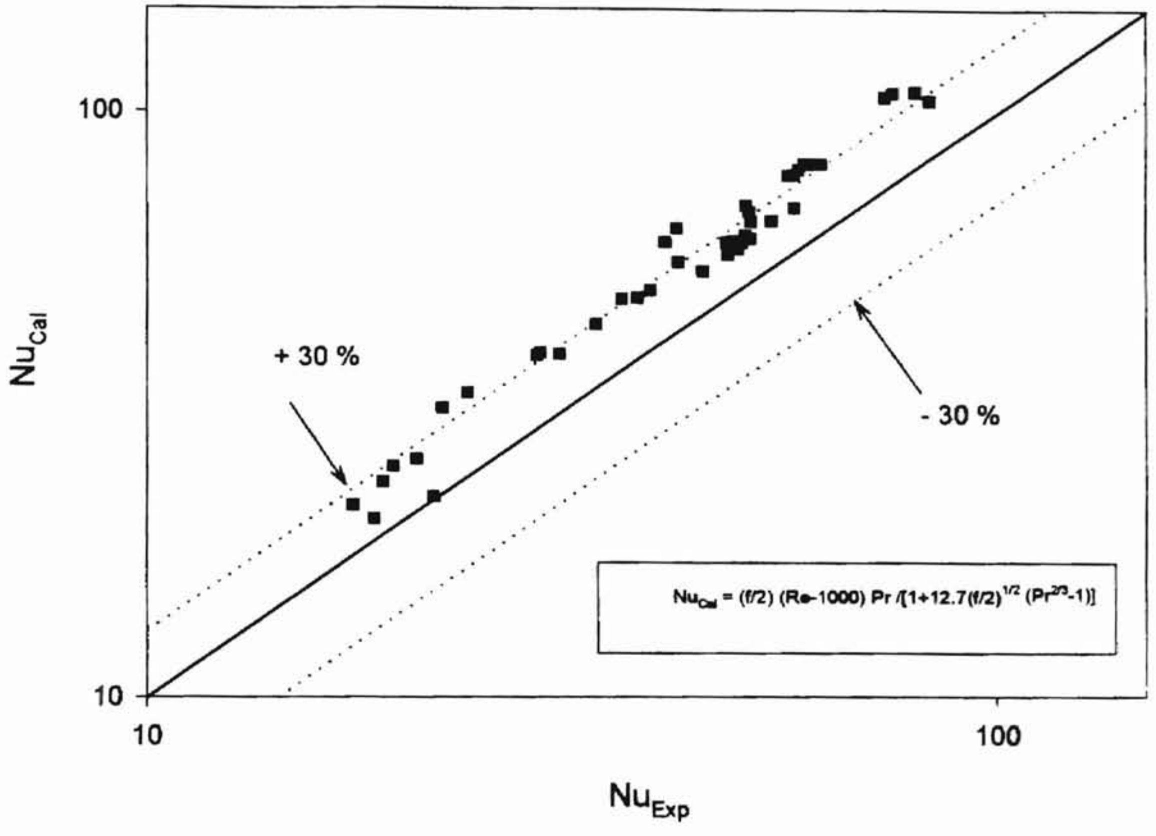


Figure 4.11: Comparison of Experimental Nusselt Number to Calculated Using Gnielinski [1] Correlation

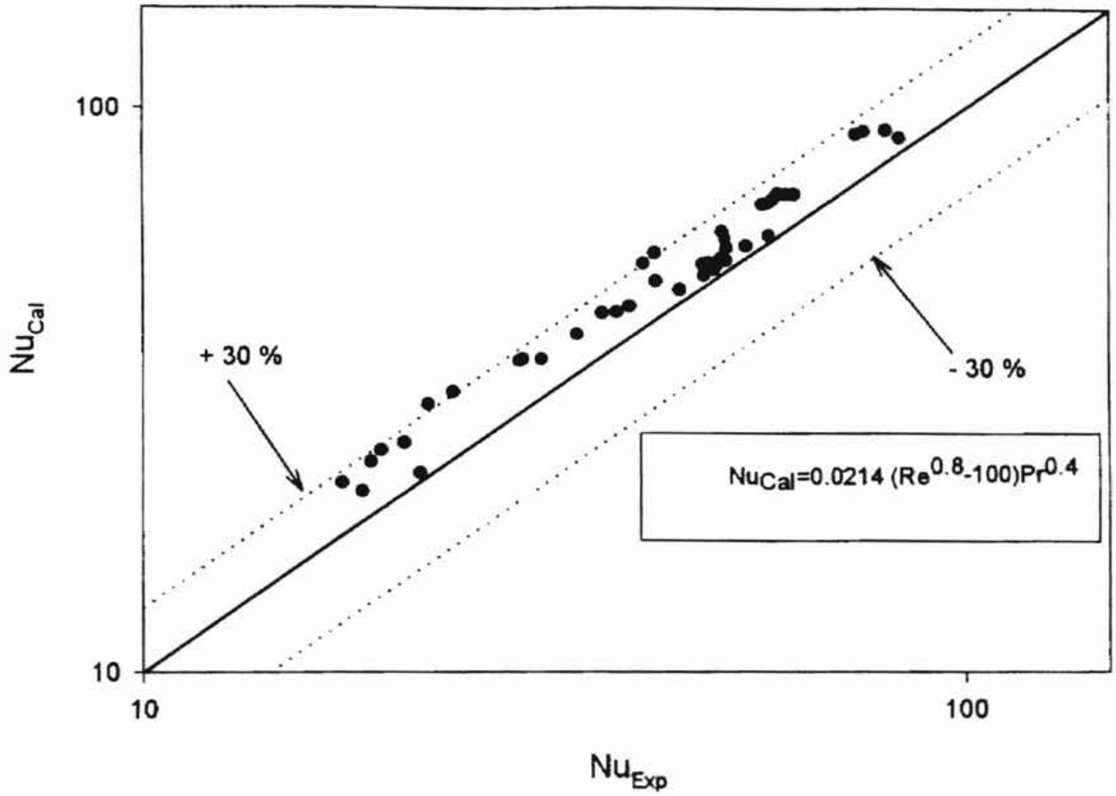


Figure 4.12: Comparison of Experimental Nusselt Number to Calculated Using Gnielinski [2] Correlation

than that for the Sieder and Tate correlation (1936) and the Colburn correlation (1933). We see from the figure that, even for Reynolds number less than 10000 (the recommended range is > 10000), the correlation provided very good Nusselt number predictions. But for Reynolds number greater than 9000, all of the test data fell within the ±30% error band.

The third Gnielinski correlation covers the Reynolds number range from 3000 to $1\text{x}10^6$. This correlation covered the entire test data range for this setup. The correlation is:

Gnielinski [3] (4.12)

$$Nu = 0.012\,(\mathrm{Re}^{0.87} - 280)\,\mathrm{Pr}^{0.4}$$

where

$1.5 \le \mathrm{Pr} \le 500,\ 3000 \le \mathrm{Re} \le 1\text{x}10^6$

The table below shows an overall view of the results for the 43 test runs used to predict the Nusselt number for this correlation.

TABLE XI

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Gnielinski [3] Correlation

	Reynolds Number	Prandtl Number	Nusselt Number Experimental	Nusselt Number Calculated	% Error $(Nu_{Cal}/Nu_{Exp} - 1)\text{x}100$
Minimum	2954.5	4.91	17.48	18.07	-9.37
Maximum	16286.4	6.3	83.37	99.21	34.53
Mean	7948.4	5.8076	45.07	52.45	15.03

Figure 4.13 shows the data comparison with this correlation. This correlation gave an average error of 15.03%, which is better than that of Sieder and Tate (1936),

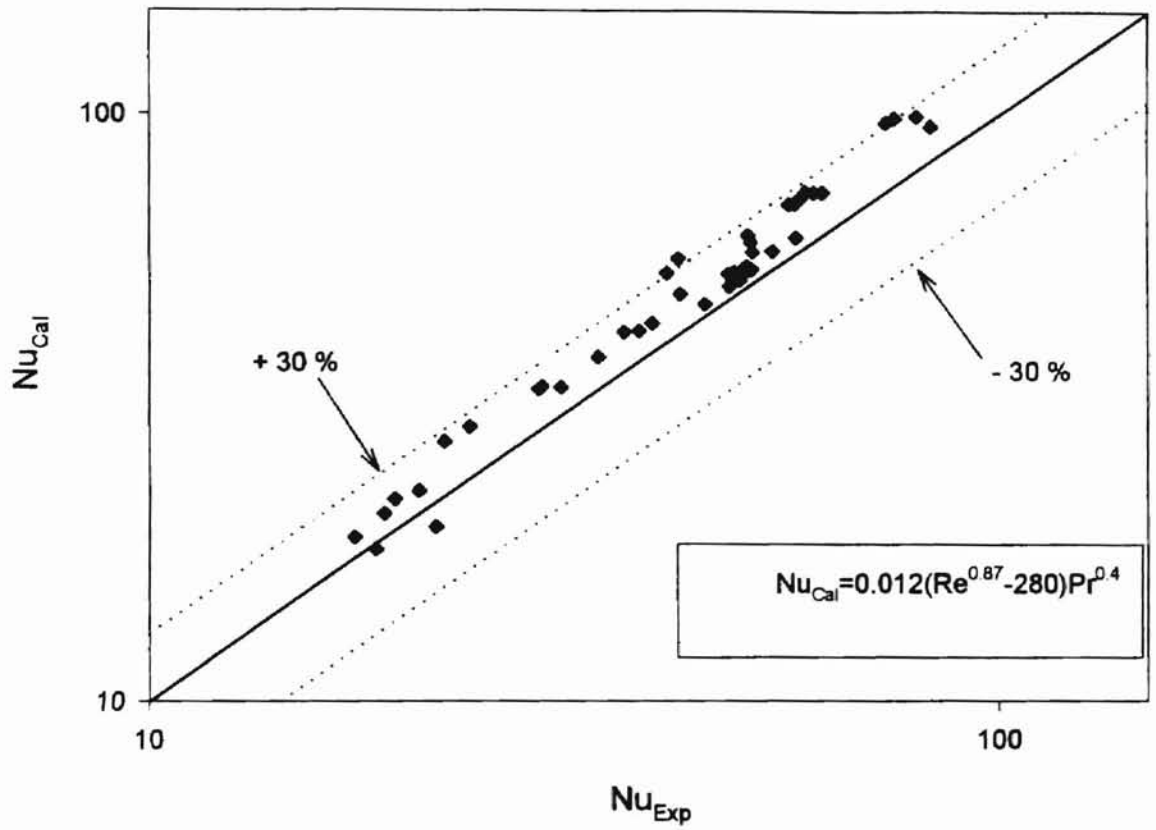


Figure 4.13: Comparison of Experimental Nusselt Number to Calculated Using Gnielinski [3] Correlation

Colburn (1933), and the first and second Gnielinski correlations. From the graph, it is evident that this correlation predicted the data well for the transitional region and turbulent region. Of the 43 test data points, 15 data points fell within the ±10 % error band, 30 fell within the ±20% error band, and 40 fell within the ±30% error band.

The Gnielinksi [3] correlation is in fact very good predictor for this test setup for transitional and turbulent flow, as it should be, since it has fit the range of test parameters (Re and Pr). From these correlation comparisons, it is clear that the test data is good enough to prove that the test setup can properly handle single-phase flows. The data obtained from this test setup compared well with these single-phase correlations. The experimental Nusselt number showed lower values as compared to those of the correlation predictions. This may be due to the fact that the power input (on which the heat flux depends) is improperly measured. This improper measurement of the power input may have resulted in a lower heat flux and hence a lower Nusselt experimental value. Therefore recalibration of the ammeter is very much desired in the future. Another possibility is the heat loss from the test section through insulation wrapped (2 inch thick) around the test section. However if this is an error the heat balance gets worse.

4.5 Best-Fit Correlation

From the comparison of experimental data with the author specified correlations, it has been demonstrated that the data obtained from this test setup is reasonably accurate and the test setup is ready for two-phase flow experiments. From Chapter III, it is evident that the mixing chamber was able to produce different flow patterns. With the single-phase data found herein, a best-fit correlation was developed to obtain better Nusselt number prediction. The third Gnielinski correlation, which predicted for the test run data very well, was used as a base correlation to obtain a best-fit correlation.

The versatility of the Gnielinski [3] equation is that it covers both the transitional and turbulent regions. Since the calculated Nusselt numbers always seemed to be higher values than the experimental Nusselt numbers, a change in constants in the this correlation may bring the Nusselt number to a reasonable value. But this correlation does not account for free convection effects in the transitional flow regime.

Since we know that Reynolds and Prandtl number are the key parameters in predicting Nusselt number, changing the constant (280 in Eq. (4.12)), or the power on the Reynolds number and Prandtl number required considerable attention. But changing the power of the Prandtl number did not bring any better change in Nusselt number prediction, since the Prandtl number range was from 4.91 and 6.30. When the power on the Prandtl number was increased to 0.44, the mean error on the Nusselt number for the 43 test runs increased to 23.41 %, which is 8% greater than that of the original Gnielinksi equation. When the power on the Pr was dropped to 0.38, the mean error changed to 11.06%, which did not improve the fit of correlation. Changing the power and the constant (280) on the Reynolds number gave a better prediction of Nusselt number for the experimental data. When the constant was changed from 280 to 430, the mean error dropped to 0.537 %, and the minimum error to –26.05 %. But a change in the power on the Reynolds number to 0.866 changed the mean error to 0.072919%, with a minimum of –29.90% and a maximum of 20.96%.

The modified correlation is therefore:

$$Nu = 0.012(\mathrm{Re}^{0.866} - 430)\,\mathrm{Pr}^{0.4} \qquad (4.13)$$

The table below shows the Reynolds and Prandtl number ranges and the Nusselt number comparison for this modified correlation.

TABLE XII

Ranges of Reynolds, Prandtl, and Nusselt Numbers, and % Error for

Modified Correlation

	Reynolds Number	Prandtl Number	Nusselt Number Experimental	Nusselt Number Calculated	% Error $(Nu_{Cal}/Nu_{Exp} - 1)\mathrm{x}100$
Minimum	2954.5	4.91	17.48	13.75	-29.90
Maximum	16286.4	6.3	83.37	91.76	20.96
Mean	7948.4	5.8076	45.07	46.76	0.0729

Figure 4.14 shows the Nusselt number comparison with this modified correlation. Out of the 43 test data points, 34 points fell within the ±15% error band, 39 within the ±20% error band, and all of the 43 data points were within the ±30% error band. This correlation shows a very good experimental Nusselt number comparison.

4.6 Problems

It was discovered that, during the initial test runs, two thermocouples (TC 7 and TC 40) were dysfunctional. They were removed and replaced with new calibrated thermocouples. Several test runs were done to insure that all of the thermocouples were functioning properly in the defined vicinity of operation.

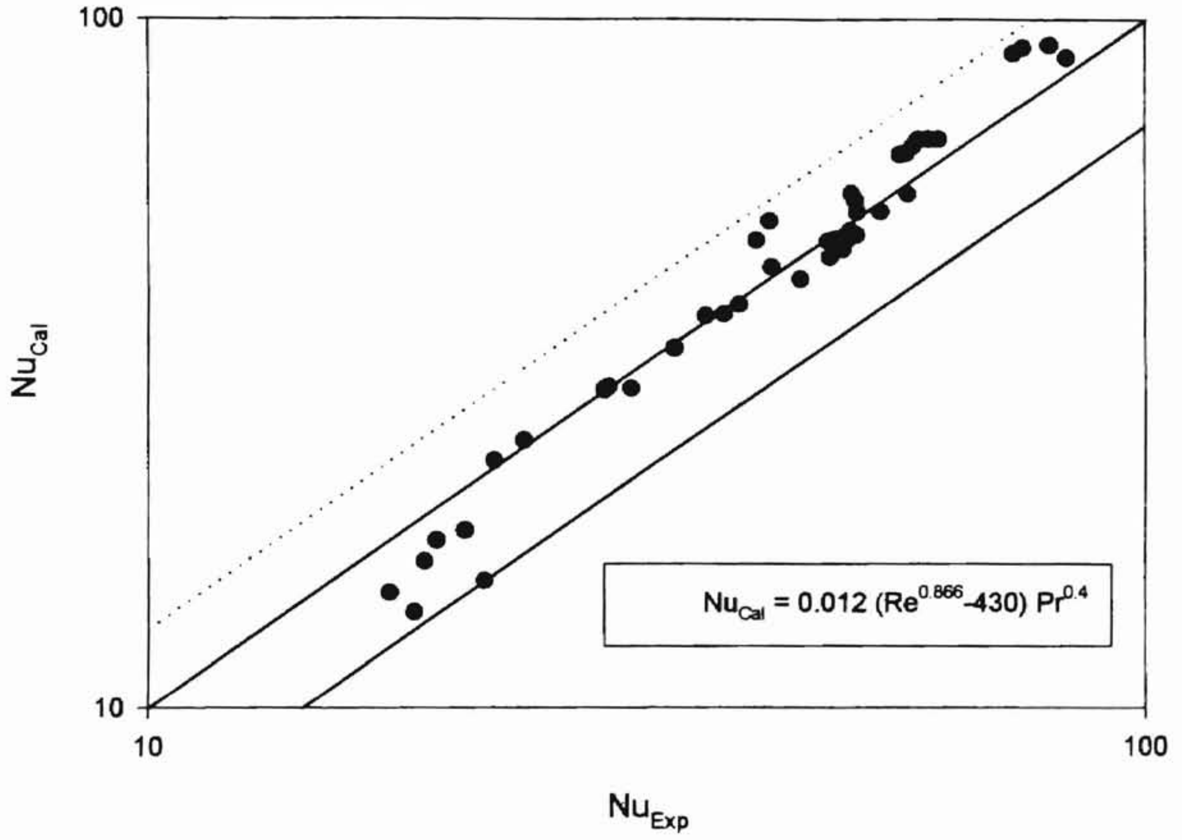


Figure 4.14: Comparison of Experimental Nusselt Number to Calculated Using Modified Gnielinski [3] Correlation

Since a comparatively low power is required in order to get a good bulk temperature difference (see, for instance, run 164 and run 1117), the test section was heated for a long time before the actual data was taken. For low flow rate test runs, the test section was heated for a long time (at least 25 minutes) to get good bulk temperature difference. The procedures followed to get good bulk temperature differences for low flow rates is described in Appendix F.

While making the flow rate measurements, reading the frequency of the frequency meter required experience in understanding the frequency meter. It is advisable to take as many readings as possible from the frequency meter. While repeating the test runs, every possible detail was looked into to produce the same conditions, like inlet bulk temperature, heat input, and flow rate, in order to provide good repeatability for this test setup.

For all of the types of test runs listed in Table IV, there were many factors which influenced obtaining good bulk temperature difference, and good heat balance errors. Maintaining the system at steady-state, getting a good bulk temperature difference and a good heat balance error were the three most essential conditions, in order to then carryout the experiment. Since the power input is low for cases 1, 2 and 3, the heat exchanger was used to insure that a reasonable temperature difference was produced in order to carry out the heat balance error calculations and correlation comparison. Many parameters influenced the temperature difference (for example, both inlet and exit bulk temperatures) which ultimately affected the heat balance error calculation and the correlation comparison. These trends are clearly shown at the beginning of this chapter.

For low flow rates and high power input, it was observed that the flow was not completely filling the tube cross-section. This caused the station A thermocouple (see Fig. 2.4 for the thermocouple locations) temperatures at several stations to rise above 100^0 C, and made the water boil. This happened in almost all of the test runs for case 7. It was necessary to insure that either the test section was not heated over a certain limit (for case 7, an amperage of 450 or less was good), or the flow rate was not below 0.92 gpm. For low flow rates, it was observed that the flow was not fully developed initially. To avoid this, the water is allowed to run for at least 30 minutes before the actual data was taken. Bubble formation in the tube was observed for all kinds of flow regimes. To avoid this, water was run for a longer time, until the flow was fully developed. The clear calming section and clear mixing section helped to visualize the flow in the tube.

Mixed convection effects were observed after station 3 (see Fig. 4.4). Attaining steady-state was easier for low power and medium power input test runs, since these test conditions could be achieved by allowing the fluid to run for a longer time to reach the steady-state without overheating the test section. For high power input test runs, careful observation was made to identify steady-state, and data was collected before any natural convection heat transfer occurred throughout the test section (by monitoring the temperatures at the top [station-A thermocouple] and bottom [station-C thermocouple]). The data acquisition system MAC-14 has a graphic option (Real Time Graphics), which helped to track the inlet and exit bulk temperatures graphically. Appendix F discusses the procedures to obtain a steady-state and a good bulk temperature difference for all of the test run cases. Appendix F also discusses how the MAC-14 used to identify the steady-state.

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The goals of this thesis as set forth in Chapter I was successfully achieved. Construction of a versatile test setup was completed, the effects of heat flux on flow rates and heat balance errors were carefully studied. The versatile design of the mixing chamber and flow-visualizing section helped to identify various kinds of flow patterns. The test setup demonstrated single-phase data that fit the applicable correlation predictions. A complete heat transfer database for the transitional and turbulent flow ranges has been assimilated. The test setup has been constructed carefully, and the data taken for the single-phase appears to be accurate.

5.1.1 Experiment Apparatus

With the completion of the setup and instrumentation, planned single-phase and two-phase (water/air) fluid flow experiments are possible to perform. This includes the study of pressure drop measurement, void fraction measurement, and re-calibration of the ammeter. The versatile design of the mixing chamber and flow-visualization section should help to further identify various kinds of flow patterns beyond those found in this study. Stratified, slug, slug/bubbly transitional, plug, and wavy flow patterns have been identified for various flow rates of water and air. All of the apparatus problems have been solved, and trouble-free experimentation should occur with its use.

5.1.2 Nusselt Numbers

The test run data covered the transitional and turbulent flow. The third Gnielinksi correlation predicted the data very well for this test setup data. For all of the types of test runs, a careful selection of the correlation has been made to fit the data even outside of the author specified ranges. The Colburn (1933), Sieder and Tate (1936), and Gnielinski's [Kakac et al. (1987)] second and third correlations predicted the test data reasonably well. A complete summary of all nine test run cases (refer to Table III) is given in Table IV of Appendix B. The Nusselt number calculations for all of the good test runs are briefly explained in Table XVI of Appendix B.

5.1.3 Calibration Runs

During the initial test runs, several problems were encountered, the majority having to do with a few faulty thermocouples. These thermocouples have been removed and replaced with good ones. During the calibration runs, it was found that the flow rate and heat fluxes have a strong influence on the heat balance errors and Nusselt number comparison. Eventually, a reliable procedure for setting the flow rate with respect to heat flux was developed (refer to Chapter IV). The heat exchanger has helped the system to attain a steady-state and it has worked well enough to keep the system at steady-state for long time periods.

5.2 Recommendations

Due to uneven distribution of heat inside the test section for low flow rates, mixed convection effects takes place under these conditions. As discussed in Chapter IV, it is believed that the heat flux could be responsible for the mixed convection effects at low flow rates. Even before starting a test run, it is advised that the experimentalist carefully verify what heat input is needed for a particular type of flow rate (refer to Chapter IV). Any slight change in the flow rate of the heat exchanger fluid will result in slight cooling or non steady-state conditions for the test setup. So it is always advisable to use the heat exchanger at full maximum flow for flow rates below 1.5 gpm, at one-half of maximum for flow rates ranging from 1.5 to 2.5 gpm, and one-quarter of maximum for flow rates ranging from 2.5 to 4.4 gpm.

Obtaining high viscosity ratios was rather difficult with this setup, because this required a high power input. At the same time, it was difficult to attain steady-state conditions for high power input.

From the correlation comparison in Chapter IV, we observed that the calculated Nusselt number was always higher than the experimental value for almost all of the correlations. This may be due to an under-estimation of the power input, which decreased the heat flux, thus increasing the Nusselt number calculated. One of the reasons for this happening is due to a slightly inaccurate calibration of the ammeter. Although this may not be critical, a slight increase of 20 amperes can improve the heat balance error. In some cases where such an amperage was applied, the heat balance errors were brought down from -6.69% to –0.89%. To solve this problem, re-calibrating the ammeter is recommended.

The Table XIII shows the heat balance errors for some of the high power runs, with the original ammeter readings and with arbitrarily modified (+20 amps to the original reading) ammeter readings.

TABLE XIII

Effect of Amplified Ammeter Reading on the Heat Balance Errors

Run #	Flow Rate (gpm)	Voltage (v)	Current (amps)	Heat balance Error	New Current (amps)	New Heat balance Error
4115	2.2817	3.78	480	-3.76%	500	0.39%
4117	2.1037	3.79	480	-8.02%	500	-1.86%
4119	2.2553	3.8	481	-8.32%	501	-2.29%
4121	2.3089	3.81	483	-8.22%	503	-2.26%
4123	2.3981	3.81	483	-6.69%	503	-0.89%
4128	2.4204	3.72	474	-7.66%	494	-1.75%
4130	2.389	3.9	490	-9.81%	510	-3.89%
4132	3.3751	3	380	-5.75%	400	0.52%
4134	3.3795	3.07	390	-7.91%	410	-1.64%

The other important parameter to be taken into consideration is the measurement of flow rate. The turbine meter measures the flow rate (gpm) as a function of frequency. The frequency reading (in Hz) was taken at several intervals of time while a given test run was conducted. At least 50 readings were taken and then averaged to substitute into the calibration equation. It is advisable to take as many frequency readings as possible to get a good flow rate measurement. The frequency meter, which gives out a digital output of the frequency, was not very consistent, and it also depended upon the experimentalist's intuition as how to take the readings over a certain length of time. It may be recommended that the data acquisition system should be used to take the frequency readings automatically from the turbine meter and average them.

To obtain better heat balance errors and Nusselt number comparisons, it is advisable to use the Eq. (4.4) described in Chapter IV. The use of this equation increased the accuracy of Nusselt number performance of the test setup.

For two-phase flows, flow rate of air ranged from 0.52 gpm to 19.5 gpm, but it is advisable to limit the flow rate to 10 gpm, because flow rates higher than this may result in excessive vibration in the test loop and may also lead to leakage. For the two-phase flow experiments, the pressure taps need to be connected to a scanivalve, which could measure the pressure at all the eleven locations (see Fig. 2.2) on the test section. Then the test runs should be made with pressure taps and compare to existing data/correlations for single-phase flows. It has to be made sure that the air should be free from dust particles before it mixes with the water. Passing the air through an air-filter can do this. The water filters should be changed for every 100 hours of operation. It is always advisable to run the two-phase flows with low power inputs, because bubbles in two-phase flow may over heat the test section.

The pressure and temperatures should be monitored for air flow rates. The electrical resistivity of the stainless steel test section vs. temperature should be determined. The heat loss from the test section (with the insulation on) should be calculated in order to see whether this calculated value could affect the over prediction of Nusselt number shown in the 43 test runs. The resistance of the stainless steel test section varies with temperature, so it is necessary to know how this effect may influence the heat balance errors and Nusselt number comparison. The ammeter should be re-calibrated. The uncertainty analysis in the prediction of heat transfer coefficient is given in Appendix G

For future two-phase flow experiments, test runs should be conducted starting with a very low flow rate of water. It would be better to divide the two-phase flows in to different categories based on the flow rates of water and air, and power input. An initial study of these specific test runs may help eliminate some cases which do not give good heat balance errors. An accurate weighing device should be used to measure the volume of water in the void-fraction measurement setup. Thermocouples placed on the inlet and exit of the heat exchanger may also provide valuable information in maintaining a steady-state. The model 5100 data logger and MAC-14 data logger should be used to compare the calibrated thermocouple temperatures.

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APPENDIX A

EQUIPMENT SPECIFICATIONS

APPENDIX A

EQUIPMENT SPECIFICATIONS

In this Appendix, a listing of all of the equipment (and their specifications) used in this experimental project has been given.

1. Test Section: A 316, #40 stainless steel circular pipe ID=1.097±0.001 inches (2.7863±0.00254 cm), OD=1.316±0.001 inches (3.3426±0.00254 cm), and 110" (9.167 ft); ordered from Stillwater Steel and Supply, Stillwater, OK.
2. D.C. Arc Welder: Lincoln Idealarc DC-600, 3-phase rectified electric welder, 100% duty cycle @ 600 amps and 44 volts at 50/60 Hz; for a maximum power of 24.6 kW.
3. Calming Section: Clear polyvinyl carbonate pipe (part number: Lextube 1.000X1.25), ID=1.0" (2.54 cm), OD=1.25" (3.175 cm). Procured from Cope Plastics Inc., Oklahoma City, OK.
4. Solvent Cement: Weldon #3, Clear Solvent Cement used to glue plastic material.
5. Thermocouple: Omega TT-T-30 copper-constantan insulated T-type thermocouple wire was used with Omega EXPP-T-20-TWSH-UL extension wire for relay to the data acquisition system. The thermocouple beads were fabricated using a Tigtech Inc. model 116SRL thermocouple welder.

6. Temperature Bath: FTS Systems, Inc. New York 12484 (model number: RC-00180-A, serial number: RC109410) used as a temperature bath for calibrating the thermocouples and bulk temperature probes.
7. Termocouple Probes: These probes were procured from OMEGA (type # TJ36-CPSS-14U-12).
8. Thermocouple Glue: Omegabond 101 epoxy adhesive (catalog # OB-101-1/2), a two-part adhesive providing a high thermal conductivity (0.6 Btu/hr-ft-F) and very high electrical resistivity of $1 x 10^{15}$ ohm-m.
9. Data Logger: A Cole-Palmer ninety-six input MAC-14 data logger was interfaced with an AT 80386 personal computer to provide digital data acquisition for the temperature measurements. It accepts input voltages from 0.3 microvolts to 10 volts, has an accuracy of ± 0.02% of range, and has 16 bit resolution.
10. Data Logger for Calibration: Electronic Controls Design (ECD) model 5100 digital data logger. The model 5100 has a resolution of 0.1 °F, over a temperature range of 158 to 752 °F and a ± 0.1 °F conformity error over the range of –105 to 400 °F.
11. Porous Bronze Tube (for mixing chamber): The porous bronze tubes (grade F100, part number 1 inch-1 ½ x 8 inch x 3/32 inch) were procured from Capstone Permaflow, CA. The porous bronze tube has a particle removal size of 15-25 microns, and maximum pore size of 45-72 microns. It has a maximum operating temperature of 900 °F, a minimum operating temperature of –452 °F, an oxidizing temperature of 400 °F, and a tensile

strength of 3000-7000 psi. The chemical composition of the porous bronze tube was 89-96% copper, and the remainder was tin.

12. Voltmeter: A Hewlett-Packard model 3468B digital multimeter was used to measure the actual voltage drop across the test section. The range available for DC voltage measurement is 1 microvolt to 300 volts. An accuracy of 1% of the reading, and a resolution of 10 microvolts are possible with this model.
13. D C Ammeter: Weston Instruments Division model 931 ammeter placed in parallel with a 50 millivolt shunt. The shunt was made and calibrated by Mr. Gerald Stotts, manager of the Electronics Laboratory, Electrical and Computer Engineering at Oklahoma State University.
14. Heat Exchanger: ITT Standard model BCF 4036 one shell and two-pass tube heat exchanger purchased from Thermal Engineering Company, Tulsa, OK.
15. Rotameter: Omega FL-9028, maximum range of 4 to 28 gpm, an accuracy of ±5% of full scale, and repeatability of ±1% of full scale.
16. Quick Closing Valves (for void fraction measurement): The two quick closing solenoid valves were procured from W&W International, model number RD 222DVYD and operate on 110V/50 Hz and 120V/60 Hz. Another solenoid valve which was procured from Automatic Switch Co. (ASCO, catalog no: 826820, serial no: 23779N2) operates on 100V/60HZ, and was placed in the by-pass line.
17. Manually Operated Valves (for void fraction measurement): Two manually operated Teflon-PFA type (model no: E-06373-25 (M)), ¼ inch valves were

procured from Omega Engineering, Inc. These valves can withstand pressures up to 40 psi, and temperatures up to 300 °F.

18. Separator: A water/air separator was procured from Hayward Industrial Products, Inc., and will be used to separate water and air from each other. The separator (type: ST-separator trap, model number: TB-534L) was a product of Wright-Austin Co. This separator can handle a maximum pressure of 160 psi at 450 °F

19. Water Tank: A 35 gallon cylindrical polyethelene tank was purchased from Atwoods of Stillwater. The approximate tank dimensions are: 18 inches (45.72 cm) in diameter, and 24 inches (60.96 cm) in height.

20. Pumps: [1]. For low flow rates, a pump manufactured by Oberdorfer Pumps, model SKH35FN193T, was used. It produces a flow rate of 4.8 gpm at 3450 rpm using a General Electric 1/3 hp motor. [2]. For high flow rates, a Westinghouse (S# 1442131, Ser. 5301) 3-phase (220/440 volts) pump was installed. The motor is rated at 1.5 HP, which should produce a flow rate of 35 gpm at 3535 rpm and 60 hz.

21. Turbine Meter: A Halliburton 1 inch turbine meter was used over a frequency range of 50 to 150 Hertz. This turbine meter had a linear accuracy of ±0.5% of full scale reading, and a repeatability of less than ±0.10% of full scale reading. This turbine meter can be used for flow rates up to 10.5 gpm.

22. Frequency Meter: A Hewlett-Packard model 5314A universal counter was used to measure the frequency of the turbine meter during data collection.

Input frequency range for the 5314A is 10 Hz to 100 MHz, with a sensitivity of 25 millivolts rms at 100 MHz, and 0.075 volts peak-to-peak at a minimum pulse of 5 nanoseconds.

23. Water Filter: [1]. An Aqua-Pure water filter model AP12T double cartridge filter system used two model AP110 H/C cartridges, which can remove 5 micron diameter dust particles. Procured from Aqua-Pure water filters, Oklahoma 73118. [2]. Teek Water Systems double cartridge filter (used before the heat exchnager).
24. Gas Flow Meter: Cole-Parmer gas flow meter model 32915 was used to measure the flow rate of air, it can withstand pressures up to 100 psig. It can measure flow rates of air from 0.26 gpm (1 lpm) to 26.15 gpm (99 lpm).

APPENDIX B

EXPERIMENTAL DATA

B.1 Summary of Test Runs

B.2 Sample Input/Output Data File for Program RHt98F

B.3 Equation for Power Input/Flow Rate

B.4 Test Run Outputs

APPENDIX B

B.1 Summary of Test Runs

In this Appendix, the results from all of the test runs are presented. Table XIV gives all pertinent findings and the nature of the initial nine test run cases (i.e., power input and flow rate). Column 1 identifies the run number. The results consist mostly of dimensionless parameters (Reynolds, Prandtl, and Nusselt numbers), flow rates, and power inputs. The results were shown for stations 5, 6, and 7 (see Fig. 2.4), where the flow was considered fully developed; but station 6 was used for all "in-depth" analysis. Other information includes the average heat flux, ratio of heat transfer coefficient at the top to that at the bottom of the pipe (h_t/h_b), ratio of temperature at the top (TC at station A) to that at the bottom (TC at station C), and the heat balance errors (explained in the Chapter IV).

Table XV gives all of the pertinent findings and nature of the "good" test runs selected from the nine test cases and these runs made by using the Eq. (4.5). (Refer to section B.3 in this appendix for a brief explanation of this equation.)

The results shown in Table XIV and Table XV are for station 6 (see Fig. 2.4), where the flow was considered fully developed, but these tables also provide the h_t/h_b values for stations 5 and 7. Table XVI provides the calculated Nusselt numbers from the Sieder and Tate (1936), Colburn (1933), Gnielinski [kakac et al. (1987)], and Ghajar and Tam (1994) correlations, and their fractional differences as compared to experimental values ($Nu_{Cal}/Nu_{Exp}-1$). These correlation values are calculated at station 6 as mentioned in Chapter IV. Since the Datared98F and RHt98F programs were used to calculate the results, sample input/output files for both of the programs are included in this appendix. The sample is for run 1114 only. Listings of these codes are given in Appendix C. The complete outputs for all of the 43 “good” runs are given in Appendix B.4.

TABLE XIV

Summary of Test Runs Ordered by Case Number

CASE 1: LOW POWER/LOW FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_s(@ 6)	h_t/h_s(@ 5)	h_t/h_s(@ 7)
135	178	1.406	250.09	0.83	-1.92%	88.82	2.1	3127.2	5.16	311107.8	1.0554	17.48	95.657	1.016588	0.6431	0.6741	0.7697
164	175	1.37	239.75	0.84	3.06%	73.92	1.89	2642.9	6.33	206827	1.0776	13.7	83.289	1.046482	0.404	0.4846	0.4504
1109	175	1.385	242.375	0.92	2.73%	83.14	1.75	3238.3	5.58	307895.4	1.0721	13.66	93.579	1.058954	0.2766	0.7454	0.2668
1111	175	1.38	241.5	0.89	5.27%	78.64	1.76	2967.6	5.93	244664.6	1.0716	14.27	87.251	1.036232	0.4648	0.51	0.5532
1112	175	1.39	243.25	0.89	1.24%	82.19	1.85	3126.3	5.59	282905.3	1.0668	14.76	91.117	1.030727	0.4966	0.5453	0.6045
1113	175	1.4	245	0.82	0.44%	85.84	2.04	2984.7	5.37	314660.6	1.0643	14.94	94.056	1.02951	0.496	0.532	0.6102
1114	175	1.405	245.875	0.82	0.95%	86.82	2.03	3018.5	5.3	404183.1	1.0793	12.08	99.155	1.073167	0.2042	0.5634	0.7792
1115	178	1.4	249.2	0.82	1.62%	84.96	2.05	2954.5	5.43	253682.5	1.0539	18.52	90.918	1.006622	0.8368	1.3982	0.7441
1155	175	1.38	241.5	0.959	4.92%	80.15	1.64	3254.4	5.81	195665.3	1.053	18.95	85.461	1.003332	0.915	1.149	1.0997
1159	175	1.39	243.25	1.0044	2.96%	80.66	1.61	3428.9	5.77	194144	1.0513	19.5	85.791	1.002131	0.9434	1.2194	1.0934
1167	175	1.395	244.125	1.2426	3.67%	80.09	1.3	4181.8	5.83	164813.1	1.0452	22.26	84.531	1.001922	0.9445	1.0474	1.0568
1169	190	1.52	288.8	1.3012	5.28%	80.33	1.44	4419.4	5.81	183739.9	1.0496	23.85	85.199	1.00143	0.9622	1.046	1.0741
1173	215	1.72	369.8	1.5093	8.81%	79.16	1.53	5053.5	5.9	186200.1	1.0532	28.75	84.258	1	1	1.1019	1.1149
1175	218	1.72	374.96	1.5173	6.64%	79.6	1.58	5106.5	5.87	192733.2	1.0541	29.01	84.721	0.9997609	1.0066	1.0809	1.1073
CASE 2: LOW POWER/MEDIUM FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_s(@ 6)	h_t/h_s(@ 5)	h_t/h_s(@ 7)
134	178	1.405	250.09	2.37	1.17%	88.5	0.73	8820.3	5.24	124269.8	1.0231	42	90.863	0.9998882	1.006	1.2105	1.2422
170	175	1.4	245	2.4	2.75%	88.03	0.68	8881.2	5.27	104343.7	1.0198	47.45	90.428	1.000898	0.9534	1.2267	1.2155
1177	178	1.42	252.76	2.14	11.03%	78.9	0.72	7103.2	5.95	100279.5	1.0296	35.45	81.644	0.999379	1.0259	1.1065	1.2153
1179	205	1.64	336.2	2.38	6.88%	78.71	0.9	7901.9	5.96	115319.2	1.0342	40.74	81.872	0.9977759	1.0798	1.1476	1.2338
CASE 3: LOW POWER/HIGH FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_s(@ 6)	h_t/h_s(@ 5)	h_t/h_s(@ 7)
133	178	1.405	250.09	4.22	8.60%	84	0.37	14870.5	5.57	72276	1.0167	60.26	85.583	1.00012	0.9914	1.2311	1.3048
172	175	1.415	247.625	4.42	-1.93%	90.96	0.39	16877.9	5.08	91414.7	1.0153	59.94	92.519	1.000328	0.9753	1.3073	1.2751
1163	175	1.39	243.25	4.47	24.87%	79.72	0.28	14952	5.91	71081.6	1.0203	49.54	81.48	0.9987587	1.0712	1.1989	1.2534
1181	185	1.479	273.615	4.43	19.64%	78.3	0.34	14569.2	6.02	65791	1.0202	56.33	80.049	0.9982309	1.1017	1.1846	1.2726
CASE 4: MEDIUM POWER/LOW FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_s(@ 6)	h_t/h_s(@ 5)	h_t/h_s(@ 7)
138	340	2.67	907.8	0.82	-1.54%	91.8	7.72	3305.9	4.78	1220175	1.171	20.28	121.507	1.141801	0.2827	0.331	0.2915
194	344	2.72	935.68	0.61	7.29%	78.45	9.74	2140.7	5.6	904194.4	1.2205	17.9	115.412	1.220107	0.2038	0.2648	0.1141
180	325	2.6	845	0.72	8.77%	96.45	7.36	3043.8	4.53	1348410	1.1575	19.41	124.999	1.136132	0.2612	0.3195	0.268
183	325	2.58	838.5	0.69	8.93%	94.64	7.66	2846.1	4.62	1280594	1.1598	19.38	123.949	1.146406	0.2417	0.3211	0.233
CASE 5: MEDIUM POWER/MEDIUM FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_s(@ 6)	h_t/h_s(@ 5)	h_t/h_s(@ 7)
137	340	2.67	907.8	2.37	-6.30%	92.25	2.77	9316.9	4.92	442842.5	1.0671	51.38	99.506	0.994325	1.1124	1.1933	1.2666
178	325	2.58	838.5	2.49	-1.64%	90.99	2.35	9628.1	5.01	385625.2	1.0622	51.14	97.525	0.9947262	1.1116	1.2075	1.263
1186	355	2.8	994	2.36	-2.29%	78.51	2.95	7920.3	5.89	305847.1	1.0874	48.09	86.877	0.9917784	1.1226	1.1579	1.2133
2101	345	2.69	928.05	1.9495	-8.93%	77.37	3.55	6478.3	5.95	342987.2	1.1024	39.15	87.37	0.996414	1.0459	1.1102	1.1432
CASE 6: MEDIUM POWER/HIGH FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_s(@ 6)	h_t/h_s(@ 5)	h_t/h_s(@ 7)
136	340	2.67	907.8	4.22	-4.26%	91.27	1.54	16286.4	5.02	267314.9	1.0433	80.18	95.656	0.9925278	1.222	1.329	1.4513
174	335	2.65	887.75	4.33	-0.99%	85.64	1.42	15661.4	5.41	223460.7	1.0467	75.44	90.127	0.9931827	1.1828	1.3217	1.3901
1184	345	2.7	931.5	4.426	-4.08%	78.96	1.5	14789.8	5.91	185128.3	1.0535	73.8	83.767	0.989578	1.2439	1.2454	1.3815

TABLE XIV (Continued)

Summary of Test Runs Ordered by Case Number

CASE 7: HIGH POWER/LOW FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re$_{SL}$	Pr$_L$	Gr	u_b/u_w	Nu$_{Exp}$	Tw$_A$	Tw$_A$/Tw$_C$	h_f/h_o(@ 6)	h_f/h_o(@ 5)	h_f/h_o(@ 7)
192	488	3.9	1903.2	0.91	2.75%	74.11	13.92	3117.1	5.76	1389924	1.3841	21.75	133.754	1.313446	0.2597	0.306	0.2524
196	488	3.92	1912.96	0.54	12.50%	82.17	21.12	2126	4.92	2107439	1.3331	22.3	149.788	1.376267	0.1583	0.1902	0.0872
1116	488	3.9	1903.2	0.83	3.18%	81.08	16.16	3121.6	5.2	1849314	1.3547	22.03	142.428	1.319377	0.2272	0.2745	0.22
1117	481	3.87	1861.47	0.82	1.86%	91.46	15.02	3446.9	4.57	2484096	1.304	22.83	150.324	1.290134	0.2139	0.263	0.211
1118	489	3.93	1921.77	0.76	0.75%	79.02	17.2	2818	5.27	2188130	1.4433	18.13	165.923	1.545824	0.1001	0.1418	0.0441
1119	485	3.915	1898.775	0.72	0.98%	88.33	17.9	2972.4	4.66	3111049	1.4143	17.62	179.472	1.56115	0.0731	0.1049	0.0299
1124	465	3.76	1748.4	0.84	1.09%	88.16	14.13	3384	4.79	4365050	1.6566	10.85	220.635	1.9973	0.001	0.0258	0.0065
1132	469	3.74	1754.06	0.82	0.42%	81.71	14.6	3084	5.18	1752949	1.3302	21.69	139.599	1.305986	0.2211	0.2677	0.1939
CASE 8: HIGH POWER/MEDIUM FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re$_{SL}$	Pr$_L$	Gr	u_b/u_w	Nu$_{Exp}$	Tw$_A$	Tw$_A$/Tw$_C$	h_f/h_o(@ 6)	h_f/h_o(@ 5)	h_f/h_o(@ 7)
188	485	3.81	1847.85	2.47	-0.39%	84.69	5.16	9051	5.33	682513.1	1.1378	54.29	98.771	0.9899283	1.1012	1.1715	1.2557
190	490	3.89	1906.1	2.61	-0.11%	91.16	5.22	9897.2	4.91	829130.3	1.1256	57.73	104.78	0.990786	1.1018	1.1789	1.2582
CASE 9: HIGH POWER/HIGH FLOW RATE																	
RUN#	*Current (A)*	*Voltage (V)*	*Power (W)*	*F.R. (gpm)*	*Hbal Error*	Tbulkin (°F)	Delta TB	Re$_{SL}$	Pr$_L$	Gr	u_b/u_w	Nu$_{Exp}$	Tw$_A$	Tw$_A$/Tw$_C$	h_f/h_o(@ 6)	h_f/h_o(@ 5)	h_f/h_o(@ 7)
185	490	3.84	1881.6	4.31	-5.01%	73.98	5.64	14680	5.79	354060.7	1.0953	83.37	88.431	0.9809693	1.2649	1.3536	1.4445
199	485	3.83	1857.55	4.3	-4.90%	88.88	3.11	16315.6	5.12	493873.4	1.0861	83.84	97.447	0.9833049	1.2635	1.3507	1.4477

TABLE XV

Summary of Good Test Runs

RUN#	Current (A)	Voltage (V)	Power (W)	F.R. (gpm)	Hbal Error	Tbulkin (°F)	Delta TB	Re_{SL}	Pr_L	Gr	u_b/u_w	Nu_{Exp}	Tw_A	Tw_A/Tw_C	h_t/h_b(@ 6)	h_t/h_b(@ 5)	h_t/h_b(@ 7)
134	178	1.405	250.09	2.37	1.17%	88.5	0.73	8820.3	5.24	124269.8	1.0231	42	90.863	0.9998882	1.006	1.2105	1.2422
135	178	1.405	250.09	0.83	-1.92%	88.82	2.1	3127.2	5.16	311107.8	1.0554	17.48	95.657	1.016588	0.6431	0.6741	0.7697
136	340	2.67	907.8	4.22	-4.26%	91.27	1.54	16286.4	5.02	267314.9	1.0433	80.18	95.656	0.9925278	1.222	1.329	1.4513
137	340	2.67	907.8	2.37	-5.30%	92.25	2.77	9316.9	4.92	442842.5	1.0671	51.38	99.506	0.994325	1.1124	1.1933	1.2666
174	335	2.65	887.75	4.33	-0.99%	85.64	1.42	15661.4	5.41	223460.7	1.0467	75.44	90.127	0.9931827	1.1828	1.3217	1.3901
178	325	2.58	838.5	2.49	-1.64%	90.99	2.35	9628.1	5.01	385625.2	1.0622	51.14	97.525	0.9947262	1.1116	1.2075	1.263
185	490	3.84	1881.6	4.31	-5.01%	73.98	5.64	14680	5.79	354050.7	1.0953	83.37	88.431	0.9809693	1.2649	1.3536	1.4445
188	485	3.81	1847.85	2.47	-0.39%	84.69	5.15	9051	5.33	682513.1	1.1378	54.29	98.771	0.9899283	1.1012	1.1715	1.2557
190	490	3.89	1906.1	2.51	-0.11%	91.16	5.22	9897.2	4.91	829130.3	1.1255	57.73	104.78	0.990786	1.1018	1.1789	1.2582
1115	178	1.4	249.2	0.82	1.62%	84.96	2.05	2954.5	5.43	253682.5	1.0539	18.52	90.918	1.006622	0.8368	1.3982	0.7441
1155	175	1.38	241.5	0.959	4.92%	80.15	1.64	3254.4	5.81	195665.3	1.053	18.95	85.461	1.003332	0.915	1.149	1.0997
1159	175	1.39	243.25	1.0044	2.96%	80.66	1.61	3428.9	5.77	194144	1.0513	19.5	85.791	1.002131	0.9434	1.2194	1.0934
1167	175	1.395	244.125	1.2428	3.57%	80.09	1.3	4181.8	5.83	164813.1	1.0452	22.26	84.531	1.001922	0.9445	1.0474	1.0568
1169	190	1.52	288.8	1.3012	5.26%	80.33	1.44	4419.4	5.81	183739.9	1.0496	23.85	85.199	1.00143	0.9622	1.046	1.0741
1173	215	1.72	369.8	1.5093	8.81%	79.16	1.53	5053.5	5.9	186200.1	1.0532	28.75	84.258	1	1	1.1019	1.1149
1175	218	1.72	374.96	1.5173	6.64%	79.5	1.58	5106.5	5.87	192733.2	1.0541	29.01	84.721	0.9997609	1.0056	1.0809	1.1073
1177	178	1.42	252.76	2.14	11.03%	78.9	0.72	7103.2	5.95	100279.5	1.0296	35.45	81.644	0.999379	1.0259	1.1065	1.2153
1179	205	1.64	336.2	2.38	6.88%	78.71	0.9	7901.9	5.96	115319.2	1.0342	40.74	81.872	0.9977759	1.0798	1.1476	1.2338
1184	345	2.7	931.5	4.426	-4.08%	78.96	1.5	14789.8	5.91	185128.3	1.0535	73.8	83.767	0.989578	1.2439	1.2454	1.3615
1186	355	2.8	994	2.36	-2.29%	78.51	2.95	7920.3	5.89	305847.1	1.0874	48.09	86.877	0.9917784	1.1226	1.1579	1.2133
1191	180	1.422	255.96	2.3638	0.03%	77.96	0.74	7761.7	6.03	90842.3	1.0281	38.43	80.559	0.9989954	1.0427	1.1713	1.1934
1193	180	1.417	255.06	2.3908	2.99%	77.84	0.71	7837.1	6.04	90955.4	1.0283	38.16	80.459	0.9993711	1.0263	1.1636	1.1772
2101	345	2.69	928.05	1.9495	-8.93%	77.37	3.55	6478.3	5.95	342987.2	1.1024	39.15	87.37	0.996414	1.0459	1.1102	1.1432
2103	236	1.835	433.06	1.91	-1.31%	77.03	1.57	6245	6.07	155603.8	1.0496	37.81	81.772	0.9987625	1.0305	1.1287	1.1689
2105	220	1.718	377.96	1.9045	0.00%	77.09	1.36	6212.9	6.08	140629.5	1.0449	36.26	81.365	0.9995025	1.0134	1.1323	1.1654
2111	205	1.585	324.925	1.5487	0.76%	76.29	1.43	5002.2	6.14	139951.2	1.0465	30.58	80.733	1.000628	0.9835	1.1026	1.1174
4101	178	1.4	249.2	1.06702	0.52%	76.16	0.99	3446.1	6.15	154940.9	1.0517	20.79	81.216	1.003506	0.9124	1.0264	1.0425
4103	209	1.6355	341.8195	1.7289	0.51%	76.96	1.35	5630.5	6.09	135358.5	1.0435	33.79	81.123	0.9998752	1.0034	1.1124	1.1334
4105	233	1.82	424.06	2.2075	1.90%	77.31	1.29	7217.6	6.06	136622	1.0432	42.2	81.36	0.9975127	1.0707	1.1503	1.1822
4107	250	1.9405	485.125	2.8005	-1.23%	77.12	1.2	9129.2	6.08	129548.6	1.0414	50.7	80.932	0.9957597	1.1242	1.1423	1.2219
4109	270	2.118	571.86	3.27551	3.01%	76.78	1.16	10629.5	6.11	129037.5	1.0421	58.42	80.6	0.9953678	1.1318	1.1942	1.2681
4115	480	3.78	1814.4	3.2817	-3.76%	76.07	5.41	7888.4	5.98	513590.6	1.1571	50.16	91.093	0.9885443	1.1004	1.1297	1.1818
4117	480	3.79	1819.2	2.1037	-8.10%	76	6.28	7003	5.94	581666.9	1.1748	45.12	93.208	0.9957708	1.0333	1.0633	1.1103
4119	481	3.8	1827.8	2.2553	-6.54%	76.05	5.91	7493.4	5.96	542370.6	1.164	48.24	92.019	0.9919035	1.0678	1.101	1.1545
4121	483	3.81	1840.23	2.3089	-6.50%	76.46	5.81	7705	5.93	539382.4	1.16	49.66	92.037	0.9903883	1.0826	1.1073	1.1606
4123	483	3.81	1840.23	2.3981	-5.07%	77.54	5.52	8093	5.85	542991.7	1.1535	51.29	92.506	0.9895763	1.0932	1.1244	1.1786
4128	474	3.72	1763.28	2.4204	-6.05%	78.17	5.29	8218.3	5.81	541271.1	1.1491	50.6	92.716	0.9897072	1.0947	1.14	1.1788
4130	490	3.9	1911	2.389	-8.13%	76.02	5.92	7935.2	5.96	555041.3	1.1681	48.88	92.236	0.9901932	1.0809	1.1263	1.1932
4132	380	3	1140	3.3751	-4.71%	75.21	2.42	10833.5	6.19	237237.3	1.0817	60.64	82.528	0.9868988	1.2055	1.2198	1.2908
4134	390	3.07	1197.3	3.3795	-6.85%	74.97	2.59	10828.1	6.2	242665.4	1.0843	62.04	82.583	0.9872658	1.1927	1.2087	1.2928
4136	265	2.05	543.25	3.2368	-1.89%	75.14	1.17	10290.5	6.26	117065.8	1.0417	57.59	78.906	0.9957787	1.1198	1.187	1.2578
4138	275	2.15	591.25	3.2368	-2.14%	74.59	1.28	10224.5	6.3	125203.7	1.0458	56.69	78.715	0.9953847	1.1198	1.1845	1.2628
4141	280	2.2	616	3.397	-3.16%	74.96	1.28	10783.6	6.27	126363.7	1.0453	59.25	79.028	0.9946408	1.1414	1.207	1.2731

TABLE XVI

Correlation Comparison with Good Test Runs

		Gnielinski [3]	Fractional	Gnielinski	Gnielinski [1]	Fractional	Gnielinski [2]	Fractional	Colburn	Fractional	Sieder & Tate	Fractional	Ghajar et al.	Fractional
RUN#	Nu_{Exp}	Nu_{Cal}	Difference	f	Nu_{Cal}	Difference	Nu_{Cal}	Difference	Nu_{Cal}	Difference	Nu_{Cal}	Difference	Nu_{Cal}	Difference
134	42	56.5034924	0.3453212	0.0081544	63.39392115	0.5093791	55.35125478	0.317887	57.26531	0.3634598	57.4486925	0.367826	61.260563	0.4585848
135	17.48	18.9339037	0.0831753	0.0112319	21.32813714	0.2201451	21.67324915	0.2398884	24.854342	0.4218731	25.0426714	0.4326471	26.6831	0.5264931
136	80.18	99.2145721	0.237398	0.006895	108.399919	0.3519571	91.45309301	0.1405973	92.205286	0.1499786	92.7540984	0.1568234	98.68963	0.230851
137	51.38	58.0964173	0.1307205	0.0080284	65.10454779	0.2671185	56.57252298	0.1010612	58.586832	0.1402653	59.1219479	0.1506802	62.839924	0.2230425
174	75.44	98.5860385	0.3068139	0.0069663	107.9065343	0.4303623	91.19763638	0.2088764	91.620233	0.2144782	92.2075539	0.2222634	98.488097	0.3055156
178	51.14	60.4017142	0.1811051	0.0079542	67.5751287	0.3213752	58.61047936	0.146079	60.511728	0.1832563	61.0250907	0.1932947	64.923527	0.2695254
185	83.37	95.3826913	0.1440889	0.0070868	104.6606243	0.2553751	88.76205782	0.0646762	88.988701	0.0673948	90.1300269	0.0810846	96.6073	0.1587777
188	54.29	58.3311348	0.0744361	0.0080946	65.35728689	0.203855	56.97990522	0.049547	58.793253	0.0829481	59.8655147	0.1026987	63.893942	0.1769007
190	57.73	61.5249867	0.0657368	0.0078928	68.76890496	0.1912161	59.52626276	0.0311149	61.44665	0.0643799	62.4721684	0.0821439	66.393849	0.1500753
1115	18.52	18.0735027	-0.024109	0.0114487	20.19955483	0.0906887	20.9500943	0.1312146	24.157295	0.3043896	24.3354972	0.3140117	25.99802	0.4037808
1155	18.95	20.7946168	0.0973413	0.0110834	23.33920505	0.2316203	23.60338198	0.2455611	26.695002	0.4087072	26.8887077	0.4189292	28.826224	0.5211727
1159	19.5	22.0161971	0.1290357	0.0108933	24.80021674	0.271806	24.72671912	0.2680369	27.770069	0.4241061	27.9652493	0.4341154	29.969638	0.5369045
1167	22.26	27.5570089	0.2379609	0.0102137	31.24099946	0.4034591	29.84805216	0.3408828	32.861889	0.4672906	32.864665	0.4764	35.239046	0.5830658
1169	23.85	29.2090781	0.2246993	0.0100358	33.14315178	0.38965	31.34991766	0.314462	34.099174	0.4297348	34.3310588	0.4394574	36.804847	0.5431802
1173	28.75	33.870879	0.1781175	0.009623	38.41523549	0.3361821	35.60760983	0.2385256	38.155076	0.3271331	38.4329607	0.3367986	41.235055	0.4342628
1175	29.01	34.1722825	0.1779484	0.009592	38.76247917	0.3361765	35.86932002	0.2364467	38.409549	0.3240106	38.6939138	0.333813	41.504101	0.4306826
1177	35.45	48.0656599	0.3558719	0.0086825	54.15921273	0.5277634	48.28085654	0.3619424	50.241592	0.4172522	50.4471908	0.4230519	54.148831	0.5274705
1179	40.74	53.4366588	0.3116509	0.0084164	60.0152448	0.4731282	53.00136085	0.3009661	54.742986	0.3437159	55.0013202	0.350057	59.042249	0.4492452
1184	73.8	96.8385318	0.3121752	0.0070727	106.211903	0.4391857	90.0545246	0.220251	90.135008	0.2213416	90.795085	0.2302857	97.423355	0.3200997
1186	48.09	53.3062848	0.1084692	0.0084107	59.88255538	0.2452185	52.85782409	0.0991438	54.629376	0.135982	55.2739811	0.1493862	59.298734	0.2330783
1191	38.43	52.7506122	0.3726415	0.0084602	59.25995473	0.5420233	52.42987765	0.3642955	54.175021	0.4097065	54.3856144	0.4151864	58.416539	0.5200765
1193	38.16	53.2896895	0.3964803	0.0084365	59.84484973	0.5682613	52.90608619	0.3864278	54.625798	0.4314937	54.8396368	0.4370974	58.909255	0.5437436
2101	39.15	43.8371142	0.1197219	0.0089228	49.51266087	0.2646912	44.54169416	0.1377189	46.673353	0.1921674	47.3147436	0.2085503	50.786535	0.2972295
2103	37.81	42.5838068	0.1262578	0.0090213	48.1046552	0.2722733	43.47330992	0.1497834	45.626451	0.2067297	45.9367242	0.2149358	49.358296	0.3054297
2105	36.26	42.3902939	0.1690649	0.0090353	47.88849281	0.3206975	43.30484342	0.1942869	45.463673	0.2538244	45.7440889	0.2615579	49.155493	0.3556396
2111	30.58	34.0498995	0.1134696	0.0096535	38.55744042	0.2608712	35.84999209	0.1723346	38.351245	0.2541284	38.5960589	0.262134	41.495441	0.356947
4101	20.79	22.7139454	0.0925419	0.0108754	25.50655753	0.2268666	25.48515352	0.2258371	28.480559	0.3699163	28.6822602	0.3796181	30.839498	0.4833814
4103	33.79	38.3689009	0.1355105	0.0093085	43.4169291	0.2849047	39.71818202	0.1754419	42.044046	0.2442748	42.2954303	0.2517144	45.453507	0.3451763
4105	42.2	49.1935675	0.1657243	0.0086418	55.37553734	0.3122165	49.31816317	0.1686769	51.199567	0.2132599	51.5036197	0.2204649	55.335125	0.3112589
4107	50.7	61.9991263	0.2228625	0.0080749	69.25979377	0.3660709	60.50616361	0.1934155	61.855056	0.2200208	62.2073451	0.2269693	66.84651	0.3184716
4109	58.42	71.8946257	0.2306509	0.007737	79.85988076	0.3669956	69.04426235	0.18186	69.97644	0.1978165	70.3816035	0.2047519	75.649606	0.2949265
4115	50.16	53.4185589	0.0649633	0.0084205	59.99296417	0.196032	52.99390026	0.0564972	54.729234	0.0910932	55.8587606	0.1136117	59.973065	0.1956353
4117	45.12	47.3591225	0.0496259	0.0087189	53.38682254	0.1832186	47.65380157	0.0561569	49.645964	0.1003095	50.7783873	0.1254075	54.499593	0.207881
4119	48.24	50.7153865	0.051314	0.0085474	57.05313579	0.1826935	50.61610524	0.0492559	52.467019	0.0876248	53.5944485	0.110996	57.532015	0.1926205
4121	49.66	52.0222154	0.0475678	0.0084783	58.48116885	0.1776313	51.75024601	0.0420911	53.558801	0.0785099	54.6833317	0.1011545	58.685595	0.1817478
4123	51.29	54.2972609	0.0586325	0.0083584	60.96291752	0.1885927	53.70699199	0.047124	55.454155	0.0811884	56.5739568	0.1030212	60.672002	0.1829207
4128	50.6	54.9684861	0.0863337	0.0083214	61.69490129	0.2192668	54.27566937	0.0726417	56.011707	0.1069507	57.1122015	0.1286996	61.227527	0.2100302
4130	48.88	53.6576725	0.0977429	0.0084061	60.25533262	0.2327196	53.19489895	0.0882713	54.927465	0.1237206	56.1353922	0.1484327	60.259641	0.2328077
4132	60.64	73.5910544	0.2135728	0.0076963	81.66719938	0.3467546	70.53602384	0.163193	71.35752	0.1767401	72.1464066	0.1897494	77.59864	0.2796609
4134	62.04	73.6036283	0.1863899	0.0076973	81.68039186	0.3165763	70.55166512	0.1371964	71.367454	0.1503458	72.1807067	0.1634543	77.642007	0.251483
4136	57.59	70.3824338	0.2221294	0.0078072	78.23953325	0.3585611	67.81875456	0.1776134	68.738776	0.1935888	69.1330581	0.2004351	74.400781	0.2919045
4138	56.69	70.128924	0.2370599	0.0078212	77.96636565	0.3753107	67.61973394	0.1927983	68.531202	0.2088764	68.9622081	0.2164792	74.241341	0.3096021
4141	59.25	73.6454504	0.2429612	0.0077061	81.72318734	0.3792943	70.6214483	0.1919232	71.399422	0.2050535	71.8436572	0.2125512	77.324296	0.3050514

B.2 Sample Input/Output Data File for Program RHt98F

A sample input/output file is given in this appendix. All of the data in the input/output file is explained carefully in this appendix. The sample input/output file discussed here is for run 1114. The complete data set and results for all the good test runs are given in section B.4 of this appendix, further information about these test runs can be obtained from:

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The files output by Datared98F are an essential input for the RHt98F program. Table XVII illustrates the input in its raw form, and lines one and two appear as follows:

```
1114 10
 1  .00   .8200  175.00    1.40   86.82   88.85   80.54
```

where the above numbers correspond to the following:

Run	1114
Total number of thermocouple stations used	10
Fluid index (1=water, 2=ethylene glycol)	1
Mass concentration of ethylene glycol (not used in this case)	0.00

Flow rate in gpm	0.8200
Current carried by the test section (amps)	175
Voltage drop across the test tube (volts)	1.40
Inlet bulk temperature (°F)	86.82
Exit bulk temperature (°F)	88.85
Room temperature (°F)	80.54

The origin of the above numbers is described in the Data Reduction section of Chapter III. All subsequent lines appear as below:

```
 1  4    7.00   90.36   90.28   90.30   90.25
 2  4   17.00   92.39   91.64   91.20   91.72
 3  4   27.00   93.96   92.26   91.95   92.36
 4  4   37.00   94.70   92.55   91.99   92.78
 5  4   47.00   94.75   92.91   92.56   93.21
 6  4   57.00   99.26   93.50   92.59   93.87
 7  4   67.00   94.16   93.51   93.23   93.57
 8  4   77.00   93.33   92.79   92.59   93.25
 9  4   87.00   92.62   93.74   93.86   93.59
10  4   97.00   93.66   93.77   94.34   92.92
```

The first column designates the station number. Column two indicates the number of thermocouple locations used at the designated station. Column three gives the length (in inches) from the beginning of the test section at each station, and columns four through seven are the outside wall thermocouple readings (at A, B, C, and D stations, respectively) for run 1114 in this example. They correspond to the thermocouple locations as illustrated in Fig. 2.4.

The data in Table XVII is the only input necessary for executing RHt98F. This input file is created by Datared98F, and is given the name rn1114.DAT by the same program automatically. A sample output for this run is given in Table XVIII. RHt98F creates the output file named rn1114.HTI. Complete listings of the programs Datared98F and RHt98F are given in Appendix C.

TABLE XVII

Sample Input Data File (rn1114.DAT) for RHt98F Program

```
1114 10

 1  .00   .8200  175.00     1.40    86.82    88.85    80.54

  1  4     7.00   90.36    90.28    90.30    90.25
  2  4    17.00   92.39    91.64    91.20    91.72
  3  4    27.00   93.96    92.26    91.95    92.36
  4  4    37.00   94.70    92.55    91.99    92.78
  5  4    47.00   94.75    92.91    92.56    93.21
  6  4    57.00   99.26    93.50    92.59    93.87
  7  4    67.00   94.16    93.51    93.23    93.57
  8  4    77.00   93.33    92.79    92.59    93.25
  9  4    87.00   92.62    93.74    93.86    93.59
 10  4    97.00   93.66    93.77    94.34    92.92
```

TABLE XVIII

Sample Output File (rn1114.HTI) from RHt98F Program

```
        *----------------------------------------*
                     RUN NUMBER 1114
               TEST FLUID IS DISTILLED WATER
        *----------------------------------------*

        VOLUMETRIC FLOW RATE =        .82    GPM
        MASS FLOW RATE       =      408.7    LBM/HR
        MASS FLUX            =      62265    LBM/(SQ.FT-HR)
        FLUID VELOCITY       =        .28    FT/S
        ROOM TEMPERATURE     =      80.54    F
        INLET TEMPERATURE    =      86.82    F
        OUTLET TEMPERATURE   =      88.85    F
        AVERAGE RE NUMBER    =       3015
        AVERAGE PR NUMBER    =       5.31
        CURRENT TO TUBE      =      175.0    AMPS
        VOLTAGE DROP IN TUBE =       1.40    VOLTS
        AVERAGE HEAT FLUX    =        337    BTU/(SQ.FT-HR)
        Q=AMP*VOLT           =        835    BTU/HR
        Q=M*C*(T2-T1)        =        828    BTU/HR
        HEAT BALANCE ERROR   =        .95    %


          OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    90.36   92.39   93.96   94.70   94.75   99.26   94.16   93.33   92.62   93.66
 2    90.28   91.64   92.26   92.55   92.91   93.50   93.51   92.79   93.74   93.77
 3    90.30   91.20   91.95   91.99   92.56   92.59   93.23   92.59   93.86   94.34
 4    90.25   91.72   92.36   92.78   93.21   93.87   93.57   93.25   93.59   92.92


          INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    90.18   92.22   93.80   94.55   94.59   99.15   93.99   93.15   92.43   93.48
 2    90.10   91.46   92.07   92.36   92.72   93.29   93.33   92.61   93.57   93.59
 3    90.12   91.01   91.76   91.80   92.37   92.39   93.05   92.40   93.68   94.17
 4    90.07   91.54   92.17   92.59   93.02   93.66   93.39   93.07   93.41   92.72


          REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1     3098    3170    3227    3254    3256    3423    3234    3204    3178    3216
 2     3095    3143    3165    3175    3188    3209    3210    3184    3219    3220
 3     3095    3127    3154    3155    3176    3177    3200    3177    3223    3241
 4     3094    3146    3169    3184    3199    3222    3212    3201    3213    3189


            INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1      310     295     272     262     271     175     298     305     339     305
 2      314     317     330     333     332     374     318     317     301     319
 3      312     325     322     330     325     341     321     324     308     288
 4      314     315     328     327     324     365     316     306     304     340
```

TABLE XVIII (Continued)

```
-----------------------------------------------------------------------------
                              *---------------*
                              RUN NUMBER 1114
                              *---------------*

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

          1       2       3       4       5       6       7       8       9      10

  1      96      58      42      37      39      15      50      63      86      64
  2      99      73      69      69      66      69      61      74      59      65
  3      98      84      72      77      70      76      65      79      59      52
  4     101      71      68      64      61      63      60      64      62      84


                              *---------------*
                              RUN NUMBER 1114
                                  SUMMARY
                              *---------------*

 ST      RE        PR      X/D     MUB      MUW      TB       TW      DENS      NU

  1   2984.17    5.37      6.4   1.907    1.839    86.96    90.12    62.14    25.53
  2   2991.02    5.36     15.5   1.903    1.809    87.15    91.56    62.14    18.33
  3   2997.88    5.34     24.6   1.899    1.790    87.35    92.45    62.14    15.82
  4   3004.74    5.33     33.7   1.894    1.783    87.54    92.82    62.14    15.29
  5   3011.61    5.31     42.8   1.890    1.776    87.74    93.18    62.13    14.85
  6   3018.48    5.30     52.0   1.886    1.747    87.93    94.62    62.13    12.08
  7   3025.36    5.29     61.1   1.881    1.771    88.13    93.44    62.13    15.21
  8   3032.24    5.27     70.2   1.877    1.783    88.32    92.81    62.13    17.98
  9   3039.14    5.26     79.3   1.873    1.774    88.52    93.27    62.13    16.97
 10   3046.03    5.25     88.4   1.869    1.770    88.71    93.49    62.12    16.88

                      NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                            MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
```

APPENDIX B

B.3 Equation for Power Input/Flow Rate

The equation given in this appendix helps to identify the kind of power input (watts) to be used for a particular flow rate (gpm). Here only two parameters are controllable, they are flow rate and current input. So, for a specific flow rate, the necessary operating power input is taken from Eq. (4.4). Based on the power input, the current is adjusted to get the desired power. The following equations were developed based on the heat balance error and flow rates from runs 2103, 2105, 2111, and 4101. The power input for any flow rate is calculated based on the equation:

$$\text{Hin (watts)} = (\text{F.R. (in gpm)} + 0.6686)/0.0068 \tag{B.1}$$

The frequency is adjusted in order to obtain a particular flow rate based on the calibration equation:

$$\text{Frq (Hz)} = (\text{F.R. (in gpm)} + 0.0091064)/0.0045026 \tag{B.2}$$

B.4 Test Run Outputs

This appendix presents the output files from program RHt98F of the all of the 43 good test runs discussed in Appendix B.1. Each output file was compressed to fit on a single page.

```
                        *---------------------------------------*
                                    RUN NUMBER  134
                              TEST FLUID IS DISTILLED WATER
                        *---------------------------------------*

                        VOLUMETRIC FLOW RATE -      2.37   GPM
                        MASS FLOW RATE       -    1180.9   LBM/HR
                        MASS FLUX            -    179910   LBM/(SQ.FT-HR)
                        FLUID VELOCITY       -       .80   FT/S
                        ROOM TEMPERATURE     -     82.10   F
                        INLET TEMPERATURE    -     88.50   F
                        OUTLET TEMPERATURE   -     89.23   F
                        AVERAGE RE NUMBER    -      8816
                        AVERAGE PR NUMBER    -      5.24
                        CURRENT TO TUBE      -     178.0   AMPS
                        VOLTAGE DROP IN TUBE -      1.40   VOLTS
                        AVERAGE HEAT FLUX    -       343   BTU/(SQ.FT-HR)
                        Q-AMP*VOLT           -       850   BTU/HR
                        Q-M*C*(T2-T1)        -       860   BTU/HR
                        HEAT BALANCE ERROR   -     -1.17   %

                          OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1     90.44   90.63   90.66   90.81   90.81   91.05   91.08   91.28   91.72   91.88
 2     90.31   90.65   90.71   90.75   90.91   91.08   91.18   91.29   91.84   92.06
 3     90.44   90.50   90.80   90.65   91.13   91.06   91.47   91.54   92.34   92.71
 4     90.33   90.60   90.65   90.86   90.96   91.09   91.13   91.70   91.80   91.08

                          INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1     90.25   90.44   90.47   90.62   90.62   90.86   90.89   91.09   91.53   91.70
 2     90.12   90.46   90.52   90.56   90.72   90.89   90.99   91.10   91.65   91.87
 3     90.25   90.31   90.61   90.46   90.95   90.87   91.29   91.35   92.16   92.54
 4     90.14   90.41   90.46   90.68   90.77   90.90   90.94   91.52   91.61   90.88

                          REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

 1      8959    8978    8981    8997    8996    9021    9024    9045    9090    9108
 2      8945    8980    8986    8990    9007    9024    9035    9046    9103    9125
 3      8959    8965    8996    8980    9030    9022    9065    9072    9155    9195
 4      8947    8975    8980    9002    9012    9026    9029    9089    9098    9023

                            INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

 1       320     323     324     323     326     324     325     329     326     316
 2       326     321     324     323     325     323     326     326     328     329
 3       320     326     320     327     319     324     316     322     311     295
 4       326     322     325     320     324     323     327     316     329     354

                                    *---------------*
                                     RUN NUMBER  134
                                    *---------------*

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

         1       2       3       4       5       6       7       8       9      10

 1       188     177     181     173     182     165     169     160     134     125
 2       207     174     176     179     171     162     161     158     129     122
 3       188     193     166     192     150     164     136     139     102      88
 4       204     179     183     167     166     161     166     127     131     208

                                    *---------------*
                                     RUN NUMBER  134
                                         SUMMARY
                                    *---------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1    8784.44   5.26     6.4   1.872   1.837   88.55   90.19   62.13   50.66
 2    8791.61   5.25    15.5   1.871   1.833   88.62   90.41   62.13   46.56
 3    8798.78   5.25    24.6   1.869   1.830   88.69   90.52   62.12   45.54
 4    8805.95   5.24    33.7   1.868   1.829   88.76   90.58   62.12   45.74
 5    8813.12   5.24    42.8   1.866   1.825   88.83   90.77   62.12   43.03
 6    8820.29   5.24    52.0   1.865   1.823   88.90   90.88   62.12   42.00
 7    8827.47   5.23    61.1   1.863   1.820   88.97   91.03   62.12   40.47
 8    8834.65   5.23    70.2   1.862   1.815   89.04   91.27   62.12   37.43
 9    8841.83   5.22    79.3   1.860   1.805   89.11   91.74   62.12   31.71
10    8849.01   5.22    88.4   1.859   1.805   89.18   91.75   62.12   32.48

                          NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                                MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
```

```
                  *----------------------------------------*
                              RUN NUMBER  135
                        TEST FLUID IS DISTILLED WATER
                  *----------------------------------------*

                  VOLUMETRIC FLOW RATE -       .83    GPM
                  MASS FLOW RATE       -     413.5    LBM/HR
                  MASS FLUX            -     63003    LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -       .28    FT/S
                  ROOM TEMPERATURE     -     82.68    F
                  INLET TEMPERATURE    -     88.82    F
                  OUTLET TEMPERATURE   -     90.92    F
                  AVERAGE RE NUMBER    -      3123
                  AVERAGE PR NUMBER    -      5.17
                  CURRENT TO TUBE      -     178.0    AMPS
                  VOLTAGE DROP IN TUBE -      1.40    VOLTS
                  AVERAGE HEAT FLUX    -       343    BTU/(SQ.FT-HR)
                  Q-AMP*VOLT           -       850    BTU/HR
                  Q-M*C*(T2-T1)        -       866    BTU/HR
                  HEAT BALANCE ERROR   -     -1.92    %

                    OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    92.41   94.06   95.36   95.99   95.80   95.83   95.59   95.93   96.65   96.92
 2    92.21   93.50   94.02   94.31   94.57   94.74   94.85   95.08   95.81   96.13
 3    92.27   93.13   93.78   93.83   94.38   94.29   94.69   94.82   95.89   96.53
 4    92.22   93.54   94.16   94.54   94.83   94.85   94.88   95.55   95.94   95.39

                    INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    92.23   93.88   95.19   95.82   95.63   95.66   95.41   95.75   96.47   96.75
 2    92.02   93.31   93.83   94.12   94.38   94.55   94.66   94.89   95.62   95.94
 3    92.08   92.94   93.59   93.64   94.19   94.10   94.50   94.63   95.70   96.35
 4    92.03   93.35   93.97   94.35   94.64   94.66   94.69   95.37   95.75   95.19

                    REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1    3208    3269    3317    3340    3333    3334    3325    3337    3364    3374
 2    3201    3248    3267    3277    3287    3293    3297    3305    3332    3344
 3    3203    3234    3258    3260    3280    3276    3291    3296    3335    3359
 4    3201    3249    3272    3286    3296    3297    3298    3323    3337    3316

                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1     319     311     293     285     297     298     306     309     305     296
 2     327     326     338     339     337     332     331     332     336     339
 3     322     334     332     339     332     337     329     337     324     305
 4     327     325     334     333     331     329     331     320     333     358

                              *---------------*
                               RUN NUMBER  135
                              *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      97      65      50      45      50      52      58      57      51      49
 2     107      78      75      74      73      72      74      73      66      65
 3     103      88      78      83      75      81      76      79      63      54
 4     106      77      72      69      68      70      73      64      64      81

                              *---------------*
                               RUN NUMBER  135
                                   SUMMARY
                              *---------------*

ST     RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   3090.98   5.23    6.4   1.863   1.798   88.96   92.09   62.12   26.64
 2   3098.22   5.22   15.5   1.859   1.772   89.16   93.37   62.12   19.82
 3   3105.46   5.20   24.6   1.855   1.757   89.37   94.14   62.12   17.46
 4   3112.70   5.19   33.7   1.850   1.750   89.57   94.48   62.11   16.98
 5   3119.96   5.18   42.8   1.846   1.746   89.77   94.71   62.11   16.89
 6   3127.22   5.16   52.0   1.842   1.745   89.97   94.74   62.11   17.48
 7   3134.48   5.15   61.1   1.837   1.744   90.17   94.82   62.11   17.96
 8   3141.76   5.14   70.2   1.833   1.737   90.37   95.16   62.11   17.43
 9   3149.04   5.12   79.3   1.829   1.723   90.58   95.89   62.10   15.71
10   3156.32   5.11   88.4   1.825   1.720   90.78   96.06   62.10   15.80

                 NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                       MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
```

```
            *-----------------------------------------*
                        RUN NUMBER  136
                  TEST FLUID IS DISTILLED WATER
            *-----------------------------------------*

            VOLUMETRIC FLOW RATE -      4.22   GPM
            MASS FLOW RATE       -    2101.6   LBM/HR
            MASS FLUX            -    320187   LBM/(SQ.FT-HR)
            FLUID VELOCITY       -      1.42   FT/S
            ROOM TEMPERATURE     -     82.92   F
            INLET TEMPERATURE    -     91.27   F
            OUTLET TEMPERATURE   -     92.81   F
            AVERAGE RE NUMBER    -     16272
            AVERAGE PR NUMBER    -      5.03
            CURRENT TO TUBE      -     340.0   AMPS
            VOLTAGE DROP IN TUBE -      2.67   VOLTS
            AVERAGE HEAT FLUX    -      1250   BTU/(SQ.FT-HR)
            Q=AMP*VOLT           -      3097   BTU/HR
            Q=M*C*(T2-T1)        -      3229   BTU/HR
            HEAT BALANCE ERROR   -     -4.26   %

              OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1     95.33   95.56   95.75   95.97   95.99   96.34   96.43   96.70   97.26   97.52
2     95.05   95.62   95.74   95.90   96.17   96.44   96.66   96.92   97.70   98.09
3     95.74   96.07   96.27   96.18   96.98   97.05   97.83   98.11   99.05   99.53
4     95.09   95.50   95.60   95.96   96.10   96.51   96.56   97.31   97.35   96.91

              INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1     94.65   94.88   95.07   95.29   95.31   95.66   95.74   96.01   96.57   96.84
2     94.36   94.94   95.05   95.22   95.48   95.75   95.97   96.23   97.01   97.40
3     95.07   95.40   95.60   95.50   96.31   96.38   97.16   97.44   98.39   98.88
4     94.40   94.81   94.91   95.28   95.41   95.83   95.87   96.63   96.66   96.21

              REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

1     16757   16799   16834   16875   16879   16944   16961   17011   17116   17166
2     16702   16810   16832   16862   16912   16963   17003   17052   17199   17272
3     16834   16895   16933   16915   17067   17079   17228   17280   17459   17551
4     16710   16787   16805   16873   16899   16976   16984   17126   17132   17047

                INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

1      1178    1185    1183    1184    1189    1189    1191    1197    1194    1187
2      1197    1190    1192    1190    1193    1192    1198    1198    1198    1198
3      1168    1172    1170    1179    1164    1171    1155    1161    1148    1135
4      1196    1193    1195    1188    1195    1190    1200    1189    1207    1228

                          *---------------*
                           RUN NUMBER  136
                          *---------------*

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

        1       2       3       4       5       6       7       8       9      10

1       359     353     348     341     356     335     342     332     297     287
2       400     348     352     350     339     327     323     313     269     255
3       316     302     298     320     268     274     235     230     196     184
4       395     362     368     343     346     320     332     282     294     351

                          *---------------*
                           RUN NUMBER  136
                              SUMMARY
                          *---------------*

ST      RE       PR     X/D    MUB     MUW      TB      TW     DENS     NU

 1   16150.01   5.07    6.4   1.812   1.747   91.37   94.62   62.09   93.57
 2   16177.25   5.06   15.5   1.809   1.740   91.52   95.01   62.09   87.21
 3   16204.51   5.05   24.6   1.806   1.737   91.67   95.16   62.09   87.10
 4   16231.79   5.04   33.7   1.803   1.734   91.82   95.32   62.09   86.73
 5   16259.08   5.03   42.8   1.800   1.728   91.97   95.63   62.09   82.96
 6   16286.39   5.02   52.0   1.797   1.723   92.11   95.90   62.09   80.18
 7   16313.72   5.01   61.1   1.794   1.717   92.26   96.19   62.08   77.39
 8   16341.07   5.01   70.2   1.791   1.710   92.41   96.58   62.08   72.90
 9   16368.43   5.00   79.3   1.788   1.699   92.56   97.16   62.08   66.07
10   16395.81   4.99   88.4   1.785   1.696   92.71   97.33   62.08   65.72

              NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                    MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
```

```
*----------------------------------------*
              RUN NUMBER  137
       TEST FLUID IS DISTILLED WATER
*----------------------------------------*

VOLUMETRIC FLOW RATE -     2.37   GPM
MASS FLOW RATE       -   1180.1   LBM/HR
MASS FLUX            -   179788   LBM/(SQ.FT-HR)
FLUID VELOCITY       -      .80   FT/S
ROOM TEMPERATURE     -    83.24   F
INLET TEMPERATURE    -    92.25   F
OUTLET TEMPERATURE   -    95.02   F
AVERAGE RE NUMBER    -     9303
AVERAGE PR NUMBER    -     4.93
CURRENT TO TUBE      -    340.0   AMPS
VOLTAGE DROP IN TUBE -     2.67   VOLTS
AVERAGE HEAT FLUX    -     1250   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -     3097   BTU/HR
Q=M*C*(T2-T1)        -     3261   BTU/HR
HEAT BALANCE ERROR   -    -5.30   %

              OUTSIDE SURFACE TEMPERATURES - DEGREES F

      1       2       3       4       5       6       7       8       9      10

1   98.19   98.80   99.23   99.60   99.68  100.19  100.42  100.83  101.46  101.81
2   97.93   99.01   99.26   99.49   99.83  100.23  100.61  101.00  101.96  102.41
3   98.60   99.47   99.77   99.72  100.60  100.75  101.72  102.31  103.59  104.08
4   98.02   98.79   99.09   99.52   99.79  100.30  100.51  101.30  101.54  101.19

              INSIDE SURFACE TEMPERATURES - DEGREES F

      1       2       3       4       5       6       7       8       9      10

1   97.51   98.12   98.55   98.92   99.00   99.51   99.73  100.14  100.77  101.13
2   97.24   98.33   98.57   98.81   99.14   99.54   99.92  100.31  101.27  101.72
3   97.93   98.80   99.10   99.04   99.93  100.07  101.05  101.64  102.93  103.43
4   97.33   98.10   98.40   98.84   99.10   99.61   99.82  100.61  100.84  100.48

              REYNOLDS NUMBER AT THE INSIDE TUBE WALL

      1       2       3       4       5       6       7       8       9      10

1    9710    9774    9820    9859    9868    9922    9947    9990   10058   10096
2    9681    9796    9823    9847    9883    9926    9966   10008   10111   10160
3    9754    9846    9878    9872    9967    9983   10088   10151   10290   10344
4    9691    9773    9804    9851    9879    9934    9956   10041   10065   10027

                INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

      1       2       3       4       5       6       7       8       9      10

1    1182    1190    1187    1186    1192    1191    1193    1198    1198    1191
2    1199    1191    1194    1193    1196    1195    1201    1204    1205    1204
3    1171    1173    1173    1183    1168    1177    1160    1160    1144    1133
4    1196    1197    1198    1192    1197    1193    1203    1197    1215    1235

                         *---------------*
                          RUN NUMBER  137
                         *---------------*

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

      1       2       3       4       5       6       7       8       9      10

1     232     219     212     208     217     207     209     205     193     189
2     249     211     213     214     212     206     204     200     179     174
3     213     192     191     203     181     186     165     158     136     131
4     244     221     220     212     213     204     208     189     193     218

                         *---------------*
                          RUN NUMBER  137
                              SUMMARY
                         *---------------*

ST     RE       PR     X/D    MUB     MUW     TB      TW     DENS     NU

 1  9178.39   5.00     6.4  1.791   1.693   92.44   97.50   62.08   60.01
 2  9206.04   4.99    15.5  1.785   1.677   92.70   98.33   62.08   53.99
 3  9233.71   4.97    24.6  1.780   1.672   92.97   98.65   62.08   53.48
 4  9261.42   4.95    33.7  1.775   1.667   93.24   98.90   62.07   53.67
 5  9289.16   4.94    42.8  1.769   1.660   93.50   99.29   62.07   52.50
 6  9316.93   4.92    52.0  1.764   1.653   93.77   99.68   62.07   51.38
 7  9344.73   4.90    61.1  1.759   1.645   94.03  100.13   62.06   49.85
 8  9372.56   4.89    70.2  1.754   1.636   94.30  100.68   62.06   47.68
 9  9400.42   4.87    79.3  1.748   1.622   94.57  101.45   62.06   44.15
10  9428.32   4.86    88.4  1.743   1.618   94.83  101.69   62.05   44.34

              NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                    MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                    *----------------------------------------*
                                 RUN NUMBER  174
                           TEST FLUID IS DISTILLED WATER
                    *----------------------------------------*

                    VOLUMETRIC FLOW RATE -      4.33   GPM
                    MASS FLOW RATE       -    2158.5   LBM/HR
                    MASS FLUX            -    328859   LBM/(SQ.FT-HR)
                    FLUID VELOCITY       -      1.46   FT/S
                    ROOM TEMPERATURE     -     79.46   F
                    INLET TEMPERATURE    -     85.64   F
                    OUTLET TEMPERATURE   -     87.06   F
                    AVERAGE RE NUMBER    -     15648
                    AVERAGE PR NUMBER    -      5.41
                    CURRENT TO TUBE      -     335.0   AMPS
                    VOLTAGE DROP IN TUBE -      2.65   VOLTS
                    AVERAGE HEAT FLUX    -      1222   BTU/(SQ.FT-HR)
                    Q-AMP*VOLT           -      3029   BTU/HR
                    Q-M*C*(T2-T1)        -      3059   BTU/HR
                    HEAT BALANCE ERROR   -      -.99   %

                      OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    89.27   89.68   90.02   90.33   90.45   90.79   90.92   91.17   91.77   91.91
 2    89.51   90.07   90.20   90.33   90.67   90.88   91.07   91.44   92.26   92.54
 3    89.91   90.39   90.71   90.60   91.46   91.40   92.20   92.37   93.57   94.07
 4    89.31   89.85   90.04   90.44   90.60   90.94   91.15   91.79   91.93   91.25

                      INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    88.61   89.01   89.36   89.67   89.79   90.13   90.26   90.50   91.10   91.25
 2    88.85   89.41   89.54   89.67   90.00   90.22   90.40   90.77   91.59   91.87
 3    89.26   89.73   90.06   89.94   90.81   90.75   91.55   91.72   92.93   93.44
 4    88.64   89.19   89.37   89.78   89.93   90.28   90.48   91.13   91.26   90.56

                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1    16067   16144   16208   16266   16288   16352   16376   16423   16536   16563
 2    16112   16217   16241   16266   16329   16369   16404   16474   16628   16681
 3    16189   16278   16339   16317   16481   16468   16621   16652   16882   16979
 4    16074   16176   16211   16287   16316   16380   16419   16541   16565   16434

                        INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1     1149    1153    1148    1147    1151    1150    1152    1158    1156    1148
 2     1147    1145    1150    1149    1153    1152    1159    1155    1158    1159
 3     1133    1135    1131    1141    1125    1134    1119    1128    1110    1093
 4     1152    1150    1154    1147    1155    1150    1157    1146    1166    1192

                                 *---------------*
                                  RUN NUMBER  174
                                 *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      400     366     343     325     328     310     311     304     270     268
 2      368     323     326     326     309     303     301     283     243     236
 3      321     293     279     300     248     262     223     224     182     168
 4      396     347     343     315     316     298     294     258     263     331

                                 *---------------*
                                  RUN NUMBER  174
                                      SUMMARY
                                 *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   15535.43   5.46     6.4   1.935   1.866   85.74   88.84   62.16   95.35
 2   15560.60   5.45    15.5   1.932   1.855   85.87   89.34   62.15   85.43
 3   15585.78   5.44    24.6   1.929   1.850   86.01   89.58   62.15   82.84
 4   15610.97   5.43    33.7   1.926   1.846   86.15   89.76   62.15   81.78
 5   15636.18   5.42    42.8   1.923   1.838   86.28   90.13   62.15   76.83
 6   15661.41   5.41    52.0   1.920   1.834   86.42   90.34   62.15   75.44
 7   15686.65   5.40    61.1   1.916   1.827   86.55   90.67   62.15   71.85
 8   15711.91   5.39    70.2   1.913   1.820   86.69   91.03   62.15   68.20
 9   15737.18   5.38    79.3   1.910   1.805   86.83   91.72   62.14   60.51
10   15762.47   5.37    88.4   1.907   1.804   86.96   91.78   62.14   61.46

                    NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                          MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
              RUN NUMBER  178
        TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -      2.49   GPM
MASS FLOW RATE       -    1240.1   LBM/HR
MASS FLUX            -    188935   LBM/(SQ.FT-HR)
FLUID VELOCITY       -       .84   FT/S
ROOM TEMPERATURE     -     81.41   F
INLET TEMPERATURE    -     90.99   F
OUTLET TEMPERATURE   -     93.34   F
AVERAGE RE NUMBER    -      9615
AVERAGE PR NUMBER    -      5.02
CURRENT TO TUBE      -     325.0   AMPS
VOLTAGE DROP IN TUBE -      2.58   VOLTS
AVERAGE HEAT FLUX    -      1155   BTU/(SQ.FT-HR)
Q-AMP*VOLT           -      2861   BTU/HR
Q-M*C*(T2-T1)        -      2907   BTU/HR
HEAT BALANCE ERROR   -     -1.64   %

                 OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1   96.29   96.82   97.28   97.60   97.69   98.15   98.38   98.77   99.37   99.60
2   96.03   97.07   97.33   97.53   97.89   98.24   98.56   98.97   99.91  100.26
3   96.58   97.35   97.77   97.69   98.59   98.66   99.56   99.90  101.16  101.70
4   96.16   96.90   97.15   97.59   97.85   98.29   98.54   99.28   99.53   99.01

                 INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1   95.67   96.19   96.66   96.98   97.06   97.52   97.75   98.14   98.74   98.98
2   95.40   96.45   96.70   96.90   97.26   97.61   97.93   98.34   99.28   99.63
3   95.96   96.73   97.15   97.07   97.98   98.04   98.95   99.29  100.56  101.11
4   95.53   96.27   96.52   96.97   97.22   97.66   97.91   98.66   98.90   98.36

                 REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

1   10000   10058   10109   10145   10154   10205   10231   10274   10341   10367
2    9970   10086   10114   10137   10176   10215   10251   10297   10402   10441
3   10032   10117   10164   10155   10256   10263   10365   10402   10545   10607
4    9985   10067   10094   10143   10172   10221   10248   10332   10359   10299

                 INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

1    1078    1088    1083    1083    1089    1088    1090    1095    1095    1087
2    1093    1084    1089    1087    1091    1089    1095    1095    1095    1096
3    1071    1074    1071    1081    1066    1075    1059    1066    1049    1034
4    1090    1088    1093    1086    1092    1088    1096    1087    1105    1128

                          *---------------*
                           RUN NUMBER  178
                          *---------------*

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

        1       2       3       4       5       6       7       8       9      10

1     238     225     214     210     217     207     207     202     189     187
2     257     213     213     214     209     204     201     195     173     169
3     222     200     192     206     180     186     164     162     138     130
4     248     222     222     211     211     201     202     183     186     217

                          *---------------*
                           RUN NUMBER  178
                              SUMMARY
                          *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS      NU

 1   9505.30   5.09     6.4   1.817   1.728   91.15   95.64   62.10   61.84
 2   9529.81   5.07    15.5   1.812   1.713   91.37   96.41   62.09   55.17
 3   9554.35   5.06    24.6   1.808   1.707   91.60   96.76   62.09   53.87
 4   9578.91   5.04    33.7   1.803   1.702   91.83   96.98   62.09   53.93
 5   9603.49   5.03    42.8   1.798   1.695   92.05   97.38   62.09   52.14
 6   9628.09   5.01    52.0   1.794   1.689   92.28   97.71   62.08   51.14
 7   9652.72   5.00    61.1   1.789   1.681   92.50   98.14   62.08   49.33
 8   9677.37   4.99    70.2   1.785   1.673   92.73   98.61   62.08   47.29
 9   9702.05   4.97    79.3   1.780   1.659   92.96   99.37   62.08   43.34
10   9726.75   4.96    88.4   1.776   1.656   93.18   99.52   62.07   43.86

                 NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                       MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
             RUN NUMBER  185
      TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -     4.31   GPM
MASS FLOW RATE       -   2150.6   LBM/HR
MASS FLUX            -   327655   LBM/(SQ.FT-HR)
FLUID VELOCITY       -     1.45   FT/S
ROOM TEMPERATURE     -    73.98   F
INLET TEMPERATURE    -    79.62   F
OUTLET TEMPERATURE   -    82.76   F
AVERAGE RE NUMBER    -    14652
AVERAGE PR NUMBER    -     5.80
CURRENT TO TUBE      -    490.0   AMPS
VOLTAGE DROP IN TUBE -     3.84   VOLTS
AVERAGE HEAT FLUX    -     2591   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -     6420   BTU/HR
Q=M*C*(T2-T1)        -     6742   BTU/HR
HEAT BALANCE ERROR   -    -5.01   %


                OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

1    87.31   87.91   88.52   89.11   89.16   89.85   90.15   90.69   91.38   91.87
2    87.80   88.79   88.90   89.13   89.66   90.04   90.53   91.21   92.50   93.14
3    88.76   90.01   90.18   90.07   91.29   91.54   92.95   93.79   95.48   96.20
4    87.35   88.11   88.63   89.12   89.51   90.16   90.47   91.39   91.79   91.54


                INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

1    85.89   86.49   87.10   87.70   87.74   88.43   88.73   89.26   89.95   90.45
2    86.38   87.37   87.48   87.71   88.24   88.62   89.10   89.78   91.07   91.71
3    87.36   88.62   88.79   88.67   89.90   90.15   91.57   92.41   94.11   94.84
4    85.93   86.68   87.21   87.70   88.09   88.74   89.04   89.96   90.35   90.09


                REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

1    15507   15616   15730   15839   15847   15976   16031   16131   16259   16352
2    15597   15780   15799   15842   15940   16010   16100   16227   16469   16590
3    15778   16011   16042   16020   16250   16296   16563   16722   17045   17184
4    15513   15652   15749   15840   15912   16033   16089   16261   16334   16285


                   INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

1     2455    2463    2456    2451    2463    2459    2463    2471    2477    2471
2     2453    2453    2461    2462    2465    2469    2479    2481    2480    2479
3     2417    2408    2413    2426    2407    2414    2389    2389    2369    2356
4     2465    2471    2468    2462    2469    2465    2481    2476    2498    2521


                          *----------------*
                           RUN NUMBER  185
                          *----------------*

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

         1       2       3       4       5       6       7       8       9      10

1      405     387     368     352     367     346     347     337     321     312
2      374     338     349     353     342     339     332     316     281     270
3      320     283     288     305     271     274     240     228     199     191
4      404     377     364     353     350     333     335     308     308     334


                          *----------------*
                           RUN NUMBER  185
                               SUMMARY
                          *----------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW    DENS      NU

 1  14409.50   5.91     6.4   2.079   1.920   79.83   86.39   62.21   97.14
 2  14463.45   5.89    15.5   2.071   1.900   80.13   87.29   62.21   89.05
 3  14517.47   5.86    24.6   2.063   1.892   80.44   87.64   62.21   88.41
 4  14571.57   5.84    33.7   2.056   1.886   80.74   87.94   62.21   88.42
 5  14625.75   5.81    42.8   2.048   1.874   81.04   88.49   62.20   85.51
 6  14680.02   5.79    52.0   2.040   1.863   81.34   88.98   62.20   83.37
 7  14734.35   5.77    61.1   2.033   1.849   81.64   89.61   62.20   79.97
 8  14788.77   5.74    70.2   2.025   1.834   81.94   90.35   62.19   75.77
 9  14843.26   5.72    79.3   2.018   1.812   82.25   91.37   62.19   69.85
10  14897.84   5.69    88.4   2.011   1.804   82.55   91.77   62.19   69.10

                NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                      MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                     *-----------------------------------------*
                                RUN NUMBER  188
                         TEST FLUID IS DISTILLED WATER
                     *-----------------------------------------*

                     VOLUMETRIC FLOW RATE -      2.47    GPM
                     MASS FLOW RATE       -    1231.5    LBM/HR
                     MASS FLUX            -    187623    LBM/(SQ.FT-HR)
                     FLUID VELOCITY       -       .83    FT/S
                     ROOM TEMPERATURE     -     73.40    F
                     INLET TEMPERATURE    -     84.69    F
                     OUTLET TEMPERATURE   -     89.84    F
                     AVERAGE RE NUMBER    -      9024
                     AVERAGE PR NUMBER    -      5.35
                     CURRENT TO TUBE      -     485.0    AMPS
                     VOLTAGE DROP IN TUBE -      3.81    VOLTS
                     AVERAGE HEAT FLUX    -      2545    BTU/(SQ.FT-HR)
                     Q-AMP*VOLT           -      6305    BTU/HR
                     Q-M*C*(T2-T1)        -      6329    BTU/HR
                     HEAT BALANCE ERROR   -      -.39    %

                       OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    96.21   97.51   98.44   99.18   99.16  100.16  100.49  101.20  102.02  102.56
 2    95.93   98.03   98.53   98.83   99.43  100.04  100.73  101.60  103.22  103.88
 3    97.14   98.92   99.41   99.38  100.76  101.15  102.92  103.96  105.92  106.77
 4    95.98   97.54   98.14   98.79   99.35  100.19  100.65  101.81  102.38  102.31

                       INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    94.83   96.12   97.05   97.80   97.77   98.77   99.10   99.80  100.62  101.16
 2    94.53   96.64   97.14   97.43   98.03   98.64   99.33  100.20  101.82  102.48
 3    95.77   97.55   98.04   98.00   99.39   99.78  101.56  102.60  104.58  105.43
 4    94.58   96.14   96.74   97.39   97.95   98.79   99.25  100.41  100.97  100.89

                       REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

 1     9838    9979   10082   10165   10161   10273   10309   10388   10479   10539
 2     9806   10037   10092   10125   10191   10258   10335   10432   10614   10688
 3     9941   10137   10191   10187   10342   10385   10585   10702   10925   11023
 4     9811    9982   10048   10120   10182   10275   10326   10455   10518   10509

                         INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

 1     2406    2423    2414    2408    2425    2419    2427    2436    2446    2441
 2     2432    2420    2426    2429    2432    2435    2446    2448    2444    2445
 3     2381    2386    2388    2402    2382    2392    2363    2363    2343    2329
 4     2430    2433    2437    2430    2434    2431    2448    2442    2466    2487

                                   *----------------*
                                    RUN NUMBER  188
                                   *----------------*

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

          1       2       3       4       5       6       7       8       9      10

 1      245     228     218     213     225     214     218     215     210     209
 2      256     217     218     222     220     218     216     209     190     188
 3      221     198     198     209     192     195     174     167     150     146
 4      254     229     227     223     222     215     217     205     206     218

                                   *----------------*
                                    RUN NUMBER  188
                                        SUMMARY
                                   *----------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1    8790.07    5.51     6.4   1.951   1.741   85.04   94.93   62.16   63.06
 2    8842.01    5.47    15.5   1.940   1.709   85.53   96.61   62.16   56.32
 3    8894.08    5.44    24.6   1.928   1.698   86.03   97.24   62.15   55.63
 4    8946.26    5.40    33.7   1.917   1.690   86.52   97.66   62.15   56.02
 5    8998.56    5.37    42.8   1.906   1.678   87.02   98.29   62.14   55.34
 6    9050.97    5.33    52.0   1.895   1.666   87.51   99.00   62.14   54.29
 7    9103.50    5.30    61.1   1.884   1.651   88.01   99.81   62.13   52.83
 8    9156.14    5.26    70.2   1.873   1.634   88.50  100.75   62.13   50.89
 9    9208.91    5.23    79.3   1.863   1.613   89.00  101.99   62.12   47.98
10    9261.78    5.20    88.4   1.852   1.605   89.49  102.49   62.12   47.97

                       NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                             MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
              RUN NUMBER  190
       TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -     2.51   GPM
MASS FLOW RATE       -   1250.0   LBM/HR
MASS FLUX            -   190447   LBM/(SQ.FT-HR)
FLUID VELOCITY       -      .85   FT/S
ROOM TEMPERATURE     -    75.42   F
INLET TEMPERATURE    -    91.16   F
OUTLET TEMPERATURE   -    96.38   F
AVERAGE RE NUMBER    -     9869
AVERAGE PR NUMBER    -     4.92
CURRENT TO TUBE      -    490.0   AMPS
VOLTAGE DROP IN TUBE -     3.89   VOLTS
AVERAGE HEAT FLUX    -     2625   BTU/(SQ.FT-HR)
Q-AMP*VOLT           -     6503   BTU/HR
Q-M*C*(T2-T1)        -     6510   BTU/HR
HEAT BALANCE ERROR   -     -.11   %

                OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1  102.47  103.61  104.46  105.27  105.17  106.20  106.58  107.33  108.17  108.62
2  102.07  104.01  104.53  104.87  105.42  106.06  106.74  107.58  109.13  109.90
3  103.25  104.89  105.40  105.37  106.77  107.16  108.95  109.95  111.86  112.82
4  102.07  103.56  104.15  104.84  105.34  106.26  106.64  107.83  108.39  108.36

                INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1  101.06  102.19  103.04  103.86  103.75  104.78  105.16  105.90  106.74  107.19
2  100.64  102.59  103.11  103.44  103.99  104.63  105.31  106.14  107.70  108.47
3  101.85  103.49  104.00  103.96  105.37  105.75  107.56  108.56  110.48  111.45
4  100.64  102.13  102.72  103.41  103.91  104.83  105.20  106.40  106.95  106.90

                REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

1   10686   10815   10913   11007   10994   11113   11157   11243   11340   11392
2   10639   10861   10920   10959   11022   11096   11174   11271   11452   11542
3   10777   10964   11023   11018   11181   11226   11436   11553   11778   11893
4   10639   10809   10876   10956   11013   11119   11162   11300   11364   11359

                 INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

1    2463    2481    2474    2467    2485    2479    2485    2494    2502    2501
2    2493    2482    2487    2490    2493    2496    2508    2511    2508    2507
3    2443    2447    2449    2464    2442    2454    2422    2424    2404    2389
4    2493    2494    2497    2490    2495    2491    2511    2504    2528    2548

                         *----------------*
                          RUN NUMBER  190
                         *----------------*

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

        1       2       3       4       5       6       7       8       9      10

1     258     243     235     227     242     230     233     229     223     224
2     273     234     234     238     238     235     232     225     206     201
3     236     213     213     225     206     209     185     179     160     154
4     273     246     244     239     240     230     235     220     221     234

                         *----------------*
                          RUN NUMBER  190
                             SUMMARY
                         *----------------*

ST      RE      PR    X/D    MUB     MUW      TB      TW     DENS     NU

 1   9621.08   5.06    6.4  1.810   1.629   91.51  101.05   62.09   66.49
 2   9676.07   5.03   15.5  1.799   1.603   92.01  102.60   62.09   59.92
 3   9731.19   5.00   24.6  1.789   1.592   92.52  103.22   62.08   59.27
 4   9786.42   4.97   33.7  1.779   1.585   93.02  103.67   62.08   59.52
 5   9841.77   4.94   42.8  1.769   1.575   93.52  104.26   62.07   59.04
 6   9897.23   4.91   52.0  1.759   1.563   94.02  105.00   62.06   57.73
 7   9952.82   4.87   61.1  1.749   1.550   94.52  105.81   62.06   56.16
 8  10008.51   4.84   70.2  1.740   1.535   95.02  106.75   62.05   54.04
 9  10064.33   4.81   79.3  1.730   1.516   95.53  107.97   62.05   50.96
10  10120.25   4.79   88.4  1.720   1.508   96.03  108.50   62.04   50.80

              NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                    MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *----------------------------------------*
                              RUN NUMBER 1115
                       TEST FLUID IS DISTILLED WATER
                 *----------------------------------------*

                 VOLUMETRIC FLOW RATE -        .82   GPM
                 MASS FLOW RATE       -      408.8   LBM/HR
                 MASS FLUX            -      62285   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -        .28   FT/S
                 ROOM TEMPERATURE     -      80.35   F
                 INLET TEMPERATURE    -      84.96   F
                 OUTLET TEMPERATURE   -      87.01   F
                 AVERAGE RE NUMBER    -       2951
                 AVERAGE PR NUMBER    -       5.44
                 CURRENT TO TUBE      -      178.0   AMPS
                 VOLTAGE DROP IN TUBE -       1.40   VOLTS
                 AVERAGE HEAT FLUX    -        343   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -        850   BTU/HR
                 Q=M*C*(T2-T1)        -        836   BTU/HR
                 HEAT BALANCE ERROR   -       1.62   %

                    OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

  1     88.32   89.12   89.25   90.52   89.62   91.10   92.24   92.05   91.69   92.45
  2     88.29   89.73   90.06   90.23   90.55   90.76   91.28   91.66   92.28   92.19
  3     88.42   89.45   90.12   90.02   90.65   90.51   91.16   91.39   92.51   92.54
  4     88.33   89.73   90.01   90.40   90.43   90.76   91.28   92.06   92.19   91.33

                    INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

  1     88.13   88.93   89.05   90.34   89.42   90.92   92.07   91.87   91.50   92.27
  2     88.10   89.55   89.88   90.04   90.37   90.57   91.09   91.47   92.10   92.00
  3     88.23   89.26   89.93   89.83   90.47   90.32   90.97   91.20   92.33   92.36
  4     88.14   89.55   89.83   90.22   90.25   90.57   91.09   91.88   92.00   91.13

                    REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

  1      3026    3054    3058    3104    3072    3125    3166    3159    3145    3173
  2      3025    3076    3088    3094    3105    3113    3131    3145    3167    3164
  3      3030    3066    3090    3086    3109    3104    3127    3135    3175    3177
  4      3026    3076    3086    3100    3101    3113    3131    3159    3164    3132

                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

  1       323     338     343     318     345     315     300     319     337     307
  2       325     312     314     324     313     324     334     325     319     331
  3       320     330     321     330     319     330     326     335     317     304
  4       324     312     315     320     316     324     334     315     321     353

                                *---------------*
                                 RUN NUMBER 1115
                                *---------------*

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

          1       2       3       4       5       6       7       8       9      10

  1       106      93      96      68      97      65      51      59      70      56
  2       108      73      71      74      69      72      69      65      58      64
  3       102      83      72      79      69      77      69      71      56      55
  4       106      73      72      70      72      72      69      58      60      82

                                *---------------*
                                 RUN NUMBER 1115
                                     SUMMARY
                                *---------------*

ST      RE       PR     X/D     MUB      MUW      TB      TW     DENS     NU

 1   2920.16    5.50     6.4   1.950    1.881   85.10   88.15   62.16   27.35
 2   2927.02    5.49    15.5   1.945    1.856   85.30   89.32   62.16   20.77
 3   2933.89    5.47    24.6   1.941    1.848   85.49   89.67   62.16   20.00
 4   2940.77    5.46    33.7   1.936    1.839   85.69   90.11   62.16   18.93
 5   2947.65    5.45    42.8   1.932    1.838   85.89   90.13   62.15   19.71
 6   2954.53    5.43    52.0   1.927    1.829   86.08   90.60   62.15   18.52
 7   2961.42    5.42    61.1   1.923    1.814   86.28   91.30   62.15   16.64
 8   2968.32    5.40    70.2   1.918    1.808   86.48   91.60   62.15   16.31
 9   2975.23    5.39    79.3   1.914    1.800   86.67   91.98   62.15   15.75
10   2982.14    5.38    88.4   1.909    1.801   86.87   91.94   62.14   16.49

                    NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                          MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                  *----------------------------------------*
                              RUN NUMBER 1155
                      TEST FLUID IS DISTILLED WATER
                  *----------------------------------------*

                  VOLUMETRIC FLOW RATE -       .96   GPM
                  MASS FLOW RATE       -     478.5   LBM/HR
                  MASS FLUX            -     72899   LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -       .32   FT/S
                  ROOM TEMPERATURE     -     79.52   F
                  INLET TEMPERATURE    -     80.15   F
                  OUTLET TEMPERATURE   -     81.79   F
                  AVERAGE RE NUMBER    -      3251
                  AVERAGE PR NUMBER    -      5.82
                  CURRENT TO TUBE      -     175.0   AMPS
                  VOLTAGE DROP IN TUBE -      1.38   VOLTS
                  AVERAGE HEAT FLUX    -       332   BTU/(SQ.FT-HR)
                  Q-AMP*VOLT           -       824   BTU/HR
                  Q-M*C*(T2-T1)        -       783   BTU/HR
                  HEAT BALANCE ERROR   -      4.92   %

                     OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1     83.41   84.94   85.51   86.01   85.12   85.64   85.50   86.18   86.44   86.73
 2     83.37   84.63   85.15   85.31   85.54   85.49   85.69   85.96   86.73   86.88
 3     83.45   84.30   84.98   85.00   85.56   85.36   85.80   85.88   86.95   87.39
 4     83.35   84.65   85.22   85.56   85.54   85.53   85.64   86.37   86.62   85.91

                      INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1     83.23   84.76   85.33   85.84   84.93   85.46   85.32   86.00   86.26   86.55
 2     83.19   84.45   84.97   85.13   85.36   85.31   85.51   85.78   86.55   86.70
 3     83.27   84.12   84.80   84.81   85.38   85.18   85.62   85.70   86.77   87.22
 4     83.17   84.47   85.04   85.38   85.36   85.35   85.46   86.19   86.44   85.71

                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

 1      3342    3404    3427    3447    3411    3432    3426    3454    3465    3477
 2      3340    3391    3412    3418    3428    3426    3434    3445    3477    3483
 3      3343    3377    3405    3406    3429    3421    3439    3442    3486    3504
 4      3339    3392    3415    3429    3428    3428    3432    3462    3472    3442

                        INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

 1       309     304     303     297     322     308     315     311     317     303
 2       312     311     314     316     306     311     310     313     311     316
 3       309     320     316     322     311     315     308     318     305     287
 4       313     310     312     310     306     311     311     303     313     340

                                *---------------*
                                 RUN NUMBER 1155
                                *---------------*

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

          1       2       3       4       5       6       7       8       9      10

 1       104      69      63      58      79      69      76      67      67      62
 2       106      77      71      72      68      73      72      71      61      63
 3       102      86      75      79      69      76      69      73      58      51
 4       107      76      69      66      68      72      73      62      63      84

                                *---------------*
                                 RUN NUMBER 1155
                                     SUMMARY
                                *---------------*

ST       RE        PR     X/D     MUB      MUW      TB       TW      DENS      NU

 1    3223.00    5.88     6.4   2.068    1.994   80.26    83.21    62.21   27.41
 2    3229.28    5.86    15.5   2.064    1.965   80.42    84.45    62.21   20.10
 3    3235.56    5.85    24.6   2.060    1.951   80.58    85.03    62.21   18.18
 4    3241.85    5.84    33.7   2.056    1.945   80.73    85.29    62.21   17.79
 5    3248.15    5.83    42.8   2.052    1.946   80.89    85.26    62.20   18.55
 6    3254.44    5.81    52.0   2.048    1.945   81.05    85.32    62.20   18.95
 7    3260.75    5.80    61.1   2.044    1.941   81.21    85.48    62.20   18.97
 8    3267.05    5.79    70.2   2.040    1.931   81.36    85.92    62.20   17.80
 9    3273.37    5.77    79.3   2.036    1.918   81.52    86.50    62.20   16.26
10    3279.69    5.76    88.4   2.032    1.917   81.68    86.55    62.20   16.65

                     NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                           MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                  *----------------------------------------*
                              RUN NUMBER 1159
                       TEST FLUID IS DISTILLED WATER
                  *----------------------------------------*

                  VOLUMETRIC FLOW RATE -      1.00   GPM
                  MASS FLOW RATE       -     501.1   LBM/HR
                  MASS FLUX            -     76344   LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -       .34   FT/S
                  ROOM TEMPERATURE     -     81.34   F
                  INLET TEMPERATURE    -     80.66   F
                  OUTLET TEMPERATURE   -     82.27   F
                  AVERAGE RE NUMBER    -      3425
                  AVERAGE PR NUMBER    -      5.78
                  CURRENT TO TUBE      -     175.0   AMPS
                  VOLTAGE DROP IN TUBE -      1.39   VOLTS
                  AVERAGE HEAT FLUX    -       335   BTU/(SQ.FT-HR)
                  Q=AMP*VOLT           -       830   BTU/HR
                  Q=M*C*(T2-T1)        -       805   BTU/HR
                  HEAT BALANCE ERROR   -      2.96   %

                    OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9       10

 1    83.79   85.21   85.69   85.96   85.30   85.97   86.00   86.52   86.71   86.99
 2    83.87   85.02   85.49   85.58   85.80   85.86   86.14   86.33   87.01   87.17
 3    83.99   84.77   85.40   85.37   85.90   85.79   86.28   86.31   87.31   87.67
 4    83.76   85.05   85.50   85.80   85.76   85.89   86.07   86.74   86.90   86.15

                    INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9       10

 1    83.61   85.03   85.51   85.78   85.11   85.79   85.82   86.34   86.53   86.81
 2    83.69   84.84   85.31   85.40   85.62   85.68   85.96   86.15   86.83   86.99
 3    83.81   84.59   85.22   85.19   85.72   85.61   86.10   86.13   87.13   87.50
 4    83.58   84.87   85.32   85.62   85.58   85.71   85.89   86.56   86.72   85.95

                    REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9       10

 1    3516    3576    3597    3608    3579    3608    3610    3632    3640    3652
 2    3519    3568    3588    3592    3601    3604    3616    3624    3653    3660
 3    3524    3557    3584    3583    3605    3601    3622    3623    3666    3682
 4    3514    3569    3588    3601    3599    3605    3613    3642    3648    3615

                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9       10

 1     312     307     306     305     323     309     314     312     318     303
 2     311     310     313     313     306     312     311     314     312     316
 3     307     318     314     319     308     314     307     317     303     287
 4     314     310     312     308     307     311     313     303     314     341

                               *---------------*
                                RUN NUMBER 1159
                               *---------------*

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

        1       2       3       4       5       6       7       8       9       10

 1     109      74      69      67      86      72      76      69      70      65
 2     106      79      74      75      72      75      73      73      64      65
 3     100      86      75      80      71      77      69      74      59      53
 4     111      78      73      70      73      74      74      64      66      90

                               *---------------*
                                RUN NUMBER 1159
                                    SUMMARY
                               *---------------*

ST     RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   3396.52   5.83    6.4   2.055   1.983   80.77   83.67   62.21   27.89
 2   3402.99   5.82   15.5   2.051   1.956   80.92   84.83   62.20   20.72
 3   3409.47   5.81   24.6   2.047   1.944   81.08   85.34   62.20   19.01
 4   3415.95   5.80   33.7   2.043   1.941   81.23   85.50   62.20   19.00
 5   3422.43   5.79   42.8   2.039   1.940   81.39   85.51   62.20   19.65
 6   3428.92   5.77   52.0   2.035   1.936   81.54   85.70   62.20   19.50
 7   3435.42   5.76   61.1   2.032   1.930   81.70   85.94   62.20   19.08
 8   3441.92   5.75   70.2   2.028   1.922   81.85   86.29   62.20   18.23
 9   3448.42   5.74   79.3   2.024   1.911   82.01   86.80   62.19   16.89
10   3454.93   5.72   88.4   2.020   1.911   82.16   86.81   62.19   17.41

                    NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                          MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                  *----------------------------------------*
                              RUN NUMBER 1167
                       TEST FLUID IS DISTILLED WATER
                  *----------------------------------------*

                  VOLUMETRIC FLOW RATE -      1.24   GPM
                  MASS FLOW RATE       -     616.6   LBM/HR
                  MASS FLUX            -     93949   LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -       .42   FT/S
                  ROOM TEMPERATURE     -     81.42   F
                  INLET TEMPERATURE    -     80.09   F
                  OUTLET TEMPERATURE   -     81.39   F
                  AVERAGE RE NUMBER    -      4178
                  AVERAGE PR NUMBER    -      5.84
                  CURRENT TO TUBE      -     175.0   AMPS
                  VOLTAGE DROP IN TUBE -      1.39   VOLTS
                  AVERAGE HEAT FLUX    -       335   BTU/(SQ.FT-HR)
                  Q=AMP*VOLT           -       830   BTU/HR
                  Q=M*C*(T2-T1)        -       800   BTU/HR
                  HEAT BALANCE ERROR   -      3.57   %

                    OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1    82.84   83.75   84.14   84.24   84.38   84.71   84.82   85.04   85.53   85.67
 2    82.88   83.78   84.04   84.10   84.44   84.60   84.79   84.93   85.55   85.74
 3    82.92   83.64   84.06   83.96   84.51   84.55   84.98   84.95   85.88   86.28
 4    82.78   83.77   84.03   84.25   84.44   84.63   84.74   85.32   85.46   84.76

                    INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1    82.66   83.57   83.96   84.06   84.20   84.53   84.64   84.86   85.35   85.50
 2    82.70   83.60   83.86   83.92   84.26   84.42   84.61   84.75   85.37   85.56
 3    82.74   83.46   83.88   83.78   84.33   84.37   84.80   84.77   85.70   86.11
 4    82.60   83.59   83.85   84.07   84.26   84.45   84.56   85.14   85.28   84.56

                    REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

 1     4277    4324    4345    4350    4357    4374    4380    4392    4417    4425
 2     4279    4326    4339    4343    4360    4369    4379    4386    4418    4428
 3     4281    4318    4340    4335    4364    4366    4389    4387    4436    4458
 4     4274    4325    4339    4350    4360    4370    4376    4407    4414    4376

                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

 1      311     312     308     309     312     309     310     313     311     301
 2      311     309     312     311     311     312     314     313     315     317
 3      309     314     310     316     309     313     306     316     302     286
 4      313     309     313     307     311     311     315     303     317     341

                               *----------------*
                                RUN NUMBER 1167
                               *----------------*

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

         1       2       3       4       5       6       7       8       9      10

 1      125      95      87      88      88      82      83      82      74      71
 2      123      93      91      92      87      86      85      84      75      74
 3      120      99      90      98      84      87      79      85      66      59
 4      129      94      91      87      87      85      86      74      77     104

                               *----------------*
                                RUN NUMBER 1167
                                    SUMMARY
                               *----------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1    4149.39   5.88    6.4   2.070   2.007   80.18   82.67   62.21   32.43
 2    4155.80   5.87   15.5   2.067   1.986   80.30   83.55   62.21   24.91
 3    4162.22   5.86   24.6   2.063   1.978   80.43   83.89   62.21   23.42
 4    4168.64   5.85   33.7   2.060   1.977   80.55   83.96   62.21   23.79
 5    4175.06   5.84   42.8   2.057   1.969   80.68   84.26   62.21   22.60
 6    4181.49   5.83   52.0   2.054   1.965   80.80   84.44   62.21   22.26
 7    4187.92   5.82   61.1   2.051   1.960   80.93   84.65   62.20   21.75
 8    4194.35   5.81   70.2   2.048   1.955   81.05   84.88   62.20   21.17
 9    4200.79   5.80   79.3   2.044   1.942   81.18   85.42   62.20   19.08
10    4207.23   5.79   88.4   2.041   1.942   81.30   85.43   62.20   19.62

                   NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                         MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                    *----------------------------------------*
                                 RUN NUMBER 1169
                          TEST FLUID IS DISTILLED WATER
                    *----------------------------------------*

                    VOLUMETRIC FLOW RATE -      1.30   GPM
                    MASS FLOW RATE       -     649.2   LBM/HR
                    MASS FLUX            -     98909   LBM/(SQ.FT-HR)
                    FLUID VELOCITY       -       .44   FT/S
                    ROOM TEMPERATURE     -     82.30   F
                    INLET TEMPERATURE    -     80.33   F
                    OUTLET TEMPERATURE   -     81.77   F
                    AVERAGE RE NUMBER    -      4415
                    AVERAGE PR NUMBER    -      5.81
                    CURRENT TO TUBE      -     190.0   AMPS
                    VOLTAGE DROP IN TUBE -      1.52   VOLTS
                    AVERAGE HEAT FLUX    -       397   BTU/(SQ.FT-HR)
                    Q-AMP*VOLT           -       985   BTU/HR
                    Q-M*C*(T2-T1)        -       933   BTU/HR
                    HEAT BALANCE ERROR   -      5.28   %

                      OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1     83.49   84.41   84.77   84.92   85.09   85.41   85.53   85.76   86.28   86.44
 2     83.51   84.44   84.72   84.79   85.14   85.31   85.52   85.66   86.33   86.54
 3     83.51   84.33   84.72   84.65   85.23   85.29   85.76   85.76   86.72   87.13
 4     83.41   84.39   84.65   84.90   85.13   85.33   85.44   86.03   86.22   85.53

                      INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1     83.28   84.20   84.56   84.71   84.88   85.20   85.32   85.55   86.07   86.23
 2     83.30   84.23   84.51   84.58   84.93   85.10   85.31   85.45   86.12   86.32
 3     83.30   84.12   84.51   84.43   85.02   85.08   85.55   85.55   86.51   86.93
 4     83.20   84.18   84.44   84.69   84.92   85.12   85.22   85.82   86.00   85.30

                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

 1      4537    4587    4607    4615    4625    4642    4649    4662    4690    4700
 2      4538    4589    4604    4608    4627    4637    4648    4656    4693    4705
 3      4538    4583    4604    4600    4632    4636    4662    4662    4715    4739
 4      4532    4586    4600    4614    4627    4638    4644    4677    4687    4648

                        INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

 1       366     367     365     365     368     365     366     369     367     357
 2       366     365     367     367     367     368     370     370     371     373
 3       365     369     366     372     365     368     360     369     356     340
 4       369     366     369     364     368     367     372     360     374     398

                                 *---------------*
                                  RUN NUMBER 1169
                                 *---------------*

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

         1       2       3       4       5       6       7       8       9      10

 1       128     101      94      94      94      89      90      89      81      78
 2       127      99      96      98      93      92      91      91      81      80
 3       127     104      96     103      90      93      83      89      71      64
 4       133     101      99      94      93      92      93      81      83     109
                                                                 .

                                 *---------------*
                                  RUN NUMBER 1169
                                      SUMMARY
                                 *---------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1    4381.94    5.86    6.4   2.063   1.993   80.43   83.27   62.21   33.61
 2    4389.43    5.85   15.5   2.060   1.971   80.57   84.18   62.21   26.42
 3    4396.92    5.84   24.6   2.056   1.964   80.70   84.50   62.21   25.14
 4    4404.41    5.83   33.7   2.053   1.961   80.84   84.60   62.21   25.40
 5    4411.92    5.82   42.8   2.049   1.954   80.98   84.94   62.20   24.15
 6    4419.42    5.81   52.0   2.046   1.949   81.12   85.12   62.20   23.85
 7    4426.93    5.80   61.1   2.042   1.944   81.26   85.35   62.20   23.33
 8    4434.45    5.78   70.2   2.039   1.938   81.40   85.59   62.20   22.77
 9    4441.97    5.77   79.3   2.036   1.925   81.53   86.17   62.20   20.58
10    4449.50    5.76   88.4   2.032   1.925   81.67   86.20   62.20   21.11

                       NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                             MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                     *----------------------------------------*
                                RUN NUMBER 1173
                          TEST FLUID IS DISTILLED WATER
                     *----------------------------------------*

                     VOLUMETRIC FLOW RATE -     1.51   GPM
                     MASS FLOW RATE       -    753.2   LBM/HR
                     MASS FLUX            -   114748   LBM/(SQ.FT-HR)
                     FLUID VELOCITY       -      .51   FT/S
                     ROOM TEMPERATURE     -    80.32   F
                     INLET TEMPERATURE    -    79.16   F
                     OUTLET TEMPERATURE   -    80.69   F
                     AVERAGE RE NUMBER    -     5052
                     AVERAGE PR NUMBER    -     5.90
                     CURRENT TO TUBE      -    215.0   AMPS
                     VOLTAGE DROP IN TUBE -     1.72   VOLTS
                     AVERAGE HEAT FLUX    -      509   BTU/(SQ.FT-HR)
                     Q=AMP*VOLT           -     1261   BTU/HR
                     Q=M*C*(T2-T1)        -     1150   BTU/HR
                     HEAT BALANCE ERROR   -     8.81   %

                      OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1        2        3        4        5        6        7        8        9       10

 1     82.54    83.43    83.84    84.02    84.15    84.53    84.72    85.00    85.55    85.72
 2     82.59    83.51    83.81    83.92    84.31    84.51    84.75    84.94    85.71    85.94
 3     82.78    83.39    83.86    83.79    84.48    84.53    85.11    85.07    86.23    86.72
 4     82.44    83.46    83.75    84.03    84.29    84.54    84.69    85.34    85.55    84.88

                      INSIDE SURFACE TEMPERATURES - DEGREES F

         1        2        3        4        5        6        7        8        9       10

 1     82.27    83.16    83.57    83.75    83.88    84.26    84.45    84.73    85.28    85.45
 2     82.32    83.24    83.54    83.65    84.04    84.24    84.48    84.67    85.44    85.66
 3     82.51    83.12    83.59    83.52    84.21    84.26    84.84    84.80    85.97    86.47
 4     82.17    83.19    83.48    83.76    84.02    84.27    84.41    85.07    85.27    84.59

                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1        2        3        4        5        6        7        8        9       10

 1     5199     5255     5282     5293     5301     5326     5338     5355     5391     5402
 2     5202     5261     5280     5287     5312     5324     5339     5352     5401     5416
 3     5215     5253     5283     5278     5323     5326     5363     5360     5435     5467
 4     5193     5257     5276     5294     5310     5326     5336     5378     5391     5347

                        INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1        2        3        4        5        6        7        8        9       10

 1      468      471      468      468      473      470      470      473      472      463
 2      471      467      470      469      470      470      474      472      475      477
 3      462      472      468      474      465      470      460      472      455      438
 4      475      468      472      466      470      470      475      462      479      503

                                 *---------------*
                                 RUN NUMBER 1173
                                 *---------------*

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

         1        2        3        4        5        6        7        8        9       10

 1      156      125      116      115      117      110      109      106       97       95
 2      154      122      118      119      112      111      109      108       95       94
 3      142      127      116      124      106      110       98      104       82       74
 4      163      124      120      115      112      110      111       96       99      125

                                 *---------------*
                                 RUN NUMBER 1173
                                     SUMMARY
                                 *---------------*

ST      RE       PR     X/D     MUB      MUW      TB      TW     DENS      NU

 1   5010.86   5.96     6.4   2.093   2.016   79.26   82.32   62.22   40.08
 2   5020.04   5.95    15.5   2.090   1.995   79.41   83.18   62.22   32.51
 3   5029.22   5.93    24.6   2.086   1.987   79.56   83.54   62.22   30.71
 4   5038.41   5.92    33.7   2.082   1.984   79.70   83.67   62.22   30.88
 5   5047.61   5.91    42.8   2.078   1.975   79.85   84.04   62.21   29.25
 6   5056.81   5.90    52.0   2.074   1.970   80.00   84.26   62.21   28.75
 7   5066.02   5.89    61.1   2.071   1.963   80.15   84.55   62.21   27.81
 8   5075.24   5.87    70.2   2.067   1.956   80.29   84.82   62.21   27.06
 9   5084.46   5.86    79.3   2.063   1.941   80.44   85.49   62.21   24.25
10   5093.69   5.85    88.4   2.059   1.940   80.59   85.54   62.21   24.70

                      NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                            MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *---------------------------------------*
                            RUN NUMBER 1175
                      TEST FLUID IS DISTILLED WATER
                 *---------------------------------------*

                 VOLUMETRIC FLOW RATE -      1.52   GPM
                 MASS FLOW RATE       -     757.1   LBM/HR
                 MASS FLUX            -    115350   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -       .51   FT/S
                 ROOM TEMPERATURE     -     81.59   F
                 INLET TEMPERATURE    -     79.50   F
                 OUTLET TEMPERATURE   -     81.08   F
                 AVERAGE RE NUMBER    -      5101
                 AVERAGE PR NUMBER    -      5.87
                 CURRENT TO TUBE      -     218.0   AMPS
                 VOLTAGE DROP IN TUBE -      1.72   VOLTS
                 AVERAGE HEAT FLUX    -       516   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -      1279   BTU/HR
                 Q=M*C*(T2-T1)        -      1194   BTU/HR
                 HEAT BALANCE ERROR   -      6.64   %

                  OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    82.99   83.67   84.19   84.43   84.65   85.00   85.16   85.41   85.97   86.14
 2    82.94   83.88   84.19   84.34   84.74   84.94   85.19   85.34   86.07   86.32
 3    83.03   83.88   84.26   84.26   84.92   85.02   85.53   85.53   86.60   87.06
 4    82.90   83.81   84.12   84.42   84.71   84.97   85.09   85.71   85.93   85.29

                  INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    82.71   83.39   83.91   84.15   84.37   84.72   84.88   85.13   85.69   85.86
 2    82.66   83.60   83.91   84.06   84.46   84.66   84.91   85.06   85.79   86.04
 3    82.75   83.60   83.98   83.98   84.64   84.74   85.26   85.25   86.33   86.80
 4    82.62   83.53   83.84   84.14   84.43   84.69   84.81   85.43   85.65   84.99

                  REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1     5255    5298    5331    5347    5361    5383    5394    5410    5446    5457
 2     5251    5311    5331    5341    5366    5379    5395    5405    5452    5468
 3     5257    5311    5336    5336    5378    5385    5418    5417    5487    5517
 4     5249    5307    5327    5346    5365    5381    5389    5429    5443    5401

                    INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1      481     487     482     482     485     482     483     486     484     475
 2      484     480     484     483     484     485     487     487     489     491
 3      480     482     480     486     478     482     473     483     469     452
 4      485     482     485     481     485     484     490     477     492     516

                           *---------------*
                            RUN NUMBER 1175
                           *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      154     134     120     117     116     110     110     109      99      97
 2      158     125     121     120     114     113     111     110      98      97
 3      152     125     118     124     108     110     100     105      85      77
 4      161     127     123     118     115     112     114     100     102     128

                           *---------------*
                            RUN NUMBER 1175
                                SUMMARY
                           *---------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   5058.70    5.93     6.4   2.085   2.007   79.61   82.69   62.22   40.84
 2   5068.25    5.92    15.5   2.081   1.987   79.76   83.53   62.22   33.36
 3   5077.80    5.90    24.6   2.077   1.978   79.91   83.91   62.21   31.46
 4   5087.35    5.89    33.7   2.073   1.974   80.06   84.08   62.21   31.29
 5   5096.92    5.88    42.8   2.069   1.964   80.21   84.48   62.21   29.52
 6   5106.49    5.87    52.0   2.065   1.959   80.37   84.70   62.21   29.01
 7   5116.06    5.85    61.1   2.061   1.953   80.52   84.96   62.21   28.30
 8   5125.65    5.84    70.2   2.057   1.947   80.67   85.22   62.21   27.66
 9   5135.24    5.83    79.3   2.053   1.932   80.82   85.86   62.21   24.96
10   5144.84    5.82    88.4   2.050   1.931   80.97   85.92   62.20   25.43

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
             RUN NUMBER 1179
      TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -     2.38   GPM
MASS FLOW RATE       -   1188.6   LBM/HR
MASS FLUX            -   181086   LBM/(SQ.FT-HR)
FLUID VELOCITY       -      .80   FT/S
ROOM TEMPERATURE     -    80.38   F
INLET TEMPERATURE    -    78.71   F
OUTLET TEMPERATURE   -    79.61   F
AVERAGE RE NUMBER    -     7897
AVERAGE PR NUMBER    -     5.97
CURRENT TO TUBE      -    205.0   AMPS
VOLTAGE DROP IN TUBE -     1.64   VOLTS
AVERAGE HEAT FLUX    -      463   BTU/(SQ.FT-HR)
Q-AMP*VOLT           -     1147   BTU/HR
Q-M*C*(T2-T1)        -     1068   BTU/HR
HEAT BALANCE ERROR   -     6.88   %

               OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1   80.83   81.29   81.48   81.66   81.93   82.12   82.22   82.49   83.39   83.44
2   80.95   81.41   81.54   81.68   82.03   82.14   82.29   82.44   83.43   83.59
3   81.17   81.55   81.69   81.68   82.25   82.30   82.74   82.65   83.76   84.04
4   80.92   81.41   81.49   81.75   81.97   82.16   82.27   83.14   83.18   82.20

               INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1   80.58   81.04   81.23   81.41   81.68   81.87   81.97   82.24   83.14   83.20
2   80.70   81.16   81.29   81.43   81.78   81.89   82.04   82.19   83.18   83.34
3   80.93   81.30   81.45   81.43   82.01   82.05   82.50   82.40   83.52   83.81
4   80.67   81.16   81.24   81.50   81.72   81.91   82.02   82.90   82.93   81.93

               REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

1    8037    8083    8102    8120    8147    8166    8176    8202    8293    8298
2    8049    8095    8108    8122    8157    8168    8182    8197    8296    8312
3    8072    8109    8123    8122    8179    8184    8228    8218    8330    8359
4    8046    8095    8103    8129    8151    8170    8180    8268    8271    8172

                 INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

1     429     429     427     428     428     427     428     434     425     413
2     427     426     427     426     428     428     431     430     430     430
3     420     423     422     427     420     423     415     430     415     398
4     428     426     429     424     429     428     432     412     436     465

                          *---------------*
                           RUN NUMBER 1179
                          *---------------*

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

        1       2       3       4       5       6       7       8       9      10

1     236     196     186     179     167     160     159     151     115     113
2     221     185     182     177     160     159     156     152     115     113
3     195     172     168     178     145     148     129     142     102      93
4     225     185     186     171     165     158     158     117     126     195

                          *---------------*
                           RUN NUMBER 1179
                               SUMMARY
                          *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   7859.36   6.00     6.4   2.106   2.056   78.77   80.72   62.22   57.01
 2   7867.86   5.99    15.5   2.104   2.045   78.86   81.17   62.22   48.13
 3   7876.36   5.98    24.6   2.102   2.041   78.94   81.30   62.22   47.14
 4   7884.86   5.98    33.7   2.100   2.038   79.03   81.45   62.22   46.05
 5   7893.37   5.97    42.8   2.097   2.029   79.12   81.80   62.22   41.49
 6   7901.88   5.96    52.0   2.095   2.026   79.20   81.93   62.22   40.74
 7   7910.40   5.96    61.1   2.093   2.021   79.29   82.13   62.22   39.12
 8   7918.91   5.95    70.2   2.090   2.013   79.38   82.43   62.22   36.39
 9   7927.44   5.94    79.3   2.088   1.995   79.46   83.19   62.22   29.83
10   7935.96   5.93    88.4   2.086   1.998   79.55   83.07   62.22   31.60

                 NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                       MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *----------------------------------------*
                              RUN NUMBER 1177
                      TEST FLUID IS DISTILLED WATER
                 *----------------------------------------*

                 VOLUMETRIC FLOW RATE -      2.14   GPM
                 MASS FLOW RATE       -    1067.2   LBM/HR
                 MASS FLUX            -    162598   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -       .72   FT/S
                 ROOM TEMPERATURE     -     80.91   F
                 INLET TEMPERATURE    -     78.90   F
                 OUTLET TEMPERATURE   -     79.62   F
                 AVERAGE RE NUMBER    -      7100
                 AVERAGE PR NUMBER    -      5.96
                 CURRENT TO TUBE      -     178.0   AMPS
                 VOLTAGE DROP IN TUBE -      1.42   VOLTS
                 AVERAGE HEAT FLUX    -       348   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -       862   BTU/HR
                 Q=M*C*(T2-T1)        -       767   BTU/HR
                 HEAT BALANCE ERROR   -     11.03   %

                     OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    80.83   81.15   81.37   81.40   81.67   81.83   81.90   82.15   84.62   84.53
 2    80.84   81.19   81.31   81.40   81.72   81.82   81.97   82.07   82.89   82.94
 3    81.01   81.38   81.39   81.31   81.87   81.88   82.31   82.13   83.18   83.39
 4    80.81   81.22   81.25   81.49   81.69   81.85   81.96   82.70   82.76   81.80

                     INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    80.64   80.96   81.18   81.21   81.48   81.64   81.71   81.96   84.46   84.37
 2    80.65   81.00   81.12   81.21   81.53   81.63   81.78   81.88   82.69   82.74
 3    80.83   81.20   81.21   81.12   81.69   81.69   82.13   81.94   83.00   83.22
 4    80.62   81.03   81.06   81.31   81.50   81.66   81.77   82.52   82.56   81.58

                     REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1     7222    7251    7271    7273    7297    7311    7318    7340    7565    7557
 2     7223    7254    7265    7273    7302    7311    7324    7333    7405    7410
 3     7239    7272    7272    7265    7315    7316    7355    7338    7433    7453
 4     7220    7257    7260    7281    7299    7313    7323    7390    7393    7306

                       INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1      321     322     319     322     322     321     323     327     277     268
 2      323     323     323     320     322     322     325     323     346     347
 3      316     317     318     324     317     320     313     328     313     296
 4      324     322     324     318     323     321     325     307     350     375

                                *---------------*
                                 RUN NUMBER 1177
                                *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      189     165     152     156     142     137     137     129      56      55
 2      189     162     158     155     139     137     134     132     108     109
 3      168     145     150     165     129     133     113     130      89      81
 4      193     160     164     148     142     135     135      99     114     186

                                *---------------*
                                 RUN NUMBER 1177
                                     SUMMARY
                                *---------------*

ST      RE        PR      X/D     MUB     MUW      TB      TW     DENS     NU

 1    7072.64    5.98     6.4    2.102   2.057   78.95   80.69   62.22   48.23
 2    7078.75    5.98    15.5    2.100   2.048   79.02   81.05   62.22   41.26
 3    7084.86    5.97    24.6    2.098   2.045   79.09   81.14   62.22   40.75
 4    7090.97    5.97    33.7    2.096   2.044   79.16   81.21   62.22   40.73
 5    7097.09    5.96    42.8    2.094   2.035   79.23   81.55   62.22   36.03
 6    7103.20    5.95    52.0    2.093   2.032   79.29   81.66   62.22   35.45
 7    7109.32    5.95    61.1    2.091   2.028   79.36   81.85   62.22   33.74
 8    7115.44    5.94    70.2    2.089   2.022   79.43   82.08   62.22   31.72
 9    7121.57    5.94    79.3    2.087   1.995   79.50   83.18   62.22   22.83
10    7127.69    5.93    88.4    2.085   2.000   79.57   82.98   62.22   24.62

                      NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                            MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *----------------------------------------*
                              RUN NUMBER 1184
                        TEST FLUID IS DISTILLED WATER
                 *----------------------------------------*

                 VOLUMETRIC FLOW RATE -     4.43   GPM
                 MASS FLOW RATE       -   2208.7   LBM/HR
                 MASS FLUX            -   336507   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -     1.49   FT/S
                 ROOM TEMPERATURE     -    81.44   F
                 INLET TEMPERATURE    -    78.96   F
                 OUTLET TEMPERATURE   -    80.46   F
                 AVERAGE RE NUMBER    -    14776
                 AVERAGE PR NUMBER    -     5.92
                 CURRENT TO TUBE      -    345.0   AMPS
                 VOLTAGE DROP IN TUBE -     2.70   VOLTS
                 AVERAGE HEAT FLUX    -     1283   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -     3178   BTU/HR
                 Q=M*C*(T2-T1)        -     3308   BTU/HR
                 HEAT BALANCE ERROR   -    -4.08   %

                  OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    83.23   83.51   83.91   84.05   84.30   84.47   84.66   84.93   85.50   85.67
 2    83.20   83.72   83.88   84.09   84.45   84.59   84.80   84.99   85.95   86.34
 3    83.82   84.45   84.26   84.33   85.17   85.34   85.95   85.95   87.32   87.95
 4    83.22   83.69   83.73   84.07   84.30   84.62   84.73   85.46   85.66   84.95

                  INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    82.53   82.81   83.21   83.35   83.60   83.77   83.96   84.23   84.79   84.97
 2    82.50   83.02   83.18   83.39   83.75   83.89   84.09   84.28   85.24   85.63
 3    83.13   83.76   83.57   83.63   84.48   84.65   85.27   85.26   86.64   87.28
 4    82.52   82.99   83.02   83.37   83.59   83.92   84.02   84.76   84.95   84.22

                  REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1    15296   15348   15423   15449   15495   15527   15562   15612   15719   15752
 2    15290   15387   15417   15456   15523   15549   15588   15623   15803   15877
 3    15408   15525   15489   15502   15660   15692   15808   15807   16067   16189
 4    15294   15381   15388   15452   15494   15555   15574   15713   15748   15612

                    INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1     1209    1215    1207    1211    1212    1214    1214    1218    1220    1212
 2     1217    1216    1215    1212    1217    1218    1223    1222    1223    1223
 3     1194    1191    1198    1204    1190    1192    1181    1193    1173    1154
 4     1217    1217    1219    1213    1221    1218    1225    1210    1230    1259

                              *----------------*
                              RUN NUMBER 1184
                              *----------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      348     337     312     314     306     304     301     293     266     262
 2      354     319     317     311     296     297     293     290     243     232
 3      293     261     284     290     245     245     221     229     182     166
 4      352     322     331     313     308     294     299     258     260     325

                              *----------------*
                              RUN NUMBER 1184
                                  SUMMARY
                              *----------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   14657.80   5.97    6.4   2.099   2.008   79.06   82.67   62.22   87.42
 2   14684.16   5.96   15.5   2.095   1.996   79.21   83.14   62.22   80.09
 3   14710.53   5.95   24.6   2.091   1.994   79.35   83.24   62.22   80.94
 4   14736.93   5.94   33.7   2.087   1.989   79.49   83.43   62.22   80.00
 5   14763.34   5.93   42.8   2.084   1.979   79.64   83.85   62.22   74.77
 6   14789.77   5.91   52.0   2.080   1.974   79.78   84.05   62.22   73.80
 7   14816.22   5.90   61.1   2.076   1.968   79.93   84.33   62.21   71.52
 8   14842.69   5.89   70.2   2.073   1.961   80.07   84.63   62.21   69.12
 9   14869.17   5.88   79.3   2.069   1.943   80.21   85.41   62.21   60.74
10   14895.68   5.87   88.4   2.065   1.940   80.36   85.53   62.21   61.03

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*----------------------------------------*
            RUN NUMBER 1186
     TEST FLUID IS DISTILLED WATER
*----------------------------------------*

VOLUMETRIC FLOW RATE -     2.36   GPM
MASS FLOW RATE       -   1177.8   LBM/HR
MASS FLUX            -   179442   LBM/(SQ.FT-HR)
FLUID VELOCITY       -      .80   FT/S
ROOM TEMPERATURE     -    83.07   F
INLET TEMPERATURE    -    78.51   F
OUTLET TEMPERATURE   -    81.46   F
AVERAGE RE NUMBER    -     7906
AVERAGE PR NUMBER    -     5.90
CURRENT TO TUBE      -    355.0   AMPS
VOLTAGE DROP IN TUBE -     2.80   VOLTS
AVERAGE HEAT FLUX    -     1369   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -     3391   BTU/HR
Q=M*C*(T2-T1)        -     3469   BTU/HR
HEAT BALANCE ERROR   -    -2.29   %

          OUTSIDE SURFACE TEMPERATURES - DEGREES F

       1      2      3      4      5      6      7      8      9     10

1   85.03  85.77  86.54  86.87  87.15  87.62  87.94  88.29  88.99  89.28
2   85.09  86.17  86.56  86.84  87.36  87.65  88.07  88.39  89.43  89.92
3   85.61  86.80  86.81  87.04  88.04  88.33  89.17  89.31  90.83  91.64
4   85.00  86.03  86.36  86.76  87.25  87.69  87.90  88.69  89.06  88.59

          INSIDE SURFACE TEMPERATURES - DEGREES F

       1      2      3      4      5      6      7      8      9     10

1   84.29  85.02  85.80  86.13  86.41  86.88  87.20  87.54  88.24  88.54
2   84.35  85.43  85.82  86.10  86.61  86.90  87.32  87.64  88.68  89.17
3   84.88  86.07  86.07  86.30  87.31  87.60  88.44  88.58  90.11  90.93
4   84.25  85.28  85.61  86.02  86.50  86.94  87.15  87.95  88.31  87.82

          REYNOLDS NUMBER AT THE INSIDE TUBE WALL

       1      2      3      4      5      6      7      8      9     10

1    8331   8405   8483   8516   8544   8591   8624   8659   8730   8760
2    8337   8445   8485   8513   8565   8594   8636   8669   8774   8824
3    8390   8510   8510   8533   8635   8664   8750   8764   8921   9005
4    8328   8431   8464   8505   8554   8598   8619   8700   8736   8687

            INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

       1      2      3      4      5      6      7      8      9     10

1    1283   1292   1281   1282   1288   1286   1286   1292   1293   1286
2    1288   1286   1286   1286   1290   1293   1297   1296   1298   1300
3    1268   1265   1275   1278   1266   1268   1255   1266   1246   1226
4    1290   1289   1291   1289   1293   1292   1301   1288   1308   1334

                    *----------------*
                     RUN NUMBER 1186
                    *----------------*

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

       1      2      3      4      5      6      7      8      9     10

1     229    214    196    195    196    190    189    188    178    176
2     228    199    196    196    190    190    187    186    168    164
3     205    178    187    189    169    169    156    160    136    126
4     232    205    203    199    194    189    193    177    178    203

                    *----------------*
                     RUN NUMBER 1186
                         SUMMARY
                    *----------------*

ST     RE       PR     X/D    MUB    MUW     TB     TW    DENS     NU

 1  7781.95   6.00    6.4  2.108  1.965  78.71  84.44  62.23  58.34
 2  7809.55   5.98   15.5  2.101  1.942  78.99  85.45  62.22  51.80
 3  7837.19   5.96   24.6  2.093  1.933  79.28  85.83  62.22  51.07
 4  7864.87   5.93   33.7  2.086  1.926  79.56  86.14  62.22  50.86
 5  7892.59   5.91   42.8  2.078  1.913  79.84  86.71  62.21  48.72
 6  7920.35   5.89   52.0  2.071  1.905  80.13  87.08  62.21  48.09
 7  7948.14   5.86   61.1  2.064  1.895  80.41  87.53  62.21  46.98
 8  7975.97   5.84   70.2  2.057  1.886  80.69  87.93  62.21  46.22
 9  8003.84   5.82   79.3  2.050  1.866  80.98  88.83  62.20  42.56
10  8031.75   5.80   88.4  2.042  1.860  81.26  89.11  62.20  42.57

          NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                *----------------------------------------*
                          RUN NUMBER 1191
                   TEST FLUID IS DISTILLED WATER
                *----------------------------------------*

                VOLUMETRIC FLOW RATE -     2.36   GPM
                MASS FLOW RATE       -   1179.8   LBM/HR
                MASS FLUX            -   179745   LBM/(SQ.FT-HR)
                FLUID VELOCITY       -      .80   FT/S
                ROOM TEMPERATURE     -    75.72   F
                INLET TEMPERATURE    -    77.96   F
                OUTLET TEMPERATURE   -    78.70   F
                AVERAGE RE NUMBER    -     7758
                AVERAGE PR NUMBER    -     6.04
                CURRENT TO TUBE      -    180.0   AMPS
                VOLTAGE DROP IN TUBE -     1.42   VOLTS
                AVERAGE HEAT FLUX    -      352   BTU/(SQ.FT-HR)
                Q-AMP*VOLT           -      872   BTU/HR
                Q-M*C*(T2-T1)        -      871   BTU/HR
                HEAT BALANCE ERROR   -      .03   %

                   OUTSIDE SURFACE TEMPERATURES - DEGREES F

       1       2       3       4       5       6       7       8       9      10

1    80.02   80.10   80.36   80.52   80.58   80.75   80.81   80.90   81.40   81.49
2    80.01   80.33   80.42   80.50   80.71   80.77   80.87   80.90   81.54   81.66
3    80.09   80.44   80.42   80.43   80.88   80.83   81.16   80.98   81.96   82.27
4    79.99   80.32   80.35   80.57   80.63   80.80   80.74   81.33   81.40   80.65

                   INSIDE SURFACE TEMPERATURES - DEGREES F

       1       2       3       4       5       6       7       8       9      10

1    79.83   79.91   80.17   80.33   80.39   80.56   80.62   80.71   81.21   81.30
2    79.82   80.14   80.23   80.31   80.52   80.58   80.68   80.71   81.35   81.47
3    79.90   80.25   80.23   80.24   80.69   80.64   80.97   80.79   81.78   82.09
4    79.80   80.13   80.16   80.38   80.44   80.61   80.55   81.14   81.21   80.44

                   REYNOLDS NUMBER AT THE INSIDE TUBE WALL

       1       2       3       4       5       6       7       8       9      10

1    7904    7912    7937    7953    7959    7976    7982    7990    8040    8049
2    7903    7935    7943    7951    7972    7978    7987    7990    8053    8065
3    7911    7945    7943    7944    7989    7984    8017    7998    8096    8127
4    7901    7934    7936    7958    7964    7981    7974    8033    8039    7964

                   INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

       1       2       3       4       5       6       7       8       9      10

1     328     334     329     329     330     329     328     334     330     320
2     329     327     327     328     329     329     331     329     332     334
3     326     325     327     331     323     327     320     332     316     301
4     330     327     329     326     331     328     334     319     335     359

                             *---------------*
                              RUN NUMBER 1191
                             *---------------*

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

       1       2       3       4       5       6       7       8       9      10

1     180     183     163     156     158     150     150     151     125     120
2     182     158     157     157     147     148     147     149     120     118
3     172     150     157     164     134     144     126     145      99      87
4     184     159     164     151     154     146     158     121     127     200

                             *---------------*
                              RUN NUMBER 1191
                                  SUMMARY
                             *---------------*

ST     RE       PR     X/D    MUB     MUW     TB      TW     DENS     NU

1   7727.17   6.06    6.4   2.126   2.079   78.01   79.84   62.23   46.94
2   7734.08   6.06   15.5   2.125   2.072   78.08   80.11   62.23   42.33
3   7740.99   6.05   24.6   2.123   2.069   78.15   80.20   62.23   41.93
4   7747.90   6.04   33.7   2.121   2.066   78.22   80.31   62.23   41.01
5   7754.81   6.04   42.8   2.119   2.061   78.29   80.51   62.23   38.72
6   7761.73   6.03   52.0   2.117   2.059   78.37   80.60   62.23   38.43
7   7768.65   6.03   61.1   2.115   2.056   78.44   80.70   62.23   37.82
8   7775.57   6.02   70.2   2.113   2.053   78.51   80.84   62.23   36.82
9   7782.50   6.01   79.3   2.111   2.039   78.58   81.38   62.23   30.58
10  7789.43   6.01   88.4   2.109   2.041   78.65   81.33   62.23   32.05

                   NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                         MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                  *----------------------------------------*
                               RUN NUMBER 1193
                        TEST FLUID IS DISTILLED WATER
                  *----------------------------------------*

                  VOLUMETRIC FLOW RATE -      2.39   GPM
                  MASS FLOW RATE       -    1193.3   LBM/HR
                  MASS FLUX            -    181801   LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -       .81   FT/S
                  ROOM TEMPERATURE     -     75.16   F
                  INLET TEMPERATURE    -     77.84   F
                  OUTLET TEMPERATURE   -     78.55   F
                  AVERAGE RE NUMBER    -      7833
                  AVERAGE PR NUMBER    -      6.05
                  CURRENT TO TUBE      -     180.0   AMPS
                  VOLTAGE DROP IN TUBE -      1.42   VOLTS
                  AVERAGE HEAT FLUX    -       352   BTU/(SQ.FT-HR)
                  Q=AMP*VOLT           -       872   BTU/HR
                  Q=M*C*(T2-T1)        -       846   BTU/HR
                  HEAT BALANCE ERROR   -      2.99   %


                    OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

  1     80.01   80.25   80.29   80.43   80.48   80.65   80.67   80.78   81.22   81.33
  2     80.01   80.32   80.38   80.41   80.61   80.65   80.73   80.76   81.37   81.50
  3     80.17   80.24   80.44   80.33   80.77   80.70   80.99   80.89   81.82   82.12
  4     79.88   80.31   80.27   80.49   80.54   80.67   80.62   81.16   81.26   80.52


                    INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

  1     79.82   80.06   80.10   80.24   80.29   80.46   80.48   80.59   81.03   81.14
  2     79.82   80.13   80.19   80.22   80.42   80.46   80.54   80.57   81.18   81.31
  3     79.98   80.05   80.25   80.14   80.58   80.51   80.80   80.70   81.64   81.94
  4     79.69   80.12   80.08   80.30   80.35   80.48   80.43   80.97   81.07   80.31


                    REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

  1     7994    8017    8021    8035    8040    8057    8059    8070    8114    8125
  2     7993    8024    8030    8033    8053    8057    8065    8068    8128    8141
  3     8010    8016    8036    8025    8069    8062    8091    8081    8174    8205
  4     7980    8023    8019    8041    8046    8059    8054    8108    8117    8042


                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

  1      326     330     329     329     331     328     328     333     331     320
  2      330     326     328     327     329     329     331     330     332     334
  3      323     330     325     331     323     327     320     330     316     301
  4      333     327     330     325     330     328     333     320     335     358


                              *---------------*
                               RUN NUMBER 1193
                              *---------------*

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

          1       2       3       4       5       6       7       8       9      10

  1      169     157     158     153     155     147     150     149     127     121
  2      171     150     151     154     145     147     147     150     121     119
  3      154     157     146     162     133     143     128     141      98      87
  4      185     151     161     147     151     146     156     123     127     198


                              *---------------*
                               RUN NUMBER 1193
                                   SUMMARY
                              *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   7803.59   6.07     6.4   2.130   2.079   77.89   79.83   62.23   44.23
 2   7810.29   6.07    15.5   2.128   2.072   77.96   80.09   62.23   40.20
 3   7816.99   6.06    24.6   2.126   2.070   78.02   80.15   62.23   40.26
 4   7823.70   6.06    33.7   2.124   2.069   78.09   80.22   62.23   40.22
 5   7830.40   6.05    42.8   2.122   2.064   78.16   80.41   62.23   38.14
 6   7837.11   6.04    52.0   2.121   2.062   78.23   80.48   62.23   38.16
 7   7843.82   6.04    61.1   2.119   2.060   78.30   80.56   62.23   37.87
 8   7850.54   6.03    70.2   2.117   2.056   78.37   80.71   62.23   36.63
 9   7857.25   6.03    79.3   2.115   2.043   78.43   81.23   62.23   30.71
10   7863.97   6.02    88.4   2.113   2.045   78.50   81.18   62.23   32.07

                    NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                          MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*----------------------------------------*
              RUN NUMBER 2101
       TEST FLUID IS DISTILLED WATER
*----------------------------------------*

 VOLUMETRIC FLOW RATE -      1.95    GPM
 MASS FLOW RATE       -     973.1    LBM/HR
 MASS FLUX            -    148254    LBM/(SQ.FT-HR)
 FLUID VELOCITY       -       .66    FT/S
 ROOM TEMPERATURE     -     68.28    F
 INLET TEMPERATURE    -     77.37    F
 OUTLET TEMPERATURE   -     80.92    F
 AVERAGE RE NUMBER    -      6464
 AVERAGE PR NUMBER    -      5.97
 CURRENT TO TUBE      -     345.0    AMPS
 VOLTAGE DROP IN TUBE -      2.69    VOLTS
 AVERAGE HEAT FLUX    -      1278    BTU/(SQ.FT-HR)
 Q=AMP*VOLT           -      3166    BTU/HR
 Q=M*C*(T2-T1)        -      3449    BTU/HR
 HEAT BALANCE ERROR   -     -8.93    %


              OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    85.06   86.24   86.97   87.36   87.47   88.07   88.36   88.75   89.48   89.78
 2    84.97   86.62   86.94   87.16   87.58   87.95   88.35   88.70   89.83   90.28
 3    85.45   86.94   87.25   87.27   88.19   88.38   89.31   89.37   91.01   91.90
 4    84.92   86.39   86.72   87.17   87.51   87.98   88.20   88.97   89.43   89.07

              INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    84.36   85.54   86.27   86.66   86.77   87.37   87.66   88.05   88.78   89.08
 2    84.27   85.92   86.24   86.46   86.88   87.25   87.64   87.99   89.12   89.57
 3    84.76   86.25   86.56   86.57   87.50   87.68   88.62   88.68   90.33   91.23
 4    84.21   85.69   86.01   86.47   86.80   87.28   87.49   88.27   88.72   88.34

              REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1    6889    6986    7048    7080    7089    7139    7164    7196    7257    7283
 2    6881    7018    7045    7063    7098    7129    7162    7192    7287    7324
 3    6922    7045    7071    7073    7150    7166    7245    7249    7389    7465
 4    6877    6999    7026    7064    7092    7131    7149    7215    7252    7221

              INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1    1208    1219    1209    1208    1215    1211    1212    1216    1219    1213
 2    1218    1211    1217    1217    1219    1220    1226    1223    1225    1229
 3    1198    1201    1202    1210    1197    1203    1188    1201    1180    1159
 4    1219    1217    1222    1216    1221    1220    1230    1216    1236    1260

                         *---------------*
                          RUN NUMBER 2101
                         *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1     178     160     151     150     155     150     151     151     144     144
 2     183     152     153     155     154     153     153     153     139     138
 3     167     144     145     152     140     143     132     138     118     109
 4     194     157     158     155     156     153     157     147     147     164

                         *---------------*
                          RUN NUMBER 2101
                              SUMMARY
                         *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   6341.32   6.10     6.4   2.137   1.966   77.61   84.40   62.24   46.58
 2   6368.62   6.07    15.5   2.128   1.933   77.95   85.85   62.23   40.08
 3   6395.97   6.04    24.6   2.119   1.923   78.29   86.27   62.23   39.67
 4   6423.36   6.01    33.7   2.110   1.917   78.63   86.54   62.23   40.01
 5   6450.79   5.98    42.8   2.101   1.907   78.97   86.99   62.22   39.48
 6   6478.28   5.95    52.0   2.092   1.898   79.32   87.39   62.22   39.15
 7   6505.81   5.93    61.1   2.083   1.887   79.66   87.85   62.22   38.58
 8   6533.38   5.90    70.2   2.074   1.879   80.00   88.25   62.21   38.33
 9   6561.00   5.87    79.3   2.066   1.857   80.34   89.24   62.21   35.54
10   6588.67   5.84    88.4   2.057   1.851   80.68   89.56   62.21   35.62

               NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                     MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                    *----------------------------------------*
                                RUN NUMBER 2103
                         TEST FLUID IS DISTILLED WATER
                    *----------------------------------------*

                    VOLUMETRIC FLOW RATE -      1.91   GPM
                    MASS FLOW RATE       -     954.9   LBM/HR
                    MASS FLUX            -    145485   LBM/(SQ.FT-HR)
                    FLUID VELOCITY       -       .65   FT/S
                    ROOM TEMPERATURE     -     69.93   F
                    INLET TEMPERATURE    -     77.03   F
                    OUTLET TEMPERATURE   -     78.60   F
                    AVERAGE RE NUMBER    -      6239
                    AVERAGE PR NUMBER    -      6.08
                    CURRENT TO TUBE      -     236.0   AMPS
                    VOLTAGE DROP IN TUBE -      1.84   VOLTS
                    AVERAGE HEAT FLUX    -       598   BTU/(SQ.FT-HR)
                    Q=AMP*VOLT           -      1481   BTU/HR
                    Q=M*C*(T2-T1)        -      1497   BTU/HR
                    HEAT BALANCE ERROR   -     -1.05   %

                      OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    80.78   81.26   81.57   81.72   81.79   82.10   82.17   82.38   82.96   83.10
 2    80.70   81.44   81.58   81.65   81.89   82.09   82.27   82.37   83.15   83.36
 3    80.91   81.42   81.72   81.62   82.19   82.20   82.70   82.65   83.78   84.23
 4    80.65   81.38   81.45   81.73   81.86   82.10   82.13   82.75   82.98   82.35

                      INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    80.45   80.93   81.24   81.39   81.46   81.77   81.84   82.05   82.63   82.78
 2    80.37   81.11   81.25   81.32   81.56   81.76   81.94   82.04   82.82   83.03
 3    80.59   81.09   81.40   81.29   81.87   81.87   82.38   82.32   83.46   83.92
 4    80.32   81.05   81.12   81.40   81.53   81.77   81.80   82.43   82.65   82.00

                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1     6447    6485    6510    6522    6527    6552    6558    6574    6621    6633
 2     6440    6500    6511    6516    6535    6551    6566    6574    6636    6653
 3     6458    6498    6522    6514    6560    6560    6601    6596    6688    6725
 4     6436    6495    6500    6523    6533    6552    6554    6605    6622    6571

                       INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1      562     569     564     564     567     565     566     570     568     560
 2      568     562     567     565     567     567     569     569     571     573
 3      559     565     560     567     557     563     553     563     548     531
 4      569     564     570     564     568     566     573     559     575     598

                                *---------------*
                                 RUN NUMBER 2103
                                *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      169     156     148     148     152     145     149     147     132     130
 2      175     147     148     151     148     146     146     147     127     126
 3      162     148     141     153     135     141     127     136     107      98
 4      178     149     154     147     150     146     152     132     133     170

                                *---------------*
                                 RUN NUMBER 2103
                                     SUMMARY
                                *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   6185.84    6.14     6.4   2.150   2.063   77.14   80.43   62.24   44.79
 2   6197.65    6.12    15.5   2.146   2.048   77.29   81.05   62.24   39.28
 3   6209.47    6.11    24.6   2.142   2.043   77.44   81.25   62.24   38.71
 4   6221.30    6.10    33.7   2.138   2.040   77.59   81.35   62.24   39.23
 5   6233.15    6.09    42.8   2.134   2.034   77.74   81.60   62.23   38.20
 6   6244.99    6.07    52.0   2.130   2.029   77.89   81.79   62.23   37.81
 7   6256.85    6.06    61.1   2.126   2.024   78.04   81.99   62.23   37.39
 8   6268.72    6.05    70.2   2.122   2.019   78.19   82.21   62.23   36.74
 9   6280.60    6.03    79.3   2.118   2.002   78.34   82.89   62.23   32.48
10   6292.48    6.02    88.4   2.114   2.001   78.49   82.93   62.23   33.27

                     NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                           MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                    *-----------------------------------------*
                                RUN NUMBER 2105
                          TEST FLUID IS DISTILLED WATER
                    *-----------------------------------------*

                    VOLUMETRIC FLOW RATE -     1.90   GPM
                    MASS FLOW RATE       -    950.7   LBM/HR
                    MASS FLUX            -   144838   LBM/(SQ.FT-HR)
                    FLUID VELOCITY       -      .64   FT/S
                    ROOM TEMPERATURE     -    70.54   F
                    INLET TEMPERATURE    -    77.09   F
                    OUTLET TEMPERATURE   -    78.45   F
                    AVERAGE RE NUMBER    -     6207
                    AVERAGE PR NUMBER    -     6.08
                    CURRENT TO TUBE      -    220.0   AMPS
                    VOLTAGE DROP IN TUBE -     1.72   VOLTS
                    AVERAGE HEAT FLUX    -      521   BTU/(SQ.FT-HR)
                    Q=AMP*VOLT           -     1291   BTU/HR
                    Q=M*C*(T2-T1)        -     1291   BTU/HR
                    HEAT BALANCE ERROR   -      .00   %


                      OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    80.52   80.93   81.19   81.31   81.36   81.65   81.71   81.89   82.44   82.56
 2    80.44   81.08   81.21   81.24   81.48   81.63   81.80   81.88   82.58   82.81
 3    80.63   80.99   81.28   81.18   81.73   81.69   82.18   82.10   83.16   83.58
 4    80.38   81.02   81.08   81.33   81.45   81.66   81.66   82.28   82.43   81.77


                      INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    80.24   80.64   80.91   81.03   81.07   81.37   81.42   81.60   82.15   82.28
 2    80.15   80.80   80.93   80.96   81.19   81.34   81.51   81.59   82.29   82.52
 3    80.35   80.70   81.00   80.89   81.45   81.41   81.90   81.82   82.88   83.31
 4    80.09   80.74   80.79   81.05   81.16   81.38   81.37   82.00   82.14   81.47


                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

 1     6401    6433    6454    6464    6468    6491    6495    6510    6554    6563
 2     6395    6446    6456    6458    6477    6489    6502    6509    6565    6583
 3     6410    6438    6461    6453    6497    6494    6533    6526    6612    6646
 4     6390    6441    6445    6465    6475    6491    6491    6541    6552    6499


                        INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

 1      488     494     490     490     493     491     491     496     493     485
 2      494     488     491     491     492     492     495     494     497     498
 3      485     492     487     493     484     490     480     490     475     459
 4      495     489     495     489     493     491     498     484     500     523


                                 *---------------*
                                  RUN NUMBER 2105
                                 *---------------*

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

          1       2       3       4       5       6       7       8       9      10

 1      159     148     141     142     146     139     142     141     125     123
 2      166     140     141     145     141     140     139     141     122     119
 3      153     145     137     148     129     137     122     132     102      92
 4      170     143     147     140     142     138     146     124     128     168


                                 *---------------*
                                  RUN NUMBER 2105
                                      SUMMARY
                                 *---------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   6161.87    6.13     6.4   2.149   2.069   77.18   80.21   62.24   42.39
 2   6172.06    6.12    15.5   2.145   2.056   77.31   80.72   62.24   37.65
 3   6182.26    6.11    24.6   2.142   2.051   77.44   80.91   62.24   37.06
 4   6192.46    6.10    33.7   2.138   2.049   77.57   80.98   62.24   37.66
 5   6202.67    6.09    42.8   2.135   2.043   77.70   81.22   62.23   36.49
 6   6212.88    6.08    52.0   2.131   2.040   77.84   81.37   62.23   36.26
 7   6223.11    6.07    61.1   2.128   2.035   77.97   81.55   62.23   35.76
 8   6233.34    6.06    70.2   2.124   2.030   78.10   81.75   62.23   35.08
 9   6243.57    6.04    79.3   2.121   2.015   78.23   82.37   62.23   30.99
10   6253.82    6.03    88.4   2.117   2.014   78.36   82.40   62.23   31.78

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *----------------------------------------*
                              RUN NUMBER 2111
                       TEST FLUID IS DISTILLED WATER
                 *----------------------------------------*

                 VOLUMETRIC FLOW RATE -     1.55   GPM
                 MASS FLOW RATE       -    772.8   LBM/HR
                 MASS FLUX            -   117739   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -      .52   FT/S
                 ROOM TEMPERATURE     -    70.40   F
                 INLET TEMPERATURE    -    76.29   F
                 OUTLET TEMPERATURE   -    77.72   F
                 AVERAGE RE NUMBER    -     4997
                 AVERAGE PR NUMBER    -     6.15
                 CURRENT TO TUBE      -    205.0   AMPS
                 VOLTAGE DROP IN TUBE -     1.59   VOLTS
                 AVERAGE HEAT FLUX    -      448   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -     1112   BTU/HR
                 Q=M*C*(T2-T1)        -     1103   BTU/HR
                 HEAT BALANCE ERROR   -      .76   %


                  OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    79.65   80.20   80.53   80.64   80.68   80.98   81.08   81.28   81.85   81.97
 2    79.60   80.31   80.51   80.55   80.80   80.96   81.15   81.25   81.96   82.16
 3    79.73   80.17   80.53   80.41   80.97   80.93   81.42   81.33   82.41   82.82
 4    79.52   80.26   80.40   80.64   80.76   80.99   81.04   81.63   81.81   81.14


                  INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    79.40   79.95   80.28   80.39   80.43   80.73   80.83   81.03   81.60   81.73
 2    79.35   80.06   80.26   80.30   80.55   80.71   80.90   81.00   81.71   81.91
 3    79.49   79.92   80.28   80.16   80.73   80.68   81.18   81.08   82.17   82.59
 4    79.27   80.01   80.15   80.39   80.51   80.74   80.79   81.39   81.56   80.88


                  REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1    5150    5185    5206    5214    5216    5235    5242    5255    5292    5300
 2    5147    5192    5205    5208    5224    5234    5246    5253    5299    5311
 3    5155    5183    5206    5199    5235    5232    5264    5258    5328    5355
 4    5141    5189    5198    5214    5221    5236    5239    5278    5289    5245


                    INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1     423     428     424     425     428     426     426     430     427     418
 2     428     423     426     425     426     426     429     427     430     432
 3     421     428     424     430     421     427     418     429     413     397
 4     430     424     429     423     428     425     431     418     434     457


                              *---------------*
                               RUN NUMBER 2111
                              *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1     140     124     117     118     122     116     117     116     103     102
 2     144     119     118     121     118     117     116     117     102     100
 3     136     126     117     128     111     118     105     114      88      80
 4     149     121     123     117     119     115     120     103     106     140


                              *---------------*
                               RUN NUMBER 2111
                                   SUMMARY
                              *---------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1    4958.75   6.20    6.4   2.171   2.090   76.39   79.38   62.25   37.24
 2    4967.43   6.19   15.5   2.167   2.075   76.52   79.99   62.25   32.17
 3    4976.11   6.18   24.6   2.163   2.068   76.66   80.25   62.24   31.10
 4    4984.80   6.17   33.7   2.159   2.066   76.80   80.31   62.24   31.72
 5    4993.49   6.16   42.8   2.155   2.060   76.94   80.56   62.24   30.80
 6    5002.19   6.14   52.0   2.152   2.056   77.07   80.72   62.24   30.58
 7    5010.89   6.13   61.1   2.148   2.051   77.21   80.93   62.24   30.00
 8    5019.60   6.12   70.2   2.144   2.046   77.35   81.13   62.24   29.50
 9    5028.32   6.11   79.3   2.141   2.030   77.49   81.76   62.24   26.08
10    5037.04   6.10   88.4   2.137   2.030   77.62   81.78   62.24   26.84

                NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                      MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                  *----------------------------------------*
                               RUN NUMBER 4101
                        TEST FLUID IS DISTILLED WATER
                  *----------------------------------------*

                  VOLUMETRIC FLOW RATE -      1.07   GPM
                  MASS FLOW RATE       -     532.7   LBM/HR
                  MASS FLUX            -     81156   LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -       .36   FT/S
                  ROOM TEMPERATURE     -     69.52   F
                  INLET TEMPERATURE    -     76.16   F
                  OUTLET TEMPERATURE   -     77.75   F
                  AVERAGE RE NUMBER    -      3442
                  AVERAGE PR NUMBER    -      6.15
                  CURRENT TO TUBE      -     178.0   AMPS
                  VOLTAGE DROP IN TUBE -      1.40   VOLTS
                  AVERAGE HEAT FLUX    -       343   BTU/(SQ.FT-HR)
                  Q=AMP*VOLT           -       850   BTU/HR
                  Q=M*C*(T2-T1)        -       845   BTU/HR
                  HEAT BALANCE ERROR   -       .52   %


                     OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1     79.08   80.26   80.96   81.23   81.08   81.40   81.44   81.78   82.40   82.58
2     79.03   80.19   80.69   80.87   81.09   81.22   81.42   81.62   82.33   82.57
3     79.13   79.96   80.67   80.66   81.16   81.12   81.57   81.52   82.56   82.99
4     78.98   80.14   80.72   81.08   81.14   81.30   81.42   82.03   82.27   81.68


                     INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1     78.89   80.08   80.78   81.05   80.89   81.22   81.25   81.59   82.22   82.40
2     78.84   80.00   80.50   80.68   80.90   81.03   81.23   81.43   82.14   82.38
3     78.95   79.77   80.48   80.47   80.97   80.93   81.39   81.33   82.38   82.82
4     78.79   79.95   80.53   80.90   80.95   81.11   81.23   81.85   82.08   81.48


                     REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

1      3527    3579    3611    3623    3616    3630    3632    3647    3675    3683
2      3525    3576    3598    3606    3616    3622    3631    3640    3671    3682
3      3529    3566    3597    3597    3619    3617    3638    3635    3682    3701
4      3523    3574    3600    3616    3618    3625    3631    3658    3669    3642


                       INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

1       319     318     315     315     322     318     321     322     319     310
2       322     319     324     323     322     322     323     322     325     327
3       317     326     322     329     320     325     317     329     315     300
4       324     320     323     318     321     320     323     312     327     349


                               *----------------*
                                RUN NUMBER 4101
                               *----------------*

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

        1       2       3       4       5       6       7       8       9      10

1       121      87      74      72      80      76      78      75      67      65
2       125      89      82      81      80      80      79      78      69      69
3       118      97      82      87      78      83      75      82      64      58
4       128      90      81      76      78      78      79      69      71      91


                               *----------------*
                                RUN NUMBER 4101
                                    SUMMARY
                               *----------------*

ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

1    3412.83   6.21     6.4   2.174   2.104   76.27   78.87   62.25   32.29
2    3419.48   6.20    15.5   2.170   2.076   76.42   79.95   62.25   23.80
3    3426.13   6.19    24.6   2.165   2.060   76.57   80.57   62.24   21.01
4    3432.78   6.17    33.7   2.161   2.055   76.73   80.77   62.24   20.77
5    3439.44   6.16    42.8   2.157   2.051   76.88   80.93   62.24   20.74
6    3446.11   6.15    52.0   2.153   2.047   77.03   81.07   62.24   20.79
7    3452.78   6.13    61.1   2.149   2.042   77.18   81.28   62.24   20.54
8    3459.46   6.12    70.2   2.145   2.035   77.34   81.55   62.24   19.94
9    3466.14   6.11    79.3   2.140   2.019   77.49   82.20   62.24   17.83
10   3472.82   6.09    88.4   2.136   2.017   77.64   82.27   62.24   18.17

                   NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                         MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *----------------------------------------*
                              RUN NUMBER 4103
                        TEST FLUID IS DISTILLED WATER
                 *----------------------------------------*

                 VOLUMETRIC FLOW RATE -      1.73   GPM
                 MASS FLOW RATE       -     863.0   LBM/HR
                 MASS FLUX            -    131486   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -       .58   FT/S
                 ROOM TEMPERATURE     -     72.68   F
                 INLET TEMPERATURE    -     76.96   F
                 OUTLET TEMPERATURE   -     78.31   F
                 AVERAGE RE NUMBER    -      5625
                 AVERAGE PR NUMBER    -      6.09
                 CURRENT TO TUBE      -     209.0   AMPS
                 VOLTAGE DROP IN TUBE -      1.64   VOLTS
                 AVERAGE HEAT FLUX    -       472   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -      1169   BTU/HR
                 Q=M*C*(T2-T1)        -      1163   BTU/HR
                 HEAT BALANCE ERROR   -       .51   %

                   OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1    79.80   80.45   80.74   80.93   81.08   81.38   81.49   81.70   82.30   82.46
2    79.78   80.55   80.76   80.86   81.19   81.38   81.55   81.69   82.44   82.64
3    79.96   80.45   80.85   80.76   81.38   81.39   81.86   81.79   82.92   83.38
4    79.77   80.55   80.71   80.98   81.19   81.38   81.50   82.09   82.32   81.61

                   INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

1    79.54   80.19   80.48   80.67   80.82   81.12   81.23   81.44   82.04   82.21
2    79.52   80.29   80.50   80.60   80.93   81.12   81.29   81.43   82.18   82.38
3    79.71   80.19   80.59   80.50   81.13   81.13   81.61   81.53   82.67   83.14
4    79.51   80.29   80.45   80.72   80.93   81.12   81.24   81.84   82.06   81.34

                   REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

1     5761    5808    5829    5842    5853    5875    5883    5898    5941    5953
2     5760    5815    5830    5837    5861    5875    5887    5897    5951    5966
3     5773    5808    5837    5830    5875    5876    5910    5904    5987    6021
4     5759    5815    5826    5846    5861    5875    5883    5926    5942    5890

                    INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

1      442     445     442     443     446     443     444     448     445     435
2      445     440     444     442     444     443     446     444     448     450
3      438     445     440     447     438     443     435     446     430     412
4      445     440     445     439     444     443     447     435     450     476

                             *---------------*
                              RUN NUMBER 4103
                             *---------------*

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

        1       2       3       4       5       6       7       8       9      10

1      177     147     139     137     137     129     130     128     112     109
2      180     141     139     140     132     129     129     128     109     108
3      165     147     134     146     123     129     115     124      93      83
4      181     141     141     133     132     129     131     112     113     152

                             *---------------*
                              RUN NUMBER 4103
                                  SUMMARY
                             *---------------*

ST     RE        PR      X/D     MUB     MUW      TB      TW     DENS     NU

 1   5584.60    6.15     6.4   2.152   2.085   77.05   79.57   62.24   45.93
 2   5593.77    6.13    15.5   2.149   2.068   77.18   80.24   62.24   37.80
 3   5602.96    6.12    24.6   2.145   2.061   77.31   80.51   62.24   36.21
 4   5612.14    6.11    33.7   2.142   2.058   77.44   80.63   62.24   36.35
 5   5621.34    6.10    42.8   2.138   2.050   77.57   80.95   62.24   34.22
 6   5630.54    6.09    52.0   2.135   2.046   77.70   81.13   62.23   33.79
 7   5639.74    6.08    61.1   2.131   2.040   77.83   81.34   62.23   32.96
 8   5648.96    6.07    70.2   2.128   2.035   77.96   81.56   62.23   32.15
 9   5658.17    6.06    79.3   2.124   2.018   78.09   82.24   62.23   27.91
10   5667.40    6.05    88.4   2.121   2.018   78.22   82.27   62.23   28.61

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
             RUN NUMBER 4105
      TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -      2.21   GPM
MASS FLOW RATE       -    1101.9   LBM/HR
MASS FLUX            -    167876   LBM/(SQ.FT-HR)
FLUID VELOCITY       -       .74   FT/S
ROOM TEMPERATURE     -     76.09   F
INLET TEMPERATURE    -     77.31   F
OUTLET TEMPERATURE   -     78.60   F
AVERAGE RE NUMBER    -      7211
AVERAGE PR NUMBER    -      6.07
CURRENT TO TUBE      -     233.0   AMPS
VOLTAGE DROP IN TUBE -      1.82   VOLTS
AVERAGE HEAT FLUX    -       584   BTU/(SQ.FT-HR)
Q-AMP*VOLT           -      1446   BTU/HR
Q-M*C*(T2-T1)        -      1419   BTU/HR
HEAT BALANCE ERROR   -      1.90   %


              OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1      2      3      4      5      6      7      8      9     10

1   80.26  80.82  81.03  81.26  81.43  81.68  81.80  82.00  82.53  82.68
2   80.29  80.93  81.11  81.25  81.55  81.71  81.88  82.03  82.72  82.94
3   80.56  80.99  81.24  81.24  81.84  81.88  82.31  82.29  83.32  83.82
4   80.13  80.92  81.02  81.30  81.51  81.71  81.82  82.38  82.57  81.93


              INSIDE SURFACE TEMPERATURES - DEGREES F

        1      2      3      4      5      6      7      8      9     10

1   79.94  80.50  80.71  80.94  81.11  81.36  81.48  81.68  82.21  82.36
2   79.97  80.61  80.79  80.93  81.23  81.39  81.56  81.71  82.40  82.62
3   80.25  80.67  80.92  80.92  81.52  81.56  82.00  81.97  83.01  83.52
4   79.81  80.60  80.70  80.98  81.19  81.39  81.50  82.06  82.25  81.59


              REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1      2      3      4      5      6      7      8      9     10

1    7392   7443   7463   7484   7500   7523   7534   7552   7601   7615
2    7395   7454   7470   7483   7511   7525   7541   7555   7619   7639
3    7420   7459   7482   7482   7538   7541   7581   7579   7675   7723
4    7380   7453   7462   7488   7507   7525   7535   7588   7604   7544


                INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1      2      3      4      5      6      7      8      9     10

1     549    553    551    551    553    552    552    556    554    545
2     553    550    551    550    553    552    555    554    556    559
3     541    549    546    551    543    546    539    549    534    517
4     557    550    553    549    554    552    557    545    560    584


                        *---------------*
                         RUN NUMBER 4105
                        *---------------*

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

        1      2      3      4      5      6      7      8      9     10

1     215    185    180    173    172    165    165    163    145    141
2     215    178    175    174    165    163    162    160    138    136
3     190    174    166    175    149    154    140    148    115    103
4     231    178    181    171    168    163    165    143    145    189


                        *---------------*
                         RUN NUMBER 4105
                             SUMMARY
                        *---------------*

ST      RE       PR     X/D    MUB     MUW     TB      TW     DENS     NU

 1   7161.43   6.12     6.4   2.143   2.075   77.40   79.99   62.24   55.44
 2   7172.64   6.10    15.5   2.140   2.059   77.52   80.60   62.24   46.79
 3   7183.86   6.09    24.6   2.136   2.054   77.64   80.78   62.24   45.88
 4   7195.09   6.08    33.7   2.133   2.050   77.77   80.94   62.23   45.32
 5   7206.33   6.07    42.8   2.130   2.042   77.89   81.26   62.23   42.69
 6   7217.57   6.06    52.0   2.126   2.038   78.02   81.43   62.23   42.20
 7   7228.82   6.05    61.1   2.123   2.033   78.14   81.63   62.23   41.20
 8   7240.07   6.04    70.2   2.120   2.028   78.27   81.86   62.23   40.07
 9   7251.34   6.03    79.3   2.116   2.013   78.39   82.47   62.23   35.30
10   7262.61   6.02    88.4   2.113   2.011   78.51   82.52   62.23   35.88

             NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                   MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
             RUN NUMBER 4107
      TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -      2.80   GPM
MASS FLOW RATE       -    1397.9   LBM/HR
MASS FLUX            -    212978   LBM/(SQ.FT-HR)
FLUID VELOCITY       -       .95   FT/S
ROOM TEMPERATURE     -     76.12   F
INLET TEMPERATURE    -     77.12   F
OUTLET TEMPERATURE   -     78.32   F
AVERAGE RE NUMBER    -      9122
AVERAGE PR NUMBER    -      6.09
CURRENT TO TUBE      -     250.0   AMPS
VOLTAGE DROP IN TUBE -      1.94   VOLTS
AVERAGE HEAT FLUX    -       668   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -      1654   BTU/HR
Q=M*C*(T2-T1)        -      1675   BTU/HR
HEAT BALANCE ERROR   -     -1.23   %

               OUTSIDE SURFACE TEMPERATURES - DEGREES F

       1      2      3      4      5      6      7      8      9      10

 1   80.26  80.68  80.87  81.02  81.20  81.30  81.41  81.54  82.01  82.14
 2   80.36  80.80  80.90  81.03  81.26  81.35  81.48  81.58  82.21  82.48
 3   80.63  80.96  81.07  81.09  81.59  81.64  82.01  81.94  82.95  83.41
 4   80.21  80.72  80.78  81.02  81.13  81.36  81.39  81.91  82.03  81.48

               INSIDE SURFACE TEMPERATURES - DEGREES F

       1      2      3      4      5      6      7      8      9      10

 1   79.89  80.31  80.50  80.65  80.83  80.93  81.04  81.17  81.64  81.77
 2   79.99  80.43  80.53  80.66  80.89  80.98  81.11  81.21  81.84  82.11
 3   80.27  80.60  80.71  80.72  81.23  81.28  81.65  81.58  82.59  83.06
 4   79.84  80.35  80.41  80.65  80.76  80.99  81.02  81.54  81.66  81.09

               REYNOLDS NUMBER AT THE INSIDE TUBE WALL

       1      2      3      4      5      6      7      8      9      10

 1    9373   9422   9444   9461   9482   9494   9507   9522   9577   9592
 2    9384   9436   9447   9462   9489   9500   9515   9526   9600   9632
 3    9416   9455   9467   9470   9528   9534   9578   9569   9688   9744
 4    9367   9426   9433   9461   9474   9501   9504   9565   9579   9513

                 INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

       1      2      3      4      5      6      7      8      9      10

 1     634    636    633    634    634    635    635    639    637    630
 2     636    634    635    634    637    637    640    638    641    642
 3     625    629    628    632    624    627    620    629    614    599
 4     639    636    638    635    640    637    642    630    645    667

                         *----------------*
                          RUN NUMBER 4107
                         *----------------*

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

       1      2      3      4      5      6      7      8      9      10

 1     235    212    206    204    200    201    201    202    181    178
 2     227    203    205    203    197    199    199    199    172    165
 3     203    191    191    199    175    179    165    176    137    124
 4     242    209    214    204    206    198    205    178    182    233

                         *----------------*
                          RUN NUMBER 4107
                              SUMMARY
                         *----------------*

ST     RE       PR     X/D    MUB     MUW     TB     TW     DENS    NU

 1   9062.98   6.13    6.4   2.148   2.074  77.20  80.00   62.24  59.23
 2   9076.20   6.12   15.5   2.145   2.064  77.32  80.42   62.24  53.33
 3   9089.43   6.11   24.6   2.142   2.061  77.43  80.54   62.24  53.33
 4   9102.67   6.10   33.7   2.139   2.057  77.55  80.67   62.24  52.99
 5   9115.91   6.09   42.8   2.136   2.051  77.66  80.93   62.24  50.72
 6   9129.16   6.08   52.0   2.133   2.048  77.78  81.04   62.23  50.70
 7   9142.42   6.07   61.1   2.130   2.044  77.89  81.20   62.23  50.01
 8   9155.69   6.06   70.2   2.127   2.040  78.01  81.37   62.23  49.19
 9   9168.96   6.05   79.3   2.123   2.026  78.12  81.93   62.23  43.50
10   9182.25   6.04   88.4   2.120   2.024  78.24  82.01   62.23  43.93

               NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                     MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                       *----------------------------------------*
                                   RUN NUMBER 4109
                             TEST FLUID IS DISTILLED WATER
                       *----------------------------------------*

                       VOLUMETRIC FLOW RATE -      3.28   GPM
                       MASS FLOW RATE       -    1635.1   LBM/HR
                       MASS FLUX            -    249114   LBM/(SQ.FT-HR)
                       FLUID VELOCITY       -      1.11   FT/S
                       ROOM TEMPERATURE     -     74.13   F
                       INLET TEMPERATURE    -     76.78   F
                       OUTLET TEMPERATURE   -     77.94   F
                       AVERAGE RE NUMBER    -     10622
                       AVERAGE PR NUMBER    -      6.12
                       CURRENT TO TUBE      -     270.0   AMPS
                       VOLTAGE DROP IN TUBE -      2.12   VOLTS
                       AVERAGE HEAT FLUX    -       788   BTU/(SQ.FT-HR)
                       Q-AMP*VOLT           -      1953   BTU/HR
                       Q-M*C*(T2-T1)        -      1894   BTU/HR
                       HEAT BALANCE ERROR   -      3.01   %


                        OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    80.05   80.36   80.58   80.73   80.84   81.03   81.13   81.32   81.80   81.98
 2    80.05   80.49   80.60   80.71   80.95   81.07   81.24   81.34   82.06   82.33
 3    80.42   80.62   80.77   80.74   81.37   81.40   81.87   81.80   82.98   83.41
 4    79.96   80.42   80.46   80.74   80.86   81.11   81.12   81.67   81.87   81.25


                        INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    79.62   79.93   80.15   80.30   80.41   80.60   80.70   80.89   81.37   81.55
 2    79.62   80.06   80.17   80.28   80.52   80.64   80.81   80.91   81.63   81.90
 3    80.00   80.19   80.34   80.31   80.95   80.98   81.45   81.38   82.57   83.00
 4    79.53   79.99   80.03   80.31   80.43   80.68   80.69   81.24   81.43   80.80


                        REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

 1    10927   10968   10999   11019   11034   11060   11073   11099   11164   11190
 2    10926   10986   11001   11016   11048   11065   11088   11102   11200   11237
 3    10977   11004   11025   11020   11107   11111   11176   11165   11329   11389
 4    10914   10977   10982   11020   11036   11070   11071   11147   11173   11087


                          INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

 1      738     741     738     739     741     741     741     744     744     735
 2      743     739     741     740     743     743     746     745     748     749
 3      728     735     733     739     728     732     722     732     714     700
 4      746     741     744     739     745     742     749     737     753     776


                                  *----------------*
                                   RUN NUMBER 4109
                                  *----------------*

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

          1       2       3       4       5       6       7       8       9      10

 1      267     250     240     237     238     232     233     229     205     199
 2      269     239     239     239     231     230     227     228     193     185
 3      232     228     224     237     199     205     184     196     148     136
 4      279     245     252     237     238     227     237     204     204     264


                                  *----------------*
                                   RUN NUMBER 4109
                                       SUMMARY
                                  *----------------*

ST        RE      PR     X/D     MUB     MUW      TB      TW    DENS      NU

 1  10554.81    6.16     6.4   2.158   2.082   76.86   79.69   62.24   68.20
 2  10569.73    6.15    15.5   2.155   2.073   76.97   80.04   62.24   62.87
 3  10584.67    6.14    24.6   2.152   2.070   77.08   80.17   62.24   62.48
 4  10599.61    6.13    33.7   2.148   2.067   77.19   80.30   62.24   62.17
 5  10614.56    6.12    42.8   2.145   2.060   77.30   80.58   62.24   59.06
 6  10629.51    6.11    52.0   2.142   2.056   77.42   80.72   62.24   58.42
 7  10644.48    6.10    61.1   2.139   2.051   77.53   80.91   62.24   57.10
 8  10659.45    6.09    70.2   2.136   2.046   77.64   81.10   62.24   55.77
 9  10674.44    6.08    79.3   2.133   2.030   77.75   81.75   62.23   48.34
10  10689.43    6.08    88.4   2.130   2.029   77.86   81.81   62.23   48.91

                         NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                               MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                      *-----------------------------------------*
                                    RUN NUMBER 4115
                             TEST FLUID IS DISTILLED WATER
                      *-----------------------------------------*

                      VOLUMETRIC FLOW RATE -      3.28   GPM
                      MASS FLOW RATE       -    1638.3   LBM/HR
                      MASS FLUX            -    249611   LBM/(SQ.FT-HR)
                      FLUID VELOCITY       -      1.11   FT/S
                      ROOM TEMPERATURE     -     74.36   F
                      INLET TEMPERATURE    -     76.07   F
                      OUTLET TEMPERATURE   -     81.48   F
                      AVERAGE RE NUMBER    -     10834
                      AVERAGE PR NUMBER    -      6.00
                      CURRENT TO TUBE      -     480.0   AMPS
                      VOLTAGE DROP IN TUBE -      3.78   VOLTS
                      AVERAGE HEAT FLUX    -      2499   BTU/(SQ.FT-HR)
                      Q-AMP*VOLT           -      6190   BTU/HR
                      Q=M*C*(T2-T1)        -      8851   BTU/HR
                      HEAT BALANCE ERROR   -    -42.97   %

                          OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    88.53   89.92   90.86   91.51   91.63   92.45   92.85   93.49   94.31   94.76
 2    88.38   90.39   90.87   91.22   91.75   92.25   92.89   93.35   94.89   95.74
 3    89.43   91.30   91.41   91.70   92.94   93.49   94.70   95.00   97.12   98.50
 4    88.20   89.99   90.50   91.05   91.60   92.37   92.51   93.57   94.23   94.25

                          INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    87.18   88.56   89.50   90.16   90.27   91.09   91.49   92.13   92.95   93.40
 2    87.01   89.03   89.51   89.86   90.38   90.88   91.52   91.98   93.52   94.37
 3    88.09   89.96   90.06   90.35   91.60   92.15   93.37   93.66   95.80   97.19
 4    86.83   88.62   89.13   89.68   90.23   91.00   91.13   92.20   92.85   92.86

                          REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

 1    11993   12188   12323   12416   12432   12550   12607   12698   12816   12881
 2    11971   12255   12323   12373   12448   12519   12611   12677   12899   13022
 3    12122   12387   12402   12443   12622   12701   12877   12920   13230   13434
 4    11945   12198   12270   12348   12426   12537   12555   12709   12802   12803

                            INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

 1     2344    2360    2349    2345    2357    2353    2355    2359    2368    2369
 2     2365    2358    2360    2364    2369    2375    2380    2382    2382    2384
 3     2320    2324    2335    2340    2323    2326    2306    2319    2294    2271
 4     2370    2369    2370    2369    2373    2372    2390    2376    2399    2423

                                    *----------------*
                                     RUN NUMBER 4115
                                    *----------------*

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

          1       2       3       4       5       6       7       8       9      10

 1      218     203     195     192     200     195     197     195     191     192
 2      223     195     196     199     199     200     198     200     184     179
 3      199     178     185     189     177     177     166     170     150     141
 4      227     203     203     202     202     198     206     195     195     206

                                    *----------------*
                                     RUN NUMBER 4115
                                         SUMMARY
                                    *----------------*

ST      RE        PR      X/D     MUB     MUW      TB      TW     DENS      NU

 1   10519.10    6.20     6.4   2.169   1.900   76.43   87.28   62.25   56.69
 2   10588.76    6.15    15.5   2.155   1.862   76.95   89.04   62.24   50.88
 3   10658.60    6.11    24.6   2.141   1.851   77.47   89.55   62.24   50.91
 4   10728.63    6.06    33.7   2.127   1.841   77.99   90.01   62.23   51.15
 5   10798.84    6.02    42.8   2.113   1.828   78.51   90.62   62.23   50.75
 6   10869.22    5.98    52.0   2.099   1.814   79.04   91.28   62.22   50.16
 7   10939.79    5.93    61.1   2.086   1.802   79.56   91.88   62.22   49.83
 8   11010.54    5.89    70.2   2.072   1.790   80.08   92.49   62.21   49.44
 9   11081.47    5.85    79.3   2.059   1.764   80.60   93.78   62.21   46.58
10   11152.57    5.81    88.4   2.046   1.751   81.12   94.45   62.20   46.03

                          NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                                MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
```

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                   *----------------------------------------*
                              RUN NUMBER 4117
                       TEST FLUID IS DISTILLED WATER
                   *----------------------------------------*

                   VOLUMETRIC FLOW RATE -      2.10   GPM
                   MASS FLOW RATE       -    1050.3   LBM/HR
                   MASS FLUX            -    160012   LBM/(SQ.FT-HR)
                   FLUID VELOCITY       -       .71   FT/S
                   ROOM TEMPERATURE     -     73.68   F
                   INLET TEMPERATURE    -     76.00   F
                   OUTLET TEMPERATURE   -     82.28   F
                   AVERAGE RE NUMBER    -      6976
                   AVERAGE PR NUMBER    -      5.97
                   CURRENT TO TUBE      -     480.0   AMPS
                   VOLTAGE DROP IN TUBE -      3.79   VOLTS
                   AVERAGE HEAT FLUX    -      2505   BTU/(SQ.FT-HR)
                   Q-AMP*VOLT           -      6207   BTU/HR
                   Q-M*C*(T2-T1)        -      6586   BTU/HR
                   HEAT BALANCE ERROR   -     -6.10   %

                     OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

  1    89.61   91.60   92.92   93.58   93.76   94.56   95.04   95.70   96.50   97.25
  2    89.47   91.86   92.54   92.94   93.45   94.05   94.74   95.37   96.92   97.78
  3    90.40   92.52   92.91   93.13   94.49   94.95   96.31   96.65   99.00  100.62
  4    89.16   91.47   92.21   92.76   93.41   94.14   94.52   95.54   96.43   96.40

                     INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

  1    88.26   90.24   91.57   92.23   92.41   93.21   93.69   94.34   95.14   95.89
  2    88.11   90.50   91.18   91.58   92.08   92.68   93.37   94.00   95.55   96.40
  3    89.06   91.17   91.56   91.78   93.15   93.60   94.98   95.31   97.67   99.31
  4    87.79   90.10   90.84   91.39   92.04   92.77   93.14   94.17   95.05   95.00

                     REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

  1    7786    7967    8088    8149    8165    8240    8284    8345    8419    8490
  2    7772    7990    8052    8089    8136    8191    8254    8313    8458    8538
  3    7859    8052    8087    8107    8234    8276    8404    8435    8657    8812
  4    7744    7954    8022    8072    8132    8199    8234    8329    8411    8407

                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

  1    2344    2357    2343    2339    2350    2348    2351    2356    2370    2363
  2    2365    2360    2366    2368    2376    2378    2385    2383    2386    2395
  3    2323    2333    2343    2350    2331    2338    2317    2331    2304    2274
  4    2373    2370    2375    2373    2377    2375    2391    2378    2398    2431

                              *----------------*
                               RUN NUMBER 4117
                              *----------------*

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

         1       2       3       4       5       6       7       8       9      10

  1     198     178     168     167     173     170     172     172     170     168
  2     202     175     174     177     179     179     179     178     166     164
  3     183     164     168     173     162     165     155     159     140     130
  4     208     181     179     180     180     178     182     175     173     184

                              *----------------*
                               RUN NUMBER 4117
                                   SUMMARY
                              *----------------*

 ST      RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

  1   6742.24   6.20     6.4   2.170   1.878   76.42   88.30   62.25   51.79
  2   6794.09   6.15    15.5   2.153   1.830   77.03   90.50   62.24   45.68
  3   6846.09   6.10    24.6   2.137   1.814   77.63   91.29   62.24   45.07
  4   6898.25   6.04    33.7   2.121   1.805   78.23   91.74   62.23   45.54
  5   6950.57   5.99    42.8   2.105   1.791   78.84   92.42   62.22   45.28
  6   7003.04   5.94    52.0   2.089   1.778   79.44   93.07   62.22   45.12
  7   7055.67   5.89    61.1   2.073   1.764   80.05   93.79   62.21   44.70
  8   7108.45   5.84    70.2   2.058   1.751   80.65   94.46   62.21   44.50
  9   7161.38   5.80    79.3   2.043   1.724   81.25   95.85   62.20   42.09
 10   7214.47   5.75    88.4   2.028   1.709   81.86   96.65   62.20   41.52

                     NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                           MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*---------------------------------------*
            RUN NUMBER 4119
     TEST FLUID IS DISTILLED WATER
*---------------------------------------*

VOLUMETRIC FLOW RATE -      2.26   GPM
MASS FLOW RATE       -    1125.9   LBM/HR
MASS FLUX            -    171542   LBM/(SQ.FT-HR)
FLUID VELOCITY       -       .76   FT/S
ROOM TEMPERATURE     -     74.64   F
INLET TEMPERATURE    -     76.05   F
OUTLET TEMPERATURE   -     81.96   F
AVERAGE RE NUMBER    -      7466
AVERAGE PR NUMBER    -      5.98
CURRENT TO TUBE      -     481.0   AMPS
VOLTAGE DROP IN TUBE -      3.80   VOLTS
AVERAGE HEAT FLUX    -      2517   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -      6236   BTU/HR
Q=M*C*(T2-T1)        -      6644   BTU/HR
HEAT BALANCE ERROR   =     -6.54   %


              OUTSIDE SURFACE TEMPERATURES - DEGREES F

      1      2      3      4      5      6      7      8      9     10

1   88.82  90.66  91.81  92.44  92.58  93.38  93.87  94.60  95.61  96.17
2   88.80  90.99  91.65  91.96  92.57  93.08  93.79  94.42  96.03  96.92
3   89.80  91.71  92.04  92.23  93.66  94.12  95.53  95.87  98.17  99.65
4   88.61  90.65  91.27  91.83  92.50  93.19  93.59  94.64  95.50  95.38

              INSIDE SURFACE TEMPERATURES - DEGREES F

      1      2      3      4      5      6      7      8      9     10

1   87.46  89.29  90.45  91.08  91.22  92.02  92.51  93.24  94.24  94.80
2   87.43  89.62  90.28  90.59  91.20  91.71  92.41  93.04  94.65  95.54
3   88.45  90.36  90.68  90.87  92.31  92.77  94.19  94.52  96.84  98.34
4   87.24  89.28  89.90  90.46  91.13  91.82  92.21  93.27  94.11  93.98

              REYNOLDS NUMBER AT THE INSIDE TUBE WALL

      1      2      3      4      5      6      7      8      9     10

1    8269   8448   8561   8623   8636   8716   8764   8836   8936   8992
2    8267   8480   8545   8575   8635   8685   8755   8817   8977   9066
3    8366   8552   8584   8602   8745   8790   8931   8965   9197   9348
4    8248   8446   8507   8562   8628   8696   8734   8839   8924   8910

               INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

      1      2      3      4      5      6      7      8      9     10

1    2358   2368   2356   2352   2366   2362   2365   2369   2378   2375
2    2373   2369   2372   2375   2381   2385   2392   2391   2395   2399
3    2332   2341   2350   2357   2338   2342   2321   2336   2310   2283
4    2378   2378   2382   2379   2383   2382   2398   2385   2409   2439

                       *---------------*
                        RUN NUMBER 4119
                       *---------------*

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

      1      2      3      4      5      6      7      8      9     10

1     214    192    183    181    189    185    187    184    179    179
2     216    187    186    190    190    192    190    189    175    171
3     194    175    179    185    172    173    161    165    145    136
4     220    193    193    193    192    190    194    185    183    196

                       *---------------*
                        RUN NUMBER 4119
                            SUMMARY
                       *---------------*

ST     RE       PR    X/D    MUB    MUW     TB      TW    DENS     NU

 1  7230.37   6.20    6.4  2.169  1.892  76.45  87.64  62.25  55.15
 2  7282.68   6.15   15.5  2.153  1.849  77.02  89.64  62.24  48.95
 3  7335.14   6.10   24.6  2.138  1.834  77.58  90.33  62.24  48.47
 4  7387.74   6.05   33.7  2.123  1.825  78.15  90.75  62.23  49.01
 5  7440.50   6.00   42.8  2.108  1.811  78.72  91.46  62.23  48.44
 6  7493.40   5.96   52.0  2.093  1.798  79.29  92.08  62.22  48.24
 7  7546.45   5.91   61.1  2.078  1.783  79.86  92.83  62.21  47.55
 8  7599.65   5.86   70.2  2.063  1.769  80.43  93.52  62.21  47.10
 9  7652.99   5.82   79.3  2.049  1.741  80.99  94.96  62.20  44.16
10  7706.48   5.77   88.4  2.035  1.727  81.56  95.66  62.20  43.73

                NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                      MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*----------------------------------------*
            RUN NUMBER 4121
      TEST FLUID IS DISTILLED WATER
*----------------------------------------*

VOLUMETRIC FLOW RATE -      2.31   GPM
MASS FLOW RATE       -    1152.6   LBM/HR
MASS FLUX            -    175608   LBM/(SQ.FT-HR)
FLUID VELOCITY       -       .78   FT/S
ROOM TEMPERATURE     -     77.29   F
INLET TEMPERATURE    -     76.46   F
OUTLET TEMPERATURE   -     82.27   F
AVERAGE RE NUMBER    -      7678
AVERAGE PR NUMBER    -      5.95
CURRENT TO TUBE      -     483.0   AMPS
VOLTAGE DROP IN TUBE -      3.81   VOLTS
AVERAGE HEAT FLUX    -      2534   BTU/(SQ.FT-HR)
Q-AMP*VOLT           -      6279   BTU/HR
Q-M*C*(T2-T1)        -      6687   BTU/HR
HEAT BALANCE ERROR   -     -6.50   %

             OUTSIDE SURFACE TEMPERATURES - DEGREES F

       1      2      3      4      5      6      7      8      9      10

1    88.64  90.53  91.70  92.33  92.61  93.41  94.00  94.67  95.76  96.28
2    88.73  90.90  91.55  91.93  92.59  93.17  93.93  94.58  96.21  97.08
3    89.74  91.70  91.98  92.27  93.73  94.29  95.70  96.08  98.45  99.85
4    88.49  90.57  91.18  91.79  92.51  93.30  93.79  94.80  95.71  95.56

             INSIDE SURFACE TEMPERATURES - DEGREES F

       1      2      3      4      5      6      7      8      9      10

1    87.27  89.15  90.33  90.96  91.24  92.04  92.63  93.29  94.38  94.90
2    87.35  89.52  90.17  90.55  91.21  91.78  92.54  93.19  94.82  95.69
3    88.38  90.34  90.61  90.90  92.37  92.93  94.35  94.72  97.11  98.52
4    87.11  89.19  89.80  90.41  91.13  91.92  92.40  93.42  94.31  94.15

             REYNOLDS NUMBER AT THE INSIDE TUBE WALL

       1      2      3      4      5      6      7      8      9      10

1    8446   8634   8752   8816   8843   8924   8964   9051   9162   9216
2    8455   8671   8736   8774   8840   8899   8975   9041   9207   9296
3    8557   8753   8781   8809   8958   9015   9159   9197   9443   9589
4    8431   8638   8698   8760   8832   8912   8961   9064   9155   9138

              INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

       1      2      3      4      5      6      7      8      9      10

1    2379   2389   2376   2373   2385   2384   2386   2391   2399   2396
2    2391   2389   2392   2395   2401   2405   2413   2411   2416   2419
3    2350   2358   2369   2375   2356   2360   2341   2354   2328   2302
4    2398   2397   2401   2398   2404   2402   2416   2405   2429   2459

                        *---------------*
                         RUN NUMBER 4121
                        *---------------*

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

       1      2      3      4      5      6      7      8      9      10

1     228    203    192    190    196    192    192    190    183    184
2     227    197    196    199    198    198    195    193    178    175
3     203    182    187    191    177    177    165    168    147    138
4     233    203    203    201    199    195    198    190    186    200

                        *---------------*
                         RUN NUMBER 4121
                             SUMMARY
                        *---------------*

ST     RE       PR     X/D     MUB     MUW     TB      TW     DENS    NU

 1  7439.76   6.16     6.4   2.158   1.895   76.85   87.53   62.24   58.29
 2  7492.51   6.11    15.5   2.143   1.851   77.41   89.55   62.24   51.29
 3  7545.41   6.07    24.6   2.128   1.836   77.97   90.23   62.23   50.78
 4  7598.45   6.02    33.7   2.113   1.826   78.53   90.70   62.23   51.09
 5  7651.64   5.97    42.8   2.098   1.810   79.09   91.48   62.22   50.17
 6  7704.98   5.93    52.0   2.084   1.796   79.64   92.17   62.22   49.66
 7  7758.46   5.88    61.1   2.069   1.780   80.20   92.98   62.21   48.67
 8  7812.08   5.84    70.2   2.055   1.766   80.76   93.66   62.21   48.21
 9  7865.85   5.79    79.3   2.041   1.737   81.32   95.16   62.20   44.94
10  7919.77   5.75    88.4   2.027   1.724   81.88   95.82   62.20   44.60

             NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                   MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *-----------------------------------------*
                              RUN NUMBER 4123
                        TEST FLUID IS DISTILLED WATER
                 *-----------------------------------------*

                 VOLUMETRIC FLOW RATE =      2.40   GPM
                 MASS FLOW RATE       =    1197.0   LBM/HR
                 MASS FLUX            =    182364   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       =       .81   FT/S
                 ROOM TEMPERATURE     =     77.57   F
                 INLET TEMPERATURE    =     77.54   F
                 OUTLET TEMPERATURE   =     83.06   F
                 AVERAGE RE NUMBER    =      8066
                 AVERAGE PR NUMBER    =      5.87
                 CURRENT TO TUBE      =     483.0   AMPS
                 VOLTAGE DROP IN TUBE =      3.81   VOLTS
                 AVERAGE HEAT FLUX    =      2534   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           =      6279   BTU/HR
                 Q=M*C*(T2-T1)        =      6597   BTU/HR
                 HEAT BALANCE ERROR   =     -5.07   %


                   OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1     89.43   91.14   92.22   92.82   93.07   93.88   94.39   95.04   96.03   96.56
 2     89.53   91.53   92.13   92.49   93.14   93.68   94.42   95.02   96.56   97.43
 3     90.57   92.26   92.59   92.86   94.32   94.84   96.21   96.53   98.85  100.31
 4     89.30   91.16   91.81   92.37   93.08   93.82   94.17   95.25   96.01   95.88


                   INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1     88.06   89.76   90.85   91.45   91.69   92.51   93.01   93.66   94.65   95.18
 2     88.15   90.15   90.75   91.11   91.76   92.29   93.03   93.63   95.17   96.04
 3     89.21   90.90   91.22   91.49   92.96   93.48   94.86   95.17   97.51   98.99
 4     87.92   89.78   90.43   90.99   91.70   92.44   92.78   93.87   94.61   94.47


                   REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

 1      8853    9030    9143    9206    9231    9317    9370    9439    9543    9600
 2      8862    9070    9133    9170    9238    9295    9372    9436    9599    9691
 3      8973    9148    9182    9210    9365    9419    9566    9599    9849   10008
 4      8838    9031    9099    9157    9232    9309    9345    9460    9539    9524


                     INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

 1      2381    2390    2379    2376    2389    2386    2388    2394    2401    2398
 2      2393    2388    2392    2395    2402    2406    2412    2411    2416    2420
 3      2351    2360    2369    2375    2356    2360    2340    2355    2327    2299
 4      2399    2398    2401    2398    2403    2402    2419    2405    2430    2461


                             *---------------*
                              RUN NUMBER 4123
                             *---------------*

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

         1       2       3       4       5       6       7       8       9      10

 1       234     211     200     198     204     199     200     198     192     192
 2       233     203     203     206     204     205     202     200     185     181
 3       208     189     193     198     182     182     170     173     151     141
 4       239     211     209     208     206     202     207     196     195     208


                             *---------------*
                              RUN NUMBER 4123
                                  SUMMARY
                             *---------------*

ST       RE       PR      X/D     MUB     MUW      TB      TW     DENS     NU

 1    7830.10    6.07     6.4   2.129   1.877   77.91   88.33   62.23   59.65
 2    7882.41    6.03    15.5   2.115   1.838   78.44   90.15   62.23   53.14
 3    7934.87    5.98    24.6   2.101   1.824   78.97   90.81   62.22   52.52
 4    7987.46    5.94    33.7   2.087   1.815   79.50   91.26   62.22   52.88
 5    8040.18    5.89    42.8   2.073   1.799   80.03   92.03   62.21   51.82
 6    8093.05    5.85    52.0   2.060   1.786   80.57   92.68   62.21   51.29
 7    8146.04    5.81    61.1   2.047   1.771   81.10   93.42   62.20   50.40
 8    8199.18    5.77    70.2   2.033   1.758   81.63   94.08   62.20   49.85
 9    8252.44    5.73    79.3   2.020   1.731   82.16   95.49   62.19   46.61
10    8305.85    5.68    88.4   2.007   1.718   82.69   96.17   62.19   46.07

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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              *---------------------------------------*
                          RUN NUMBER 4128
                   TEST FLUID IS DISTILLED WATER
              *---------------------------------------*

              VOLUMETRIC FLOW RATE -     2.42   GPM
              MASS FLOW RATE       -   1208.0   LBM/HR
              MASS FLUX            -   184043   LBM/(SQ.FT-HR)
              FLUID VELOCITY       -      .82   FT/S
              ROOM TEMPERATURE     -    75.95   F
              INLET TEMPERATURE    -    78.17   F
              OUTLET TEMPERATURE   -    83.46   F
              AVERAGE RE NUMBER    -     8192
              AVERAGE PR NUMBER    -     5.83
              CURRENT TO TUBE      -    474.0   AMPS
              VOLTAGE DROP IN TUBE -     3.72   VOLTS
              AVERAGE HEAT FLUX    -     2428   BTU/(SQ.FT-HR)
              Q=AMP*VOLT           -     6016   BTU/HR
              Q=M*C*(T2-T1)        -     6380   BTU/HR
              HEAT BALANCE ERROR   -    -6.05   %

                 OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    89.89   91.42   92.36   92.98   93.17   94.04   94.50   95.07   96.01   96.59
 2    89.65   91.80   92.34   92.70   93.33   93.89   94.54   95.15   96.67   97.51
 3    90.78   92.59   92.88   93.15   94.53   94.99   96.27   96.64   98.90  100.32
 4    89.52   91.49   92.01   92.54   93.20   93.93   94.29   95.28   96.12   96.03

                 INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1    88.57   90.09   91.04   91.66   91.84   92.72   93.18   93.74   94.68   95.26
 2    88.32   90.47   91.01   91.37   92.00   92.56   93.20   93.81   95.33   96.17
 3    89.47   91.28   91.57   91.83   93.22   93.68   94.97   95.34   97.61   99.05
 4    88.18   90.16   90.68   91.21   91.87   92.60   92.95   93.95   94.78   94.67

                 REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1     8988    9147    9247    9313    9332    9425    9474    9534    9634    9697
 2     8961    9187    9244    9282    9349    9408    9477    9542    9705    9795
 3     9082    9273    9303    9331    9479    9528    9666    9705    9951   10107
 4     8948    9154    9209    9265    9335    9412    9450    9556    9645    9633

                   INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1     2286    2303    2293    2289    2303    2298    2300    2307    2316    2312
 2     2311    2302    2305    2308    2313    2317    2323    2321    2325    2330
 3     2263    2272    2279    2285    2267    2273    2254    2266    2240    2214
 4     2315    2310    2313    2312    2316    2316    2330    2318    2340    2369

                             *---------------*
                              RUN NUMBER 4128
                             *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1      227     208     199     197     204     197     198     197     191     190
 2      236     201     201     203     202     201     199     197     182     178
 3      206     185     189     193     179     180     168     171     149     138
 4      239     207     207     207     204     200     204     195     192     204

                             *---------------*
                              RUN NUMBER 4128
                                  SUMMARY
                             *---------------*

ST     RE       PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   7963.32   6.02    6.4   2.113   1.870   78.53   88.64   62.23   59.18
 2   8014.07   5.98   15.5   2.099   1.831   79.03   90.50   62.22   52.22
 3   8064.95   5.93   24.6   2.086   1.819   79.54   91.07   62.22   51.91
 4   8115.95   5.89   33.7   2.073   1.809   80.05   91.52   62.21   52.18
 5   8167.08   5.85   42.8   2.060   1.795   80.56   92.23   62.21   51.25
 6   8218.33   5.81   52.0   2.047   1.782   81.07   92.89   62.20   50.60
 7   8269.71   5.77   61.1   2.034   1.768   81.58   93.57   62.20   49.84
 8   8321.21   5.73   70.2   2.022   1.755   82.09   94.21   62.19   49.31
 9   8372.84   5.69   79.3   2.009   1.728   82.60   95.60   62.19   45.98
10   8424.59   5.65   88.4   1.997   1.715   83.10   96.29   62.18   45.35

                NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                      MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*----------------------------------------*
              RUN NUMBER 4132
       TEST FLUID IS DISTILLED WATER
*----------------------------------------*

VOLUMETRIC FLOW RATE -      3.38   GPM
MASS FLOW RATE       -    1685.2   LBM/HR
MASS FLUX            -    256746   LBM/(SQ.FT-HR)
FLUID VELOCITY       -      1.14   FT/S
ROOM TEMPERATURE     -     77.10   F
INLET TEMPERATURE    -     75.21   F
OUTLET TEMPERATURE   -     77.63   F
AVERAGE RE NUMBER    -     10817
AVERAGE PR NUMBER    -      6.20
CURRENT TO TUBE      -     380.0   AMPS
VOLTAGE DROP IN TUBE -      3.00   VOLTS
AVERAGE HEAT FLUX    -      1570   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -      3889   BTU/HR
Q=M*C*(T2-T1)        -      4073   BTU/HR
HEAT BALANCE ERROR   -     -4.71   %

          OUTSIDE SURFACE TEMPERATURES - DEGREES F

       1       2       3       4       5       6       7       8       9      10

1    81.47   82.11   82.49   82.81   83.01   83.38   83.63   84.00   84.55   84.79
2    81.40   82.37   82.58   82.82   83.25   83.51   83.84   84.17   85.06   85.51
3    82.33   83.04   83.06   83.20   84.14   84.46   85.15   85.34   86.72   87.68
4    81.39   82.06   82.36   82.71   83.07   83.52   83.73   84.36   84.68   84.27

          INSIDE SURFACE TEMPERATURES - DEGREES F

       1       2       3       4       5       6       7       8       9      10

1    80.62   81.26   81.64   81.96   82.16   82.53   82.78   83.15   83.70   83.94
2    80.54   81.52   81.73   81.97   82.40   82.65   82.98   83.31   84.20   84.65
3    81.49   82.20   82.22   82.36   83.30   83.62   84.32   84.51   85.90   86.87
4    80.53   81.20   81.50   81.86   82.21   82.66   82.87   83.51   83.82   83.39

          REYNOLDS NUMBER AT THE INSIDE TUBE WALL

       1       2       3       4       5       6       7       8       9      10

1    11401   11491   11545   11590   11618   11670   11706   11758   11836   11871
2    11390   11528   11557   11591   11652   11688   11735   11782   11909   11973
3    11524   11624   11627   11646   11781   11826   11925   11952   12151   12292
4    11389   11483   11526   11575   11626   11690   11719   11809   11854   11793

          INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

       1       2       3       4       5       6       7       8       9      10

1     1464    1469    1466    1466    1471    1471    1472    1475    1478    1472
2     1478    1471    1471    1471    1475    1478    1482    1481    1484    1487
3     1442    1445    1451    1456    1442    1443    1433    1441    1422    1399
4     1478    1479    1477    1474    1480    1478    1484    1476    1493    1519

                    *----------------*
                     RUN NUMBER 4132
                    *----------------*

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

       1       2       3       4       5       6       7       8       9      10

1      278     259     252     248     251     245     245     240     228     227
2      285     248     249     249     242     241     238     234     212     207
3      235     219     227     231     206     203     189     192     164     148
4      286     264     260     254     250     241     243     227     226     256

                    *----------------*
                     RUN NUMBER 4132
                         SUMMARY
                    *----------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1   10674.18    6.29     6.4   2.199   2.054   75.37   80.80   62.26   70.77
 2   10706.04    6.27    15.5   2.192   2.035   75.61   81.55   62.25   64.65
 3   10737.93    6.25    24.6   2.186   2.030   75.84   81.77   62.25   64.71
 4   10769.87    6.23    33.7   2.179   2.023   76.07   82.04   62.25   64.37
 5   10801.83    6.21    42.8   2.173   2.011   76.30   82.52   62.25   61.79
 6   10833.84    6.19    52.0   2.166   2.003   76.54   82.87   62.25   60.64
 7   10865.89    6.17    61.1   2.160   1.994   76.77   83.24   62.24   59.34
 8   10897.97    6.15    70.2   2.154   1.985   77.00   83.62   62.24   58.02
 9   10930.09    6.13    79.3   2.147   1.966   77.23   84.40   62.24   53.57
10   10962.25    6.11    88.4   2.141   1.959   77.47   84.71   62.24   52.99

              NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                    MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                *---------------------------------------*
                            RUN NUMBER 4134
                     TEST FLUID IS DISTILLED WATER
                *---------------------------------------*

                VOLUMETRIC FLOW RATE -      3.38   GPM
                MASS FLOW RATE       -    1687.4   LBM/HR
                MASS FLUX            -    257089   LBM/(SQ.FT-HR)
                FLUID VELOCITY       -      1.14   FT/S
                ROOM TEMPERATURE     -     73.26   F
                INLET TEMPERATURE    -     74.97   F
                OUTLET TEMPERATURE   -     77.56   F
                AVERAGE RE NUMBER    -     10810
                AVERAGE PR NUMBER    -      6.21
                CURRENT TO TUBE      -     390.0   AMPS
                VOLTAGE DROP IN TUBE -      3.07   VOLTS
                AVERAGE HEAT FLUX    -      1649   BTU/(SQ.FT-HR)
                Q-AMP*VOLT           -      4085   BTU/HR
                Q-M*C*(T2-T1)        -      4365   BTU/HR
                HEAT BALANCE ERROR   -     -6.85   %


                  OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    81.75   82.32   82.77   83.04   83.14   83.48   83.68   83.99   84.53   84.83
 2    81.76   82.61   82.82   83.04   83.35   83.58   83.90   84.12   85.09   85.63
 3    82.57   83.26   83.27   83.40   84.26   84.53   85.25   85.34   86.85   87.78
 4    81.65   82.38   92.55   82.92   83.14   83.63   83.67   84.34   84.70   84.39


                  INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

 1    80.86   81.42   81.88   82.15   82.24   82.58   82.78   83.09   83.63   83.93
 2    80.86   81.71   81.92   82.14   82.45   82.68   83.00   83.22   84.19   84.73
 3    81.69   82.38   82.38   82.51   83.38   83.65   84.38   84.46   85.98   86.92
 4    80.75   81.48   81.65   82.02   82.24   82.73   82.76   83.44   83.79   83.47


                  REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

 1    11450   11529   11594   11632   11646   11694   11722   11766   11843   11886
 2    11450   11570   11600   11631   11675   11707   11753   11784   11922   11999
 3    11567   11664   11665   11684   11807   11845   11949   11961   12180   12316
 4    11434   11537   11561   11614   11645   11715   11719   11816   11866   11820


                   INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

 1     1543    1549    1543    1544    1548    1549    1549    1553    1557    1553
 2     1554    1549    1550    1550    1554    1556    1560    1560    1562    1565
 3     1522    1525    1530    1534    1520    1522    1509    1518    1498    1478
 4     1557    1555    1557    1553    1560    1555    1566    1555    1573    1596


                             *---------------*
                              RUN NUMBER 4134
                             *---------------*

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

          1       2       3       4       5       6       7       8       9      10

 1      270     257     247     246     253     250     252     250     239     237
 2      271     245     246     247     246     247     245     246     221     213
 3      232     218     227     231     209     209     195     200     169     154
 4      277     255     259     253     255     245     255     237     236     262


                             *---------------*
                              RUN NUMBER 4134
                                  SUMMARY
                             *---------------*

ST       RE       PR     X/D     MUB     MUW      TB      TW    DENS      NU

 1   10657.16   6.31     6.4   2.205   2.048   75.14   81.04   62.26   68.66
 2   10691.26   6.29    15.5   2.198   2.030   75.39   81.75   62.26   63.69
 3   10725.40   6.27    24.6   2.191   2.025   75.64   81.96   62.25   64.08
 4   10759.59   6.25    33.7   2.184   2.019   75.89   82.21   62.25   64.08
 5   10793.82   6.23    42.8   2.177   2.010   76.14   82.58   62.25   62.85
 6   10828.10   6.20    52.0   2.170   2.002   76.39   82.91   62.25   62.04
 7   10862.42   6.18    61.1   2.164   1.994   76.64   83.23   62.24   61.36
 8   10896.78   6.16    70.2   2.157   1.986   76.89   83.55   62.24   60.68
 9   10931.18   6.14    79.3   2.150   1.966   77.14   84.40   62.24   55.71
10   10965.63   6.12    88.4   2.143   1.958   77.39   84.76   62.24   54.83

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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*-----------------------------------------*
              RUN NUMBER 4136
       TEST FLUID IS DISTILLED WATER
*-----------------------------------------*

VOLUMETRIC FLOW RATE -     3.24   GPM
MASS FLOW RATE       -   1616.1   LBM/HR
MASS FLUX            -   246228   LBM/(SQ.FT-HR)
FLUID VELOCITY       -     1.09   FT/S
ROOM TEMPERATURE     -    71.42   F
INLET TEMPERATURE    -    75.14   F
OUTLET TEMPERATURE   -    76.31   F
AVERAGE RE NUMBER    -    10283
AVERAGE PR NUMBER    -     6.26
CURRENT TO TUBE      -    265.0   AMPS
VOLTAGE DROP IN TUBE -     2.05   VOLTS
AVERAGE HEAT FLUX    -      748   BTU/(SQ.FT-HR)
Q=AMP*VOLT           -     1853   BTU/HR
Q=M*C*(T2-T1)        -     1888   BTU/HR
HEAT BALANCE ERROR   -    -1.89   %

               OUTSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1   78.51   78.77   78.95   79.07   79.13   79.32   79.38   79.55   80.03   80.16
 2   78.50   78.90   78.97   79.04   79.25   79.36   79.51   79.58   80.26   80.51
 3   78.83   78.98   79.13   79.06   79.63   79.65   80.07   80.00   81.07   81.59
 4   78.46   78.79   78.83   79.07   79.17   79.39   79.38   79.94   80.04   79.46

               INSIDE SURFACE TEMPERATURES - DEGREES F

        1       2       3       4       5       6       7       8       9      10

 1   78.10   78.36   78.54   78.66   78.72   78.91   78.97   79.13   79.62   79.75
 2   78.08   78.49   78.56   78.63   78.84   78.95   79.09   79.16   79.84   80.09
 3   78.42   78.57   78.72   78.65   79.22   79.24   79.67   79.59   80.67   81.20
 4   78.04   78.38   78.41   78.66   78.75   78.98   78.96   79.53   79.62   79.03

               REYNOLDS NUMBER AT THE INSIDE TUBE WALL

        1       2       3       4       5       6       7       8       9      10

 1   10596   10631   10655   10671   10679   10704   10712   10735   10799   10817
 2   10595   10648   10657   10667   10695   10709   10729   10739   10830   10863
 3   10640   10659   10679   10670   10747   10749   10806   10796   10941   11012
 4   10589   10633   10639   10671   10684   10713   10712   10788   10800   10720

                INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

        1       2       3       4       5       6       7       8       9      10

 1     710     713     710     711     713     713     713     717     715     707
 2     715     710     713     712     714     714     717     716     719     721
 3     702     708     705     711     701     705     696     705     689     672
 4     716     713     716     711     716     714     720     707     724     747

                          *---------------*
                           RUN NUMBER 4136
                          *---------------*

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

        1       2       3       4       5       6       7       8       9      10

 1     246     235     229     229     234     228     232     229     204     201
 2     249     225     229     231     225     225     224     226     193     186
 3     219     218     215     230     197     203     184     196     151     135
 4     253     234     241     229     232     223     234     200     207     267

                          *---------------*
                           RUN NUMBER 4136
                               SUMMARY
                          *---------------*

ST     RE        PR     X/D     MUB     MUW      TB      TW     DENS     NU

 1  10216.67   6.31     6.4   2.203   2.122   75.22   78.16   62.26   63.32
 2  10231.43   6.30    15.5   2.200   2.115   75.33   78.45   62.26   59.82
 3  10246.19   6.29    24.6   2.197   2.112   75.44   78.56   62.25   59.86
 4  10260.96   6.28    33.7   2.194   2.110   75.56   78.65   62.25   60.29
 5  10275.74   6.27    42.8   2.191   2.103   75.67   78.88   62.25   57.99
 6  10290.53   6.26    52.0   2.187   2.100   75.78   79.02   62.25   57.59
 7  10305.33   6.25    61.1   2.184   2.096   75.89   79.17   62.25   56.84
 8  10320.14   6.24    70.2   2.181   2.091   76.01   79.35   62.25   55.65
 9  10334.95   6.23    79.3   2.178   2.076   76.12   79.94   62.25   48.81
10  10349.77   6.22    88.4   2.175   2.074   76.23   80.02   62.25   49.22

                NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                      MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                 *-----------------------------------------*
                              RUN NUMBER 4138
                       TEST FLUID IS DISTILLED WATER
                 *-----------------------------------------*

                 VOLUMETRIC FLOW RATE -      3.24   GPM
                 MASS FLOW RATE       -    1616.3   LBM/HR
                 MASS FLUX            -    246246   LBM/(SQ.FT-HR)
                 FLUID VELOCITY       -      1.09   FT/S
                 ROOM TEMPERATURE     -     70.69   F
                 INLET TEMPERATURE    -     74.59   F
                 OUTLET TEMPERATURE   -     75.87   F
                 AVERAGE RE NUMBER    -     10218
                 AVERAGE PR NUMBER    -      6.31
                 CURRENT TO TUBE      -     275.0   AMPS
                 VOLTAGE DROP IN TUBE -      2.15   VOLTS
                 AVERAGE HEAT FLUX    -       814   BTU/(SQ.FT-HR)
                 Q=AMP*VOLT           -      2017   BTU/HR
                 Q=M*C*(T2-T1)        -      2066   BTU/HR
                 HEAT BALANCE ERROR   -     -2.44   %

                   OUTSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1   78.28   78.56   78.78   78.89   78.96   79.16   79.24   79.44   79.92   80.07
 2   78.24   78.70   78.78   78.86   79.09   79.20   79.36   79.47   80.19   80.43
 3   78.60   78.83   78.96   78.90   79.50   79.52   80.01   79.95   81.09   81.61
 4   78.19   78.57   78.63   78.89   79.00   79.23   79.25   79.80   79.99   79.39

                   INSIDE SURFACE TEMPERATURES - DEGREES F

         1       2       3       4       5       6       7       8       9      10

 1   77.84   78.11   78.34   78.45   78.51   78.71   78.79   78.99   79.47   79.63
 2   77.79   78.26   78.33   78.41   78.64   78.75   78.91   79.02   79.74   79.98
 3   78.16   78.39   78.52   78.46   79.06   79.08   79.58   79.51   80.66   81.19
 4   77.74   78.12   78.18   78.45   78.55   78.78   78.80   79.36   79.54   78.93

                   REYNOLDS NUMBER AT THE INSIDE TUBE WALL

         1       2       3       4       5       6       7       8       9      10

 1   10562   10599   10629   10644   10653   10679   10690   10717   10781   10801
 2   10557   10618   10629   10639   10670   10685   10706   10721   10817   10849
 3   10606   10636   10653   10645   10726   10728   10794   10786   10940   11012
 4   10550   10601   10608   10644   10658   10689   10691   10765   10790   10708

                     INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

         1       2       3       4       5       6       7       8       9      10

 1     764     767     764     765     768     767     768     771     771     763
 2     770     765     768     767     769     769     773     772     774     777
 3     756     761     759     765     754     758     748     758     741     724
 4     772     769     772     766     772     769     775     764     779     803

                             *---------------*
                              RUN NUMBER 4138
                             *---------------*

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

         1       2       3       4       5       6       7       8       9      10

 1     241     231     223     225     229     224     227     223     202     198
 2     247     221     225     227     221     222     221     221     189     185
 3     216     212     211     224     193     200     179     191     148     134
 4     251     231     236     225     228     220     229     200     201     255

                             *---------------*
                              RUN NUMBER 4138
                                 SUMMARY
                             *---------------*

ST      RE        PR     X/D     MUB     MUW      TB      TW     DENS      NU

 1   10146.40   6.36     6.4   2.219   2.130   74.68   77.88   62.26   62.62
 2   10162.49   6.35    15.5   2.215   2.121   74.80   78.22   62.26   58.70
 3   10178.60   6.33    24.6   2.212   2.118   74.92   78.34   62.26   58.70
 4   10194.72   6.32    33.7   2.208   2.115   75.05   78.44   62.26   59.14
 5   10210.85   6.31    42.8   2.205   2.108   75.17   78.69   62.26   56.97
 6   10226.99   6.30    52.0   2.201   2.105   75.29   78.83   62.26   56.69
 7   10243.14   6.29    61.1   2.198   2.100   75.41   79.02   62.25   55.68
 8   10259.30   6.28    70.2   2.194   2.095   75.54   79.22   62.25   54.52
 9   10275.47   6.27    79.3   2.191   2.078   75.66   79.85   62.25   47.91
10   10291.65   6.26    88.4   2.187   2.076   75.78   79.93   62.25   48.43

                  NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                        MUB AND MUW ARE GIVEN IN LBM/(FT*HR)
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                  *-----------------------------------------*
                               RUN NUMBER 4141
                        TEST FLUID IS DISTILLED WATER
                  *-----------------------------------------*

                  VOLUMETRIC FLOW RATE -      3.40    GPM
                  MASS FLOW RATE       -    1696.2    LBM/HR
                  MASS FLUX            -    258421    LBM/(SQ.FT-HR)
                  FLUID VELOCITY       -      1.15    FT/S
                  ROOM TEMPERATURE     -     70.77    F
                  INLET TEMPERATURE    -     74.96    F
                  OUTLET TEMPERATURE   -     76.24    F
                  AVERAGE RE NUMBER    -     10775
                  AVERAGE PR NUMBER    -      6.27
                  CURRENT TO TUBE      -     280.0    AMPS
                  VOLTAGE DROP IN TUBE -      2.20    VOLTS
                  AVERAGE HEAT FLUX    -       848    BTU/(SQ.FT-HR)
                  Q=AMP*VOLT           -      2101    BTU/HR
                  Q=M*C*(T2-T1)        -      2168    BTU/HR
                  HEAT BALANCE ERROR   -     -3.18    %

                      OUTSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

  1     78.30   78.67   78.94   79.12   79.24   79.49   79.61   79.84   80.33   80.48
  2     78.27   78.80   78.95   79.09   79.39   79.56   79.73   79.88   80.62   80.88
  3     78.69   78.98   79.16   79.15   79.83   79.91   80.41   80.36   81.53   82.07
  4     78.31   78.72   78.85   79.14   79.34   79.58   79.67   80.21   80.41   79.78

                      INSIDE SURFACE TEMPERATURES - DEGREES F

          1       2       3       4       5       6       7       8       9      10

  1     77.84   78.21   78.48   78.66   78.78   79.03   79.15   79.38   79.87   80.02
  2     77.81   78.34   78.49   78.63   78.93   79.10   79.27   79.42   80.15   80.41
  3     78.23   78.52   78.70   78.69   79.38   79.45   79.96   79.90   81.08   81.63
  4     77.85   78.26   78.39   78.68   78.88   79.12   79.20   79.75   79.94   79.30

                      REYNOLDS NUMBER AT THE INSIDE TUBE WALL

          1       2       3       4       5       6       7       8       9      10

  1     11085   11137   11175   11200   11216   11251   11268   11300   11369   11391
  2     11080   11155   11176   11195   11237   11261   11285   11306   11410   11446
  3     11140   11180   11206   11204   11300   11311   11382   11374   11541   11619
  4     11086   11144   11162   11202   11230   11264   11276   11353   11380   11289

                      INSIDE SURFACE HEAT FLUXES BTU/HR/FT2

          1       2       3       4       5       6       7       8       9      10

  1       793     796     793     794     797     796     797     800     800     791
  2       799     794     796     795     798     798     801     800     803     805
  3       783     788     787     793     783     786     777     787     770     752
  4       798     796     799     794     799     797     803     792     808     832

                                *---------------*
                                 RUN NUMBER 4141
                                *---------------*

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

          1       2       3       4       5       6       7       8       9      10

  1       284     262     248     244     246     236     237     230     208     204
  2       289     250     249     247     235     232     230     228     194     189
  3       245     235     230     242     204     207     186     197     152     137
  4       285     257     258     243     239     230     234     206     206     264

                                *---------------*
                                 RUN NUMBER 4141
                                     SUMMARY
                                *---------------*

ST       RE        PR      X/D     MUB     MUW      TB      TW     DENS     NU

 1    10698.86    6.32     6.4   2.208   2.129   75.05   77.93   62.26   72.12
 2    10715.78    6.31    15.5   2.205   2.118   75.17   78.33   62.26   65.81
 3    10732.72    6.30    24.6   2.201   2.113   75.29   78.51   62.26   64.59
 4    10749.67    6.29    33.7   2.198   2.109   75.42   78.66   62.25   64.06
 5    10766.63    6.28    42.8   2.194   2.101   75.54   78.99   62.25   60.31
 6    10783.60    6.27    52.0   2.191   2.096   75.66   79.17   62.25   59.25
 7    10800.58    6.26    61.1   2.187   2.090   75.78   79.39   62.25   57.65
 8    10817.57    6.25    70.2   2.184   2.084   75.91   79.61   62.25   56.19
 9    10834.57    6.24    79.3   2.180   2.068   76.03   80.26   62.25   49.21
10    10851.58    6.22    88.4   2.177   2.066   76.15   80.34   62.25   49.70

                     NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT
                           MUB AND MUW ARE GIVEN IN LBM/(FT*HR)s
```

APPENDIX C

COMPUTER PROGRAMS

C.1 Program Datared98F

C.2 Program RHt98F

C.3 Program Phasel

APPENDIX C

COMPUTER PROGRAMS

In this Appendix, a listing of all of the computer programs (Datared98F, RHt98, and PhaseI) are presented.

C.1 Program Datared98F

As mentioned in Chapter III, Datared98F reduces the data obtained from the data logger (MAC-14), and creates an output file which will be used as an input file for the program RHt98 for the calculation of heat balance error, Nusselt number, heat transfer coefficient, and several other flow parameters. The original code was developed in 1989 by Mr. Y. H. Zurigat and modified by Mr. Dongwoo Kim and this author for specific application to the test runs presented in Appendix B. The following is a complete listing of this modified program.

```
C**********************************************************************
C
C              DATARED98F.FOR
C
C     THIS PROGRAM TAKES A DATA FILE FROM THE DATA LOGGER AND CONVERTS
C     IT TO A FORM THAT THE RHT98 PROGRAM CAN READ.
C
C     This Program has been Modified by DongWoo Kim, and Venkata Ryali
C     August'98
C
C**********************************************************************

      CHARACTER FNAME*10, ONAME*10, JUNK*4, RUN*4
      DIMENSION T(45), SUM(45), x(10)

      PRINT*, ''
      PRINT*,''
      PRINT*, 'ENTER THE RUN NUMBER (4 digits)'
      READ(*,10) RUN
 10   FORMAT(A4)

      FNAME='RN'//RUN//'.TMP'
```

```
      OPEN (UNIT=5,FILE=FNAME,STATUS='OLD')

      DO 20 I=1,45
        SUM(I) = 0.0
 20   CONTINUE

      READ(5,30) JUNK
 30   FORMAT(4(/),A4)

      NPTS=0

      DO 60 WHILE(.NOT.EOF(5))

          READ(5,40) (T(I),I=1,45)
 40       FORMAT(11X,45(F10.5,1x))

        DO 50 I=1,45
          SUM(I)=SUM(I)+T(I)
 50     CONTINUE

        NPTS=NPTS+1
          Write(*,*) 'Reading Line =',NPTS
 60   CONTINUE
          WRITE(*,*) T(2)
          pause

      DO 70 I = 1,45
        T(I) = SUM(I)/NPTS
 70   CONTINUE

kdw   convert temp's from 'C to 'F
     Do k=1,45
          T(K)=1.8*T(k)+32.0
     enddo

 80   PRINT*, ''
      PRINT*, ''
      PRINT*, 'FLUID INDEX (1 = water, 2 = ethylene glycol)'
      READ*, IFLUID

      IF (IFLUID.EQ.1) THEN
        ETH = 0.0
      ELSEIF (IFLUID.EQ.2) THEN
        PRINT*, ''
        PRINT*, ''
        PRINT*, 'MASS CONCENTRATION OF ETHYLENE GLYCOL (0 < X <= 1)'
        READ*, ETH
      ELSE
        PRINT*, ''
        PRINT*, ''
        PRINT*, 'MUST ENTER EITHER 1 OR 2'
        GOTO 80
      ENDIF

      PRINT*, ''
      PRINT*, ''
      PRINT*, 'FLOW RATE (gal/min)'
      READ*, FLOW

      PRINT*, ''
      PRINT*, ''
      PRINT*, 'CURRENT (amps)'
```

```
     READ*, CURR

     PRINT*, ' '
     PRINT*, ' '
     PRINT*, 'VOLTAGE DROP ACROSS TEST SECTION (volts)'
     READ*, VOLT

     ONAME='RN'//RUN//'.DAT'
     OPEN (UNIT=3,FILE=ONAME)

     WRITE (3,100) RUN,IFLUID,ETH,FLOW,CURR,VOLT,T(42),T(43),T(44)
 90   FORMAT(3(/),1X,A4,1X,'03',/,2X,I1,2X,F6.4,2X,F6.4,2X,F6.2,2X,
  +       F6.2,2X,F6.2,2X,F6.2,2X,F6.2)
100   FORMAT(A4,1X,'10',/,1X,I1,2X,F3.2,2X,F6.4,2X,F6.2,2X,F6.2,
  +       2X,F6.2,2X,F6.2,2X,F6.2)


x(1)=7.0

Do J=2,10

x(J)=x(j-1)+10.0

Write(*,*) x(j)

Enddo
Initial=2
Do J=1,10

WRITE (3,120) J,X(J),(T(I), I=Initial,Initial+3)
     Initial=Initial+4
        Enddo
         Write(3,123)
123   FORmat(2x,'0')
110   FORMAT(2X,'16',2X,'4',3X,'144.00',2X,4(F6.2,2X))
120   FORMAT(1X,I2,2X,'4',3X,F6.2,2X,4(F6.2,2X))

      STOP
      End
```

C.2 Program RHt98F

Program RHt98 takes the output file obtained from program Datared98F, and then calculates the heat balance error, Nusselt number, and several other flow parameters as explained in Chapter III. This code was first developed by the students of Dr. J. D. Parker and Dr. K. J. Bell. It was later modified by Mr. Y. H. Zurigat and Mr. Mailello in 1989. It has been modified for the test cases presented herein by Mr. Dongwoo Kim and this author. The following is complete listing of this modified program.

```
C ***********************************************************************
C *                  " RHt98F "                    *
C *                                  *
C *  A PROGRAM TO CALCULATE THE INSIDE WALL TEMPERATURES AND       *
C *  LOCAL HEAT TRANSFER COEFFICIENTS FOR GIVEN OUTSIDE WALL      *
C *  TEMPERATURES FOR SINGLE PHASE HEAT TRANSFER STUDIES IN      *
C *  HORIZONTAL TUBES. THE PROGRAM ALSO CALCULATES THE PERTINENT  *
C *  FLUID FLOW & HEAT TRANSFER DIMENSIONLESS NUMBERS.           *
C *                                  *
C *  THE MATHEMATICAL ALGORITHM OF THIS PROGRAM HAS BEEN DEVELOPED  *
C *  BY THE STUDENTS OF DR. J.D. PARKER & DR. K.J. BELL OF         *
C *  OKLAHOMA STATE UNIVERSITY.                       *
C *                                  *
C *  THE PROGRAM WAS MODIFIED BY:                       *
C *                                  *
C *          Y. H. ZURIGAT  (APRIL 1989)          *
C *                                  *
C *  AND REMODIFIED FOR INTERACTIVE USE ON PC's BY:              *
C *                                  *
C *          D. R. MAIELLO  (DECEMBER 1989)          *
C *                                  *
C *  AND REMODIFIED FOR A SPECIFIC PURPOSE BY:                 *
C *                                  *
C *          DARREN WARNECKER  (NOVEMBER 1994)          *
C *  AND REMODIFIED BY DONGWOO KIM, AND  RYALI VENKATA (AUGUST'98)
```

```
C *                                        *
C *  UNDER THE SUPERVISION OF: DR. A.J. GHAJAR                   *
C *                   SCHOOL OF MECHANICAL &             *
C *                    AEROSPACE ENGINEERING           *
C *                   OKLAHOMA STATE UNIVERSITY            *
C *                   STILLWATER, OK 74078          *
C *                                        *
C ******************************************************************
C
C ******************************************************************
C *                                        *
C *                 SUBROUTINE LISTING              *
C *                                        *
C *    NAME      FUNCTION                         *
C *    -------   ---------------------------     *
C *    GEOM      Prompts for pipe dimensions and          *
C *              calculates geometry for finite        *
C *              differencing                   *
C *                                        *
C *    BET      Calculates fluid Thermal Expansion Coefficient *
C *                                        *
C *    CONDFL    Calculates fluid Thermal Conductivity        *
C *                                        *
C *    DENS     Calculates fluid Density               *
C *                                        *
C *    MEW      Calculates fluid Viscosity              *
C *                                        *
C *    PRNUM     Calculates fluid Prandtl Number            *
C *                                        *
C *    SPHEAT    Calculates fluid Specific Heat            *
C *                                        *
C *    PRNT     Prints calculated data to output files       *
C *                                        *
C ******************************************************************
C
C
C ******************************************************************
C *                                        *
C *                  MAIN PROGRAM                *
C *                                        *
C ******************************************************************


      CHARACTER INFILE*36,SUMFILE*11,FNAME*4,RUN*4
      DIMENSION TCHCK1(8),TCHCK2(8),QAVG(31),DELX(10),
     +     CONDK(31,8),RSVTY(31,8)
        INTEGER  RSWT,STN
        COMMON/STATION/STN

      COMMON /PRINT/ IPICK,REN(31,8),TBULK(31),VEL,REYNO,PRNO,GW,
     +        HTCOFF(31,8),H(31),RENO(31),GRNO(31),PR(31),
     +        SNUS(31),VISBW(31),SHTHB(32),QFLXID(31,8),QFLXAV,
     +        QGEXPT,QBALC,QPCT,IPMAX,TAVG(31),VISCA(31),
     +        VISWLA(31),ROWA(31)
     +    /INPUT/ TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,FLOWRT,NRUN,VFLOW,
     +        TIN,TOUT,TOSURF(31,8),TISURF(31,8),IP(32),KST(32)
     +    /TEMP1/ TWALL(31,8),AMPS(31,8),RESIS(31,8),POWERS(32),
     +        TPOWER
     +    /MAIN1/ IST,KOUNT,NSTN
     +    /GEOM1/ XAREA(31),R(31),LTP(32),LTH(32),DELZ(31),LHEAT,
```

```
 +          LTEST,LOD(31),DOUT,DIN,DELR,NODES,NSLICE,PI

   REAL*4 LTH,LTP,LTEST,LHEAT,H,HTCOFF,LOD,LENGTH
        DATA DELX/7.0,17.0,27.0,37.0,47.0,57.0,67.0,77.0,87.0,97.0/

C   DELX, LENGTH WERE CREATED BY RYALI TO CALCULATE THE TBULK FOR HIS
C    SETUP
        LENGTH=104.D0
C ------------------------------------
C ----- INITIALIZE OUTPUT DATA ARRAYS TO ZERO -----
C ------------------------------------


 1200    WRITE(*,*)


   1 DO 101 I=1,8
          DO 101 J=1,31
            TOSURF(J,I)=0.
            TISURF(J,I)=0.
            REN(J,I)=0.
            QFLXID(J,I)=0.
 101      HTCOFF(J,I)=0.

    G=32.174

 C ------------------------------
 C ---- ASSIGN FOR INPUT DATA FILE NAME ----
 C ------------------------------

    PRINT*,''
    PRINT*,''
    PRINT*, 'Enter the file number.'
    READ(*,1003) RUN

    DO 2 J=1,18
   2 INFILE='RN'//RUN//'.DAT'
    OPEN(5,FILE=INFILE)

    READ(5,1003)FNAME
    REWIND 5

 C -----------------------------------------------
 C ---- ASSIGN FILE NAMES TO VARIABLES AND OPEN OUTPUT FILES ----
 C -----------------------------------------------


    SUMFILE='RN'//FNAME//'.HTT'
    OPEN(6,FILE=SUMFILE)
 C -------------------------
 C ---- ASSIGN FOR UNITS INPUT ----
 C -------------------------

    7 IPICK = 1

 C ------------------------------------------
 C ---- READ RUN NUMBER AND # STATIONS FROM INPUT FILE ----
 C ------------------------------------------

    8 READ(5,1004) NRUN,NSTN

 C --------------------
```

```
C ---- CHECK FOR END OF FILE ----
C ----------------------------

     IF (NRUN .EQ. 0) GO TO 99

C ------------------------------------
C ---- READ DATA FROM INPUT FILE -----
C ------------------------------------

     X2=0.0
     IPMAX=0
     READ(5,1005)MFLUID,X2,FLOWRT,TAMPS,VOLTS,TIN,TOUT,TROOM
          Write(*,*) 'Tin =', Tin
          Pause

     IF(X2.LT.0.0.OR.X2.GT.1.0)THEN
          WRITE(*,*)' WARNING : MASS CONCENTRATION IS OUT OF RANGE'
          STOP
     END IF

     DO 9 IST=1,NSTN
      READ(5,1006)KST(IST),IP(IST),LTH(IST),
    +   (TOSURF(IST,IPR),IPR=1,IP(IST))
      IF(IST.NE.1)THEN
            IF(IP(IST).GE.IPMAX)IPMAX=IP(IST)
      ELSE
    9 ENDIF

     VFLOW=FLOWRT

C ---------------------------------------------
C ----CALCULATION OF MASS FLOW RATE IN LBM/HR ----
C ---------------------------------------------

     CALL DENS(TIN,MFLUID,X2,ROW)
     RMFL=VFLOW*0.133666*60.0*ROW

C ----------------
          CALL GEOM
C ----------------

     NNODE=NODES-1

C ------------------------------------
C ---- START SOLUTION WITH STATION 1 ----
C ------------------------------------

     DO 30 IST=1,NSTN
          IPP= IP(IST)
          DO 10 IPR=1,IPP
  10      TCHCK1(IPR)=0.0

C ---------------------------------------------
C ----  SET ALL RADIAL TEMPERATURES EQUAL  ----
C ---- TO THE OUTSIDE SURFACE TEMPERATURES ----
C ---------------------------------------------

          DO 11 ISL=1,NODES
            DO 11 IPR=1,IPP
  11        TWALL(ISL,IPR)=TOSURF(IST,IPR)
          KOUNT=1
```

```
C ----------------------------------------------------
C ---- CALCULATE THERMAL CONDUCTIVITY OF STAINLESS STEEL ----
C ----     FOR EACH NODE IN BTU/(HR-FT-DEGF)          ----
C ----------------------------------------------------

   12 DO 13 ISL=1,NODES
         DO 13 IPR=1,IPP
           CONDK(ISL,IPR)=7.27+0.0038*TWALL(ISL,IPR)
   13 CONTINUE

C ----------------------------------------------------
C ---- CALCULATE ELECTRICAL RESISTIVITY OF STAINLESS STEEL ----
C ----      FOR EACH NODE IN OHMS-SQIN/IN             ----
C ----------------------------------------------------

      DO 14 ISL=1,NODES
         IPP= IP(IST)
         DO 14 IPR=1,IPP
           RSVTY(ISL,IPR)=(27.67+0.0213*TWALL(ISL,IPR))/1.E6
   14 CONTINUE

C ----------------------------------------------------
C ----   CALCULATE RESISTANCE FOR EACH SEGMENT, ALSO     ----
C ---- CALCULATE EQUIVALENT RESISTANCE FOR PARALLEL CIRCUITS ----
C ----------------------------------------------------

      DELR = (DOUT-DIN)/2.0/NSLICE
      R(1) = DOUT/2.0
      DO 15  I=1,NSLICE
   15  R(I+1)=R(I)-DELR
      IPP= IP(IST)
         XAREA(1)=(R(1)-DELR/4.0)*PI*DELR/IPP
      XAREA(NODES)=(R(NODES)+DELR/4.0) *PI*DELR/IPP
      DO 16 I=2,NSLICE
   16  XAREA (I)= 2.0*R(I)*PI*DELR/IPP

      RINV = 0.0
      DO 17 ISL=1,NODES
         DO 17 IPR=1,IPP
           RESIS(ISL,IPR) = RSVTY(ISL,IPR)*DELZ(IST)/XAREA(ISL)
           RINV = RINV +1.0/RESIS(ISL,IPR)
   17 CONTINUE

C ------------------------------------
C ---- CALCULATE CURRENT FOR EACH SEGMENT ----
C ------------------------------------

      OHMS = 1.0/RINV
      AMP=0.0
      DO 18 ISL=1,NODES
         DO 18 IPR=1,IPP
           AMPS(ISL,IPR) = TAMPS*OHMS/RESIS(ISL,IPR)
           AMP=AMP+AMPS(ISL,IPR)
   18 CONTINUE

C ----------------------------------------------------
C ----       CALCULATE TEMPERATURES AT NODE 2          ----
C ---- TEMPERATURES AT NODE 1 ARE OUTSIDE WALL TEMPERATURES ----
C ----------------------------------------------------

         ISL=1
         DO 20 IPR=1,IPP
```

```
          ITHCTL=IPP
          IMINS=IPR-1
          IPLUS=IPR+1
          NMINS = ISL - 1
          NPLUS = ISL + 1
                IF(IMINS.EQ.0 .AND. IPP.EQ. ITHCTL) IMINS=ITHCTL
                IF(IPLUS.EQ.(ITHCTL+1) .AND.  IPP.EQ. ITHCTL) IPLUS=1
          A= 3.41214*12.0*AMPS(ISL,IPR)*AMPS(ISL,IPR)
     +      *RSVTY(ISL,IPR)/XAREA(ISL)
          B = IPP*DELR*(CONDK(ISL,IPR)+CONDK(ISL,IPLUS))
     +      *(TWALL(ISL,IPR)-TWALL(ISL,IPLUS))/(8.0*PI*R(ISL))
          C = IPP*DELR*(CONDK(ISL,IPR)+CONDK(ISL,IMINS))
     +      *(TWALL(ISL,IPR)-TWALL(ISL,IMINS))/(8.0*PI*R(ISL))
          X = PI*(R(ISL)-DELR/2.0)*(CONDK(ISL,IPR)+CONDK(NPLUS,IPR))
     +      /(IPP*DELR)
 20     TWALL(NPLUS,IPR) = TWALL(ISL,IPR)-(A-B-C)/X

C ----------------------------------------
C ---- CALCULATE REMAINING NODAL TEMPERATURES ----
C ----------------------------------------

        DO 21 ISL=2,NNODE
          DO 21 IPR=1,IPP
              ITHCTL=IPP
              IMINS=IPR-1
              IPLUS=IPR+1
              NMINS=ISL-1
              NPLUS=ISL+1
              IF(IMINS.EQ.0 .AND. IPP .EQ. ITHCTL) IMINS=ITHCTL
              IF(IPLUS.EQ.(ITHCTL+1) .AND. IPP .EQ. ITHCTL) IPLUS=1
              A= 3.41214*12.0*AMPS(ISL,IPR)*AMPS(ISL,IPR)
     +      *RSVTY(ISL,IPR)/XAREA(ISL)
              B =PI*(R(ISL)+DELR/2.)*(CONDK(ISL,IPR)+CONDK(NMINS,IPR))
     +      *(TWALL(ISL,IPR)-TWALL(NMINS,IPR))/(IPP*DELR)
              C = IPP*DELR*(CONDK(ISL,IPR)+CONDK(ISL,IPLUS))
     +      *(TWALL(ISL,IPR)-TWALL(ISL,IPLUS))/(4.0*PI*R(ISL))
              D = IPP*DELR*(CONDK(ISL,IPR)+CONDK(ISL,IMINS))
     +      *(TWALL(ISL,IPR)-TWALL(ISL,IMINS))/(4.0*PI*R(ISL))
              X =PI*(R(ISL)-DELR/2.)*(CONDK(ISL,IPR)+CONDK(NPLUS,IPR))
     +      /(IPP*DELR)
 21     TWALL(NPLUS,IPR) = TWALL(ISL,IPR)- (A-B-C-D)/X

C ------------------------------------------------
C ---- CHECK FOR THE CONVERGENCE OF THE WALL TEMPERATURES ----
C ------------------------------------------------

        TCHCK = 0.0
        DO 22 IPR=1,IPP
          TCHCK2(IPR)=TWALL(NODES,IPR)
 22     TCHCK = TCHCK + ABS(TCHCK2(IPR)-TCHCK1(IPR))
        IF (TCHCK .GT. 0.001) GO TO 23
        GO TO 26
 23    DO 24 IPR=1,IPP
 24     TCHCK1(IPR) = TCHCK2(IPR)
        KOUNT = KOUNT+1
        GO TO 12
        WRITE(6,1007) IST,KOUNT
 26    DO 27 IPR=1,IPP
 27     TISURF( IST ,IPR)=TWALL(NODES,IPR)

C ------------------------------------------------------
C ---- CALCULATE POWER GENERATED IN EACH SEGMENT IN BTU/HOUR ----
```

```
C ----------------------------------------------

        POWER =0.0
        DO 28 ISL=1,NODES
          DO 28 IPR=1,IPP
          POWER=POWER+AMPS(ISL,IPR)*AMPS(ISL,IPR)*RESIS(ISL,IPR)
 28   CONTINUE

        POWERS(IST)=POWER*3.41214

C ---------------------------------------
C ---- CALCULATE HEAT FLUX AT INSIDE SURFACE ----
C ---------------------------------------

   ISL=NODES
   IPP= IP(IST)
        ITHCTL=IPP
   DO 29 IPR=1,IPP
        IPLUS=IPR+1
        IMINS=IPR-1
        IF(IMINS.EQ.0 .AND. IPP .EQ. ITHCTL) IMINS=ITHCTL
        IF(IPLUS.EQ.(ITHCTL+1).AND. IPP.EQ. ITHCTL) IPLUS=1
        Q1 = PI*(CONDK(ISL-1,IPR)+CONDK(ISL,IPR))*(R(ISL-1)-DELR/2.0)*
   +    (TWALL(ISL,IPR)-TWALL(ISL-1,IPR))/(IPP*DELR)
        Q2 = IPP*(CONDK(ISL,IPLUS)+CONDK(ISL,IPR))*DELR
   +    *(TWALL(ISL,IPR)-TWALL(ISL,IPLUS))/(PI*R(ISL)*8.0)
        Q4 = IPP*(CONDK(ISL,IPR)+CONDK(ISL,IMINS))*DELR
   +    *(TWALL(ISL,IPR)-TWALL(ISL,IMINS))/(PI*R(ISL)*8.0)
        QGEN=3.41214*12.0*AMPS(ISL,IPR)*AMPS(ISL,IPR)
   +    *RSVTY(ISL,IPR)/XAREA(ISL)
 29   QFLXID(IST,IPR) =(QGEN-Q1-Q2-Q4)*IPP*12.0/(2.0*PI*R(ISL))

 30 CONTINUE

C ------------------------------------------
C ---- CALCULATE REYNOLDS NUMBERS AT INSIDE TUBE SURFACE ----
C ------------------------------------------

   DO 40 IST=1,NSTN
        IPP= IP(IST)
        DO 40 IPR=1,IPP
          TR=TISURF(IST,IPR)
          CALL MEW(TR,MFLUID,X2,VISS)
          REN(IST,IPR)=RMFL*48.0/(PI*DIN*VISS)

 40 CONTINUE

C ---------------------------------------
C ---- CALCULATE TOTAL POWER GENERATED IN BTU/HOUR ----
C ---------------------------------------

   TPOWER=0.0
   DO 45 IST=1,NSTN
 45 TPOWER=TPOWER+POWERS(IST)

C ---------------------------------------------
C ---- CALCULATE BULK FLUID TEMPERATURE AT EACH STATION,DEG.F ----
C ---------------------------------------------

   TBULK(1)=TIN+(TOUT-TIN)*LTP(1)/LTEST
   DO 50 IST =2,NSTN
 50   TBULK(IST) = TBULK(IST-1) + (TOUT-TIN)*LTP(IST)/LTEST
```

```
C   CHANGED HERE BY RYALI

C    DO 50 IST =1,NSTN

C 50    TBULK(IST)=TIN+(TOUT-TIN)*DELX(IST)/LENGTH
C50  TBULK(IST) = TBULK(IST-1) + (TOUT-TIN)*LTP(IST)/LTEST


C ---------------------------------------------------------
C ---- CALCULATION OF INPUT AND OUTPUT HEAT TRANSFER RATE,BTU/HR ----
C -----   AND OVERALL AVERAGE REYNOLDS AND PRANDTL NUMBERS      ----
C ---------------------------------------------------------

   QGCALC=TPOWER
   QGEXPT =TAMPS*VOLTS*3.41214
   QIN=QGEXPT
   QFLXAV=QIN/(3.1416*DIN/12.0*(LHEAT/12.0))

C ----- CALCULATE FLUID PROPERTIES AT TAVE ----

   T=(TOUT+TIN)/2.0
   CALL SPHEAT(T,MFLUID,X2,SPHT)
   CALL MEW(T,MFLUID,X2,VISC)
   CALL CONDFL(T,MFLUID,X2,COND)

   QBALC=RMFL*SPHT*(TOUT-TIN)
   QPCT=(QIN-QBALC)*100.0/QIN
   AID=PI*DIN*DIN/4.0/144.0
   GW=RMFL/AID
   REYNO=GW*DIN/12.0/VISC
   PRNO=VISC*SPHT/COND

C ------------------------------------------------------
C ----- CALCULATION OF PERIPHERAL HEAT TRANSFER COEFFICIENT ----
C -----    FROM EXPERIMENTAL DATA,BTU/(HR-SQ.FT-DEG.F)     -----
C ------------------------------------------------------

   DO 55 IST=1,NSTN
        IPP= IP(IST)
        DO 55 IPR=1,IPP
        HTCOFF(IST,IPR) =QFLXID(IST,IPR)/(TISURF(IST,IPR)-TBULK(IST))
 55 CONTINUE

C ----------------------------------------------------------
C ---- CALCULATE RATIO OF TOP/BOTTOM HEAT TRANSFER COEFFICIENTS ----
C ----------------------------------------------------------

   DO 65 IST=1,NSTN
        IPP= IP(IST)
        IF (IPP.EQ. 4) GO TO 60
          SHTHB(IST)=HTCOFF(IST,1)/HTCOFF(IST,2)
          GO TO 65
 60   SHTHB(IST)=HTCOFF(IST,1)/HTCOFF(IST,3)
 65 CONTINUE

C ------------------------------------------------------
C ---- CALCULATION OF OVERALL HEAT TRANSFER COEFFICIENT ----
C ------------------------------------------------------

   DO 75 IST=1,NSTN
        QQ=0.0
```

```
        TT=0.0
        IPP= IP(IST)
        DO 70 J=1,IPP
          TT=TT+TISURF(IST,J)
          QQ=QQ+QFLXID(IST,J)
 70    CONTINUE
        TAVG(IST)=TT/IPP
        QAVG(IST)=QQ/IPP
        H(IST)=QAVG(IST)/(TAVG(IST)-TBULK(IST))

 75 CONTINUE

C -----------------------------
C ---- CALCULATE FLUID PROPERTIES ----
C -----------------------------

   DO 85 IST=1,NSTN
         T=TBULK(IST)
         CALL MEW(T,MFLUID,X2,VISC)
        IF(IST.EQ.6)PRINT*,IST,T,(T-32)/1.8,VISC
         CALL SPHEAT(T,MFLUID,X2,SPHT)
C       IF(IST.EQ.6)PRINT*,IST,T,SPHT
         CALL CONDFL(T,MFLUID,X2,COND)
C       IF(IST.EQ.6)PRINT*,IST,TCOND
         CALL DENS(T,MFLUID,X2,ROW)
C       IF(IST.EQ.6)PRINT*,IST,T,ROW
         CALL BET(T,MFLUID,X2,BETA)
C       IF(IST.EQ.6)PRINT*,IST,T,BETA
C       PAUSE
         VISCA(IST)=VISC
         ROWA(IST) =ROW
         PR(IST) = VISC*SPHT/COND
         RENO(IST) = GW*DIN/(12.0*VISC)
         GRNO(IST)=G*BETA*ROW**2*(DIN/12)**3*(TAVG(IST)-TBULK(IST))
  +      /VISC**2 *3600.0**2
         TIS=0.0
         IPP= IP(IST)
C       IF(IST.EQ.6)PRINT*,IST,T,PR(IST),RENO(IST),GW,GRNO(IST)
         DO 80 IPR=1,IPP
 80     TIS=TIS+TISURF(IST,IPR)
         T=TIS/IPP
         CALL MEW(T,MFLUID,X2,VISWL)
         VISWLA(IST)= VISWL
         VISBW(IST) = VISC/VISWL
        IF(IST.EQ.6)PRINT*,IST,T,(T-32)/1.8
         SNUS(IST)=H(IST)*DIN/(12.0*COND)
        IF(IST.EQ.6)PRINT*,H(IST),SNUS(IST),DIN,COND
         TWALL(IST,1)=TAVG(IST)
 85 CONTINUE

C -----------------------------------
C ---- CALCULATE FLUID VELOCITY IN FT/SEC ---
C -----------------------------------

         VEL = VFLOW/(2.462557*DIN*DIN)

C ------------------
C ---- PRODUCE OUTPUT ----
C ------------------

   CALL PRNT
```

```
C ---------------------------------------------
C ---- PROMPT USER FOR PROGRAM TERMINATION OR CONTINUATION ---
C ---------------------------------------------


   KEEP = 2
   GO TO 8

  99 STOP

 1002 FORMAT(A36)
 1003 FORMAT(A4)
 1004 FORMAT(I4,I3)
 1005 FORMAT(I2,F5.2,F8.4,5F8.2)
 1006 FORMAT(I3,I3,F9.2,8F8.2)
 1007 FORMAT(//5X,'TEMPERATURES AT STATION',I3,' DO NOT CONVERGE AFTER',
   +      I3,' ITERATIONS. JUMP TO NEXT STATION')
 1008 FORMAT(///////////////,6X,'DATA REDUCTION COMPLETED FOR RUN # ',I4,
   +    //////////)
        CLOSE(6)
END

C ********************************************************************
C *                                            *
C *              SUBROUTINE GEOM                            *
C *                                            *
C *            ALL LENGTH IN INCHES                           *
C *                                            *
C ********************************************************************

    SUBROUTINE GEOM

    COMMON /MAIN1/ IST,KOUNT,NSTN
   +     /GEOM1/ XAREA(31),R(31),LTP(32),LTH(32),DELZ(31),LHEAT,
   +           LTEST,LOD(31),DOUT,DIN,DELR,NODES,NSLICE,PI

    REAL*4 LTH,LTP,LTEST,LHEAT,LOD

    NSLICE=10
    NODES= NSLICE + 1

C ----------------------
C ---- PROMPT FOR PIPE SIZE ---
C ----------------------

  1 IPSO = 2

    DOUT=1.315
    DIN=1.097
CC    DIN=.621
C       CHANGED LHEAT (LENGTH OF THE HEATING SECTION TO 104in)
C   LHEAT=230.75
C   BY RYALI
    LHEAT=104
C -----------------------------------------
C ---- CALCULATE GEOMETRY FOR FINITE DIFFERENCING ---
C -----------------------------------------

  2 PI = 3.141592654
    LTEST = LHEAT+0.5

    DO 3 I=1,NSTN
```

```
  3   LOD(I)=LTH(I)/DIN
    LTH(NSTN+1)=LHEAT
    LTP(1)=LTH(1)
          SUM=LTP(1)
     DO 4 I=2,NSTN
          LTP(I) =  LTH(I)-LTH(I-1)
  4   SUM=SUM+LTP(I)
          LTP(NSTN+1)=LHEAT-SUM
     DELZ(1) = LTH(1)+( LTH(2)-LTH(1))/2.0
     DO 5 I=2,NSTN
  5   DELZ(I) = ( LTH(I+1)-LTH(I-1))/2.0
     RETURN
     END

C *********************************************************************
C *                                             *
C *                SUBROUTINE BET                         *
C *                                             *
C *  CALCULATES THE THERMAL EXPANSION COEFFICIENT (BETA) FOR PURE   *
C *  WATER AND ANY CONCENTRATION OF ETHYLENE GLYCOL/WATER SOLUTION.  *
C *  THE INPUT IS TEMPERATURE IN DEGREES F AND THE OUTPUT IS 1/F.   *
C *                                             *
C *********************************************************************

      SUBROUTINE BET(TF,MFLUID,X,BETA)
      T = (TF-32.0)/1.8

C ---- PURE WATER ----

      IF(MFLUID.GT.1)GO TO 1
       PDRT=0.0615-0.01693*T+2.06E-4*T**2-1.77E-6*T**3+6.3E-9*T**4
          GO TO 2

C ---- ETHYLENE GLYCOL ----

    1  PDRTA = -1.2379*1.E-4 - 9.9189*1.E-4*X +4.1024*1.E-4*X*X
       PDRTB = 2.*((-2.9837E-06*T+2.4614E-06*X*T -9.5278E-8*X*X*T))
       PDRT=(PDRTA+PDRTB)*1000.
    2 CALL DENS(TF,MFLUID,X,ROW)
       ROW=ROW/.062427
       BETAC= -(1.0/ROW)*(PDRT)
       BETAF =(1.0/BETAC)*1.8
       BETA  = 1.0/BETAF

       RETURN
       END

C *********************************************************************
C *                                             *
C *                SUBROUTINE CONDFL                      *
C *                                             *
C *   CALCULATES THE THERMAL CONDUCTIVITY (COND) FOR PURE WATER    *
C *    AND ANY CONCENTRATION OF ETHYLENE GLYCOL/WATER SOLUTION.    *
C *         THE INPUT IS TEMPERATURE IN DEGREES F              *
C *          AND THE OUTPUT IS IN BTU/HR-FT-F              *
C *                                             *
C *       TEMPERATURE RANGE:                             *
C *          PURE WATER       0 - 100 C                *
C *          E.G. MIXTURES     0 - 150 C                *
C *                                             *
C *********************************************************************
```

```
      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 1

C ----- PURE WATER ----

     IF(T.LT.0.0.OR.T.GT.100.0)THEN
      WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE CONDFL'
      STOP
     END IF

      COND=CONW*0.5778
         GO TO 2

C ---- ETHYLENE GLYCOL -----

    1 IF(T.LT.0.0.OR.T.GT.150.0)THEN
      WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE CONDFL'
      STOP
     END IF

      CETH=0.24511+0.0001755*T-8.52E-7*T*T
      CF=0.6635-0.3698*X-0.000885*T
      COND=(1.0-X)*CONW+X*CETH-CF*(CONW-CETH)*(1.0-X)*X
     COND=COND*0.5778
    2 RETURN
     END

C ********************************************************************
C *                                        *
C *              SUBROUTINE DENS                       *
C *                                        *
C *     CALCULATES THE FLUID DENSITY (ROW) FOR PURE WATER        *
C *    AND ANY CONCENTRATION OF ETHYLENE GLYCOL/WATER SOLUTION.   *
C * THE INPUT IS TEMPERATURE IN DEGREES F AND THE OUTPUT IS LB/FT**3. *
C *                                        *
C *       TEMPERATURE RANGE:                           *
C *          PURE WATER        0 - 100 C           *
C *          E.G. MIXTURES      0 - 150 C           *
C *                                        *
C ********************************************************************

     SUBROUTINE DENS(TF,MFLUID,X,ROW)
     DIMENSION D(3,3),AD(3,3)

     T=(TF-32.0)/1.8
     IF(MFLUID.GT.1) GO TO 1

C ---- PURE WATER ----

     IF(T.LT.0..OR.T.GT.100.0)THEN
         WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE DENS'
         STOP
     END IF

     ROWSI=999.86+.061464*T-.0084648*T**2+6.8794E-5*T**3-4.4214E-7
    +    *T**4+1.2505E-9*T**5
     ROW=ROWSI*0.062427
```

```
C   CALCULATING THE ROW WITH T IF DEGREE F
C   BY RYALI
C    ROW=1/(2.101E-8*TF**2-1.303E-6*TF+0.01602)

     GO TO 4

C ---- ETHYLENE GLYCOL ----

   1 IF(T.LT.0.0.OR.T.GT.150.0)THEN
        WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE DENS'
        STOP
     END IF

     AD(1,1)=1.0004
     AD(1,2)=0.17659
     AD(1,3)=-0.049214
     AD(2,1)=-1.2379E-04
     AD(2,2)=-9.9189E-04
     AD(2,3)= 4.1024E-04
     AD(3,1)=-2.9837E-06
     AD(3,2)= 2.4614E-06
     AD(3,3)= -9.5278E-08

     DO 2 I=1,3
      DO 2 J=1,3
   2  D(I,J)=AD(I,J)*X**(J-1)*T**(I-1)
     SUM=0.0
     DO 3 I=1,3
      DO 3 J=1,3
   3  SUM=SUM+D(I,J)
     SUM=SUM*1.E6/1000.0
     ROW=SUM*0.062427

   4 RETURN
     END

C ***********************************************************************
C *                                   *
C *            SUBROUTINE MEW                     *
C *                                   *
C *    CALCULATES THE DYNAMIC VISCOSITY (VISC) FOR PURE WATER      *
C *    AND ANY CONCENTRATION OF ETHYLENE GLYCOL/WATER SOLUTION.     *
C * THE INPUT IS TEMPERATURE IN DEGREES F AND THE OUTPUT IS LB/HR.FT.  *
C *                                   *
C *      TEMPERATURE RANGE:                         *
C *          PURE WATER      10 - 100 C              *
C *          E.G. MIXTURES    0 - 150 C              *
C *                                   *
C ***********************************************************************

     SUBROUTINE MEW(TF,MFLUID,X,VISC)
     DIMENSION V(3,3),AV(3,3),V2(3)

     T=(TF-32.0)/1.8
     IF(MFLUID.GT.1) GO TO 1

C ---- PURE WATER ----

     IF(T.LT.10..OR.T.GT.100.0)THEN
      WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE MEW'
      STOP
     END IF
```

```
      VISC=2.4189*1.0019*10.0**((1.3272*(20.0-T)-0.001053*(20-T)
     +     **2)/(T+105.0))
          GO TO 4

C ----- ETHYLENE GLYCOL -----

    1 IF(T.LT.0..OR.T.GT.150.0)THEN
       WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE MEW'
       STOP
      END IF

      AV(1,1)=0.55164
      AV(1,2)=2.6492
      AV(1,3)=0.82935
      AV(2,1)=-0.027633
      AV(2,2)=-0.031496
      AV(2,3)= 0.0048136
      AV(3,1)= 6.0629E-17
      AV(3,2)= 2.2389E-15
      AV(3,3)= 5.879E-16

      DO 2 I=1,2
          DO 2 J=1,3
           V(I,J)=AV(I,J)*X**(J-1)*T**(I-1)
    2    V2(J)=AV(3,J)*X**(J-1)

           SUM=0.0
      DO 3 I=1,3
    3  SUM=SUM+V2(I)
       V3=SUM**0.25*T*T
       VISC=V3 + V(1,1)+V(1,2)+V(1,3)+V(2,1)+V(2,2)+V(2,3)
      VISC=EXP(VISC)*2.4189

    4 RETURN
      END

C ******************************************************************
C *                                 *
C *             SUBROUTINE PRNUM                  *
C *                                 *
C *     CALCULATES THE PRANDTL NO.(PRN) FOR PURE WATER        *
C *   AND ANY CONCENTRATION OF ETHYLENE GLYCOL/WATER SOLUTION.    *
C *        THE INPUT IS TEMPERATURE IN DEGREES F.         *
C *                                 *
C *        TEMPERATURE RANGE:                   *
C *           PURE WATER       10 - 100 C           *
C *           E.G. MIXTURES     0 - 150 C           *
C *                                 *
C ******************************************************************

      SUBROUTINE PRNUM(TF,MFLUID,X,PRN)
      DIMENSION P(3,3),AP(3,3),P2(3)

      T=(TF-32.0)/1.8
      IF(MFLUID.GT.1) GO TO 1

C ----- PURE WATER -----

      IF(T.LT.10.OR.T.GT.100.0)THEN
       WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE PRNUM'
       STOP
```

```
      END IF

           CALL SPHEAT(TF,MFLUID,X,SPHT)
           CALL MEW(TF,MFLUID,X,VISC)
           CALL CONDFL(TF,MFLUID,X,COND)
           PRN=SPHT*VISC/COND
           RETURN

C ----- ETHYLENE GLYCOL -----

    1 IF(T.LT.0.0.OR.T.GT.150.0)THEN
      WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE PRNUM'
      STOP
      END IF

      AP(1,1)=2.5735
      AP(1,2)=3.0411
      AP(1,3)=0.60237
      AP(2,1)=-0.031169
      AP(2,2)=-0.025424
      AP(2,3)= 0.0037454
      AP(3,1)= 1.1605E-16
      AP(3,2)= 2.5283E-15
      AP(3,3)= 2.3777E-16

      DO 2 I=1,2
           DO 2 J=1,3
            P(I,J)=AP(I,J)*X**(J-1)*T**(I-1)
    2  P2(J)=AP(3,J)*X**(J-1)

           SUM=0.0

           DO 3 I=1,3
    3  SUM=SUM+P2(I)
      P3=SUM**0.25*T*T
      PRN=P3+P(1,1)+P(1,2)+P(1,3)+P(2,1)+P(2,2)+P(2,3)
      PRN=EXP(PRN)

      RETURN
      END

C ************************************************************************
C *                                              *
C *               SUBROUTINE SPHEAT                          *
C *                                              *
C *     CALCULATES THE SPECIFIC HEAT (SPHT) FOR PURE WATER          *
C *    AND ANY CONCENTRATION OF ETHYLENE GLYCOL/WATER SOLUTION.    *
C *        THE INPUT IS TEMPERATURE IN DEGREES F             *
C *         AND THE OUTPUT IS IN BTU/(LBM-DEGF).           *
C *                                              *
C *       TEMPERATURE RANGE:                              *
C *          PURE WATER        0 - 100 C              *
C *          E.G. MIXTURES     0 - 150 C              *
C *                                              *
C ************************************************************************

      SUBROUTINE SPHEAT(TF,MFLUID,X,SPHT)

      T=(TF-32.0)/1.8
      IF(MFLUID .GT. 1.0)GO TO 1

C ----- PURE WATER -----
```

```
    IF(T.LT.0.0.OR.T.GT.100.0)THEN
     WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE SPHT'
     STOP
    END IF

    SPHT=-1.475E-7*T**3+3.66E-5*T*T-.0022*T+4.216
    SPHT=SPHT/4.1868

    RETURN

C ----- ETHYLENE GLYCOL -----

  1 IF(T.LT.0.0.OR.T.GT.150.0)THEN
     WRITE(*,*)' TEMPERATURE IS OUT OF RANGE IN SUBROUTINE SPHT'
     STOP
    END IF

     CALL MEW(TF,MFLUID,X,VISC)
     CALL CONDFL(TF,MFLUID,X,COND)
     CALL PRNUM(TF,MFLUID,X,PRN)
     SPHT = PRN*COND/VISC
    RETURN
    END

C *********************************************************************
C *                                 *
C *              SUBROUTINE PRINT-OUT                 *
C *                                 *
C *        PRINTS DATA TO OUTPUT FILES:                   *
C *                                 *
C *            "RN(run #).SUM"    - Device #6            *
C *            "RN(run #).DAT"    - Device #9            *
C *                                 *
C *********************************************************************

    SUBROUTINE PRNT

    INTEGER IREN(31,8),IDFLX(31,8),IHCOF(31,8),hHAU(10,4),hSDT(10,4)
        INTEGER STN
    COMMON /PRINT/ IPICK,REN(31,8),TBULK(31),VEL,REYNO,PRNO,GW,
   +         HTCOFF(31,8),H(31),RENO(31),GRNO(31),PR(31),
   +         SNUS(31),VISBW(31),SHTHB(32),QFLXID(31,8),QFLXAV,
   +         QGEXPT,QBALC,QPCT,IPMAX,TAVG(31),VISCA(31),
   +         VISWLA(31),ROWA(31)
   +     /INPUT/ TROOM,VOLTS,TAMPS,RMFL,MFLUID,X2,FLOWRT,NRUN,VFLOW,
   +         TIN,TOUT,TOSURF(31,8),TISURF(31,8),IP(32),KST(32)
   +     /TEMP1/ TWALL(31,8),AMPS(31,8),RESIS(31,8),POWERS(32),
   +         TPOWER
   +     /MAIN1/ IST,KOUNT,NSTN
   +     /GEOM1/ XAREA(31),R(31),LTP(32),LTH(32),DELZ(31),LHEAT,
   +         LTEST,LOD(31),DOUT,DIN,DELR,NODES,NSLICE,PI

     REAL*4 LTH,LTP,LTEST,LHEAT,H,HTCOFF,LOD
        REAL*8 muW(10),Twl(10),muB(10),Tbl(10),kL(10),nHAU(10),nSDTT(10)
   +    ,aPTP,fPTP,fGNL,nDTB(10),nPTP(10),nGNL(10),nCLB(10),
        +    nSDTL(10),TMP,AmBmW,fCHR,nCHRL,nCHRT,nCHR(10),nGHJL(10),
        +    nGHJT(10),cPTP
        REAL*8 LovD,DovL
       COMMON/STATION/STN
       LovD=94.80401d0
       DovL=0.010548d0
```

```
         AmBmW=0.0
         DO 5000 IST=1,10
         nGNL(IST)=0.0
         nGHJt(IST)=0.0
         nPTP(IST)=0.0
 5000 CONTINUE
C ------------------------------------
C ---- SET FLAG FOR STATION OUTPUT CONTROL ----
C ------------------------------------

CC      ATST=NSTN/9.
      ATST=NSTN/11.
      IFST=INT(ATST)+1

C --------------------------------.
C ---- PRINT RUN NUMBER & TUBE DATA ----
C --------------------------------

C ---- ENGLISH UNITS ----

      WRITE(6,2001)NRUN

C ---- PRINT FLUID-TYPE DESCRIPTION ----

      IF(MFLUID.EQ.1)THEN
           WRITE(6,2003)
      ELSE
       WRITE(6,2004)X2
      ENDIF

C ---- PRINT TUBE DATA ----

      IGW=GW
      IREYN=REYNO
      IFXA=QFLXAV
      IQEX=QGEXPT
      IQBL=QBALC

      WRITE(6,2016)VFLOW,RMFL,IGW,VEL,TROOM,TIN,TOUT,IREYN,PRNO,
     +         TAMPS,VOLTS,IFXA,IQEX,IQBL,QPCT

C ------------------------------------------
C ---- PRINT TUBE OUTSIDE SURFACE TEMPERATURES ----
C ------------------------------------------

C ---- ENGLISH UNITS ----

      DO 5 K=1,NSTN
      IF(IP(K).EQ.2)THEN
           TOSURF(K,3)=TOSURF(K,2)
           TOSURF(K,2)=0.0
           TOSURF(K,4)=0.0
          ELSE
    5 ENDIF

      WRITE(6,2005)
      DO 7 ICNT=1,IFST
cc       KMIN=1+(ICNT-1)*9
cc       KMAX=KMIN+8
       KMIN=1+(ICNT-1)*10
       KMAX=KMIN+9
       IF(NSTN.LT.KMAX)KMAX=NSTN
```

```
        DO 6 IPR=1,IPMAX
         IF(IPR.EQ.1)WRITE(6,2006)(KST(K),K=KMIN,KMAX)
cc       IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+8))WRITE(6,2007)
         IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+9))WRITE(6,2007)
     WRITE(6,2008)IPR,(TOSURF(IST,IPR),IST=KMIN,KMAX)

  6  CONTINUE
  7  CONTINUE

C -----------------------------------------------
C ---- PRINT INSIDE SURFACE TEMPERATURES TO OUTPUT FILE ----
C -----------------------------------------------

C ---- ENGLISH UNITS ----

     DO 14 K=1,NSTN
     IF(IP(K).EQ.2)THEN
          TISURF(K,3)=TISURF(K,2)
          TISURF(K,2)=0.0
          TISURF(K,4)=0.0
         ELSE
 14  ENDIF

     WRITE(6,2010)
     DO 16 ICNT=1,IFST
cc     KMIN=1+(ICNT-1)*9
cc     KMAX=KMIN+8
      KMIN=1+(ICNT-1)*10
      KMAX=KMIN+9
      IF(NSTN.LT.KMAX)KMAX=NSTN
         DO 15 IPR=1,IPMAX
          IF(IPR.EQ.1)WRITE(6,2006)(KST(K),K=KMIN,KMAX)
cc        IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+8))WRITE(6,2007)
          IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+9))WRITE(6,2007)
      WRITE(6,2008)IPR,(TISURF(IST,IPR),IST=KMIN,KMAX)


  15  CONTINUE
  16  CONTINUE

C ------------------------------
C ---- PRINT REYNOLDS NUMBERS TO OUTPUT FILE ----
C ------------------------------

  22 DO 29 K=1,NSTN
    IF(IP(K).EQ.2)THEN
          IREN(K,1)=INT(REN(K,1))
          IREN(K,3)=INT(REN(K,2))
          IREN(K,2)=0
          IREN(K,4)=0
         ELSE
          DO 28 L=1,IPMAX
  28   IREN(K,L)=INT(REN(K,L))
  29 ENDIF

     WRITE(6,2014)
     DO 31 ICNT=1,IFST
cc     KMIN=1+(ICNT-1)*9
cc     KMAX=KMIN+8
      KMIN=1+(ICNT-1)*10
      KMAX=KMIN+9
      IF(NSTN.LT.KMAX)KMAX=NSTN
```

```
         DO 30 IPR=1,IPMAX
          IF(IPR.EQ.1)WRITE(6,2006)(KST(K),K=KMIN,KMAX)
cc        IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+8))WRITE(6,2007)
          IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+9))WRITE(6,2007)

        WRITE(6,2015)IPR,(IREN(IST,IPR),IST=KMIN,KMAX)
 30   CONTINUE
 31  CONTINUE

C -----------------------------------------
C ----- PRINT INSIDE HEAT FLUXES TO OUTPUT FILE ----
C -----------------------------------------

C ---- ENGLISH UNITS ----

     DO 35 K=1,NSTN
     IF(IP(K).EQ.2)THEN
          IDFLX(K,1)=INT(QFLXID(K,1))
          IDFLX(K,3)=INT(QFLXID(K,2))
          IDFLX(K,2)=0
          IDFLX(K,4)=0
         ELSE
          DO 34 L=1,IPMAX
 34   IDFLX(K,L)=INT(QFLXID(K,L))
 35 ENDIF

     WRITE(6,2020)
     DO 37 ICNT=1,IFST
cc     KMIN=1+(ICNT-1)*9
cc     KMAX=KMIN+8
      KMIN=1+(ICNT-1)*10
      KMAX=KMIN+9
      IF(NSTN.LT.KMAX)KMAX=NSTN
          DO 36 IPR=1,IPMAX
           IF(IPR.EQ.1)WRITE(6,2006)(KST(K),K=KMIN,KMAX)
cc         IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+8))WRITE(6,2007)
           IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+9))WRITE(6,2007)
        WRITE(6,2021)IPR,(IDFLX(IST,IPR),IST=KMIN,KMAX)
 36   CONTINUE
 37  CONTINUE

C -----------------------------------------
C ---- PRINT PERIPHERAL HEAT TRANSFER COEFFICIENTS ----
C -----------------------------------------

       WRITE(6,2017)NRUN
C          WRITE(7,2017)NRUN
C ---- ENGLISH UNITS ----

     DO 46 K=1,NSTN
     IF(IP(K).EQ.2)THEN
          IHCOF(K,1)=INT(HTCOFF(K,1))
          IHCOF(K,3)=INT(HTCOFF(K,2))
          IHCOF(K,2)=0
          IHCOF(K,4)=0
         ELSE
          DO 45 L=1,IPMAX
 45   IHCOF(K,L)=INT(HTCOFF(K,L))
 46 ENDIF

      WRITE(6,2023)
C         WRITE(7,2023)
```

```
    DO 48 ICNT=1,IFST
cc      KMIN=1+(ICNT-1)*9
cc      KMAX=KMIN+8
     KMIN=1+(ICNT-1)*10
     KMAX=KMIN+9
     IF(NSTN.LT.KMAX)KMAX=NSTN
         DO 47 IPR=1,IPMAX

         IF(IPR.EQ.1)WRITE(6,2006)(KST(K),K=KMIN,KMAX)
cc       IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+8))WRITE(6,2007)
     IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+9))WRITE(6,2007)
       WRITE(6,2021)IPR,(IHCOF(IST,IPR),IST=KMIN,KMAX)

C        IF(IPR.EQ.1)WRITE(7,2006)(KST(K),K=KMIN,KMAX)
C        IF(IPR.EQ.1 .AND. KMAX.LT.(KMIN+9))WRITE(7,2007)
C       WRITE(7,2021)IPR,(IHCOF(IST,IPR),IST=KMIN,KMAX)
  47  CONTINUE
  48  CONTINUE


C ------------------------------------
C ---- PRINT SUMMATION DATA FOR OUTPUT FILE ----
C ------------------------------------

  55 WRITE(6,2028)NRUN


    WRITE(6,2029)
DO 56 J=1,NSTN
    WRITE(6,2030)KST(J),RENO(J),PR(J),LOD(J),VISCA(J),VISWLA(J),
   +          TBULK(J),TAVG(J),ROWA(J),SNUS(J)
C    WRITE(7,2030)KST(J),RENO(J),PR(J),LOD(J),VISCA(J),VISWLA(J),
C   +          TBULK(J),TAVG(J),ROWA(J),SNUS(J)


  56 CONTINUE

C ---- PRINT NOTE GIVING UNITS ----

    WRITE(6,2032)
    RETURN

 2001 FORMAT(/,18X,'*',41('-'),'*',/32X,'RUN NUMBER ',I4)
 2003 FORMAT(25X,'TEST FLUID IS DISTILLED WATER',/18X,'*',41('-'),'*')
 2004 FORMAT(19X,'MASS FRACTION OF ETHYLENE GLYCOL =',F8.4,/18X,'*',
   +     41('-'),'*')
 2005 FORMAT(//20X,'OUTSIDE SURFACE TEMPERATURES - DEGREES F')'
cc 2006 FORMAT(/,9X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,/)
 2006 FORMAT(/,9X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,6X,I2,
   +     6X,I2,/)
 2007 FORMAT(' ')
cc 2008 FORMAT(3X,I1,1X,9F8.2)
 2008 FORMAT(3X,I1,1X,10F8.2)
 2010 FORMAT(//20X,'INSIDE SURFACE TEMPERATURES - DEGREES F')
 2014 FORMAT(//20X,'REYNOLDS NUMBER AT THE INSIDE TUBE WALL')
cc 2015 FORMAT(3X,I1,9I8)
 2015 FORMAT(3X,I1,10I8)
 2016 FORMAT(/,18X,'VOLUMETRIC FLOW RATE =',F9.2,3X,'GPM',
   +     /18X,'MASS FLOW RATE',7X,'=',F9.1,3X,'LBM/HR',
   +     /18X,'MASS FLUX',12X,'=',I9,3X,'LBM/(SQ.FT-HR)',
   +     /18X,'FLUID VELOCITY',7X,'=',F9.2,3X,'FT/S',
   +     /18X,'ROOM TEMPERATURE',5X,'=',F9.2,3X,'F',
```

```
     +     /18X,'INLET TEMPERATURE',4X,'=',F9.2,3X,'F',
     +     /18X,'OUTLET TEMPERATURE',3X,'=',F9.2,3X,'F',
     +     /18X,'AVERAGE RE NUMBER',4X,'=',I9,
     +     /18X,'AVERAGE PR NUMBER',4X,'=',F9.2,
     +     /18X,'CURRENT TO TUBE',6X,'=',F9.1,3X,'AMPS',
     +     /18X,'VOLTAGE DROP IN TUBE =',F9.2,3X,'VOLTS',
     +     /18X,'AVERAGE HEAT FLUX',4X,'=',I9,3X,'BTU/(SQ.FT-HR)'
     +     /18X,'Q=AMP*VOLT',11X,'=',I9,3X,'BTU/HR',
     +     /18X,'Q=M*C*(T2-T1)',8X,'=',I9,3X,'BTU/HR',
     +     /18X,'HEAT BALANCE ERROR',3X,'=',F9.2,3X,'%')
CC 2017 FORMAT(//////31X,'*',15('-'),'*',/32X,'RUN NUMBER ',I4,/31X,'*',
 2017 FORMAT(//31X,'*',15('-'),'*',/32X,'RUN NUMBER ',I4,/31X,'*',
     +       15('-'),'*')
 2020 FORMAT(//22X,'INSIDE SURFACE HEAT FLUXES BTU/HR/FT2')
cc 2021 FORMAT(3X,I1,9I8)
 2021 FORMAT(3X,I1,10I8)
CC 2023 FORMAT(//14X,'PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/',
 2023 FORMAT(/14X,'PERIPHERAL HEAT TRANSFER COEFFICIENT BTU/',
     +     '(SQ.FT-HR-F)')
 2028 FORMAT(//31X,'*',15('-'),'*',/32X,'RUN NUMBER ',I4,/36X,
     +     'SUMMARY',/31X,'*',15('-'),'*')
 2029 FORMAT(/1X,'ST',6X,'RE',7X,'PR',5X,'X/D',5X,'MUB',5X,'MUW',
     +     5X,'TB',6X,'TW',5X,'DENS',6X,'NU',/)
cc 2030 FORMAT(1X,I2,3X,F7.2,3X,F5.2,3X,F5.1,3X,F5.3,3X,F5.3,
 2030 FORMAT(1X,I2,3X,F8.2,2X,F5.2,3X,F5.1,3X,F5.3,3X,F5.3,
     +     2(2X,F6.2),3X,F5.2,3X,F5.2)
 2032 FORMAT(/,20X,'NOTE: TBULK IS GIVEN IN DEGREES FAHRENHEIT',/,
     +       26X,'MUB AND MUW ARE GIVEN IN LBM/(FT*HR)')

      END
```

C.3 Program PhaseI

This appendix discusses the PhaseI program which calculates the all of the two-phase heat transfer parameters used to predict the heat transfer coefficient using twenty correlations and seven two-phase data sets

We have programmed [in FORTRAN] the 20 basic correlations that are found to fit the seven sets of data [from different experimental studies] that we have located. These 20 correlations are:

Author:	Subroutine names:
[1]. Aggour, M.A. (1978)	HAGGOUR
[2]. Chu, Y-C. and B.G. Jones (1980)	HCHU
[3]. Davis, E.J. and M.M. David (1964)	HDAVIS
[4]. Dorresteijn, W.R. (1970)	HDORREST
[5]. Dusseau (1968)	HDUSSEAU
[6]. Elamavaluthi, G. and N.S. Srinivas (1984)	HELAM
[7]. Groothius and Hendal (1959)	HGROOTH
[8]. Hughmark (1965)	HHUGH
[9]. Khoze, A.N., Dunayev and Sparin (1976)	HKHOZE
[10]. King C.D.G. (1952)	HKING
[11]. Knot, Anderson, Acrivos and Peterson (1959)	HKNOT
[12]. Kudirka, Grosh and McFadden (1965)	HKUDIRKA
[13]. Martin and Sims (1971)	HMARTIN

Author:	Subroutine names:
[14]. Oliver, D.R. and S.J. Wright (1964)	HOLIVER
[15]. Ravipudi and Godbold (1978)	HRAVIPUDI
[16]. Rezkallah and Sims (1987)	HREZKALLAH
[17]. Serizawa, Kataoka and Michiyoshi (1975)	HSERIZAWA
[18]. Shah (1981)	HSHAH
[19]. Ueda and Hanaoka (1967)	HUEDA
[20]. Vijay, M.M., M.A. Aggour and G.E. Sims (1982)	HVIJAY

The above correlation numbers are consistent with previously published documents. (For a complete discussion of the correlations referenced above, see the Oklahoma State University, JIP Literature Search Survey Reports, Parts I and II; and National Heat Transfer Conference paper, "An Evaluation of Several Heat Transfer Correlations for Two-Phase Flow with Different Flow Patterns in Vertical and Horizontal Tubes," by Kim, Ghajar and Dougherty, Baltimore, MD, August 1997.)

A example of the FORTRAN subroutines for these correlations is presented in this Appendix. Each subroutine name is started with H followed by part or all of the correlation name, e.g., for Aggour's correlation, the subroutine is HAGGOUR. There is also a subroutine (PROPERTIES) which provides the properties of the fluids used in the data found, the gases being air, helium, and freon-12; and the liquids being water, glycerin, and silicone. The Nomenclature of the variables used in this program is provided in Define.for (see pp. 242-243) and Define1.for (see pp. 244-246). In order to demonstrate the ability of these correlations to predict the data, a MAIN routine is provided which reads in all of the data points and compares the original researchers data to calculations from our chosen correlations.

The Code calculates the heat transfer coefficient in two different ways:

[1] It can calculate the heat transfer coefficients by directly taking ReSL, PrL etc. directly from an original experimenatl data set, or

[2] it can calculate ReSL, PrL etc. from the data in the experimental data set, then use these parameters to calculate the heat transfer coefficient.

The toggle used to choose the above option in the Code is KMSWT. If KMSWT is 1, the code performs the calculations by method [1] stated above; or else if KMSWT is 2, the code performs the calculation by method [2]. The Code also asks the user to input the desired correlation number to perform the calculations.

A sample-input data is given below. The variables assigned to these values are clearly explained in the PhaseI program.

```
7
1 1 1 139
VIJAY AIR-WATER VERTICAL DATA
0.038333D0 1.99983261D0
11 69.400000   86.258400   0.033000    4242.820000 0.033655
   125280.000000     4363.200000 125742.000000     6.839000    0.813000
   5592.870000 566.760000  0.710000    8995.980000 0.751000
   616.640000  0.000000    0.000000    8.253000    7.415000
```

A sample output file is given below, and all of the tables are explained herein. This sample output file is obtained by using Aggour's (1978) correlation to calculate the heat transfer coefficient for the Vijay (1978) air-water data.

The Line 1 shows whether the user or code has chosen the correlation to perform the calculations. Line 2 shows the correlation and correlation number used. Line 3 shows the number of data sets used. In this code, we used 7 sets of data. Line 8 shows the name of the data set used, and line 9 shows the orientation of the pipe (vertical/horizontal). Lines 10-11 show the type of gas/liquid used in this data set. Line 12 shows the number of data points in this data set. Lines 15-19 show the two digit flow pattern designations used in this code. These flow pattern designations were used throughout the output file, which makes it easier to identify the type of flow pattern present with a two-digit number.

Lines 21-23 explain the laminar/turbulent conditions depending on the Reynolds number. From line 25, the first table (overall table) is printed out. As an example, in line 41, this table clearly shows the data set point number (1 in this case), flow pattern type (11 in this case), ReSL, PrL, ReSG, VsL, VsG, muWmuB, hTPEX (experimental heat transfer coefficient), NuTPCAL (calculated Nusselt number), and their differences (line 42) as compared to the input data set values. Here, for this case, the differences for ReSL, PrL, ReSG, VsL, VsG, and muWmuB are zero, since these parameters were directly taken from the data set (i.e., KIMSWT=1) to perform the calculations. The hTPEX and NuTPCAL columns do shows differences, since they are compared with the calculated hTP and experimental NuTP values respectively.

Line 43 show the correlation name/number, and whether or not the parameters ReSL, PrL, ReSG, VsL, VsG, and muWmuB were within the range (1) or out of the range (0) specified by the author of the correlation. This type of data is given for all of the data set points through line 552.

```
Line 1  THE USER HAS DECIDED WHICH CORRELATION TO USE.
        CORRELATION USED IS                 :AGGOUR
        THE NUMBER OF DATA SETS IS          :           7

Line 8                  VIJAY AIR-WATER VERTICAL DATA
          ORIENTATION(HORIZONTAL=2,VERTICAL=1)          : 1
Line 10   GASEOUS FLUIDS(AIR=1,HELIUM=2,FREON=3)        : 1
          LIQUID FLUIDS(WATER=1,GLYCERIN=2,SILICONE=3) : 1
```

```
         TOTAL NUMBER OF DATA POINTS IN THIS SET       :139

Line 14                      FLOW PATTERN DESIGNATIONS
Line 15    00 = ALL FLOW PATTERNS
           11 = BUBBLY   55 = CHURN              15 = BUBBLY-CHURN    34 = FROTH-ANNULAR
           22 = SLUG     12 = BUBBLY-SLUG        23 = SLUG-FROTH      35 = FROTH-CHURN
           33 = FROTH    13 = BUBBLY-FROTH       24 = SLUG-ANNULAR    45 = ANNULAR-CHURN
           44 = ANNULAR  14 = BUBBLY-ANNULAR 25 = SLUG-CHURN          46 = ANNULAR-MIST

Line 21   IN THE FOLLOWING TABLES "L"=LAMINAR POINTS, "T"=TURBULENT POINTS
          (ReSL<2000=LAM; ReSL>2000=TUR), EXCEPT SHAHS CORRELATION, WHERE 2000 IS
          REPLACED BY 170

================================BEGIN: OVERALL TABLE=====================================


Line 27      0-->NO RANGE TO COMPARE WITH.
             1-->INDICATES VALUES WITHIN RANGE.
             ANY OTHER NUMBER OTHER THAN THESE INDICATES FRACTION
             OUT OF RANGE WITH MAX OR MIN VALUE FROM THE DATA;
             ****-->INDICATES THE CALCULATED VALUE IS OVER 100%
             OUT OF RANGE WITH EITHER THE MAX OR MIN VALUE FROM
             DATA.
             IN THE FOLLOWING CALCULATIONS,ReSL,PrL,ReSG,etc., ARE TAKEN FROM THE
             FUNDAMENTAL DATA SET (RATHER THAN BEING COMPUTED FROM FUNDAMENTAL
             PROPERTIES).


Line 40  PT #  PAT  L/T    ReSL        PrL        ReSG        VsL        VsG      muW/muB   hTPEX   NuTPCAL
          1     11   T  1.257E+05 6.839E+00 5.668E+02 1.253E+05 4.363E+03 8.130E-01 5.593E+03 .166E+02
         ERRORS=         .000E+00  .000E+00  .000E+00  .000E+00  .000E+00 -.100E+02 -.236E+00 -.236E+00
Line 43  AGGOUR     [ 1]     0         1         1         0         0         0
..
..
.
Line 549 PT #  PAT  L/T    ReSL        PrL        ReSG        VsL        VsG      muW/muB   hTPEX   NuTPCAL
         139    46   L  2.318E+02 6.982E+00 1.527E+05 2.160E+02 1.657E+06 8.580E-01 6.941E+02 .641E+01
         ERRORS=         .000E+00  .000E+00  .000E+00  .000E+00  .000E+00 -.100E+02  .544E+00 -.294E+01
Line 552 AGGOUR     [ 1]     0         1         1         0         0         0

===================================END: OVERALL TABLE====  ===============================
```

The following table (XIX), shows the rms and mean values for hTP for all of the flow patterns. This table also gives the number of data point predictions within ±10%, ±15%, ±20%, ±25%, ±30%, and ±50% [for hTP differences] of the data for each flow pattern and for all data points. This table also shows the number of data points that fall in the laminar or turbulent (L/T) regime of flow. The percentage differences are computed as follows:

$$\text{mean} = \frac{1}{n}\sum_{i=1}^{n} \text{difference}_i \qquad \text{rms} = \frac{1}{\sqrt{n}}\left(\sum_{i=1}^{n} (\text{difference}_i)^2\right)^{1/2}$$

where n is the total number of data points

difference=$(hTP_{Cal}/hTP_{Exp} - 1)$

TABLE XIX

MEAN and RMS Values for hTP, the Number of Data Points for the Specified Flow Pattern and Regime (L/T) Combination

```
=============================BEGIN: RMS/MEAN ERROR TABLE===============================
 FOR THE FOLLOWING TABLE:
 IN PRINTING THE MEAN AND RMS VALUES FOR TWO-PHASE FILM COEFFICIENT(hTP) FOR
  "NO PT", THE NUMBER GIVEN IS THE NUMBER OF DATA POINTS FOR THE SPECIFIED FLOW
   PATTERN AND REGIME (L/T) COMBINATION.
 FOR ALL %-HEADING COLUMNS, THE NUMBER GIVEN IS THE NUMBER OF HEAT TRANSFER
  COEFFICIENT CORRELATION PREDICTIONS THAT FALL WITHIN +-xx% OF THE EXPERIMENTAL
    DATA.
 "MEAN"-IS THE AVERAGE ERROR OF ALL CORRELATION PREDICTIONS AS COMPARED TO ALL
  DATA FOR THAT FLOW PATTERN/REGIME COMBINATION.
 "R.M.S"-IS THE R.M.S ERROR OF ALL CORRELATION PREDICTIONS AS COMPARED TO ALL
  DATA FOR THAT FLOW PATTERN/REGIME COMBINATION.

-------------------------------------------------------------------------------------
PAT   NO PT        MEAN      R.M.S   +-10%    +-15%    +-20%    +-25%    +-30%    +-50%
      L   T                          L   T    L   T    L   T    L   T    L   T    L   T
-------------------------------------------------------------------------------------
11    0  25      -17.21      18.97   0   4    0   7    0  11    0  23    0  25    0  25
22    3  22       -6.73      11.69   2  10    3  17    3  20    3  22    3  22    3  22
33    0  25      -43.95      47.63   0   0    0   1    0   2    0   2    0   2    0  19
44    4  21      -10.40      38.36   0   6    0   7    0  11    0  11    0  14    0  17
13    0   7      -29.86      31.10   0   0    0   0    0   1    0   2    0   4    0   7
24    7   3       39.91      61.48   1   0    1   0    1   1    1   2    1   3    2   3
34    0   4      -29.82      30.16   0   0    0   0    0   0    0   1    0   1    0   4
46   12   5       -5.37     126.03   0   0    0   0    0   0    0   0    0   0    0   0
00   26 113      -14.27      56.26   3  20    4  32    4  46    4  63    4  71    5  97
00     139       -14.27      56.26    23       36       50       67       75       102
-------------------------------------------------------------------------------------

==============================END: RMS/MEAN ERROR TABLE==============================
```

Aggour did not specify an ReSL range, hence the following statement is printed out. Otherwise, the following table gives the number of points within the range for the ReSL parameter with respect to hTP differences.

```
**THE PARAMETER ReSL RANGE IS NOT APPLICABLE**.
```

The following table (XX) gives the number of points within the author [of correlation] specified range for the V_{SG}/V_{SL} parameter with respect to ±10%, ±20%, etc., hTP differences, for all of the flow patterns and for laminar/turbulent (L/T) regimes.

TABLE XX

Number of Points within the Author Specified Range for VsG/ VsL Parameter with Respect to hTP Differences.

```
===============================BEGIN: VsG/VsL ERROR TABLE================================
THE FOLLLOWING TABLE GIVES THE NUMBER OF POINTS WITHIN THE RANGE
 FOR VsG/VsL PARAMETER WITH RESPECT TO hTP ERROR

PAT     NO PT      10%      15%      20%      25%      30%      50%
        L   T     L   T    L   T    L   T    L   T    L   T    L   T

11      0  25     0   4    0   7    0  11    0  23    0  25    0  25
22      3  22     2  10    3  17    3  20    3  22    3  22    3  22
33      0  25     0   0    0   1    0   2    0   2    0   2    0  19
44      0  21     0   6    0   7    0  11    0  11    0  14    0  17
13      0   7     0   0    0   0    0   1    0   2    0   4    0   7
24      6   3     1   0    1   0    1   1    1   2    1   3    1   3
34      0   4     0   0    0   0    0   0    0   1    0   1    0   4
46      0   6     0   0    0   0    0   0    0   0    0   0    0   0

================================END: VsG/VsL ERROR TABLE=================================
```

In this table (XXI), the number of data points that fall within the author [of correlation] specified range for the parameters ReSL, PrL, ReSG, VsG/ VsL and Mg/Ml are printed. If the parameter has no author specified range, the code prints out zeroes in the appropriate location(s) as well as the message NO RANGE under that parameter.

TABLE XXI

Number of Points that Fall within the Author [of Correlation] Specified Range for that Column Parameter (ReSL, PrL, ReSG, VsL/VsG, and Mg/Ml)

```
===========================BEGIN: AUTHOR-SPECIFIED RANGE TABLE===========================
 FOR "NO PT", THE NUMBER GIVEN IS THE NUMBER OF DATA POINTS FOR THE SPECIFIED
  FLOW PATTERN AND FLOW REGIME (L/T) COMBINATION.
 FOR ALL OTHER COLUMNS, THE NUMBER GIVEN IS THE NUMBER OF DATA POINTS THAT FALL
  WITHIN THE AUTHOR [OF CORRELATION]- SPECIFIED RANGE FOR THAT COLUMN PARAMETER
  (ReSL,PrL,ReSG).

PAT     NO PT      ReSL       PrL        ReSG      VsG/VsL     Mg/Ml
        L   T     L   T      L   T      L   T      L   T      L   T
                 NO RANGE

11      0  25     0   0      0  25      0  25      0  25      0  25
22      3  22     0   0      3  22      3  22      3  22      3  22
33      0  25     0   0      0  25      0  25      0  25      0  25
44      4  21     0   0      3  20      4  21      0  21      0  21
13      0   7     0   0      0   7      0   7      0   7      0   7
24      7   3     0   0      5   3      7   3      6   3      7   3
34      0   4     0   0      0   4      0   4      0   4      0   4
46     12   6     0   0     12   6     12   6      0   6      1   6
MEAN  -14.27        .00    -15.98     -14.27     -30.91     -23.96
RMS    56.26        .00     55.77      56.26      36.57      54.93

==============================END: AUTHOR-SPECIFIED RANGE TABLE==========================
```

The following table (XXII) shows the number of data points for parameters ReSL, PrL, ReSG, VsG/ VsL and Mg/Ml within ±15% of the author [of correlation] specified range for those parameters.

TABLE XXII

Number of Points for ReSL, PrL, ReSG, VsG/VsL, and Mg/Ml within ±15% of the Author Specified Range.

```
=============================BEGIN: 15% ERROR BAND TABLE===============================

 NUMBER OF POINTS FOR ResL,PrL,ResG,VsG/VsL,MG/ML WITHIN +-15%.

 PAT    NO PT      ReSL       PrL        ReSG    VsG/VsL     Mg/Ml
        L   T     L    T    L    T     L    T    L    T     L    T
                  NO RANGE

 11     0  25     0    0    0   25     0   25    0   25     0   25
 22     3  22     0    0    3   22     3   22    3   22     3   22
 33     0  25     0    0    0   25     0   25    0   25     0   25
 44     4  21     0    0    4   21     4   21    0   21     0   21
 13     0   7     0    0    0    7     0    7    0    7     0    7
 24     7   3     0    0    7    3     7    3    6    3     7    3
 34     0   4     0    0    0    4     0    4    0    4     0    4
 46    12   6     0    0   12    6    12    6    1    6     1    6

===============================END: 15% ERROR BAND TABLE===============================
```

The following table (XXIII) shows the number of data points for parameters ReSL, PrL, ReSG, VsG/ VsL and Mg/Ml within ±30% of the author [of correlation] specified range for those parameters.

TABLE XXIII

Number of Points for ReSL, PrL, ReSG, VsG/VsL, and Mg/Ml within ±30% of the Author Specified Range.

```
=============================BEGIN: 30% ERROR BAND TABLE===============================

 NUMBER OF POINTS FOR ResL,PrL,ResG,VsG/VsL,MG/ML WITHIN +-30%.

 PAT    NO PT      ReSL       PrL        ReSG    VsG/VsL     Mg/Ml
        L   T     L    T    L    T     L    T    L    T     L    T
                  NO RANGE
```

```
11     0  25    0    0     0  25    0  25    0  25    0  25
22     3  22    0    0     3  22    3  22    3  22    3  22
33     0  25    0    0     0  25    0  25    0  25    0  25
44     4  21    0    0     4  21    4  21    0  21    0  21
13     0   7    0    0     0   7    0   7    0   7    0   7
24     7   3    0    0     7   3    7   3    7   3    7   3
34     0   4    0    0     0   4    0   4    0   4    0   4
46    12   6    0    0    12   6   12   6    1   6    1   6
____________________________________________________________

===============================END: 30% ERROR BAND TABLE===============================
```

The first 24 pages of the code are given in this appendix. The correlation subroutines are all similar, so only one correlation subroutine has been given in this appendix. A complete listing of this code can be obtained from:

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```
CCCCCC
C                         PHASE-I.FOR

C  PHASE-I HEAT TRANSFER COEFFICIENT FORTRAN CODING FOR
C   "Paraffin Deposition Prediction in Multiphase Flowlines and Wellbores"
C    Joint Industry Project.


C  MAIN PROGRAM TO DEMONSTRATE CALCULATION OF HEAT TRANSFER COEFFICIENT
C    FOR TWO PHASE FLOW WITH VARIOUS TUBE ORIENTATIONS,FLUID COMBINATIONS
C    AND FLOW PATTERNS.

C BY: RYALI, VENKATA KAMAL KUMAR; OKLA ST. UNIV./MECH-AERO ENGR.
C DATE LAST CHANGED:11/18/98

      INCLUDE 'DEFINE.FOR'

        IMPLICIT NONE

        REAL*8 L,D,LoverD,DoverL,muWmuB,VsL,VsG,kL,kG,muG,muL,hTP,mL,mG,P,
       *       ReSG,BETA,muW,VDOT,ReSL,PrL,D2,ERRR1,ERRR2,ERRR3,ERRR4,
       *       ERRR5,ERRR6,ERRR7,PI,ERR,NuTP,Nu,NuER,cpL
        REAL*8 ReSLL,ReSGG,PrLL,VsLL,VsGG,hTPEX,TBULK,ALPHA,muWmB,TWALL
        REAL*8 MNH1(16),RMH1(16),MNH(16),RMH(16),TMEAN,TRMS
        REAL*8 ERCKMIN(6),ERCKMAX(6),MNRSL,MNRSG,MNVVL,MNMML,MNPRL,RMRSL,
       *       RMRSG,RMVVL,RMPRL,RMMML
      REAL*8 DtpbyDL,DPL,hLCAL,DPtpf
        REAL*8 ECK1,ECK2
      REAL*8 MDGML
      INTEGER I,M,N,MNG,MNL,NSETS,NUMSETS,NPT,IFLAGRG,IFLAGPL,IFLAGRL,
       *        IFLAGMM,IFLAGVV,IFLAGVG,IFLAGVL,IFLAGMB,COR,KIMSWT,RYSWT,
       *        J,F,JJ
      INTEGER MN(16),MNLL(16),MNTT(16),CL(16,6),CT(16,6),LL(16),NP(16),
       *        CLT(16,6),CTT(16,6),TCL(6),TCT(6),JJJ,ERSL(16,2,2),
       *        EPRL(16,2,2),ERSG(16,2,2),EVSL(16,2,2),EMGL(16,2,2),
       *        RRSL(16,2),RPRL(16,2),RRSG(16,2),RVSL(16,2),RMGL(16,2),
       *        PRCL(2,16,6),PRCT(2,16,6),RCOM(16,2),RCOM1(16,2),
       *        RCOM2(16,2)
        INTEGER TMNL,TMNT,TMN,PP,TPRCL(16),
     *       TPRCT(16),TOTPAR(2,16,2),TOGG(2),PCOR
        INTEGER ERR1(2),ERR2(2),ERR3(2),ERR4(2),ERR5(2),CHPL,CHRL,CHRG
        INTEGER FLSWT

        CHARACTER*1  LAMTUR
        CHARACTER*2  AP
      CHARACTER*8 RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
      CHARACTER*14 CORREL(20)
        CHARACTER*15 FILEIN,FILEOUT
        CHARACTER*40 TITLE

      COMMON/CHECKL/CL,MNLL,CLT,TCL
        COMMON/CHECKT/CT,MNTT,CTT,TCT
      COMMON/COUNT1/MNH,RMH,MNH1,RMH1,N,AP,LL
      COMMON/ECHECK/ECK1,ECK2
        COMMON/ECOUNT/ERR1,ERR2,ERR3,ERR4,ERR5,IFLAGRG,IFLAGPL,
       *       IFLAGRL,IFLAGMM,IFLAGVV,IFLAGMB,IFLAGVL,IFLAGVG,
     *         CHPL,CHRG,CHRL
        COMMON/ECOUNT2/ERSL,EPRL,ERSG,EVSL,EMGL,RRSL,RPRL,RRSG,RVSL,RMGL,
       *       RCOM,RCOM1,RCOM2,MNRSL,MNRSG,MNVVL,MNMML,MNPRL,
       *       RMRSL,RMRSG,RMVVL,RMPRL,RMMML
      COMMON/PARCHK/PRCL,PRCT,TPRCL,TPRCT

      COMMON/RANGE/RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
      COMMON/TEMP/MDGML
        COMMON/TOT/TMNL,TMNT,TMN,NP,PP,MN
      COMMON/TOTPART/TOTPAR,TOGG,PCOR
        COMMON/TPHASEA/ReSL,PrL,ReSG,LAMTUR,COR,NUMSETS
            COMMON/TPHASEB/VsL,VsG,muWmuB,kL,kG,muG,muL,muW,mL,mG
```

```
      COMMON/TPHASEC/KIMSWT,ReSLL,ReSGG,PrLL,VsLL,VsGG,muWmB
      COMMON/TPHASEG/cpL,L
   COMMON/TPHASEH/DtpbyDL,DPL,hLCAL,DPtpf
      DATA CORREL/'AGGOUR','CHU','DAVIS','DORRESTIJIN','DUSSEAU','ELAMA'
     *            ,'GROOTHUIS','HUGHMARK','KHOZE','KING','KNOTT',
     *            'KUDIRKA','MARTIN','OLIVER','RAVIPUDI','REZKALLAH',
     *            'SERIZAWA','SHAH','UEDA','VIJAY'/
      DATA ECK1/0.15/
      DATA ECK2/0.30/
      DATA ERCKMIN/-10,-15,-20,-25,-30,-50/
      DATA ERCKMAX/10,15,20,25,30,50/
      DATA LL/11,22,33,44,55,12,13,14,15,23,24,25,34,35,45,46/

C  FOR ERROR CALCULATIONS, THE EXPERIMENTAL HEAT TRANSFER COEFFICIENT(hTPEX)
C      IS CONSIDERED TO BE CORRECT (OR ACCURATE).

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cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc

      DATA PI/3.14592653589793D0/
      AP='00'
   OPEN(UNIT=7,FILE='P2.OUT')

C     ASKING THE USER TO INPUT THE I/O FILE NAMES HE/SHE WANTS TO USE, OR TO USE
C      THE DEFAULT I/O FILES.

      WRITE(*,*)'DO YOU WANT TO CHANGE THE INPUT/OUTPUT FILE NAMES OR'
      WRITE(*,*)'KEEP THE DEFAULTS P1.INP,P1.OUT? IF YES, ENTER 1; ELSE'
      WRITE(*,*)'ENTER 0;'
      READ(*,*)FLSWT
      IF(FLSWT.EQ.1)THEN
     WRITE(*,*)'ENTER THE NAME OF THE INPUT FILE(MAX CHARACTER 14)'
     READ(*,12)FILEIN
     WRITE(*,*)'ENTER THE NAME OF THE OUTPUT FILE(MAX CHARACTER 14)'
     READ(*,12)FILEOUT
12       FORMAT(A15)
      ENDIF

      IF(FLSWT.EQ.0)THEN
     FILEIN='P1.INP'
     FILEOUT='p1.out'
      ENDIF

      KIMSWT=0

C     ASKING THE USER WHETHER TO CALCULATE THE ERRORS BASED ON THE Re, Pr,
C      etc. TAKEN DIRECTLY FROM THE DATA SET OR TO RECALUATE THE Re, Pr, etc.,
C      FROM THE DATA AVAILABLE FROM THE DATA SET.

      WRITE(*,*)'IF YOU WANT TO CALCULATE BY TAKING Re, Pr, etc. '
   WRITE(*,*)'DIRECTLY FROM DATA SET, ENTER 1;'
   WRITE(*,*)' OR CALCULATE Re, Pr, etc., ENTER 0'
      READ(*,*)KIMSWT

C     ASKING THE USER WHETHER TO CALCULATE THE ERRORS BASED ON HIS CHOSEN CORRELATION
C      OR BASED ON THE COMPUTER CHOSEN CORRELATION FOR THAT FLOW PATTERN.

      WRITE(*,*)'LET THE COMPUTER CHOOSE THE BEST CORRELATION?'
      WRITE(*,*)'      ENTER 1 =YES OR 0=NO'
      READ(*,*)RYSWT
      IF(RYSWT.EQ.0)THEN
     WRITE(*,*)'AGGOUR[1]    CHU/JONES[2] DAVIS[3]       DORRESTEIJ[4]'
     WRITE(*,*)'DUSSEAU[5]   ELAMAVAL[6]  GROOTHUIS[7]   HUGHMARK[8]'
     WRITE(*,*)'KHOZE[9]     KING[10]     KNOT[11]       KUDIRKA[12]'
     WRITE(*,*)'MARTIN[13]   OLIVER[14]   RAVIPUDI[15]   REZKALLAH[16]'
     WRITE(*,*)'SERIZAWA[17]SHAH[18]      UEDA[19]       VIJAY[20]'
     WRITE(*,*)'ENTER THE NUMBER OF THE CORRELATION DESIRED'
     READ(*,*)COR
     PCOR=COR
      ENDIF
```

```
      OPEN(UNIT=6,FILE=FILEOUT)
      WRITE(6,*)'THE USER HAS DECIDED WHICH CORRELATION TO USE.'
      WRITE(6,*)'CORRELATION USED IS                    :',CORREL(COR)

C-----OPENING MASTER TEST DATA INPUT FILE

      OPEN(UNIT=1,FILE=FILEIN)

C-----INPUT NUMBER OF DATA SETS

      READ(1,*) NSETS
      WRITE(6,*)'THE NUMBER OF DATA SETS IS          :',NSETS
      WRITE(6,*)
      WRITE(6,*)
      DO 2200 NUMSETS=1,NSETS

C-----INPUT HORIZONTAL/VERTICAL,FLUID TYPES AND NO. OF DATA POINTS

      READ(1,*)M,MNG,MNL,NPT

C     TITLE OF THE DATA SET USED

      READ(1,101)TITLE
      WRITE(6,103)TITLE
      WRITE(6,102)M,MNG,MNL,NPT
102   FORMAT('ORIENTATION(HORIZONTAL=2,VERTICAL=1)          :',I2,/,
     *    'GASEOUS FLUIDS(AIR=1,HELIUM=2,FREON=3)        :',I2,/,
     *    'LIQUID FLUIDS(WATER=1,GLYCERIN=2,SILICONE=3) :',I2,/,
     *    'TOTAL NUMBER OF DATA POINTS IN THIS SET       :',I3)

C     DATA EXISTS FOR COMBINATIONS 1-1, 1-2,1-3, 2-1, 3-1, NOT ALL
C      COMBINATIONS ARE POSSIBLE

      WRITE(6,*)
101   FORMAT(A40)
103   FORMAT(//,20X,A40)

C  PRINTING OUT THE FLOW PATTERN DESIGNATIONS

   WRITE(6,*)'                              FLOW PATTERN DESIGNATIONS'
      WRITE(6,*)' 00 = ALL FLOW PATTERNS'
      WRITE(6,*)' 11 = BUBBLY   55 = CHURN           15 = BUBBLY-CHURN ',
     *          '  34 = FROTH-ANNULAR'
      WRITE(6,*)' 22 = SLUG     12 = BUBBLY-SLUG     23 = SLUG-FROTH   ',
     *          '  35 = FROTH-CHURN'
      WRITE(6,*)' 33 = FROTH    13 = BUBBLY-FROTH    24 = SLUG-ANNULAR ',
     *          '  45 = ANNULAR-CHURN'
      WRITE(6,*)' 44 = ANNULAR  14 = BUBBLY-ANNULAR 25 = SLUG-CHURN   ',
     *          '  46 = ANNULAR-MIST'
      WRITE(6,*)
   WRITE(6,*)'IN THE FOLLOWING TABLES "L"=LAMINAR POINTS,',
   *         ' "T"=TURBULENT POINTS      ',
     *          '             (ReSL<2000=LAM; ReSL>2000=TUR), EXCEPT ',
     *          'SHAHS CORRELATION, WHERE 2000 IS          ',
     *          ' REPLACED BY 170'
   WRITE(6,*)
   WRITE(6,1203)
1203       FORMAT('=================================BEGIN: OVERALL ',
     *          'TABLE===============================')

   WRITE(6,*)
      WRITE(6,*)'0-->NO RANGE TO COMPARE WITH.'
      WRITE(6,*)'1-->INDICATES VALUES WITHIN RANGE.'
      WRITE(6,*)'ANY OTHER NUMBER OTHER THAN THESE INDICATES FRACTION'
      WRITE(6,*)'   OUT OF RANGE WITH MAX OR MIN VALUE FROM THE DATA;'
   WRITE(6,*)'   ****-->INDICATES THE CALCULATED VALUE IS OVER 100% '
      WRITE(6,*)'   OUT OF RANGE WITH EITHER THE MAX OR MIN VALUE FROM '
      WRITE(6,*)'   DATA.'
   WRITE(6,*)

C     CHECKING IF KMSWT IS 1/0. IF KMSWT IS 1, THEN THE CODE CALCULATES THE
```

```
C      ERRORS USING Re, Pr, etc., FROM THE DATA SET. ELSEIF KMSWT IS 0, THEN
C      THE CODE COMPUTES THE Re, Pr, etc., FROM THE INFORMATION AVAILABLE FROM
C      THE DATA AND THEN USES THE SAME TO CALCULATE THE ERRORS

       IF(KIMSWT.EQ.1)THEN
      WRITE(6,*)'IN THE FOLLOWING CALCULATIONS,ReSL,PrL,ReSG,etc.,',
     *              ' ARE TAKEN FROM THE                 FUNDAMENTAL ',
     *              'DATA SET (RATHER THAN BEING COMPUTED FROM ',
     *              'FUNDAMENTAL PROPERTIES).'
    ELSE
         WRITE(6,*)'IN THE FOLLOWING CALCULATIONS,ReSL,PrL,ReSG,etc.,',
     *               'ARE CALCULATED FROM FUNDAMENTAL DATA.'
       ENDIF

   WRITE(6,*)
   WRITE(6,*)

508    FORMAT(1X,'PAT',3X,'NO',3X,'ReSL',3X,'PrL',3X,'ReSG',3X,'VsL/VsG'
     *        ,3X,'muW/muB')

C-----INPUT PIPE DIAMETER AND LENGTH

      READ(1,*)D,L
      LoverD=L/D
      DoverL=1.D0/LoverD

C      FOR THE PLETCHER AIR-WATER DATA (DATA SET 4), PRESSURE IS NOT PROVIDED AS
C       INPUT, THEREFORE THE CORRELATIONS 3,2,10,17 CANNOT BE USED SINCE THESE
C       CORRELATIONS NEED PRESSURE TO CALCULATE THE hTP.
C       HERE THE CODE SKIPS THE ERROR CALCULATIONS FOR THE ABOVE CASE.

   IF(COR.EQ.3.AND.NUMSETS.EQ.4)THEN
     WRITE(6,*)
     WRITE(6,*)"   THERE IS NOT ENOUGH DATA TO TO CALCULATE THE HEAT"
     WRITE(6,*)"          TRANSFER PARAMETERS (PRESSURE IS NOT GIVEN)."
   ENDIF
   IF(COR.EQ.2.AND.NUMSETS.EQ.4)THEN
     WRITE(6,*)
     WRITE(6,*)"   THERE IS NOT ENOUGH DATA TO TO CALCULATE THE HEAT"
     WRITE(6,*)"          TRANSFER PARAMETERS (PRESSURE IS NOT GIVEN)."
   ENDIF
   IF(COR.EQ.10.AND.NUMSETS.EQ.4)THEN
     WRITE(6,*)
     WRITE(6,*)"   THERE IS NOT ENOUGH DATA TO TO CALCULATE THE HEAT"
     WRITE(6,*)"          TRANSFER PARAMETERS (PRESSURE IS NOT GIVEN)."
   ENDIF
   IF(COR.EQ.17.AND.NUMSETS.EQ.4)THEN
     WRITE(6,*)
     WRITE(6,*)"   THERE IS NOT ENOUGH DATA TO TO CALCULATE THE HEAT"
     WRITE(6,*)"          TRANSFER PARAMETERS (PRESSURE IS NOT GIVEN)."
   ENDIF
   IF(COR.EQ.10.AND.NUMSETS.NE.3)THEN
     WRITE(6,*)
     WRITE(6,*)"   KING CORRELATION CAN BE USED FOR KING'S DATA ONLY"
   ENDIF


      DO 1000 I=1,NPT

C-----INPUT ONE DATA POINT FROM MASTER FILE

       READ(1,*) N,TBULK,TWALL,ALPHA,P,BETA,VsLL,VsGG,ReSLL,PrLL,
     *           muWmB,hTPEX,ReSGG,D2,mL,mG,Nu,DtpbyDL,hLCAL,DPL,DPtpf

C SKIPPING THE HEAT TRANSFER CALCULATIONS FOR CERTAIN CASES.

   IF(COR.EQ.3.AND.NUMSETS.EQ.4)GOTO 1000
   IF(COR.EQ.2.AND.NUMSETS.EQ.4)GOTO 1000
   IF(COR.EQ.10.AND.NUMSETS.NE.3)GOTO 1000
   IF(COR.EQ.17.AND.NUMSETS.EQ.4)GOTO 1000
```

```
C-----CALCULATE VOLUME FLOW RATE FOR USE IN SUBROUTINES

      VDOT=(VsLL+VsGG)*(PI*D**2.D0)/4.D0

C     IF RYSWT IS 0 THEN THE USER CHOSEN CORRELATION IS USED, ELSEIF
C      RYSWT IS 1 THEN THE COMPUTER CHOOSES THE BEST FITTED CORRELATION FOR
C      THAT FLOW PATTERN.

      IF(RYSWT.EQ.0) THEN
     CALL RYALI(COR,D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
     *            DoverL,LoverD,hTP,NuTP)
      ELSEIF(RYSWT.EQ.1) THEN

        IF(M.EQ.1.AND.MNG.EQ.1.AND.MNL.EQ.1)THEN
         IF(N.EQ.22)THEN
         CALL HAGGOUR(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
     *                   LoverD,hTP,NuTP)
          ENDIF
          IF(N.EQ.11.OR.N.EQ.33.OR.N.EQ.13.OR.N.EQ.34.OR.N.EQ.46)THEN
            CALL HKNOT(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,LoverD,hTP,
     *                 NuTP)
          ENDIF
          IF(N.EQ.44.OR.N.EQ.24) THEN
         CALL HRAVIPUDI(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,NuTP)
          ENDIF
        ENDIF

C----------------VIJAY AIR-GLYCERIN (VERTICAL-57 PTS)

        IF(M.EQ.1.AND.MNG.EQ.1.AND.MNL.EQ.2)THEN
          IF(N.EQ.11.OR.N.EQ.22.OR.N.EQ.33.OR.N.EQ.44.OR.N.EQ.12.
     *      OR.N.EQ.24)THEN
         CALL HAGGOUR(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
     *                   LoverD,hTP,NuTP)
          ENDIF
        ENDIF

C ----------REZKALLAH AIR-SILICONE(VERTICAL-162 PTS)

        IF(M.EQ.1.AND.MNG.EQ.1.AND.MNL.EQ.3)THEN
          IF(N.EQ.11.OR.N.EQ.33.OR.N.EQ.13.OR.N.EQ.34.OR.N.EQ.46)THEN
            CALL HSHAH(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,DoverL,hTP,
     *                 NuTP)
          ENDIF
          IF(N.EQ.22)THEN
            CALL HREZKALLAH(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,
     *                      BETA,DoverL,hTP,NuTP)
          ENDIF
          IF(N.EQ.55.OR.N.EQ.44.OR.N.EQ.12.OR.N.EQ.25.OR.N.EQ.45)THEN
         CALL HRAVIPUDI(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,NuTP)
          ENDIF
        ENDIF

C----------------KING AIR-WATER(HORIZONTAL-21 PTS)

        IF(M.EQ.2.AND.MNG.EQ.1.AND.MNL.EQ.1)THEN
          IF(N.EQ.22)THEN
            CALL HRAVIPUDI(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,NuTP)
          ENDIF

C----------------PLETCHER AIR-WATER(HORIZONTAL-48 PTS)

          IF(N.EQ.44)THEN

C     2880 Psf PRESSURE USED BECAUSE PRESSURE IS NOT AVAILABLE IN
C       ORIGINAL PLETCHER DATA

            P=2880.D0
```

```
            CALL HRAVIPUDI(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,NuTP)
          ENDIF
        ENDIF
   ENDIF

C     TOGG(1) AND TOGG(2) DECIDES THAT PARTICULAR CORRELATION HAS THE
C      ReSL VsG/VsL RANGES AVAILABLE OR NOT TO CALCULATE ERRORS.
C      TOGG(*)=1 MEANS THAT THE CORRELATION HAS THE ReSL, VsG/VsL RANGES
C      TO COMPARE.

   IF(PCOR.EQ.2.OR.PCOR.EQ.4.OR.PCOR.EQ.5.OR.PCOR.EQ.6.OR.PCOR.EQ.7.
      *  OR.PCOR.EQ.9.OR.PCOR.EQ.10.OR.PCOR.EQ.11.OR.PCOR.EQ.12.OR.PCOR
      *  .EQ.14.OR.PCOR.EQ.15.OR.PCOR.EQ.16.OR.PCOR.EQ.18.OR.PCOR.EQ.20)
     *THEN
     TOGG(1)=1
   ENDIF

   IF(PCOR.EQ.1.OR.PCOR.EQ.2.OR.PCOR.EQ.4.OR.PCOR.EQ.6.OR.PCOR.EQ.7.
      *  OR.PCOR.EQ.10.OR.PCOR.EQ.11.OR.PCOR.EQ.12.OR.PCOR.EQ.15.OR.PCOR
      *  .EQ.16.OR.PCOR.EQ.18.OR.PCOR.EQ.19.OR.PCOR.EQ.20)
     *THEN
     TOGG(2)=1
   ENDIF

C   CALCULATING THE hTP ERROR

CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC

    ERR=100.D0*((hTPEX-hTP)/hTPEX)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC


C     HERE THE hTP ERRORS ARE STORED IN INTEGER VARIABLES FOR EVERY FLOW
C      PATTERN BASED ON THE ERROR RANGE TO BE PRINTED OUT IN THE OUTPUT FILE.


      DO 1001 JJ=1,16
     IF(N.EQ.LL(JJ))THEN
       F=JJ

C     HERE THE hTP ERRORS ARE STORED AS INTEGER VARIABLES FOR LAMINAR FLOW

       IF(LAMTUR.EQ.'L')THEN
         DO 199 J=1,6
           IF(ERR.GE.ERCKMIN(J).AND.ERR.LE.ERCKMAX(J))THEN
             CL(F,J)=CL(F,J)+1
             IF(IFLAGRL.EQ.1)THEN
               PRCL(1,F,J)=PRCL(1,F,J)+1
             ENDIF
             IF(IFLAGVV.EQ.1)THEN
               PRCL(2,F,J)=PRCL(2,F,J)+1
             ENDIF
           ENDIF
  199       CONTINUE
         MNLL(F)=MNLL(F)+1
       ENDIF

C     HERE THE hTP ERRORS ARE STORED AS INTEGER VARIABLES FOR TURBULENT FLOW

       IF(LAMTUR.EQ.'T')THEN
         DO 1199 J=1,6
           IF(ERR.GE.ERCKMIN(J).AND.ERR.LE.ERCKMAX(J))THEN
             CT(F,J)=CT(F,J)+1
             IF(IFLAGRL.EQ.1)THEN
               PRCT(1,F,J)=PRCT(1,F,J)+1
             ENDIF
                IF(IFLAGVV.EQ.1)THEN
               PRCT(2,F,J)=PRCT(2,F,J)+1
                ENDIF
              ENDIF
```

```
 1199       CONTINUE
         MNTT(F)=MNTT(F)+1
       ENDIF
       MNH1(F)=MNH1(F)+(ERR/100.D0)
       RMH1(F)=RMH1(F)+(ERR/100.D0)**2.D0
       MN(F)=MN(F)+1
       GOTO 1002
     ENDIF
 1001 CONTINUE
 1002 CONTINUE

CC  CALCULATING NO. OF POINTS WITHIN AUTHOR SPECIFIED RANGE FOR
CC   ReSL,PrL,ReSG,VsL/VsG,muW/muB
CCC
CC  ALSO CALCULATING +-15%,+-30% ERRORS FOR RESL,PRL,RESG WITHIN
CC   RANGE OF AUTHOR'S SPECIFICATIONS

      DO 1009 JJ=1,16
     IF(N.EQ.LL(JJ))THEN
       F=JJ
C
C     RMS AND MEAN CALCULATION FOR THOSE WITHIN THE AUTHOR SPECIFIED RANGE.
C

        IF(IFLAGRL.EQ.1)THEN
       MNRSL=MNRSL+(ERR/100.D0)
       RMRSL=RMRSL+(ERR/100.D0)**2.D0
        ENDIF
     IF(IFLAGPL.EQ.1)THEN
       MNPRL=MNPRL+(ERR/100.D0)
       RMPRL=RMPRL+(ERR/100.D0)**2.D0
     ENDIF
     IF(IFLAGRG.EQ.1)THEN
       MNRSG=MNRSG+(ERR/100.D0)
       RMRSG=RMRSG+(ERR/100.D0)**2.D0
     ENDIF
     IF(IFLAGVV.EQ.1)THEN
       MNVVL=MNVVL+(ERR/100.D0)
       RMVVL=RMVVL+(ERR/100.D0)**2.D0
     ENDIF
     IF(IFLAGMM.EQ.1)THEN
       MNMML=MNMML+(ERR/100.D0)
       RMMML=RMMML+(ERR/100.D0)**2.D0
     ENDIF

C     CHECKING THE NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE AND
C      ERROR RANGE FOR EVERY PARAMETER, FOR LAMINAR POINTS.

       IF(LAMTUR.EQ.'L')THEN
         IF(ERR1(1).EQ.1.OR.IFLAGRL.EQ.1)ERSL(F,1,1)=ERSL(F,1,1)+1
            IF(ERR1(2).EQ.1.OR.IFLAGRL.EQ.1.OR.ERR1(1).EQ.1)
     *        ERSL(F,2,1)=ERSL(F,2,1)+1
         IF(ERR2(1).EQ.1.OR.IFLAGPL.EQ.1)EPRL(F,1,1)=EPRL(F,1,1)+1
         IF(ERR2(2).EQ.1.OR.ERR2(1).EQ.1.OR.IFLAGPL.EQ.1)
     *        EPRL(F,2,1)=EPRL(F,2,1)+1
         IF(ERR3(1).EQ.1.OR.IFLAGRG.EQ.1)ERSG(F,1,1)=ERSG(F,1,1)+1
         IF(ERR3(2).EQ.1.OR.ERR3(1).EQ.1.OR.IFLAGRG.EQ.1)
     *        ERSG(F,2,1)=ERSG(F,2,1)+1
         IF(ERR4(1).EQ.1.OR.IFLAGVV.EQ.1)EVSL(F,1,1)=EVSL(F,1,1)+1
         IF(ERR4(2).EQ.1.OR.ERR4(1).EQ.1.OR.IFLAGVV.EQ.1)
     *        EVSL(F,2,1)=EVSL(F,2,1)+1
         IF(ERR5(1).EQ.1.OR.IFLAGMM.EQ.1)EMGL(F,1,1)=EMGL(F,1,1)+1
         IF(ERR5(2).EQ.1.OR.ERR5(1).EQ.1.OR.IFLAGMM.EQ.1)
     *        EMGL(F,2,1)=EMGL(F,2,1)+1

C     COUNTING THE NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE
C      OF ALL OF THE PARAMETERS

                 IF(IFLAGRL.EQ.1)RRSL(F,1)=RRSL(F,1)+1
         IF(IFLAGPL.EQ.1)RPRL(F,1)=RPRL(F,1)+1
         IF(IFLAGRG.EQ.1)RRSG(F,1)=RRSG(F,1)+1
```

```
        IF(IFLAGVV.EQ.1)RVSL(F,1)=RVSL(F,1)+1
        IF(IFLAGMM.EQ.1)RMGL(F,1)=RMGL(F,1)+1
      ENDIF

C     CHECKING THE NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE AND
C      ERROR RANGE FOR EVERY PARAMETER, FOR TURBULENT POINTS.

      IF(LAMTUR.EQ.'T')THEN
        IF(ERR1(1).EQ.1.OR.IFLAGRL.EQ.1)ERSL(F,1,2)=ERSL(F,1,2)+1
        IF(ERR1(2).EQ.1.OR.ERR1(1).EQ.1.OR.IFLAGRL.EQ.1)
     *         ERSL(F,2,2)=ERSL(F,2,2)+1
        IF(ERR2(1).EQ.1.OR.IFLAGPL.EQ.1)EPRL(F,1,2)=EPRL(F,1,2)+1
        IF(ERR2(2).EQ.1.OR.ERR2(1).EQ.1.OR.IFLAGPL.EQ.1)
     *         EPRL(F,2,2)=EPRL(F,2,2)+1
        IF(ERR3(1).EQ.1.OR.IFLAGRG.EQ.1)ERSG(F,1,2)=ERSG(F,1,2)+1
        IF(ERR3(2).EQ.1.OR.ERR3(1).EQ.1.OR.IFLAGRG.EQ.1)
     *         ERSG(F,2,2)=ERSG(F,2,2)+1
        IF(ERR4(1).EQ.1.OR.IFLAGVV.EQ.1)EVSL(F,1,2)=EVSL(F,1,2)+1
        IF(ERR4(2).EQ.1.OR.ERR4(1).EQ.1.OR.IFLAGVV.EQ.1)
     *         EVSL(F,2,2)=EVSL(F,2,2)+1
        IF(ERR5(1).EQ.1.OR.IFLAGMM.EQ.1)EMGL(F,1,2)=EMGL(F,1,2)+1
        IF(ERR5(2).EQ.1.OR.ERR5(1).EQ.1.OR.IFLAGMM.EQ.1)
     *         EMGL(F,2,2)=EMGL(F,2,2)+1

C     COUNTING THE NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE
C      OF ALL OF THE PARAMETERS

            IF(IFLAGRL.EQ.1)RRSL(F,2)=RRSL(F,2)+1
         IF(IFLAGPL.EQ.1)RPRL(F,2)=RPRL(F,2)+1
         IF(IFLAGRG.EQ.1)RRSG(F,2)=RRSG(F,2)+1
         IF(IFLAGVV.EQ.1)RVSL(F,2)=RVSL(F,2)+1
         IF(IFLAGMM.EQ.1)RMGL(F,2)=RMGL(F,2)+1

       ENDIF
     ENDIF
 1009 CONTINUE

C     STORING THE TOTAL POINTS WITHIN THE RANGE FOR THE PARTICULAR
C      PARAMETER SPECIFIED TO PRINT OUT THE TABLE IN PRINT SUBROUTINE

   DO 889 PP=1,16
     TOTPAR(1,PP,1)=RRSL(PP,1)
     TOTPAR(1,PP,2)=RRSL(PP,2)
     TOTPAR(2,PP,1)=RVSL(PP,1)
     TOTPAR(2,PP,2)=RVSL(PP,2)
  889 CONTINUE

C--------CALCULATING ERRORS

      ERRR1=-10.D0
      ERRR2=-10.D0
      ERRR3=-10.D0
      ERRR4=-10.D0
      ERRR5=-10.D0
      ERRR6=-10.D0
      IF(ReSLL.NE.0.D0)  ERRR1=1.D0-ReSL/ReSLL
      IF(PrLL.NE.0.D0)   ERRR2=1.D0-PrL/PrLL
      IF(ReSGG.NE.0.D0)  ERRR3=1.D0-ReSG/ReSGG
      IF(VsLL.NE.0.D0) ERRR4=1.D0-VsL/VsLL
      IF(VsGG.NE.0.D0) ERRR5=1.D0-VsG/VsGG
      ERRR7=(hTPEX-hTP)/hTPEX
      IF(Nu.NE.0)THEN
        NuER=(Nu-NuTP)/Nu
      ELSE
        NuER=100.0
      ENDIF


C--------WRITE OUT DATA TO P1.OUT

      WRITE(6,224)
```

```
224    FORMAT('PT #',2X,'PAT',2X,'L/T',4X,'ReSL',7X,'PrL',6X,
     *        'ReSG',7X,'VsL',6X,'VsG',6X,'muW/muB',3X,'hTPEX',4X,'NuTPCAL
     *        ')


       WRITE(6,202)I,N,LAMTUR,ReSLL,PrLL,ReSGG,VsLL,VsGG,muWmB,hTPEX,Nu
     *
202    FORMAT(1X,I3,3X,I2,3X,A1,1X,(1P9E10.3))

C--------WRITE OUT ERRORS IN CALCULATIONS AS COMPARED TO DATA

       WRITE(6,203)ERRR1,ERRR2,ERRR3,ERRR4,ERRR5,ERRR6,ERRR7,NuER
203    FORMAT('ERRORS=',7X,8E10.3)

C       PRINTING OUT THE INTEGER ERROR VALUES FOR PARAMETERS ReSL, PrL, ReSG.

       WRITE(6,301)CORREL(COR),COR,CHRL,CHPL,CHRG,IFLAGVL,IFLAGVG,IFLAGMB
301    FORMAT(A10,'[',I2,']',3X,I4,5(6X,I4),/)


 1000 CONTINUE



       WRITE(6,*)
   WRITE(6,1204)
1204        FORMAT('========================================END: OVERALL ',
     *           'TABLE========================================')

C      SKIPPING THE PRINTING PROCEDURE FOR THE MENTIONED CORRELATIONS
C       FOR WHICH DATA IS INSUFFICIENT.

   IF(COR.EQ.3.AND.NUMSETS.EQ.4)GOTO 2200
   IF(COR.EQ.2.AND.NUMSETS.EQ.4)GOTO 2200
   IF(COR.EQ.10.AND.NUMSETS.NE.3)GOTO 2200
   IF(COR.EQ.17.AND.NUMSETS.EQ.4)GOTO 2200

CCC    CALLING PRINT SUBROUTINE TO PRINT R.M.S AND MEAN VALUES
CCC     FOR hTP

       CALL PRINTING(TMEAN,TRMS)
   WRITE(6,*)
   WRITE(6,*)

CCC    CALLING THE SUBROUTINE SECOND TO PRINT OUT THE TABLES
CCC     FOR PARAMETER RANGES, +/-15%, +/-30% ERROR BAND RANGES.


   CALL SECOND(TMEAN,TRMS)

CCC    INITIALIZING ALL THE VARIABLES FOR NEXT DATA SET CALCULATIONS.

2222  WRITE(6,*)

       MNRSL=0
   MNRSG=0
   MNVVL=0
   MNPRL=0
   MNMML=0
   RMRSL=0
   RMRSG=0
   RMPRL=0
   RMVVL=0
   RMMML=0
       TMN=0
       TMNL=0
       TMNT=0
       TMEAN=0
       TRMS=0
       DO 2010 JJ=1,16
         MN(JJ)=0
```

```
        MNLL(JJ)=0
        MNTT(JJ)=0
        MNH1(JJ)=0
        RMH1(JJ)=0
        RMH(JJ)=0
        MNH(JJ)=0
     TPRCT(JJ)=0
     TPRCL(JJ)=0
     DO 2023 JJJ=1,2
       RCOM(JJ,JJJ)=0
       RCOM1(JJ,JJJ)=0
       RCOM2(JJ,JJJ)=0
       RRSL(JJ,JJJ)=0
       RRSG(JJ,JJJ)=0
       RPRL(JJ,JJJ)=0
       RVSL(JJ,JJJ)=0
       RMGL(JJ,JJJ)=0
       ERSL(JJ,JJJ,1)=0
       EPRL(JJ,JJJ,1)=0
       ERSG(JJ,JJJ,1)=0
       EVSL(JJ,JJJ,1)=0
       EMGL(JJ,JJJ,1)=0
       ERSL(JJ,JJJ,2)=0
       EPRL(JJ,JJJ,2)=0
       ERSG(JJ,JJJ,2)=0
       EVSL(JJ,JJJ,2)=0
       EMGL(JJ,JJJ,2)=0
2023    CONTINUE
      DO 2011 J=1,6
       TCL(J)=0
       TCT(J)=0
       CL(JJ,J)=0
       CT(JJ,J)=0
       CLT(JJ,J)=0
       CTT(JJ,J)=0
       PRCL(1,JJ,J)=0
       PRCT(1,JJ,J)=0
       PRCL(2,JJ,J)=0
       PRCT(2,JJ,J)=0
2011    CONTINUE
2010  CONTINUE
2200  CONTINUE

   CLOSE(1)
   CLOSE(6)
      CLOSE(7)
      STOP
      END



      SUBROUTINE SECOND(TMEAN,TRMS)

CCC    THIS SUBROUTINE PRINTS THE TABLES FOR PARAMETERS WHICH ARE
CC      WITHIN +/- 15%, 30% RANGES
CCC    SECOND PART OF THE MAIN PROGRAM
CCC
C   TRRSL = TOTAL POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR ReSL
C   TRRSG = TOTAL POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR ReSG
C   TRPRL = TOTAL POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR PrL
C   TRVSL = TOTAL POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR VsL/VsG
C   TRMGL = TOTAL POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR mG/mL

   INCLUDE 'DEFINE.FOR'

      REAL*8 MNRSL,MNRSG,MNVVL,MNMML,MNPRL,RMRSL,RMRSG,RMVVL,RMPRL,RMMML
     *        ,TMEAN,TRMS
   INTEGER MN(16),MNLL(16),MNTT(16),CL(16,6),CT(16,6),NP(16),
     *         CLT(16,6),CTT(16,6),TCL(6),TCT(6),ERSL(16,2,2),
     *         EPRL(16,2,2),ERSG(16,2,2),EVSL(16,2,2),EMGL(16,2,2),
```

```
     *         RRSL(16,2),RPRL(16,2),RRSG(16,2),RVSL(16,2),RMGL(16,2),
     *         TO1(16,2),TO2(16,2),RCOM(16,2),RCOM1(16,2),
     *         RCOM2(16,2),TRRSL,TRPRL,TRRSG,TRMGL,TRVSL,N
   CHARACTER*2 AP
   CHARACTER*8 RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
   COMMON/CHECKL/CL,MNLL,CLT,TCL
      COMMON/CHECKT/CT,MNTT,CTT,TCT
      COMMON/ECOUNT2/ERSL,EPRL,ERSG,EVSL,EMGL,RRSL,RPRL,RRSG,RVSL,RMGL,
     *        RCOM,RCOM1,RCOM2,MNRSL,MNRSG,MNVVL,MNMML,MNPRL,
     *        RMRSL,RMRSG,RMVVL,RMPRL,RMMML
   COMMON/RANGE/RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
      COMMON/TOT/TMNL,TMNT,TMN,NP,PP,MN

      DATA NP/11,22,33,44,55,12,13,14,15,23,24,25,34,35,45,46/

      AP='OO'

C  REINITIALIZING THE TRRSL, TRPRL, etc TO ZERO

   TRRSL=0
   TRPRL=0
   TRRSG=0
   TRMGL=0
   TRVSL=0

   WRITE(6,1212)
1212       FORMAT(/,'==================================BEGIN: AUTHOR-',
     *         'SPECIFIED RANGE TABLE==========================',/)


      WRITE(6,*)
      WRITE(6,*)'FOR "NO PT", THE NUMBER GIVEN IS THE NUMBER OF DATA ',
     *             'POINTS FOR THE SPECIFIED'
      WRITE(6,*)' FLOW PATTERN AND FLOW REGIME (L/T) COMBINATION.'
      WRITE(6,*)'FOR ALL OTHER COLUMNS, THE NUMBER GIVEN IS THE NUMBER',
     *        ' OF DATA POINTS THAT FALL'
      WRITE(6,*)' WITHIN THE AUTHOR [OF CORRELATION]- SPECIFIED RANGE ',
     *         'FOR THAT COLUMN PARAMETER'
      WRITE(6,*)' (ReSL,PrL,ReSG).'


      WRITE(6,*)
   WRITE(6,909)
   WRITE(6,705)
      WRITE(6,707)

C     PRINTING OUT WHETHER THE PARAMETERS ReSL, PrL, etc., HAVE RANGES TO
C      CHECK OR NOT.

   WRITE(6,908)RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
   WRITE(6,909)
   DO 888 PP=1,16
        IF(MN(PP).NE.0)THEN
          WRITE(6,514)NP(PP),MNLL(PP),MNTT(PP),RRSL(PP,1),RRSL(PP,2)
     *         ,RPRL(PP,1),RPRL(PP,2),RRSG(PP,1),RRSG(PP,2),RVSL(PP,1),
     *         RVSL(PP,2),RMGL(PP,1),RMGL(PP,2)
       TRRSL=TRRSL+RRSL(PP,1)+RRSL(PP,2)
       TRPRL=TRPRL+RPRL(PP,1)+RPRL(PP,2)
          TRRSG=TRRSG+RRSG(PP,1)+RRSG(PP,2)
       TRVSL=TRVSL+RVSL(PP,1)+RVSL(PP,2)
          TRMGL=TRMGL+RMGL(PP,1)+RMGL(PP,2)
     ENDIF

  888 CONTINUE

C     CALCULATING/PRINTING THE MEAN AND R.M.S FOR hTP ERRORS FOR EVERY
C      ReSL, PrL, etc. WITHIN THE RANGE.

   IF(TRRSL.NE.0)THEN
     MNRSL=MNRSL*100.D0/TRRSL
     RMRSL=((RMRSL/TRRSL)**.5D0)*100.D0
```

```
  ENDIF
  IF(TRPRL.NE.0)THEN
    MNPRL=MNPRL*100.D0/TRPRL
    RMPRL=((RMPRL/TRPRL)**.5D0)*100.D0
  ENDIF
  IF(TRRSG.NE.0)THEN
    MNRSG=MNRSG*100.D0/TRRSG
    RMRSG=((RMRSG/TRRSG)**.5D0)*100.D0
  ENDIF
  IF(TRVSL.NE.0)THEN
    MNVVL=MNVVL*100.D0/TRVSL
    RMVVL=((RMVVL/TRVSL)**.5D0)*100.D0
  ENDIF
  IF(TRMGL.NE.0)THEN
    MNMML=MNMML*100.D0/TRMGL
    RMMML=((RMMML/TRMGL)**.5D0)*100.D0
     ENDIF

  WRITE(6,917)TMEAN,MNRSL,MNPRL,MNRSG,MNVVL,MNMML
  WRITE(6,918)TRMS,RMRSL,RMPRL,RMRSG,RMVVL,RMMML

 917 FORMAT('MEAN',1X,F7.2,2X,F7.2,2X,F7.2,2X,F7.2,2X,F7.2,2X,F7.2)
 918 FORMAT('RMS ',1X,F7.2,2X,F7.2,2X,F7.2,2X,F7.2,2X,F7.2,2X,F7.2)
  WRITE(6,909)
     WRITE(6,1213)
1213      FORMAT(/,'===================================END: AUTHOR-',
    *       'SPECIFIED RANGE TABLE==========================',/)


 519 FORMAT(1X,I2,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3
    *       ,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3)


 542 FORMAT(1X,A2,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,
    *        I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3)


 544 FORMAT(1X,A2,6X,I3,8X,I3,8X,I3,7X,I3,8X,I3,7X,I3)

     WRITE(6,*)
  WRITE(6,1214)

C      PRINTING THE TABLE FOR 15% ERROR BAND TABLE FOR ReSL, PrL, etc.

1214      FORMAT(/,'==================================BEGIN: 15% ERROR ',
    *       'BAND TABLE================================',/)

     WRITE(6,*)
     WRITE(6,706)
     WRITE(6,*)
     WRITE(6,909)
     WRITE(6,705)

     WRITE(6,707)
  WRITE(6,908)RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
     WRITE(6,909)

C      CALCULATING THE TOTAL NUMBER OF POINTS FOR +/- 15%, +/- 30% FOR ALL THE
C       PARAMETERS

     DO 887 PP=1,16
    TO1(PP,1)=ERSL(PP,1,1)+ERSG(PP,1,1)+EVSL(PP,1,1)+EPRL(PP,1,1)+
    *             EMGL(PP,1,1)
    TO1(PP,2)=ERSL(PP,1,2)+ERSG(PP,1,2)+EVSL(PP,1,2)+EPRL(PP,1,2)+
    *             EMGL(PP,1,2)
      TO2(PP,1)=ERSL(PP,2,1)+ERSG(PP,2,1)+EVSL(PP,2,1)+EPRL(PP,2,1)+
    *             EMGL(PP,2,1)
      TO2(PP,2)=ERSL(PP,2,2)+ERSG(PP,2,2)+EVSL(PP,2,2)+EPRL(PP,2,2)+
    *             EMGL(PP,2,2)
 887 CONTINUE
```

```
C     PRINTING THE NUMBER OF POINTS FOR ALL THE PARAMETERS WITHIN +/- 30%
C      OF THE AUTHOR SPECIFIED RANGES

      DO 8891 PP=1,16
     IF(MN(PP).NE.0)THEN
       WRITE(6,514)NP(PP),MNLL(PP),MNTT(PP),ERSL(PP,1,1),
    *          ERSL(PP,1,2),EPRL(PP,1,1),EPRL(PP,1,2),ERSG(PP,1,1),
    *          ERSG(PP,1,2),EVSL(PP,1,1),EVSL(PP,1,2),EMGL(PP,1,1),
    *          EMGL(PP,1,2)
        ENDIF
 8891 CONTINUE

      WRITE(6,909)
      WRITE(6,*)
   WRITE(6,1215)
 1215     FORMAT(/,'====================================END: 15% ERROR ',
    *       'BAND TABLE=================================',/)

      WRITE(6,*)
      WRITE(6,*)
   WRITE(6,1216)

C     PRINTING THE TABLE FOR 30% ERROR BAND TABLE FOR ReSL, PrL, etc.

 1216     FORMAT(/,'==================================BEGIN: 30% ERROR ',
    *       'BAND TABLE=================================',/)

      WRITE(6,906)
      WRITE(6,*)
      WRITE(6,909)
      WRITE(6,705)
   WRITE(6,707)
   WRITE(6,908)RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
      WRITE(6,909)

C     PRINTING THE NUMBER OF POINTS FOR ALL THE PARAMETERS WITHIN +/- 30%
C      OF THE AUTHOR SPECIFIED RANGES

      DO 899 PP=1,16
        IF(MN(PP).NE.0)THEN
       WRITE(6,514)NP(PP),MNLL(PP),MNTT(PP),ERSL(PP,2,1),
    *          ERSL(PP,2,2),EPRL(PP,2,1),EPRL(PP,2,2),ERSG(PP,2,1),
    *          ERSG(PP,2,2),EVSL(PP,2,1),EVSL(PP,2,2),EMGL(PP,2,1),
    *          EMGL(PP,2,2)
        ENDIF
  899 CONTINUE

      WRITE(6,909)

   WRITE(6,1217)
 1217     FORMAT(/,'====================================END: 30% ERROR BAN',
    *       'D TABLE=================================',/)


   41 FORMAT(1X,I3,2X,I3,2X,I3,2X,I3,2X,I3,3X,I3,2X,I3,3X,I3,2X,I3,3X,

    *        I3,2X,I3,3X,I3,2X,I3)


      WRITE(6,*)
      WRITE(6,*)
  514 FORMAT(1X,I2,2X,I3,1X,I3,2X,I3,1X,I3,2X,I3,1X,I3,2X,I3,1X,I3,2X,I3
     *       ,1X,I3,2X,I3,1X,I3,2X,I3,1X,I3,2X,I3,1X,I3)
  705 FORMAT(1X,'PAT',3X,'NO PT',5X,'ReSL',5X,'PrL',6X,'ReSG',3X,
    *        'VsG/VsL',3X,'Mg/Ml')
  707 FORMAT(7X,'L',3X,'T',4X,'L',3X,'T',4X,'L',3X,'T',4X,'L',3X,'T'
    *        ,4X,'L',3X,'T',4X,'L',3X,'T')
  706 FORMAT(1X,'NUMBER OF POINTS FOR ResL,PrL,ResG,VsG/VsL,MG/ML '
 *        'WITHIN+-15%.')
  906     FORMAT(1X,'NUMBER OF POINTS FOR ResL,PrL,ResG,VsG/VsL,MG/ML '
 *        'WITHIN+-30%.')
```

```
  908 FORMAT(15X,A8,3X,A8,3X,A8,3X,A8,3X,A8)
  909 FORMAT(1X,'____________________________________________________________
     *____')

   RETURN

   END



      SUBROUTINE PRINTING(TMEAN,TRMS)

CCC    THIS SUBROUTINE PRINTS THE RMS AND MEAN VALUES CALULATED ON
CCC     THE BASIS OF hTP, AND VsG/VsL, ReSL RANGE TABLES

CCC
C BY: RYALI VENKATA KAMAL KUMAR; OKLA ST. UNIV./MECH-AERO ENGR.
C DATE LAST CHANGED: 7/29/98

   INCLUDE 'DEFINE.FOR'

      REAL*8  MNH1(16),RMH1(16),MNH(16),RMH(16),TMEAN,TRMS
   INTEGER TCL(6),TCT(6),TC(6),F,TPRCL(16),TPRCT(16),TOGG(2)
      INTEGER MN(16),MNLL(16),MNTT(16),CL(16,6),CT(16,6),LL(16),NP(16)
      INTEGER CLT(16,6),CTT(16,6),PRCL(2,16,6),PRCT(2,16,6),
     *         TOTPAR(2,16,2),K,PCOR,N
      INTEGER TMNL,TMNT,TMN

   CHARACTER*2  AP
      COMMON/CHECKL/CL,MNLL,CLT,TCL
      COMMON/CHECKT/CT,MNTT,CTT,TCT
      COMMON/COUNT1/MNH,RMH,MNH1,RMH1,N,AP,LL
   COMMON/PARCHK/PRCL,PRCT,TPRCL,TPRCT
      COMMON/TOT/TMNL,TMNT,TMN,NP,PP,MN
   COMMON/TOTPART/TOTPAR,TOGG,PCOR
      DATA LL/11,22,33,44,55,12,13,14,15,23,24,25,34,35,45,46/

C--- PRINTING MEAN AND RMS VALUES FOR hTP

   WRITE(6,1207)
 1207      FORMAT(/,'==================================BEGIN: RMS/MEAN ',
     *        'ERROR TABLE=================================')
      WRITE(6,*)'FOR THE FOLLOWING TABLE:'
      WRITE(6,*)'IN PRINTING THE MEAN AND RMS VALUES FOR TWO-PHASE ',
     *           'FILM COEFFICIENT(hTP) FOR     "NO PT", THE NUMBER ',
     *           'GIVEN IS THE NUMBER OF DATA POINTS FOR THE SPECIFIED ',
     *           'FLOW   PATTERN AND REGIME (L/T) COMBINATION.'
   WRITE(6,*)'FOR ALL %-HEADING COLUMNS, THE NUMBER GIVEN IS THE ',
     *           'NUMBER OF HEAT TRANSFER      COEFFICIENT CORRELATION ',
     *           'PREDICTIONS THAT FALL WITHIN +-xx% OF THE ',
     *           'EXPERIMENTAL   DATA.'
      WRITE(6,*)'"MEAN"-IS THE AVERAGE ERROR OF ALL CORRELATION ',
     *           'PREDICTIONS AS COMPARED TO ALL   DATA FOR THAT FLOW ',
     *           'PATTERN/REGIME COMBINATION.'
      WRITE(6,*)'"R.M.S"-IS THE R.M.S ERROR OF ALL CORRELATION ',
     *           'PREDICTIONS AS COMPARED TO ALL    DATA FOR THAT FLOW ',
     *           'PATTERN/REGIME COMBINATION.'
      WRITE(6,*)
      WRITE(6,9091)
   WRITE(6,501)
 9091 FORMAT('____________________________________________________________
     *____________________')

  501 FORMAT('PAT',2X,'NO PT',6X,'MEAN',5X,'R.M.S',2X,'+-10%',3X,
     *        '+-15%',2X,' +-20%',2X,' +-25%',3X,'+-30%',3X,'+-50%')
      WRITE(6,522)
      WRITE(7,522)
  522 FORMAT(5X,'L',3X,'T',22X,'L',3X,'T',3X,'L',3X,'T',3X,'L',3X,'T'
     *      ,3X,'L',3X,'T',3X,'L',3X,'T',3X,'L',3X,'T')
   WRITE(6,9091)
```

```
C     PRINTING OUT THE MEAN, R.M.S AND NO. OF POINTS WITHIN +-10%, +-15%,
C       etc.,FOR EACH FLOW PATTERN.

   DO 662 F=1,16

     IF(MN(F).NE.0)THEN
       MNH(F)=MNH1(F)*100.D0/MN(F)
       RMH(F)=((RMH1(F)/MN(F))**.5D0)*100.D0
          WRITE(6,503)LL(F),MNLL(F),MNTT(F),MNH(F),RMH(F),CL(F,1),
     *         CT(F,1),CL(F,2),CT(F,2),CL(F,3),CT(F,3),CL(F,4),CT(F,4),
     *         CL(F,5),CT(F,5),CL(F,6),CT(F,6)
     ENDIF
  662 CONTINUE

  503 FORMAT(I2,2X,I2,2X,I2,2X,F8.2,2X,F8.2,1X,I2,2X,I2,10
     *       (2X,I2))

CC
CCC CALCULATION FOR TOTAL MEAN AND R.M.S ERRORS FOR ALL THE FLOW PATTERNS
CC

      DO 334 PP=1,16
        TMNL=MNLL(PP)+TMNL
        TMNT=MNTT(PP)+TMNT
        TMN=TMNL+TMNT
  334 CONTINUE

      DO 336 PP=1,16
        TMEAN=MN(PP)*MNH(PP)+TMEAN
        TRMS=RMH1(PP)+TRMS
  336 CONTINUE

C     CALCULATING THE TOTAL MEAN, R.M.S FOR THE ENTIRE DATA SET.

      TMEAN=TMEAN/TMN
      TRMS=(TRMS/TMN)**0.5D0*100.D0

C     CALCULATING THE TOTAL NO.OF POINTS FOR THE ENTIRE DATA SET.

      DO 666 P=1,6
        DO 665 PP=1,16
       TCL(P)=CL(PP,P)+TCL(P)
          TCT(P)=CT(PP,P)+TCT(P)
  665   CONTINUE
        TC(P)=TCL(P)+TCT(P)
  666 CONTINUE


      WRITE(6,505)AP,TMNL,TMNT,TMEAN,TRMS,TCL(1),TCT(1),(TCL(P),
     *            TCT(P),P=2,6)
  505 FORMAT(A2,1X,I3,1X,I3,1X,F9.2,2X,F8.2,I3,1X,I3,10(1X,I3))
      WRITE(6,506)AP,TMN,TMEAN,TRMS,(TC(P),P=1,6)
  506 FORMAT(A2,4X,I3,2X,F9.2,1X,F9.2,2X,I3,6X,I3,4(5X,I3))
   WRITE(6,9091)
   WRITE(6,1206)
 1206       FORMAT(/,'====================================END: RMS/MEAN ERROR',
     *        ' TABLE=================================')
   WRITE(6,9092)
 9092       FORMAT(//)

C     PRINTING THE NO.OF POINTS FOR ReSL, VsG/VsL PARAMETERS WITHIN
C       +-10%, +-15%, etc., FOR EACH FLOW PATTERN; UNLESS THE RANGE
C       WAS NOT GIVEN BY THE AUTHOR

      IF(TOGG(1).NE.1)THEN
    WRITE(6,*)'**THE PARAMETER ReSL RANGE IS NOT APPLICABLE**.'
    WRITE(6,*)
   ENDIF

   IF(TOGG(2).NE.1)THEN
```

```
    WRITE(6,*)'**THE PARAMETER VsG/VsL RANGE IS NOT APPLICABLE**.'
    WRITE(6,*)
    WRITE(6,*)
   ENDIF

   DO 671 K=1,2

   IF(TOGG(K).EQ.1)THEN
     IF(K.EQ.1)THEN
       WRITE(6,*)
       WRITE(6,1208)
 1208           FORMAT(/,'===================================BEGIN: ReSL ',
     *            'ERROR TABLE=================================',/)

       WRITE(6,509)
  509      FORMAT('THE FOLLLOWING TABLE GIVES THE NUMBER OF POINTS',
     *            ' IN THE RANGE')
           WRITE(6,515)
  515      FORMAT(1X,'FOR ReSL PARAMETER WITH RESPECT TO hTP ERROR' )
     ENDIF

     IF(K.EQ.2)THEN
       WRITE(6,*)
           WRITE(6,1209)
 1209           FORMAT(/,'===================================BEGIN: VsG/VsL ',
     *         'ERROR TABLE=================================',/)
           WRITE(6,491)
  491      FORMAT('THE FOLLLOWING TABLE GIVES THE NUMBER OF POINTS',
     *            ' WITHIN THE RANGE')
       WRITE(6,493)
  493           FORMAT(1X,'FOR VsG/VsL PARAMETER WITH RESPECT TO hTP ',
     *            'ERROR')
     ENDIF

        WRITE(6,517)
  517   FORMAT('__________________________________________________________',
     *          '______________')

     WRITE(6,510)
  510   FORMAT('PAT',3X,'NO PT',6X,'10%',5X,
     *          '15%',4X,' 20%',4X,' 25%',5X,'30%',5X,'50%')
        WRITE(6,512)
        WRITE(7,512)
  512   FORMAT(6X,'L',3X,'T',5X,'L',3X,'T',3X,'L',3X,'T',3X,'L',3X,'T'
     *          ,3X,'L',3X,'T',3X,'L',3X,'T',3X,'L',3X,'T')
     WRITE(6,517)

C  PRINTING OUT THE TOTAL NUMBER OF POINTS FOR THE ReSL & VsG/VsL
C       PARAMETERS WHICH FALL WITHIN +- 10%, 15%, 20%, etc. OF AUTHOR'S hTP
C       DATA

     DO 663 F=1,16
          IF(MN(F).NE.0)THEN
         WRITE(6,513)LL(F),TOTPAR(K,F,1),TOTPAR(K,F,2),PRCL(K,F,1),
     *            PRCT(K,F,1),PRCL(K,F,2),PRCT(K,F,2),PRCL(K,F,3),
     *            PRCT(K,F,3),PRCL(K,F,4),PRCT(K,F,4),PRCL(K,F,5),
     *            PRCT(K,F,5),PRCL(K,F,6),PRCT(K,F,6)
          ENDIF
  663   CONTINUE

  513   FORMAT(I2,3X,I2,2X,I2,2X,12(2X,I2))
     WRITE(6,517)

     IF(K.EQ.1)THEN
       WRITE(6,1210)
 1210           FORMAT(/,'====================================END: ReSL ',
     *            'ERROR TABLE==================================',/)
     ELSEIF(K.EQ.2)THEN
          WRITE(6,1211)
 1211           FORMAT(/,'====================================END: VsG/VsL ',
     *            'ERROR TABLE==================================',/)
```

```
        ENDIF

      ENDIF
  671 CONTINUE

        RETURN
        END


        SUBROUTINE RYALI(COR,D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
       *                  DoverL,LoverD,hTP,NuTP)

C     THIS SUBROUTINE CALLS THE AUTHOR SPECIFIED CORRELATION.

        INCLUDE 'DEFINE.FOR'
        REAL*8 hTP,D,LoverD,DOVERL
        REAL*8 TBULK,ALPHA,P,TWALL,VDOT,BETA,NuTP
        INTEGER COR
      CHARACTER*8 RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE
      COMMON/RANGE/RLRANGE,PLRANGE,RGRANGE,VVRANGE,MMRANGE

C       CHECKING WHETHER THE PARAMETERS ReSL, PrL, etc., HAVE A RANGE
C        TO CHECK OR NOT AND THEN CALLING THE SUBROUTINE THE USER HAS CHOSEN.

      IF(COR.EQ.1)THEN
        RLRANGE='NO RANGE'
        PLRANGE='        '
        RGRANGE='        '
        VVRANGE='        '
        MMRANGE='        '

        CALL HAGGOUR(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
       *               LoverD,hTP,NuTP)
      ELSEIF(COR.EQ.4)THEN
        RLRANGE='        '
        PLRANGE='NO RANGE'
        RGRANGE='NO RANGE'
        VVRANGE='        '
        MMRANGE='NO RANGE'

        CALL HDORREST(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,ALPHA,hTP,
       *               NuTP)
      ELSEIF(COR.EQ.13)THEN
        RLRANGE='NO RANGE'
        PLRANGE='NO RANGE'
        RGRANGE='NO RANGE'
        VVRANGE='NO RANGE'
        MMRANGE='NO RANGE'

          CALL HMARTIN(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,DoverL,hTP,
       *              NuTP)
      ELSEIF(COR.EQ.11)THEN
        RLRANGE='        '
        PLRANGE='NO RANGE'
        RGRANGE='        '
        VVRANGE='        '
        MMRANGE='        '

        CALL HKNOT(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,LoverD,hTP,NuTP)

      ELSEIF(COR.EQ.12)THEN
        RLRANGE='        '
        PLRANGE='        '
        RGRANGE='NO RANGE'
        VVRANGE='        '
        MMRANGE='        '

        CALL HKUDIRKA(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,NuTP)

      ELSEIF(COR.EQ.15)THEN
        RLRANGE='        '
```

```
        PLRANGE='NO RANGE'
        RGRANGE='        '
        VVRANGE='        '
        MMRANGE='NO RANGE'

        CALL HRAVIPUDI(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,NuTP)

      ELSEIF(COR.EQ.16)THEN
        RLRANGE='        '
        PLRANGE='        '
        RGRANGE='NO RANGE'
        VVRANGE='        '
        MMRANGE='NO RANGE'

        CALL HREZKALLAH(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,
        *                  BETA,DoverL,hTP,NuTP)

      ELSEIF(COR.EQ.17)THEN
        RLRANGE='NO RANGE'
        PLRANGE='NO RANGE'
        RGRANGE='NO RANGE'
        VVRANGE='NO RANGE'
        MMRANGE='NO RANGE'

        CALL HSERIZAWA(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,hTP,DOVERL,
        *                NuTP)

      ELSEIF(COR.EQ.18)THEN
        RLRANGE='        '
        PLRANGE='NO RANGE'
        RGRANGE='NO RANGE'
        VVRANGE='        '
        MMRANGE='NO RANGE'

        CALL HSHAH(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,DoverL,hTP,NuTP)

      ELSEIF(COR.EQ.19)THEN
        RLRANGE='NO RANGE'
        PLRANGE='        '
        RGRANGE='NO RANGE'
        VVRANGE='        '
        MMRANGE='        '

        CALL HUEDA(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA,ALPHA,hTP,NuTP)

      ELSEIF(COR.EQ.9)THEN
        RLRANGE='        '
        PLRANGE='        '
        RGRANGE='        '
        VVRANGE='NO RANGE'
        MMRANGE='NO RANGE'

        CALL HKHOZE(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,LoverD,hTP,
        *             NuTP)
      ELSEIF(COR.EQ.2)THEN
        RLRANGE='        '
        PLRANGE='NO RANGE'
        RGRANGE='        '
        VVRANGE='        '
        MMRANGE='NO RANGE'

        CALL HCHU(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
        *           LoverD,hTP,NuTP)

      ELSEIF(COR.EQ.3)THEN
        RLRANGE='NO RANGE'
        PLRANGE='NO RANGE'
        RGRANGE='NO RANGE'
        VVRANGE='NO RANGE'
        MMRANGE='NO RANGE'
```

```
  CALL HDAVIS(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *             LoverD,hTP,NuTP)

ELSEIF(COR.EQ.5)THEN
  RLRANGE='        '
  PLRANGE='NO RANGE'
  RGRANGE='        '
  VVRANGE='NO RANGE'
  MMRANGE='        '

  CALL HDUSSEAU(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *               LoverD,hTP,NuTP)

ELSEIF(COR.EQ.6)THEN
  RLRANGE='        '
  PLRANGE='NO RANGE'
  RGRANGE='NO RANGE'
  VVRANGE='        '
  MMRANGE='NO RANGE'

  CALL HELAM(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *            LoverD,hTP,NuTP)

ELSEIF(COR.EQ.7)THEN
  RLRANGE='        '
  PLRANGE='NO RANGE'
  RGRANGE='NO RANGE'
  VVRANGE='        '
  MMRANGE='        '

  CALL HGROOTH(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *              LoverD,hTP,NuTP)

ELSEIF(COR.EQ.8)THEN
  RLRANGE='NO RANGE'
  PLRANGE='NO RANGE'
  RGRANGE='NO RANGE'
  VVRANGE='NO RANGE'
  MMRANGE='NO RANGE'

  CALL HHUGH(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *            LoverD,hTP,NuTP)
ELSEIF(COR.EQ.14)THEN
  RLRANGE='        '
  PLRANGE='NO RANGE'
  RGRANGE='NO RANGE'
  VVRANGE='NO RANGE'
  MMRANGE='NO RANGE'

  CALL HOLIVER(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *              LoverD,hTP,NuTP)
ELSEIF(COR.EQ.10)THEN
  RLRANGE='        '
  PLRANGE='NO RANGE'
  RGRANGE='        '
  VVRANGE='        '
  MMRANGE='NO RANGE'

  CALL HKING(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *              LoverD,hTP,NuTP)

ELSEIF(COR.EQ.20)THEN
  RLRANGE='        '
  PLRANGE='NO RANGE'
  RGRANGE='        '
  VVRANGE='        '
  MMRANGE='NO RANGE'

  CALL HVIJAY(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
  *                 LoverD,hTP,NuTP)
```

```
   ENDIF
      RETURN
      END


      SUBROUTINE PROPERTIES(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA)

CCC   THIS SUBROUTINE CALCULATES PROPERTIES OF FLUIDS USED IN TWO-PHASE
CCC     HEAT TRANSER CORRELATIONS

CCC     CURRENTLY GASES: AIR, HELIUM, AND FREON-12; AND LIQUIDS:  WATER,
CCC       GLYCERIN, and SILICONE ARE AVAILABLE. USER CAN ADD OTHER FLUIDS
CCC      (MNG=1,2,3 AND MNL=1,2,3) AS SHOWN IN THIS SUBROUTINE

      INCLUDE 'DEFINE.FOR'
      IMPLICIT NONE
      INTEGER MNG,MNL,COR,NUMSETS
   REAL*8 D,rhoG,AREA,ReSL,VsL,VsG,PrL,muWmuB,muG,muL,muW,mL,mG,
     *        kL,kG,ReSG,P,TWALL,TBULK,CPL,rhoL,R,VDOT,BETA,PI,L
      CHARACTER*1  LAMTUR
      COMMON/TPHASEA/ReSL,PrL,ReSG,LAMTUR,COR,NUMSETS
      COMMON/TPHASEB/VsL,VsG,muWmuB,kL,kG,muG,muL,muW,mL,mG
      COMMON/TPHASED/rhoL,rhoG
      COMMON/TPHASEG/cpL,L
   DATA PI/3.14592653589793D0/
      DATA R/53.34D0/


      AREA=PI*D**2.D0/4.D0

C     -----------AIR PROPERTIES

      IF(MNG.EQ.1)THEN
     kG=-6.514D-9*TBULK**2.D0+2.591D-5*TBULK+0.01313D0
     muG=-2.673D-8*TBULK**2.D0+6.819D-5*TBULK+0.03936D0
     rhoG=(P*144.D0)/(R*(TBULK+459.67D0))
      ENDIF

C     -----------HELIUM PROPERTIES

      IF(MNG.EQ.2)THEN
     kG=-1.333D-7*TBULK**2.D0+12.333D-5*TBULK+0.0784
     muG=0.0481D0
     rhoG=P/(386.D0*(TBULK+459.67D0))
      ENDIF

C     -----------FREON-12 PROPERTIES

      IF(MNG.EQ.3)THEN
     kG=4.79D-03+7.615D-06*TBULK**1.11944
       muG=25.833D-03+8.458D-06*(TBULK)**(0.90906D0)
C    rhoG=
      ENDIF

C
C  USER MAY ADD OTHER GASES' PROPERTIES HERE (MNG=4,5,6, etc.)
C

C     -----------WATER PROPERTIES

      IF(MNL.EQ.1)THEN
     cpL=1.337D-6*TBULK**2.D0-3.374D-4*TBULK+1.018D0
     kL=4.722D-4*TBULK+0.3149D0
     muL=(1.207D-5*TBULK**2.D0+3.863D-3*TBULK
     *       +0.09461D0)**(-1.D0)
     muW=(1.207D-5*TWALL**2.D0+3.863D-3*TWALL
     *       +0.09461D0)**(-1.D0)
     rhoL=(2.101D-8*TBULK**2.D0-1.303D-6*TBULK+
     *        0.01602D0)**(-1.D0)
      ENDIF
```

```
C     -----------GLYCERIN PROPERTIES

      IF(MNL.EQ.2)THEN
        cpL=.513123D0+.000824729D0*TBULK
     kL=0.1645
     muL=-0.01225126D0*TBULK**3.D0+4.707399D0*TBULK**2.D0-610.142D0*
     *       TBULK+26970.75D0
     muW=-0.01225126D0*TWALL**3.D0+4.707399D0*TWALL**2.D0-610.142D0*
     *       TWALL+26970.75D0
     rhoL=80.1747D0-0.02131D0*TBULK
   ENDIF


C     -----------SILICONE PROPERTIES

      IF(MNL.EQ.3) THEN
     cpL=1.80178D-4*TBULK+0.3839D0
     kL=0.06773D0
     muL=-5.1D-6*TBULK**3.D0+2.41D-3*TBULK**2.D0-
     *       0.41076D0*TBULK+31.18D0
     muW=-5.1D-6*TWALL**3.D0+2.41D-3*TWALL**2.D0-
     *       0.41076D0*TWALL+31.18D0
     rhoL=(920.D0/16.D0)
      ENDIF
C
C  USER MAY ADD OTHER LIQUIDS' PROPERTIES HERE (MNL=4,5,6, etc.)
C
      PrL=cpL*muL/kL
   ReSG=rhoG*VsG*D/muG
   ReSL=rhoL*VsL*D/muL
   VsG=BETA*VDOT/AREA
      VsL=(1.D0-BETA)*VDOT/AREA


      RETURN
      END

      SUBROUTINE HAGGOUR(D,MNG,MNL,TBULK,TWALL,ALPHA,VDOT,P,BETA,
     *                     LoverD,hTP,NuTP)

C THIS SUBROUTINE IS TO CALCULATE TWO PHASE HEAT TRANSFER
C      USING AGGOUR (1978) CORRELATION.

      INCLUDE 'DEFINE1.FOR'

      IMPLICIT NONE
      REAL*8 NuSP,hSP,hTP,D,LoverD,MGML,VSVL,NuTP
      REAL*8 ReSL,VsL,VsG,kL,TBULK,ALPHA,PrL,muWmuB,muG,muL,muW,kG,
     *        mL,mG,ReSG,P,TWALL,VDOT,BETA,x,kTP
      REAL*8 ReSLL,ReSGG,PrLL,VsLL,VsGG,muWmB,MDGML
      REAL*8 ECK1,ECK2
   REAL*8 ERR(5)
      INTEGER ERR1(2),ERR2(2),ERR3(2),ERR4(2),ERR5(2),CHPL,CHRL,CHRG
   INTEGER MNG,MNL,IFLAGRG,IFLAGPL,IFLAGRL,IFLAGVV,IFLAGMM,
     *         IFLAGVL,IFLAGVG,IFLAGMB,COR,KIMSWT,NUMSETS
   CHARACTER*1  LAMTUR
      COMMON/ECHECK/ECK1,ECK2
   COMMON/ECOUNT/ERR1,ERR2,ERR3,ERR4,ERR5,IFLAGRG,IFLAGPL,
     *        IFLAGRL,IFLAGMM,IFLAGVV,IFLAGMB,IFLAGVL,IFLAGVG,
    *         CHPL,CHRG,CHRL
   COMMON/TPHASEA/ReSL,PrL,ReSG,LAMTUR,COR,NUMSETS
      COMMON/TPHASEB/VsL,VsG,muWmuB,kL,kG,muG,muL,muW,mL,mG
      COMMON/TPHASEC/KIMSWT,ReSLL,ReSGG,PrLL,VsLL,VsGG,muWmB

C     CALLING THE FLAGS SUBROUTINE TO GIVE THE VALUES FOR IFLAGRL, IFLAGPL, etc.

   CALL FLAGS

C----GIVING THE CORRELATION NUMBER AS DEFINED IN THE 3rd QUARTER REPORT TO
C      THE PARAFFIN DEPOSITION IN MULTIPHASE FLOWLINES AND WELLBORES JIP(OCT 1, 1997),
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C      HEAT TRANSFER SECTION, PP. 8-17.

C      COR=1

C---------------------------- CALL PROPERTIES SUBROUTINE IN ORDER TO HAVE
C                             THE VALUES OF PROPERTIES REQUIRED FOR CALCULATION

      CALL PROPERTIES(D,MNG,MNL,TBULK,TWALL,VDOT,P,BETA)

C---COMPUTE DYNAMIC VISCOSITY RATIO
      muWmuB=muW/muL
      MGML=muG/muL

C---COMPUTING MASS FLOW RATE RATIO
   MDGML=mG/mL

C---CALCULATING THE HEAT TRANSFER COEFFICIENT BASED ON THE AUTHOR'S INPUT
C    DATA AVAILABLE (KIMSWT=1); OTHERWISE (KIMSWT.NE.1),USE THE DATA
C    CALCULATED IN THE "PROPERTIES" SUBROUTINE

      IF(KIMSWT.EQ.1)THEN
        ReSL=ReSLL
        ReSG=ReSGG
        VsL=VsLL
        VsG=VsGG
        PrL=PrLL
        VSVL=VsG/VsL
     IF(MNG.EQ.1)muWmuB=muWmB
   ENDIF

C----COMPUTING TWO-PHASE QUALITY AND THERMAL CONDUCITVITY

           x=mG/(mG+mL)
   kTP=kL*(1.D0-x)+kG*x

C----CHECK FOR LAMINAR OR TURBULENT FLOW

   IF(ReSL.LT.2000.D0)THEN

C-------------------- LAMINAR IF ReSL < 2000

     NuSP=1.615D0*(ReSL*PrL*1.D0/LoverD)**(1.D0/3.D0)
     *         *muWmuB**(-0.14D0)

C----CALCULATING HEAT TRANSFER COEFFICIENT

             hSP=NuSP*kL/D
     hTP=hSP*(1.D0-ALPHA)**(-1.D0/3.D0)
     LAMTUR='L'

C------------------- TURBULENT IF ReSL > 2000

      ELSE
     hSP=0.0155D0*ReSL**0.83D0*PrL**0.5D0*
     *       muWmuB**(-0.33D0)*kL/D

C---CALCULATING HEAT TRANSFER COEFFICIENT

         hTP=hSP*(1.D0-ALPHA)**(-0.83D0)
     LAMTUR='T'

   ENDIF
   NuTP=hTP*D/kTP

C---CHECKING AUTHOR SPECIFIED RANGES FOR ReSL,ReSG, etc.
C---A POSITIVE ERR(*) MEANS "BELOW" THE AUTHOR'S RANGE, AND A NEGATIVE ERR(*)
C    MEANS "ABOVE" THE AUTHOR'S RANGE

   IF(ReSG.LT.13.95D0)THEN
     IFLAGRG=111
         CHRG=NINT((ReSG-13.95D0)/13.95D0)
```

```
        ERR(3)=(1-ReSG/13.95D0)
         ELSEIF(ReSG.GT.2.95D05)THEN
        IFLAGRG=111
           CHRG=NINT((ReSG-2.95D05)/2.95D05)
        ERR(3)=(1-ReSG/2.95D05)
         ENDIF
         IF(ABS(ERR(3)).LE.ECK1)THEN
           ERR3(1)=1
      ENDIF
         IF(ABS(ERR(3)).LE.ECK2)THEN
           ERR3(2)=1
         ENDIF

         IF(PrL.LT.5.78D0)THEN
        IFLAGPL=111
        CHPL=NINT((PrL-5.78D0)/5.78D0)
        ERR(2)=(1-PrL/5.78D0)
         ELSEIF(PrL.GT.7.04D0)THEN
        IFLAGPL=111
        CHPL=NINT((PrL-7.04D0)/7.04D0)
        ERR(2)=(1-PrL/7.04D0)
         ENDIF
         IF(ABS(ERR(2)).LE.ECK1)THEN
        ERR2(1)=1
      ENDIF
         IF(ABS(ERR(2)).LE.ECK2)THEN
        ERR2(2)=1
         ENDIF

      IF(MDGML.LT.2.2D-06)THEN
        IFLAGMM=111
        ERR(5)=(1-MDGML/2.2D-06)
      ELSEIF(MDGML.GT.0.7738D0)THEN
        IFLAGMM=111
        ERR(5)=(1-MDGML/0.7738D0)
      ENDIF
      IF(ABS(ERR(5)).LE.ECK1)THEN
        ERR5(1)=1
      ENDIF
      IF(ABS(ERR(5)).LE.ECK2)THEN
        ERR5(2)=1
      ENDIF

      IF(VSVL.LT.0.02D0)THEN
        IFLAGVV=111
        ERR(4)=(1.-VSVL/0.02D0)
      ELSEIF(VSVL.GT.470.0D0)THEN
        IFLAGVV=111
        ERR(4)=(1.-VSVL/470.0D0)
      ENDIF
      IF(ABS(ERR(4)).LE.ECK1)THEN
        ERR4(1)=1
      ENDIF
      IF(ABS(ERR(4)).LE.ECK2)THEN
        ERR4(2)=1
      ENDIF

C      FOR PARAMETERS WHICH DID NOT HAVE ANY RANGES TO CHECK, THE VARIABLES
C       TO IDENTIFY THEM WERE SET TO ZERO.

      CHRL=0
      IFLAGRL=0
         IFLAGVL=0
         IFLAGVG=0
         IFLAGMB=0

         RETURN
         END
```

```
SUBROUTINE FLAGS


INTEGER ERR1(2),ERR2(2),ERR3(2),ERR4(2),ERR5(2),IFLAGRG
  *        ,IFLAGPL,IFLAGRL,IFLAGMM,IFLAGVV,IFLAGMB,IFLAGVL,
  *         IFLAGVG,CHPL,CHRG,CHRL
COMMON/ECOUNT/ERR1,ERR2,ERR3,ERR4,ERR5,IFLAGRG,IFLAGPL,
  *        IFLAGRL,IFLAGMM,IFLAGVV,IFLAGMB,IFLAGVL,IFLAGVG,
*          CHPL,CHRG,CHRL

CHRG=1
CHRL=1
CHPL=1
   IFLAGRG=1
   IFLAGPL=1
   IFLAGRL=1
   IFLAGVL=1
   IFLAGVG=1
   IFLAGMB=1
   IFLAGMM=1
   IFLAGVV=1
   ERR1(1)=0
   ERR1(2)=0
   ERR2(1)=0
   ERR2(2)=0
   ERR3(1)=0
   ERR3(2)=0
   ERR4(1)=0
   ERR4(2)=0
   ERR5(1)=0
   ERR5(2)=0

RETURN
END
```

```
** PROGRAM DEFINE.FOR*********************************************
CC  THIS FILE HAS ALL THE VARIABLES DEFINED WHICH WERE USED IN THE
CC       CORRELATION SUBROUTINES


C ALPHA  = VOID FRACTION
C COR    = CORRELATION NUMBER
C D      = DIAMETER OF PIPE (ft)
C DoverL = RATIO OF PIPE DIAMETER TO LENGTH
C DPL    = SINGLE PHASE DIFFERENTIAL PRESSURE   (COL 20)
C DtpbyDL= RATIO OS TWO-PHASE AND SINGLE-PHASE PRESSURE
C          DIFFERENCE (DP/DL)_tp/(DP/DL)_sl(COL 18) IN KING DATA
C Ptpf   = TWO-PHASE DIFFERENTIAL PRESSURE (COL 21) IN PLETCHER DATA
C ERR(5) = REAL VALUES OF ERRORS FOR RESL,PRL,RESG,VSG/VSL,MG/ML
C ERR1(1)= NO OF POINTS OF ReSL WITHIN +/- 15% OF AUTHOR SPECIFIED
C              RANGE.
C     (2)= WITHIN +/- 30%
C ERR2(1)= NO OF POINTS OF ReSG WITHIN +/- 15% OF AUTHOR SPECIFIED
C              RANGE.
C     (2)= WITHIN +/- 30%
C ERR3(1)= NO OF POINTS OF PrL WITHIN +/- 15% OF AUTHOR SPECIFIED
C              RANGE.
C     (2)= WITHIN +/- 30%
C ERR4(1)= NO OF POINTS OF VsG/VsL WITHIN +/- 15% OF AUTHOR SPECIFIED
C              RANGE.
C     (2)= WITHIN +/- 30%
C ERR5(1)= NO OF POINTS OF mG/mL WITHIN +/- 15% OF AUTHOR SPECIFIED
C              RANGE.
C     (2)= WITHIN +/- 30%
C hTP    = TWO PHASE HEAT TRANSFER COEFFICIENT -- CALCULATED (Btu/hr-ft^2-F)
C hTPEX  = TWO PHASE HEAT TRANSFER COEFFICIENT -- FROM DATA SET (Btu/hr-ft^2-F)
C IFLAGRG= FLAG TO CHECK WHETHER ReSG IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGPL= FLAG TO CHECK WHETHER PrL IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGRL= FLAG TO CHECK WHETHER ReSL IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGVL= FLAG TO CHECK WHETHER VsL IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGVG= FLAG TO CHECK WHETHER VsG IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGMB= FLAG TO CHECK WHETHER muW/muB IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGMM= FLAG TO CHECK WHETHER mG/mL IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C IFLAGVV= FLAG TO CHECK WHETHER VsG/VsL IS WITHIN RANGE OR NOT
C        = 1 WITHIN RANGE
C        = 0 OUT OF RANGE
C kG     = GAS THERMAL CONDUCTIVITY (Btu/hr-ft-F)
C kL     = LIQUID THERMAL CONDUCTIVITY (Btu/hr-ft-F)
C L      = PIPE LENGTH (ft)
C LAMTUR = VARIABLE WHICH INDICATES THAT THE GIVEN DATA POINT IS LAMINAR OR
C           TURBULENT, L- LAMINAR, T- TURBULENT
C LoverD = RATIO OF PIPE LENGTH TO DIAMETER
C mG     = GAS MASS FLOW RATE (lbm/hr)
C mL     = LIQUID MASS FLOW RATE (lbm/hr)
C MNG    = GASEOUS PHASE COMPONENT DESIGNATOR
C     (=1)= AIR
C     (=2)= HELIUM
C     (=3)= FREON-12
C MNL    = LIQUID PHASE COMPONENT DESIGNATOR
C     (=1)= WATER
C     (=2)= GLYCERIN
C     (=3)= SILICONE
```

```
C muB     = DYNAMIC VISCOSITY OF LIQUID AT BULK TEMPERATURE (lbm/ft-hr)
C muG     = DYNAMIC VISCOSITY OF GAS AT WALL TEMPERATURE (lbm/ft-hr)
C muL     = DYNAMIC VISCOSITY OF LIQUID (lbm/ft-hr)
C muW     = DYNAMIC VISCOSITY OF LIQUID AT WALL TEMPERATURE (lbm/ft-hr)
C muWmuB = muW/muB -- CALCULATED
C muWmB   = muW/muB -- FROM DATA SET
C P       = PRESSURE (lbf/ft^2)
C PrL     = LIQUID PRANDTL NUMBER (CALCULATED)
C PrLL    = LIQUID PRANDTL NUMBER (FROM DATA SET)
C ReSG    = SUPERFICIAL GAS REYNOLDS NUMBER (CALCULATED)
C ReSGG   = SUPERFICIAL GAS REYNOLDS NUMBER (FROM DATA SET)
C ReSL    = SUPERFICIAL LIQUID REYNOLDS NUMBER (CALCULATED)
C ReSLL   = SUPERFICIAL LIQUID REYNOLDS NUMBER (FROM DATA SET)
C RMGL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR mG/mL
C RL      = LIQUID VOLUME FRACTION (=1-ALPHA), DIMENSIONLESS
C RPRL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR PrL
C RRSL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR ReSL
C RRSG    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR ReSG
C RVSL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR VsG/VsL
C RMXYZ   = R.M.S hTP ERROR FOR ReSL,ReSG,PrL,VsL/VsG,mG/mL WHICH ARE WITHIN THE
C             AUTHORS SPECIFIED RANGE.
C TBULK   = BULK TEMPERATURE (F)
C TWALL   = WALL TEMPERATURE (F)
C VDOT    = TOTAL VOLUMETRIC FLOW RATE (ft^3/hr)
C VsG     = SUPERFICIAL VELOCITY OF GAS -- CALCULATED (ft/hr)
C VsGG    = SUPERFICIAL VELOCITY OF GAS -- FROM DATA SET (ft/hr)
C VsL     = SUPERFICIAL VELOCITY OF LIQUID -- CALCULATED (ft/hr)
C VsLL    = SUPERFICIAL VELOCITY OF LIQUID -- FROM DATA SET (ft/hr)
```

**** PROGRAM DEFINE1.FOR***

```
CC  THIS FILE HAS ALL THE VARIABLES DEFINED WHICH WERE USED IN THE PHASE-I
CC     CODE
C ALPHA  = VOID FRACTION
C BETA   = VOLUMETRIC RATIO OF GAS FLOW RATE TO TOTAL FLOW RATE
C COR    = CORRELATION NUMBER
C CL(*,*)= NO. OF POINTS FOR EACH FLOW PATTERN AND LAMINAR POINT THAT SHOWS
C           hTP ERRORS WITHIN +/- ERROR RANGE.
C CT(*,*)= NO. OF POINTS FOR EACH FLOW PATTERN AND TURBULENT POINT THAT SHOWS
C           hTP ERRORS WITHIN +/- ERROR RANGE.
C D      = DIAMETER OF PIPE (ft)
c D2        = DUMMY VARIABLE
C DoverL = RATIO OF PIPE DIAMETER TO LENGTH
C DPL    = SINGLE PHASE DIFFERENTIAL PRESSURE   (COL 20)
C DtpbyDL= RATIO OS TWO-PHASE AND SINGLE-PHASE PRESSURE
C           DIFFERENCE (DP/DL)_tp/(DP/DL)_sl(COL 18) IN KING DATA
C Ptpf   = TWO-PHASE DIFFERENTIAL PRESSURE (COL 21) IN PLETCHER DATA
C EMGL   = NO. OF POINTS OF mG/mL WITHIN +/-15% AND +/- 30%
C           THE AUTHOR SPECIFIED RANGE
C EPRL   = NO. OF POINTS OF PrL WITHIN +/-15% AND +/- 30%
C           THE AUTHOR SPECIFIED RANGE
C ERSL   = NO. OF POINTS OF ReSL WITHIN +/-15% AND +/- 30%
C           THE AUTHOR SPECIFIED RANGE
C ERSG   = NO. OF POINTS OF ReSG WITHIN +/-15% AND +/- 30%
C           THE AUTHOR SPECIFIED RANGE
C EVSL   = NO. OF POINTS OF VsG/VsL WITHIN +/-15% AND +/- 30%
C           THE AUTHOR SPECIFIED RANGE
C ERRR1  = FRACTIONAL ERROR BETWEEN ReSL COMPUTED AND FROM DATA
C ERRR2  = FRACTIONAL ERROR BETWEEN PrL  COMPUTED AND FROM DATA
C ERRR3  = FRACTIONAL ERROR BETWEEN ReSG COMPUTED AND FROM DATA
C ERRR4  = FRACTIONAL ERROR BETWEEN VsL  COMPUTED AND FROM DATA
C ERRR5  = FRACTIONAL ERROR BETWEEN VsG  COMPUTED AND FROM DATA
C ERRR6  = FRACTIONAL ERROR BETWEEN VISCOSITY RATIO COMPUTED AND FROM DATA
C ERRR7  = FRACTIONAL ERROR BETWEEN hTP  COMPUTED AND FROM DATA
C ERR(5) = REAL VALUES OF ERRORS FOR RESL,PRL,RESG,VSG/VSL,MG/ML
C ERR1(1)= NO OF POINTS OF ReSL WITHIN +/- 15% WITHIN AUTHOR SPECIFIED
C                RANGE.
C      (2)= WITHIN +/- 30%
C ERR2(1)= NO OF POINTS OF ReSG WITHIN +/- 15% WITHIN AUTHOR SPECIFIED
C                RANGE.
C      (2)= WITHIN +/- 30%
C ERR3(1)= NO OF POINTS OF PrL WITHIN +/- 15% WITHIN AUTHOR SPECIFIED
C                RANGE.
C      (2)= WITHIN +/- 30%
C ERR4(1)= NO OF POINTS OF VsL/VsG WITHIN +/- 15% WITHIN AUTHOR SPECIFIED
C                RANGE.
C      (2)= WITHIN +/- 30%
C ERR5(1)= NO OF POINTS OF mG/mL WITHIN +/- 15% WITHIN AUTHOR SPECIFIED
C                RANGE.
C      (2)= WITHIN +/- 30%
C FLSWT  = USER INPUT VARIABLE WHICH THE USER DECIDES WHETHER TO USE THE
C           I/O FILES PROVIDED BY THE CODE (0) OR THE USER DECIDES TO
C           USE HIS OWN I/O FILES
C FILEIN = NAME OF THE INPUT FILE PROVIDED BY THE USER
C FILEOUT= NAME OF THE OUTPUT FILE PROVIDED BY THE USER
C hL     = IS IS SINGLE PHASE HEAT TRANSFER COEFFICIENT(hLCAL) FOR KING DATA
C hTP    = TWO PHASE HEAT TRANSFER COEFFICIENT -- CALCULATED (Btu/hr-ft^2-F)
C hTPEX  = TWO PHASE HEAT TRANSFER COEFFICIENT -- FROM DATA SET (Btu/hr-ft^2-F)
C IFLAGRG= FLAG TO CHECK WHETHER ReSG IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
C         = 1 WITHIN RANGE
C         = 0 OUT OF RANGE
C IFLAGPL= FLAG TO CHECK WHETHER PrL IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
C         = 1 WITHIN RANGE
C         = 0 OUT OF RANGE
C IFLAGRL= FLAG TO CHECK WHETHER ReSL IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
C         = 1 WITHIN RANGE
C         = 0 OUT OF RANGE
C IFLAGVL= FLAG TO CHECK WHETHER VsL IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
C         = 1 WITHIN RANGE
C         = 0 OUT OF RANGE
C IFLAGVG= FLAG TO CHECK WHETHER VsG IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
```

```
C          = 1 WITHIN RANGE
C          = 0 OUT OF RANGE
C IFLAGMB= FLAG TO CHECK WHETHER muW/muB IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
C          = 1 WITHIN RANGE
C          = 0 OUT OF RANGE
C IFLAGMM= FLAG TO CHECK WHETHER mG/mL IS WITHIN AUTHOR SPECIFIED RANGE OR NOT
C          = 1 WITHIN RANGE
C          = 0 OUT OF RANGE
C IFLAGVV= FLAG TO CHECK WHETHER VsG/VsL IS WITHIN AUTHOR SPECIFIEDRANGE OR NOT
C          = 1 WITHIN RANGE
C          = 0 OUT OF RANGE
C kG      = GAS CONDUCTIVITY (Btu/hr-ft-F)
C kL      = LIQUID CONDUCTIVITY (Btu/hr-ft-F)
C KIMSWT = USER INPUT IF KIMSWT IS 1 THEN CODE CALCULATES THE HEAT
C            HEAT TRANSFER PARAMETERS FROM ReSL, ReSG etc. PROVIDED BY THE
C            INPUT FILE; IF KIMSWT IS 0 THEN CODE CALCULATES THE PARAMETERS
C            BY CALCULATING THE ReSL, ReSG, etc.
C L       = PIPE LENGTH (ft)
C LAMTUR = VARIABLE WHICH INDICATES THAT THE GIVEN DATA POINT IS LAMINAR OR
C            TURBULENT; L- LAMINAR, T- TURBULENT
C LoverD = RATIO OF PIPE LENGTH TO DIAMETER
C M=1     = VERTICAL PIPE
C M=2     = HORIZONTAL PIPE
C mG      = GAS MASS FLOW RATE (lbm/hr)
C mL      = LIQUID MASS FLOW RATE (lbm/hr)
C MN***   = MEAN hTP ERROR FOR ReSL,ReSG,PrL,VsL/VsG,mG/mL WHICH ARE WITHIN THE
C            AUTHORS SPECIFIED RANGE.
C MNG     = GASEOUS PHASE COMPONENT DESIGNATOR
C     (=1)= AIR
C     (=2)= HELIUM
C     (=3)= FREON-12
C MNL     = LIQUID PHASE COMPONENT DESIGNATOR
C     (=1)= WATER
C     (=2)= GLYCERIN
C     (=3)= SILICONE
C MNH1(*)= MEAN VALUE OF hTP ERRORS
C MN(*)   = NO. OF POINTS IN EACH DATA SET FOR EACH FLOW PATTERN
C muB     = DYNAMIC VISCOSITY OF LIQUID AT BULK TEMPERATURE (lbm/ft-hr)
C muG     = DYNAMIC VISCOSITY OF GAS AT WALL TEMPERATURE (lbm/ft-hr)
C muL     = DYNAMIC VISCOSITY OF LIQUID (lbm/ft-hr)
C muW     = DYNAMIC VISCOSITY OF LIQUID AT WALL TEMPERATURE (lbm/ft-hr)
C muWmuB = muW/muB -- CALCULATED
C muWmB  = muW/muB -- FROM DATA SET
C N       = TYPE OF FLOW PATTERN
C      11 = BUBBLY
C      22 = SLUG
C      33 = FROTH
C      44 = ANNULAR
C      55 = CHURN
C      12 = BUBBLY - SLUG
C      13 = BUBBLY - FROTH
C      14 = BUBBLY - ANNULAR
C      15 = BUBBLY - CHURN
C      23 = SLUG - FROTH
C      24 = SLUG - ANNULAR
C      25 = SLUG - CHURN
C      34 = FROTH - ANNULAR
C      35 = FROTH - CHURN
C      45 = ANNULAR - CHURN
C      46 = ANNULAR - MIST
C NPT     = NUMBER OF DATA POINTS IN EACH DATA SET
C NSETS   = NUMBER OF SEPARATE DATA SETS TO BE TESTED
C P       = PRESSURE (lbf/ft^2)
C PRCL(X,Y,Z)= NO. OF LAMINAR POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR
C                 A GIVEN PARAMETER
C PRCT(X,Y,Z)= NO. OF TURBULENT POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR
C                 A GIVEN PARAMETER
C             X= 1 FOR ReSL PARAMETER
C             X= 2 VsL/VsG PARAMETER
C             Y= 1 +/- 15% ERROR
C             Y= 2 +/- 30% ERROR
```

```
C           Z= FOR EACH FLOW PATTERN
C PrL     = LIQUID PRANDTL NUMBER (CALCULATED)
C PrLL    = LIQUID PRANDTL NUMBER (FROM DATA SET)
C RMH1(X)= RMS VALUE OF hTP VALUES
C       X = FLOW PATTERNS
C ReSG    = SUPERFICIAL GAS REYNOLDS NUMBER (CALCULATED)
C ReSGG   = SUPERFICIAL GAS REYNOLDS NUMBER (FROM DATA SET)
C ReSL    = SUPERFICIAL LIQUID REYNOLDS NUMBER (CALCULATED)
C ReSLL   = SUPERFICIAL LIQUID REYNOLDS NUMBER (FROM DATA SET)
C RMGL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR mG/mL
C RPRL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR PrL
C RRSL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR ReSL
C RRSG    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR ReSG
C RVSL    = NO. OF POINTS WITHIN THE AUTHOR SPECIFIED RANGE FOR VsL/VsG
C RMXYZ   = R.M.S hTP ERROR FOR ReSL,ReSG,PrL,VsL/VsG,mG/mL WHICH ARE WITHIN THE
C            AUTHORS SPECIFIED RANGE.
C TMNL    = TOTAL NO. OF LAMINAR POINTS IN EACH DATA SET
C TMNT    = TOTAL NO. OF TURBULENT POINTS IN EACH DATA SET
C TMN     = TOTAL NO. OF POINTS IN EACH DATA SET
C TMEAN   = OVERALL MEAN VALUE OF hTP ERRORS
C TRMS    = OVERALL RMS VALUE OF hTP ERRORS
C TBULK   = BULK TEMPERATURE (F)
C TWALL   = WALL TEMPERATURE (F)
C TOGGLE = THIS SWITCH HELPS TO PRINT THE VsG/VsL OR ReSL RANGE TABLE
C            IF AVAILABLE FOR THAT DATA SET.
C VDOT    = TOTAL VOLUMETRIC FLOW RATE (ft^3/hr)
C VsG     = SUPERFICIAL VELOCITY OF GAS -- CALCULATED (ft/hr)
C VsGG    = SUPERFICIAL VELOCITY OF GAS -- FROM DATA SET (ft/hr)
C VsL     = SUPERFICIAL VELOCITY OF LIQUID -- CALCULATED (ft/hr)
C VsLL    = SUPERFICIAL VELOCITY OF LIQUID -- FROM DATA SET (ft/hr)
```

APPENDIX D

CALIBRATION CURVES FOR WALL THERMOCOUPLES AND BULK TEMPERATURE PROBES

APPENDIX D

CALIBRATION CURVES FOR WALL THERMOCOUPLES AND BULK TEMPERATURE PROBES

In this Appendix, the calibration curves for all of the thermocouples used on the test section and for the inlet/exit bulk temperature probes are given. The regression coefficient for all of these thermocouples is approximately equal to 1.000 (regression: predicting the future values by using the present value; the closer the regression coefficient is to 1, the higher the accuracy to predict the future value). Figures D.1 to D.4 show how the difference between the thermocouple readings and bath temperature changed with the temperature of the bath. As explained in Chapter III, the thermocouples appear to have small, but consistent errors as bath temperature increases. However, these errors are attributable to the bath temperature being more difficult to maintain constant as the bath temperature deviated from the ambient temperature.

Y= Thermocouple Reading in °C.

X= Temperature of the Bath in °C.

TC 1 : $Y=0.984557*X+0.63491$ $R^2=1.000$
TC 2 : $Y=0.983405*X+0.771464$ $R^2=0.9999$
TC 3 : $Y=0.984072*X+0.730135$ $R^2=0.9999$
TC 4 : $Y=0.984011*X+0.67914$ $R^2=0.9999$
TC 5 : $Y=0.983774*X+0.805216$ $R^2=0.9999$
TC 6 : $Y=0.983422*X+0.700356$ $R^2=0.9999$
TC 7 : $Y=0.983998*X+0.813274$ $R^2=0.9998$
TC 8 : $Y=0.983366*X+0.651619$ $R^2=1.000$
TC 9 : $Y=0.983293*X+0.78138$ $R^2=0.9999$
TC 10 : $Y=0.983042*X+0.671963$ $R^2=1.000$
TC 11 : $Y=0.983419*X+0.761119$ $R^2=1.000$

TC 12 : Y=0.98315*X+0.663013 R^2=1.000
TC 13 : Y=0.982752*X+0.755736 R^2=1.000
TC 14 : Y=0.983079*X+0.693533 R^2=0.9999
TC 15 : Y=0.983934*X+0.742681 R^2=1.000
TC 16 : Y=0.983793*X+0.644655 R^2=1.000
TC 17 : Y=0.9832823*X+0.753102 R^2=1.000
TC 18 : Y=0.9828835*X+0.698383 R^2=1.000
TC 19 : Y=0.9827634*X+0.788053 R^2=0.9999
TC 20 : Y=0.9835481*X+0.676779 R^2=0.9999
TC 21 : Y=0.9825978*X+0.803249 R^2=1.000
TC 22 : Y=0.9824387*X+0.73387 R^2=1.000
TC 23 : Y=0.982791*X+0.796852 R^2=1.000
TC 24 : Y=0.9828552*X+0.710093 R^2=1.000
TC 25 : Y=0.9839026*X+0.777476 R^2=0.9999
TC 26 : Y=0.9826202*X+0.731173 R^2=1.000
TC 27 : Y=0.9829349*X+0.800486 R^2=1.000
TC 28 : Y=0.9832472*X+0.716721 R^2=1.000
TC 29 : Y=0.98298*X+0.787335 R^2=1.000
TC 30 : Y=0.9841836*X+0.66775 R^2=1.000
TC 31 : Y=0.9835554*X+0.79781 R^2=1.000
TC 32 : Y=0.9830942*X+0.719171 R^2=1.000
TC 33 : Y=0.97965*X+0.8512889 R^2=1.000
TC 34 : Y=0.980067*X+0.9614704 R^2=1.000
TC 35 : Y=0.97980496*X+0.8937116 R^2=1.000
TC 36 : Y=0.979507*X+0.9358338 R^2=1.000
TC 37 : Y=0.97837*X+1.0141242 R^2=1.000
TC 38 : Y=0.979588*X+0.942584 R^2=0.9998
TC 39 : Y=0.980335*X+0.9596527 R^2=1.000
TC 40 : Y=0.980926*X+0.8599794 R^2=0.9999

The calibration equations for the inlet and exit bulk thermocouple probes are:

inlet thermocouple probe:

Y=0.978992397*X+0.694780824 R^2=0.9999

exit thermocouple probe:

Y=0.9802038*X+0.677827405 R^2=0.9999

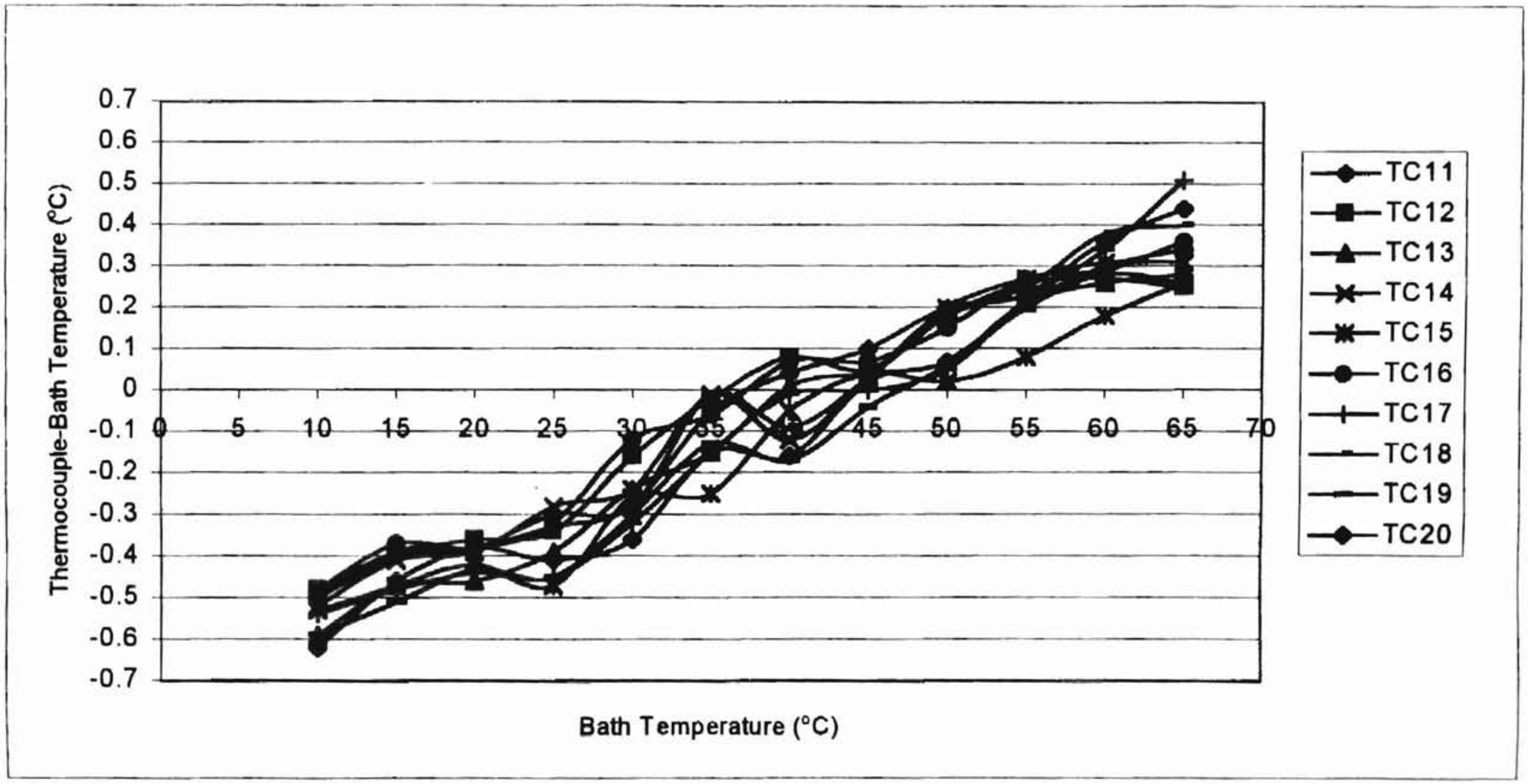

Figure D.1: Trend of Difference Between Thermocouples (11-20) and Bath Temperature vs. Bath Temperature

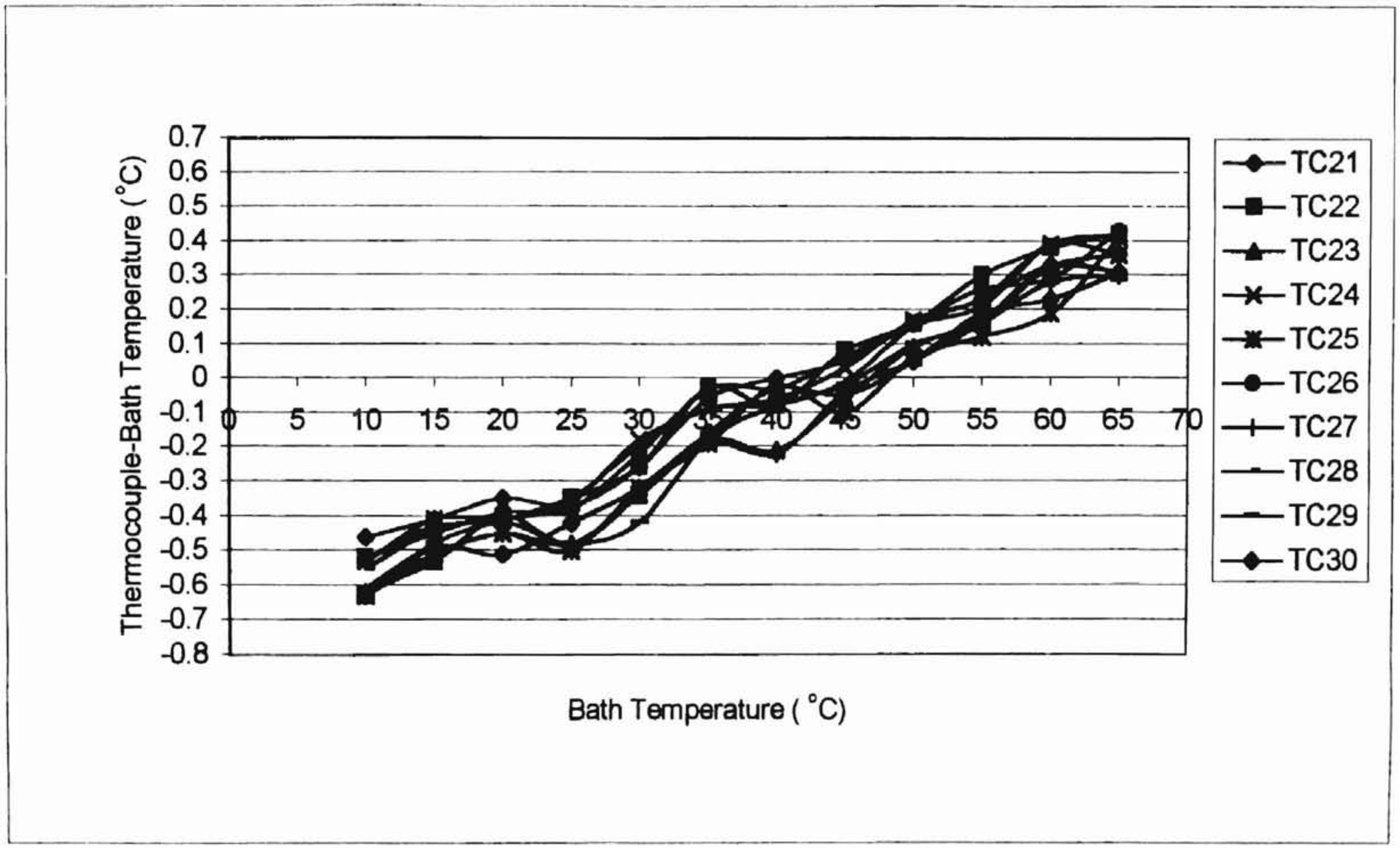

Figure D.2: Trend of Difference Between Thermocouples (21-30) and Bath Temperature vs. Bath Temperature

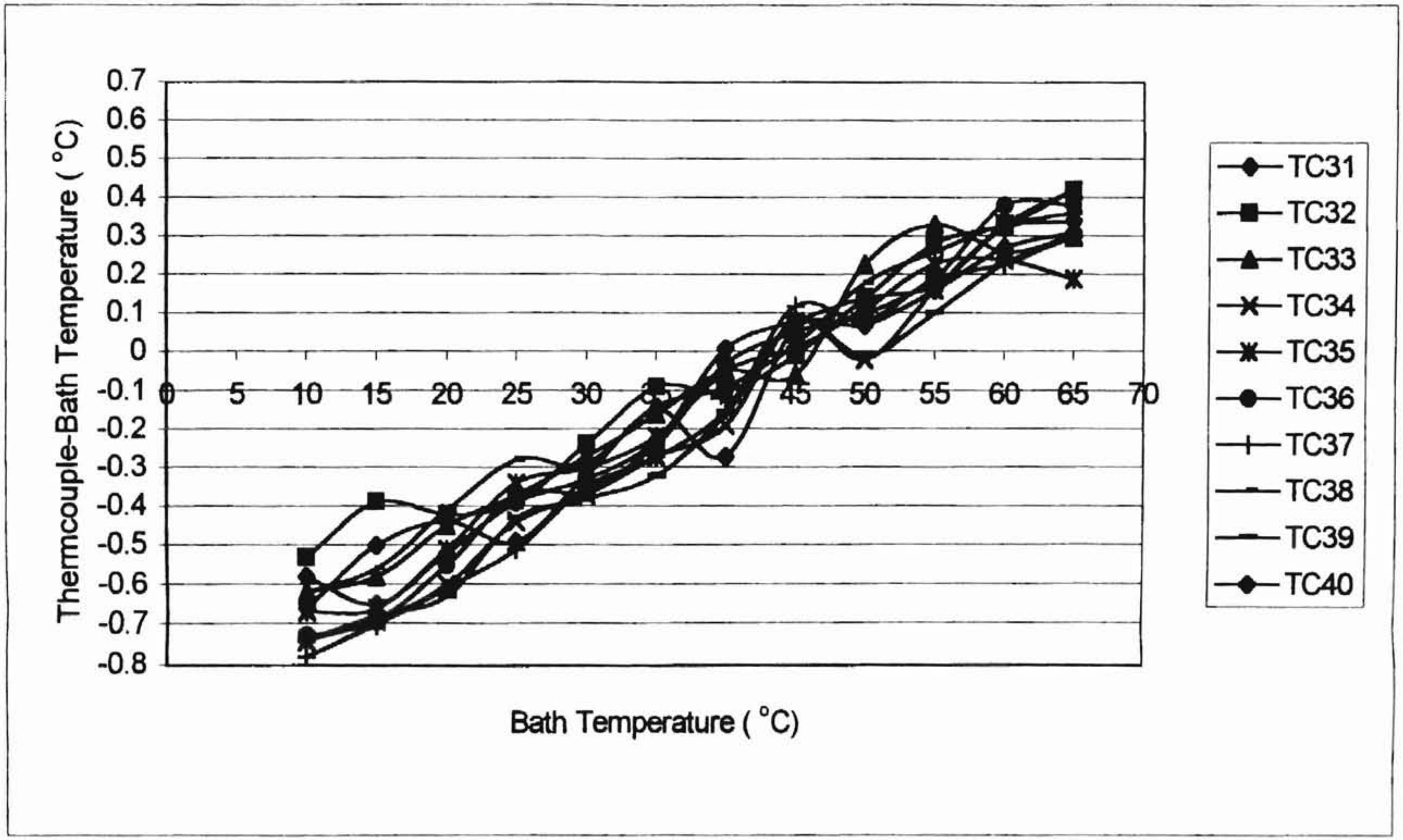

Figure D.3: Trend of Difference Between Thermocouples (31-40) and Bath Temperature vs. Bath Temperature

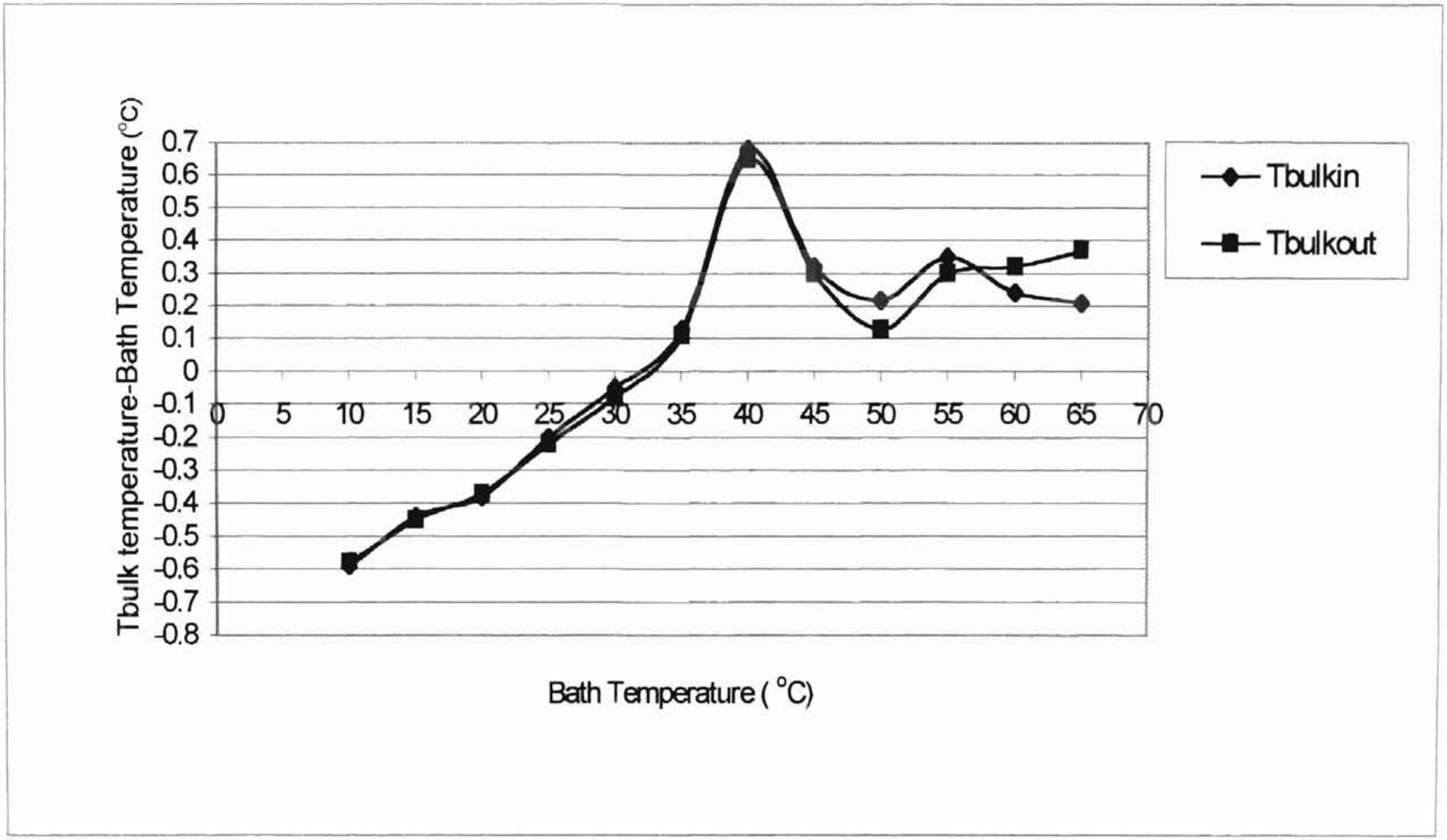

Figure D.4: Trend of Difference Between Bulk Temperature (Inlet and Exit) and Bath Temperature vs. Bath Temperature

APPENDIX E

SAMPLE CALCULATION AND ANALYSIS

APPENDIX E

SAMPLE CALCULATION AND ANALYSIS

In this Appendix, the physical properties of water were hand calculated for a test run (run 0172) at station 6, and then they were compared with the calculated properties from the computer program RHt98F. This was done to verify that the computer program was calculating all parameters properly. It was evident that the hand calculations were approximately the same as the program RHt98F results. The bulk temperature (Tbulk) and average wall temperature (Twall) were taken at station 6. [A greater number of digits of accuracy are shown to demonstrate that the difference between the code and hand calculations are well below measurement accuracy.]

Tbulk = 91.17374 °F (32.8743 °C) (at Station 6)

Twall = 92.51445 °F (33.61914 °C) (at Station 6)

1) Specific Heat (C_{PL}) of Water in kJ/(kg-k), T in °C (calculated at Tbulk).

$C_{PL} = -1.475E\text{-}7\,(T)^3 + 3.66E\text{-}5\,(T)^2 - .0022\,(T) + 4.216$

$C_{PL} = C_{PL}/4.1868$ 4.1868 conversion factor to Btu/lbm- °F

$C_{PL} = 4.17799/4.1868 = 0.99789589$ Btu/lbm- °F

From program RHt98F: 0.9978959 Btu/lbm- °F

Error = -1.0 E-06%

2) Thermal Conductivity, k_L in w/m-°K, T in °C (calculated at Tbulk)

   k_L= 5.6276E-1+1.874e-3 (T)-6.80E-6 $(T)^2$

   $k_L = k_L$ (0.5778)   0.5778 conversion factor to (Btu/hr-ft- °F)

   k_L = 0.6169575 (0.5778)=0.3564780 (Btu/hr-ft- °F)

   From program RHt98F: 0.3565127 Btu/hr-ft- °F

   Error = -9.7 E-03%

3) Density, ρ_L in kg/m^3, T in °C (calculated at Tbulk)

   ρ_L = 999.86+6.1464e-2 (T)-8.4648e-3 $(T)^2$+6.8794e-5 $(T)^3$-4.4214e-7 $(T)^4$

   +1.2505e-9 $(T)^5$

   @ Tbulk = 32.87374 °C

   $\rho_L = \rho_L$ (0.062427)   0.062427: conversion factor to lb/ft^3

   ρ_L = 994.7081 (0.062427)=62.096645 lb/ft^3

   From program RHt98F: 62.096650 lb/ft^3

   Error = -8.4 E-06%

4) Viscosity μ (in lb/hr-ft) at Tbulk (°C) and Twall (°C)

   μ = 2.4189 $(1.0019)^{10\wedge((1.327(20-(T))-1.053E-3(20-(T))\wedge 2)/((T)+105))}$

   μ_b (at Tbulk) = 1.8166239 lb/hr-ft

   From program RHt98F: 1.816546 lb/hr-ft

   μ_w (at Twall) = 1.789193805   lb/hr-ft

   From program RHt98F: 1.789113 lb/hr-ft

μ_b / μ_w = 1.015330977 lb/hr-ft

From program RHt98F: 1.015333 lb/hr-ft

Error = -1.99 E-6%

5) Prandtl Number

$Pr = \mu_b (C_{PL})/k_L$ = (1.8166239) (0.99789589)/(0.3564780)

Pr = 5.08531

From program RHt98F: 5.084597

Error = 0.014%

6) Reynolds Number

$Re = \dot{m}_L (D/12.0)\ \mu_b$

D = 1.097 inch

$\dot{m}_L$ = 335381 lbm/(ft^2-hr) from the code, taken as Constant.

Re = 335381 (1.097/12) (1.8166239)=16877.138

From program RHt98F: 16877.88

Error = -4.39 E-3%

7) Heat Transfer Coefficient (Btu/ft^2-hr-°F)

$h = q''_{avg}/(T_{wall}-T_{bulk})$

q''_{avg} (heat flux) = 313.396 (Btu/(ft^2-hr)) from the code, Twall=92.51445 °F

Tbulk=91.17374 °F

h = 233.5795366 Btu/ft^2-hr-°F

From program RHt98F: 233.7522 Btu/ft^2-hr-°F

Error = -0.073%

8) Nusselt Number

$Nu = h\ (D/12.0)\ k_L$ D=1.097 inch

Nu=233.5795366 (1.097/12) 0.3564780

Nu = 59.9447516

From program RHt98F: 59.938540

Error = 0.01%

It is evident from these comparisons, that the computer code is working well enough to carry out further data reduction of the test runs.

APPENDIX F

STEADY STATE CRITERION

Appendix F

Steady State Criterion

Described herein is a detailed procedure regarding how to attain the inlet bulk temperature, steady state, and maximum bulk temperature difference, for all of the nine cases of experimental test runs (see Table XIV). However, to attain a maximum temperature difference and steady-state, it is entirely based upon the skill and knowledge of the experimentalist, and how he/she operates the heat exchanger to bring about these conditions. Several test runs have been done to carefully monitor how the heat exchanger controls the bulk temperatures and the attainment of steady-state. Based on experience from 20 test runs, the following procedure is presented to control the temperature difference and to attain steady-state. Some of the abbreviated terms used in the discussion below are:

DeltaTB= difference between exit and inlet bulk temperatures

DeltaTBin= change in the inlet bulk temperature in one minute

DeltaTBot= change in the exit bulk temperature in one minute

Case 1 (Low Power/Low Flow Rate)

Power Input: 180 A/1.40V

Flow rate (main loop): 0.75 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 20 minutes. It is necessary to run for 20 minutes since it takes a longer time to get a good DeltaTB.

2. After 20 minutes, it is observed that DeltaTB=4.5 °F.

3. Now DeltaTBin and DeltaTBot are monitored carefully. It was found that for this case, DeltaTBin=0.09 °F /min, DeltaTBot=0.1 °F /min.

4. Then switch on the heat exchanger at 1.5 gpm. Allow it to run for 2 minutes, and then the DeltaTBin and DeltaTBot are recorded:

   DeltaTBin=0.07 °F /min DeltaTBot=0.07 °F /min

5. Because of low flow rate and low power input, this case can be run at 1.5 gpm (heat exchanger flow rate.)

6. DeltaTB is always 4.5 °F throughout the run.

<u>Case 2 (Low Power/Medium Flow Rate)</u>

Power Input: 180 A/1.40V

Flow rate (main loop): 2.4 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 15 minutes. This has been done to get a good DeltaTB for this type of flow rate and power input.

2. After 15 minutes, it is observed that without the heat exchanger:

   DeltaTBin=0.18 °F/min DeltaTBot=0.18 °F/min

   DeltaTB in one minute=2.5 °F

3. Run the heat exchanger at 1.5 gpm for 2 minutes, and the monitored bulk temperatures are:

   DeltaTBin=0.07 °F/min DeltaTBot=0.07 °F/min

   DeltaTB in one minute =2.8 °F

4. Run the heat exchanger at 2.5 gpm for 2 minutes, and the monitored bulk

Temperatures are:

DeltaTBin=0.56 °F/min DeltaTBot=0.56 °F/min

DeltaTB in one minute =2.4 °F

5. Run the heat exchanger at 4.5 gpm for 2 minutes, and the monitored bulk temperatures are:

   DeltaTBin=0.63 °F/min DeltaTBot=0.63 °F/min

   DeltaTB in one minute =2.2 °F

6. Here we see a gradual increase in inlet and outlet bulk temperatures for heat exchanger flow rates less than 1.5 gpm; but at the same time the DeltaTB decreases, which clearly shows that steady-state can be reached with less than 1.5 gpm (1.0-1.4 gpm) through the heat exchanger. Also the DeltaTBin and DeltaTBot were minimum at 1.5 gpm flow rate on the heat exchanger.

<u>Case 3 (Low Power/ High Flow Rate)</u>

Power Input: 180 A/1.40V

Flow rate (main loop): 4.15 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 10 minutes. Due to a high flow, the flow in the test section attains steady-state and well-developed flow in a short time.

2. After 10 minutes, it is observed without the operation of heat exchanger:

   DeltaTBin=0.1 °F/min DeltaTBot=0.1 °F/min

   DeltaTB in one minute =1.5 °F

3. Run the heat exchanger at 1.0 gpm for 2 minutes, and the monitored bulk temperatures are:

DeltaTBin=-0.054 °F/min   DeltaTBot=-0.36 °F/min

DeltaTB in one minute =1.0 °F

4. Run the heat exchanger at 1.5 gpm for 2 minute and the monitored the bulk temperatures are:

   DeltaTBin=-0.126 °F/min   DeltaTBot=-0.9 °F/min

   DeltaTB in one minute =1.7 °F

5 Here as we increase the flow rate through the heat exchanger, we see that DeltaTBin and DeltaTBot decrease, that is the fluid is cooling. So it is always advisable to use a very low flow rate about (0.5 gpm) through the heat exchanger for this case.

Case 4 (Medium Power/Low Flow Rate)

Power Input: 330 A/2.65V

Flow rate (main loop): 0.75 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 10 minutes.
2. After 10 minutes, it is observed without the heat exchanger:

   DeltaTBin=0.36 °F/min   DeltaTBot=1.8 °F/min

   DeltaTB in one minute =8.19 °F

3. Run the heat exchanger at 1.5 gpm for 2 minutes, and the monitored bulk temperatures are:

   DeltaTBin=0.34 °F/min   DeltaTBot=0.43 °F/min

   DeltaTB in one minute =8.3 °F

4. Run the heat exchanger at 2.5 gpm for 2 minutes, and the monitored bulk temperatures are:

DeltaTBin=0.324 °F/min DeltaTBot=0.414 °F/min

DeltaTB in one minute =8.316 °F

5. Run the heat exchanger at3.5 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.25 °F/min DeltaTBot=0.23 °F/min

   DeltaTB in one minute =8.36 °F

6. Run the heat exchanger at 5.5 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.18 °F/min DeltaTBot=0.21 °F/min

   DeltaTB in one minute =8.5 °F

7. It was observed that for this case, the DeltaTB increases as the flow through the heat exchanger increases. This was because the DeltaTBin is decreasing more rapidly than DeltaTBot is decreasing.

8. For this run, it is advisable to run the heat exchanger between 1.5 and 2.5 gpm flow rate to reach steady-state.

Case 5 (Medium Power/ Medium Flow Rate):

Power Input: 330 A/2.65V

Flow rate (main loop): 2.4 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 10 minutes.

2. After 10 minutes, it is observed without the heat exchanger:

   DeltaTBin=0.72 °F/min DeltaTBot=0.9 °F/min

   DeltaTB in one minute =3.0 °F

3. Run the heat exchanger at 1.5 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.36 °F/min DeltaTBot=0.36 °F/min

   DeltaTB in one minute =3.2 °F

4. Run the heat exchanger at 2.0 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.36 °F/min DeltaTBot=0.36 °F/min

   DeltaTB in one minute =3.2 °F

5. Run the heat exchanger at 2.5 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.36 °F/min DeltaTBot=0.36 °F/min

   DeltaTB in one minute =3.3 °F

6. Run the heat exchanger at 3.0 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.18 °F/min DeltaTBot=0.18 °F/min

   DeltaTB in one minute =3.4 °F

7. For this case, DeltaTBin and DeltaTBot remain the same for 1.5-2.5 gpm flow rate through the heat exchanger, and this type of run also satisfies the stability criterion for this range of flow rates.

<u>Case 6 (Medium Power/High Flow Rate):</u>

Power Input: 330 A/2.65V

Flow rate (main loop): 4.15 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 10 minutes.
2. After 10 minutes, it is observed without the heat exchanger:

   DeltaTBin=0.2 °F/min   DeltaTBot=0.2 °F/min

   DeltaTB in one minute =1.33 °F
3. Run the heat exchanger at 1.5 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.18 °F/min   DeltaTBot=0.18 °F/min

   DeltaTB in one minute =1.4 °F
4. Run the heat exchanger at 2.5 gpm for 2 minutes and the monitored bulk temperatures are:

   DeltaTBin=0.1 °F/min   DeltaTBot=0.11 °F/min

   DeltaTB in one minute =1.35 °F
5. In this case, we see that DeltaTB starts to drop, after 2.5 gpm through the heat exchanger. So for flow rates less than 1.5 gpm through the heat exchanger, the fluid reaches steady-state, since the DeltaTB is a maximum at this point.

Case 7 (High Power/Low Flow Rate):

Power Input: 500 A/4.62V

Flow rate (main loop): 0.75 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 2 minutes. For this power, it is enough to run the fluid for 2 minutes for the system to be ready for any experimentation.
2. After 2 minutes, it is observed without the heat exchanger:

DeltaTBin=0.36 °F/min DeltaTBot=3.6 °F/min

DeltaTB in one minute =18 °F

3. Run the heat exchanger at 1.5 gpm for 1 minute and the monitored bulk temperatures are:

DeltaTBin=0.34 °F/min DeltaTBot=3.6 °F/min

DeltaTB in one minute =17.64 °F

4. Run the heat exchanger at 2.5 gpm for 1 minute and the monitored bulk temperatures are:

DeltaTBin=0.32 °F/min DeltaTBot=3.6 °F/min

DeltaTB in one minute =18.9 °F

5. Run the heat exchanger at 4.5 gpm for 1 minute and the monitored bulk temperatures are:

DeltaTBin=0.31 °F/min DeltaTBot=3.6 °F/min

DeltaTB in one minute =18 °F

6. Run the heat exchanger at 5.5 gpm for 1 minute and the monitored bulk temperatures are:

DeltaTBin=0.27 °F/min DeltaTBot=2.52 °F/min

DeltaTB in one minute =18 °F

7. In this case, DeltaTB goes to a maximum value at a heat exchanger flow rate of 2.5 gpm, after which DeltaTB remians almost constant. So a good DeltaTB is reached at a flow rate 2.5 gpm from the heat exchanger for this case.

DeltaTBin=0.36 °F/min DeltaTBot=3.6 °F/min

DeltaTB in one minute =18 °F

3. Run the heat exchanger at 1.5 gpm for 1 minute and the monitored bulk temperatures are:

   DeltaTBin=0.34 °F/min DeltaTBot=3.6 °F/min

   DeltaTB in one minute =17.64 °F

4. Run the heat exchanger at 2.5 gpm for 1 minute and the monitored bulk temperatures are:

   DeltaTBin=0.32 °F/min DeltaTBot=3.6 °F/min

   DeltaTB in one minute =18.9 °F

5. Run the heat exchanger at 4.5 gpm for 1 minute and the monitored bulk temperatures are:

   DeltaTBin=0.31 °F/min DeltaTBot=3.6 °F/min

   DeltaTB in one minute =18 °F

6. Run the heat exchanger at 5.5 gpm for 1 minute and the monitored bulk temperatures are:

   DeltaTBin=0.27 °F/min DeltaTBot=2.52 °F/min

   DeltaTB in one minute =18 °F

7. In this case, DeltaTB goes to a maximum value at a heat exchanger flow rate of 2.5 gpm, after which DeltaTB remians almost constant. So a good DeltaTB is reached at a flow rate 2.5 gpm from the heat exchanger for this case.

Case 9 (High Power/High Flow Rate):

Power Input: 500 A/4.62V

Flow rate (main loop): 4.15 gpm

1. After setting the flow rate and power input, the fluid is allowed to run for 2 minutes. This time is enough to get the system ready for experimentation.
2. After 2 minutes, it is observed without the heat exchanger

   DeltaTBin=0.54 °F/min DeltaTBot=0.72 °F/min

   DeltaTB in one minute =5.81 °F
3. Run the heat exchanger at 1.5 gpm for 1 minute and the monitored bulk temperatures are:

   DeltaTBin=1.17 °F/min DeltaTBot=1.26 °F/min

   DeltaTB in one minute =5.6 °F
4. Since the power was high, in this case it will be reasonable to operate the heat exchanger at less than 1.5 gpm flow rate.

Observation from the above test cases:

1. To reach steady-state, the following are the parameters that should be considered:
   a. Initial DeltaTB
   b. Flow rate
   c. Power input
   d. Initial Tbulkin
2. To reach a particular steady-state condition, we need to control inlet bulk temperature, which is possible by adjusting the heat exchanger flow rate.

3. In this setup, DeltaTB is very low for low and medium power input, which makes the fluid reach steady-state conditions very quickly; or rather, the flow is always at steady-state after about 15 minutes of operation for low and medium power inputs.
4. At high power input, there is a high DeltaTB, which makes a very good run.
5. Steady-state can be reached based upon the ability of the experimentalist. For my test run, I assumed 0.25~0.55 °F/minute in Tbulkin to be equivalent to steady-state.
6. To get a maximum DeltaTB for low and medium power inputs, we start the heat exchanger at a high flow rate and then gradually decrease it; but we have to understand the stability criterion for every type of run. This can be achieved only through constant experimenting and time spent using the heat exchanger.

However with the help of the Real Time Graphics (RTG) display, the exit bulk temperature, the inlet bulk temperature, and the tank temperature are plotted on a single graph, to clearly see when steady-state is reached. Figures F.1 and F.2 shows how the Real Time Graphics (RTG) display provides the plots for inlet bulk, exit bulk, and tank temperatures. Note that, after some time (Figs. F.1 and F.2), the inlet and exit bulk temperatures remain almost constant. This was when the system appeared to have reached steady-state. After steady-state conditions were reached, 60 to 100 data points were taken to calculate the heat transfer parameters. Figure F.2 shows the steady-state results for a particular test run. Thus, it was much easier to identify steady-state using the RTG.

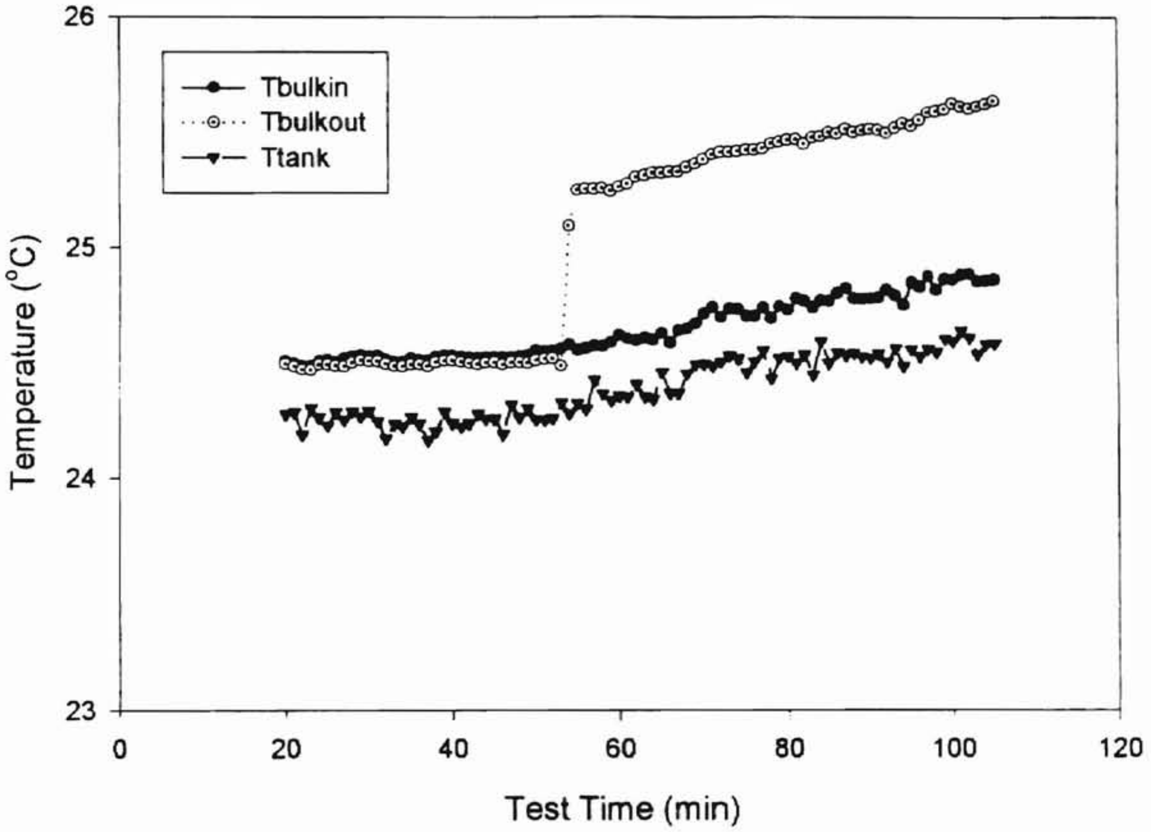

Figure F.1: Steady State Criterion for Test Run 4103

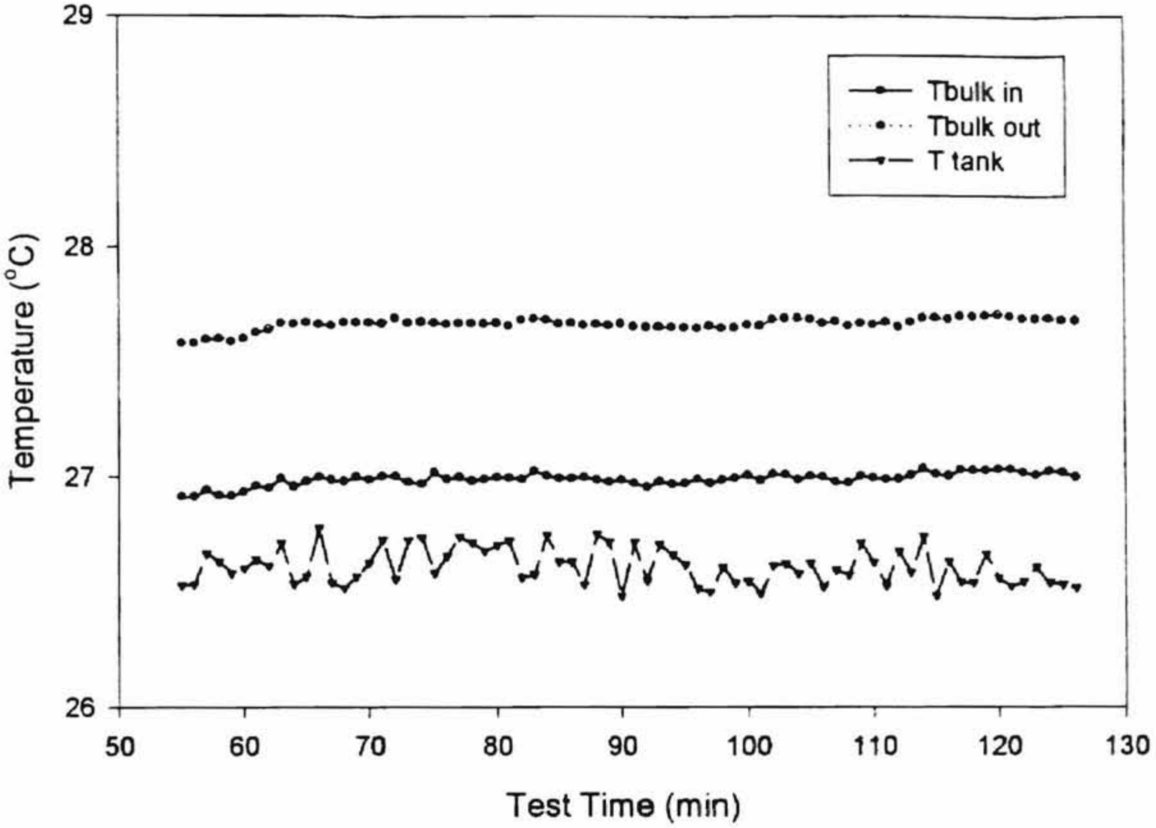

Figure F.2: Steady State Criterion for a Test Run 1161

APPENDIX G

Uncertainty Analysis

APPENDIX G

Uncertainty Analysis

The uncertainty in the prediction of heat transfer coefficient is covered in this appendix.

h=q"/DeltaTB (G.1)

where: q" is the heat input per unit area = VI/A (G.2)

the error in predicting the voltage= ±1%

the error in predicting the amperage=±10/500=±0.02%

the variation of temperature is ±0.3 °F

A is a constant

for a minimum DeltaTB of 1 °F, the error in predicting the DeltaTB is:

±0.3/1=±0.3

for a maximum DeltaTB of 6.3 °F, the error in predicting the DeltaTB is:

±0.3/6.3=±0.0476

These can be used to determine overall percentage error for computing h using Eq. (G.1).

2

VITA

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