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An experimental study of heat transfer through liquid foam.

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AN EXPERIMENTAL STUDY
OF
HEAT TRANSFER THROUGH LIQUID FOAM

by

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ABSTRACT

An experimental investigation was carried out to determine the thermal conductivity and the total solar transmissivity of liquid foam and to check the feasibility of its use as an insulation medium between the walls of a greenhouse in a hot climate to act both as an insulator and as a translucent medium to attenuate thermal radiation.

Two test rigs were designed and fabricated; one for thermal conductivity tests and one for solar transmissivity tests. An online data acquisition program was developed for fast collection of information and in situ data reduction.

As a translucent medium to attenuate radiation, liquid foam was found to be very effective. A 25 mm layer was found to transmit only 50% of the incident radiation. In addition, it was found that the thermal conductivity is independent of the solute concentration of the surfactant solution, decreases with an increase in the temperature difference and increases rapidly with an increase in the mean temperature. The results revealed that a vertical annular liquid foam layer of 25 mm thickness has a thermal conductance 1.86 times that of air for a mean temperature of 25°C and a temperature difference of 10°C.

An uncertainty analysis showed that the values of the thermal conductivities and the solar transmissivities had uncertainties of approximately 5.7% and 8.9% respectively.

DEDICATION

To Him

who is our source of knowledge

ACKNOWLEDGEMENT

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NOMENCLATURE

C	Circumference of the Ring (m)
CF	Correction Factor
D_1	Diameter of the Hot Surface (m)
D_2	Diameter of the Cold Surface (m)
k	Thermal Conductivity (W/m.°C)
I	Solar Intensity (W/m^2) ; Electric Current (A)
L	Length of the Heater Surface (m)
P	Surface Tensiometer Dial Reading ($N/m.10^3$)
Q	Heat Power Input (W)
r	Radius of wire (m)
R	Radius of the Ring (m) ; Resistance of the Known Resistor (Ω)
S	Surface Tension (N/m)
SF	Scale Factor
T_{hot}	Average Temperature of the Hot Surface (°C)
T_{cold}	Average Temperature of the Cold Surface (°C)
X	Layer Thickness (m)
V	Voltage drop (V) ; D.C. Voltage Signal (V)
V_i	Volume of the ith component (m^3)

NOMENCLATURE

Greek Letters

δ	Uncertainty
ρ	Density (kg/m^3)
σ	Standard Deviation
θ_l	Volumetric Liquid Content
τ	Solar Transmissivity

Subscripts

eq	Equation
i	ith Variable
liq	Liquid
rand	Random
resist	Resistor
sig	Signal
syst	Systematic

CHAPTER 1

INTRODUCTION

1.1 MOTIVATION OF THE PRESENT STUDY

Greenhouses are used for cultivating out-of-season plants and protecting tender plants against excessive heat and cold. They are typically buildings with a glass or plastic roof and sides enclosing a space in which temperature and humidity can be controlled.

Solar greenhouses must be climatically planned; designs for cold climates are not totally acceptable in hot climates. Hot desert climates require that the design be able to let the visible light come in but attenuate infrared solar radiation. The present study is motivated by the need to find an insulation material to be used between the glass walls of a greenhouse in a hot climate which can act both as an insulator and as a translucent medium to attenuate infra red radiation. For this application, most insulation materials are unsuitable since they are opaque. Multiple glazing can achieve the insulation effect but does not appreciably attenuate the radiation. Translucent liquid foams may offer a better option. Since there is no information available in the literature regarding the heat transfer and transmissivity of liquid foams, the need for such a study arises.

1.2 BACKGROUND INFORMATION ABOUT LIQUID FOAM

Foam may be defined as the agglomerations of gas bubbles separated from each other by thin liquid films [2]. There are two types of foam; liquid foam and solid foam. Liquid foams are formed by dispersion of gases in liquids whereas solid foams are formed by dispersion of gases in solids.

In all true foams, whether the films are liquid or solid, each bubble is closed, i.e., it has no gas-filled channels connecting it with the neighboring bubbles. When such connections exist, the material is referred to as a sponge. In a sponge, both phases are continuous whereas in foams, the gas forms a discontinuous or dispersed phase and the continuous phase is solid or liquid.

Foams may be differentiated from gas emulsions on the basis of the thickness of liquid films around each bubble of gas. However, it is impossible to draw sharp boundaries between them. If we define the volumetric liquid content θ_l as:

$$\theta_l = V_{liq} / V_{total} \tag{1.1}$$

Then, if

	$\theta_l < 0.1$	Foams
	$\theta_l > 0.9$	Gas emulsions
	$0.1 < \theta_l < 0.9$	Grey area

1.3 SCOPES AND OBJECTIVES OF THE PRESENT STUDY

The purpose of the present study is to experimentally determine the thermal conductance and the total solar transmissivity of liquid foam.

The main objectives of the study may be listed as follows:

1. To measure the thermal conductivity of foams at various temperature levels and heat fluxes.
2. To observe the behavior of the bubbles with respect to time when subjected to a constant heat flux.
3. To study the effect of mixture properties (eg., solute concentration) on the thermal conductivity of foams.
4. To measure the total solar transmissivity of foams.
5. To determine the correlation between the solar transmissivity and the bubble layer thickness.

These objectives were achieved by designing, fabricating and testing two separate test rigs, one for conductivity tests and one for solar transmissivity tests.

1.4 LITERATURE REVIEW

To the best of the author's knowledge, most of the literature on foam deals with its structure and with the surface chemistry of lamellae or films that separate the cells of internal-phase fluid [1]. These subjects have been discussed in books by Bikerman [2], and Rosen [3]. Liquid foams were also studied for measurements of the surface viscosity and other flow properties [4]. However, the heat transfer studies in the past deal only with solid foams [5,6].

CHAPTER 2

DETAILS OF THE EXPERIMENTAL SETUP

2.1 DESIGN OF THE THERMAL CONDUCTIVITY TEST FACILITY

A schematic of the test facility for thermal conductivity measurement is shown in Figure 2.1.

The requirement that the test cell design be able to measure the thermal conductivity of foams over a period of time and also allow the foam to be observed when subjected to a steady temperature gradient dictated the design of the apparatus. A cross-section of the thermal conductivity cell is shown in Fig 2.2.

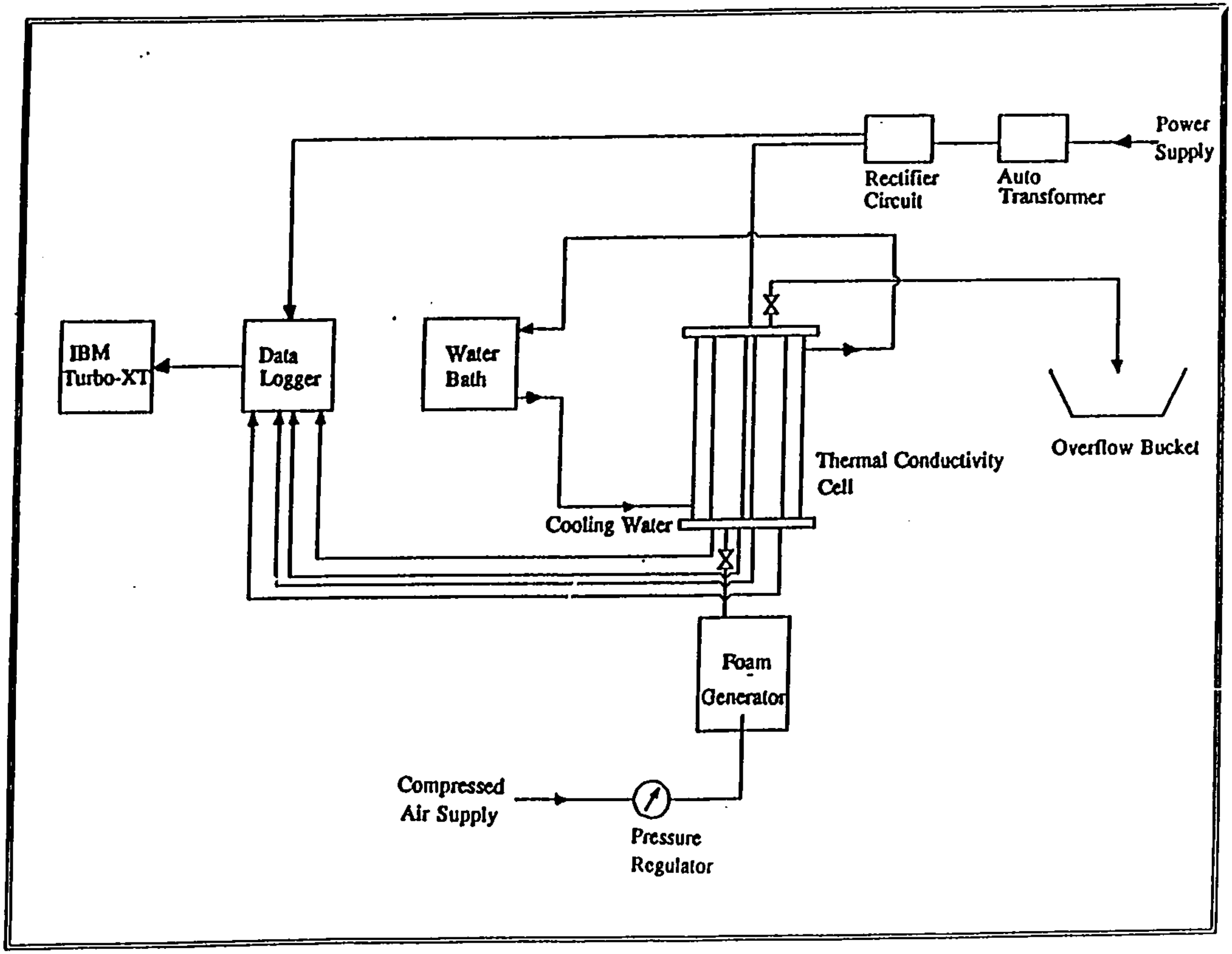


Figure 2.1 Schematic Of Experimental Test Facility For Thermal Conductivity Measurement

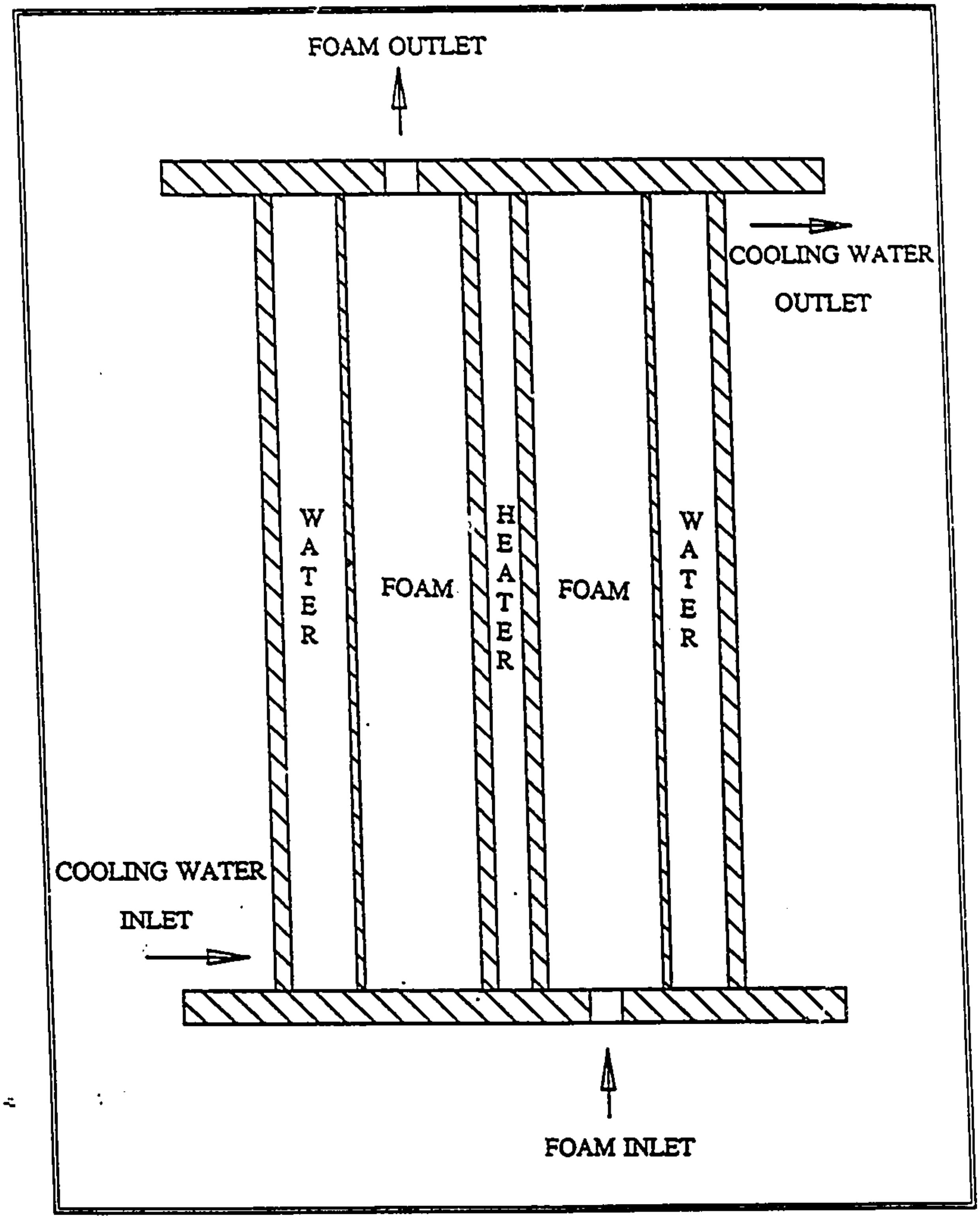


Figure 2.2 Cross Section Of The Thermal Conductivity Cell

A radial heat flow design was selected to minimize the need for using guard heaters which cause the following problems [7].

a. More time is needed to achieve steady state.

b. There is a chance of undetected temperature fluctuations and connected with it a remaining temperature difference influencing heat flow from the main heater.

c. Difficulties in heating uniformly.

d. Difficulties in alignment, and in insulating and sealing the guard heaters.

Guard heaters, and the difficulties introduced by them, can be avoided by using arrangements where the heat source is completely surrounded by the test material and the heat sink. There were two possible choices: a spherical arrangement and a cylindrical arrangement. The spherical arrangement has the disadvantage that a spherical heater producing uniform heat flux is difficult to fabricate whereas a cylindrical arrangement has the advantage that it is easy to fabricate a heater producing uniform heat flux. In the concentric cylindrical arrangement selected, an electric heater was surrounded by an annular layer of foam, which in turn, was enclosed within a water jacket heat sink. The end effects were minimized by choosing a poor conductor and by selecting a large length to diameter ratio [7].

To be able to observe the response of the bubbles, the outer layers of the conductivity cell were made of transparent polycarbonate plastic. In the outer annulus heat sink, water was circulated both circumferentially and longitudinally. The water was supplied by a circulating, controlled temperature water bath which maintained the water supply temperature. This allowed the cold surface temperature to be controlled at any desired level between 20°C and 50°C. The design details of the cooling chamber are given in section 2.1.6. The individual components of the thermal conductivity cell are described in the following sections and the details of the foaming unit are given in section 2.3.

2.1.1 HEATING ELEMENT

The selection of the heating element type was based on the criterion that it must produce uniform heat flux along the length. Length and diameter were chosen so that a large length to thickness of specimen was obtained. This large ratio was desirable to reduce any error caused by unequal layer thickness at the ends since the heat transfer areas of the ends are small compared with that of the annulus [7].

A Fast Heat, standard cartridge heater CS 010096 with stainless steel sheath 0.5 in. (12.7 mm) nominal diameter, 10 in. (254 mm) sheath length and 9.5 in. (241.3 mm) heated length, 475 W rating at 120 V, supplied by Acrolab Instrument, Windsor, Ontario, was selected. The cross section of the heater is shown in the Figure 2.3. The exact diameter

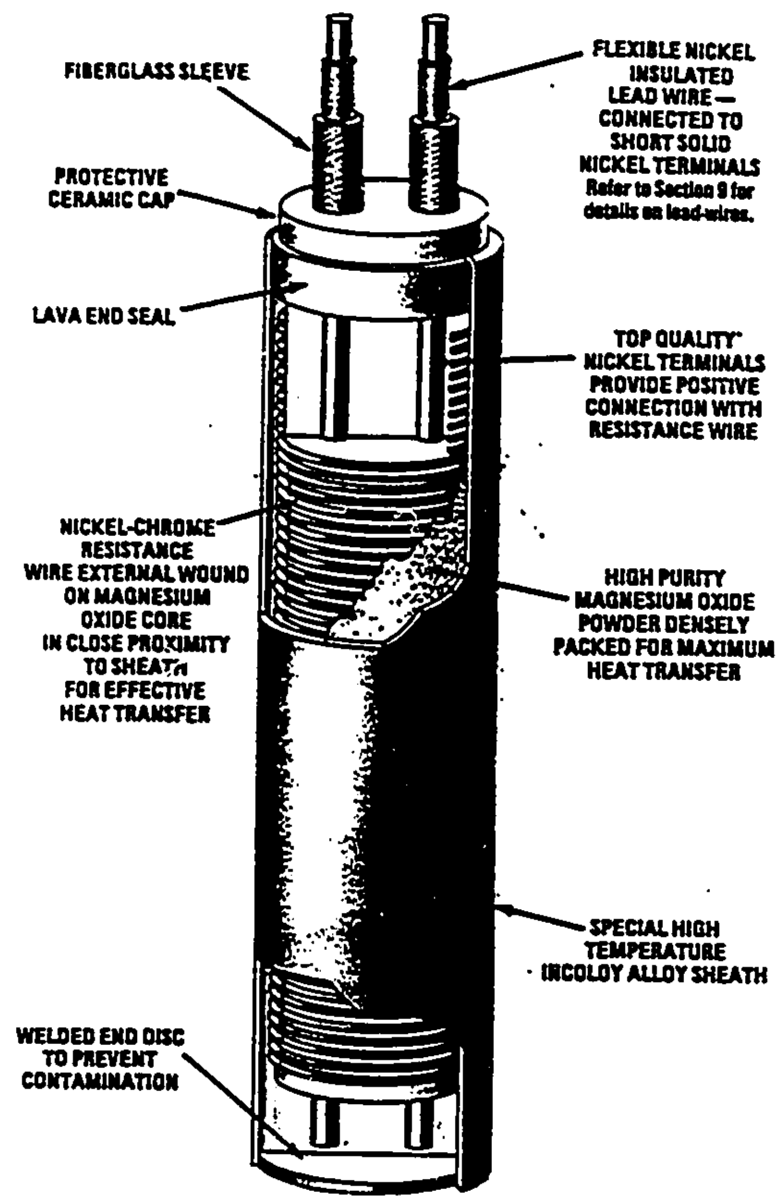


Figure 2.3 Cross Section Of The Heating Element

of the heater was 0.497 in. (12.6238 mm) with the tolerances +0.000 in. and -0.004 in. (0.1016 mm).

The electric power was supplied to the heater through a Variac autotransformer capable of delivering from 0 V to 135 V for an input of 115 V. Typical heat inputs for the present study were in the range from 2.3 W to 8.3 W.

2.1.2 COPPER SLEEVE

In order to facilitate the mounting of thermocouples for measuring the temperature of the heated surface, the sleeve shown in Figure 2.4 was designed. The material of the sleeve was selected based on the following criteria:

a: It should be a good conductor so that the temperature drop across the sleeve will be small and hence avoid excessively high temperature in the heater element.

b: It should be easily machined so that the slots for running the thermocouple wires can easily be cut.

Based on the above criteria, the sleeve was made of copper of 0.5 in (12.7 mm) ID and

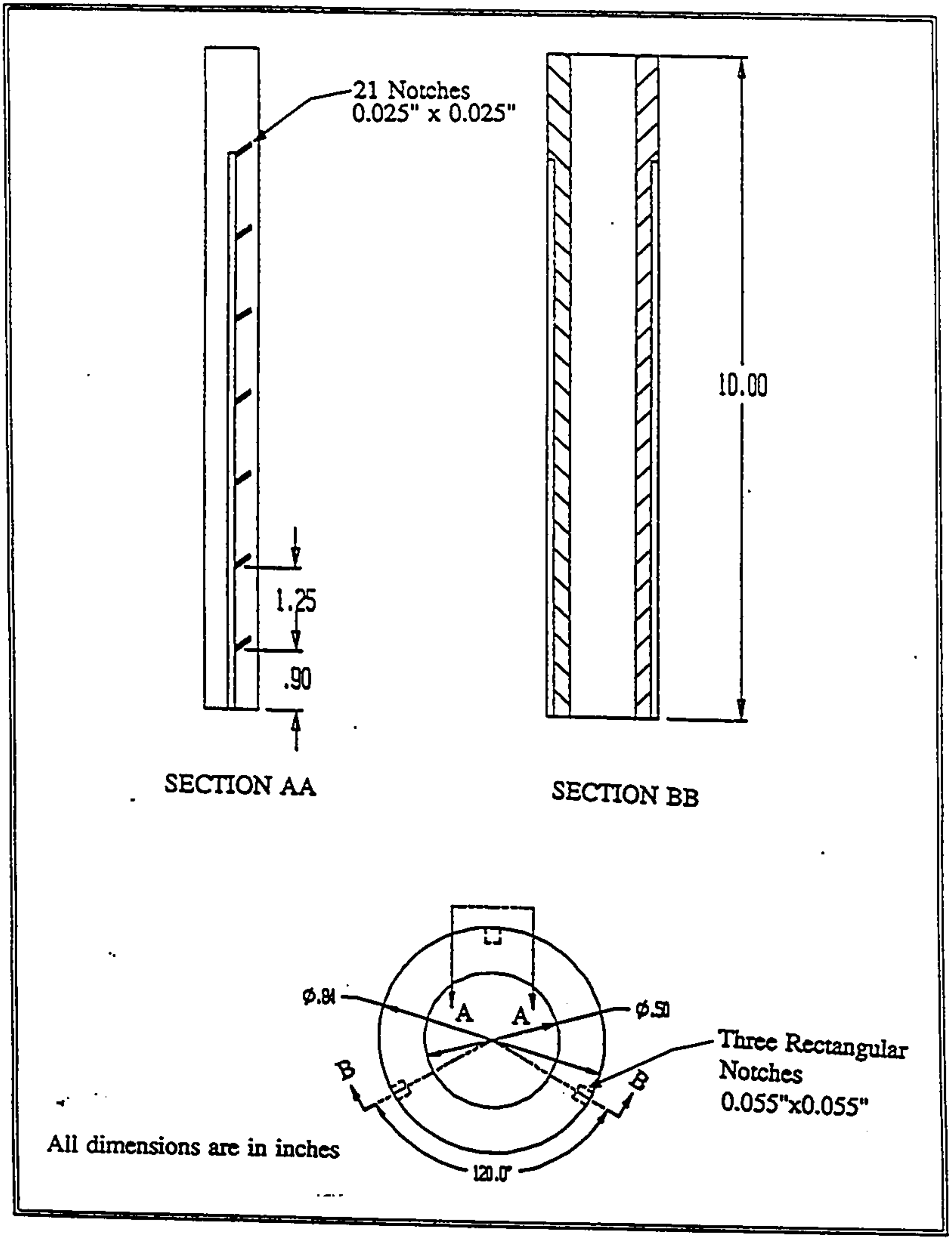


Figure 2.4 Copper Sleeve

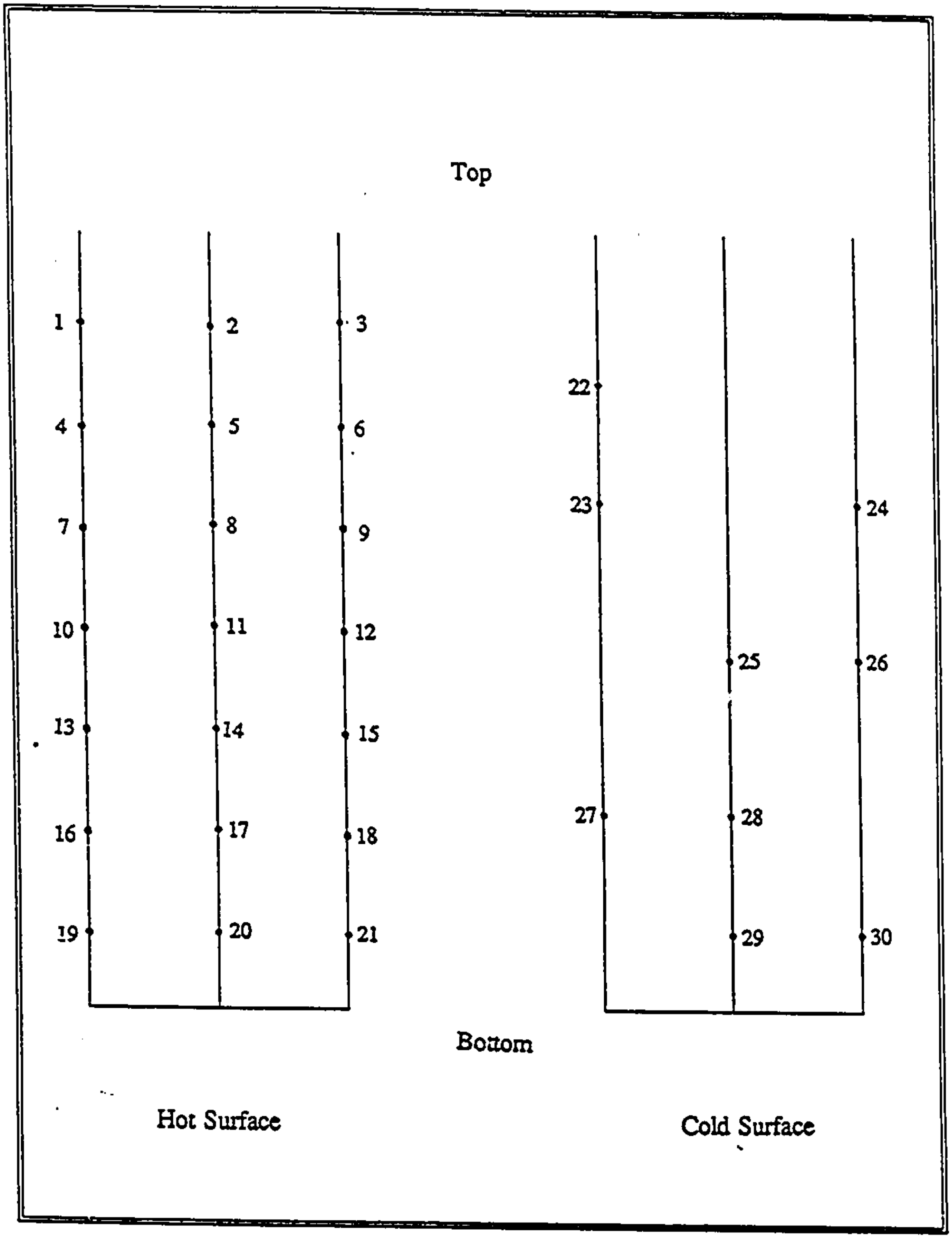


Figure 2.5 **Numbering System For Thermocouples**

0.84 in. (21.336 mm) OD. Three longitudinal slots, each separated by 120°, were cut along the length of the outer surface for mounting thermocouples. In each slot, there were seven thermocouples installed at equal lengths along the sleeve. The numbering system of the thermocouples is shown in Figure 2.5. The discontinuity in the heat flux lines introduced by these slots was minimized by selecting very thin wire thermocouples and hence reducing the slot sizes. Although it would be more advantageous to cut these slots along the inner surface of the sleeve, they were cut along the outer surface because of the difficulty in machining the sleeve inner surface. However, the error introduced by the discontinuity in heat flux lines was expected to be negligibly small since the slots size was less than 6% of the total surface area and since the slots were filled completely with a sealing material - Seal All - and the surface was smoothed with a fine emery paper.

2.1.3 SELECTION OF THERMOCOUPLES

The selection of the thermocouples used was based on the following criteria:

a: It must have a high Seebeck coefficient.

b: It must have very little error by conduction along the wires.

c: It must have a fast response to record temperature changes.

Based on the first criterion, type - T (Copper/Constantan - 55% copper & 45% nickel) thermocouples were selected since they have a reasonably high Seebeck coefficient of 38°μV/°C at 0°C, with guaranteed limits of error ±1.0°C or 0.4% (whichever is greater) and a maximum useful temperature range from -200 to 350°C [9]. However, one thermocouple was checked by inserting it in the ice and the error was found to be -0.1±0.05°C.

The second and third criteria required the use of very fine wires. However, due consideration was also given to durability and rigidity which decrease with the reduction of wire size. American Wire Gage(AWG) # 36, 0.0050 in. (0.127 mm) wire diameter, was selected. PFA - Teflon thermocouple insulation was chosen since it has excellent resistance to water, solvents, acidic or basic fluids, abrasion and is flexible. Its operating temperature range is from -267 to 260°C [9] which adequately covers the temperature range in the present study.

Thermocouples TFCP-005 (copper) and TFCC-005 (constantan) (type -T, teflon insulation, 36 AWG size) supplied by Omega Engineering Inc, Stamford, Connecticut, were selected.

2.1.4 TUBE FOR ENCLOSING FOAM

The inner tube for enclosing the foam was constructed from a polycarbonate plastic tube 2.875 in. (73.025 mm) ID, 3.0 in. (76.20 mm) OD and 9.875 in. (250.825 mm) length.

Three slots, each separated by 120°, were cut on the inside surface along the length for mounting the thermocouples. In each slot, there were three thermocouples installed at different lengths as shown in Figure 2.6. The numbering system of the thermocouples is shown in Figure 2.5. These slots were filled completely with the sealing material -Seal All.

2.1.5 END COVERS FOR THE THERMAL CONDUCTIVITY CELL

The end covers for sealing the thermal conductivity cell, as shown in Figures 2.7 and 2.8, were made from polycarbonate plastic plate 5 in. (127.00 mm) square and 0.75 in. (19.05 mm) thick. Two radial slots were cut on both covers at radii 1.5 in. (38.1 mm) and 2 in. (50.8 mm) to fix the covers on the cell. The depth of these slots were 0.25 in. (6.35 mm) for the top cover and 0.125 in. (3.175 mm) for the bottom cover. In both covers, a hole of 0.5 in. (12.7 mm) diameter was drilled at 0.9375 in. (23.8125 mm) from the center for the foam entrance and exit. Also, a hole of 0.84 in. (21.336 mm) diameter and 0.25 in. (6.35 mm) depth was drilled at the center on both covers for fixing them over the heater sleeve. On the top cover, a hole of 0.375 in. (9.525 mm) diameter was drilled to allow the heater leads pass through it. On the bottom cover, a hole of 0.25 in. (6.35 mm) diameter was drilled to facilitate in fixing the heater inside the sleeve.

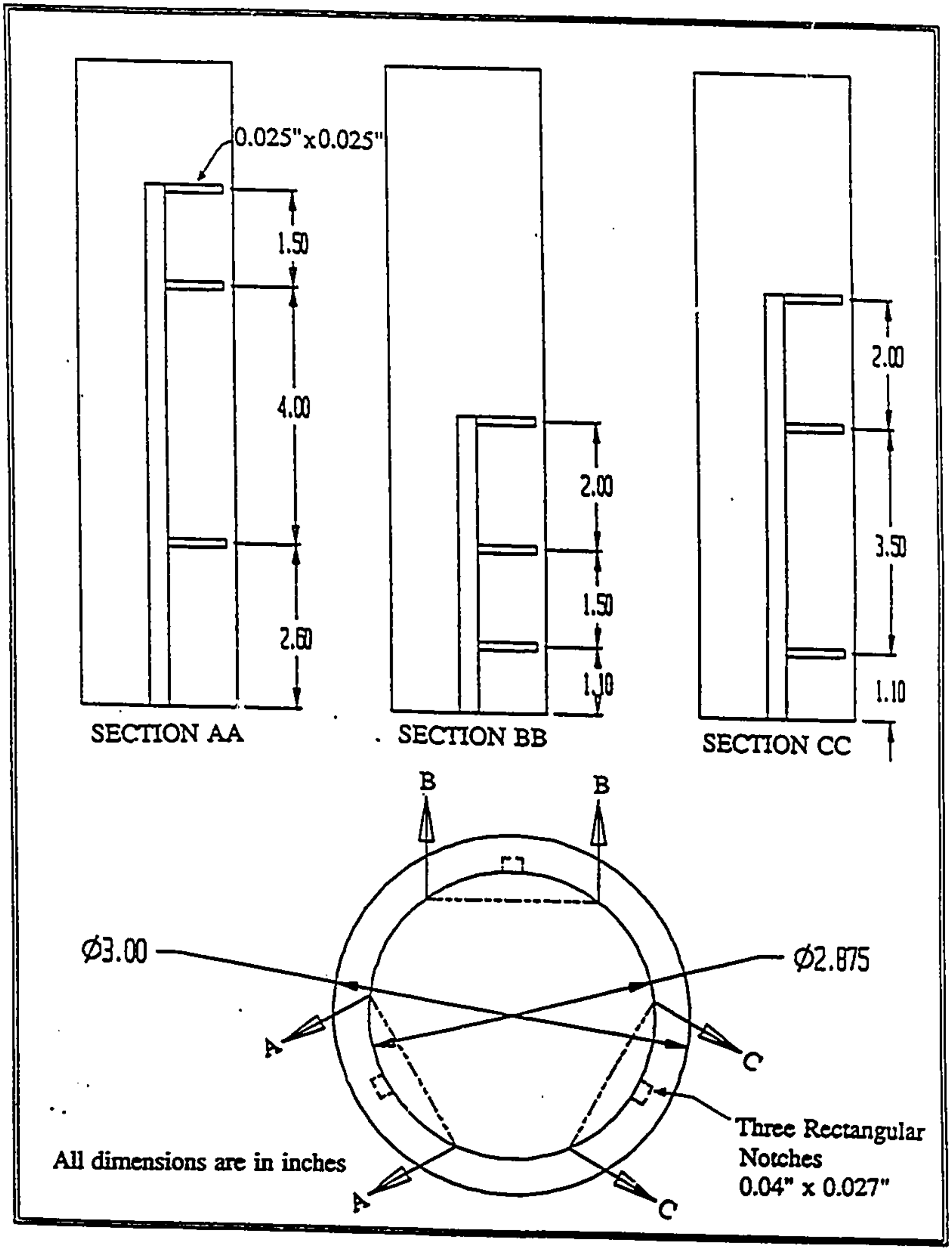


Figure 2.6 Tube For Enclosing Foams

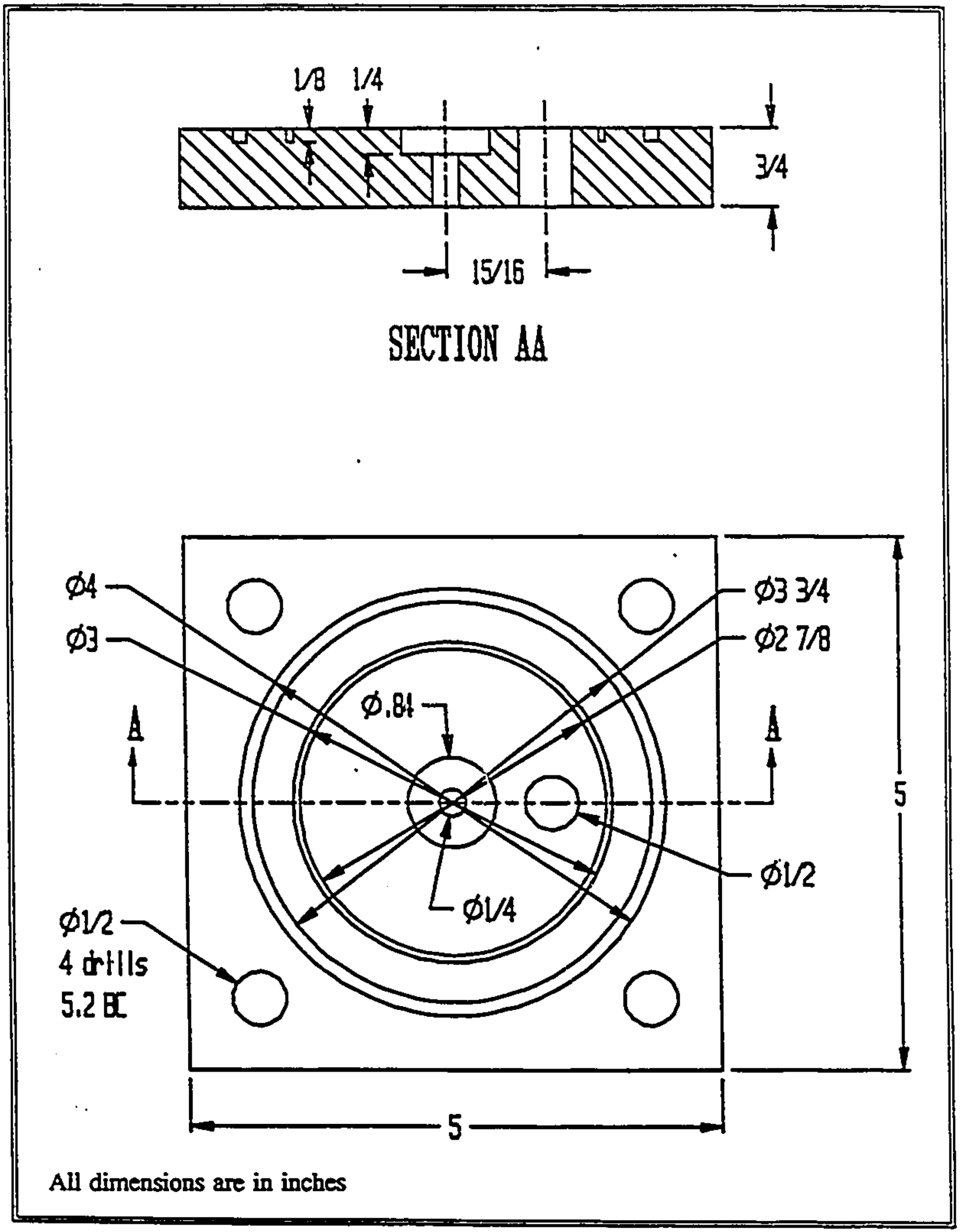


Figure 2.7 Bottom End Cover

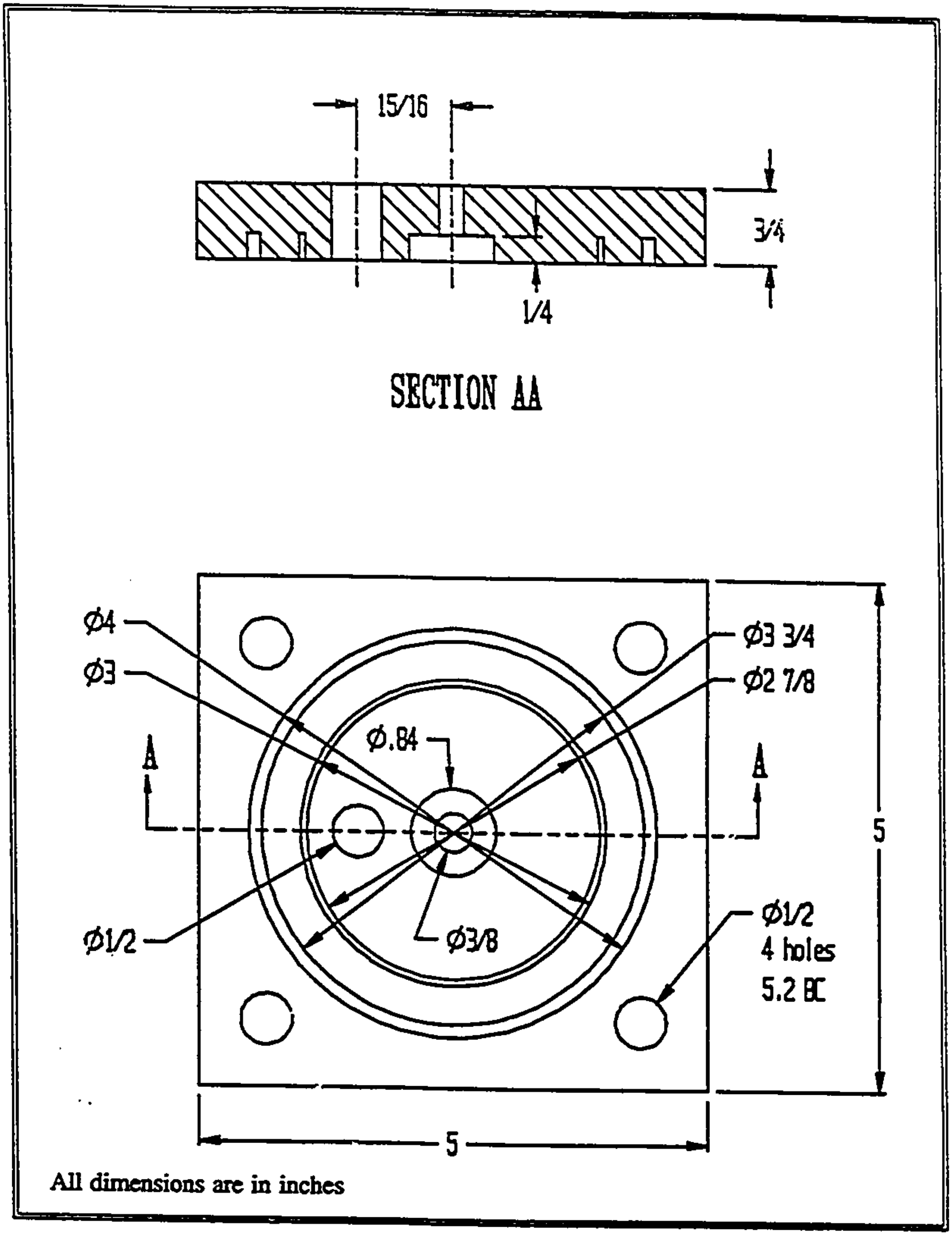
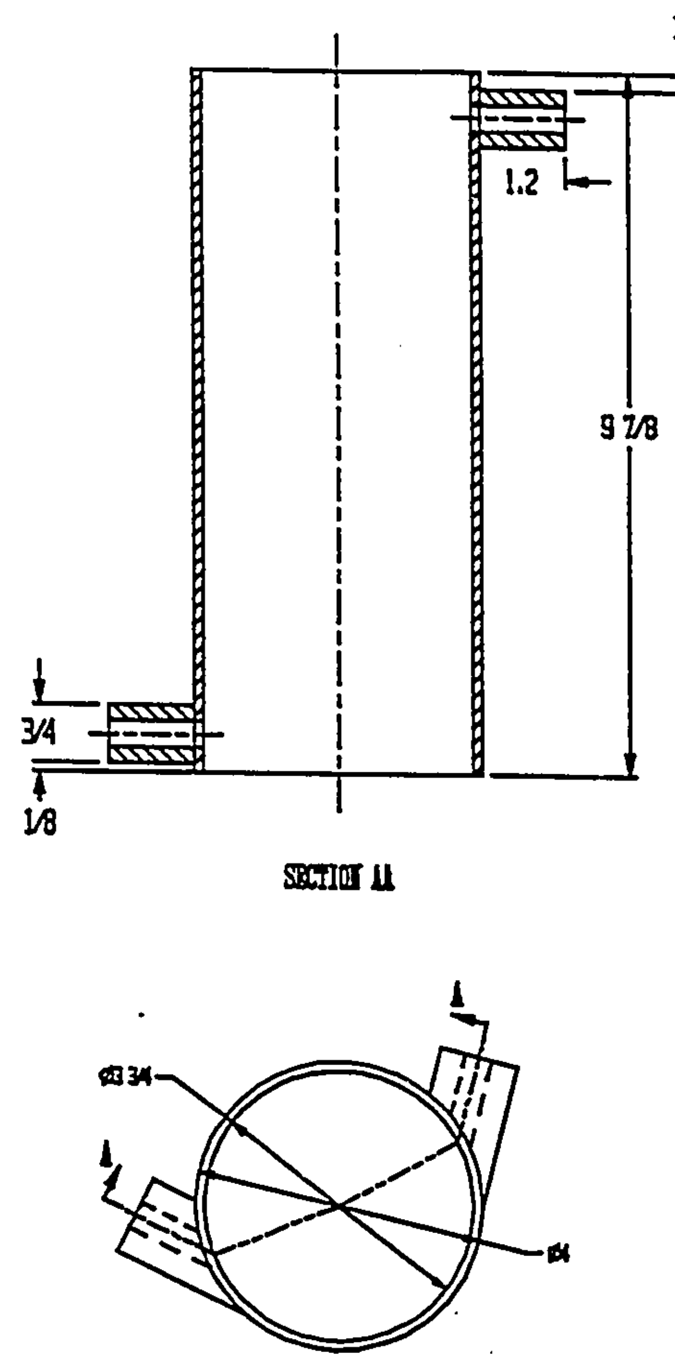


Figure 2.8 Top End Cover

2.1.6 COOLING MECHANISM

Water was used as a cooling medium to remove the energy added in the test section and to maintain the cold surface at the constant temperature. For establishing a stable cooling flow rate at a constant temperature, an Exacal Constant Temperature Bath Circulator model EX - 200 supplied by Acadian Instrument Ltd, Etobicoke Ontario, was used. The water bath allowed the cold surface temperature to be controlled at any desired level between 20 ± 0.01°C to 60 ± 0.01°C.

A cooling chamber, as shown in Figure 2.9, was designed by using a polycarbonate plastic tube of 3.75 in. (95.25 mm) ID, 4.00 in. (101.6 mm) OD and 9.875 in. (250.825 mm) length. The tube was placed concentrically with the tube enclosing the foam. Hence, an annulus of 3/8 in. (9.525 mm) width was obtained for cooling water which was circulated circumferentially and longitudinally. Two 3/8 in. (9.525 mm) diameter holes were drilled near the bottom and the top end of the tube for cooling water entrance and exit. Two thermocouples were placed in the inlet and the outlet of the cooling water to determine if there was any substantial increase in the cooling water temperature, and hence to adjust the cooling water flow rate, if required, to obtain the uniform temperature at the cold surface.



All dimensions are in inches

Figure 2.9 Cooling Chamber

2.1.7 ASSEMBLY

The inner tube for enclosing the foam and the heater sleeve were both cemented and placed on the bottom cover, whereas, the outer polycarbonate tube was tightly fitted in the groove provided on the bottom cover. The cell was sealed after placing the heater inside the sleeve and fitting the top cover. Vacuum grease was used to seal the system.

2.2 DESIGN OF THE RADIATION TEST FACILITY

A schematic of the test facility for the solar transmissivity measurement is shown in Figure 2.10.

The radiation cell was designed so that the foam layer thickness could easily be varied in order to study the relationship between the foam layer thickness and the solar transmissivity. A cross section of the radiation cell is shown in Figure 2.11. The individual components of the radiation cell are described in the following sections.

2.2.1 RADIATION TEST CELL

The radiation test cell was made of a 5 in. MJ neoprene rubber coupling having exact dimensions of 5.5 in. (139.7 mm) ID, 6.2 in. (157.48 mm) OD and 4.0 in. (101.6 mm)

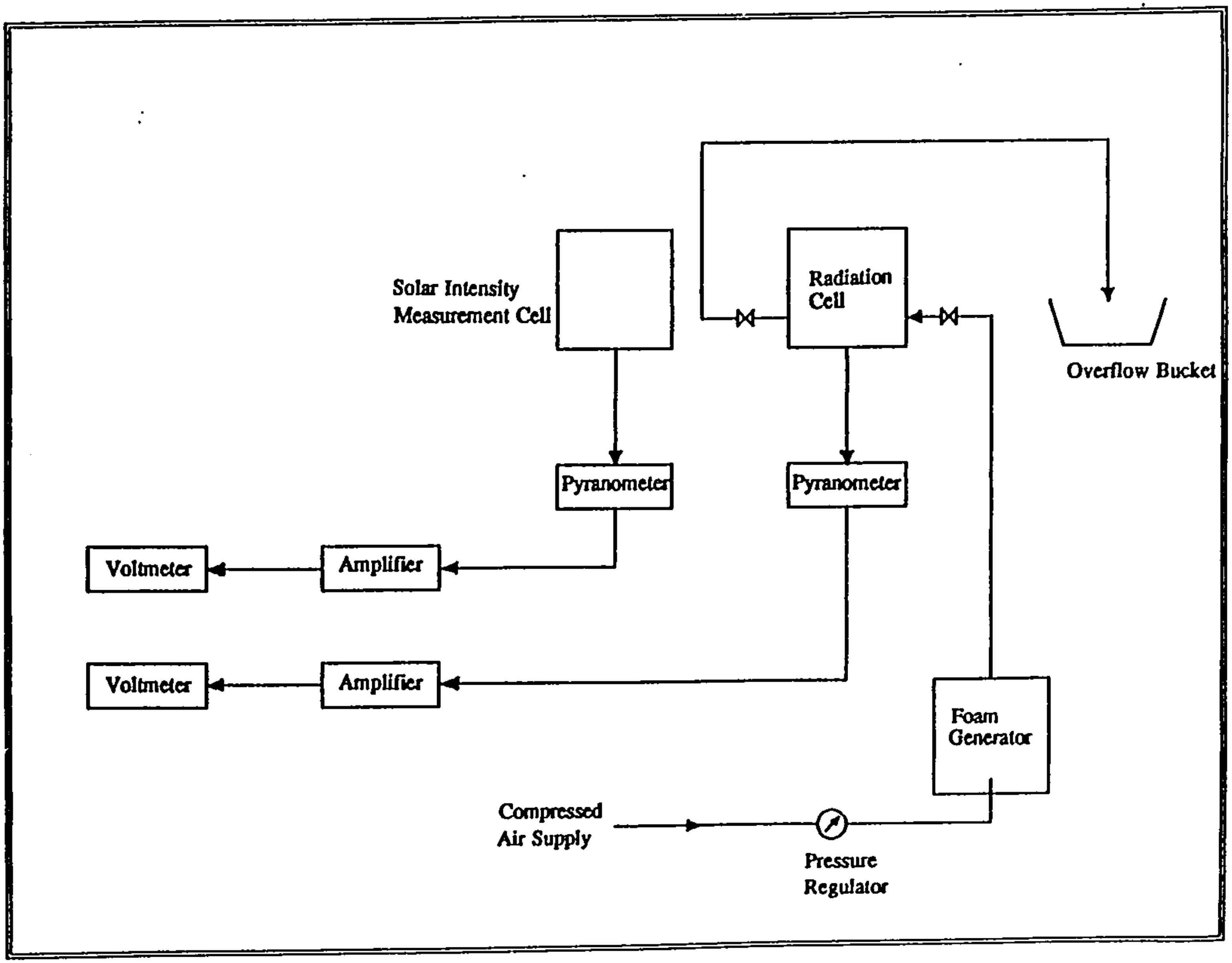


Figure 2.10 **Schematic Of Experimental Test Facility For Transmissivity Measurement**

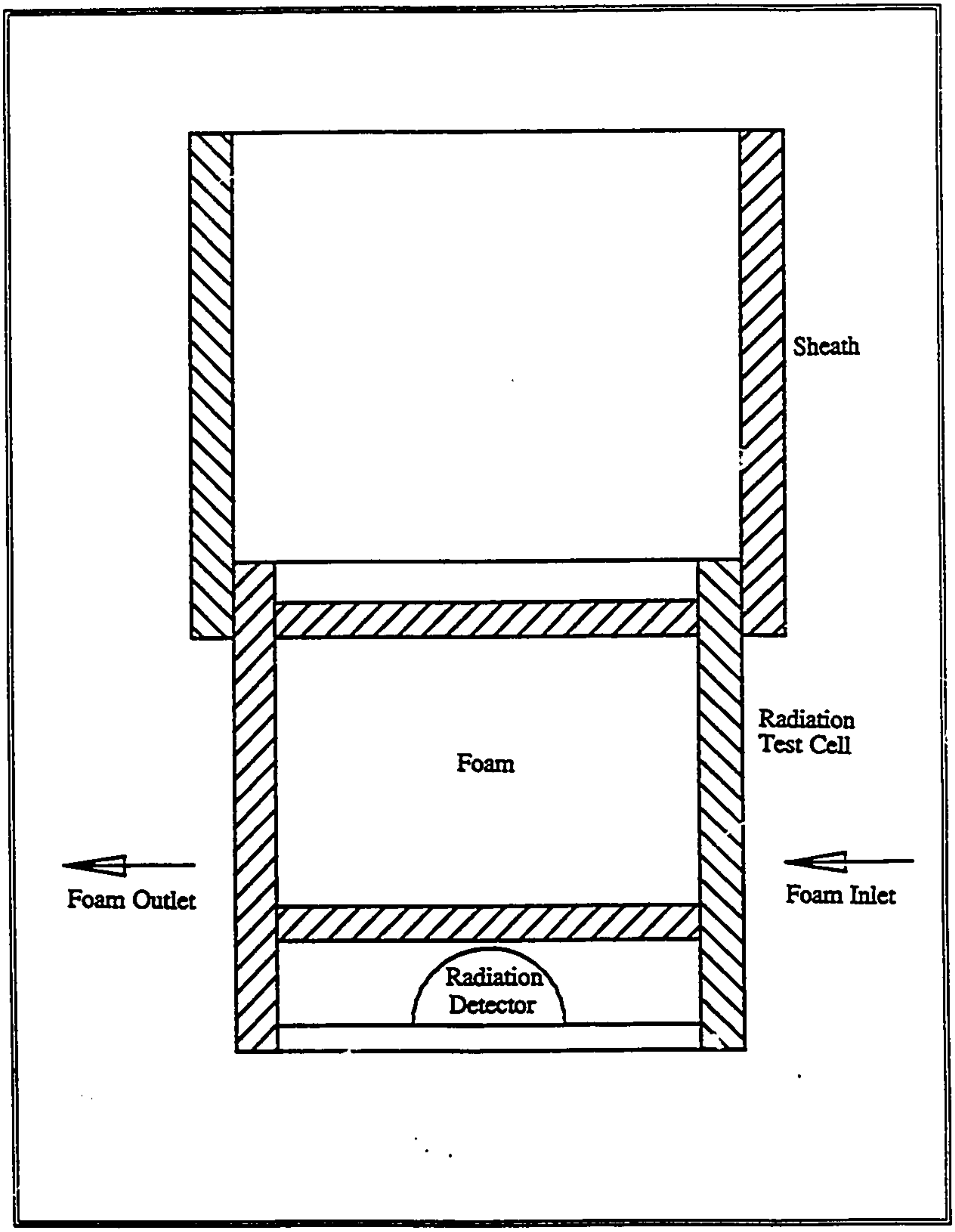


Figure 2.11 Cross Section Of The Radiation Cell With Pyranometer

length as shown in Figure 2.12. Two 0.25 in. (6.35 mm) holes were drilled on the wall of the coupling at a length of 2.75 in. (69.85 mm) from the top for the foam entrance and exit.

The cell was sealed by two plexiglas circular plates of 5.5 in. (139.7 mm) diameter and 0.375 in. (9.525 mm) thickness. The plates were fixed by using clamps. The position of the bottom plate was fixed whereas that of the top plate was varied to achieve the desired layer thickness.

2.2.2 SHEATH FOR THE RADIATION TEST CELL

To meet the requirement that the solar radiation fall on the radiation detector only normally, a sheath was fixed on the top of the radiation test cell. The sheath was made from a 6 in. (152.4 mm) long acrylonitrile-butadiene-styrene (ABS) plastic tube of 6 in. (152.4 mm) ID and 6.75 in. (171.45 mm) OD.

2.2.3 RADIATION DETECTOR

The solar radiation intensity was measured by using an Eppley radiometer/pyranometer supplied by the Eppley Laboratory Inc, Newport, Rhode Island. The radiometer generated a d.c. voltage signal which was amplified by an amplifier and was measured by a Fluke73

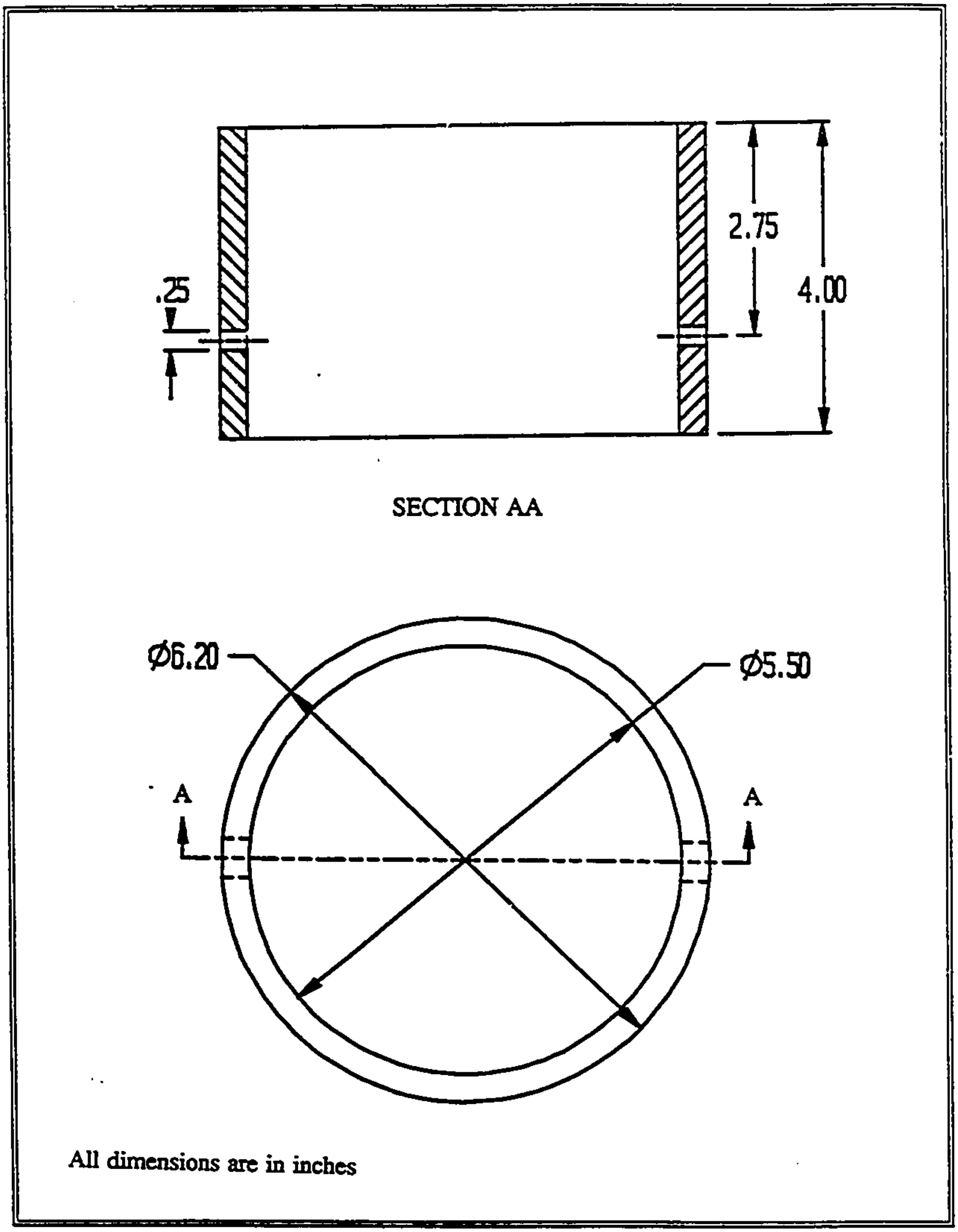


Figure 2.12 Radiation Test Cell

multimeter. The radiation intensity was calculated by using the following expression:

$$I = V / Const \qquad (2.1)$$

where

I = Solar intensity (W/m^2)

V = D.C. voltage signal (V)

Const = Constant for the instrument ($V/W.m^{-2}$)

The value of the constant for the radiation detector used was 10.21 x 10^{-6} $V/W.m^{-2}$ obtained from the manufacturer's catalogue. This value of the calibration constant was checked by comparing the readings of two detectors. These reading were found to agree very well within ±0.5%. Hence, it was concluded that calibration constants for both detectors were valid.

2.2.4 ASSEMBLY OF THE RADIATION CELL

The radiation detector was fixed over a tripod stand with an angular adjustment so that it could be positioned to point at the sun directly during the course of experiments. The sides of the detector were sealed to stop any radiation from these directions. A flange was fixed on the top of the detector to facilitate in mounting the radiation test cell. The radiation test cell was fitted in the groove provided on the top of the radiation detector. A small clearance was kept between the bottom cover of the test cell and the hemisphere glass cover of the detector to avoid any damage to the detector glass. The assembly was completed by fixing the sheath on the test cell.

2.2.5 SOLAR INTENSITY MEASUREMENT CELL

In order to measure the incident solar intensity simultaneously with the reading for the test cell, a solar intensity measurement cell was designed. This cell was composed of a radiation detector over which an ABS plastic sheath of 6 in. (152.4 mm) ID, 6.75 in. (171.45 mm) OD and 9.5 in. (241.3 mm) long was fixed. This cell and the radiation test cell were fixed over the same tripod so that they would point in the same direction. The value of the calibration constant for this detector was 11.06 x 10^{-6} V/W.m^{-2}.

2.3 DESIGN OF THE FOAMING UNIT

The design of the foaming unit depended on the method of foam generation. Hence, a brief description of various methods of foam generation is given below.

2.3.1 METHODS OF FOAM GENERATION

Foams may be generated by two different methods; by condensation and by dispersion [2].

In condensation methods, the future dispersed (or discontinuous) phase originally is present as a solute, that is, as molecules dissolved in the liquid (or continuous phase). Foams are obtained when these molecules combine to larger aggregates. Foams on beer and soft drinks, on boiling liquids and chemical fire-fighting foams are some examples of foams generated by condensation.

In dispersion methods, the future dispersed phase is initially available as a large volume of gas and this is then divided and mixed with the dispersion medium (or continuous phase). Dispersion foams are encountered in laundering, in making mechanical fire-fighting foams and so on. Dispersion methods may be further subdivided as a) agitation methods and b) gas injection methods. In agitation methods, foams are obtained by shaking or whipping a surfactant solution. In injection methods, a gas is injected into the surfactant solution to produce foams.

2.3.2 SELECTION OF A SUITABLE METHOD

The selection of a suitable method of foam generation was based on the following desirable properties:

a. It should produce bubbles which are highly stable.

b. It should produce bubbles of uniform sizes.

c. It should be easily controllable.

d. It should produce bubbles in such a way that they can easily be transferred from the foam generating unit to the test cell.

Some preliminary experiments were conducted to select a suitable method of foam generation and these experiments are described below.

2.3.2.1 Injection Of Compressed Air Through A Single Orifice

Based on the ease of controllability, experiments for foam generation were started by injecting compressed air into the surfactant solution through a single orifice. This method had the advantage that there was no need of a separate mechanism for transferring the foam from the generating unit to the test cell since the compressed air provided the necessary force required to transfer the foam. However, this method produced bubbles of large sizes which were highly unstable. Hence, this method was not suitable for the present study and was rejected.

2.3.2.2 Agitation Methods

The two agitation methods investigated were a) shaking a cylinder partly filled with the liquid and b) stirring the liquid solution using a stirrer. These methods produced bubbles of minute sizes which were relatively more stable. But they required the design of a foam transfer mechanism. Hence, a piston-cylinder arrangement as shown in Figure 2.13 was designed.

2.3.2.3 Injection Of Compressed Air Through Multiple Orifices

In this method, the compressed air was injected into the surfactant solution through multiple orifices using a sintered air stone. The method produced fairly stable, small bubbles of reasonably uniform size which were desirable for the present study. Also, it did not require the use of a separate transfer mechanism. Hence, this method was selected for generating the foam in the present study.

2.3.3 DETAILS OF THE FOAMING UNIT DESIGN

The foaming unit was constructed from a polycarbonate plastic tube of 2.875 in. (73.025 mm) ID, 3.0 in. (76.20 mm) OD, and 5.75 in. (146.05 mm) length. The tube was cemented at the bottom with a 4.0 in. (101.6 mm) square and 0.375 in. (9.525 mm) thick polycarbonate plastic plate. A hole of 0.375 in. (9.525 mm) diameter was drilled at the center of the plate. At the top, a flange was provided to facilitate the sealing of the unit. Figure 2.14 shows the details of the unit. A sintered air stone was fixed at the bottom side of the unit which was connected to the compressed air supply.

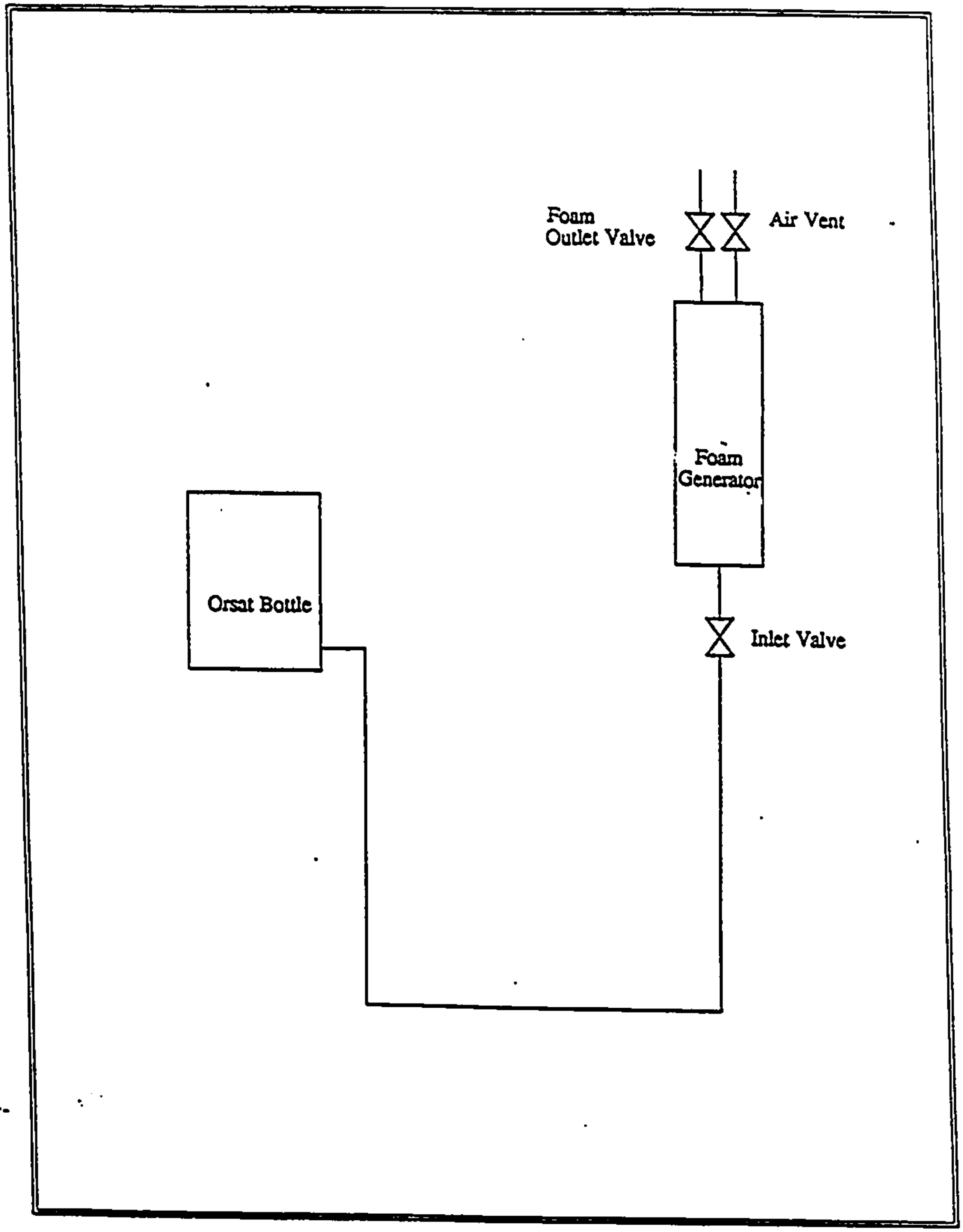
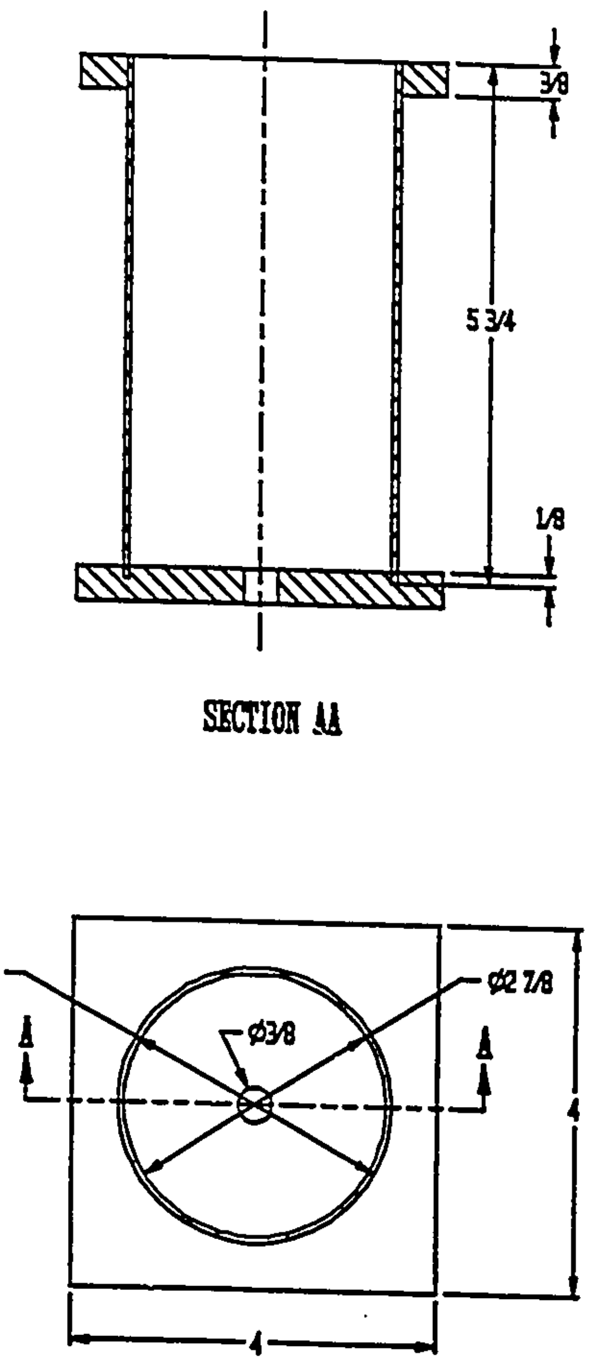


Figure 2.13 Foam Transfer Mechanism For Agitation Methods



All dimensions are in inches

Figure 2.14 Foaming Unit

The unit was sealed by using a 4.0 in. (101.6 mm) square polycarbonate plastic plate as shown in Figure 2.15. The unit was filled with the surfactant solution up to the level of the air stone. Sodium lauryl sulphate solution was used as the surfactant. The end plate was then bolted at the top and the compressed air was supplied through the bottom. Foam, thus generated, was transferred to the thermal conductivity cell through a 0.375 in. (9.525 mm) diameter flexible tubing connecting the foaming unit and the thermal conductivity cell.

2.4 DATA ACQUISITION SYSTEM

A reliable, fast and convenient on-line data analysis method was developed for thermal conductivity measurement using an 8082-A electronic measurement system interfaced with an IBM Turbo-XT computer through a 50 conductor ribbon cable connector. The meaurement system uses a 12 bit-plus-sign, dual-slope integrating A/D converter to convert all voltages to digital words.

A data acquisition program "SCAN" was written in QUICKBASIC for continuous scanning, recording and analysis of the temperatures and power. The program was divided into three modules viz., COMP.BAS, COMPLOGR.BAS, and COMPTOOL.BAS. A listing of all three modules is given in Appendix H.

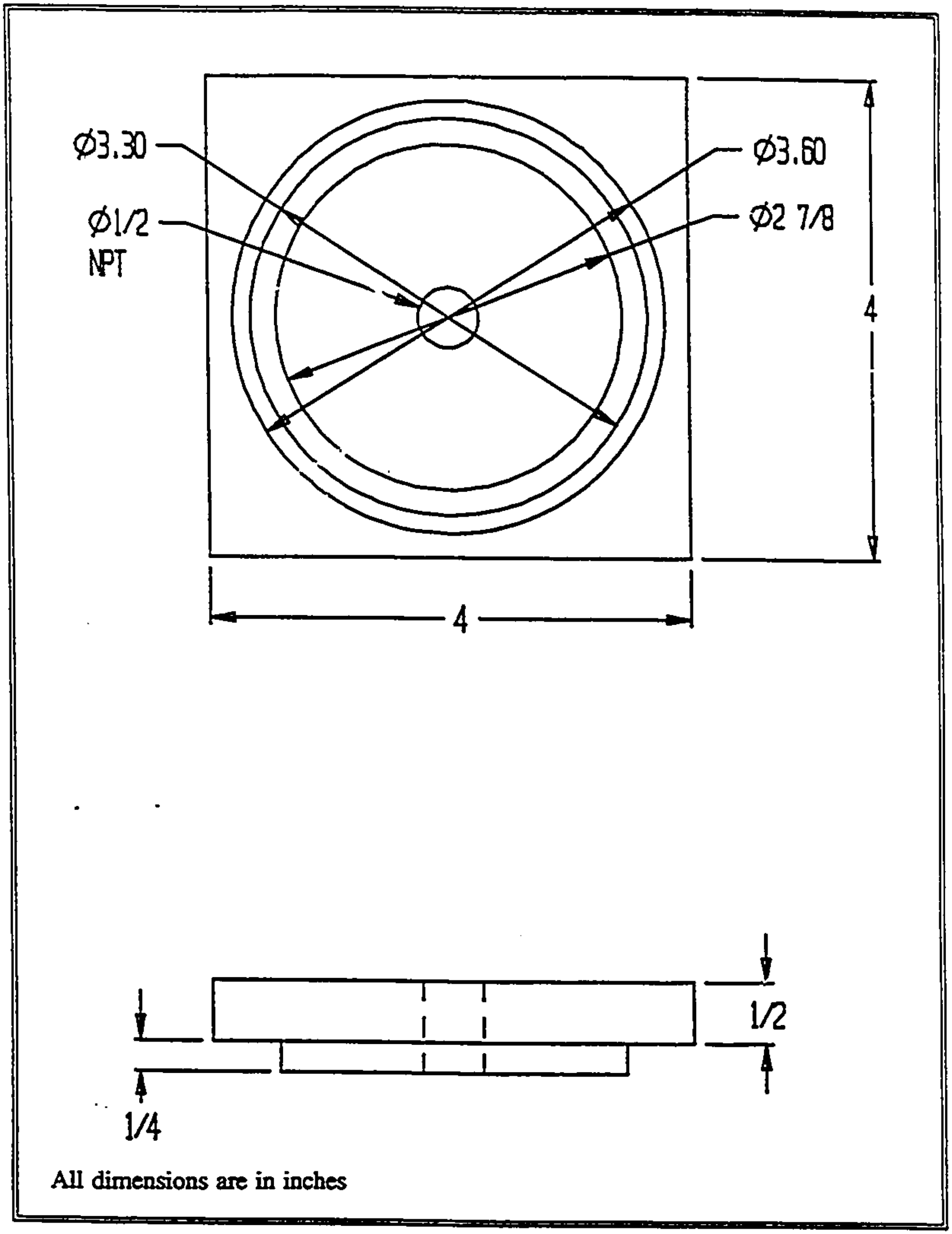


Figure 2.15 Top Cover For Foaming Unit

COMP.BAS was the main module which contained the main program and subroutines for initialization, screen designing, scanning, calculations and producing outputs. The calls to the system subroutines are also made from this module. Special thanks to Mr. Ignacio R. Martin Dominguez for designing the structure of the module and for providing many subroutines for designing screen menus.

The module COMPLOGR.BAS contained system subroutines designed to interface with the electronic measurement system. These subroutines were taken from Level1-QUICKBASIC software, version 3.0, supplied by Sciemetric Instrument Inc. For detailed description of these subroutines, please refer to [8]. The module COMPTOOL.BAS contained some useful subroutines for providing data manipulation.

The program calculates the power to the heater by using the following correlation, which was obtained by calibrating a specially designed rectifier circuit:

$$Q = 0.40867 + 3.28535\, V_{sig} + 0.81020\, V_{sig}^{2} + 1.21878\, V_{sig}^{2.5} - 0.14001\, V_{sig}^{3.5} \tag{2.2}$$

where V_{sig} is the d.c. voltage signal generated by the rectifier circuit and measured by the data logger. The circuit diagram of the system is shown in Figure 2.16 and its calibration details are described in Appendix A.

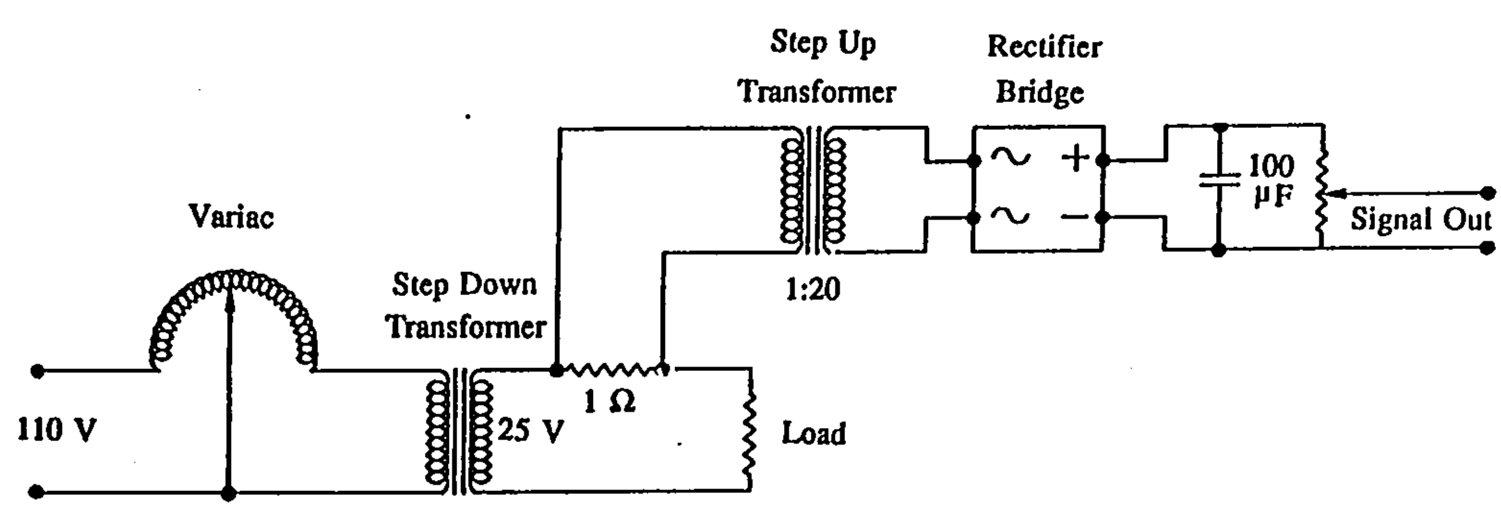


Figure 2.16 **Circuit Diagram For Power Measuring System**

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 PREPARATION OF THE SURFACTANT SOLUTION

A known mass of sodium lauryl sulphate was mixed with a known mass of water. The solution was then stirred to produce a homogeneous solution.

3.2 TESTING PROCEDURE

3.2.1 THERMAL CONDUCTIVITY MEASUREMENT

The following procedure was followed during the course of experimental runs.

1. The foaming unit was filled with the surfactant solution approximately 12 mm above the level of the air stone.

2. The temperature control for the water bath was set to achieve the desired cooling surface temperature. The constant temperature water circulation was turned on and the cooling water circulation rate for the water bath was set.
3. The desired power supply to the heater was obtained by setting the input voltage using a Variac.
4. The data logger was turned on.
5. The computer was turned on and the data acquisition program was loaded.
6. Foam inlet and outlet valves were opened.
7. The valve for the compressed air supply was opened and air was injected into the solution at a pressure of approximately 4500 N/m^2.
8. When the conductivity cell was completely filled with the foam, the air supply valve was closed.
9. The program was run to monitor temperatures until steady state conditions were reached.
10. Complete data were recorded on the disk when the steady state conditions were achieved.

Since the foam is quite an unstable substance and does not last very long, hence, to achieve steady state conditions in short time, the heater was preheated before injecting the foam inside the conductivity cell. For each set of readings, at least 3 runs were required. The initial run for each set was used to observe the response of bubbles and to obtain a rough idea of the true value of the thermal conductivity. This rough value helped in preheating the heater. During all successive runs, the foam inlet valve was opened to supply foam at a very low rate to the thermal conductivity cell. This was necessary to compensate for the foam drainage.

3.2.2 SOLAR TRANSMISSIVITY MEASUREMENT

The following procedure was followed during the course of experimental runs.

1. The top plexiglas plate in the radiation cell was adjusted to achieve the desired layer thickness and the radiation cell was placed over the pyranometer.
2. The stand over which the radiation cell and the solar intensity measurement cell were mounted was adjusted so that both pyranometers pointed directly at the sun.
3. The amplifiers were turned on.
4. Simultaneous readings from both voltmeters were taken which were subsequently used to calculate the solar transmissivity of the air layer enclosed between the plexiglas plates.
5. The foaming unit was filled with the surfactant solution approximately 12 mm above the level of the air stone.
6. Foam inlet and outlet valves were opened.
7. The valve for the compressed air supply was opened and air was injected into the solution at a pressure of approximately 4500 N/m^2.

8. When the radiation cell was completely filled with the foam, the air supply valve was closed.
9. Following steps 2 and 3, simultaneous readings from both voltmeters were taken which were subsequently used to calculate the transmissivity of the foam layer.

3.3 CALCULATION PROCEDURE

3.3.1 THERMAL CONDUCTIVITY TESTS

The thermal conductivity of the foam k was determined by using Fourier's Law of heat conduction for two concentric cylinders:

$$Q = \frac{2 \pi k L (T_{hot} - T_{cold})}{\ln\left(\frac{D_2}{D_1}\right)}$$

or

$$k = \frac{Q \ln\left(\frac{D_2}{D_1}\right)}{2 \pi L (T_{hot} - T_{cold})} \tag{3.1}$$

where

Q Heat Power Input

D_1 Diameter of the Hot Surface

D_2 Diameter of the Cold Surface

L Length of the Heater Surface

T_{hot} Average Temperature of the Hot Surface

T_{cold} Average Temperature of the Cold Surface

T_{hot} was found by the weighted average of the readings of 21 thermocouples evenly located on the heater sleeve:

$$T_{hot} = \frac{1}{21} \sum_{i=1}^{21} T_i \tag{3.2}$$

where T_i is the reading of the ith thermocouple.

Similarly, T_{cold} was found by the weighted average oı the readings of 9 thermocouples located on the cold surface:

$$T_{cold} = 0.2\ T_{22} + \sum_{i=23}^{30} 0.1\ T_i \tag{3.3}$$

Here T_{22} was given a double weight since at that location, only one thermocouple was used to measure the temperature whereas for other locations, the average of two thermocouple readings was used to measure the temperature.

3.3.2 SOLAR TRANSMISSIVITY TESTS

The solar transmissivity of the foam was found by dividing the radiation energy transmitted through the foam by the total radiation incident upon it.

3.4 POST PROCESSING OF DATA

Although, the data acquisition program was capable of doing all the calculations, in order to improve the processing speed, the data was post processed by using an IBM 80386 computer.

The program generated data in ASCII text file which were imported in QuattroPro for processing. A macro was written in QuattroPro which performed the desired calculations and presented the results. QuattroPro was also used to post process the radiation data.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 THERMAL CONDUCTIVITY TESTS

4.1.1 INTRODUCTION

The effects of three parameters, viz., solute concentration, temperature difference, and the mean temperature, on the thermal conductivity were investigated. To ensure repeatability, results were compiled by carrying out about 55 runs for 15 different sets of parameter combinations by varying the parameters one by one. These results are given in tabular form in Appendix Tables G1 - G15, and are discussed in the following sections. For each experimental run, the average values of ten readings of temperatures and power were used for the calculation of the thermal conductivity.

The results show that the value of the thermal conductivity of foam at a room temperature of 25°C, a temperature difference of 10°C and any solute concentration is 0.199 ± 0.011 W/m.°C. The effects of various parameters on the value of the thermal conductivity are discussed in the following sections. An uncertainty analysis, described in Appendix B, was done to find the uncertainty for each test.

4.1.2 EFFECT OF SOLUTE CONCENTRATION

Since the solute concentration has an effect on the surface tension of the solution (Appendix C), it was considered as one of the parameters on which the thermal conductivity of liquid foam may depend. Hence, to study its effects, experiments were carried out for various solute concentrations. All the experiments were conducted at a mean temperature of approximately 25°C with a temperature difference of approximately 10°C. The results of these experiments are given in Table 4.1. Solute concentration is expressed as grams of the solute (i.e. sodium lauryl sulphate) in 1000 grams of water. The detailed results for each run are given in Appendix G.

In Figure 4.1, the thermal conductivity is plotted against the solute concentration. The figure shows that there is no appreciable effect of solute concentration on the thermal conductivity of foam. The slight variations in the value of the thermal conductivity fall within the confidence limits of the data. This suggests that the thermal conductivity of foam is independent of the solute concentration over the range tested.

TABLE 4.1 EFFECT OF SOLUTE CONCENTRATION

Set #	Solute Concentration (gm/1000 gm Water)	Thermal Conductivity (W/m.°C)	Uncertainty (W/m.°C)	T_{mean} (°C)	Temp Difference (°C)
1	1	0.198	0.011 (5.69%)	25.48	10.48
2	2	0.193	0.011 (5.69%)	25.37	10.65
3	4	0.199	0.011 (5.69%)	25.25	10.15
4	6	0.197	0.011 (5.69%)	24.80	9.61
5	8	0.205	0.012 (5.69%)	24.71	9.14

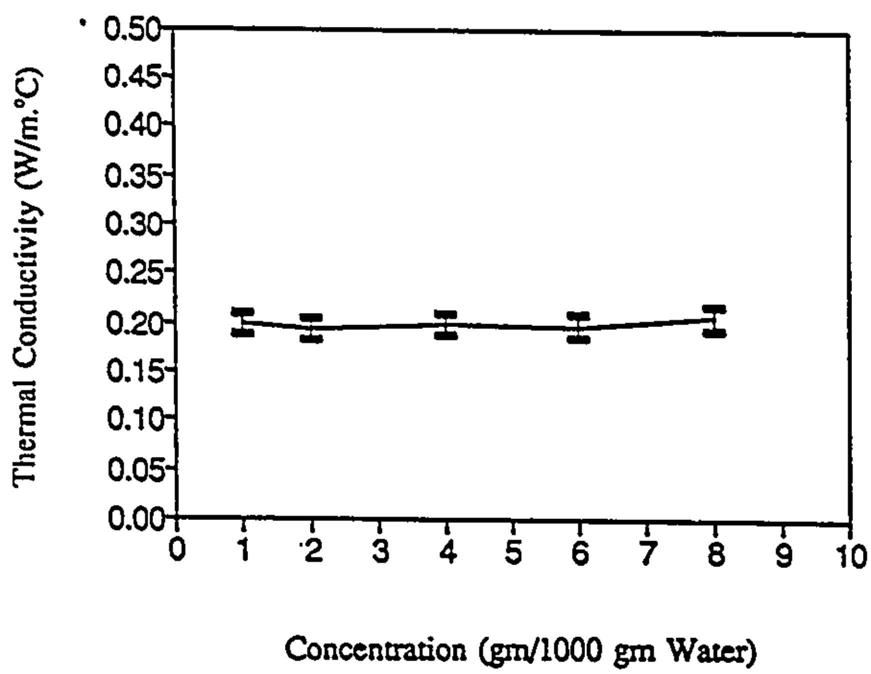


Figure 4.1 Effect Of Solute Concentration

4.1.3 EFFECT OF TEMPERATURE DIFFERENCE

To investigate the effect of temperature difference on the thermal conductivity of foam, experiments were conducted by varying the temperature differences. All experiments were carried out at a fixed mean temperature of approximately 40°C. Table 4.2 shows the results of these experiments. The detailed results of each set are given in Appendix G. The smallest temperature difference selected was based on the fact that it could be determined with a reasonable accuracy, since, as the temperature difference becomes small, the percent error in its estimation becomes large. The largest temperature difference selected was governed by the condition that the foam should remain intact until steady state conditions were reached. For a temperature difference larger than 20°C, it became increasingly difficult to achieve this criterion due to foam breakdown.

The results of these experiments are plotted in Figure 4.2. The figure shows that the value of the thermal conductivity decreases with an increase in the temperature difference. The reason for this decrease is that as the temperature difference increases, foam moves away from the hot surface at a fast rate. Besides, at high temperature, the rate of foam drainage increases [2] and hence the foam ratio changes with an increase in the air content. Since air has more resistance to the heat flux, therefore, the thermal conductivity decreases.

TABLE 4.2 EFFECT OF TEMPERATURE DIFFERENCE

Solution Concentration : 4 gm Sodium Lauryl Sulphate / 1000 gm Water

Set #	Temperature Difference (°C)	Thermal Conductivity (W/m.°C)	Uncertainty (W/m.°C)	T_{mean} (°C)
6	9.02	0.335	0.019 (5.69%)	39.71
7	12.27	0.308	0.017 (5.69%)	40.49
8	16.07	0.281	0.016 (5.69%)	40.51
9	20.52	0.254	0.014 (5.69%)	40.13
10	25.12	0.236	0.013 (5.69%)	40.20
11	29.76	0.226	0.013 (5.69%)	40.35

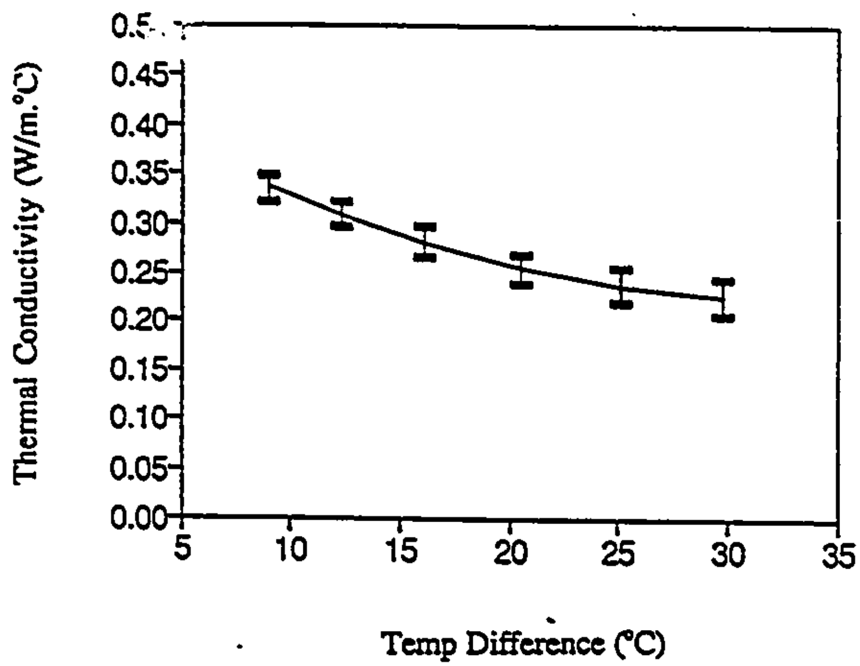


Figure 4.2 Effect Of Temperature Difference

One of the secondary objectives of this study was to qualitatively investigate the response of the bubbles when subjected to a temperature gradient. This objective was also fulfilled during these sets of experiments. It was observed that bubbles move away from the hot surface with time when subjected to a temperature gradient with an average speed of the order of 0.5 mm/sec. The rate of movement increases with an increase in the temperature gradient.

4.1.4 EFFECT OF MEAN TEMPERATURE VARIATION

In order to study the effect of the mean temperature on the thermal conductivity of foam, experiments were conducted by varying the mean temperature. In all these experiments, the temperature difference was kept constant at about 10°C and the solute concentration was 4 gm of sodium lauryl sulphate per 1000 gm of water. The selection of this temperature difference was based on the fact that it was close to the future intended application of the foam. The range of the mean temperatures selected was based on the ease of maintaining the cold surface temperature constant. The results of these experiments are shown in Table 4.3 and are plotted in Figure 4.3.

Figure 4.3 reveals that the thermal conductivity of foam increases with an increase in the mean temperature. The reason for this increase is that the thermal conductivities of air and liquid constituting the foam increase with an increase in the mean temperature [12]

TABLE 4.3 EFFECT OF MEAN TEMPERATURE VARIATION

Solution Concentration : 4 gm Sodium Lauryl Sulphate / 1000 gm Water

Set #	T_{mean} (°C)	Thermal Conductivity (W/m.°C)	Uncertainty (W/m.°C)	Temperature Difference (°C)
3	25.25	0.199	0.011 (5.69%)	10.15
12	29.88	0.212	0.012 (5.69%)	9.71
13	35.17	0.276	0.016 (5.69%)	10.25
6	39.71	0.335	0.019 (5.69%)	9.02
14	44.91	0.399	0.023 (5.69%)	9.33
15	49.11	0.436	0.025 (5.70%)	9.70

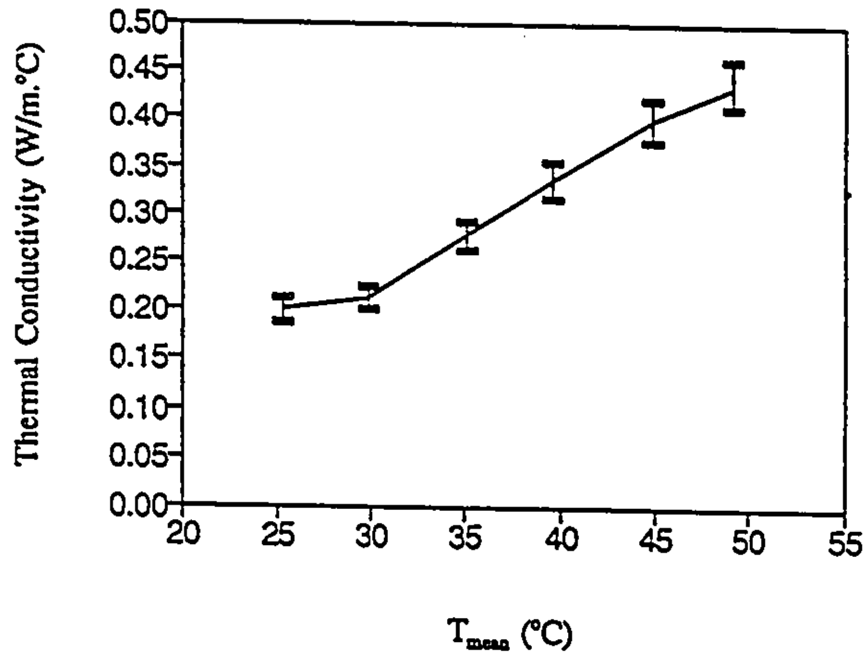


Figure 4.3 Effect Of Mean Temperature

and hence results in an increase of the thermal conductivity of the foam. This increase in the thermal conductivity is further supported by an increase in the natural convection and the radiation effects at higher temperatures. There is also a decreasing effect on the thermal conductivity with an increase in the mean temperature caused by a higher drainage rate and hence a higher foam ratio. However, this decreasing effect is less dominant than the increasing effect. Hence the overall effect is an increase in the thermal conductivity with an increase in temperature.

4.2 RADIATION TESTS

4.2.1 INTRODUCTION

Radiation tests were carried out to determine the total solar transmissivity of foam and a correlation between its transmissivity and the layer thickness. The results are discussed in the following sections. For each experimental run, the average values of five readings of the d.c. voltage signal were used for the calculation of the solar transmissivity.

To ensure the same readings from both the radiation test cell and the solar intensity measurement cell, the reading of the solar intensity measurement cell was compared with that of the radiation test cell and both readings were found to agree very well.

4.2.2 SOLAR TRANSMISSIVITY

The solar transmissivity of foam was found by modelling the plexiglas and foam as grey materials. The assumption of using a grey body model for plexiglas was verified by running experiments with a single and a double plexiglas plate arrangements. From these experiments, it was found that the transmissivity of a double plate arrangement was equal to the square of the value of transmissivity for a single plate arrangement.

Table 4.4 shows the results of transmissivity tests. The results reveal that the solar transmissivity of liquid foam decreases rapidly with an increase in the layer thickness. For a layer thickness of 1.0 in.(25.4 mm), its transmissivity was found to be 0.464.

4.2.3 CORRELATION BETWEEN TRANSMISSIVITY AND THE THICKNESS

To determine the correlation between the foam's transmissivity and its layer thickness, its transmissivity was found for various layer thicknesses (see Table 4.4). All these experiments were conducted at a temperature of 25°C and a pressure of 1 atmosphere (1.01325×10^5 N/m^2). By using the method of least squares, the following correlation was found between the transmissivity and the layer thickness:

$$\tau = \exp(-31.78\, X) \tag{4.1}$$

TABLE 4.4 SOLAR TRANSMISSIVITY OF LIQUID FOAM

Air / Foam Layer Thickness	AIR			FOAM			Transmissivity	Uncertainty
	Incident Radiation I_1 (W/m^2)	Transmitted Radiation I_2 (W/m^2)	τ_1[1] (I_2/I_1)	Incident Radiation I_1 (W/m^2)	Transmitted Radiation I_2 (W/m^2)	τ_2[2] (I_2/I_1)	τ_{foam} (τ_2/τ_{1avg})	$\delta\tau_{foam}$
(mm)								
25.4 (1.0")	719.71	587.66	0.817	723.33	274.24	0.379	0.464	0.026 (5.64%)
33.02 (1.3")	692.59	564.15	0.815	719.71	235.06	0.327	0.400	0.025 (6.24%)
40.64 (1.6")	714.29	581.78	0.814	717.90	150.83	0.210	0.257	0.022 (8.74%)
50.8 (2.0")	719.71	591.58	0.822	714.29	117.53	0.165	0.202	0.020 (9.79%)
63.5 (2.5")	705.24	577.86	0.819	719.71	80.31	0.112	0.137	0.020 (14.28%)

[1] τ_1 is the transmissivity of the air layer enclosed between two plexiglas plates, each of 0.375 in. (9.525 mm) thick.
[2] τ_2 is the transmissivity of the foam layer enclosed between two plexiglas plates, each of 0.375 in. (9.525 mm) thick.

where

$$X = \text{Layer Thickness (m)}$$

The constant 31.78 is called the extinction coefficient, which is a property of the material and has units of reciprocal length. This value of the constant is independent of the wavelength of the incident radiation since foam was modelled as a grey gas [14].

The transmissivity is plotted as a function of the layer thickness in Figure 4.4. The continuous line in the figure is the plot of Equation (4.1). The figure shows that the proposed expression models the foam transmissivity very well with an average difference of 5.55% with the experimental values.

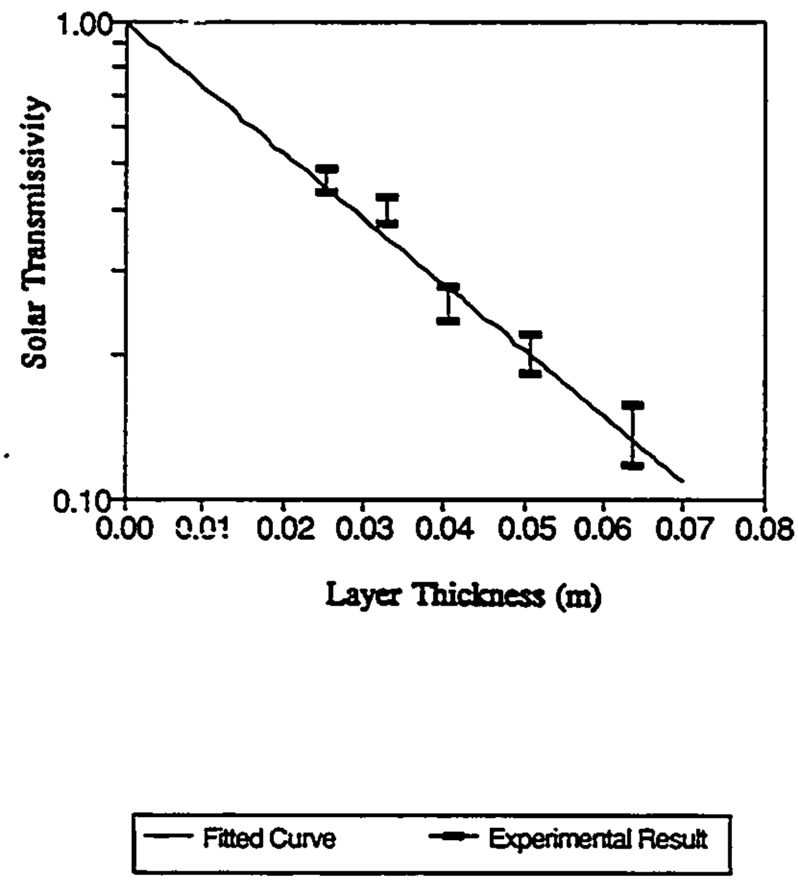


Figure 4.4 Effect Of Layer Thickness On Solar Transmissivity

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONTRIBUTION OF THE PRESENT STUDY

The thermal conductivity and the total solar transmissivity of liquid foam were investigated and reported for the first time. The design and commissioning of the experimental setup for such investigation are described. An online data acquisition program was developed in QUICKBASIC for IBM personal computers for continuous scanning and analysis of the data.

The results reported and described in chapter IV indicate that the thermal conductivity of liquid foam is quite high and foam is not as good an insulator as air. At a room temperature of approximately 25°C, its thermal conductivity was found to be 1.86 times higher than that of an air layer of equal thickness, when both molecular conductivity and the natural convection are considered in the air layer (Appendix F).

The effects of three parameters, viz., the solute concentration, the temperature difference and the temperature, on the thermal conductivity were investigated and the results lead to the following conclusions:

1. The thermal conductivity of the foam is independent of the solute concentration of the solution.
2. The thermal conductivity of the foam decreases with an increase in the temperature difference. This decrease is due to an increase in the foam ratio (more air content) and due to a higher migration rate of the foam from the hot surface.
3. There is a rapid increase in the thermal conductivity with an increase in the mean temperature. This increase in partly due to an increase in the thermal conductivities of liquid and air constituting the foam and partly due to increase in the natural convection and the radiation effect.

The results of the radiation tests reveal that the solar transmissivity of liquid foam is very low and its value decreases exponentially with an increase in the layer thickness. For a layer thickness of 1.0 in. (25.4 mm), the attenuation of radiation is approximately 55.6%.

An uncertainty analysis showed that the values of the thermal conductivities and the solar transmissivities had uncertainties of approximately 5.7% and 8.9% respectively.

5.2 RECOMMENDATIONS FOR FUTURE WORK

1. The major difficulty in the present study was the generation of stable bubbles. Hence future investigations should be carried out by adding some additives in the surfactant solution which can stabilize the film layers around bubbles.
2. The effect of the bubble size on the thermal conductivity and the solar transmissivity should be investigated. This will require a means of generating bubbles of different sizes. During the course of the present study, attempts were made to vary the size of bubbles by the use of some fine size screens. However, these attempts were not very successful since they produced highly unstable and nonuniform size bubbles. This problem may possibly be overcome by the use of certain additives.
3. The uncertainty analysis indicates that the major source of error in the estimation of the thermal conductivity was the measurement of input heat power. It should be noted that the power requirements in this study are very low and analog wattmeters are not very

accurate for the measurement of such a low power. However, the accuracy can be improved by employing a specially designed more accurate power measuring device.

4. The accuracy of the radiation tests can be improved by using a more sensitive radiation detector.

5. Future studies should be carried out to find the solar transmissivities in the spectrum of visible light and infrared radiation.

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APPENDIX A

CALIBRATION OF THE POWER MEASURING SYSTEM

The power measuring system, as shown in Figure 2.16, was calibrated by using two Fluke-73 multimeters and a standard 1Ω resistor. The calibration was done by loading the system in both forward and reverse directions. The system was calibrated in the power range from 0.5W to 17.5W which adequately covers the power range in the present study.

The power was varied by changing the input voltage by using a Varic transformer. The current was calculated by measuring the voltage drop across the standard 1Ω resistor using Ohm's law. Then, by measuring the voltage drop across the heater, power was calculated by using the following expression

$$Q = V_{heater}\ I \tag{A.1}$$

where

Q = Electrical Power (W)

V_{heater} = Voltage Drop across the Heater (V)

I = Electrical Current (A)

and

$$I = \frac{V_{resist}}{R} \tag{A.2}$$

where

V_{resist} = Voltage Drop across the known Resistor (V)

R = Resistance of the known Resistor (Ω)

Hence, Equation (A.1) becomes

$$Q = V_{heater}\ \frac{V_{resist}}{R} \tag{A.3}$$

Corresponding to each Variac setting, the rectifier circuit generated a d.c. voltage signal which was measured by the data logger. For each setting, twenty readings of voltage signals were taken which were then averaged out. The results of the calibration test are given in Table A.1.

By applying the method of least squares, the power and the voltage signal were correlated by the following expression

$$Q = 0.40867 + 3.28535\ V_{sig} + 0.81020\ V_{sig}^{2} + 1.21878\ V_{sig}^{2.5} - 0.14001\ V_{sig}^{3.5} \qquad \text{(A.4)}$$

The error between the measured power and the estimated power by using Equation (A.4) at each data point is given in Table A.2 and is shown graphically in Fig A.1. The figure shows that the correlation equation relates the data very well with an average error of 0.47% and a maximum error of 1.52%. The uncertainty analysis described in Appendix B2 shows that the equation estimates the power with an average accuracy of 5.59%.

TABLE A-1 CALIBRATION DATA

V_{resist} (V)	V_{heater} (V)	Power (W)	Signal (V)	V_{resist} (V)	V_{heater} (V)	Power (W)	Signal (V)
0.2000	2.9300	0.586	0.052	0.6500	9.4600	6.149	1.074
0.1990	2.9100	0.579	0.054	0.6755	9.7950	6.617	1.133
0.2260	3.3050	0.747	0.096	0.6760	9.8550	6.662	1.138
0.2260	3.3010	0.746	0.100	0.7005	10.1950	7.142	1.196
0.2480	3.6300	0.900	0.139	0.7025	10.2000	7.166	1.199
0.2505	3.6600	0.917	0.148	0.7235	10.4750	7.579	1.250
0.2740	4.0000	1.096	0.189	0.7255	10.5650	7.665	1.256
0.2735	3.9950	1.093	0.196	0.7515	10.9050	8.195	1.318
0.3027	4.4200	1.338	0.251	0.7520	10.9600	8.242	1.321
0.3030	4.4200	1.339	0.259	0.7745	11.2350	8.702	1.373
0.3250	4.7400	1.541	0.301	0.7755	11.2950	8.759	1.378
0.3268	4.7700	1.559	0.312	0.8005	11.6250	9.306	1.436
0.3500	5.1050	1.787	0.357	0.8012	11.6780	9.356	1.439
0.3525	5.1450	1.814	0.371	0.8265	12.0050	9.922	1.501
0.3780	5.5150	2.085	0.422	0.8278	12.0400	9.967	1.504
0.3770	5.4970	2.072	0.427	0.8500	12.3650	10.510	1.557
0.4010	5.8500	2.346	0.475	0.8510	12.3650	10.523	1.558
0.4015	5.8590	2.352	0.486	0.8760	12.7630	11.180	1.615
0.4238	6.1750	2.617	0.528	0.8765	12.7500	11.175	1.623
0.4237	6.1800	2.618	0.537	0.9000	13.0600	11.754	1.675
0.4480	6.5300	2.925	0.585	0.9040	13.1700	11.906	1.683
0.4482	6.5410	2.952	0.593	0.9020	13.1150	11.830	1.685
0.4750	6.9200	3.287	0.648	0.9250	13.4750	12.464	1.734
0.4742	6.9120	3.278	0.655	0.9285	13.5100	12.544	1.749
0.5020	7.3200	3.675	0.712	0.9520	13.8650	13.199	1.799
0.4995	7.2850	3.639	0.715	0.9528	13.8650	13.211	1.808
0.5260	7.6700	4.034	0.769	0.9740	14.1950	13.826	1.854
0.5272	7.6850	4.052	0.781	0.9765	14.2100	13.876	1.866
0.5502	8.0210	4.413	0.828	0.9998	14.5550	14.552	1.925
0.5495	8.0100	4.401	0.834	1.0275	14.9650	15.377	1.983
0.5745	8.3350	4.788	0.891	1.0265	14.9450	15.341	1.988
0.5745	8.3700	4.809	0.893	1.0478	15.2550	15.984	2.039
0.6008	8.7180	5.238	0.954	1.0560	15.3800	16.241	2.053
0.6015	8.7650	5.272	0.958	1.0750	15.6650	16.840	2.102
0.6265	9.0700	5.682	1.013	1.0775	15.6750	16.890	2.110
0.6265	9.1250	5.717	1.017	1.0980	15.9750	17.541	2.159
0.6498	9.4150	6.118	1.071	1.1000	16.0280	17.631	2.163

TABLE A-2 CALIBRATION DATA AND CURVE FITTING ERROR

Signal (V)	Power (W)	Power est (W)	Fit Error (%)	Signal (V)	Power (W)	Power est (W)	Fit Error (%)
0.052	0.586	0.583	0.01	1.074	6.149	6.148	0.00
0.054	0.579	0.588	0.02	1.133	6.617	6.622	0.00
0.096	0.747	0.736	0.02	1.138	6.662	6.659	0.00
0.100	0.746	0.750	0.01	1.196	7.142	7.143	0.00
0.139	0.900	0.891	0.01	1.199	7.166	7.170	0.00
0.148	0.917	0.922	0.01	1.250	7.579	7.607	0.00
0.189	1.096	1.079	0.02	1.256	7.665	7.660	0.00
0.196	1.093	1.104	0.01	1.318	8.195	8.210	0.00
0.251	1.338	1.323	0.01	1.321	8.242	8.236	0.00
0.259	1.339	1.354	0.01	1.373	8.702	8.712	0.00
0.301	1.541	1.529	0.01	1.378	8.759	8.759	0.00
0.312	1.559	1.576	0.01	1.436	9.306	9.315	0.00
0.357	1.787	1.774	0.01	1.439	9.356	9.345	0.00
0.371	1.814	1.836	0.01	1.501	9.922	9.944	0.00
0.422	2.085	2.074	0.01	1.504	9.967	9.975	0.00
0.427	2.072	2.095	0.01	1.557	10.510	10.518	0.00
0.475	2.346	2.331	0.01	1.558	10.523	10.529	0.00
0.486	2.352	2.387	0.01	1.615	11.180	11.120	0.01
0.528	2.617	2.601	0.01	1.623	11.175	11.197	0.00
0.537	2.618	2.647	0.01	1.683	11.906	11.845	0.01
0.585	2.925	2.905	0.01	1.685	11.830	11.863	0.00
0.593	2.932	2.950	0.01	1.734	12.464	12.409	0.00
0.648	3.287	3.257	0.01	1.749	12.544	12.573	0.00
0.655	3.278	3.298	0.01	1.799	13.199	13.138	0.00
0.712	3.675	3.637	0.01	1.808	13.211	13.243	0.00
0.715	3.639	3.655	0.00	1.854	13.826	13.777	0.00
0.769	4.034	3.990	0.01	1.866	13.876	13.919	0.00
0.781	4.052	4.064	0.00	1.925	14.552	14.610	0.00
0.828	4.413	4.373	0.01	1.925	14.591	14.620	0.00
0.834	4.401	4.415	0.00	1.983	15.377	15.321	0.00
0.891	4.788	4.798	0.00	1.988	15.341	15.384	0.00
0.893	4.809	4.813	0.00	2.039	15.984	16.015	0.00
0.954	5.238	5.242	0.00	2.053	16.241	16.197	0.00
0.958	5.272	5.273	0.00	2.102	16.840	16.814	0.00
1.013	5.682	5.679	0.00	2.110	16.890	16.923	0.00
1.017	5.717	5.713	0.00	2.159	17.541	17.557	0.00
1.071	6.118	6.129	0.00	2.163	17.631	17.605	0.00

Correlation Expression

$$Y = 0.40867 + 3.28535\,X + 0.81020\,X^{2} + 1.21878\,X^{2.5} - 0.14001\,X^{3.5}$$

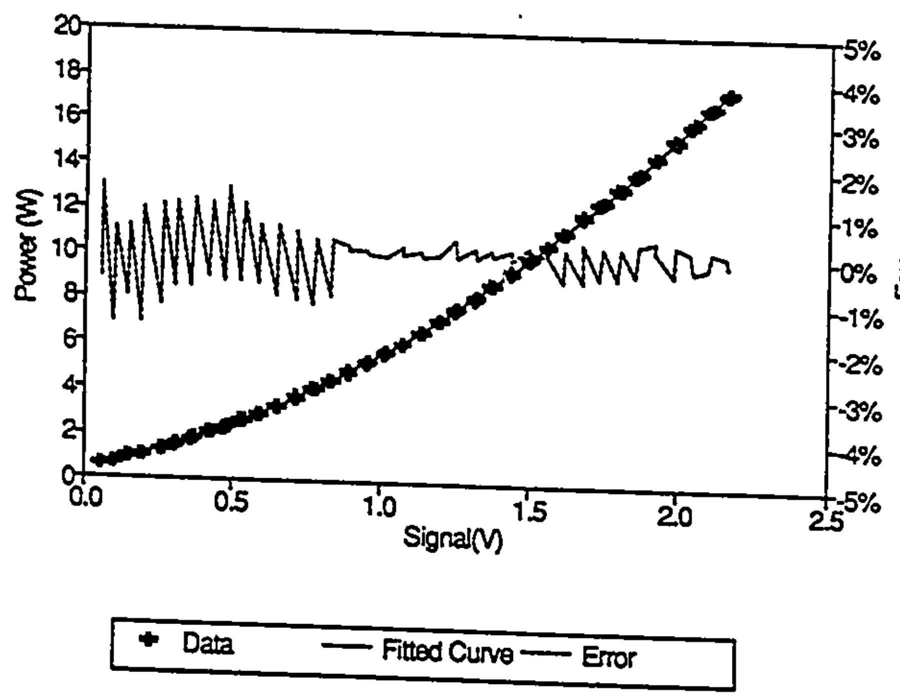


Figure A.1 Calibration Curve For Power Measuring System

APPENDIX B

UNCERTAINTY ANALYSIS

B.1 UNCERTAINTY ANALYSIS FOR THE THERMAL CONDUCTIVITY

B.1.1 INTRODUCTION

The value of the thermal conductivity like most physical quantities was found in two distinct steps. First, independent variables such as T_{hot}, and T_{cold} etc, which can be measured directly, were measured. Second, using these measured values of the independent variables, the value of the thermal conductivity was calculated. Hence, the estimation of uncertainties also involved two steps viz, i) to estimate the uncertainties in the independent variables and ii) to find out how these uncertainties "propagate" through the calculations to produce an uncertainty in the final answer [10].

Since

$$k = \frac{Q \ln\left(\frac{D_2}{D_1}\right)}{2 \pi L (T_{hot} - T_{cold})} \tag{B.1}$$

Therefore, the uncertainty in the thermal conductivity δk was found as

$$\delta k = \left[\left(\frac{\partial k}{\partial Q}\,\delta Q\right)^2 + \left(\frac{\partial k}{\partial T_{hot}}\,\delta T_{hot}\right)^2 + \left(\frac{\partial k}{\partial T_{cold}}\,\delta T_{cold}\right)^2 + \left(\frac{\partial k}{\partial D_1}\,\delta D_1\right)^2 + \left(\frac{\partial k}{\partial D_2}\,\delta D_2\right)^2 + \left(\frac{\partial k}{\partial L}\,\delta L\right)^2 \right]^{1/2} \tag{B.2}$$

where δi represents the uncertainty in the i variable.

And the fractional uncertainty was found as

$$\left(\frac{\delta k}{k}\right) = \left[\left(\frac{1}{k}\frac{\partial k}{\partial Q}\,\delta Q\right)^2 + \left(\frac{1}{k}\frac{\partial k}{\partial T_{hot}}\,\delta T_{hot}\right)^2 + \left(\frac{1}{k}\frac{\partial k}{\partial T_{cold}}\,\delta T_{cold}\right)^2 + \left(\frac{1}{k}\frac{\partial k}{\partial D_1}\,\delta D_1\right)^2 + \left(\frac{1}{k}\frac{\partial k}{\partial D_2}\,\delta D_2\right)^2 + \left(\frac{1}{k}\frac{\partial k}{\partial L}\,\delta L\right)^2 \right]^{1/2} \tag{B.3}$$

By substituting the partial derivatives of k with respect to all independent variables, the Equation (B.3) becomes

$$\left(\frac{\delta k}{k}\right) = \left[\left(\frac{\delta Q}{Q}\right)^2 + \left(\frac{\delta T_{hot}}{T_{hot}-T_{cold}}\right)^2 + \left(\frac{\delta T_{cold}}{T_{hot}-T_{cold}}\right)^2 + \left(\frac{\delta D_1}{D_1 \ln\left(\frac{D_2}{D_1}\right)}\right)^2 + \left(\frac{\delta D_2}{D_2 \ln\left(\frac{D_2}{D_1}\right)}\right)^2 + \left(\frac{\delta L}{L}\right)^2 \right]^{1/2} \tag{B.4}$$

Since the total uncertainty in a quantity is composed of two components viz. systematic or bias component and the random or repeatability component [10]. Hence, the systematic component δk_{syst} and the random component δk_{rand} were found by using Equation (B.4) with δi replaced by δi_{syst} and δi_{rand} respectively. The total uncertainty δk was found by combining the two components by the root-sum-square (RSS) as following

$$\delta k = \left[(\delta k_{syst})^2 + (\delta k_{rand})^2 \right]^{1/2} \tag{B.5}$$

B.1.2 SYSTEMATIC UNCERTAINTY

B.1.2.1 Uncertainty in Q

The power was calculated by measuring the d.c. voltage signal and using the correlation equation described in the Appendix A. Hence, the systematic uncertainty in Q was due to the uncertainties in the correlation equation and in the voltage measurement, and was found as

$$\delta Q_{syst} = \left[(\delta Q_{eq})^2 + \left(\frac{\partial Q}{\partial V_{sig}} \delta_{signal} \right)^2 \right]^{1/2} \tag{B.6}$$

where

$$\frac{\partial Q}{\partial V_{sig}} = 3.28535 + 1.6204\, V_{sig} + 3.04695\, V_{sig}^{1.5} - 0.490035\, V_{sig}^{2.5} \tag{B.7}$$

and

$$\delta Q_{eq} = 5.59\%$$

$$\delta_{signal\ syst} = 2.44\times10^{-4}\ \mathrm{V}$$

B.1.2.2 Uncertainties in T_{hot} and T_{cold}

The test for uniformity of thermocouple readings, described in Appendix E, showed that all the thermocouple readings were very uniform and that the smallest increment, which could be detected by the A/D converter was 0.05°C. Hence, the systematic uncertainty for all thermocouple readings was 0.03°C. The uncertainties in T_{hot} and T_{cold} were found as following:

$$\delta T_{hot\ syst} = \left[\sum_{i=1}^{21} \left(\frac{\partial T_{hot}}{\partial T_i}\ \delta T_{syst} \right)^2 \right]^{1/2} \tag{B.8}$$

Since

$$\frac{\partial T_{hot}}{\partial T_i} = \frac{1}{21}$$

$$\therefore \quad \delta T_{hot\ syst} = \frac{\delta T_{syst}}{\sqrt{21}} \tag{B.9}$$

For T_{cold} :

$$\delta T_{cold_{syst}} = \left[\sum_{i=22}^{30} \left(\frac{\partial T_{cold}}{\partial T_i} \delta T_{syst} \right)^2 \right]^{1/2} \qquad (B.10)$$

$$\because \quad \frac{\partial T_{cold}}{\partial T_i} = 0.1 \qquad \text{for } i = 23, \ldots, 30$$

$$\frac{\partial T_{cold}}{\partial T_{22}} = 0.2$$

$$\therefore \quad \delta T_{cold_{syst}} = \sqrt{0.12}\; \delta T_{syst} \qquad (B.11)$$

B.1.2.3 Uncertainties in Geometric Constants

The manufacturing tolerance of the outside diameter (i.e. D_2) was ±0.03" and the fabrication tolerances of the inside diameter (i.e. D_1) and the length were ±0.005" and ±0.03".

B.1.3 RANDOM UNCERTAINTY

For each experimental run, the average values of ten readings of temperatures and power were used in the calculation of the thermal conductivity k. The standard deviation of these readings gave the random uncertainties.

B.1.3.1 Uncertainty in Q

$$\delta Q_{rand} = \sigma_Q \tag{B.12}$$

B.1.3.2 Uncertainties in T_{hot} and T_{cold}

Random uncertainty in T_{hot} was found by using Eq (B.8) with δT_{syst} replaced by σ_{Ti} i.e.

$$\delta T_{hot\,syst} = \left[\sum_{i=1}^{21} \left(\frac{\sigma_{Ti}}{21} \right)^2 \right]^{1/2}$$

$$\delta T_{hot\,syst} = \frac{1}{21} \left[\sum_{i=1}^{21} \sigma^2{}_{Ti} \right]^{1/2} \tag{B.13}$$

Random uncertainty in T_{cold} was found by using Eq (B.10) with δT_{syst} replaced by σ_{Ti} i.e.

$$\delta T_{cold\,rand} = \left[(0.2\ \sigma_{T22})^2 + \sum_{i=23}^{30} (0.1\ \sigma_{Ti})^2 \right]^{1/2}$$

$$\delta T_{cold\,rand} = 0.1 \left[4\ \sigma^2{}_{T22} + \sum_{i=23}^{30} \sigma^2{}_{Ti} \right]^{1/2} \tag{B.14}$$

Random uncertainties in the measurement of geometric constants i.e., D_1, D_2, and L were 0%. Hence using these equations, the uncertainty was calculated for each experimental run and is reported along with the results.

B.2 UNCERTAINTY ANALYSIS FOR THE POWER CORRELATION

B.2.1 UNCERTAINTY IN THE POWER MEASUREMENT

From Equation (A.3)

$$Q = f\left(V_{resist}, V_{heater}, R\right) \tag{B.15}$$

Hence according to Eq (B.2) the uncertainty in Q is

$$\delta Q = \left[\left(\frac{\partial Q}{\partial V_{resist}}\,\delta V_{resist}\right)^2 + \left(\frac{\partial Q}{\partial V_{heater}}\,\delta V_{heater}\right)^2 + \left(\frac{\partial Q}{\partial R}\,\delta R\right)^2\right]^{1/2} \tag{B.16}$$

And the fractional Uncertainty is

$$\left(\frac{\delta Q}{Q}\right) = \left[\left(\frac{1}{Q}\,\frac{\partial Q}{\partial V_{resist}}\,\delta V_{resist}\right)^2 + \left(\frac{1}{Q}\,\frac{\partial Q}{\partial V_{heater}}\,\delta V_{heater}\right)^2 + \left(\frac{1}{Q}\,\frac{\partial Q}{\partial R}\,\delta R\right)^2\right]^{1/2} \tag{B.17}$$

where

$$\frac{1}{Q}\,\frac{\partial Q}{\partial V_{resist}} = \frac{1}{V_{resist}}$$

$$\frac{1}{Q}\,\frac{\partial Q}{\partial V_{heater}} = \frac{1}{V_{heater}}$$

and

$$\frac{1}{Q}\frac{\partial Q}{\partial R} = \frac{-1}{R}$$

$$\therefore \qquad \frac{\delta Q}{Q} = \left[\left(\frac{\delta V_{resist}}{V_{resist}} \right)^2 + \left(\frac{\delta V_{heater}}{V_{heater}} \right)^2 + \left(\frac{\delta R}{R} \right)^2 \right]^{1/2} \qquad (B.18)$$

B.2.1.1 Random Uncertainty

$$\left(\frac{\delta Q}{Q} \right)_{rand} = \left[\left(\frac{\sigma_{V_{resist}}}{V_{resist}} \right)^2 + \left(\frac{\sigma_{V_{heater}}}{V_{heater}} \right)^2 + \left(\frac{\sigma_R}{R} \right)^2 \right]^{1/2} \qquad (B.19)$$

The random uncertainty was calculated for each data point and is given in Table B.1. The average random uncertainty was found to be 0.09%.

B.2.1.2 Systematic Uncertainty

$$\left(\frac{\delta Q}{Q} \right)_{syst} = \left[\left(\frac{(\delta V_{resist})_{syst}}{V_{resist}} \right)^2 + \left(\frac{(\delta V_{heater})_{syst}}{V_{heater}} \right)^2 + \left(\frac{(\delta R)_{syst}}{R} \right)^2 \right]^{1/2} \qquad (B.20)$$

The accuracy of the multimeters used was ±(3% + 2 units in the least significant digits) [11]. Hence for voltages in the range of 0V to 3.2V, the accuracy was ±(3% + 0.002V), and, for voltages in the range of 3.2V to 32V, the accuracy was ±(3% + 0.02V). The accuracy of the resistor was ± 3%. Hence, using these values, the systematic uncertainty was calculated by using Equation (B.20) at each data point and is given in Table B.1. The average systematic uncertainty was found to be 5.57%.

B.2.1.3 Total Uncertainty In The Power Measurement

Total uncertainty was found by combining random and systematic uncertainties according to Equation (B.5). Table B.1 lists the total uncertainties at each data point. The average uncertainty in the power measurement was 5.57%.

B.2.2 UNCERTAINTY IN THE VOLTAGE MEASUREMENT

The d.c. voltage signal was measured by the data logger with an accuracy of ±0.024% of full scale deflection and a maximum voltage measurement range of 4.096V. Hence the systematic uncertainty in the d.c. voltage measurement was $\delta_{signal\ syst} = 2.44 \times 10^{-4}$ V.

The random uncertainty was found by calculating the standard deviations of the twenty readings for each setting. The total uncertainty was found by combining the two uncertainties according to Equation (B.5) Table lists uncertainties at each data point. The average uncertainty in the signal measurement was 0.098%.

B.2.3 UNCERTAINTY IN THE CORRELATION FOR POWER ESTIMATION

The total uncertainty in the estimation of power by the power-signal correlation (i.e. Equation A.4) was composed of three parts viz. uncertainty in the curve fitting, uncertainty in the power measurement, and the uncertainty in the voltage signal measurement. These uncertainties were combined as following:

$$\overline{\delta Q_{ec}} = \left[\left(\overline{\delta_{curve}}\right)^2 + \left(\overline{\delta Q}\right)^2 + \left(\overline{\delta_{signal}}\right)^2 \right]^{1/2} \qquad \text{(B.21)}$$

where δQ_{ec} represents the average percent fractional uncertainty.

Since

$$\overline{\delta_{curve}} = 0.47\%$$

$$\overline{\delta Q} = 5.57\%$$

$$\overline{\delta_{signal}} = 0.098\%$$

$$\therefore \quad \overline{\delta Q_{ec}} = 5.59\%$$

Hence the average uncertainty in the use of the correlation equation was 5.59%.

TABLE B-1 UNCERTAINTY IN POWER MEASUREMENT

R = 1 Ω δR = 3%

V_{resist} (V)	δ_{syst} (%)	δ_{rand} (%)	V_{heater} (V)	δ_{syst} (%)	δ_{rand} (%)	Power (W)	δ_{syst} (%)	δ_{rand} (%)	δ_{total} (%)
0.2000	4.00	0.00	2.930	3.07	0.00	0.586	5.87	0.00	5.87
0.1990	4.01	0.00	2.910	3.07	0.00	0.579	5.87	0.00	5.87
0.2260	3.88	0.00	3.305	3.61	0.14	0.747	6.09	0.14	6.09
0.2260	3.88	0.00	3.301	3.61	0.08	0.746	6.09	0.08	6.09
0.2480	3.81	0.00	3.630	3.55	0.00	0.900	6.01	0.00	6.01
0.2505	3.80	0.00	3.660	3.55	0.00	0.917	6.00	0.00	6.00
0.2740	3.73	0.00	4.000	3.50	0.00	1.096	5.93	0.00	5.93
0.2735	3.73	0.01	3.995	3.50	0.14	1.093	5.93	0.14	5.93
0.3027	3.66	0.01	4.420	3.45	0.00	1.338	5.86	0.01	5.86
0.3030	3.66	0.00	4.420	3.45	0.00	1.339	5.86	0.00	5.86
0.3250	3.62	0.00	4.740	3.42	0.00	1.541	5.81	0.00	5.81
0.3268	3.61	0.01	4.770	3.42	0.00	1.559	5.81	0.01	5.81
0.3500	3.57	0.00	5.105	3.39	0.15	1.787	5.77	0.15	5.77
0.3525	3.57	0.01	5.145	3.39	0.15	1.814	5.76	0.15	5.76
0.3780	3.53	0.00	5.515	3.36	0.15	2.085	5.72	0.15	5.73
0.3770	3.53	0.00	5.497	3.36	0.14	2.072	5.73	0.14	5.73
0.4010	3.50	0.00	5.850	3.34	0.00	2.346	5.69	0.00	5.69
0.4015	3.50	0.01	5.859	3.34	0.09	2.352	5.69	0.09	5.69
0.4238	3.47	0.01	6.175	3.32	0.15	2.617	5.67	0.15	5.67
0.4237	3.47	0.01	6.180	3.32	0.00	2.618	5.67	0.01	5.67
0.4480	3.45	0.00	6.530	3.31	0.00	2.925	5.64	0.00	5.64
0.4482	3.45	0.01	6.541	3.31	0.09	2.932	5.64	0.09	5.64
0.4750	3.42	0.00	6.920	3.29	0.00	3.287	5.61	0.00	5.61
0.4742	3.42	0.01	6.912	3.29	0.12	3.278	5.62	0.12	5.62
0.5020	3.40	0.00	7.320	3.27	0.00	3.675	5.59	0.00	5.59
0.4995	3.40	0.01	7.285	3.27	0.15	3.639	5.59	0.15	5.60
0.5260	3.38	0.00	7.670	3.26	0.00	4.034	5.57	0.00	5.57
0.5272	3.38	0.01	7.685	3.26	0.15	4.052	5.57	0.15	5.57
0.5502	3.36	0.01	8.021	3.25	0.09	4.413	5.56	0.09	5.56
0.5495	3.36	0.01	8.010	3.25	0.00	4.401	5.56	0.01	5.56
0.5745	3.35	0.01	8.335	3.24	0.15	4.788	5.54	0.16	5.54
0.5745	3.35	0.01	8.370	3.24	0.00	4.809	5.54	0.01	5.54
0.6008	3.33	0.01	8.718	3.23	0.12	5.238	5.53	0.12	5.53
0.6015	3.33	0.02	8.765	3.23	0.15	5.272	5.53	0.16	5.53
0.6265	3.32	0.02	9.070	3.22	0.00	5.682	5.51	0.02	5.51
0.6265	3.32	0.02	9.125	3.22	0.16	5.717	5.51	0.16	5.51
0.6498	3.31	0.01	9.415	3.21	0.16	6.118	5.50	0.16	5.50
0.6500	3.31	0.00	9.460	3.21	0.00	6.149	5.50	0.00	5.50

TABLE B-1 Continued

V_{resist} (V)	δ_{syst} (%)	δ_{rand} (%)	V_{heater} (V)	δ_{syst} (%)	δ_{rand} (%)	Power (W)	δ_{syst} (%)	δ_{rand} (%)	δ_{total} (%)
0.6755	3.30	0.02	9.795	3.20	0.16	6.617	5.49	0.16	5.49
0.6760	3.30	0.00	9.855	3.20	0.16	6.662	5.49	0.16	5.49
0.7005	3.29	0.02	10.195	3.20	0.16	7.142	5.48	0.16	5.48
0.7025	3.28	0.02	10.200	3.20	0.00	7.166	5.48	0.02	5.48
0.7235	3.28	0.02	10.475	3.19	0.16	7.579	5.47	0.16	5.47
0.7255	3.28	0.02	10.565	3.19	0.16	7.665	5.47	0.16	5.47
0.7515	3.27	0.02	10.905	3.18	0.16	8.195	5.46	0.16	5.46
0.7520	3.27	0.00	10.960	3.18	0.00	8.242	5.46	0.00	5.46
0.7745	3.26	0.02	11.235	3.18	0.16	8.702	5.45	0.16	5.45
0.7755	3.26	0.02	11.295	3.18	0.16	8.759	5.45	0.16	5.45
0.8005	3.25	0.02	11.625	3.17	0.16	9.306	5.44	0.16	5.45
0.8012	3.25	0.01	11.678	3.17	0.13	9.356	5.44	0.13	5.44
0.8265	3.24	0.02	12.005	3.17	0.16	9.922	5.43	0.16	5.44
0.8278	3.24	0.01	12.040	3.17	0.00	9.967	5.43	0.01	5.43
0.8500	3.24	0.00	12.365	3.16	0.16	10.510	5.43	0.16	5.43
0.8510	3.24	0.00	12.365	3.16	0.16	10.523	5.43	0.16	5.43
0.8760	3.23	0.00	12.763	3.16	0.15	11.180	5.42	0.15	5.42
0.8765	3.23	0.02	12.750	3.16	0.00	11.175	5.42	0.02	5.42
0.9000	3.22	0.00	13.060	3.15	0.00	11.754	5.42	0.00	5.42
0.9040	3.22	0.00	13.170	3.15	0.00	11.906	5.41	0.00	5.41
0.9020	3.22	0.00	13.115	3.15	0.16	11.830	5.41	0.16	5.42
0.9250	3.22	0.00	13.475	3.15	0.16	12.464	5.41	0.16	5.41
0.9285	3.22	0.02	13.510	3.15	0.00	12.544	5.41	0.02	5.41
0.9520	3.21	0.00	13.865	3.14	0.16	13.199	5.40	0.16	5.41
0.9528	3.21	0.01	13.865	3.14	0.16	13.211	5.40	0.16	5.41
0.9740	3.21	0.00	14.195	3.14	0.16	13.826	5.40	0.16	5.40
0.9765	3.20	0.02	14.210	3.14	0.00	13.876	5.40	0.02	5.40
0.9998	3.20	0.01	14.555	3.14	0.16	14.552	5.39	0.16	5.40
1.0275	3.19	0.02	14.965	3.13	0.16	15.377	5.39	0.16	5.39
1.0265	3.19	0.02	14.945	3.13	0.16	15.341	5.39	0.16	5.39
1.0478	3.19	0.01	15.255	3.13	0.16	15.984	5.38	0.16	5.39
1.0560	3.19	0.00	15.380	3.13	0.00	16.241	5.38	0.00	5.38
1.0750	3.19	0.00	15.665	3.13	0.16	16.840	5.38	0.16	5.38
1.0775	3.19	0.02	15.675	3.13	0.16	16.890	5.38	0.16	5.38
1.0980	3.18	0.00	15.975	3.13	0.16	17.541	5.38	0.16	5.38
1.1000	3.18	0.00	16.028	3.12	0.13	17.631	5.37	0.13	5.38

TABLE B-2 UNCERTAINTY IN VOLTAGE SIGNAL MEASUREMENT

Signal (V)	δ_{syst} (%)	δ_{rand} (%)	δ_{total} (%)	Signal (V)	δ_{syst} (%)	δ_{rand} (%)	δ_{total} (%)
0.052	0.47	0.06	0.47	1.074	0.02	0.11	0.11
0.054	0.46	0.26	0.52	1.133	0.02	0.05	0.05
0.096	0.25	0.14	0.29	1.138	0.02	0.19	0.19
0.100	0.24	0.09	0.26	1.196	0.02	0.08	0.08
0.139	0.17	0.06	0.18	1.199	0.02	0.04	0.05
0.148	0.17	0.13	0.21	1.250	0.02	0.04	0.05
0.189	0.13	0.07	0.15	1.256	0.02	0.17	0.18
0.196	0.12	0.13	0.18	1.318	0.02	0.05	0.05
0.251	0.10	0.03	0.10	1.321	0.02	0.04	0.05
0.259	0.09	0.11	0.14	1.373	0.02	0.06	0.06
0.301	0.08	0.05	0.09	1.378	0.02	0.05	0.06
0.312	0.08	0.15	0.17	1.436	0.02	0.03	0.04
0.357	0.07	0.09	0.11	1.439	0.02	0.07	0.07
0.371	0.07	0.11	0.13	1.501	0.02	0.07	0.07
0.422	0.06	0.00	0.06	1.504	0.02	0.08	0.09
0.427	0.06	0.12	0.13	1.557	0.02	0.04	0.04
0.475	0.05	0.00	0.05	1.558	0.02	0.09	0.09
0.486	0.05	0.15	0.16	1.615	0.02	0.02	0.03
0.528	0.05	0.03	0.06	1.623	0.02	0.09	0.09
0.537	0.05	0.21	0.21	1.675	0.01	0.09	0.09
0.585	0.04	0.00	0.04	1.683	0.01	0.00	0.01
0.593	0.04	0.12	0.13	1.685	0.01	0.20	0.20
0.648	0.04	0.08	0.09	1.734	0.01	0.03	0.03
0.655	0.04	0.12	0.12	1.749	0.01	0.11	0.11
0.712	0.03	0.00	0.03	1.799	0.01	0.01	0.02
0.715	0.03	0.03	0.04	1.808	0.01	0.03	0.03
0.769	0.03	0.00	0.03	1.854	0.01	0.03	0.03
0.781	0.03	0.10	0.10	1.866	0.01	0.04	0.04
0.828	0.03	0.04	0.05	1.925	0.01	0.06	0.06
0.834	0.03	0.07	0.07	1.983	0.01	0.05	0.05
0.891	0.03	0.08	0.08	1.988	0.01	0.05	0.05
0.893	0.03	0.05	0.06	2.039	0.01	0.04	0.04
0.954	0.03	0.05	0.06	2.053	0.01	0.02	0.03
0.958	0.03	0.06	0.06	2.102	0.01	0.02	0.03
1.013	0.02	0.05	0.05	2.110	0.01	0.04	0.04
1.017	0.02	0.05	0.06	2.159	0.01	0.04	0.05
1.071	0.02	0.06	0.07	2.163	0.01	0.03	0.03

B.3 UNCERTAINTY ANALYSIS FOR THE RADIATION TESTS

B.3.1 UNCERTAINTY IN THE MEASUREMENT OF TRANSMISSIVITY

The transmissivity of a medium is found as

$$\tau = \frac{I_2}{I_1} \qquad \text{(B.22)}$$

where

I_1 = Incident Radiation Intensity (W/m^2)

I_2 = Transmitted Radiation Intensity (W/m^2)

Hence the uncertainty in τ is:

$$\delta\tau = \left(\left(\frac{\partial\tau}{\partial I_2}\,\delta I_2\right)^2 + \left(\frac{\partial\tau}{\partial I_1}\,\delta I_1\right)^2\right)^{1/2} \qquad \text{(B.23)}$$

And the fractional uncertainty:

$$\frac{\partial\tau}{\tau} = \left(\left(\frac{\delta I_2}{I_2}\right)^2 + \left(\frac{\delta I_1}{I_1}\right)^2\right)^{1/2} \qquad \text{(B.24)}$$

B.3.2 UNCERTAINTY IN THE MEASUREMENT OF RADIATION INTENSITY

The radiation intensity was found by measuring the voltage signal generated by the radiation detector. Hence,

$$I = f(V) \tag{B.25}$$

where

V = d.c. voltage signal

And the fractional uncertainty is:

$$\frac{\delta I}{I} = \frac{\delta V}{V} \tag{B.26}$$

Hence, the fractional uncertainty in the radiation measurement is equal to the fractional uncertainty in voltage measurement. Here δV is composed of two components viz, random and systematic, which are related to each other according to Equation (B.5). Table B.3 lists the total uncertainties each experimental run.

B.3.3 UNCERTAINTY IN THE ESTIMATION OF FOAM TRASMISSIVITY

Since foam transmissivity was found as:

$$\tau_{foam} = \frac{\tau_2}{\tau_1} \tag{B.27}$$

where

τ_1 = Transmissivity of two plexiglas plates enclosing air

τ_2 = Transmissivity of two plexiglas plates enclosing foam

Hence the fractional uncertainty in the estimation of the solar transmissivity was found as:

$$\frac{\delta\tau_{foam}}{\tau_{foam}} = \left(\left(\frac{\delta\tau_1}{\tau_1}\right)^2 + \left(\frac{\delta\tau_2}{\tau_2}\right)^2\right)^{1/2} \tag{B.28}$$

TABLE B.3 UNCERTAINTY IN VOLTAGE SIGNAL MEASUREMENT (RADIATION TESTS)

Air / Foam Layer Thickness (mm)	AIR						FOAM					
	Solar Intensity			Radiation Test Cell			Solar Intensity			Radiation Test Cell		
	δV_{rand} (%)	δV_{syst} (%)	δV_{total} (%)	δV_{rand} (%)	δV_{syst} (%)	δV_{total} (%)	δV_{rand} (%)	δV_{syst} (%)	δV_{total} (%)	δV_{rand} (%)	δV_{syst} (%)	δV_{total} (%)
25.4 (1.0")	0.00	2.37	2.37	0.62	1.96	2.05	0.00	4.27	4.27	0.00	1.95	1.95
33.02 (1.3")	0.85	2.44	2.58	0.64	2.01	2.10	0.00	4.87	4.87	0.62	1.96	2.05
40.64 (1.6")	0.82	2.38	2.52	0.00	1.97	1.97	3.18	7.19	7.87	0.62	1.96	2.05
50.6 (2.0")	0.81	2.36	2.49	0.62	1.96	2.05	0.00	9.03	9.03	0.00	1.97	1.97
63.5 (2.5")	0.00	2.39	2.39	0.00	1.98	1.98	4.88	12.90	13.79	0.62	1.96	2.05

APPENDIX C

RELATIONSHIP BETWEEN SURFACE TENSION AND SOLUTE CONCENTRATION

The surface tension of a solution depends upon the concentration of the solute and, in general, is different from that of the pure solvent. The surface tension of water is reduced considerably by a wide range of organic compounds such as those which, like soaps, have fairly long hydrocarbon chains attached to groups sufficiently hydrophilic to make the molecules as a whole water soluble [13].

The surface tension of a number of samples of sodium lauryl sulphate solution with different solute concentration was measured to find out the exact relationship between the two quantities. The measurement was done by using a Fisher Surface Tensiometer supplied by Fisher Scientific Co, USA. This apparatus employs the principle of measuring the maximum pull necessary to detach a circular platinum-iridium ring of circular wire from the surface of a liquid, the angle of contact being zero. The surface tension of the liquid is then found by applying the following correction factor:

$$CF = 0.7250 + \sqrt{\frac{0.01452\,P}{C^2\,(\rho_{liq}-\rho_{air})} + 0.04534 - \frac{1.679\,r}{R}} \qquad (C.1)$$

where

r = Radius of wire (0.01778 cm)

R = Radius of the ring (0.9 cm)

C = Circumference of the ring (5.655 cm)

ρ_{liq} = Density of the liquid (1 gm/cm^3)

ρ_{air} = Density of air (≈ 0 gm/cm^3)

P = Dial reading ($N/m.10^3$)

And the surface tension S is found as

$$S = P \times CF \qquad (C.2)$$

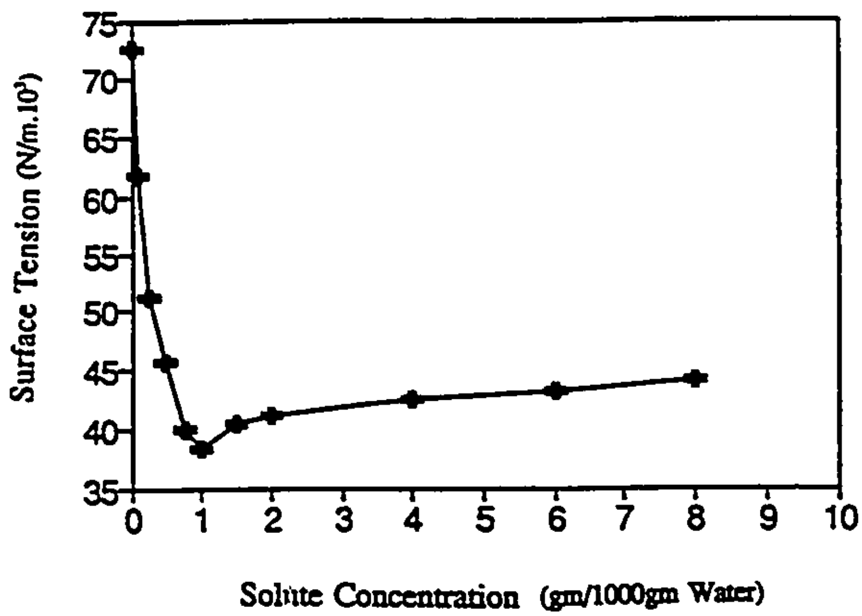
Since the circular ring used in the present study was not very uniform and was cemented at one corner, the apparatus was calibrated by measuring the surface tension of distilled water. Then, by comparing the measured value of the surface tension of distilled water with the reported value in literature, a scale factor of 1.38 was found. Subsequently, all readings were multiplied by this scale factor.

Table C.1 lists the values of surface tension of various samples. All dial readings listed are the average of five readings. The variation of surface tension with the solute concentration is plotted in Figure C.1. The figure shows that the surface tension of the solution decreases considerably with an addition of very small quantity of the solute and reaches a minimum value at the solute concentration of 1 gm/1000 gm of water. Beyond this point, the surface tension increases with an increase in the solute concentration, though always below the value for water.

TABLE C-1 SURFACE TENSION OF VARIOUS SODIUM LAURYL SULPHATE SOLUTIONS

Temperature : 22°C

Concentration (gm/1000 gm Water)	Dial Reading ($N/m.10^3$) P	Correction Factor CF	Scale Factor SF	Surface Tension ($N/m.10^3$) S = P x CF x SF
0.00	57.04	0.92	1.38	72.50
0.10	49.14	0.91	1.38	61.82
0.25	41.22	0.90	1.38	51.29
0.50	37.00	0.90	1.38	45.76
0.75	32.58	0.89	1.38	40.02
1.00	31.26	0.89	1.38	38.32
1.50	32.84	0.89	1.38	40.36
2.00	33.46	0.89	1.38	41.16
4.00	34.44	0.89	1.38	42.38
6.00	35.04	0.89	1.38	43.20
8.00	35.68	0.89	1.38	44.04



Temperature : 22°C

Figure C.1 Effect Of Solute Concentration On Surface Tension

APPENDIX D

LIST OF EQUIPMENT AND INSTRUMENTATION

1. **Acrylonitrile-Butadiene-Styrene (ABS) Plastic Tube**

   6 in. (152.4 mm) ID, 6.75 in. (171.45 mm) OD: AIN Plastics of Michigan, Southfield, MI.

2. **Cartridge Heater**

   Catalogue # CS 010096, Fast Heat, Hi Temp, stainless steel sheath, 0.5 in. (12.7 mm) nominal diameter, 10 in. (254 mm) sheath length, 475 W rating at 120 V: Acrolab Instruments, Windsor, Ontario.

3. **Computer**

   IBM Turbo-XT, 640K RAM, 20M hard disk storage capacity.

   International Business Machines, USA.

4. **Constant Temperature Bath**

Exacal Constant Temperature Bath Circulator, model EX - 200, 115 V, single phase, temperature range from -30°C to 120°C: Neslab Instruments Inc., Newington, NH.

5. **Data Logger**

Electronic Measurement System, model 8082-A.

Sciemetric Instruments, Manotick, Ontario.

6. **Digital Multimeter**

Fluke 73, AC voltage measurement range 0 V - 750 V, DC voltage measurement range 0 V - 1000 V, resistance measurement range 0 Ω - 32 MΩ , AC/DC current measurement range 0 - 10 Amp.

John Fluke Mfg Co. Inc, Everett, Washington.

7. **Fisher Surface Tensiometer**

Model 20, surface tension measurement range 0 - 90 dyne/cm.

Fisher Scientific Co, USA.

8. **MJ Rubber Coupling**

5 in. CI/PL to 5 in. CI/PL: Veteran Plumbing, Windsor, Ontario.

9. **Plexiglas Plate**

0.375 in. (9.525 mm) thick, 5.5 in. (139.7 mm)

AIN Plastics of Michigan, Southfield, MI.

10. Polycarbonate Machine Plate

0.75 in. (19.05 mm) thick, 5.0 in. (127 mm) square plate.

AIN Plastics of Michigan, Southfield, MI.

11. Polycarbonate Tubing

a) 2.875 in. (73.025 mm) ID, 3.0 in. (76.20 mm) OD.

b) 3.75 in. (95.25 mm) ID, 4.00 in. (101.6 mm) OD.

AIN Plastics of Michigan, Southfield, MI.

12. Pressure Gauges

Model Norgen BO7-201 MIKA, inlet pressure 150 psig max, outlet pressure 100 psig max, operating temp 125°F: Littleton Co, USA.

13. Pyranometer / Radiation Detector

Model 8-48: The Eppley Laboratory, Inc, Newport, RI.

14. Regulated Power Supply

Model 22-8244, input 120 VAC, output 12 VDC.

Tandy Electronics Ltd, Ontario.

15. Seal All

Adhesive, 5 to 10 minute setting time.

Allen - Stevenson Products Ltd, Windsor, Ontario.

16. Vacuum Grease

Dow Corning Corporation, Midland, MI.

17. Variac

Type WIOMT3, input 115 V, output 0 V - 135 V.

General Radio Company, Concord, MA.

APPENDIX E

RESULTS OF UNIFORMITY TESTS

E.1 INTRODUCTION

The accuracy of the results depends greatly on the maintenance of uniform hot and cold surface temperatures. In order to check whether all thermocouples gave the same reading when immersed in a uniform temperature bath, the bath water, at room temperature, was circulated through both the foam and the outer annulus and the thermocouple readings were taken. Five tests were carried out at different times. For each test, ten readings were taken. The results of these tests, shown in Tables E.1 - E.5, indicate that all thermocouple outputs were uniform with an average standard deviation of 0.03°C. Hence, the uniformity of thermocouple readings was ensured. From these experiments, the smallest increment for the A/D converter of the data logger appeared to be 0.05°C.

TABLE E-1 UNIFORMITY TEST # 1

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.110	0.000	0.000
T_2	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.210	0.000	0.000
T_3	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.155	0.015	0.062
T_4	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_5	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_6	24.21	24.21	24.21	24.16	24.21	24.21	24.21	24.21	24.21	24.16	24.200	0.020	0.083
T_7	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.110	0.000	0.000
T_8	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_9	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{10}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{11}	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.110	0.000	0.000
T_{12}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{13}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{14}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{15}	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.110	0.000	0.000
T_{16}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{17}	24.11	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.155	0.015	0.062
T_{18}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{19}	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.110	0.000	0.000
T_{20}	24.11	24.11	24.11	24.11	24.16	24.16	24.16	24.16	24.16	24.16	24.140	0.024	0.101
T_{21}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{22}	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.21	24.210	0.000	0.000
T_{23}	24.11	24.11	24.11	24.11	24.11	24.11	24.16	24.16	24.16	24.16	24.130	0.024	0.102
T_{24}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{25}	24.11	24.11	24.16	24.11	24.16	24.16	24.16	24.16	24.16	24.16	24.145	0.023	0.095
T_{26}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{27}	24.11	24.11	24.11	24.11	24.11	24.11	24.16	24.16	24.16	24.16	24.130	0.024	0.102
T_{28}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{29}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
T_{30}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.160	0.000	0.000
Avg	24.15	24.15	24.15	24.15	24.15	24.15	24.16	24.16	24.16	24.15	24.153		
Std	0.031	0.030	0.029	0.028	0.028	0.028	0.026	0.026	0.026	0.025			
%Std	0.127	0.124	0.121	0.116	0.116	0.116	0.106	0.106	0.106	0.103			

TABLE E-2 UNIFORMITY TEST # 2

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.06	24.06	24.01	24.090	0.033	0.138
T_2	24.21	24.21	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.155	0.035	0.145
T_3	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.06	24.06	24.06	24.095	0.023	0.095
T_4	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.06	24.140	0.033	0.137
T_5	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_6	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_7	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.06	24.06	24.06	24.095	0.023	0.095
T_8	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_9	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{10}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{11}	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.06	24.06	24.06	24.095	0.023	0.095
T_{12}	24.16	24.16	24.16	24.16	24.11	24.16	24.11	24.06	24.06	24.06	24.120	0.044	0.181
T_{13}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{14}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{15}	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.06	24.06	24.06	24.095	0.023	0.095
T_{16}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{17}	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.11	24.140	0.024	0.101
T_{18}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{19}	24.11	24.11	24.11	24.11	24.11	24.11	24.11	24.06	24.06	24.06	24.095	0.023	0.095
T_{20}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{21}	24.16	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.145	0.023	0.095
T_{22}	24.21	24.21	24.21	24.21	24.21	24.21	24.16	24.16	24.16	24.16	24.190	0.024	0.101
T_{23}	24.16	24.16	24.16	24.11	24.16	24.11	24.06	24.06	24.06	24.11	24.115	0.042	0.172
T_{24}	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.11	24.140	0.024	0.101
T_{25}	24.16	24.16	24.16	24.11	24.16	24.16	24.11	24.11	24.11	24.11	24.135	0.025	0.104
T_{26}	24.21	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.11	24.145	0.032	0.133
T_{27}	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.11	24.140	0.024	0.101
T_{28}	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.11	24.140	0.024	0.101
T_{29}	24.16	24.16	24.16	24.16	24.16	24.16	24.11	24.11	24.11	24.11	24.140	0.024	0.101
T_{30}	24.16	24.16	24.16	24.16	24.16	24.21	24.11	24.11	24.11	24.11	24.145	0.032	0.133
Avg	24.16	24.15	24.15	24.15	24.15	24.15	24.13	24.10	24.10	24.10	24.134		
Std	0.027	0.025	0.023	0.025	0.024	0.026	0.028	0.025	0.025	0.029			
%Std	0.111	0.103	0.094	0.103	0.099	0.108	0.116	0.103	0.103	0.119			

TABLE E-3 UNIFORMITY TEST # 3

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_{1}	24.10	24.10	24.10	24.05	24.05	24.05	24.05	24.05	24.05	24.05	24.065	0.023	0.095
T_{2}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.10	24.10	24.10	24.135	0.023	0.095
T_{3}	24.10	24.10	24.10	24.10	24.05	24.05	24.05	24.05	24.05	24.05	24.070	0.024	0.102
T_{4}	24.15	24.15	24.15	24.15	24.10	24.10	24.10	24.10	24.10	24.10	24.120	0.024	0.102
T_{5}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.10	24.10	24.140	0.020	0.083
T_{6}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{7}	24.10	24.10	24.10	24.10	24.05	24.05	24.05	24.05	24.05	24.05	24.070	0.024	0.102
T_{8}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.10	24.15	24.145	0.015	0.062
T_{9}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.10	24.10	24.10	24.135	0.023	0.095
T_{10}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{11}	24.15	24.10	24.15	24.15	24.10	24.10	24.10	24.10	24.10	24.10	24.115	0.023	0.095
T_{12}	24.15	24.15	24.15	24.15	24.10	24.10	24.10	24.10	24.10	24.10	24.120	0.024	0.102
T_{13}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.10	24.10	24.15	24.140	0.020	0.083
T_{14}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{15}	24.10	24.10	24.10	24.10	24.10	24.10	24.10	24.10	24.10	24.10	24.100	0.000	0.000
T_{16}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{17}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{18}	24.20	24.20	24.20	24.15	24.15	24.20	24.15	24.15	24.15	24.15	24.170	0.024	0.101
T_{19}	24.15	24.15	24.15	24.10	24.10	24.10	24.10	24.10	24.10	24.10	24.115	0.023	0.095
T_{20}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{21}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{22}	24.25	24.25	24.25	24.25	24.25	24.25	24.25	24.25	24.25	24.25	24.250	0.000	0.000
T_{23}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{24}	24.15	24.20	24.20	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.160	0.020	0.083
T_{25}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{26}	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.200	0.000	0.000
T_{27}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{28}	24.20	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.155	0.015	0.062
T_{29}	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.15	24.150	0.000	0.000
T_{30}	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.200	0.000	0.000
Avg	24.15	24.15	24.15	24.15	24.14	24.14	24.14	24.13	24.13	24.13	24.142		
Std	0.031	0.033	0.031	0.034	0.042	0.044	0.042	0.043	0.044	0.043			
%Std	0.130	0.136	0.130	0.141	0.175	0.181	0.175	0.180	0.182	0.180			

TABLE E-4 UNIFORMITY TEST # 4

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	23.32	23.27	23.27	23.26	23.26	23.26	23.26	23.26	23.26	23.26	23.268	0.018	0.076
T_2	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_3	23.32	23.32	23.32	23.31	23.31	23.31	23.31	23.31	23.31	23.31	23.313	0.005	0.020
T_4	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.31	23.358	0.017	0.071
T_5	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_6	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_7	23.32	23.32	23.32	23.31	23.31	23.31	23.31	23.31	23.31	23.31	23.313	0.005	0.020
T_8	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_9	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_{10}	23.42	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.368	0.018	0.076
T_{11}	23.37	23.32	23.32	23.31	23.31	23.31	23.31	23.31	23.31	23.31	23.318	0.018	0.076
T_{12}	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_{13}	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_{14}	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_{15}	23.32	23.32	23.32	23.31	23.31	23.31	23.31	23.31	23.31	23.31	23.313	0.005	0.020
T_{16}	23.37	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.363	0.005	0.020
T_{17}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{18}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{19}	23.32	23.32	23.31	23.31	23.31	23.31	23.36	23.31	23.31	23.31	23.317	0.015	0.064
T_{20}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{21}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{22}	23.42	23.42	23.41	23.41	23.41	23.41	23.41	23.41	23.41	23.41	23.412	0.004	0.017
T_{23}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{24}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{25}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{26}	23.42	23.42	23.41	23.41	23.41	23.41	23.41	23.41	23.41	23.41	23.412	0.004	0.017
T_{27}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{28}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{29}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
T_{30}	23.37	23.37	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.36	23.362	0.004	0.017
Avg	23.37	23.36	23.36	23.35	23.35	23.35	23.35	23.35	23.35	23.35	23.355		
Std	0.026	0.029	0.028	0.029	0.029	0.029	0.028	0.029	0.029	0.030			
%Std	0.110	0.125	0.118	0.125	0.125	0.125	0.120	0.125	0.125	0.128			

TABLE E-5 UNIFORMITY TEST # 5

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	22.87	22.87	22.82	22.82	22.82	22.77	22.77	22.77	22.77	22.77	22.805	0.039	0.171
T_2	22.92	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.880	0.020	0.087
T_3	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_4	22.87	22.87	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.840	0.024	0.107
T_5	22.87	22.87	22.82	22.87	22.82	22.87	22.82	22.82	22.82	22.82	22.840	0.024	0.107
T_6	22.92	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.880	0.020	0.087
T_7	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_8	22.87	22.87	22.82	22.87	22.87	22.82	22.87	22.82	22.87	22.82	22.850	0.024	0.107
T_9	22.87	22.87	22.82	22.82	22.87	22.82	22.82	22.82	22.82	22.87	22.840	0.024	0.107
T_{10}	22.92	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.880	0.020	0.087
T_{11}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_{12}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_{13}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_{14}	22.92	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.880	0.020	0.087
T_{15}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_{16}	22.87	22.87	22.82	22.82	22.87	22.82	22.82	22.82	22.82	22.82	22.835	0.023	0.100
T_{17}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.830	0.020	0.088
T_{18}	22.92	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.880	0.020	0.087
T_{19}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.77	22.825	0.027	0.118
T_{20}	22.87	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.77	22.825	0.027	0.118
T_{21}	22.87	22.87	22.82	22.82	22.82	22.87	22.87	22.82	22.82	22.82	22.840	0.024	0.107
T_{22}	22.92	22.97	22.92	22.92	22.92	22.92	22.92	22.92	22.92	22.87	22.920	0.022	0.098
T_{23}	22.87	22.87	22.82	22.82	22.82	22.87	22.87	22.82	22.87	22.82	22.845	0.025	0.109
T_{24}	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.82	22.870	0.022	0.098
T_{25}	22.92	22.82	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.82	22.865	0.027	0.118
T_{26}	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.82	22.870	0.022	0.098
T_{27}	22.87	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.82	22.77	22.820	0.022	0.098
T_{28}	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.82	22.870	0.022	0.098
T_{29}	22.87	22.87	22.82	22.82	22.82	22.82	22.87	22.82	22.87	22.82	22.840	0.024	0.107
T_{30}	22.92	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.87	22.82	22.870	0.022	0.098
Avg	22.89	22.88	22.84	22.85	22.85	22.84	22.85	22.84	22.84	22.83	22.849		
Std	0.024	0.029	0.028	0.028	0.028	0.031	0.031	0.030	0.031	0.030			
%Std	0.105	0.127	0.122	0.123	0.123	0.135	0.136	0.132	0.135	0.131			

APPENDIX F

TABLES F-1...F-5

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	33.99	34.02	34.02	34.02	34.02	34.02	33.98	33.98	33.98	33.98	34.001	0.019	0.056
T_2	34.03	34.12	34.12	34.12	34.12	34.12	34.07	34.07	34.07	34.07	34.091	0.031	0.091
T_3	33.99	34.07	34.07	34.07	34.07	34.07	34.02	34.02	34.02	33.98	34.038	0.034	0.101
T_4	34.08	34.17	34.17	34.12	34.17	34.17	34.12	34.12	34.12	34.12	34.136	0.030	0.088
T_5	34.12	34.12	34.12	34.12	34.12	34.12	34.07	34.07	34.07	34.07	34.100	0.024	0.072
T_6	34.12	34.17	34.12	34.12	34.17	34.17	34.12	34.12	34.07	34.07	34.125	0.035	0.103
T_7	34.12	34.12	34.12	34.12	34.12	34.12	34.07	34.07	34.07	34.07	34.100	0.024	0.072
T_8	34.12	34.17	34.17	34.17	34.17	34.17	34.12	34.12	34.12	34.12	34.145	0.025	0.073
T_9	34.17	34.17	34.17	34.17	34.17	34.17	34.12	34.12	34.12	34.12	34.150	0.024	0.072
T_{10}	34.17	34.17	34.17	34.17	34.17	34.17	34.12	34.12	34.12	34.12	34.150	0.024	0.072
T_{11}	34.07	34.07	34.07	34.07	34.07	34.12	34.02	34.07	34.02	34.07	34.065	0.027	0.079
T_{12}	34.17	34.17	34.17	34.17	34.17	34.17	34.12	34.12	34.12	34.12	34.150	0.024	0.072
T_{13}	34.12	34.12	34.12	34.12	34.12	34.12	34.07	34.07	34.07	34.07	34.100	0.024	0.072
T_{14}	34.12	34.12	34.12	34.12	34.12	34.12	34.07	34.07	34.07	34.07	34.100	0.024	0.072
T_{15}	34.07	34.07	34.07	34.07	34.07	34.07	34.02	34.02	34.02	34.02	34.050	0.024	0.072
T_{16}	33.98	33.98	33.98	33.98	33.98	33.98	33.93	33.93	33.93	33.93	33.960	0.024	0.072
T_{17}	33.98	33.98	33.98	33.98	33.98	33.98	33.93	33.93	33.93	33.93	33.960	0.024	0.072
T_{18}	34.02	34.02	34.02	34.02	34.02	34.02	33.98	33.98	33.98	33.98	34.004	0.020	0.058
T_{19}	33.93	33.93	33.93	33.93	33.93	33.93	33.88	33.88	33.88	33.88	33.910	0.024	0.072
T_{20}	33.93	33.93	33.93	33.93	33.93	33.93	33.88	33.88	33.88	33.88	33.910	0.024	0.072
T_{21}	33.93	33.93	33.93	33.98	33.98	33.93	33.88	33.93	33.93	33.93	33.935	0.027	0.079
T_{22}	25.78	25.78	25.78	25.78	25.78	25.78	25.73	25.78	25.78	25.78	25.775	0.015	0.058
T_{23}	25.68	25.68	25.68	25.68	25.68	25.68	25.63	25.63	25.63	25.63	25.660	0.024	0.095
T_{24}	25.68	25.68	25.68	25.68	25.68	25.68	25.63	25.68	25.68	25.68	25.675	0.015	0.058
T_{25}	25.68	25.63	25.68	25.68	25.63	25.68	25.63	25.63	25.63	25.63	25.650	0.024	0.095
T_{26}	25.73	25.73	25.73	25.73	25.73	25.73	25.68	25.68	25.68	25.68	25.710	0.024	0.095
T_{27}	25.63	25.63	25.63	25.63	25.63	25.63	25.58	25.58	25.58	25.58	25.610	0.024	0.096
T_{28}	25.68	25.68	25.68	25.68	25.68	25.63	25.63	25.63	25.63	25.63	25.655	0.025	0.097
T_{29}	25.68	25.68	25.68	25.68	25.68	25.63	25.63	25.63	25.63	25.63	25.655	0.025	0.097
T_{30}	25.68	25.68	25.68	25.68	25.68	25.63	25.63	25.63	25.63	25.63	25.655	0.025	0.097
T_{31}	25.53	25.53	25.53	25.53	25.53	25.48	25.48	25.48	25.48	25.48	25.505	0.025	0.098
T_{32}	25.53	25.58	25.53	25.53	25.53	25.48	25.48	25.48	25.48	25.48	25.510	0.033	0.130
Q	1.099	1.100	1.098	1.101	1.102	1.103	1.103	1.103	1.104	1.104	1.102	0.002	0.184

Avg T_{hot} 34.06 **Avg T_{cold}** 25.68 **T_{mean}** 29.87 **Temp Diff** 8.37

Thermal Conductivity 0.107 ± 0.006

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.890	0.000	0.000
T_2	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.990	0.000	0.000
T_3	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.890	0.000	0.000
T_4	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.030	0.000	0.000
T_5	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.990	0.000	0.000
T_6	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.030	0.000	0.000
T_7	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.030	0.000	0.000
T_8	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.080	0.000	0.000
T_9	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.130	0.000	0.000
T_{10}	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.13	40.130	0.000	0.000
T_{11}	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.030	0.000	0.000
T_{12}	40.13	40.13	40.13	40.15	40.13	40.13	40.13	40.13	40.13	40.13	40.132	0.006	0.015
T_{13}	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.08	40.080	0.000	0.000
T_{14}	40.08	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.035	0.015	0.037
T_{15}	40.08	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.03	40.035	0.015	0.037
T_{16}	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.840	0.000	0.000
T_{17}	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.890	0.000	0.000
T_{18}	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.99	39.990	0.000	0.000
T_{19}	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.840	0.000	0.000
T_{20}	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.84	39.840	0.000	0.000
T_{21}	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.89	39.890	0.000	0.000
T_{22}	26.13	26.13	26.13	26.13	26.08	26.08	26.08	26.08	26.08	26.08	26.100	0.024	0.094
T_{23}	25.94	25.94	25.89	25.94	25.89	25.89	25.89	25.89	25.89	25.89	25.905	0.023	0.088
T_{24}	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.94	25.94	25.980	0.020	0.077
T_{25}	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.890	0.000	0.000
T_{26}	26.03	26.03	26.03	25.99	25.99	25.99	25.99	25.99	25.99	25.99	26.002	0.018	0.070
T_{27}	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.89	25.890	0.000	0.000
T_{28}	25.94	25.94	25.94	25.94	25.94	25.94	25.94	25.94	25.94	25.94	25.940	0.000	0.000
T_{29}	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.990	0.000	0.000
T_{30}	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.99	25.990	0.000	0.000
T_{31}	25.45	25.45	25.45	25.45	25.40	25.45	25.40	25.40	25.45	25.45	25.435	0.023	0.090
T_{32}	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.35	25.350	0.000	0.000
Q	2.011	2.009	2.011	2.008	2.010	2.012	2.010	2.011	2.008	2.011	2.010	0.001	0.068

Avg T_{hot} 39.99 Avg T_{cold} 25.98 T_{mean} 32.98 Temp Diff 14.01

Thermal Conductivity 0.116 ± 0.007

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.290	0.000	0.000
T_2	40.34	40.34	40.34	40.39	40.39	40.34	40.34	40.34	40.34	40.34	40.350	0.020	0.050
T_3	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.29	40.290	0.000	0.000
T_4	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.440	0.000	0.000
T_5	40.39	40.39	40.39	40.39	40.39	40.39	40.39	40.34	40.34	40.34	40.375	0.023	0.057
T_6	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.39	40.435	0.015	0.037
T_7	40.39	40.39	40.39	40.39	40.39	40.39	40.39	40.39	40.39	40.39	40.390	0.000	0.000
T_8	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.440	0.000	0.000
T_9	40.48	40.48	40.44	40.48	40.44	40.44	40.44	40.44	40.44	40.44	40.452	0.018	0.045
T_{10}	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.44	40.440	0.000	0.000
T_{11}	40.39	40.34	40.34	40.39	40.39	40.34	40.34	40.34	40.34	40.34	40.355	0.023	0.057
T_{12}	40.44	40.44	40.44	40.48	40.48	40.44	40.44	40.44	40.44	40.44	40.448	0.016	0.040
T_{13}	40.39	40.34	40.34	40.39	40.39	40.39	40.39	40.34	40.34	40.34	40.365	0.025	0.062
T_{14}	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.34	40.340	0.000	0.000
T_{15}	40.29	40.29	40.34	40.34	40.34	40.34	40.29	40.29	40.34	40.29	40.315	0.025	0.062
T_{16}	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.100	0.000	0.000
T_{17}	40.15	40.15	40.15	40.15	40.15	40.15	40.15	40.15	40.15	40.10	40.145	0.015	0.037
T_{18}	40.24	40.24	40.24	40.24	40.24	40.24	40.20	40.20	40.24	40.20	40.228	0.018	0.046
T_{19}	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.050	0.000	0.000
T_{20}	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.05	40.050	0.000	0.000
T_{21}	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.10	40.100	0.000	0.000
T_{22}	26.01	26.01	26.01	26.01	26.01	26.01	26.01	25.96	25.96	25.96	25.995	0.023	0.088
T_{23}	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.76	25.76	25.76	25.795	0.023	0.089
T_{24}	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.810	0.000	0.000
T_{25}	25.71	25.76	25.76	25.76	25.76	25.71	25.71	25.71	25.71	25.71	25.730	0.024	0.095
T_{26}	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.81	25.810	0.000	0.000
T_{27}	25.71	25.71	25.71	25.71	25.71	25.71	25.71	25.66	25.66	25.71	25.700	0.020	0.078
T_{28}	25.71	25.71	25.71	25.71	25.71	25.71	25.71	25.71	25.71	25.71	25.710	0.000	0.000
T_{29}	25.76	25.76	25.76	25.76	25.76	25.76	25.71	25.71	25.71	25.71	25.740	0.024	0.095
T_{30}	25.76	25.76	25.76	25.76	25.76	25.76	25.71	25.71	25.71	25.71	25.740	0.024	0.095
T_{31}	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.47	25.47	25.47	25.505	0.023	0.090
T_{32}	25.56	25.52	25.52	25.52	25.52	25.52	25.52	25.52	25.47	25.52	25.519	0.020	0.079
Q	2.035	2.041	2.039	2.040	2.042	2.044	2.043	2.042	2.043	2.040	2.041	0.002	0.121

Avg T_{hot} 40.30 Avg T_{cold} 25.80 T_{mean} 33.05 Temp Diff 14.50

Thermal Conductivity 0.114 ± 0.006

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	38.64	38.64	38.64	38.64	38.60	38.60	38.60	38.60	38.64	38.60	38.620	0.020	0.052
T_2	38.69	38.69	38.69	38.69	38.69	38.69	38.69	38.64	38.69	38.69	38.685	0.015	0.039
T_3	38.60	38.60	38.60	38.60	38.60	38.60	38.60	38.60	38.60	38.60	38.600	0.000	0.000
T_4	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.790	0.000	0.000
T_5	38.69	38.69	38.69	38.69	38.69	38.69	38.69	38.69	38.69	38.69	38.690	0.000	0.000
T_6	38.79	38.79	38.79	38.79	38.74	38.74	38.74	38.74	38.74	38.74	38.760	0.024	0.063
T_7	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.740	0.000	0.000
T_8	38.84	38.84	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.800	0.020	0.052
T_9	38.84	38.84	38.84	38.84	38.84	38.84	38.84	38.84	38.84	38.84	38.840	0.000	0.000
T_{10}	38.84	38.84	38.84	38.84	38.84	38.84	38.84	38.79	38.84	38.84	38.835	0.015	0.039
T_{11}	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.740	0.000	0.000
T_{12}	38.88	38.88	38.88	38.88	38.88	38.88	38.88	38.88	38.88	38.88	38.880	0.000	0.000
T_{13}	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.79	38.74	38.79	38.785	0.015	0.039
T_{14}	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.740	0.000	0.000
T_{15}	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.74	38.740	0.000	0.000
T_{16}	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.450	0.000	0.000
T_{17}	38.50	38.50	38.50	38.50	38.50	38.50	38.50	38.50	38.50	38.50	38.500	0.000	0.000
T_{18}	38.64	38.64	38.64	38.64	38.64	38.64	38.64	38.64	38.64	38.64	38.640	0.000	0.000
T_{19}	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.450	0.000	0.000
T_{20}	38.45	38.50	38.50	38.45	38.45	38.45	38.45	38.45	38.45	38.45	38.460	0.020	0.052
T_{21}	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.55	38.550	0.000	0.000
T_{22}	20.33	20.33	20.33	20.33	20.33	20.33	20.33	20.33	20.33	20.33	20.330	0.000	0.000
T_{23}	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.080	0.000	0.000
T_{24}	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.130	0.000	0.000
T_{25}	19.98	20.03	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.985	0.015	0.075
T_{26}	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.13	20.130	0.000	0.000
T_{27}	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.98	19.980	0.000	0.000
T_{28}	20.03	20.03	20.03	20.03	20.03	20.03	20.03	20.03	20.03	20.03	20.030	0.000	0.000
T_{29}	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.080	0.000	0.000
T_{30}	20.13	20.13	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.08	20.090	0.020	0.100
T_{31}	19.56	19.56	19.51	19.56	19.51	19.56	19.51	19.51	19.51	19.51	19.530	0.024	0.125
T_{32}	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.46	19.460	0.000	0.000
Q	2.513	2.514	2.518	2.518	2.515	2.481	2.482	2.482	2.513	2.546	2.508	0.019	0.774

Avg T_{hot} 38.68 **Avg T_{cold}** 20.12 **T_{mean}** 29.40 **Temp Diff** 18.56

Thermal Conductivity 0.110 ± 0.006

TABLE F-5 RESULTS (AIR 5)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	38.39	38.44	38.39	38.39	38.34	38.34	38.34	38.34	38.34	38.34	38.365	0.034	0.087
T_2	38.44	38.44	38.44	38.44	38.39	38.39	38.39	38.39	38.39	38.39	38.410	0.024	0.064
T_3	38.39	38.39	38.39	38.39	38.34	38.34	38.34	38.34	38.34	38.34	38.360	0.024	0.064
T_4	38.54	38.54	38.54	38.54	38.49	38.49	38.49	38.49	38.49	38.49	38.510	0.024	0.064
T_5	38.44	38.44	38.44	38.44	38.39	38.39	38.39	38.39	38.39	38.39	38.410	0.024	0.064
T_6	38.54	38.54	38.54	38.54	38.49	38.49	38.49	38.49	38.49	38.49	38.510	0.024	0.064
T_7	38.49	38.49	38.49	38.49	38.44	38.44	38.44	38.44	38.44	38.44	38.460	0.024	0.064
T_8	38.54	38.54	38.54	38.54	38.49	38.49	38.49	38.49	38.49	38.49	38.510	0.024	0.064
T_9	38.54	38.54	38.54	38.54	38.49	38.49	38.49	38.49	38.49	38.49	38.510	0.024	0.064
T_{10}	38.54	38.54	38.54	38.49	38.49	38.49	38.49	38.49	38.49	38.49	38.505	0.023	0.060
T_{11}	38.39	38.39	38.39	38.44	38.39	38.39	38.39	38.39	38.39	38.39	38.395	0.015	0.039
T_{12}	38.54	38.54	38.54	38.54	38.49	38.49	38.49	38.49	38.49	38.49	38.510	0.024	0.064
T_{13}	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.39	38.390	0.000	0.000
T_{14}	38.39	38.39	38.39	38.39	38.34	38.34	38.34	38.34	38.34	38.34	38.360	0.024	0.064
T_{15}	38.34	38.34	38.34	38.34	38.34	38.30	38.30	38.30	38.34	38.34	38.328	0.018	0.048
T_{16}	38.06	38.06	38.06	38.06	38.06	38.01	38.01	38.01	38.01	38.01	38.035	0.025	0.066
T_{17}	38.10	38.10	38.10	38.10	38.06	38.06	38.06	38.06	38.06	38.06	38.076	0.020	0.051
T_{18}	38.25	38.25	38.25	38.25	38.20	38.20	38.20	38.20	38.20	38.20	38.220	0.024	0.064
T_{19}	38.06	38.06	38.06	38.06	38.01	38.01	38.01	38.01	38.01	38.01	38.030	0.024	0.064
T_{20}	38.01	38.01	38.01	38.01	38.01	38.01	38.01	38.01	38.01	38.01	38.010	0.000	0.000
T_{21}	38.06	38.06	38.06	38.06	38.06	38.06	38.06	38.06	38.06	38.06	38.060	0.000	0.000
T_{22}	20.12	20.12	20.12	20.12	20.07	20.07	20.07	20.07	20.07	20.07	20.090	0.024	0.122
T_{23}	19.89	19.89	19.89	19.89	19.85	19.85	19.85	19.85	19.85	19.85	19.866	0.020	0.099
T_{24}	19.89	19.94	19.94	19.94	19.89	19.89	19.89	19.89	19.89	19.89	19.905	0.023	0.115
T_{25}	19.80	19.80	19.80	19.80	19.75	19.75	19.75	19.75	19.75	19.75	19.770	0.024	0.124
T_{26}	19.85	19.85	19.85	19.85	19.80	19.80	19.85	19.85	19.80	19.85	19.835	0.023	0.116
T_{27}	19.75	19.75	19.75	19.75	19.70	19.70	19.70	19.70	19.70	19.70	19.720	0.024	0.124
T_{28}	19.75	19.75	19.75	19.75	19.70	19.70	19.70	19.70	19.70	19.70	19.720	0.024	0.124
T_{29}	19.80	19.80	19.80	19.80	19.75	19.75	19.75	19.75	19.75	19.75	19.770	0.024	0.124
T_{30}	19.80	19.80	19.80	19.80	19.75	19.75	19.75	19.75	19.75	19.75	19.770	0.024	0.124
T_{31}	19.60	19.60	19.60	19.60	19.55	19.55	19.55	19.60	19.55	19.60	19.580	0.024	0.125
T_{32}	19.60	19.60	19.60	19.55	19.55	19.55	19.55	19.55	19.55	19.55	19.565	0.023	0.117
Q	2.498	2.498	2.498	2.499	2.503	2.496	2.495	2.497	2.498	2.496	2.498	0.002	0.090

Avg T_{hot} 38.33 **Avg T_{cold}** 19.85 **T_{mean}** 29.09 **Temp Diff** 18.48

Thermal Conductivity 0.110 ± 0.006

APPENDIX G

TABLES G-1...G-15

TABLE G-1 RESULTS (SET # 1)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	30.46	30.46	30.46	30.42	30.46	30.42	30.42	30.46	30.43	30.43	30.442	0.018	0.06
T_2	30.51	30.51	30.51	30.56	30.56	30.51	30.51	30.56	30.53	30.53	30.529	0.022	0.07
T_3	30.42	30.42	30.42	30.42	30.37	30.37	30.37	30.42	30.39	30.34	30.394	0.028	0.09
T_4	30.61	30.61	30.61	30.66	30.66	30.66	30.66	30.66	30.63	30.63	30.639	0.022	0.07
T_5	30.56	30.56	30.56	30.56	30.56	30.56	30.56	30.56	30.53	30.53	30.554	0.012	0.04
T_6	30.61	30.61	30.61	30.61	30.61	30.61	30.61	30.61	30.58	30.58	30.604	0.012	0.04
T_7	30.66	30.66	30.66	30.66	30.71	30.66	30.71	30.71	30.68	30.68	30.679	0.022	0.07
T_8	30.76	30.76	30.76	30.76	30.76	30.76	30.76	30.76	30.73	30.73	30.754	0.012	0.04
T_9	30.76	30.76	30.76	30.76	30.76	30.76	30.76	30.80	30.77	30.77	30.766	0.012	0.04
T_{10}	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.80	30.77	30.82	30.799	0.011	0.04
T_{11}	30.76	30.76	30.76	30.76	30.76	30.76	30.76	30.76	30.77	30.77	30.762	0.004	0.01
T_{12}	30.80	30.80	30.80	30.85	30.85	30.85	30.85	30.85	30.82	30.82	30.829	0.022	0.07
T_{13}	30.85	30.85	30.85	30.85	30.85	30.90	30.90	30.90	30.87	30.87	30.869	0.022	0.07
T_{14}	30.85	30.85	30.85	30.85	30.85	30.90	30.90	30.90	30.87	30.87	30.869	0.022	0.07
T_{15}	30.80	30.80	30.80	30.80	30.85	30.85	30.85	30.85	30.82	30.82	30.824	0.022	0.07
T_{16}	30.76	30.80	30.80	30.80	30.80	30.80	30.80	30.85	30.82	30.82	30.805	0.022	0.07
T_{17}	30.76	30.76	30.76	30.80	30.80	30.80	30.80	30.80	30.82	30.82	30.792	0.022	0.07
T_{18}	30.85	30.85	30.85	30.85	30.85	30.90	30.90	30.90	30.87	30.87	30.869	0.022	0.07
T_{19}	30.71	30.71	30.76	30.76	30.76	30.76	30.76	30.80	30.77	30.77	30.756	0.026	0.08
T_{20}	30.76	30.76	30.80	30.80	30.80	30.80	30.80	30.85	30.82	30.82	30.801	0.025	0.08
T_{21}	30.80	30.80	30.80	30.80	30.80	30.85	30.85	30.85	30.82	30.82	30.819	0.022	0.07
T_{22}	20.25	20.25	20.25	20.25	20.25	20.25	20.30	20.25	20.22	20.27	20.254	0.019	0.09
T_{23}	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.12	20.12	20.144	0.012	0.06
T_{24}	20.20	20.20	20.20	20.20	20.20	20.20	20.25	20.20	20.22	20.22	20.209	0.016	0.08
T_{25}	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.17	20.22	20.199	0.011	0.06
T_{26}	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.35	20.32	20.32	20.309	0.016	0.08
T_{27}	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.17	20.22	20.199	0.011	0.06
T_{28}	20.20	20.20	20.25	20.25	20.25	20.25	20.25	20.25	20.22	20.22	20.234	0.021	0.10
T_{29}	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.30	20.27	20.32	20.299	0.011	0.06
T_{30}	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.35	20.32	20.32	20.344	0.012	0.06
T_{31}	19.50	19.50	19.50	19.50	19.50	19.55	19.55	19.50	19.52	19.52	19.514	0.020	0.10
T_{32}	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.45	19.42	19.42	19.444	0.012	0.06
Q	2.552	2.564	2.550	2.556	2.556	2.552	2.553	2.560	2.557	2.545	2.555	0.005	0.20

Avg T_{hot} 30.72 **Avg T_{cold}** 20.24 **T_{mean}** 25.48 **Temp Diff** 10.48

Thermal Conductivity 0.198 ± 0.011

TABLE G-2 RESULTS (SET # 2)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	30.42	30.42	30.42	30.42	30.42	30.42	30.45	30.45	30.45	30.45	30.432	0.015	0.05
T_2	30.51	30.51	30.51	30.51	30.51	30.51	30.55	30.55	30.55	30.55	30.526	0.020	0.06
T_3	30.42	30.42	30.42	30.42	30.42	30.42	30.45	30.45	30.41	30.41	30.424	0.014	0.04
T_4	30.61	30.61	30.61	30.61	30.61	30.61	30.65	30.65	30.65	30.65	30.626	0.020	0.06
T_5	30.56	30.56	30.56	30.56	30.56	30.56	30.60	30.60	30.60	30.60	30.576	0.020	0.06
T_6	30.61	30.61	30.61	30.61	30.61	30.61	30.65	30.65	30.65	30.65	30.626	0.020	0.06
T_7	30.66	30.66	30.66	30.66	30.66	30.66	30.70	30.70	30.70	30.70	30.676	0.020	0.06
T_8	30.76	30.76	30.76	30.71	30.71	30.71	30.75	30.75	30.75	30.75	30.741	0.021	0.07
T_9	30.76	30.76	30.76	30.76	30.76	30.76	30.79	30.79	30.75	30.79	30.768	0.015	0.05
T_{10}	30.76	30.76	30.76	30.76	30.76	30.76	30.79	30.79	30.79	30.79	30.772	0.015	0.05
T_{11}	30.71	30.71	30.71	30.76	30.71	30.71	30.75	30.75	30.75	30.75	30.731	0.021	0.07
T_{12}	30.80	30.80	30.80	30.80	30.80	30.80	30.84	30.84	30.84	30.84	30.816	0.020	0.06
T_{13}	30.80	30.80	30.80	30.80	30.80	30.80	30.84	30.84	30.84	30.84	30.816	0.020	0.06
T_{14}	30.80	30.80	30.80	30.80	30.80	30.80	30.84	30.84	30.84	30.84	30.816	0.020	0.06
T_{15}	30.80	30.80	30.76	30.76	30.80	30.76	30.79	30.84	30.79	30.79	30.789	0.023	0.08
T_{16}	30.76	30.71	30.71	30.71	30.71	30.71	30.75	30.75	30.75	30.75	30.731	0.021	0.07
T_{17}	30.76	30.71	30.71	30.71	30.71	30.71	30.75	30.75	30.75	30.75	30.731	0.021	0.07
T_{18}	30.80	30.80	30.80	30.80	30.80	30.80	30.84	30.79	30.79	30.79	30.801	0.014	0.04
T_{19}	30.66	30.66	30.66	30.66	30.66	30.66	30.70	30.70	30.70	30.65	30.671	0.019	0.06
T_{20}	30.71	30.71	30.71	30.71	30.71	30.66	30.70	30.70	30.70	30.70	30.701	0.014	0.05
T_{21}	30.71	30.71	30.71	30.71	30.71	30.71	30.75	30.75	30.75	30.70	30.721	0.019	0.06
T_{22}	20.05	20.05	20.05	20.05	20.05	20.05	20.09	20.09	20.09	20.09	20.066	0.020	0.10
T_{23}	19.95	19.95	19.95	19.95	19.95	19.95	19.99	19.99	19.99	19.99	19.966	0.020	0.10
T_{24}	20.05	20.00	20.00	20.00	20.00	20.00	20.04	20.04	20.04	20.04	20.021	0.021	0.11
T_{25}	20.00	20.00	20.00	20.00	20.00	20.00	20.04	20.04	20.04	20.04	20.016	0.020	0.10
T_{26}	20.10	20.10	20.10	20.10	20.10	20.14	20.14	20.14	20.14	20.09	20.115	0.021	0.10
T_{27}	19.95	19.95	19.95	19.95	20.00	19.99	19.99	19.99	19.99	19.99	19.975	0.021	0.10
T_{28}	20.00	20.00	20.00	20.00	20.00	20.04	20.04	20.04	20.04	20.04	20.020	0.020	0.10
T_{29}	20.10	20.10	20.05	20.05	20.10	20.09	20.09	20.09	20.09	20.09	20.085	0.018	0.09
T_{30}	20.05	20.05	20.05	20.05	20.05	20.09	20.09	20.09	20.09	20.09	20.070	0.020	0.10
T_{31}	19.35	19.35	19.35	19.35	19.30	19.39	19.34	19.34	19.34	19.34	19.345	0.021	0.11
T_{32}	19.25	19.25	19.25	19.25	19.25	19.29	19.24	19.24	19.24	19.24	19.250	0.014	0.07
Q	2.535	2.534	2.532	2.539	2.537	2.538	2.536	2.534	2.543	2.544	2.537	0.004	0.15

Avg T_{hot} 30.69 Avg T_{cold} 20.04 T_{mean} 25.37 Temp Diff 10.65

Thermal Conductivity 0.193 ± 0.011

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.060	0.000	0.00
T_2	30.21	30.16	30.16	30.16	30.16	30.16	30.16	30.16	30.16	30.16	30.165	0.015	0.05
T_3	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.06	30.01	30.01	30.050	0.020	0.07
T_4	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.21	30.21	30.250	0.020	0.07
T_5	30.21	30.21	30.21	30.21	30.16	30.16	30.16	30.16	30.16	30.16	30.180	0.024	0.08
T_6	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.26	30.21	30.21	30.250	0.020	0.07
T_7	30.31	30.31	30.31	30.31	30.31	30.31	30.31	30.31	30.26	30.26	30.300	0.020	0.07
T_8	30.40	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.355	0.015	0.05
T_9	30.40	30.40	30.40	30.40	30.35	30.35	30.40	30.35	30.35	30.35	30.375	0.025	0.08
T_{10}	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.400	0.000	0.00
T_{11}	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.350	0.000	0.00
T_{12}	30.45	30.45	30.45	30.40	30.45	30.45	30.40	30.40	30.40	30.40	30.425	0.025	0.08
T_{13}	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.450	0.000	0.00
T_{14}	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.450	0.000	0.00
T_{15}	30.45	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.405	0.015	0.05
T_{16}	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.400	0.000	0.00
T_{17}	30.40	30.40	30.40	30.40	30.40	30.40	30.35	30.35	30.35	30.35	30.380	0.024	0.08
T_{18}	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.45	30.450	0.000	0.00
T_{19}	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.35	30.350	0.000	0.00
T_{20}	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.40	30.400	0.000	0.00
T_{21}	30.40	30.40	30.45	30.40	30.40	30.40	30.40	30.45	30.40	30.40	30.410	0.020	0.07
T_{22}	20.21	20.21	20.21	20.21	20.21	20.21	20.21	20.21	20.16	20.21	20.205	0.015	0.07
T_{23}	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.110	0.000	0.00
T_{24}	20.21	20.21	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.170	0.020	0.10
T_{25}	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.11	20.16	20.16	20.155	0.015	0.07
T_{26}	20.26	20.31	20.26	20.26	20.26	20.26	20.26	20.26	20.26	20.26	20.265	0.015	0.07
T_{27}	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.11	20.110	0.000	0.00
T_{28}	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.160	0.000	0.00
T_{29}	20.21	20.21	20.21	20.16	20.16	20.16	20.16	20.16	20.16	20.16	20.175	0.023	0.11
T_{30}	20.26	20.21	20.21	20.21	20.21	20.21	20.21	20.21	20.21	20.21	20.215	0.015	0.07
T_{31}	19.44	19.49	19.44	19.44	19.44	19.44	19.49	19.44	19.44	19.44	19.450	0.020	0.10
T_{32}	19.39	19.39	19.34	19.34	19.39	19.34	19.34	19.34	19.34	19.34	19.355	0.023	0.12
Q	2.496	2.494	2.481	2.487	2.493	2.493	2.486	2.493	2.492	2.482	2.490	0.005	0.20

Avg T_{hot} 30.33 **Avg T_{cold}** 20.18 **T_{mean}** 25.25 **Temp Diff** 10.15

Thermal Conductivity 0.199 ± 0.011

TABLE G-4 RESULTS (SET # 4)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	29.45	29.45	29.45	29.45	29.45	29.45	29.45	29.45	29.45	29.45	29.450	0.000	0.00
T_2	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.550	0.000	0.00
T_3	29.45	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.50	29.495	0.015	0.05
T_4	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.650	0.000	0.00
T_5	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.550	0.000	0.00
T_6	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.600	0.000	0.00
T_7	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.60	29.645	0.015	0.05
T_8	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.690	0.000	0.00
T_9	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.60	29.65	29.645	0.015	0.05
T_{10}	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.690	0.000	0.00
T_{11}	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.650	0.000	0.00
T_{12}	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.690	0.000	0.00
T_{13}	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.690	0.000	0.00
T_{14}	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.69	29.690	0.000	0.00
T_{15}	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.650	0.000	0.00
T_{16}	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.600	0.000	0.00
T_{17}	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.60	29.600	0.000	0.00
T_{18}	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.65	29.650	0.000	0.00
T_{19}	29.50	29.50	29.50	29.55	29.50	29.50	29.50	29.50	29.50	29.50	29.505	0.015	0.05
T_{20}	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.50	29.545	0.015	0.05
T_{21}	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.55	29.550	0.000	0.00
T_{22}	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.060	0.000	0.00
T_{23}	19.96	19.96	19.96	19.96	19.96	19.96	19.96	20.01	19.96	19.96	19.965	0.015	0.08
T_{24}	20.01	19.96	20.01	20.01	20.01	20.01	20.01	20.01	20.01	20.01	20.005	0.015	0.07
T_{25}	19.96	19.96	19.96	19.96	19.96	20.01	20.01	20.01	19.96	19.96	19.975	0.023	0.11
T_{26}	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.06	20.060	0.000	0.00
T_{27}	19.91	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.955	0.015	0.08
T_{28}	19.91	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.955	0.015	0.08
T_{29}	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.960	0.000	0.00
T_{30}	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.96	19.960	0.000	0.00
T_{31}	19.76	19.76	19.76	19.76	19.76	19.76	19.76	19.76	19.76	19.76	19.760	0.000	0.00
T_{32}	19.76	19.71	19.71	19.71	19.71	19.76	19.76	19.76	19.76	19.76	19.740	0.024	0.12
Q	2.328	2.334	2.331	2.333	2.337	2.338	2.337	2.339	2.338	2.339	2.335	0.004	0.15

Avg T_{hot} 29.61 **Avg T_{cold}** 20.00 **T_{mean}** 24.80 **Temp Diff** 9.61

Thermal Conductivity 0.197 ± 0.011

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	28.98	28.98	28.98	28.98	28.98	28.98	29.03	29.03	29.03	29.03	29.000	0.024	0.08
T_2	29.08	29.08	29.08	29.08	29.08	29.08	29.13	29.13	29.13	29.13	29.100	0.024	0.08
T_3	28.98	28.98	28.98	28.98	28.98	28.98	28.98	28.98	28.98	29.03	28.985	0.015	0.05
T_4	29.17	29.17	29.17	29.17	29.17	29.17	29.17	29.22	29.22	29.22	29.185	0.023	0.08
T_5	29.13	29.13	29.13	29.13	29.13	29.13	29.13	29.13	29.13	29.13	29.130	0.000	0.00
T_6	29.17	29.17	29.17	29.17	29.17	29.17	29.17	29.17	29.17	29.17	29.170	0.000	0.00
T_7	29.22	29.22	29.22	29.22	29.22	29.22	29.22	29.22	29.22	29.27	29.225	0.015	0.05
T_8	29.27	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.315	0.015	0.05
T_9	29.27	29.27	29.27	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.305	0.023	0.08
T_{10}	29.32	29.32	29.32	29.37	29.37	29.37	29.37	29.37	29.37	29.37	29.355	0.023	0.08
T_{11}	29.27	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.32	29.315	0.015	0.05
T_{12}	29.37	29.37	29.37	29.37	29.37	29.37	29.37	29.37	29.42	29.42	29.380	0.020	0.07
T_{13}	29.37	29.37	29.42	29.42	29.42	29.42	29.42	29.42	29.47	29.47	29.420	0.032	0.11
T_{14}	29.37	29.42	29.42	29.42	29.42	29.42	29.42	29.42	29.47	29.47	29.425	0.027	0.09
T_{15}	29.32	29.37	29.37	29.37	29.37	29.37	29.37	29.42	29.42	29.42	29.380	0.030	0.10
T_{16}	29.32	29.32	29.32	29.37	29.37	29.37	29.37	29.37	29.37	29.37	29.355	0.023	0.08
T_{17}	29.32	29.32	29.32	29.37	29.37	29.37	29.37	29.37	29.37	29.37	29.355	0.023	0.08
T_{18}	29.37	29.42	29.42	29.42	29.42	29.42	29.42	29.47	29.47	29.47	29.430	0.030	0.10
T_{19}	29.27	29.32	29.32	29.32	29.32	29.32	29.37	29.37	29.37	29.37	29.335	0.032	0.11
T_{20}	29.32	29.32	29.37	29.37	29.37	29.37	29.37	29.42	29.42	29.42	29.375	0.035	0.12
T_{21}	29.37	29.37	29.37	29.37	29.37	29.42	29.42	29.42	29.42	29.42	29.395	0.025	0.09
T_{22}	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.150	0.000	0.00
T_{23}	20.05	20.10	20.10	20.05	20.10	20.05	20.05	20.05	20.10	20.05	20.070	0.024	0.12
T_{24}	20.10	20.15	20.10	20.15	20.15	20.15	20.10	20.15	20.15	20.10	20.130	0.024	0.12
T_{25}	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.100	0.000	0.00
T_{26}	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.200	0.000	0.00
T_{27}	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.10	20.100	0.000	0.00
T_{28}	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.15	20.150	0.000	0.00
T_{29}	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.200	0.000	0.00
T_{30}	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.20	20.200	0.000	0.00
T_{31}	19.45	19.45	19.45	19.50	19.45	19.45	19.45	19.50	19.50	19.45	19.465	0.023	0.12
T_{32}	19.38	19.38	19.38	19.38	19.38	19.38	19.38	19.43	19.43	19.43	19.395	0.023	0.12
Q	2.308	2.311	2.304	2.306	2.311	2.310	2.308	2.315	2.310	2.314	2.310	0.003	0.13

Avg T_{hot} 29.28 Avg T_{cold} 20.15 T_{mean} 24.71 Temp Diff 9.14

Thermal Conductivity 0.205 ± 0.012

TABLE G-6 RESULTS (SET # 6)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	43.89	43.94	43.94	43.94	43.94	43.94	43.94	43.98	43.98	43.93	43.942	0.024	0.05
T_2	43.80	43.80	43.84	43.94	43.98	44.03	44.03	44.07	44.12	44.12	43.973	0.117	0.27
T_3	43.94	43.94	43.94	43.94	43.94	43.94	43.94	44.02	44.02	44.02	43.964	0.037	0.08
T_4	44.13	44.13	44.17	44.17	44.17	44.17	44.17	44.21	44.16	44.16	44.164	0.022	0.05
T_5	44.03	44.03	44.03	44.03	44.03	44.03	44.03	44.07	44.02	44.12	44.042	0.029	0.07
T_6	44.13	44.08	44.13	44.13	44.17	44.22	44.22	44.26	44.26	44.28	44.188	0.066	0.15
T_7	44.22	44.22	44.22	44.22	44.22	44.22	44.22	44.26	44.26	44.26	44.232	0.018	0.04
T_8	44.24	44.24	44.29	44.29	44.29	44.29	44.29	44.33	44.33	44.38	44.297	0.040	0.09
T_9	44.22	44.22	44.22	44.17	44.17	44.17	44.22	44.26	44.26	44.21	44.212	0.032	0.07
T_{10}	44.29	44.29	44.29	44.29	44.29	44.34	44.34	44.38	44.38	44.38	44.327	0.040	0.09
T_{11}	44.24	44.24	44.24	44.24	44.24	44.24	44.24	44.28	44.28	44.28	44.252	0.018	0.04
T_{12}	44.29	44.29	44.29	44.29	44.29	44.34	44.34	44.38	44.38	44.38	44.327	0.040	0.09
T_{13}	44.34	44.34	44.34	44.39	44.39	44.39	44.39	44.42	44.42	44.42	44.384	0.031	0.07
T_{14}	44.34	44.34	44.34	44.34	44.34	44.34	44.34	44.38	44.38	44.38	44.352	0.018	0.04
T_{15}	44.29	44.24	44.24	44.29	44.29	44.29	44.24	44.33	44.33	44.33	44.287	0.035	0.08
T_{16}	44.24	44.24	44.24	44.24	44.24	44.29	44.29	44.33	44.33	44.33	44.277	0.040	0.09
T_{17}	44.24	44.24	44.24	44.24	44.24	44.24	44.24	44.28	44.33	44.28	44.257	0.029	0.07
T_{18}	44.34	44.34	44.34	44.34	44.34	44.34	44.34	44.38	44.38	44.42	44.356	0.027	0.06
T_{19}	44.22	44.22	44.22	44.22	44.22	44.22	44.22	44.26	44.26	44.26	44.232	0.018	0.04
T_{20}	44.22	44.22	44.24	44.24	44.24	44.24	44.24	44.28	44.28	44.28	44.248	0.022	0.05
T_{21}	44.24	44.24	44.24	44.24	44.29	44.29	44.29	44.33	44.33	44.33	44.282	0.038	0.08
T_{22}	35.23	35.23	35.18	35.18	35.18	35.18	35.18	35.22	35.17	35.17	35.192	0.023	0.07
T_{23}	35.13	35.13	35.13	35.13	35.13	35.13	35.08	35.12	35.12	35.12	35.122	0.015	0.04
T_{24}	35.18	35.18	35.18	35.18	35.18	35.18	35.18	35.22	35.17	35.17	35.182	0.013	0.04
T_{25}	35.18	35.18	35.18	35.18	35.18	35.18	35.18	35.22	35.22	35.22	35.192	0.018	0.05
T_{26}	35.28	35.28	35.28	35.28	35.28	35.28	35.28	35.31	35.31	35.31	35.289	0.014	0.04
T_{27}	35.13	35.13	35.13	35.13	35.13	35.13	35.13	35.17	35.17	35.17	35.142	0.018	0.05
T_{28}	35.18	35.18	35.18	35.18	35.18	35.18	35.18	35.22	35.22	35.22	35.192	0.018	0.05
T_{29}	35.23	35.23	35.23	35.23	35.23	35.23	35.27	35.27	35.27	35.27	35.246	0.020	0.06
T_{30}	35.28	35.23	35.23	35.23	35.28	35.28	35.31	35.27	35.31	35.31	35.273	0.031	0.09
T_{31}	34.22	34.22	34.22	34.22	34.22	34.22	34.25	34.25	34.25	34.30	34.237	0.025	0.07
T_{32}	34.17	34.17	34.17	34.17	34.17	34.17	34.21	34.21	34.25	34.21	34.190	0.027	0.08
Q	3.723	3.727	3.732	3.720	3.721	3.726	3.713	3.712	3.710	3.730	3.721	0.007	0.20

Avg T_{hot} 44.22 **Avg T_{cold}** 35.20 **T_{mean}** 39.71 **Temp Diff** 9.02

Thermal Conductivity 0.335 ± 0.019

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	46.48	46.43	46.43	46.38	46.38	46.38	46.41	46.41	46.41	46.41	46.412	0.029	0.06
T_2	46.62	46.57	46.57	46.57	46.53	46.53	46.55	46.55	46.55	46.55	46.559	0.025	0.05
T_3	46.48	46.48	46.43	46.38	46.43	46.38	46.41	46.41	46.46	46.46	46.432	0.035	0.08
T_4	46.71	46.67	46.62	46.57	46.48	46.43	46.46	46.55	46.60	46.65	46.574	0.089	0.19
T_5	46.24	46.20	46.24	46.34	46.38	46.38	46.46	46.46	46.46	46.46	46.362	0.098	0.21
T_6	46.48	46.57	46.62	46.62	46.62	46.62	46.65	46.65	46.65	46.65	46.613	0.050	0.11
T_7	46.76	46.71	46.71	46.67	46.57	46.53	46.55	46.51	46.55	46.51	46.607	0.090	0.19
T_8	46.85	46.81	46.81	46.76	46.76	46.76	46.74	46.74	46.70	46.74	46.767	0.042	0.09
T_9	46.85	46.81	46.81	46.76	46.76	46.71	46.74	46.70	46.65	46.60	46.739	0.073	0.16
T_{10}	46.81	46.81	46.76	46.81	46.76	46.76	46.74	46.74	46.70	46.65	46.754	0.049	0.10
T_{11}	46.76	46.71	46.71	46.71	46.71	46.67	46.74	46.70	46.70	46.65	46.706	0.029	0.06
T_{12}	46.85	46.85	46.81	46.81	46.81	46.81	46.84	46.84	46.84	46.79	46.825	0.020	0.04
T_{13}	46.81	46.81	46.81	46.81	46.81	46.81	46.84	46.84	46.79	46.79	46.812	0.016	0.03
T_{14}	46.76	46.76	46.76	46.76	46.76	46.76	46.79	46.79	46.74	46.74	46.762	0.016	0.03
T_{15}	46.76	46.76	46.76	46.71	46.71	46.71	46.74	46.74	46.74	46.70	46.733	0.022	0.05
T_{16}	46.62	46.62	46.62	46.62	46.62	46.62	46.65	46.65	46.60	46.60	46.622	0.016	0.03
T_{17}	46.62	46.62	46.62	46.57	46.57	46.57	46.60	46.60	46.60	46.60	46.597	0.020	0.04
T_{18}	46.71	46.71	46.71	46.67	46.67	46.71	46.70	46.70	46.70	46.70	46.698	0.015	0.03
T_{19}	46.48	46.48	46.48	46.48	46.48	46.48	46.51	46.51	46.51	46.51	46.492	0.015	0.03
T_{20}	46.48	46.53	46.48	46.53	46.48	46.53	46.55	46.55	46.51	46.51	46.515	0.026	0.06
T_{21}	46.57	46.57	46.57	46.57	46.57	46.57	46.60	46.60	46.55	46.55	46.572	0.016	0.03
T_{22}	34.28	34.33	34.33	34.33	34.33	34.28	34.31	34.26	34.26	34.21	34.292	0.039	0.11
T_{23}	34.33	34.33	34.33	34.28	34.28	34.28	34.26	34.21	34.21	34.21	34.272	0.047	0.14
T_{24}	34.33	34.33	34.38	34.38	34.33	34.33	34.31	34.31	34.26	34.26	34.322	0.039	0.11
T_{25}	34.38	34.43	34.43	34.43	34.38	34.38	34.41	34.41	34.41	34.36	34.402	0.024	0.07
T_{26}	34.52	34.52	34.52	34.52	34.47	34.47	34.50	34.50	34.50	34.45	34.497	0.024	0.07
T_{27}	34.33	34.33	34.33	34.33	34.33	34.33	34.36	34.36	34.36	34.36	34.342	0.015	0.04
T_{28}	34.38	34.38	34.38	34.38	34.38	34.38	34.41	34.36	34.36	34.36	34.377	0.014	0.04
T_{29}	34.38	34.38	34.38	34.38	34.38	34.38	34.41	34.41	34.36	34.36	34.382	0.016	0.05
T_{30}	34.38	34.38	34.33	34.33	34.33	34.33	34.36	34.36	34.36	34.36	34.352	0.019	0.06
T_{31}	33.29	33.29	33.29	33.29	33.29	33.29	33.32	33.32	33.32	33.32	33.302	0.015	0.04
T_{32}	33.29	33.29	33.29	33.29	33.24	33.29	33.32	33.32	33.27	33.27	33.287	0.022	0.07
Q	4.660	4.657	4.646	4.666	4.657	4.641	4.646	4.651	4.641	4.655	4.652	0.008	0.17

Avg T_{hot} 46.63 Avg T_{cold} 34.35 T_{mean} 40.49 Temp Diff 12.27

Thermal Conductivity 0.308 ± 0.017

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	48.47	48.47	48.51	48.51	48.56	48.60	48.65	48.69	48.69	48.74	48.589	0.094	0.19
T_2	48.61	48.61	48.66	48.66	48.70	48.74	48.79	48.79	48.83	48.83	48.722	0.081	0.17
T_3	48.47	48.51	48.51	48.56	48.56	48.65	48.65	48.69	48.74	48.74	48.608	0.094	0.19
T_4	48.70	48.75	48.75	48.80	48.80	48.88	48.93	48.93	48.97	49.02	48.853	0.102	0.21
T_5	48.61	48.61	48.66	48.66	48.70	48.74	48.79	48.83	48.83	48.88	48.731	0.093	0.19
T_6	48.70	48.70	48.75	48.75	48.80	48.83	48.88	48.88	48.93	48.97	48.819	0.090	0.18
T_7	48.47	48.47	48.51	48.56	48.56	48.65	48.65	48.69	48.74	48.79	48.609	0.106	0.22
T_8	48.61	48.66	48.70	48.75	48.80	48.88	48.93	48.97	49.02	49.02	48.834	0.143	0.29
T_9	48.42	48.51	48.61	48.66	48.70	48.79	48.83	48.88	48.93	48.97	48.730	0.173	0.35
T_{10}	48.37	48.47	48.61	48.66	48.74	48.79	48.83	48.83	48.88	48.93	48.711	0.173	0.36
T_{11}	48.42	48.42	48.37	48.47	48.37	48.37	48.41	48.46	48.46	48.51	48.426	0.046	0.09
T_{12}	48.70	48.70	48.70	48.75	48.79	48.83	48.88	48.88	48.93	48.97	48.813	0.095	0.19
T_{13}	48.42	48.47	48.47	48.47	48.51	48.55	48.55	48.55	48.60	48.60	48.519	0.058	0.12
T_{14}	48.37	48.42	48.47	48.47	48.46	48.51	48.46	48.51	48.55	48.60	48.482	0.061	0.13
T_{15}	48.51	48.51	48.51	48.56	48.60	48.65	48.65	48.69	48.74	48.74	48.616	0.087	0.18
T_{16}	48.19	48.19	48.19	48.19	48.27	48.27	48.27	48.27	48.27	48.32	48.243	0.046	0.09
T_{17}	48.14	48.19	48.19	48.14	48.22	48.18	48.18	48.22	48.22	48.27	48.195	0.037	0.08
T_{18}	48.33	48.33	48.33	48.33	48.32	48.41	48.41	48.46	48.51	48.51	48.394	0.073	0.15
T_{19}	48.09	48.09	48.09	48.09	48.18	48.18	48.22	48.22	48.27	48.27	48.170	0.071	0.15
T_{20}	48.09	48.14	48.14	48.14	48.22	48.22	48.27	48.27	48.32	48.32	48.213	0.078	0.16
T_{21}	48.14	48.14	48.19	48.19	48.27	48.27	48.27	48.32	48.32	48.37	48.248	0.075	0.16
T_{22}	32.27	32.27	32.27	32.27	32.31	32.26	32.26	32.26	32.26	32.26	32.269	0.014	0.04
T_{23}	32.32	32.27	32.27	32.22	32.26	32.21	32.21	32.21	32.21	32.16	32.234	0.043	0.13
T_{24}	32.36	32.36	32.36	32.32	32.36	32.31	32.31	32.31	32.31	32.26	32.326	0.032	0.10
T_{25}	32.56	32.51	32.51	32.51	32.50	32.50	32.45	32.45	32.40	32.36	32.475	0.057	0.17
T_{26}	32.75	32.70	32.70	32.70	32.69	32.69	32.65	32.65	32.65	32.60	32.678	0.039	0.12
T_{27}	32.61	32.61	32.61	32.61	32.60	32.60	32.60	32.60	32.60	32.55	32.599	0.017	0.05
T_{28}	32.61	32.61	32.61	32.61	32.60	32.60	32.60	32.60	32.60	32.60	32.604	0.005	0.02
T_{29}	32.70	32.70	32.70	32.65	32.69	32.69	32.69	32.69	32.69	32.69	32.689	0.014	0.04
T_{30}	32.65	32.65	32.65	32.65	32.69	32.69	32.65	32.65	32.65	32.65	32.658	0.016	0.05
T_{31}	31.39	31.39	31.39	31.39	31.43	31.39	31.39	31.39	31.39	31.39	31.394	0.012	0.04
T_{32}	31.39	31.35	31.35	31.35	31.39	31.39	31.39	31.39	31.34	31.39	31.373	0.021	0.07
Q	5.561	5.559	5.555	5.557	5.559	5.552	5.544	5.543	5.556	5.562	5.555	0.007	0.12

Avg T_{hot} 48.55 Avg T_{cold} 32.48 T_{mean} 40.51 Temp Diff 16.07

Thermal Conductivity 0.281 ± 0.016

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	50.47	50.47	50.47	50.52	50.56	50.60	50.60	50.65	50.65	50.70	50.569	0.080	0.16
T_2	50.57	50.57	50.57	50.61	50.65	50.70	50.74	50.74	50.74	50.79	50.668	0.080	0.16
T_3	50.43	50.47	50.47	50.47	50.56	50.60	50.60	50.65	50.65	50.70	50.560	0.090	0.18
T_4	50.71	50.71	50.75	50.75	50.84	50.88	50.88	50.93	50.93	50.98	50.836	0.094	0.19
T_5	50.52	50.57	50.57	50.57	50.65	50.70	50.74	50.74	50.74	50.79	50.659	0.090	0.18
T_6	50.66	50.66	50.71	50.75	50.79	50.84	50.84	50.88	50.88	50.93	50.794	0.091	0.18
T_7	50.47	50.47	50.47	50.52	50.60	50.65	50.70	50.74	50.84	50.84	50.630	0.140	0.28
T_8	50.38	50.43	50.47	50.52	50.65	50.70	50.74	50.79	50.84	50.88	50.640	0.170	0.34
T_9	50.71	50.71	50.75	50.80	50.84	50.88	50.88	50.93	50.98	50.98	50.846	0.097	0.19
T_{10}	50.52	50.57	50.57	50.61	50.65	50.70	50.70	50.74	50.74	50.79	50.659	0.084	0.17
T_{11}	50.24	50.24	50.29	50.24	50.14	49.93	50.14	50.18	50.23	50.23	50.186	0.097	0.19
T_{12}	50.57	50.61	50.61	50.66	50.70	50.74	50.79	50.79	50.84	50.84	50.715	0.095	0.19
T_{13}	50.24	50.24	50.29	50.29	50.37	50.37	50.42	50.42	50.42	50.46	50.352	0.077	0.15
T_{14}	50.29	50.29	50.33	50.37	50.42	50.42	50.46	50.46	50.46	50.51	50.401	0.073	0.15
T_{15}	50.33	50.33	50.38	50.42	50.42	50.42	50.46	50.46	50.51	50.51	50.424	0.061	0.12
T_{16}	49.96	49.91	49.96	49.95	49.95	49.93	49.95	49.95	50.00	50.00	49.956	0.026	0.05
T_{17}	49.91	49.91	49.91	49.95	49.93	49.83	49.79	49.74	49.69	49.65	49.831	0.103	0.21
T_{18}	50.05	50.05	50.05	50.09	50.09	50.14	50.14	50.14	50.14	50.14	50.103	0.040	0.08
T_{19}	49.79	49.79	49.75	49.79	49.83	49.83	49.83	49.83	49.83	49.83	49.810	0.027	0.05
T_{20}	49.75	49.75	49.75	49.79	49.79	49.79	49.79	49.79	49.79	49.79	49.778	0.018	0.04
T_{21}	49.84	49.84	49.84	49.88	49.88	49.88	49.88	49.88	49.88	49.88	49.868	0.018	0.04
T_{22}	29.64	29.64	29.64	29.68	29.68	29.68	29.68	29.63	29.63	29.63	29.653	0.022	0.08
T_{23}	29.59	29.59	29.59	29.58	29.58	29.58	29.53	29.53	29.53	29.53	29.563	0.027	0.09
T_{24}	29.78	29.73	29.73	29.73	29.73	29.73	29.73	29.68	29.68	29.68	29.720	0.030	0.10
T_{25}	29.93	29.93	29.88	29.92	29.87	29.82	29.82	29.77	29.77	29.73	29.844	0.069	0.23
T_{26}	30.17	30.12	30.12	30.16	30.16	30.12	30.12	30.07	30.07	30.02	30.113	0.045	0.15
T_{27}	29.98	29.98	29.98	30.02	30.07	30.07	30.02	30.02	30.02	30.02	30.018	0.031	0.10
T_{28}	29.98	29.98	29.98	30.02	30.02	30.02	30.02	30.02	30.02	30.02	30.008	0.018	0.06
T_{29}	30.12	30.12	30.12	30.16	30.16	30.16	30.16	30.16	30.16	30.16	30.148	0.018	0.06
T_{30}	30.03	30.03	30.03	30.07	30.07	30.02	30.02	30.02	30.02	30.02	30.033	0.019	0.06
T_{31}	28.66	28.66	28.66	28.70	28.70	28.70	28.70	28.70	28.70	28.70	28.688	0.018	0.06
T_{32}	28.57	28.57	28.57	28.60	28.60	28.60	28.60	28.60	28.60	28.60	28.591	0.014	0.05
Q	6.415	6.404	6.421	6.441	6.432	6.429	6.434	6.419	6.422	6.408	6.422	0.011	0.18

Avg T_{hot} 50.39 Avg T_{cold} 29.88 T_{mean} 40.13 Temp Diff 20.52

Thermal Conductivity 0.254 ± 0.014

TABLE G-10 RESULTS (SET # 10)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	53.06	53.06	53.11	53.11	53.16	53.16	53.20	53.25	53.25	53.30	53.166	0.079	0.15
T_2	53.16	53.20	53.20	53.25	53.25	53.30	53.34	53.34	53.39	53.44	53.287	0.086	0.16
T_3	53.02	53.02	53.06	53.06	53.11	53.11	53.16	53.16	53.20	53.25	53.115	0.073	0.14
T_4	53.25	53.30	53.30	53.34	53.39	53.39	53.44	53.48	53.53	53.53	53.395	0.094	0.18
T_5	53.11	53.16	53.16	53.20	53.25	53.25	53.30	53.34	53.34	53.39	53.250	0.088	0.16
T_6	53.25	53.25	53.30	53.30	53.34	53.34	53.44	53.44	53.48	53.53	53.367	0.094	0.18
T_7	53.06	53.06	53.11	53.16	53.20	53.25	53.30	53.34	53.34	53.39	53.221	0.115	0.22
T_8	53.16	53.20	53.25	53.30	53.34	53.34	53.39	53.44	53.48	53.53	53.343	0.114	0.21
T_9	53.16	53.20	53.25	53.30	53.30	53.34	53.39	53.44	53.48	53.53	53.339	0.115	0.21
T_{10}	52.83	52.83	52.88	52.92	52.97	53.06	53.11	53.16	53.20	53.25	53.021	0.148	0.28
T_{11}	52.23	52.41	52.60	52.74	52.83	52.88	52.97	53.06	53.11	53.16	52.799	0.292	0.55
T_{12}	52.74	52.88	52.97	53.02	53.06	53.11	53.20	53.25	53.30	53.34	53.087	0.182	0.34
T_{13}	52.41	52.46	52.46	52.51	52.51	52.55	52.55	52.55	52.55	52.60	52.515	0.054	0.10
T_{14}	52.27	52.27	52.27	52.27	52.41	52.55	52.65	52.69	52.79	52.88	52.505	0.226	0.43
T_{15}	52.41	52.51	52.55	52.51	52.55	52.65	52.74	52.79	52.83	52.88	52.642	0.151	0.29
T_{16}	51.95	51.99	51.99	52.04	52.04	52.09	52.13	52.13	52.04	52.18	52.058	0.069	0.13
T_{17}	51.85	51.85	51.90	51.90	51.85	51.85	51.90	51.95	51.95	51.95	51.895	0.042	0.08
T_{18}	52.09	52.09	52.09	52.13	52.18	52.23	52.23	52.27	52.27	52.37	52.195	0.090	0.17
T_{19}	51.72	51.72	51.76	51.76	51.81	51.85	51.90	51.95	51.99	52.04	51.850	0.109	0.21
T_{20}	51.72	51.76	51.76	51.81	51.85	51.85	51.90	51.95	51.99	52.04	51.863	0.101	0.19
T_{21}	51.76	51.81	51.81	51.85	51.85	51.90	51.95	51.99	52.04	52.09	51.905	0.103	0.20
T_{22}	27.40	27.40	27.35	27.35	27.35	27.35	27.35	27.35	27.35	27.35	27.360	0.020	0.07
T_{23}	27.30	27.25	27.25	27.25	27.20	27.20	27.20	27.20	27.20	27.20	27.225	0.034	0.12
T_{24}	27.40	27.35	27.35	27.35	27.35	27.35	27.30	27.30	27.30	27.30	27.335	0.032	0.12
T_{25}	27.84	27.74	27.64	27.55	27.50	27.45	27.40	27.35	27.35	27.30	27.512	0.171	0.62
T_{26}	27.89	27.79	27.74	27.69	27.64	27.59	27.55	27.55	27.50	27.50	27.644	0.125	0.45
T_{27}	27.94	27.94	27.94	27.94	27.94	27.94	27.94	27.89	27.89	27.84	27.920	0.033	0.12
T_{28}	27.99	27.99	27.94	27.94	27.89	27.89	27.89	27.89	27.84	27.84	27.910	0.051	0.18
T_{29}	28.08	28.08	28.08	28.13	28.08	28.08	28.08	28.08	28.08	28.08	28.085	0.015	0.05
T_{30}	28.03	28.03	28.03	28.03	28.03	28.03	28.03	28.03	28.03	28.03	28.030	0.000	0.00
T_{31}	26.44	26.44	26.44	26.44	26.44	26.44	26.40	26.40	26.40	26.40	26.424	0.020	0.07
T_{32}	26.40	26.35	26.35	26.35	26.35	26.35	26.35	26.35	26.35	26.35	26.355	0.015	0.06
Q	7.301	7.323	7.318	7.285	7.328	7.342	7.325	7.293	7.320	7.339	7.317	0.018	0.24

Avg T_{hot} 52.75 Avg T_{cold} 27.64 T_{mean} 40.20 Temp Diff 25.12

Thermal Conductivity 0.236 ± 0.013

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_{1}	55.68	55.68	55.72	55.72	55.72	55.77	55.82	55.86	55.91	55.91	55.779	0.085	0.15
T_{2}	55.77	55.77	55.77	55.82	55.82	55.86	55.86	55.95	55.95	56.00	55.857	0.080	0.14
T_{3}	55.68	55.68	55.68	55.72	55.72	55.77	55.77	55.82	55.86	55.91	55.761	0.077	0.14
T_{4}	55.95	55.95	55.95	56.00	56.00	56.05	56.07	56.12	56.16	56.21	56.046	0.088	0.16
T_{5}	55.72	55.72	55.77	55.77	55.82	55.86	55.86	55.95	55.95	56.00	55.842	0.095	0.17
T_{6}	55.86	55.91	55.91	55.95	55.95	56.00	56.05	56.07	56.12	56.12	55.994	0.088	0.16
T_{7}	55.72	55.77	55.82	55.82	55.86	55.91	55.95	56.00	56.05	56.07	55.897	0.113	0.20
T_{8}	55.82	55.86	55.86	55.91	55.91	55.95	56.00	56.07	56.12	56.16	55.966	0.111	0.20
T_{9}	55.82	55.82	55.36	55.91	55.91	56.00	56.00	56.07	56.12	56.16	55.967	0.116	0.21
T_{10}	55.35	55.40	55.49	55.54	55.59	55.63	55.72	55.77	55.86	55.91	55.626	0.179	0.32
T_{11}	55.17	55.31	55.35	55.40	55.45	55.54	55.59	55.68	55.72	55.82	55.503	0.193	0.35
T_{12}	55.49	55.54	55.59	55.63	55.68	55.72	55.82	55.86	55.95	56.00	55.728	0.165	0.30
T_{13}	54.71	54.71	54.75	54.75	54.84	54.89	54.98	55.08	55.17	55.26	54.914	0.190	0.35
T_{14}	54.66	54.61	54.43	54.34	54.66	54.98	55.12	55.22	55.35	55.45	54.882	0.373	0.68
T_{15}	54.89	54.98	54.98	55.08	55.12	55.17	55.26	55.35	55.49	55.54	55.186	0.209	0.38
T_{16}	54.01	54.01	54.15	54.15	54.15	54.20	54.20	54.20	54.24	54.29	54.160	0.086	0.16
T_{17}	54.10	54.06	54.10	54.06	54.24	54.20	54.01	53.92	53.87	53.83	54.039	0.127	0.24
T_{18}	54.29	54.29	54.34	54.34	54.38	54.47	54.57	54.52	54.43	54.06	54.369	0.137	0.25
T_{19}	53.83	53.87	53.92	53.96	54.01	54.10	54.15	54.24	54.29	54.38	54.075	0.178	0.33
T_{20}	53.92	53.96	53.96	54.01	54.06	54.15	54.20	54.29	54.38	54.43	54.136	0.174	0.32
T_{21}	53.96	53.96	54.01	54.06	54.10	54.20	54.24	54.34	54.43	54.47	54.177	0.180	0.33
T_{22}	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.21	25.16	25.205	0.015	0.06
T_{23}	25.11	25.11	25.11	25.06	25.06	25.06	25.06	25.06	25.06	25.02	25.071	0.028	0.11
T_{24}	25.21	25.16	25.16	25.16	25.16	25.16	25.16	25.16	25.16	25.11	25.160	0.022	0.09
T_{25}	25.36	25.31	25.26	25.26	25.21	25.16	25.16	25.11	25.11	25.06	25.200	0.092	0.36
T_{26}	25.65	25.56	25.51	25.46	25.41	25.41	25.36	25.31	25.26	25.21	25.414	0.129	0.51
T_{27}	25.85	25.85	25.85	25.80	25.80	25.75	25.70	25.65	25.60	25.56	25.741	0.103	0.40
T_{28}	25.80	25.85	25.80	25.80	25.75	25.70	25.65	25.56	25.51	25.41	25.683	0.139	0.54
T_{29}	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.10	26.05	26.095	0.015	0.06
T_{30}	25.95	25.95	26.00	25.95	25.95	25.95	25.95	25.95	25.95	26.00	25.960	0.020	0.08
T_{31}	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.13	24.18	24.135	0.015	0.06
T_{32}	24.08	24.08	24.03	24.03	24.08	24.03	24.03	24.03	24.03	24.08	24.050	0.024	0.10
Q	8.274	8.289	8.266	8.276	8.284	8.281	8.298	8.303	8.259	8.282	8.281	0.013	0.15

Avg T_{hot} 55.23 Avg T_{cold} 25.47 T_{mean} 40.35 Temp Diff 29.76

Thermal Conductivity 0.226 ± 0.013

TABLE G-12 RESULTS (SET # 12)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	34.44	34.44	34.44	34.44	34.44	34.39	34.39	34.39	34.42	34.42	34.421	0.022	0.06
T_2	34.53	34.48	34.48	34.44	34.44	34.44	34.39	34.39	34.42	34.42	34.443	0.041	0.12
T_3	34.44	34.44	34.44	34.39	34.44	34.39	34.39	34.39	34.42	34.42	34.416	0.022	0.07
T_4	34.63	34.63	34.63	34.58	34.58	34.58	34.53	34.53	34.56	34.56	34.581	0.036	0.11
T_5	34.58	34.53	34.53	34.53	34.48	34.48	34.48	34.48	34.51	34.51	34.511	0.031	0.09
T_6	34.63	34.63	34.63	34.58	34.58	34.58	34.53	34.53	34.56	34.61	34.586	0.037	0.11
T_7	34.73	34.73	34.73	34.73	34.68	34.68	34.68	34.68	34.71	34.71	34.706	0.022	0.06
T_8	34.82	34.77	34.77	34.77	34.77	34.73	34.73	34.73	34.76	34.76	34.761	0.026	0.07
T_9	34.82	34.77	34.77	34.77	34.77	34.73	34.73	34.73	34.76	34.76	34.761	0.026	0.07
T_{10}	34.87	34.87	34.87	34.82	34.82	34.82	34.82	34.82	34.85	34.85	34.841	0.022	0.06
T_{11}	34.82	34.82	34.82	34.77	34.77	34.77	34.77	34.77	34.76	34.76	34.783	0.025	0.07
T_{12}	34.92	34.87	34.87	34.87	34.87	34.82	34.82	34.82	34.85	34.85	34.856	0.030	0.09
T_{13}	34.97	34.92	34.92	34.92	34.92	34.92	34.87	34.87	34.90	34.90	34.911	0.027	0.08
T_{14}	34.92	34.92	34.92	34.92	34.87	34.87	34.87	34.87	34.90	34.90	34.896	0.022	0.06
T_{15}	34.92	34.87	34.87	34.87	34.82	34.82	34.82	34.85	34.80	34.80	34.844	0.037	0.11
T_{16}	34.87	34.87	34.87	34.87	34.82	34.82	34.82	34.85	34.85	34.85	34.849	0.021	0.06
T_{17}	34.87	34.87	34.87	34.82	34.82	34.82	34.82	34.85	34.85	34.85	34.844	0.021	0.06
T_{18}	34.97	34.92	34.92	34.92	34.92	34.92	34.87	34.90	34.90	34.90	34.914	0.024	0.07
T_{19}	34.87	34.87	34.82	34.82	34.82	34.82	34.82	34.80	34.80	34.80	34.824	0.025	0.07
T_{20}	34.87	34.87	34.87	34.87	34.82	34.82	34.82	34.85	34.85	34.80	34.844	0.025	0.07
T_{21}	34.92	34.92	34.92	34.87	34.87	34.87	34.87	34.90	34.90	34.85	34.889	0.025	0.07
T_{22}	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.07	25.07	25.07	25.049	0.014	0.05
T_{23}	24.94	24.94	24.94	24.94	24.94	24.94	24.94	25.02	25.02	24.97	24.959	0.032	0.13
T_{24}	24.99	24.99	24.99	24.99	24.99	24.99	24.99	25.07	25.02	25.02	25.004	0.025	0.10
T_{25}	24.99	24.99	24.99	24.99	24.99	24.99	25.04	25.07	25.02	25.07	25.014	0.032	0.13
T_{26}	25.09	25.09	25.09	25.09	25.09	25.14	25.09	25.17	25.17	25.17	25.119	0.036	0.15
T_{27}	24.94	24.99	24.99	24.99	24.99	24.99	24.99	25.02	25.02	25.02	24.994	0.022	0.09
T_{28}	24.99	24.99	24.99	24.99	24.99	24.99	24.99	25.02	25.02	25.02	24.999	0.014	0.05
T_{29}	24.99	25.04	25.04	25.04	25.04	25.04	25.04	25.07	25.07	25.07	25.044	0.022	0.09
T_{30}	25.04	25.04	25.04	25.04	25.04	25.04	25.04	25.12	25.07	25.07	25.054	0.025	0.10
T_{31}	24.25	24.25	24.25	24.25	24.30	24.25	24.25	24.33	24.33	24.33	24.279	0.036	0.15
T_{32}	24.20	24.20	24.20	24.20	24.20	24.20	24.20	24.23	24.23	24.23	24.209	0.014	0.06
Q	2.537	2.534	2.534	2.530	2.543	2.543	2.541	2.540	2.546	2.545	2.539	0.005	0.20

Avg T_{hot} 34.74 Avg T_{cold} 25.03 T_{mean} 29.88 Temp Diff 9.71

Thermal Conductivity 0.212 ± 0.012

TABLE G-13 RESULTS (SET # 13)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	39.75	39.75	39.84	39.94	39.99	40.04	40.08	40.13	40.13	40.22	39.987	0.156	0.39
T_2	40.13	40.13	40.18	40.18	40.18	40.23	40.23	40.27	40.27	40.31	40.211	0.058	0.14
T_3	39.99	40.04	40.04	40.08	40.08	40.08	40.13	40.13	40.18	40.22	40.097	0.066	0.16
T_4	40.08	40.13	40.18	40.23	40.27	40.27	40.27	40.32	40.32	40.41	40.248	0.092	0.23
T_5	39.80	39.75	39.75	39.75	39.75	39.75	39.84	39.84	39.84	39.98	39.805	0.070	0.18
T_6	40.23	40.27	40.27	40.27	40.27	40.32	40.32	40.32	40.41	40.41	40.309	0.058	0.14
T_7	40.13	40.13	40.18	40.18	40.18	40.23	40.23	40.23	40.31	40.36	40.216	0.070	0.17
T_8	40.32	40.32	40.32	40.32	40.32	40.32	40.32	40.37	40.41	40.41	40.343	0.037	0.09
T_9	40.18	40.18	40.23	40.23	40.23	40.23	40.27	40.27	40.31	40.36	40.249	0.053	0.13
T_{10}	40.37	40.37	40.37	40.37	40.37	40.37	40.37	40.37	40.41	40.41	40.378	0.016	0.04
T_{11}	40.27	40.27	40.27	40.32	40.32	40.32	40.32	40.32	40.36	40.41	40.318	0.041	0.10
T_{12}	40.37	40.42	40.42	40.42	40.42	40.42	40.46	40.46	40.50	40.50	40.439	0.039	0.10
T_{13}	40.46	40.46	40.46	40.46	40.46	40.46	40.46	40.51	40.55	40.55	40.483	0.037	0.09
T_{14}	40.42	40.42	40.42	40.42	40.42	40.46	40.46	40.46	40.50	40.50	40.448	0.031	0.08
T_{15}	40.37	40.37	40.37	40.37	40.37	40.37	40.37	40.42	40.46	40.46	40.393	0.037	0.09
T_{16}	40.32	40.32	40.32	40.37	40.37	40.37	40.37	40.37	40.41	40.41	40.363	0.032	0.08
T_{17}	40.32	40.32	40.32	40.32	40.37	40.37	40.37	40.37	40.41	40.41	40.358	0.034	0.08
T_{18}	40.42	40.42	40.42	40.46	40.46	40.46	40.46	40.46	40.50	40.55	40.461	0.038	0.09
T_{19}	40.27	40.32	40.32	40.32	40.32	40.32	40.32	40.32	40.36	40.41	40.328	0.034	0.08
T_{20}	40.32	40.37	40.37	40.37	40.37	40.37	40.37	40.37	40.41	40.41	40.373	0.024	0.06
T_{21}	40.37	40.37	40.37	40.37	40.37	40.37	40.37	40.42	40.46	40.46	40.393	0.037	0.09
T_{22}	29.99	29.99	29.99	29.99	29.99	29.94	29.94	29.94	29.98	29.98	29.973	0.022	0.07
T_{23}	29.94	29.94	29.94	29.94	29.94	29.94	29.94	29.94	29.94	29.94	29.940	0.000	0.00
T_{24}	30.04	30.04	30.04	30.04	29.99	29.99	29.99	29.99	30.03	30.03	30.018	0.023	0.08
T_{25}	30.04	30.04	30.04	30.04	30.04	30.04	30.04	30.04	30.08	30.08	30.048	0.016	0.05
T_{26}	30.14	30.14	30.14	30.14	30.14	30.14	30.14	30.14	30.18	30.18	30.148	0.016	0.05
T_{27}	30.04	30.04	30.04	30.04	30.04	30.04	30.04	30.04	30.08	30.08	30.048	0.016	0.05
T_{28}	30.09	30.09	30.04	30.09	30.04	30.09	30.09	30.04	30.08	30.08	30.073	0.022	0.07
T_{29}	30.09	30.09	30.09	30.09	30.09	30.09	30.09	30.09	30.13	30.13	30.098	0.016	0.05
T_{30}	30.14	30.14	30.14	30.14	30.14	30.14	30.14	30.09	30.18	30.18	30.143	0.024	0.08
T_{31}	29.19	29.19	29.14	29.19	29.14	29.14	29.14	29.14	29.18	29.18	29.163	0.023	0.08
T_{32}	29.14	29.14	29.14	29.14	29.09	29.09	29.09	29.09	29.13	29.13	29.118	0.023	0.08
Q	3.484	3.485	3.487	3.481	3.474	3.482	3.484	3.472	3.478	3.485	3.481	0.005	0.14

Avg T_{hot} 40.30 Avg T_{cold} 30.05 T_{mean} 35.17 Temp Diff 10.25

Thermal Conductivity 0.276 ± 0.016

TABLE G-14 RESULTS (SET # 14)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	49.18	49.22	49.22	49.22	49.22	49.22	49.08	48.85	48.80	48.85	49.086	0.171	0.35
T_2	49.18	49.13	49.08	48.99	49.04	49.18	49.37	49.41	49.51	49.55	49.244	0.190	0.39
T_3	49.22	49.22	49.27	49.27	49.27	49.32	49.37	49.41	49.41	49.46	49.322	0.081	0.16
T_4	49.41	49.37	49.37	49.41	49.41	49.46	49.51	49.55	49.60	49.65	49.474	0.094	0.19
T_5	49.32	49.32	49.37	49.32	49.32	49.27	49.22	49.22	49.13	49.08	49.257	0.089	0.18
T_6	49.51	49.55	49.55	49.60	49.60	49.60	49.65	49.65	49.69	49.69	49.609	0.058	0.12
T_7	49.60	49.60	49.60	49.60	49.60	49.60	49.65	49.60	49.60	49.55	49.600	0.022	0.05
T_8	49.65	49.65	49.65	49.65	49.65	49.69	49.69	49.74	49.74	49.74	49.685	0.039	0.08
T_9	49.60	49.60	49.60	49.60	49.60	49.60	49.60	49.60	49.60	49.60	49.600	0.000	0.00
T_{10}	49.69	49.69	49.69	49.69	49.74	49.74	49.74	49.74	49.79	49.74	49.725	0.032	0.06
T_{11}	49.65	49.65	49.65	49.65	49.65	49.65	49.69	49.65	49.69	49.65	49.658	0.016	0.03
T_{12}	49.69	49.69	49.69	49.69	49.69	49.69	49.74	49.74	49.74	49.74	49.710	0.024	0.05
T_{13}	49.74	49.79	49.79	49.79	49.79	49.79	49.79	49.79	49.83	49.83	49.793	0.024	0.05
T_{14}	49.74	49.74	49.74	49.74	49.74	49.74	49.74	49.74	49.79	49.79	49.750	0.020	0.04
T_{15}	49.69	49.69	49.69	49.69	49.69	49.65	49.65	49.65	49.65	49.69	49.674	0.020	0.04
T_{16}	49.65	49.65	49.65	49.65	49.65	49.65	49.65	49.65	49.69	49.69	49.658	0.016	0.03
T_{17}	49.60	49.60	49.65	49.65	49.65	49.65	49.65	49.65	49.65	49.65	49.640	0.020	0.04
T_{18}	49.69	49.69	49.74	49.74	49.74	49.74	49.74	49.74	49.74	49.79	49.735	0.027	0.05
T_{19}	49.55	49.55	49.55	49.55	49.55	49.55	49.60	49.60	49.60	49.60	49.570	0.024	0.05
T_{20}	49.60	49.60	49.60	49.60	49.60	49.60	49.60	49.65	49.65	49.65	49.615	0.023	0.05
T_{21}	49.60	49.60	49.65	49.65	49.65	49.65	49.65	49.65	49.65	49.65	49.640	0.020	0.04
T_{22}	40.27	40.27	40.23	40.23	40.18	40.18	40.13	40.13	40.08	40.08	40.178	0.068	0.17
T_{23}	40.18	40.18	40.18	40.18	40.18	40.13	40.13	40.13	40.13	40.13	40.155	0.025	0.06
T_{24}	40.23	40.23	40.18	40.18	40.18	40.18	40.18	40.18	40.18	40.18	40.190	0.020	0.05
T_{25}	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.270	0.000	0.00
T_{26}	40.37	40.32	40.37	40.37	40.32	40.37	40.37	40.37	40.32	40.32	40.350	0.024	0.06
T_{27}	40.23	40.23	40.23	40.23	40.23	40.23	40.23	40.23	40.23	40.23	40.230	0.000	0.00
T_{28}	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.270	0.000	0.00
T_{29}	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.27	40.270	0.000	0.00
T_{30}	40.32	40.32	40.32	40.32	40.32	40.32	40.32	40.32	40.32	40.32	40.320	0.000	0.00
T_{31}	39.20	39.15	39.15	39.15	39.15	39.20	39.15	39.15	39.15	39.15	39.160	0.020	0.05
T_{32}	39.15	39.11	39.15	39.20	39.15	39.15	39.15	39.15	39.11	39.15	39.147	0.024	0.06
Q	4.581	4.570	4.596	4.583	4.604	4.594	4.583	4.593	4.588	4.587	4.588	0.009	0.20

Avg T_{hot} 49.57 Avg T_{cold} 40.24 T_{mean} 44.91 **Temp Diff** 9.33

Thermal Conductivity 0.399 ± 0.023

TABLE G-15 RESULTS (SET # 15)

	Scan 1	Scan 2	Scan 3	Scan 4	Scan 5	Scan 6	Scan 7	Scan 8	Scan 9	Scan 10	Avg	Std Dev	%Std Dev
T_1	53.66	53.75	53.80	53.85	53.85	53.96	54.01	54.01	54.05	54.10	53.904	0.136	0.25
T_2	53.99	53.99	53.99	54.03	54.03	54.15	54.15	54.15	54.19	54.19	54.086	0.082	0.15
T_3	53.80	53.80	53.85	53.89	53.89	54.01	54.05	54.05	54.05	54.10	53.949	0.109	0.20
T_4	53.85	53.89	53.94	54.03	54.08	54.19	54.24	54.28	54.28	54.33	54.111	0.168	0.31
T_5	53.85	53.85	53.85	53.89	53.89	54.01	54.01	54.01	54.05	54.10	53.951	0.090	0.17
T_6	53.94	54.03	54.08	54.08	54.13	54.19	54.24	54.24	54.28	54.28	54.149	0.110	0.20
T_7	54.08	54.08	54.08	54.08	54.08	54.15	54.19	54.19	54.19	54.24	54.136	0.060	0.11
T_8	54.13	54.08	54.08	54.08	54.08	54.19	54.15	54.19	54.19	54.24	54.141	0.057	0.10
T_9	53.99	54.03	53.99	53.99	53.89	53.96	53.91	54.01	53.96	54.01	53.974	0.042	0.08
T_{10}	53.85	53.85	53.94	53.99	53.99	54.10	54.10	54.15	54.15	54.19	54.031	0.118	0.22
T_{11}	53.99	53.89	53.85	53.75	53.75	53.82	53.87	53.87	53.87	53.87	53.853	0.066	0.12
T_{12}	54.03	54.03	54.03	54.03	54.03	54.10	54.05	54.10	54.10	54.10	54.060	0.033	0.06
T_{13}	54.03	54.03	54.03	54.03	54.08	54.15	54.15	54.15	54.15	54.10	54.090	0.054	0.10
T_{14}	53.94	53.94	53.89	53.94	53.99	54.05	54.05	54.05	54.05	54.01	53.991	0.057	0.11
T_{15}	53.85	53.85	53.85	53.89	53.94	54.10	54.10	54.15	54.19	54.19	54.011	0.140	0.26
T_{16}	53.80	53.80	53.80	53.80	53.80	53.91	53.91	53.91	53.91	53.96	53.860	0.062	0.11
T_{17}	53.75	53.75	53.75	53.80	53.87	53.87	53.87	53.87	53.91	53.91	53.835	0.062	0.12
T_{18}	53.85	53.89	53.89	53.89	53.96	53.96	54.01	54.01	54.01	54.01	53.948	0.059	0.11
T_{19}	53.62	53.62	53.62	53.62	53.73	53.73	53.73	53.73	53.77	53.77	53.694	0.062	0.12
T_{20}	53.62	53.62	53.62	53.62	53.73	53.73	53.73	53.77	53.77	53.77	53.698	0.066	0.12
T_{21}	53.66	53.66	53.66	53.71	53.77	53.77	53.77	53.82	53.82	53.82	53.746	0.065	0.12
T_{22}	44.20	44.15	44.10	44.10	44.12	44.08	44.03	44.03	44.03	43.98	44.082	0.063	0.14
T_{23}	44.25	44.25	44.20	44.20	44.22	44.17	44.12	44.12	44.12	44.08	44.173	0.057	0.13
T_{24}	44.25	44.25	44.20	44.20	44.22	44.22	44.17	44.17	44.12	44.12	44.192	0.044	0.10
T_{25}	44.34	44.29	44.29	44.29	44.36	44.36	44.31	44.31	44.31	44.31	44.317	0.026	0.06
T_{26}	44.44	44.44	44.39	44.34	44.41	44.41	44.41	44.41	44.41	44.41	44.407	0.026	0.06
T_{27}	44.34	44.34	44.34	44.29	44.36	44.36	44.36	44.36	44.36	44.36	44.347	0.021	0.05
T_{28}	44.34	44.34	44.34	44.29	44.41	44.36	44.36	44.36	44.36	44.36	44.352	0.028	0.06
T_{29}	44.29	44.29	44.29	44.29	44.36	44.36	44.36	44.36	44.36	44.36	44.332	0.034	0.08
T_{30}	44.25	44.25	44.25	44.25	44.36	44.36	44.31	44.31	44.31	44.31	44.296	0.042	0.09
T_{31}	43.16	43.11	43.16	43.11	43.23	43.18	43.18	43.18	43.23	43.18	43.172	0.039	0.09
T_{32}	43.21	43.21	43.16	43.21	43.23	43.23	43.23	43.23	43.23	43.23	43.217	0.021	0.05
Q	5.212	5.220	5.216	5.184	5.227	5.226	5.220	5.233	5.215	5.221	5.217	0.013	0.24

Avg T_{hot} 53.96 Avg T_{cold} 44.26 T_{mean} 49.11 Temp Diff 9.70

Thermal Conductivity 0.436 ± 0.025

APPENDIX H

DATA ACQUISITION PROGRAM
(Source Code)

COMP.BAS

```
DECLARE FUNCTION AutoPower! ()
DECLARE SUB autovolts (chan%)
DECLARE SUB ScrnDispTempC ()
DECLARE SUB ScrnDispTempD ()
DECLARE SUB ScrnDispHdrsTempD ()
DECLARE SUB ScrnDispHdrsTempC ()
DECLARE SUB ScrnDispHdrsRes ()
DECLARE SUB LeeDeLogger ()
DECLARE SUB HazCalculos ()
DECLARE SUB Initlevel1 ()
DECLARE SUB ScrnDispRes ()
DECLARE SUB IniciaMonitoreo ()
DECLARE SUB InventaTemps ()
DECLARE SUB ImpTempA ()
DECLARE SUB RecordMsg ()
DECLARE SUB LPCenter (TextoS)
DECLARE SUB ScrnDispHdrsTempB ()
DECLARE SUB MesConLetras (strDate$)
DECLARE SUB ScrnDispTempA ()
DECLARE SUB ScrnDispTempB ()
DECLARE SUB ScrnDispHdrsTempA ()
DECLARE SUB printerror ()
DECLARE SUB thermocouple (chan%, range%, type$)
DECLARE SUB InitParam ()
DECLARE SUB GetSingle (singlevar!, numchars%, places%)
DECLARE SUB TransactionSummary (item%)
DECLARE SUB LCenter (text$)
DECLARE SUB ScrollUp ()
DECLARE SUB ScrollDown ()
DECLARE SUB Initialize ()
DECLARE SUB Intro ()
DECLARE SUB SparklePause ()
DECLARE SUB Center (row%, text$)
DECLARE SUB FancyCls (dots%, Background%)
DECLARE SUB LoadState ()
DECLARE SUB SaveState ()
```

```
DECLARE SUB MenuSystem ()
DECLARE SUB TempRecord ()
DECLARE SUB MakeBackup ()
DECLARE SUB RestoreBackup ()
DECLARE SUB Box (Row1%, Col1%, Row2%, Col2%, NumLen%)
DECLARE SUB NetWorthReport ()
DECLARE SUB EditAccounts ()
DECLARE SUB PrintHelpLine (help$)
DECLARE SUB EditTrans (item%)
DECLARE FUNCTION Cvdt$ (X#)
DECLARE FUNCTION Cvst$ (X!)
DECLARE FUNCTION Cvit$ (X%)
DECLARE FUNCTION Menu% (CurrChoiceX%, MaxChoice%, choice$(), ItemRow%(), ItemCol%(), help$(), BarMode%, NumLen%,
Valores$())
DECLARE FUNCTION Trim$ (X$)

TYPE ParameterType
    Qin       AS SINGLE
    Dia1      AS SINGLE
    Dia2      AS SINGLE
    Length    AS SINGLE
END TYPE

TYPE ControlType
    DataSetVis   AS STRING * 13
    MonitKind    AS STRING * 9
    Imprime      AS STRING * 11
END TYPE

TYPE ResultsType
    TempHotAvg    AS SINGLE
    TempColdAvg   AS SINGLE
    ThermCond     AS SINGLE
END TYPE

' $INCLUDE: 'loggrvar.inc'

DIM SHARED ScrollUpAsm(1 TO 7)
DIM SHARED ScrollDownAsm(1 TO 7)
DIM SHARED colors%(0 TO 20, 1 TO 4)
DIM SHARED ColorPref
DIM SHARED Par  AS ParameterType
DIM SHARED Res  AS ResultsType
DIM SHARED Cont  AS ControlType
DIM SHARED TemCop(1 TO 32)  AS SINGLE
DIM SHARED Imprime          AS INTEGER
DIM SHARED Fecha$
DIM SHARED Tiempo$
DIM SHARED voltdc

    Initlevel1
    DO: LOOP UNTIL INKEY$ <> ""
    ColorPref = 1
    Imprime = False%
    Fecha$ = DATE$
    MesConLetras Fecha$

    Initialize      'Initialize program
    Intro           'Display introduction screen
```

```
  InitParam
  MenuSystem        'This is the main program
  COLOR 7, 0        'Clear screen and end
  CLS

  END
'+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
'The following data defines the color schemes available via the main menu.
'
'    scm  dots  bar  back  title  shdow  choice  curs  cursbk  shdow
'-----------------------------------------------------------------------
DATA 0,   7,   15,  7,    0,     7,     0,      15,   0,      0
DATA 1,   9,   12,  3,    0,     1,     15,     0,    7,      0
DATA 3,   15,  13,  1,    14,    3,     15,     0,    7,      0
DATA 7,   12,  15,  4,    14,    0,     15,     15,   1,      0
'-----------------------------------------------------------------------
'The following data is actually a machine language program to
'scroll the screen up or down very fast using a BIOS call
'-----------------------------------------------------------------------
DATA &HB8,&H01,&H06,&HB9,&H01,&H04,&HBA,&H4E,&H16,&HB7,&H00,&HCD,&H10,&HCB
DATA &HB8,&H01,&H07,&HB9,&H01,&H04,&HBA,&H4E,&H16,&HB7,&H00,&HCD,&H10,&HCB
'-----------------------------------------------------------------------

FUNCTION AutoPower
'=======================================================================

   meas = 0!
   voltdc = 0!
   voltsum = 0!
   voltno% = 10
   FOR count% = 1 TO voltno%
      autovolts (51)
      IF er = 0 THEN
         voltdc = meas
      ELSE
         printerror
      END IF
      voltsum = voltsum + voltdc
   NEXT count%
   voltdc = voltsum / voltno%
   IF voltdc < 2.2 AND voltdc > 0.05 THEN
      AutoPower = .40867 + 3.28535 * voltdc + .8102 * (voltdc) ^ 2 + 1.21878 * (voltdc) ^ 2.5 - .14001 * (voltdc) ^ 3.5
    ELSE
      PRINT " error: The voltage signal is out of the range of correlation equation"
    END IF

END FUNCTION

SUB Box (Row1%, Col1%, Row2%, Col2%, NumLen%) STATIC
'=======================================================================
   BoxWidth = Col2% - Col1% + 1 + NumLen%

   LOCATE Row1%, Col1%
   PRINT "┌"; STRING$(BoxWidth - 2, "─"); "┐";

   FOR A = Row1% + 1 TO Row2% - 1
      LOCATE A, Col1%
      PRINT "│"; SPACE$(BoxWidth - 2); "│";
   NEXT A
```

```
   LOCATE Row2%, Col1%
   PRINT "└"; STRING$(BoxWidth - 2, "─"); "┘";

END SUB

SUB Center (row%, text$)
'=========================================================================
   LOCATE row%, 41 - LEN(text$) / 2
   PRINT text$;
END SUB

FUNCTION Cvdt$ (X#)
'=========================================================================
   Cvdt$ = RIGHT$(STR$(X#), LEN(STR$(X#)) - 1)

END FUNCTION

FUNCTION Cvit$ (X%)
'=========================================================================
   Cvit$ = RIGHT$(STR$(X%), LEN(STR$(X%)) - 1)
END FUNCTION

FUNCTION Cvst$ (X!)
'=========================================================================
   Cvst$ = RIGHT$(STR$(X!), LEN(STR$(X!)) - 1)
END FUNCTION

SUB FancyCls (dots%, Background%)
'=========================================================================
   VIEW PRINT 2 TO 24
   COLOR dots%, Background%
   CLS 2

   FOR A = 95 TO 1820 STEP 45
      row = A / 80 + 1
      col = A MOD 80 + 1
      LOCATE row, col
      PRINT CHR$(249);
   NEXT A

   VIEW PRINT

END SUB

SUB HazCalculos
'==============================================================================
        Pi = 3.14159
        Thot = 0!
        Tcold = 0!

     D1 = Par.Dia1                  ' m
     D2 = Par.Dia2                  ' m
      L = Par.Length                ' m
     'Q = Par.Qin                   ' W
      Q = AutoPower                  ' W

    FOR i = 1 TO 21
       Thot = Thot + TermCop(i)
    NEXT i
```

```
   Thot = Thot / 21!

   Tcold = .2 * TermCop(22)
   FOR i = 23 TO 30
      Tcold = Tcold + .1 * TermCop(i)
   NEXT i

   DelTemp = Thot - Tcold
   K = Q * LOG(D2 / D1) / (2! * Pi * L * DelTemp) * 1000
        Res.ThermCond = K
       Res.TempHotAvg = Thot
      Res.TempColdAvg = Tcold
            Par.Qin = Q
END SUB

SUB ImpTempA
'=================================================================================
 Temp$ = Fecha$ + "  " + Tiempo$

 OPEN "lpt1:" FOR OUTPUT AS #1

 LPCenter "U n i v e r s i t y   of   W i n d s o r"
 LPCenter "Department of Mechanical Engineering": PRINT #1,
 'LPCenter " ": PRINT #1,
 LPCenter "Heat Transfer thru Liquid Foams": PRINT #1,
 LPCenter Temp$
 PRINT #1, STRING$(80, "="): PRINT #1,

 '        1-10   11-20   21-30    31-40   41-50   51-60   61-70    71-80
 '       123456789 123456789 1234567890 123456789 123456789 123456789 123456789 1234567890
 PRINT #1, "  T.C.  T.C.  T.C.  T.C.  T.C.  T.C.  T.C.  T.C.  T.C.  T.C."
 PRINT #1, "   1     2     3     4     5     6     7     8     9    10 "
 PRINT #1, "  °C    °C    °C    °C    °C    °C    °C    °C    °C    °C "
 FORMAT$ = " ###.## ###.## ###.## ###.## ###.## ###.## ###.## ###.## ###.## ###.##"
 PRINT #1, USING FORMAT$; TermCop(1); TermCop(2); TermCop(3); TermCop(4); TermCop(5); TermCop(6); TermCop(7);
TermCop(8);                TermCop(9); TermCop(10)
 PRINT #1, STRING$(78, "-")
 PRINT #1,
 PRINT #1,
 PRINT #1, "  T.C.   T.C.  T.C.   T.C.  T.C.  T.C.  T.C.  T.C.  T.C."
 PRINT #1, "  11     12    13     14    15    16    17    18    19 "
 PRINT #1, "  °C     °C    °C     °C    °C    °C    °C    °C    °C "
 FORMAT$ = " ###.##  ###.##  ###.##  ###.## ###.## ###.## ###.## ###.## ###.##"
 PRINT #1, USING FORMAT$; TermCop(11); TermCop(12); TermCop(13); TermCop(14); TermCop(15); TermCop(16);
TermCop(17);                TermCop(18); TermCop(19)
 PRINT #1, STRING$(78, "-")
 PRINT #1,
 PRINT #1,
 PRINT #1, "  T.C.   T.C.  T.C.   T.C.  T.C.  T.C.  T.C.  T.C.  T.C."
 PRINT #1, "  20     21    22     23    24    25    26    27    28 "
 PRINT #1, "  °C     °C    °C     °C    °C    °C    °C    °C    °C "
 FORMAT$ = "  ###.##  ###.## ###.##  ###.## ###.## ###.## ###.## ###.## ###.##"
 PRINT #1, USING FORMAT$; TermCop(20); TermCop(21); TermCop(22); TermCop(23); TermCop(24); TermCop(25);
TermCop(26);                TermCop(27); TermCop(28)
 PRINT #1, STRING$(78, "-")
 PRINT #1,
 PRINT #1,
 PRINT #1, "  T.C.   T.C.  T.C.   T.C.  ""T.C.  T.C.  T.C. "
 PRINT #1, "  29     30    31     32   "" 33    34    35 "
```

```
 PRINT #1, "  °C    °C    °C    °C  "' °C    °C    °C "
 FORMAT$ = " ###.## ###.## ###.## ###.## "'###.## ###.## ###.##"
 PRINT #1, USING FORMAT$; TermCop(29); TermCop(30); TermCop(31); TermCop(32) '; TermCop(33); TermCop(34);
TermCop(35)
 PRINT #1, STRING$(78, "-")
 PRINT #1,
 PRINT #1,

 '        1-10   11-20   21-30   31-40   41-50   51-60   61-70   71-80
 '       123456789 123456789 1234567890 123456789 123456789 123456789 123456789 1234567890
 PRINT #1, "Hot Surface  Cold Surface  Heated Surface  Heat input  "
 PRINT #1, " Diameter     Diameter      Length               "
 PRINT #1, "  ( mm )       ( mm )       ( mm )       ( W )   "
 FORMAT$ = " ###.###      ###.###      ###.###      ###.###### "
 PRINT #1, USING FORMAT$; Par.Dia1; Par.Dia2; Par.Length; Par.Qin
 PRINT #1, STRING$(78, "-")
 PRINT #1,
 PRINT #1,
 PRINT #1, "  Avg Hot   Avg Cold     Thermal  "
 PRINT #1, "   Temp      Temp     Conductivity "
 PRINT #1, "   (C)       (C)        (W/m.C)   "
'          10       20       30       40       50       60       70       80
'        123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 FORMAT$ = " ###.##     ###.##     ####.#### "
'          1          2          3

 PRINT #1, USING FORMAT$; Res.TempHotAvg; Res.TempColdAvg; Res.ThermCond

 PRINT #1, STRING$(78, "-")


 CLOSE

END SUB

SUB IniciaMonitoreo STATIC
'==========================================================
 Tecla$ = ""
 Done = False%
 Center 24, " Hit any key to Stop "
 VIEW PRINT 15 TO 23
 CLS
DO
 DO

  Tiempo$ = TIME$

  IF LoggerOn THEN
    LeeDeLogger
  ELSE
    InventaTemps
  END IF

  HazCalculos

  IF RTRIM$(Cont.DataSetVis) = "T.C. 1 to 10" THEN
    ScrnDispTempA
  ELSE
    IF RTRIM$(Cont.DataSetVis) = "T.C. 11 to 19" THEN
```

```
      ScrnDispTempB
    ELSE
      IF RTRIM$(Cont.DataSetVis) = "T.C. 20 to 28" THEN
        ScrnDispTempC
      ELSE
        IF RTRIM$(Cont.DataSetVis) = "T.C. 29 to 32" THEN
          ScrnDispTempD
        ELSE
          IF RTRIM$(Cont.DataSetVis) = "Temp Record" THEN
            TempRecord
            EXIT DO
          ELSE
            ScrnDispRes
          END IF
        END IF
      END IF
    END IF
  END IF

  IF Imprime THEN
    ImpTempA
    Imprime = False%
    Cont.Imprime = "Screen"
  END IF

  Tecla$ = INKEY$


 LOOP UNTIL Tecla$ <> ""

 Center 23, "<Space Bar> to Continue or any other key to return to the Menu"

 DO
  Tecla$ = INKEY$
 LOOP UNTIL Tecla$ <> ""

 IF Tecla$ = " " THEN
   Done = False%
 ELSE
   Done = True
 END IF

PRINT : PRINT

LOOP UNTIL Done

VIEW PRINT

END SUB

SUB Initialize
'=======================================================================
   WIDTH , 25
   VIEW PRINT

   FOR ColorSet = 1 TO 4
     FOR X = 1 TO 10
       READ colors%(X, ColorSet)
     NEXT X
```

```
    NEXT ColorSet

    P = VARPTR(ScrollUpAsm(1))
    DEF SEG = VARSEG(ScrollUpAsm(1))
    FOR i = 0 TO 13
      READ j
      POKE (P + i), j
    NEXT i

    P = VARPTR(ScrollDownAsm(1))
    DEF SEG = VARSEG(ScrollDownAsm(1))
    FOR i = 0 TO 13
      READ j
      POKE (P + i), j
    NEXT i

    DEF SEG

END SUB

SUB InitParam
'=========================================================================

      Par.Dia1 = 21.336
      Par.Dia2 = 73.025
    Par.Length = 241.3
    Par.Qin = AutoPower
      'Par.Qin = 51

    Cont.DataSetVis = "T.C. 1 to 10"
     Cont.MonitKind = "Single"
       Cont.Imprime = "Screen"

END SUB

SUB Intro
'=========================================================================
    SCREEN 0
    WIDTH 80, 25
    COLOR 7, 0
    CLS

    Center 4, "University of Windsor"
    Center 5, "Mechanical Engineering"
    COLOR 15
     Center 7, "▄▄▄▄▄▄▄▄▄▄  ▄▄▄▄▄▄▄▄▄▄   ▄    ▄     ▄"
     Center 8, "█       █        █ █   █▄   █"
     Center 9, "█▄▄▄▄▄▄▄▄ █       █ █   █ ▀▄ █"
    Center 10, "    █  █     █▄▄▄▄▄▄▄▄█   █  ▀▄█"
    Center 11, "▄▄▄▄▄▄▄▄█ █▄▄▄▄▄▄▄▄▄ █    █  █   ▀█"
    COLOR 7
    Center 13, "Data Acquisition Program"
    Center 16, "written by"
    Center 18, "Tariq Shamim"
    Center 19, "&"
    Center 20, "Ignacio R. Martín Domínguez"
    Center 24, "Press any key to continue"

    SparklePause
```

```
END SUB

SUB InventaTemps
'==========================================================================
  TermCop(1) = 34!
  TermCop(2) = 35!
  TermCop(3) = 29.2
  TermCop(4) = 35!
  TermCop(5) = 39.5
  TermCop(6) = 32.6
  TermCop(7) = 35.6
  TermCop(8) = 44.3
  TermCop(9) = 44.6
  TermCop(10) = 23.4
  TermCop(11) = 27.83
  TermCop(12) = 41!
  TermCop(13) = 37.6
  TermCop(14) = 35.22
  TermCop(15) = 35.22
  TermCop(16) = 28.7
  TermCop(17) = 25.9
  TermCop(18) = 25.9
  TermCop(19) = 29.6
  TermCop(20) = 32.6
  TermCop(21) = 35.6
  TermCop(22) = 29.4
  TermCop(23) = 21.83
  TermCop(24) = 21!
  TermCop(25) = 27.6
  TermCop(26) = 25.22
  TermCop(27) = 25.22
  TermCop(28) = 25.9
  TermCop(29) = 29.6
  TermCop(30) = 22.6
  TermCop(31) = 21.6
  TermCop(32) = 23.4
' TermCop(33) = 33.4
' TermCop(34) = 15.6
' TermCop(35) = 23.4
END SUB

SUB LCenter (text$)
'==========================================================================
   LPRINT TAB(41 - LEN(text$) / 2); text$
END SUB

SUB LeeDeLogger
'==========================================================================

  FOR i% = 1 TO 32
    meas = 0!
    thermocouple i% + 1, 3, "T"
    IF er = 0 THEN
      TermCop(i%) = meas
    ELSE
      printerror
    END IF
  NEXT i%
```

```
END SUB

SUB LPCenter (Texto$)
'=====================================================================

PRINT #1, TAB((40 - LEN(Texto$) \ 2)); Texto$

END SUB

FUNCTION Menu% (CurrChoiceX%, MaxChoice%, choice$(), ItemRow%(), ItemCol%(), help$(), BarMode%, NumLen%, Valores$())
'==============================================================================================
  Currchoice% = CurrChoiceX%

  'if in bar mode, color in menu bar, else color box/shadow
  'bar mode means you are currently in the menu bar, not a sub menu
  IF BarMode% THEN
    COLOR colors%(7, ColorPref), colors%(4, ColorPref)
    LOCATE 1, 1
    PRINT SPACE$(80);
  ELSE
    FancyCls colors%(2, ColorPref), colors%(1, ColorPref)
    COLOR colors%(7, ColorPref), colors%(4, ColorPref)
    Box ItemRow%(1) - 1, ItemCol%(1) - 1, ItemRow%(MaxChoice%) + 1, ItemCol%(1) + LEN(choice$(1)) + 1, NumLen%

    COLOR colors%(10, ColorPref), colors%(6, ColorPref)
    FOR A = 1 TO MaxChoice% + 1
      LOCATE ItemRow%(1) + A - 1, ItemCol%(1) + LEN(choice$(1)) + NumLen% + 2
      PRINT CHR$(178); CHR$(178);
    NEXT A
    LOCATE ItemRow%(MaxChoice%) + 2, ItemCol%(MaxChoice%) + NumLen% + 2
    PRINT STRING$(LEN(choice$(MaxChoice%)) + 2, 178);
  END IF

  'print the choices
  COLOR colors%(7, ColorPref), colors%(4, ColorPref)
  FOR A = 1 TO MaxChoice%
    LOCATE ItemRow%(A), ItemCol%(A)
    PRINT choice$(A);
  NEXT A

  IF NumLen% > 0 THEN
   COLOR colors%(7, ColorPref), colors%(4, ColorPref)
   FOR A = 1 TO MaxChoice%
    LOCATE ItemRow%(A), ItemCol%(A) + LEN(choice$(A)) + 1
    PRINT Valores$(A);
   NEXT A
  END IF

  finished% = False%

  WHILE NOT finished%

    GOSUB MenuShowCursor
    GOSUB MenuGetKey
    GOSUB MenuHideCursor

    SELECT CASE Kbd$
      CASE CHR$(0) + "H": GOSUB MenuUp
      CASE CHR$(0) + "P": GOSUB MenuDown
```

```
        CASE CHR$(0) + "K": GOSUB MenuLeft
        CASE CHR$(0) + "M": GOSUB MenuRight
        CASE CHR$(13): GOSUB MenuEnter
        CASE CHR$(27): GOSUB MenuEscape
        CASE ELSE: BEEP
    END SELECT
  WEND

  Menu% = Currchoice%

  EXIT FUNCTION


MenuEnter:
'-----------------------------------
  finished% = True
  RETURN

MenuEscape:
'-----------------------------------
  Currchoice% = 0
  finished% = True
  RETURN

MenuUp:
'-----------------------------------
  IF BarMode% THEN
     BEEP
  ELSE
     Currchoice% = (Currchoice% + MaxChoice% - 2) MOD MaxChoice% + 1
  END IF
  RETURN

MenuLeft:
'-----------------------------------
  IF BarMode% THEN
     Currchoice% = (Currchoice% + MaxChoice% - 2) MOD MaxChoice% + 1
  ELSE
     Currchoice% = -2
     finished% = True
  END IF
  RETURN

MenuRight:
'-----------------------------------
  IF BarMode% THEN
     Currchoice% = (Currchoice%) MOD MaxChoice% + 1
  ELSE
     Currchoice% = -3
     finished% = True
  END IF
  RETURN

MenuDown:
'-----------------------------------
  IF BarMode% THEN
     finished% = True
  ELSE
     Currchoice% = (Currchoice%) MOD MaxChoice% + 1
```

```
  END IF
  RETURN

MenuShowCursor:
'-----------------------------------
  COLOR colors%(8, ColorPref), colors%(9, ColorPref)
  LOCATE ItemRow%(Currchoice%), ItemCol%(Currchoice%)
  PRINT choice$(Currchoice%);
  PrintHelpLine help$(Currchoice%)
  RETURN

MenuGetKey:
'-----------------------------------
  Kbd$ = ""
  WHILE Kbd$ = ""
    Kbd$ = INKEY$
  WEND
  RETURN

MenuHideCursor:
'-----------------------------------
  COLOR colors%(7, ColorPref), colors%(4, ColorPref)
  LOCATE ItemRow%(Currchoice%), ItemCol%(Currchoice%)
  PRINT choice$(Currchoice%);
  RETURN


END FUNCTION

SUB MenuSystem
'===================================================================
 DIM choice$(20), MenuRow%(20), menuCol%(20), help$(20), BarMen%(20), Valores$(20)
  LOCATE , , 0
  choice% = 1
  finished% = False%

  WHILE NOT finished%
    GOSUB MenuSystemMain

    subchoice% = -1
    WHILE subchoice% < 0
      SELECT CASE choice%
        CASE 1: GOSUB MenuSystemFile
        CASE 2: GOSUB MenuSystemParam
        CASE 3: GOSUB MenuSystemScan
        CASE 4: GOSUB MenuSystemColors
        CASE 5: GOSUB MenuSystemAbout
      END SELECT
      FancyCls colors%(2, ColorPref), colors%(1, ColorPref)

      SELECT CASE subchoice%
        CASE -2: choice% = (choice% + NumItemsBar% - 2) MOD NumItemsBar% + 1
        CASE -3: choice% = (choice%) MOD NumItemsBar% + 1
      END SELECT
    WEND
  WEND
  EXIT SUB
```

```
MenuSystemMain:
'-----------------------------------
   FancyCls colors%(2, ColorPref), colors%(1, ColorPref)
   COLOR colors%(7, ColorPref), colors%(4, ColorPref)
   Box 9, 19, 14, 61, 0
   Center 11, "Use arrow keys to navigate menu system"
   Center 12, "Press Enter to select a menu item"

   choice$(1) = " File "
   choice$(2) = " Parameters "
   choice$(3) = " Scaning "
   choice$(4) = " Colors "
   choice$(5) = " About "

   NumItemsBar% = 5

   MenuRow%(1) = 1: menuCol%(1) = 2

   FOR i = 2 TO NumItemsBar%
     MenuRow%(i) = 1
     menuCol%(i) = menuCol%(i - 1) + LEN(choice$(i - 1)) + 6
   NEXT i

   FOR i = 1 TO NumItemsBar%
     BarMen%(i) = menuCol%(i) + 1
   NEXT i


   help$(1) = "Exit the Data Aquisition Program"
   help$(2) = "Set values for the non-instrumented parameters"
   help$(3) = "Controls for Scaning the experiment"
   help$(4) = "Set screen colors"
   help$(5) = "About the origin of the program"

   DO
      Newchoice% = Menu%(choice%, NumItemsBar%, choice$(), MenuRow%(), menuCol%(), help$(), True, 0, Valores$())
   LOOP WHILE Newchoice% = 0
   choice% = Newchoice%
   RETURN


MenuSystemFile:
'-----------------------------------
   choice$(1) = " Exit  to DOS  "

   MenuRow%(1) = 4: menuCol%(1) = 2

   help$(1) = "Exit the Data Aquisition Program"

   subchoice% = Menu%(1, 1, choice$(), MenuRow%(), menuCol%(), help$(), False%, 0, Valores$())

   SELECT CASE subchoice%
      CASE 1: finished% = True
      CASE ELSE
   END SELECT
RETURN


MenuSystemParam:
```

```
'..................................
    choice$(1) = " Dia of the Hot Surface       ( mm ) : "
    choice$(2) = " Dia of the Cold Surface      ( mm ) : "
    choice$(3) = " Length of the Heated Surface ( mm ) : "
    choice$(4) = " Heat input                   ( W ) : "

   NumItems% = 4

   FOR i = 1 TO NumItems%
    MenuRow%(i) = i + 3
    menuCol%(i) = BarMen%(2)
   NEXT i

   help$(1) = "OD of the Heater Sleeve"
   help$(2) = "ID of the Tube enclosing Foams"
   help$(3) = "Length of the heated Surface"
   help$(4) = "Electrical Power input"

   Currchoice% = 1

  DO
    Valores$(1) = STR$(Par.Dia1)
    Valores$(2) = STR$(Par.Dia2)
    Valores$(3) = STR$(Par.Length)
    Valores$(4) = STR$(Par.Qin)

   subchoice% = Menu%(Currchoice%, NumItems%, choice$(), MenuRow%(), menuCol%(), help$(), False%, 6, Valores$())
   Currchoice% = subchoice%

   SELECT CASE subchoice%
      CASE 1
          LOCATE MenuRow%(1), menuCol%(1) + LEN(choice$(1))
          GetSingle Par.Dia1, 6, 3
          IF Par.Dia1 < 0! THEN Par.Dia1 = 0!

      CASE 2
          LOCATE MenuRow%(2), menuCol%(2) + LEN(choice$(2))
          GetSingle Par.Dia2, 6, 3
          IF Par.Dia2 < 0! THEN Par.Dia2 = 0!

      CASE 3
          LOCATE MenuRow%(3), menuCol%(3) + LEN(choice$(3))
          GetSingle Par.Length, 6, 3
          IF Par.Length < 0! THEN Par.Length = 0!
          IF Par.Length > 250.825 THEN Par.Length = 250.825

      CASE 4
          LOCATE MenuRow%(4), menuCol%(4) + LEN(choice$(4))
          'GetSingle Par.Qin, 6, 6
          Par.Qin = AutoPower
          IF Par.Qin < 0! THEN Par.Qin = 0!

      CASE ELSE
   END SELECT
   LOOP UNTIL subchoice% <= 0
RETURN


MenuSystemScan:
```

```
'..........................................
    choice$(1) = " Change shown data set :"
    choice$(2) = " Data destination     :"
    choice$(3) = " Scan                  "

   NumItems% = 3

   FOR i = 1 TO NumItems%
     MenuRow%(i) = i + 3
     menuCol%(i) = BarMen%(3)
   NEXT i

   help$(1) = " Togles the set of variables being monitored on the screen"
   help$(2) = " Togles the Printer destination of the FIRST monitored data"
   help$(3) = " Initiate the scaning process "

   Currchoice% = 1

  DO
    Valores$(1) = RTRIM$(Cont.DataSetVis)
    Valores$(2) = RTRIM$(Cont.Imprime)
    Valores$(3) = ""

   subchoice% = Menu%(Currchoice%, NumItems%, choice$(), MenuRow%(), menuCol%(), help$(), False%, 14, Valores$())

   Currchoice% = subchoice%

   SELECT CASE subchoice%
      CASE 1
         IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 1 to 10" THEN
           Cont.DataSetVis = "T.C. 11 to 19"
         ELSE
           IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 11 to 19" THEN
             Cont.DataSetVis = "T.C. 20 to 28"
           ELSE
             IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 20 to 28" THEN
               Cont.DataSetVis = "T.C. 29 to 32"
             ELSE
               IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 29 to 32" THEN
                 Cont.DataSetVis = "Temp Record"
               ELSE
                 IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "Temp Record" THEN
                   Cont.DataSetVis = "Results"
                 ELSE

                   Cont.DataSetVis = "T.C. 1 to 10"
                 END IF
               END IF
             END IF
           END IF
         END IF

      CASE 2
         IF Imprime THEN
           Imprime = False%
           Cont.Imprime = "Screen"
         ELSE
           Imprime = True
           Cont.Imprime = "Scr and Prn"
```

```
        END IF

    CASE 3
        IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 1 to 10" THEN
          ScmDispHdrsTempA
        ELSE
          IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 11 to 19" THEN
            ScmDispHdrsTempB
          ELSE
            IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 20 to 28" THEN
              ScmDispHdrsTempC
            ELSE
              IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "T.C. 29 to 32" THEN
                ScmDispHdrsTempD
              ELSE
                IF LTRIM$(RTRIM$(Cont.DataSetVis)) = "Temp Record" THEN
                  RecordMsg
                ELSE
                  ScmDispHdrsRes

                END IF
              END IF
            END IF
          END IF
        END IF
        LOCATE 14, 1: PRINT STRING$(80, "=")
        IniciaMonitoreo

    CASE ELSE
  END SELECT
 LOOP UNTIL subchoice% <= 0
RETURN


MenuSystemColors:
'-----------------------------------
   choice$(1) = " Monochrome Scheme "
   choice$(2) = " Cyan/Blue Scheme  "
   choice$(3) = " Blue/Cyan Scheme  "
   choice$(4) = " Red/Grey Scheme   "

   NumItems% = 4

   FOR i = 1 TO NumItems%
     MenuRow%(i) = i + 3
     menuCol%(i) = ParMen%(4)
   NEXT i

   help$(1) = "Color scheme for monochrome and LCD displays"
   help$(2) = "Color scheme featuring cyan"
   help$(3) = "Color scheme featuring blue"
   help$(4) = "Color scheme featuring red"

   subchoice% = Menu%(1, NumItems%, choice$(), MenuRow%(), menuCol%(), help$(), False%, 0, Valores$())

   SELECT CASE subchoice%
      CASE 1 TO 4
         ColorPref = subchoice%
      CASE ELSE
```

```
  END SELECT
  RETURN


MenuSystemAbout:
'.....................................
  choiceS(1) = " Who to blame"

  NumItems% = 1

  FOR i = 1 TO NumItems%
    MenuRow%(i) = i + 3
    menuCol%(i) = BarMen%(5)
  NEXT i

  helpS(1) = "Names follow!!!"

  subchoice% = Menu%(1, 1, choiceS(), MenuRow%(), menuCol%(), helpS(), False%, 0, ValoresS())

  SELECT CASE subchoice%
     CASE 1: Intro
     CASE ELSE
  END SELECT
RETURN


END SUB

SUB MesConLetras (strDateS)
'=======================================================================
   MesesS = "JanFebMarAprMayJunJulAugSepOctNovDec"
     MesS = MIDS(MesesS, VAL(LEFTS(strDateS, 2)) * 3 - 2, 3)
 strDateS = MesS + MIDS(strDateS, 3, 4) + "19" + RIGHTS(strDateS, 2)
END SUB

SUB PrintHelpLine (helpS)
'=======================================================================
  COLOR colors%(5, ColorPref), colors%(4, ColorPref)
  LOCATE 25, 1
  PRINT SPACES(80);
  Center 25, helpS
END SUB

SUB RecordMsg
'=======================================================================
LOCATE 11, 1: PRINT " TEMPERATURES ARE BEING RECORDED IN A FILE"

END SUB

SUB ScrnDispHdrsRes
'=======================================================================
             '        10        20        30        40        50        60        70        80
             ' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
             ' 1234567--1234567--1234567--1234567--1234567--1234567--1234567--1234567--1234567
 LOCATE 10, 1: PRINT "  Avg Hot   Avg Cold     Thermal     "
 LOCATE 11, 1: PRINT "   Temp       Temp     Conductivity  "
 LOCATE 12, 1: PRINT "   (C)        (C)        (W/m.C)     "

END SUB
```

```
SUB ScrnDispHdrsTempA
'===========================================================================
            '       10        20        30        40        50        60        70        80
            ' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 LOCATE 11, 1: PRINT " Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp "
 LOCATE 12, 1: PRINT " TC1    TC2    TC3    TC4    TC5    TC6    TC7    TC8    TC9    TC10 "
 LOCATE 13, 1: PRINT "  C      C      C      C      C      C      C      C      C      C "
END SUB

SUB ScrnDispHdrsTempB
'===========================================================================
            '       10        20        30        40        50        60        70        80
            ' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 LOCATE 11, 1: PRINT " Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp "
 LOCATE 12, 1: PRINT " TC11   TC12   TC13   TC14   TC15   TC16   TC17   TC18   TC19 "
 LOCATE 13, 1: PRINT "  C      C      C      C      C      C      C      C      C "
END SUB

SUB ScrnDispHdrsTempC
'===========================================================================
            '       10        20        30        40        50        60        70        80
            ' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 LOCATE 11, 1: PRINT " Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp   Temp "
 LOCATE 12, 1: PRINT " TC20   TC21   TC22   TC23   TC24   TC25   TC26   TC27   TC28 "
 LOCATE 13, 1: PRINT "  C      C      C      C      C      C      C      C      C "

END SUB

SUB ScrnDispHdrsTempD
'===========================================================================
            '       10        20        30        40        50        60        70        80
            ' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 LOCATE 11, 1: PRINT " Temp   Temp   Temp   Temp "'  Temp   Temp   Temp "
 LOCATE 12, 1: PRINT " TC29   TC30   TC31   TC32 "'  TC33   TC34   TC35 "
 LOCATE 13, 1: PRINT "  C      C      C      C "'    C      C      C "

END SUB

SUB ScrnDispRes
'===========================================================================
'       10        20        30        40        50        60        70        80
' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 FORMATS = " ###.##,   ###.##,   ####.####"
'      1       2        3
 PRINT USING FORMATS; Res.TempHotAvg; Res.TempColdAvg; Res.ThermCond
END SUB

SUB ScrnDispTempA
'===========================================================================

'     1      2      3      4      5      6      7      8      9      10
'  123456 123456 123456 123456 123456 123456 123456 123456 123456 123456
      '       10        20        30        40        50        60        70        80
      ' 123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 FORMATS = "###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##"

 PRINT USING FORMATS; TermCop(1); TermCop(2); TermCop(3); TermCop(4); TermCop(5); TermCop(6); TermCop(7);
TermCop(8); TermCop(9); TermCop(10)
END SUB
```

```
SUB ScrnDispTempB
'============================================================================
'          10        20        30        40        50        60        70        80
'  123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 FORMAT$ = "###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.## "
'         1       2       3       4       5       6       7       8       9
'         123456  123456  123456  123456  123456  123456  123456  123456  123456

 PRINT USING FORMAT$; TermCop(11); TermCop(12); TermCop(13); TermCop(14); TermCop(15); TermCop(16); TermCop(17);
TermCop(18); TermCop(19)
END SUB

SUB ScrnDispTempC
'============================================================================
'          10        20        30        40        50        60        70        80
'  123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 FORMAT$ = "###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.##, ###.## "
'         1       2       3       4       5       6       7       8       9
'         123456  123456  123456  123456  123456  123456  123456  123456  123456

 PRINT USING FORMAT$; TermCop(20); TermCop(21); TermCop(22); TermCop(23); TermCop(24); TermCop(25); TermCop(26);
TermCop(27); TermCop(28)

END SUB

SUB ScrnDispTempD
'============================================================================
'          10        20        30        40        50        60        70        80
'  123456789 123456789 123456789 123456789 123456789 123456789 123456789 123456789
 FORMAT$ = "###.##, ###.##, ###.##, ###.##" ', ###.##, ###.##, ###.## "
'         1       2       3       4       5       6       7
'         123456  123456  123456  123456  123456  123456  123456

 PRINT USING FORMAT$; TermCop(29); TermCop(30); TermCop(31); TermCop(32) '; TermCop(33); TermCop(34); TermCop(35)

END SUB

SUB ScrollDown
'============================================================================
   DEF SEG = VARSEG(ScrollDownAsm(1))
   CALL Absolute(VARPTR(ScrollDownAsm(1)))
   DEF SEG
END SUB

SUB ScrollUp
'============================================================================
   DEF SEG = VARSEG(ScrollUpAsm(1))
   CALL Absolute(VARPTR(ScrollUpAsm(1)))
   DEF SEG
END SUB

SUB SparklePause
'============================================================================
   COLOR 4, 0
   A$ = "*    *    *    *    *    *    *    *    *    *    *    *    *    *    *    *    *    *    *    *    "
   WHILE INKEY$ <> "": WEND 'Clear keyboard buffer

   WHILE INKEY$ = ""
      FOR A = 1 TO 5
```

```
        LOCATE 1, 1                         'print horizontal sparkles
        PRINT MID$(A$, A, 80);
        LOCATE 22, 1
        PRINT MID$(A$, 6 - A, 80);

        FOR B = 2 TO 21                      'Print Vertical sparkles
          C = (A + B) MOD 5
          IF C = 1 THEN
            LOCATE B, 80
            PRINT "*";
            LOCATE 23 - B, 1
            PRINT "*";
          ELSE
            LOCATE B, 80
            PRINT " ";
            LOCATE 23 - B, 1
            PRINT " ";
          END IF
        NEXT B
      NEXT A
    WEND
END SUB

SUB TempRecord
'==========================================================================
  DIM Temp(1 TO 32, 1 TO 10)
  DIM Heat(1 TO 10)
  DIM SigVolt(1 TO 10)
  INPUT "Enter the name of the output file(drive a, ext WQ1)"; name$
  IF name$ = "" THEN
    name$ = "a:blank.wq1"
  END IF
  OPEN name$ FOR OUTPUT AS #2
  time1$ = TIME$

  FOR count1% = 1 TO 10
    IF LoggerOn THEN
      LeeDeLogger
    ELSE
      InventaTemps
    END IF
    FOR count2% = 1 TO 32
      Temp(count2%, count1%) = TermCop(count2%)
    NEXT count2%
    Heat(count1%) = AutoPower
    SigVolt(count1%) = voltdc

  NEXT count1%
  time2$ = TIME$
  FOR count2% = 1 TO 32
    FOR count1% = 1 TO 10
      FORMAT$ = "###.##"
      PRINT #2, USING FORMAT$; Temp(count2%, count1%);
    NEXT count1%
    PRINT #2,
  NEXT count2%
  PRINT #2,

  PRINT #2, "Signal (V)"
```

```
 FOR count1% = 1 TO 10
    FORMAT$ = "##.######"
    PRINT #2, USING FORMAT$; SigVolt(count1%);
 NEXT count1%
 PRINT #2,

 PRINT #2, "Heat Input (W)"
 FOR count1% = 1 TO 10
    FORMAT$ = "###.######"
    PRINT #2, USING FORMAT$; Heat(count1%);
 NEXT count1%
 PRINT #2,
 PRINT #2,

 PRINT #2, "Scan started at"; time1$
 PRINT #2, "Scan stopped at"; time2$

 CLOSE #2

END SUB

FUNCTION Trim$ (X$)
'==========================================================================
  IF X$ = "" THEN
     Trim$ = ""
  ELSE
     lastChar = 0
     FOR A = 1 TO LEN(X$)
        y$ = MID$(X$, A, 1)
        IF y$ <> CHR$(0) AND y$ <> " " THEN
           lastChar = A
        END IF
     NEXT A
     Trim$ = LEFT$(X$, lastChar)
  END IF

END FUNCTION
```

COMPLOGR.BAS

```
DECLARE SUB thermocouple (chan%, range%, type$)
DECLARE SUB thermistor (chan%, range%, ty$)
DECLARE SUB atod1 (chan%, range%, func%)
DECLARE SUB updateref ()
DECLARE SUB loadmodules ()
DECLARE SUB initmodule (md%)
DECLARE SUB viaregistertest ()
DECLARE SUB viainitialize ()
DECLARE SUB autozero (printon%)
DECLARE SUB restorevia ()
DECLARE SUB atod2 ()
DECLARE SUB initlev1errors ()
DECLARE SUB timedelay (seconds!)
DECLARE SUB printerror ()
DECLARE SUB timeinit ()
DECLARE SUB timeelapsed (time!)
DECLARE SUB changemodule (md%)
DECLARE SUB volts (chan%, range%)
DECLARE SUB ohms3w (chan%, range%)

' $INCLUDE: 'loggrvar.inc'


' Roundoff functions
' -----------------
  DEF fna (x) = INT(x + .5)
  DEF fnb (x) = INT(x * 10 + .5) / 10
  DEF fnc (x) = INT(x * 100 + .5) / 100
  DEF fnd (x) = INT(x * 1000 + .5) / 1000
  DEF fne (x) = INT(x * 10000 + .5) / 10000
  DEF fnf (x) = INT(x * 100000 + .5) / 100000
  DEF fng (x) = INT(x * 1000000 + .5) / 1000000

SUB atod1 (chan%, range%, func%) STATIC
  ' func% 0: DCV 1:mA 2:ohms3 3:Hz 4:Vhg 5:Vlg 6:ohms2 7:ACV

  meas = 0!
  ' Check parameters
  model% = model%(module%)
  SELECT CASE model%
    CASE 81, 161, 321, 641, 7000, 7001, 8082
    CASE ELSE
      er = 24
      EXIT SUB
  END SELECT
  IF (func% < 0) OR (func% > 7) THEN
    er = 17
    EXIT SUB
  END IF
  IF (func% > 3) AND (model% <> 7000) THEN
    er = 5
    EXIT SUB
  END IF
  IF (model% = 7001) AND ((func% = 1) OR (func% = 3) OR (func% = 6) OR (func% = 7)) THEN
    er = 17
```

```
  EXIT SUB
END IF
IF (chan% < 0) OR (chan% > mxaich%(module%)) THEN
  er = 2
  EXIT SUB
END IF
IF (range% < 0) OR (range% > 3) THEN
  er = 3
  EXIT SUB
END IF

' Autozero if volts or mA and only if azmode% is 1
IF (azmode%(module%) = 1) AND ((func% = 0) OR (func% = 1)) THEN
  CALL autozero(0)
END IF


IF (model% = 7000) OR (model% = 7001) OR (model% = 321) OR (model% = 641) OR (model% = 8082) THEN
  OUT badd% + 12, 204 ' hold a/d
  OUT badd% + 2, 191  ' reinit via registers
  OUT badd% + 3, 255  ' reinit via registers
  IF INP(badd% + 2) <> 191 THEN
    CALL viainitialize: er = 1: EXIT SUB
  END IF
  ' Set up channel, range and function inside module
  IF (model% = 7000) THEN
    OUT badd% + 1, (func% * 32) OR chan%
  ELSE
    OUT badd% + 1, (func% * 64) OR chan%
  END IF
  IF (func% = 2) THEN
    OUT badd%, (INP(badd%) AND &HF0) OR (4 * range%)
  ELSE
    OUT badd%, (INP(badd%) AND &HF0) OR range%
  END IF
  IF (func% = 2) AND (range% = 3) THEN
    CALL timedelay(.08)
  ELSE
    CALL timedelay(.03)
  END IF
  CALL atod2
  IF er <> 0! THEN
    CALL viainitialize
    EXIT SUB
  END IF
ELSEIF (model% = 81) OR (model% = 161) THEN
'  CALL atod161(chan%, range%, func%)
'  IF func% = 3 THEN EXIT SUB
ELSE
  er = 5
  EXIT SUB
END IF
' conv (global) now contains a/d counts: convert to milli-volts
SELECT CASE model%
  CASE 7000, 81, 161
    conv = conv * 1.220703125#
  CASE 321, 641, 8082
    ' Do nothing
  CASE 7001
```

```
    conv = conv * 3.66210937#
   CASE ELSE
  END SELECT
  ' Autozero the reading
  IF (azmode%(module%) = 1) AND ((func% = 0) OR (func% = 1)) THEN
   conv = conv - azero(range%, module%)
  END IF
END SUB

SUB atod2 STATIC
  IF (INP(badd% + 2) <> 191) THEN CALL restorevia: er = 1: EXIT SUB
  conv = 0!
  CALL timedelay(.01)   ' analog stabilizing time
  OUT badd% + 12, 206
  CALL timeinit
  DO
   astat% = INP(badd% + 13) AND 2
   CALL timeelapsed(time)
   IF (time > .5) THEN CALL restorevia: er = 10: EXIT DO: EXIT SUB
  LOOP WHILE (astat% = 0)
  CALL restorevia
  ' A/D low/high byte address depends on model number
  IF (model%(module%) = 7000) THEN
   hadd% = badd% + 21
  ELSE
   hadd% = badd% + 17
  END IF
  ladd% = hadd% - 1
  l1% = INP(ladd%)
  l2% = INP(ladd%)
  h1% = INP(hadd%) AND &H3F
  h2% = INP(hadd%) AND &H3F
  IF ((l1% <> l2%) OR (h1% <> h2%)) THEN er = 11: EXIT SUB
  IF ((h1% AND 16) = 16) THEN er = 9!: CALL timedelay(.5): EXIT SUB
  conv = 256 * (h1% AND &HF) + l1%
  IF (h1% AND 32) = 0 THEN conv = -conv
  IF ((INP(badd% + 13) AND 2) = 2) THEN er = 8
END SUB

SUB autoohms3w (chan%) STATIC
  IF (model%(module%)) = 7000 THEN fscale = 5! ELSE fscale = 4.096
  CALL ohms3w(chan%, 3)
  IF er <> 0! THEN EXIT SUB
  m = meas
  range% = 1
  DO
   IF (ABS(m) < 1.8 * refres(module%, range%)) THEN
    CALL ohms3w(chan%, range%)
    IF er <> 0! THEN er = 0: meas = m
    EXIT SUB
   END IF
   range% = range% + 1
  LOOP WHILE (range% < 3)
END SUB

SUB autovolts (chan%) STATIC
  CALL volts(chan%, 0)
  IF er <> 0! THEN EXIT SUB
  IF (model%(module%)) = 7000 THEN fscale = 5! ELSE fscale = 4.096
```

```
 m = meas
 range% = 3
 DO
  IF (ABS(m) < .9 * fscale / gain(range%, module%)) THEN
    CALL volts(chan%, range%)
    IF er <> 0! THEN er = 0: meas = m
    EXIT SUB
  END IF
  range% = range% - 1
 LOOP WHILE (range% > 0)
END SUB

SUB autozero (printon%) STATIC
 IF (azmode%(module%) = 0) THEN EXIT SUB
 dtime = TIMER - tlastaz(module%)
 IF (dtime < azper(module%)) THEN EXIT SUB
 IF printon% THEN PRINT "          AZ (ch="; azch%(module%); ") ";
 erl = 0
 azmode%(module%) = 0 ' this prevents recursive calls (atod1..autozero)
 FOR range% = 0 TO 3
  CALL atod1(azch%(module%), range%, 0)
  IF er = 0 THEN
    IF ABS(conv) > 200 THEN
     erl = 16
     IF printon% THEN PRINT "[BAD:"; INT(conv); "] ";
    ELSE
     azero(range%, module%) = conv
     tlastaz(module%) = TIMER
     IF printon% THEN PRINT INT(conv);
     er = 0
    END IF
  ELSE
    erl = ERR
  END IF
 NEXT range%
 er = erl
 IF printon% THEN
  IF er = 0 THEN
    PRINT "  ";
  ELSE
    CALL printerror
  END IF
 END IF
 azmode%(module%) = 1
END SUB

SUB changemodule (md%) STATIC
 IF (md% < 1) OR (md% > nmodules%) THEN er = 4: EXIT SUB
 module% = md%
 ' set the base address in the scalar badd%
 badd% = baddm%(md%)
END SUB

SUB initlevlerrors STATIC
 ' general    1234567890
 ermes$(0) = "NoError   "
 ermes$(1) = "CntTlkUnit: cant find meas control unit"
 ermes$(2) = "BadChannel: bad channel"
 ermes$(3) = "BadRange  : bad range"
```

```
  ermes$(4) = "BadModule : bad meas/cont module number"
  ermes$(5) = "BadFuncton: bad meas/cont function for this model"
  ermes$(6) = "BadValue  : as loaded from module file"
  ermes$(7) = "BadScnFun : bad scan function or not yet installed"
  ' a/d
  ermes$(8) = "A/Dinopert: a/d converter inoperative"
  ermes$(9) = "OverRange : signal overrange"
  ermes$(10) = "A/DTimeOut: a/d converter timed out"
  ermes$(11) = "A/DDigRead: a/d converter digital read"
  ermes$(12) = "Res<0     : resistance less than 0"
  ermes$(13) = "BadTcpType: bad thermocouple type"
  ermes$(14) = "TcpTmp2Big: thermocouple: degrees out of equation range"
  ermes$(15) = "BadRefTemp: thermocouple reftemp < 5 or > 40 c"
  ermes$(16) = "AzToHigh  : auto-zero count too high"
  ermes$(17) = "BadA/DfFun: illegal function number in atod1"
  ermes$(18) = "ThmBadRes : thermistor r<55 or >56k"
  ermes$(19) = "ReftError : reference temp error"
  ermes$(20) = ""
  ermes$(21) = "IllegParam: illegal parameter"
  ermes$(23) = "BadThmType: illegal thermistor type"
  ermes$(24) = "BadModel  : Bad product model number"

END SUB

SUB Initlevel1 STATIC
'==========================================================================
  CLS
  PRINT
  PRINT "Initializing: Level 1 "
  measmodulefile$ = "MODULES.PAR"
  CALL initlev1errors

  CALL loadmodules
  ' initialize each module
  FOR i% = 1 TO nmodules%
    CALL initmodule(i%)
  NEXT i%
  PRINT
  PRINT "Initialization complete."
  CALL timedelay(11)
END SUB

SUB initmodule (md%) STATIC
  ' This routine initializes one module
  CALL changemodule(md%)
  PRINT "Module "; md%; " Model "; model%(md%); " Address "; baddm%(md%)
  er = 0
  regsok% = 1
  model% = model%(module%)
  IF (model% = 321) OR (model% = 641) OR (model% = 7000) OR (model% = 8082) THEN
    CALL viaregistertest
    IF (er = 0) THEN
      PRINT " --->Registers test OK."
      LoggerOn = True
    ELSE
      PRINT " --->Registers test BAD?"; CHR$(7)
      er = 0
      regsok% = 0
      LoggerOn = False
```

```
  END IF
  CALL viainitialize
 ELSEIF (model% = 81) OR (model% = 161) THEN
  regsok% = 1
 END IF

 IF (mxaich%(module%) > 0) AND (regsok% <> 0) THEN
  ' unit does have analog inputs
  ' Module has analog inputs so autozero and do a reftemp scan
  er = 0
  IF azmode%(module%) THEN CALL autozero(1)
 'if Labmate: measure 2-wire ohms on AZ channel (if azmode% on)
  IF (model% = 7000) AND (azmode%(module%) <> 0) THEN
  '  azohms = 0
  '  CALL ohms2w(azch%(module%)) 'dummy conversion
  '  er = 0
  '  CALL ohms2w(azch%(module%))
  '  IF er = 0 THEN azohms = meas ELSE azohms = 500: er = 0
  END IF
  IF rfmode%(module%) THEN
    CALL updateref
    IF er <> 0! THEN reftemp(module%) = -100!: er = 0
    PRINT
    PRINT "          Reference temperature = "; reftemp(module%)
  END IF
 END IF

 ' Initialize DACs if they exist
' FOR i% = 0 TO mxaoch%(module%)
'   CALL dac(i%, 0)
' NEXT i%

 ' Initialize Digital Outputs if they exist
' FOR i% = 0 TO mxdoch%(module%)
'   CALL digitaloutput(i%, 0)
' NEXT i%

 ' Initialize Counter Inputs if they exist
' FOR i% = 0 TO mxcich%(module%)
'   CALL resetcounter(i%)
' NEXT i%

 ' Initialize Relay Outputs if they exist
 rbyte%(module%) = 0
' FOR i% = 0 TO mxroch%(module%)
'   CALL relay(i%, 0)
' NEXT i%

 PRINT
END SUB

SUB loadmodules STATIC
 PRINT
 PRINT "Loading measurement/control module file : "; measmodulefile$
 CLOSE #1
 OPEN measmodulefile$ FOR INPUT AS #1
 IF er <> 0! THEN
   PRINT "NOVA aborted due to missing input file: "; measmodulefile$
   BEEP
```

```
  STOP
END IF
INPUT #1, nmodules%
' Read away 3 top lines in file
LINE INPUT #1, a$
LINE INPUT #1, a$
LINE INPUT #1, a$
PRINT
PRINT "Module Parameters:"
PRINT "      bas az az rf rf gains....... reference resistors......... mV   clock"
PRINT "model add ch pr ch pr 10   100 500 Rng1  Rng2  Rng3   r18  r19   1403 freq hz"
PRINT "----- --- -- -- -- -- ---- --- --- ----- ----- ------ ---- ----- ---- -------"
REM    641 640 00 60 01 60 10.0 100 500 100.0 10000 100000 1000 10000 2500 1000000
f1$ = "##### ### ## ## ## ## ##.# ### ### ###.# ##### ###### #### ##### #### #######"
FOR i = 1 TO nmodules%
  gain(0, i) = 1!
  INPUT #1, model%(i), baddm%(i), azch%(i), azper(i), refchan%(i), refper(i), gain(1, i), gain(2, i), gain(3, i), refres(1, i), refres(2,
i), refres(3,i),              r18(i), r19(i), v1403(i), clkfrq(i)
  PRINT USING f1$; model%(i); baddm%(i); azch%(i); azper(i); refchan%(i); refper(i); gain(1, i); gain(2, i); gain(3, i); refres(1, i);
                refres(2, i); refres(3i); r18(i); r19(i); v1403(i); clkfrq(i)
  IF (baddm%(i) < 512) OR (baddm%(i) > 1023) THEN
    PRINT "Error: illegal base address for module "; i; " (="; baddm%(i); ")"
    PRINT "Module eliminated."
    model%(i) = 0
  END IF
NEXT i
PRINT
CLOSE #1
' Assign maximum channel numbers and initialize autozero/reftemp timers
FOR i% = 1 TO nmodules%
  tlastaz(i%) = -100
  tlastrf(i%) = -100
  mxaich%(i%) = -1
  mxaoch%(i%) = -1
  mxdich%(i%) = -1
  mxdoch%(i%) = -1
  mxroch%(i%) = -1
  mxcich%(i%) = -1
  byte%(i%) = 0
  IF model%(i%) = 321 THEN
    mxaich%(i%) = 31
    mxdich%(i%) = 15
  END IF
  IF model%(i%) = 1 THEN 'rb01
    mxroch%(i%) = 7
  END IF
  IF (model%(i%) = 641) OR (model%(i%) = 8082) THEN
    mxaich%(i%) = 63
    mxdich%(i%) = 15
  END IF
  IF model%(i%) = 7000 THEN
    mxaich%(i%) = 15
    mxaoch%(i%) = 1
    mxdich%(i%) = 7
    mxdoch%(i%) = 7
    mxroch%(i%) = 1
    mxcich%(i%) = 2
  END IF
  IF model%(i%) = 81 THEN
```

```
    mxaich%(i%) = 7
    mxdich%(i%) = 3
    mxcich%(i%) = 0
   END IF
   IF model%(i%) = 161 THEN
    mxaich%(i%) = 15
    mxdich%(i%) = 7
    mxcich%(i%) = 1
   END IF
   ' Determine if thermocouple reftemp scans are required
   IF (refchan%(i%) >= 0) AND (refchan%(i%) <= mxaich%(i%)) THEN
    rfmode%(i%) = 1
   ELSE
    rfmode%(i%) = 0
   END IF
  ' Determine if autozeroing is required
   IF (azch%(i%) >= 0) AND (azch%(i%) <= mxaich%(i%)) THEN
    azmode%(i%) = 1
   ELSE
    azmode%(i%) = 0
   END IF
 NEXT i%
END SUB

SUB ohms3w (chan%, range%) STATIC
 IF (range% < 1) THEN er = 3: EXIT SUB
 CALL atod1(chan%, range%, 2)
 IF er <> 0! THEN EXIT SUB
 model% = model%(module%)
 IF (model% = 7000) OR (model% = 81) OR (model% = 161) THEN
  meas = conv * refres(range%, module%) / 2500
 ELSE
  meas = conv * refres(range%, module%) / 2048
 END IF
 ' strip meaningless fraction off
 IF range% = 1 THEN meas = fnc(meas) ELSE meas = INT(meas)
 ' ohms cant be less than 0
 IF (meas < 0) THEN er = 12
END SUB

SUB printerror STATIC
 IF (er = 0) THEN EXIT SUB
 PRINT "Error "; er; " "; ermesS(er)
 meas = 0
 er = 0
END SUB

SUB restorevia STATIC
 OUT badd% + 12, 204 ' hold a/d
 OUT badd%, INP(badd%) AND &HF0 ' set for volts, gain 0
 z% = INP(badd% + 1)' clear ifr
END SUB

SUB thermistor (chan%, range%, tyS) STATIC
 ' tyS is the type: "3" is 3k @ 25C, etc
 CALL ohms3w(chan%, range%)
 IF er <> 0! THEN EXIT SUB
 IF meas <= 0 THEN
  er = 18
```

```
    EXIT SUB
  END IF
  lr = LOG(meas)
  SELECT CASE tyS
    CASE "3.1"
      'type "3.1" includes quadratic term, based on least squares every degree (-30..150)
      meas = 1 / (.001403 + lr * (.0002375 + lr * (-3.188E-08 + lr * 1.006E-07))) - 273.15
    CASE "3"  ' YSI44005, 3k @ 25
      meas = 1 / (1.400406E-03 + lr * (2.377609E-04 + lr * lr * 9.744748E-08)) - 273.15
    CASE "5"
      meas = 1 / (1.28279E-03 + lr * (2.36509E-04 + lr * lr * 9.206623E-08)) - 273.15
    CASE "10"
      meas = 1 / (.0010287 + lr * (2.39222E-04 + lr * lr * 1.56244E-07)) - 273.15
    CASE ELSE
      er = 23
      meas = 0
  END SELECT
  meas = fnc(meas)
END SUB

SUB thermocouple (chan%, range%, typeS) STATIC
  IF rfmode%(module%) = 0 THEN er = 19: EXIT SUB 'ref temp mode is off
  CALL updateref
  IF er <> 0! THEN EXIT SUB
  reft = reftemp(module%)
  IF ((reft < 5) OR (reft > 40)) THEN er = 15: EXIT SUB
  CALL volts(chan%, range%)
  IF er <> 0! THEN EXIT SUB
  vcomp = meas * 1000 'need mv

  reft = reftemp(module%)

  SELECT CASE typeS
    CASE "T"
      vtypet = -.0012 + reft * (.038619 + reft * (4.3656E-05 + reft * -2.0671E-08))
      vcomp = vcomp + vtypet
      meas = -.0099 + vcomp * (25.8827 + vcomp * (-.69646 + vcomp * .02613))
    CASE "E"
      vtypee = 2.5577E-04 + reft * (.05855 + reft * (4.9214E-05 + reft * -3.0384E-08))
      vcomp = vcomp + vtypee
      meas = -.0264 + vcomp * (17.07668 + vcomp * (-.23082 + vcomp * .00538))
    CASE "J"
      vtypej = 8.3934E-04 + reft * (.05037 + reft * (2.8571E-05 + reft * -5.7363E-08))
      vcomp = vcomp + vtypej
      meas = -.0316 + vcomp * (19.84916 + vcomp * (-.21026 + vcomp * 8.96989E-03))
    CASE ELSE
      er = 13
    END SELECT
  IF (meas < -30) OR (meas > 150) THEN er = 14 'limits of curve fit
  meas = fnc(meas)
END SUB

SUB timedelay (seconds) STATIC
  tstart = TIMER
  DO
    telap = TIMER - tstart
    IF telap < 0 THEN telap = telap + 86400
  LOOP WHILE (telap < seconds)
END SUB
```

```
SUB timeelapsed (time) STATIC
 time = TIMER - timestart
 IF time < 0 THEN time = time + 86400
END SUB

SUB timeinit STATIC
 timestart = TIMER
END SUB

SUB updateref STATIC
 ' Check whether enough time has elapsed to do a reftemp
 telapsed = TIMER - tlastrf(module%)
 IF telapsed < 0 THEN telapsed = telapsed + 86400
 IF (telapsed < refper(module%)) AND (reftemp(module%) <> 0) THEN EXIT SUB
 ' Measure the reference thermistor
 CALL thermistor(refchan%(module%), 2, "3")
 IF er <> 0! THEN EXIT SUB
 reftemp(module%) = meas
 tlastrf(module%) = TIMER
END SUB

SUB viainitialize STATIC
 OUT badd% + 2, 0
 OUT badd% + 3, 0
 OUT badd% + 11, 0
 OUT badd% + 14, 128
 OUT badd% + 12, &HCC
 OUT badd% + 2, 191
 OUT badd% + 3, 255
 ' hold a/d, wait for worst case conversion
 OUT badd% + 12, 204
 CALL timedelay(.15)
 ' clear ifr
 z% = INP(badd% + 1)
END SUB

SUB viaregistertest STATIC
 er = 0
 OUT badd% + 2, 85
 OUT badd% + 3, 170
 IF (INP(badd% + 2) <> 85) OR (INP(badd% + 3) <> 170) THEN er = 1
END SUB

SUB volts (chan%, range%) STATIC
 CALL atod1(chan%, range%, 0)
 IF er <> 0! THEN EXIT SUB
 meas = conv / (gain(range%, module%) * 1000)  ' conv in mV
 IF range% = 0 THEN
  meas = fnd(meas)
 ELSEIF range% = 1 THEN
  meas = fne(meas)
 ELSEIF range% = 2 THEN
  meas = fnf(meas)
 ELSEIF range% = 3 THEN
  meas = fng(meas)
 END IF
END SUB
```

COMPTOOL.BAS

```
DECLARE FUNCTION Redondea! (Variable!, Decimales%)
DECLARE SUB StringToInteger (anystr$, intvar%, badnum%)
DECLARE SUB GetInput (instr$, maxlen%)
DECLARE SUB DisplayBox (topline%, leftcol%, bottomline%, rightcol%)

' $INCLUDE: 'loggrvar.inc'

DIM SHARED converterror%

END
ValError:
  converterror% = True
  RESUME NEXT
DisplayDateAndTime:
  xPos% = POS(0)
  yPos% = CSRLIN
  COLOR 7, 0
  LOCATE 1, 1
  PRINT Fecha$;
  LOCATE 1, 70
  PRINT TIME$;
  LOCATE yPos%, xPos%
RETURN

SUB GetInput (instr$, maxlen%)
'==========================================================================
  CONST insert% = 1, overstrike% = 2
  firstcol% = POS(0)
  insertmode% = overstrike%
  curpos% = 1
  PRINT instr$;
  COLOR , 1
  PRINT SPACE$(maxlen% - LEN(instr$) + 1);
  LOCATE , firstcol%
  COLOR 23, 12
  IF LEN(instr$) = 0 THEN
    PRINT " "; CHR$(29);
  ELSE
    PRINT LEFT$(instr$, 1); CHR$(29);
  END IF
  COLOR 7, 0
  DO
   onechar$ = INKEY$
  LOOP WHILE onechar$ = ""
  DO UNTIL onechar$ = CHR$(13)
   IF curpos% > maxlen% THEN
     PRINT " "; CHR$(29);
   ELSEIF curpos% > LEN(instr$) THEN
     COLOR , 1
     PRINT " "; CHR$(29);
     COLOR , 0
   ELSE
     PRINT MID$(instr$, curpos%, 1); CHR$(29);
```

```
END IF
IF LEFT$(onechar$, 1) = CHR$(0) THEN
  IF RIGHT$(onechar$, 1) = CHR$(77) THEN
    IF curpos% <= LEN(instr$) THEN
      curpos% = curpos% + 1
    END IF
  ELSEIF RIGHT$(onechar$, 1) = CHR$(75) THEN
    IF curpos% > 1 THEN
      curpos% = curpos% - 1
    END IF
  ELSEIF RIGHT$(onechar$, 1) = CHR$(83) THEN
    IF curpos% <= LEN(instr$) THEN
      instr$ = LEFT$(instr$, curpos% - 1) + MID$(instr$, curpos%+ 1)
      PRINT MID$(instr$, curpos%); " ";
    END IF
  ELSEIF RIGHT$(onechar$, 1) = CHR$(82) THEN
    IF insertmode% = overstrike% THEN
      insertmode% = insert%
    ELSE
      insertmode% = overstrike%
    END IF
  END IF
ELSEIF onechar$ = CHR$(8) THEN
  IF curpos% > 1 THEN
    IF curpos% > LEN(instr$) THEN
      PRINT CHR$(29); " ";
    ELSE
      PRINT CHR$(29); MID$(instr$, curpos%); " ";
    END IF
    instr$ = LEFT$(instr$, curpos% - 2) + MID$(instr$, curpos%)
    curpos% = curpos% - 1
   END IF
ELSEIF
        insertmode% = overstrike% THEN
  IF curpos% <= LEN(instr$) THEN
    MID$(instr$, curpos%, 1) = onechar$
    PRINT onechar$;
    curpos% = curpos% + 1
  ELSEIF curpos% <= maxlen% THEN
    instr$ = instr$ + onechar$
    PRINT onechar$;
    curpos% = curpos% + 1
  ELSE
    BEEP
  END IF
ELSEIF curpos% <= maxlen% THEN
  instr$ = LEFT$(instr$, curpos% - 1) + onechar$ + MID$(instr$, curpos%)
  PRINT MID$(instr$, curpos%);
  curpos% = curpos% + 1
ELSE
  BEEP
END IF
COLOR 23, 12
LOCATE , firstcol% + curpos% - 1
IF curpos% > LEN(instr$) THEN
  PRINT " "; CHR$(29);
ELSE
  PRINT MID$(instr$, curpos%, 1); CHR$(29);
END IF
```

```
      COLOR 7, 0
      DO
        onechar$ = INKEY$
      LOOP WHILE onechar$ = ""
    LOOP
    LOCATE , firstcol%
    PRINT instr$; SPACE$(maxlen% - LEN(instr$))
END SUB

SUB GetInteger (intvar%, numchars%)
'==========================================================================
  linenum% = CSRLIN
  colnum% = POS(0)
  DO
    ValError% = False%
    LOCATE linenum%, colnum%
    tempstr$ = ""
    CALL GetInput(tempstr$, numchars%)
    IF tempstr$ <> "" THEN
      CALL StringToInteger(tempstr$, intvar%, ValError%)
      IF ValError% THEN BEEP
    END IF
  LOOP WHILE ValError%
  LOCATE linenum%, colnum%
  tempstr$ = STR$(intvar%)
  PRINT tempstr$; SPACE$(numchars% - LEN(tempstr$))
END SUB

SUB GetSingle (singlevar!, numchars%, places%)
'==========================================================================
  linenum% = CSRLIN
  colnum% = POS(0)
  DO
    LOCATE linenum%, colnum%
    tempstr$ = ""
    CALL GetInput(tempstr$, numchars%)
    IF tempstr$ <> "" THEN
      converterror% = False%
      ON ERROR GOTO ValError
      singlevar! = VAL(tempstr$)
      ON ERROR GOTO 0
      IF converterror% THEN
        BEEP
      ELSE
        IF places% > 0 THEN
          singlevar! = INT(singlevar! * 10 ^ places% +.5) / 10 ^ places%
        ELSE
          singlevar! = INT(singlevar!)
        END IF
      END IF
    END IF
  LOOP WHILE converterror%
  LOCATE linenum%, colnum%
  tempstr$ = STR$(singlevar!)
  PRINT tempstr$; SPACE$(numchars% - LEN(LTRIM$(RTRIM$(tempstr$))) + 1)
END SUB

SUB GetString (stringvar$, numchars%)
'==========================================================================
```

```
  tempstr$ = ""
  linenum% = CSRLIN
  colnum% = POS(0)
  CALL GetInput(tempstr$, numchars%)
  IF tempstr$ <> "" THEN
    stringvar$ = tempstr$
  END IF
  LOCATE linenum%, colnum%
  PRINT LEFT$(stringvar$, numchars%);
END SUB

FUNCTION Redondea (Variable!, Decimales%)
'=====================================================================
  Redondea = INT(Variable! * 10 ^ Decimales% + .5) / 10 ^ Decimales%

END FUNCTION

SUB StringToInteger (anystr$, intvar%, badnum%)
'=====================================================================
    intvar% = 0
    badnum% = False%
  negative% = False%
    anystr$ = LTRIM$(RTRIM$(anystr$))
  FOR cnt% = 1 TO LEN(anystr$)
    onechar$ = MID$(anystr$, cnt%, 1)
    IF cnt% = 1 AND onechar$ = "-" THEN
      negative% = True
    ELSEIF onechar$ < "0" OR onechar$ > "9" THEN
      badnum% = True
      EXIT SUB
    ELSE
      digit% = VAL(onechar$)
      IF intvar% > 3276 OR intvar% < -3276 THEN
        badnum% = True
        EXIT SUB
      ELSEIF intvar% = 3276 AND digit% > 7 THEN
        badnum% = True
        EXIT SUB
      ELSEIF intvar% = -3276 AND digit% = 9 THEN
        badnum% = True
        EXIT SUB
      ELSEIF negative% THEN
        intvar% = intvar% * 10 - digit%
      ELSE
        intvar% = intvar% * 10 + digit%
      END IF
    END IF
  NEXT cnt%
END SUB
```

VITA AUCTORIS

1964	Born in Karachi, Pakistan on August 7.
1979	Received Secondary School Certificate from Karachi Board of Secondary Education, Karachi, Pakistan.
1981	Received F.Sc. (Pre Engineering) from Adamjee Government Science College, Karachi, Pakistan.
1986	Received Post Graduate Diploma in Production & Operations Management from Institute of Management Sciences, Karachi, Pakistan.
1988	Received Bachelor of Engineering (Mechanical Engineering) from N.E.D. University of Engineering & Technology, Karachi, Pakistan.
1988	Joined Siemens Engineering Company Limited, Karachi, Pakistan as a Trainee Engineer.
1989	Joined Fauji Fertilizer Company Limited, Rawalpindi, Pakistan as a Project Engineer (App).
1989	Joined King Fahd University of Petroleum & Minerals, Dhahran, Saudi Arabia as a Research Assistant.
1992	Currently a candidate for the degree of Master of Applied Science at the University of Windsor, Windsor, Ontario.