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Torres, Edgardo I.

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THESIS

NATURAL CONVECTION COOLING OF A 3 BY 3 ARRAY OF RECTANGULAR PROTRUSIONS IN AN ENCLOSURE FILLED WITH DIELECTRIC LIQUID: EFFECTS OF BOUNDARY CONDITIONS AND COMPONENT ORIENTATION

by

Edgardo I. Torres

December 1988

Thesis Advisor: Yogendra Joshi

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In the first study, using the same equipment set-up of Benedict [Ref. 13], the influence of changing the enclosure bottom surface boundary condition on flow patterns and heat transfer characteristics was examined. Both insulated and uniform temperature boundary conditions were considered.

In the second set of experiments, a new chamber with the protrusions oriented vertically was assembled and effects of component orientation on the heat transfer characteristics were examined. In addition, timewise variations of temperature in several locations were measured and interpreted at different power levels.

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Natural Convection Cooling of a 3 by 3 Array of Rectangular Protrusions in an Enclosure Filled with Dielectric Liquid: Effects of Boundary Conditions and Component Orientation

by

Edgardo I. Torres
LT, Columbian Navy
B.S., Columbian Naval Academy, 1986

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ABSTRACT

An experimental investigation of natural convection immersion cooling of two configurations of discrete heat sources in an enclosure filled with Fluorinert FC-75 has been conducted. A three by three array of rectangular protrusions was employed.

In the first study, using the same equipment set-up of Benedict [Ref. 13], the influence of changing the enclosure bottom surface boundary condition on flow patterns and heat transfer characteristics was examined. Both insulated and uniform temperature boundary conditions were considered.

In the second set of experiments, a new chamber with the protrusions oriented vertically was assembled and effects of component orientation on the heat transfer characteristics were examined. In addition, timewise variations of temperature in several locations were measured and interpreted at different power levels.

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TABLE OF SYMBOLS AND ABBREVIATIONS

Symbol	Description	Units
A	Area	m^2
α	Thermal diffusivity	m^2/sec
β	Volumetric expansion coefficient	1/K
c_p	Specific heat	J/kg-°C
emf	Thermocouple voltage	volt
g	Acceleration of gravity	m/sec^2
Gr	Grashof number	Dimensionless
h	Heat transfer coefficient	W/m^2-°C
k	Thermal conductivity	W/m-°C
L	Characteristic length	m
L1	Component length in the vertical direction	m
L2	Summation of the ratios of the component fluid exposed areas to their perimeters	m
Nu	Nusselt number	Dimensionless
Nu1	Nusselt number with length scale L1	Dimensionless
Nu2	Nusselt number with length scale L2	Dimensionless
ν	Kinematic viscosity	m^2/sec
ω	Uncertainty in the variables	Various

Power	Power dissipated by the heaters	W
Pr	Prandtl number	Dimensionless
Q_{conv}	Energy added to the fluid	W
Q_{in}	Energy input to the heaters	W
Q_{loss}	Energy loss by conduction	W
Q_{net}	Net power dissipated by the heater	W
R_c	Total thermal resistance	°C/W
R_p	Resistance of the precision resistor	ohms
Ra_f	Flux-based Rayleigh number	Dimensionless
Ra_t	Temperature-based Rayleigh number	Dimensionless
D	Density	kg/m^3
T_{avg}	Average of component temperature	°C
T_b	Back surface temperature of board	°C
T_c	Average heat exchanger temperature	°C
T_f	Average film temperature	°C
T_s	Back surface temperature of the component	°C
T_{sink}	Average temperature of the heat exchangers	°C
V_h	Voltage Across the Heaters	Volts
V_{in}	Input voltage	Volts
w	Chamber width	m
W	Unit of power	W

I. INTRODUCTION

A. STATEMENT OF THE PROBLEM

With the increase in circuit packaging density associated with the miniaturization of microelectronic components, heat dissipation has become a major problem in the design and construction of digital computers and high-power electronic equipment in general. Several alternatives to the solution of the problem have been studied in the past 10 years, including that of Chu [Ref. 1]. Among these, immersion cooling appears to be one of the most effective for achieving high heat-transfer coefficients.

B. IMMERSION COOLING: ANALYTICAL AND EXPERIMENTAL STUDIES

From the construction of the first electronic digital computer, the solution to the problem of heat dissipation from high packaging density electronic equipment has not been easy. Even though very interesting forced convection methods have been studied and very frequently used (Chu [Ref. 1] describes several methods of air- and water-forced convection cooling), the hardware that has to be added to supply the additional power and to store and circulate the cooling liquid can be cumbersome in any application.

The direct immersion of the electronic circuitry into dielectric liquids improves its cooling capability significantly. Baker [Ref. 2] found liquid cooling by free convection to be more than three times as effective as free convective air cooling of the same device. He made heat transfer measurements from thin-film tantalum nitride resistors evaporated on Corning 7059 glass substrates. The substrates were 1.0 by 2.6 by 0.12 cm. All resistors were rectangular, with their height (dimension parallel to the flow) one-half their base. The surface areas of the resistors were 0.0106, 0.104, 0.477, and 2.00 cm^2. Two liquids were used in the study: freon with a Prandtl number of 3.9, and Dow Corning #200 silicone dielectric liquid with a Prandtl number of 126. The results showed that the heat transfer coefficient is approximately proportional to the cube root of the reciprocal of viscosity. It was also found that the convection coefficient does increase significantly as the source size decreases. The free convection heat transfer coefficient for the smallest source was more than an order of magnitude greater than for the largest source operated under the same conditions.

In a following study, Baker [Ref. 3] also examined different cooling techniques, such as nucleate boiling, forced convection, and bubble-induced mixing for cooling small heat sources.

Park and Bergles [Ref. 4] conducted experimental studies of natural convection from discrete flush-mounted rectangular heat sources on a circuit board substrate. Micro-electronic circuit elements were simulated with thin foil heaters supplied with DC power. Measurements were also made for protruding heaters of varying widths, in water and R-113. They found and documented the increase in heat transfer coefficient with decreasing width. This effect was greater in R-113 than in water. Also, for protruding heaters, the heat transfer coefficients for the upper heaters in an array were found to be higher than those for the lower heaters. This behavior was not observed for flush-mounted heaters. As the distance between heaters increased, so did the heat transfer coefficients.

Chen, et al. [Ref. 5] made an experimental study of natural convection heat transfer in a liquid-filled rectangular enclosure with 10 protruding heaters from one vertical wall. The top surface of the enclosure maintained at a uniform temperature acted as the heat sink. All other surfaces, except the heater locations, were unheated. The enclosure was 16.7 cm in height, 2.3 cm in width, and 19.6 cm in depth (horizontal z-direction of the heaters). The 10 heaters were 0.8 cm high, 1.11 cm wide, and 19.6 cm deep. The vertical spacing between heaters was equal to the heater height. Distilled water and ethylene glycol were used as working fluids. Experimental results show that the bottom heater (heater 1), except for high Rayleigh number runs, has the highest heat transfer coefficient. The heat transfer coefficients at heaters 7, 8, and 9 are nearly the same and present the lowest values among the heaters. It was also shown that heat transfer coefficient decreases up to heater 7. At high Rayleigh numbers, the top heater (10) has the highest heat transfer coefficients. The flow visualization carried out indicates a core flow within the enclosure and a recirculating cell in the gap between heaters. Approximate measurements of the fluid velocity were provided from the particle traces in the flow visualization.

Keyhani, et al. [Ref. 6] experimentally studied the buoyancy-driven flow and heat transfer in a vertical cavity with discrete flush heat sources on one vertical wall while the other vertical wall was cooled at a constant temperature. This enclosure contained 11 alternatively unheated and flush-mounted rows of isoflux heated strips. The liquid was ethylene-glycol with a Prandtl number of 150.

To examine the flow structure, visualization experiments were conducted for several power inputs. Finely ground aluminum powder (5 to 20 microns in size) was used to visualize the flow. The observed flow for a power input of 10 watts was highly structured except for small regions near the end walls. A primary flow circulating from the hot wall to the cold wall, a secondary flow with the same sense of circulation as the primary flow, and a tertiary flow in the opposite direction of the secondary flow were observed in the photographs taken at this power level. At a higher power level of 40 watts, the flow pattern above the mid-height region of the cavity showed transition from laminar to turbulent flow along the surface with heaters. The downward flow along the cold wall was still laminar. For a fixed power input, the heat transfer coefficient generally decreased with increase in height (or heater number). The rate at which Nusselt number decreased with the increase in heater number was found to be a strong function of the heater location.

Kelleher, et al. [Ref. 7] and Lee, et al. [Ref. 8] studied experimentally and numerically the cooling by natural convection of a water-filled rectangular enclosure with a long heater protruding from one vertical wall and conducted flow visualization and heat transfer measurements with the heater at three different elevations. They found the two-dimensional flow to be dual-celled, consisting of a buoyancy-driven upper cell, in which the major part of the fluid motion takes place and which accounts for the majority of the convective heat transfer, and a shear-driven lower cell in which the fluid motion arises due to the viscous drag from the upper cell.

Liu, et al. [Ref. 9] used a three-dimensional finite difference method to study the natural convection cooling of an array of chips mounted on a vertical wall of a three-dimensional rectangular enclosure filled with a dielectric fluid Fluorinert FC 75. They found the long time solution to be oscillatory. Maximum chip temperatures were found on the top surfaces of the three top chips. However, these maximum temperatures did not all occur at the same time, but alternated among these three chips as time proceeded in a rather regular fashion. It was also observed that the bottom sink was quite ineffective in removing heat from the enclosure and that the convective circulation was essentially limited to the chip areas.

Joshi, et al. [Ref. 10] carried out an experimental investigation to study the natural convection cooling of a 3 by 3 array of heated protrusions in a rectangular enclosure filled with dielectric fluid FC-75. They observed that at low power levels (0.1 watts), the flow structure was largely determined by the thermal conditions at the enclosure surfaces. With increasing power levels (0.7 to 3.0 watts), an upward flow developed adjacent to each column of components. The flow away from the elements became strongly three-dimensional and time-dependent with increasing thermal inputs. Component surface temperatures were used to obtain a heat transfer correlation over the range of power levels examined.

Liu, et al. [Ref. 11] carried out a three-dimensional numerical study of immersion cooling of a chip array by laminar natural convection in a rectangular enclosure filled with a dielectric liquid. They determined the local temperature responses on the chip surfaces, their dynamic behaviors, and their dependence on the enclosure gap size. It was found that the temperature responses are decidedly oscillatory with wave forms ranging from simple to complex, and that maximum chip surface temperatures occur on the top row of chips for large gap sizes but oscillate among all three rows of chips for small gap sizes.

C. OBJECTIVES

The work reported here is a continuation of thesis research conducted at the Naval Postgraduate School by Pamuk [Ref. 12] and Benedict [Ref. 13]. The numerical studies by Liu, et al. [Ref. 9] and Liu, et al. [Ref. 11] were the motivation for some of the specific investigations carried out.

The objectives of the present investigation are twofold: The first is to examine the effect of bottom surface boundary condition on thermal transport in the natural convection cooling of a 3 by 3 array of horizontally arranged protruding elements on a vertical wall. The second objective is to examine heat transfer, fluid flow characteristics, and the influence of the width of the chamber during the natural convection cooling of a 3 by 3 array of vertically arranged protruding elements on a vertical wall. Temperature fluctuation measurements were plotted and compared with existing numerical analysis of Liu, et al. [Refs. 9 and 11] and Benedict [Ref. 13]. For both studies, flow visualizations were also carried out.

II. EXPERIMENTAL SET-UP

A. GENERAL CONSIDERATIONS

Two different experimental configurations were used for the studies reported here. In the first, a 3 by 3 array of rectangular elements with the largest dimension aligned horizontally was examined. In the second study, the largest dimensions were in the vertical direction. The two experimental configurations are next described.

The details of the experimental procedures are available in Benedict [Ref. 13]. The Data Acquisition Programs were the same as used by Pamuk [Ref. 12] and Benedict [Ref. 13] with minor modifications in output format and number of channels. These programs are collected in Appendix D.

1. Experimental Set-Up for the Horizontal Arrangement

A schematic sketch of the arrangement is provided in Figure 2.1 (after Benedict [Ref. 13]). The configuration is the same as the one used by Joshi, et al. [Ref. 9] and Benedict [Ref. 13]. The distribution of the components and the top view of the chamber are illustrated in Figures 2.2 and 2.3 (both after Benedict [Ref. 13]).

This part of the thesis examines the effect of changing the enclosure bottom surface boundary condition on the overall thermal behavior of the system. A more detailed description of the experimental arrangement can be found in Benedict [Ref. 13].

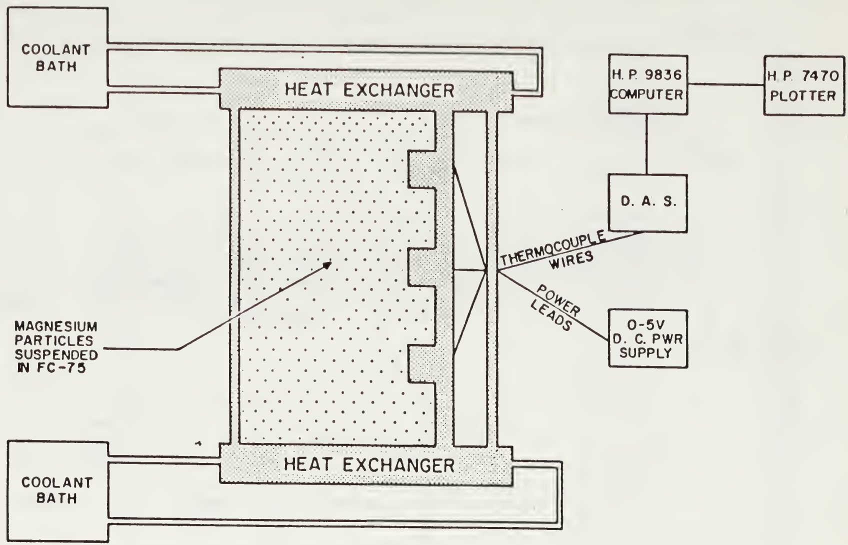


Figure 2.1 **Schematic of Entire Assembly**

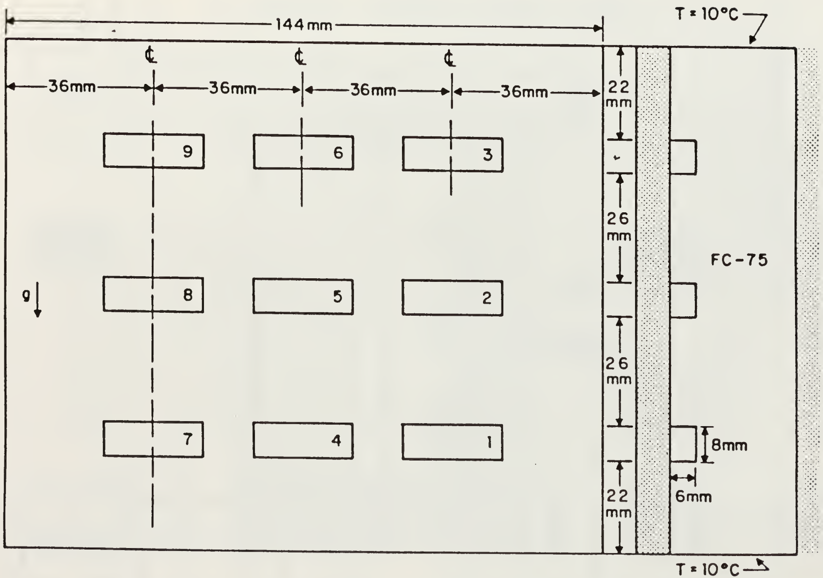


Figure 2.2 **Simulated Circuit Card for the Horizontal Arrangement**

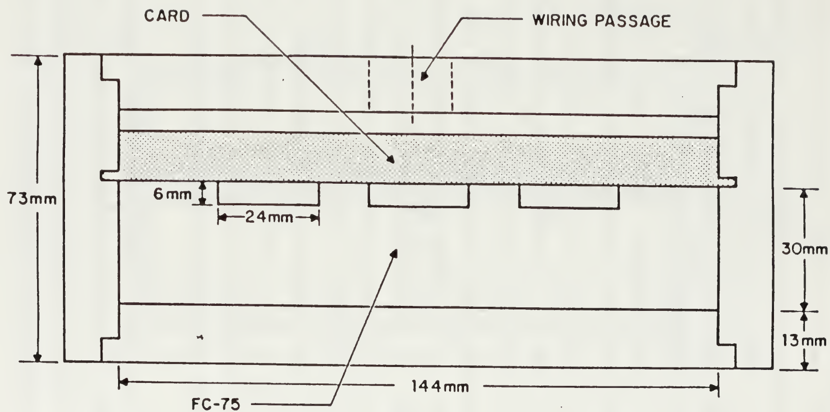


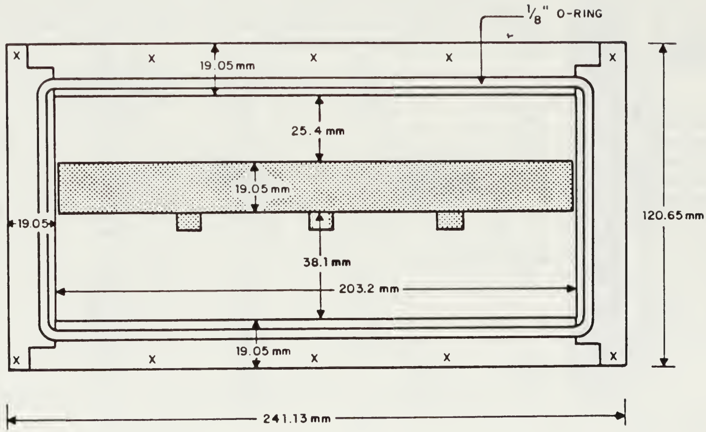
Figure 2.3 **Top View of Horizontally Arranged Components Chamber**

2. Experimental Set-Up for the Vertical Arrangement

The chamber assembly, illustrated in Figure 2.4 was made of 19.05 mm plexiglass with dimensions of 241.13 mm length, 152.0 mm height, and 120.65 mm width. As in the first arrangement, the chamber was filled with FC-75, a dielectric fluid through tubing at the bottom of the chamber.

In both experimental configurations, two heat exchangers, one at the top and one at the bottom, were used (see Figure 2.1). The design of the exchangers for the first configuration is described in Joshi, et al. [Ref. 10]. In the second study, several modifications were made to reduce the heat transfer from the outside environment to the colder circulating water. The resulting design is seen in Figure 2.5. The external walls of both top and bottom heat exchangers were made of plexiglass. The walls acting as the top and bottom of the fluid-filled enclosure were aluminum plates 3 mm thick, chosen to provide an almost isothermal surface condition. Inlet and outlet headers were provided for flow distribution. Three thermocouples, symmetrically placed along the plate length, were used for the calculation of the average surface temperatures. The heat exchangers could be accessed easily to block one or more of the channels to reduce the coolant flow rates.

A 3 by 3 array of discrete protrusions, vertically arranged (see Figure 2.6), was mounted on a 19.05 mm thick plexiglass card. The card was slid into the chamber and was kept in location by plexiglass supports that prevented its linear movement as well as rotation.



TOP VIEW

Figure 2.4 **Chamber Assembly for the Vertical Arrangement**

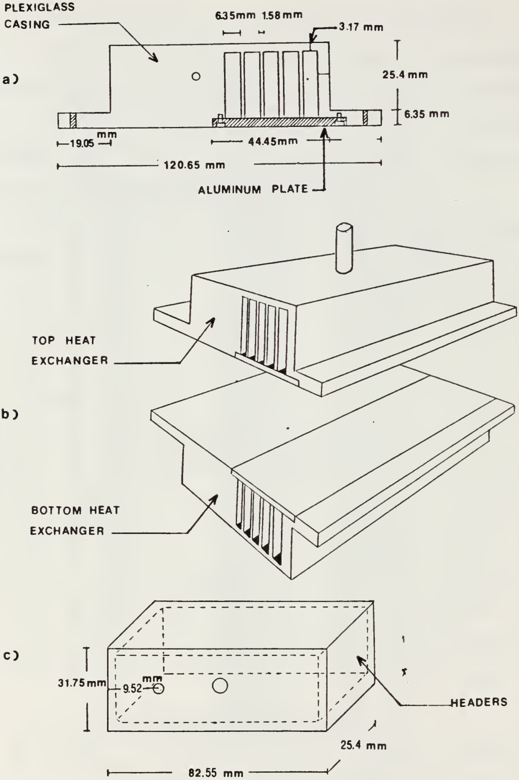


Figure 2.5 **Heat Exchangers**

(a) Cross-Sectional View; (b) Isometric View; (c) Inlet and Outlet Headers

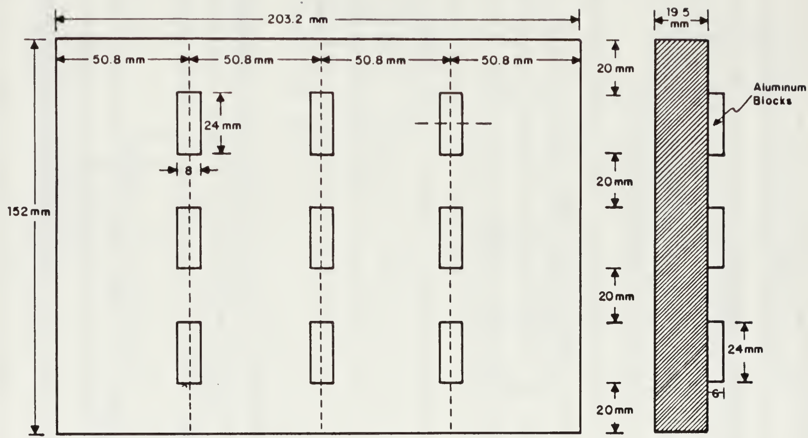


Figure 2.6 **Simulated Circuit Card for the Vertical Arrangement**

The chamber design allowed the replacement of the card in a simple way. The upper heat exchanger could be removed and the new card could be easily installed. This permits the installation of different card configurations (staggered, flush mounted, etc.) in the future without much additional effort. By moving the card back or forth, the chamber width could be changed. This was done in order to study the effect of this parameter in the overall heat transfer.

The heated components in both studies were aluminum blocks of 8 mm by 24 mm and 6 mm high (see Figure 2.7—after Benedict [Ref. 13]). The dimensions and geometry simulate approximately a 20-pin dual-in-line-package. A nearly uniform heat flux condition was maintained at the base of each block by attaching a foil-type heater with a resistance of about 11 ohms. The foil heaters contained a network of Iconel foil mounted on a Kapton backing and were 23.6 mm by 7.6 mm in dimension and were bonded to the base of each aluminum block using a high thermal conductivity epoxy (Omega Bond 101).

Temperatures at the center of each fluid exposed component face were determined using .127 mm diameter copper-constantan thermocouples. Thermocouple locations on each heater are illustrated in Figure 2.7.

All the thermocouples were connected to an HP-3497 automatic data acquisition system controlled by an HP-9826 microcomputer. Power to the heaters was supplied by a 0-40 volt, 0-1A DC

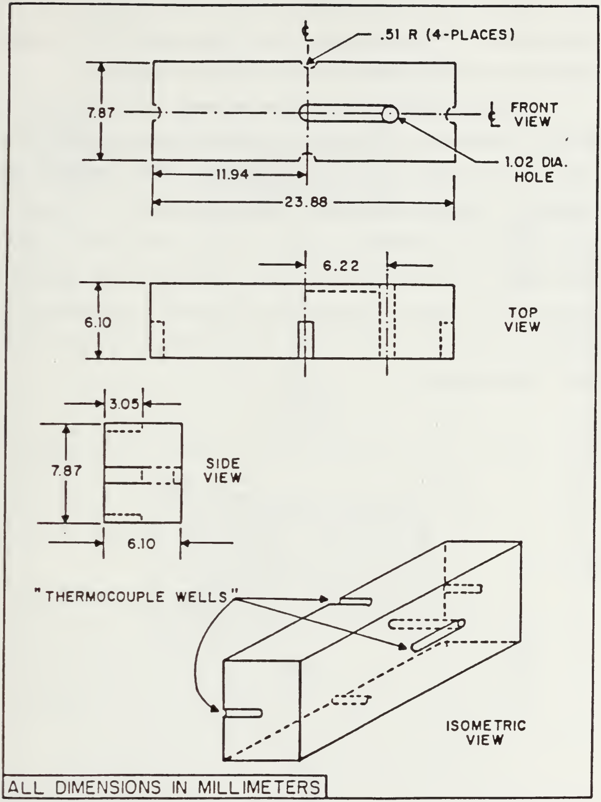


Figure 2.7 **Heating Element and Thermocouple Location**

power supply. A simultaneous measurement of the overall voltage drop, along with the voltage drop across each heater, allowed the computation of the power dissipation through individual heaters.

Flow visualization was carried out with a 4 mw Helium-Neon laser for illumination. To produce a plane of light, a cylindrical lens was used (see Figure 2.8—after Benedict [Ref. 13]). The laser sheet illuminated magnesium particles (specific gravity of 1.74) that were added to the FC-75 (specific gravity of 1.76 at 25° C). This technique allowed for the visualization of a single two-dimensional plane of the flow field. Time exposure photographs of the flow were obtained using a Nikon F-3 camera with a 50 mm lens, a MD-4 motor drive, and a MT-2 intervalometer.

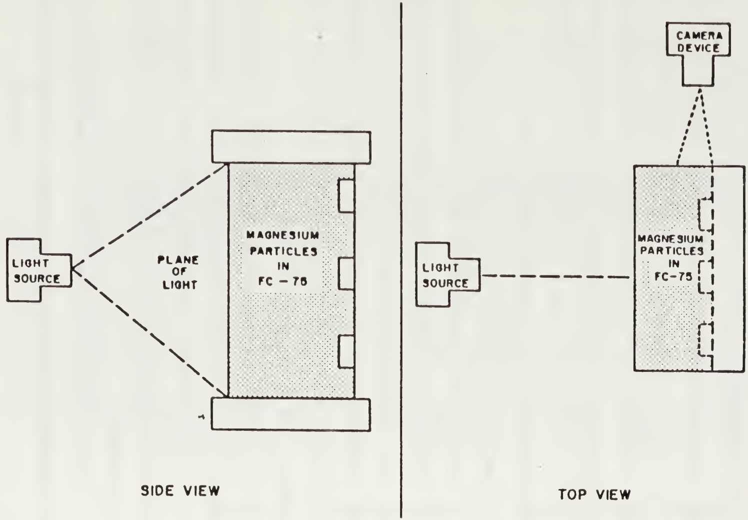


Figure 2.8 **Flow Visualization Set-Up**

III. RESULTS AND DISCUSSIONS FOR HORIZONTAL ARRANGEMENT

A. FLOW PATTERNS

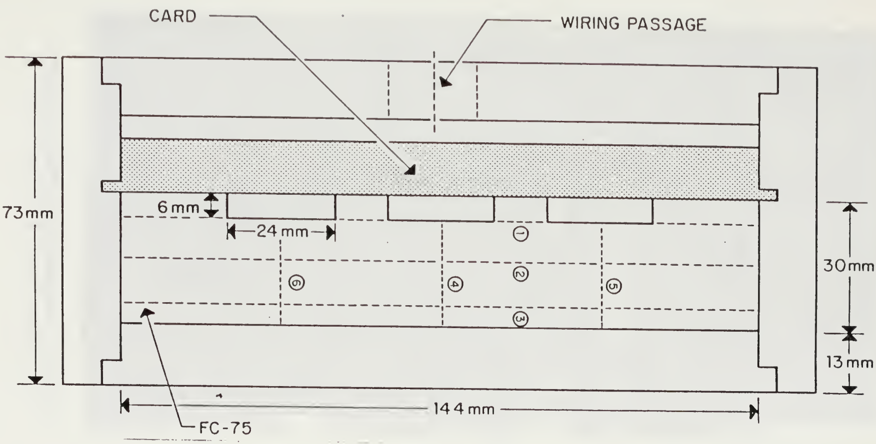
Flow visualization was carried out in six vertical planes, seen in Figure 3.1 (after Benedict [Ref. 13], for the two different bottom boundary conditions: 20° C and insulated. The three-dimensional transport responses, across the range of power dissipation of 0.1 W to 3.0 W, were inferred from these visualizations. In the following, a detailed description of the observed flows is provided.

1. Flow Patterns for the Bottom Boundary at 20° C

The flow patterns observed at several power dissipation levels from no dissipation to 3.0 W are collected in Figures 3.2 to 3.7. Visualization with no power (see Figures 3.2 and 3.3) was to examine the natural convection flow due only to the difference in temperature between the two heat exchangers, and its possible influence on the flow patterns, with the heaters turned on.

At no power, the flow consisted of a single clockwise cell that occupied the entire chamber. This overall flow was established as a result of the temperature differences between the enclosure walls. The three-dimensionality of the flow was evident from visualizations in the various planes.

At 0.1 W, the pattern observed at no power in Figures 3.2 and 3.3 was completely distorted and no remains of the strong clockwise



The six vertical flow visualization planes are identified in the sketch.

Figure 3.1 **Top View of the Enclosure With the Card Placed in Position** a

b

c

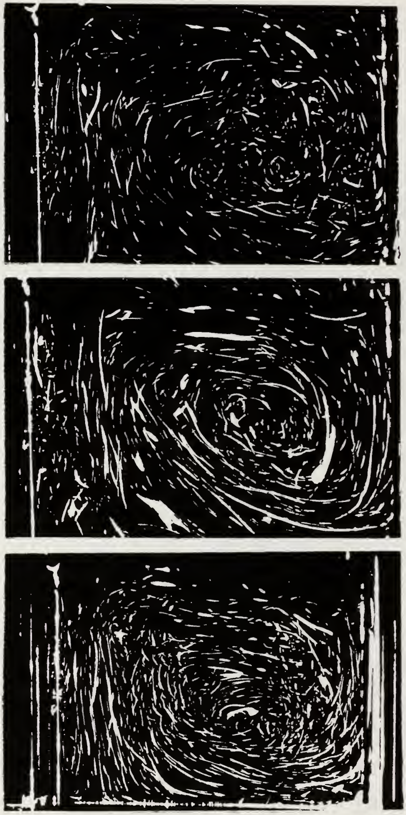


Figure 3.2 **Visualization With No Power in Planes 1 (a), 2 (b), and 3 (c)**

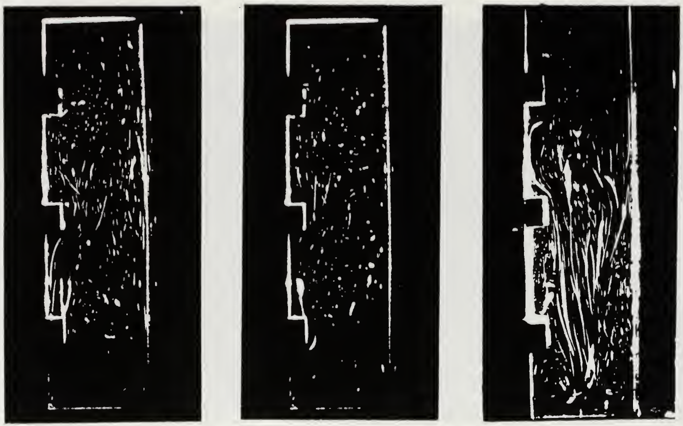


Figure 3.3 **Visualization With No Power in Planes 4 (a), 5 (b), and 6 (c)**

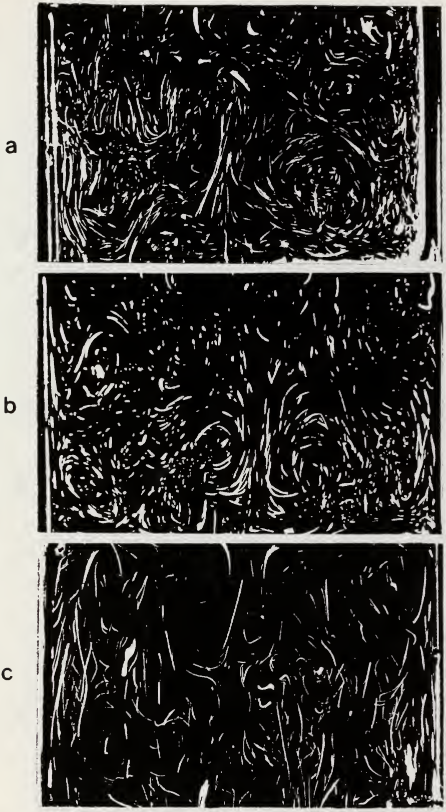


Figure 3.4 **Visualization with 1.1 W in Planes 1 (a), 2 (b), and 3 (c)**

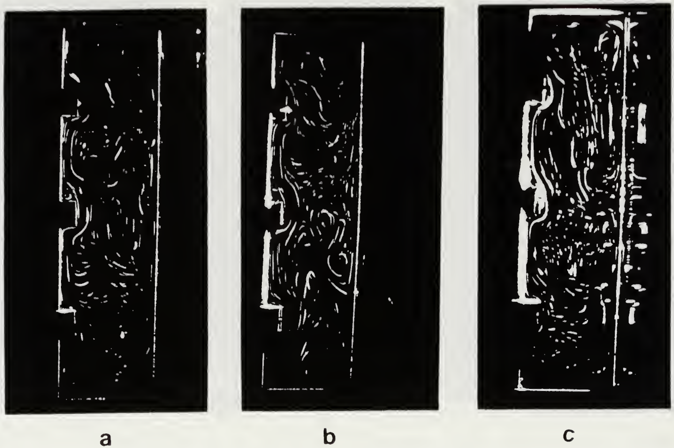


Figure 3.5 **Visualization With 1.1 W in Planes 4 (a), 5 (b), and 6 (c)**

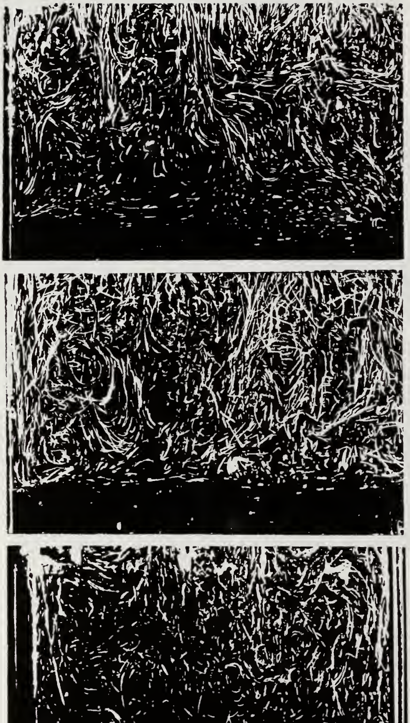


Figure 3.6 **Visualization with 3.0 W in Planes 1 (a), 2 (b), and 3 (c)**

Figure 3.7 **Visualization With 3.0 W in Planes 4 (a), 5 (b), and 6 (c)**

flow were seen. Joshi, et al. [Ref. 10] at the same power level reported two very well defined large clockwise cells, one on each side of the central component column. The present visualization showed that the flow now was completely dominated by the relatively high temperature of the bottom heat exchanger. The effects of the buoyancy forces due to the power dissipation were small except in plane 1 (close to the heaters), where there was a well defined upflow.

In plane 2, the particle traces showed a decrease in velocity. Also, dark regions, as observed in Joshi, et al. [Ref. 10], were seen. These were, however, thinner and not well defined. These nearly quiescent regions appear due to the stable stratification produced by the bottom heat exchanger. Descending fluid from the top is unable to penetrate the colder layer of fluid at the bottom. In plane 3, a downflow resulted due to an increase in the density of the colder fluid, in contact with the upper heat exchanger, at 10° C.

At 1.1 W (see Figure 3.4), a well defined pattern could be observed in planes 1 and 2. Along the central column of heaters, the upflow was wider and stronger than near the adjacent columns. This flow was the result of the interaction of an upflow along the central column, a clockwise flow around the right column (heaters 1, 2, and 3), and a counterclockwise flow around the left column (heaters 7, 8, and 9). In plane 3, a downflow of cold liquid was seen. In Figure 3.5, flow patterns at 1.1 W in planes 4, 5, and 6 are illustrated. It is possible in these pictures to appreciate in a side view the strong upflow adjacent to the components. The basic difference with the flow pattern found in the study by Joshi, et al. [Ref. 10] at the same power level is still that the inactive zone in the bottom of the chamber is not well defined.

With further increase in the power level, the flow in plane 1 exhibited stronger upflow near the components. The buoyancy forces generated by the power dissipation here were strong enough to extend their influence to planes 2 and 3. At 3.0 W, a very thin, dark layer was still observed at the bottom of the chamber (see Figure 3.6). A view of the flow patterns in planes 4, 5, and 6 is illustrated in Figure 3.7. This figure shows a buoyant fluid layer adjacent to the components. In the remaining chamber, the motion was completely random.

2. Flow Pattern With the Bottom Boundary Insulated

The flow pattern for this condition showed similar trends as discussed in section A.1. The induced flow due to the difference in temperature between the two heat exchangers was not appreciable.

B. HEAT TRANSFER MEASUREMENTS

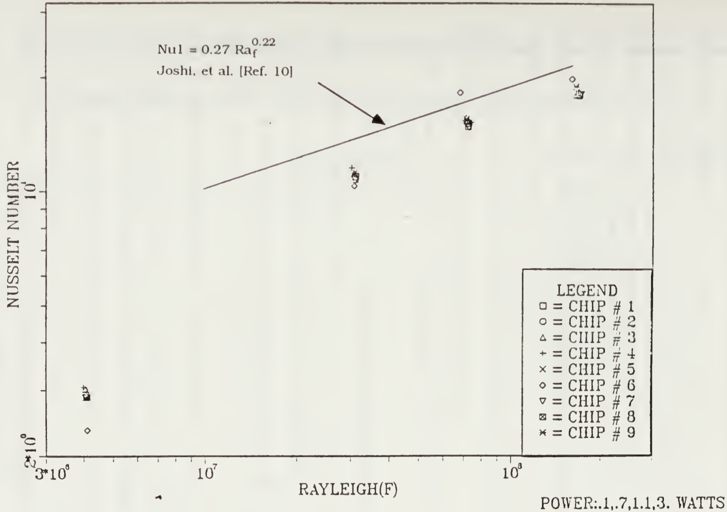
Heat transfer measurements were made at power levels of 0.1, 0.7, 1.1, 1.5, and 3.0 watts for the two bottom surface boundary conditions. The temperature at the top heat exchanger was maintained constant at 10° C in all experiments. Temperature and flux-based Rayleigh numbers (Ra_t and Ra_f) were calculated in a manner identical to that discussed in Joshi, et al. [Ref. 10] and plotted versus Nusselt number (Nu1). These are defined in the Table of Symbols and Abbreviations.

1. Heat Transfer Measurements With the Bottom Boundary at 20° C

Component surface temperature measurements at various power levels are collected in Tables 1 through 8 in Appendix C. The nondimensional heat transfer parameters in the form of Nusselt versus Rayleigh numbers are illustrated in Figures 3.8 and 3.9. In the same plots, the correlations found by Joshi, et al. [Ref. 10] were also plotted.

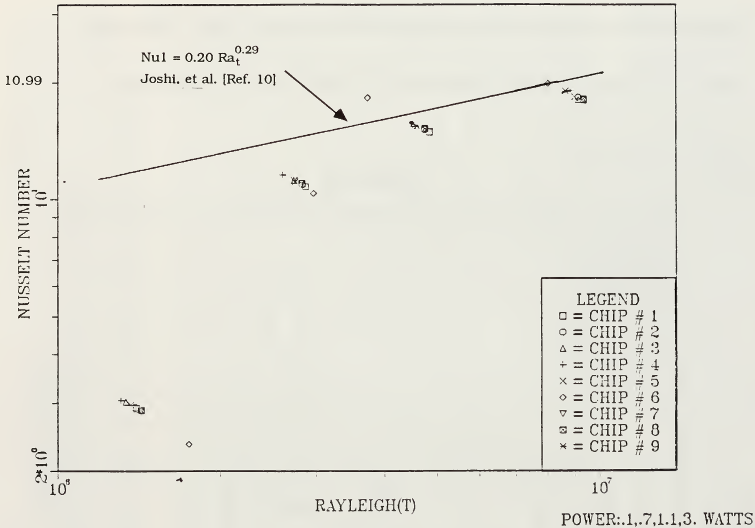
We can see that having the bottom heat exchanger at 20° C results in general in lower Nusselt numbers than those found by Joshi, et al. [Ref. 10] in the range of Rayleigh numbers considered. At higher power levels, when the temperature of the heaters was considerably higher than the bulk temperature of the dielectric fluid, the difference in Nusselt numbers is smaller than at lower power levels. The Nusselt number at a flux-based Rayleigh number of 10^6 found by Joshi, et al. [Ref. 10] was 20.4, while the Nusselt number obtained here for the same Rayleigh number was 19. At lower power levels 0.1 W and 0.7 W, the differences in Nusselt number were greater, and the decrease in the heat transfer coefficient was significant. The Nusselt number found by Joshi, et al. [Ref. 10] was 10.5 at a flux-based Rayleigh number of 10^6, while the Nusselt obtained with the present configuration was 2.9.

At power levels of 0.1 W and 0.7 W, a small increase in the upper heaters' temperatures over the lower ones was observed. At higher power levels, the highest temperatures were found irregularly in different components.



Correlation found by Joshi, et al. [Ref.10] is plotted with a continuous line.

Figure 3.8 **Plot of Flux-Based Rayleigh Number Versus Nusselt Number**



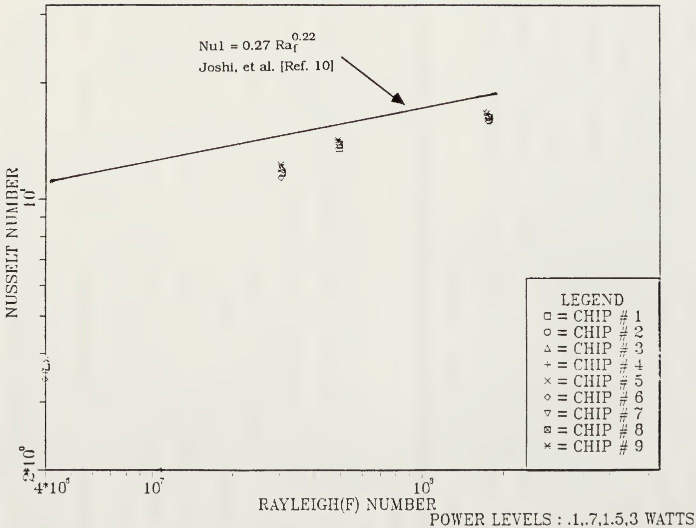
Correlation found by Joshi, et al. [Ref.10] is plotted with a continuous line.

Figure 3.9 **Plot of Temperature-Based Rayleigh Number Versus Nusselt Number**

The component that presented the largest variations from the mean in the heat transfer coefficients was the upper component in the central column (heater 6). This is evidenced as deviations from the general trend of the obtained data. The variations (lower heat transfer coefficient at low power levels, and higher heat transfer coefficients at higher power levels) are expected because this component receives the influence of the combined upflowing streams (produced by the other heaters), as was observed and documented in the flow visualization results in Section A.1. The effect is greater at higher power levels when the component's temperature is substantially larger than the bottom heat exchanger temperature.

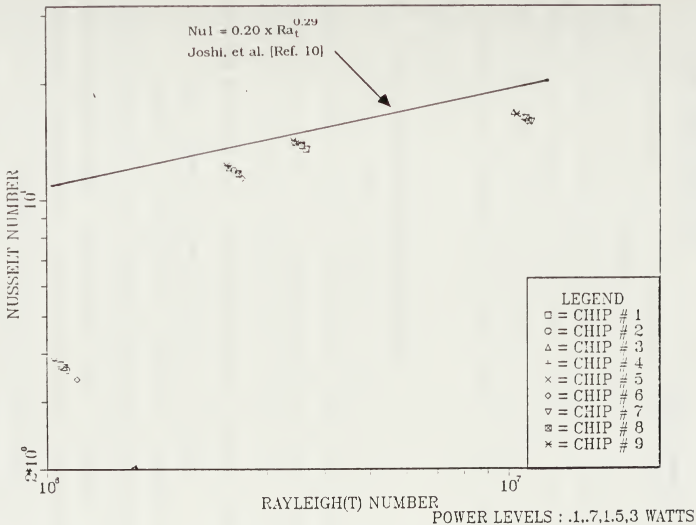
2. Heat Transfer Measurements With the Bottom Boundary Insulated

The results of the temperature measurements with the bottom boundary insulated and the reduced dimensionless parameters are collected in Tables 9 through 16 in Appendix C. In Figures 3.10 and 3.11, flux and temperature Rayleigh numbers versus Nusselt numbers were plotted. Correlations found by Joshi, et al. [Ref. 10] were also plotted for comparison. It was seen that having the bottom heat exchanger insulated improved the cooling at low power levels (0.1 W and 0.7 W) over that obtained with the bottom boundary maintained at 20° C. This result is expected because now the temperature of the bottom boundary was 15° C at 0.1 W and 17° C at 0.7 W. At a power level of 3.0 W, no cooling improvement was observed. The temperature for the bottom boundary at 3.0 W was 22° C.



Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

Figure 3.10 **Plot of Flux-Based Rayleigh Number Versus Nusselt Number**



Correlation found by Joshi, et al. [Ref. 10] is plotted with a continuous line.

Figure 3.11 **Plot of Temperature-Based Rayleigh Number Versus Nusselt Number**

Comparisons with the correlation obtained by Joshi, et al. [Ref. 10] show a decrease in the heat transfer coefficient when the lower boundary was insulated. This was evidenced by the lower Nusselt numbers at all power levels.

IV. RESULTS AND DISCUSSIONS FOR VERTICAL ARRANGEMENT

A. FLOW VISUALIZATION

The visualization for this experiment was tried for a chamber width of 9 mm. As was expected, there was almost no flow in the narrow gap between components and the front wall. A boundary layer-like behavior was observed on the vertical side faces of the components. The photography process was complicated because the thickness of the plane to be illuminated by the laser sheet for this chamber width was only 3 mm.

B. HEAT TRANSFER MEASUREMENTS

Component surface temperature measurements were made for chamber widths of 30 mm and 9 mm (see Figure 4.1). The power level range was 0.1 W to 3.0 W. Temperatures of the top and bottom boundaries were maintained constant at 10° C. Plots of Nu1 versus Ra_f are provided for comparisons with data obtained by Benedict [Ref. 13].

1. Heat Transfer Measurement for w = 30 mm

Tables 17 through 28 in Appendix C compile component surface temperature and resulting nondimensional heat transfer data for this gap size with increasing power levels. The mean values of the component averaged temperatures over the nine heated components were 13° C for 0.1 W and 47° C for 3.0 W. In the range 0.1 W to 1.1 W, the lowest T_{avg} levels were on the bottom-row components

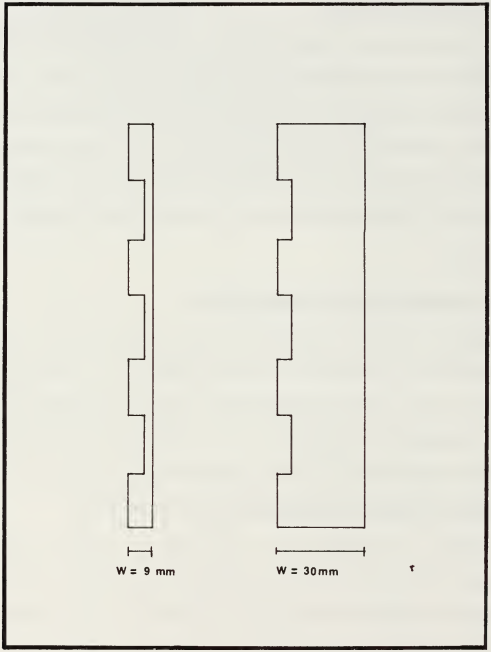
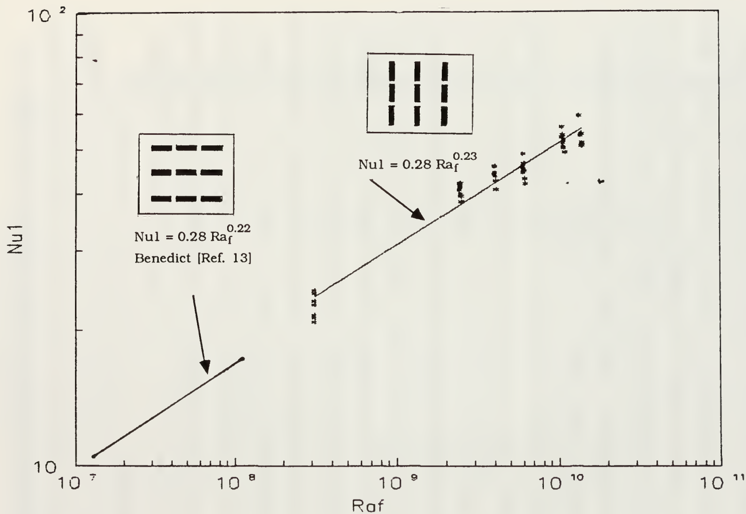


Figure 4.1 **Side View Showing the Chamber Widths Used in the Experiment**

(components 1, 4, and 7). The observed tendency was that temperatures on specific locations on the components in the top row were higher than those in the same location on the components in lower rows. As was pointed out by Liu, et al. [Ref. 11], the possible reason for this might be that components in the top row are in contact with warmer liquid, and the upper-row components are located in the heated wake regions of the lower rows. Additionally, the stratified fluid away from the components, which feeds fluid toward the component rows, is also at higher temperature for the upper rows.

Analyzing individual components in the middle and lower rows, for all power levels, the minimum measured temperatures were on the bottom surfaces. This trend is also supported by Liu, et al. [Ref. 9]. On the top row components, the lowest temperatures were on either one of the vertical side faces. Maximum temperatures were found generally on the component surface facing the front chamber wall. Liu, et al. [Ref. 11] obtained numerically maximum temperatures in the surfaces facing upward and attributed this to the fact that the heated flow coming off the vertical surfaces reduced the heat transfer coefficient at the component top surface. At higher power levels, oscillations in temperature changed the locations of the maximum and minimum instantaneous values, but the general tendencies found earlier were still noticed.

In Figure 4.2, a plot of Nu1 versus Ra_f is seen. Data obtained from Benedict [Ref. 13] is also plotted. A linear least squares fit to the present measurements in Figure 4.2 was performed. This is given by:



The curve fit for the horizontal arrangement is from Benedict [Ref. 13]. Present measurements and curve fit are for the vertical arrangement.

Figure 4.2 **Comparison of the Nondimensional Heat Transfer Measurements for Two Different Component Orientations**

$$Nu1 = 0.28\ Ra_f^{0.23} \text{ in the range } 3 * 10^8 < Ra_f < 10^{10}$$

$$\text{and } 15 < Pr < 30.2 \qquad (4.1)$$

and the one obtained with the data from Benedict [Ref. 13] was:

$$Nu1 = 0.28\ Ra_f^{0.22} \text{ in the range } 10^7 < Ra_f < 2 * 10^8$$

$$\text{and } 15 < Pr < 30.2 \qquad (4.2)$$

Comparisons between Equations 4.1 and 4.2 indicate that Nu appears not to depend on the orientation of the components in the range of Ra_f and Pr considered. This is illustrated in Figure 4.2

2. Heat Transfer Measurement for w = 9 mm

In Tables 29 through 40 in Appendix C, component temperatures and resulting nondimensional heat transfer data are compiled. Decreasing the chamber width from 30 mm to 9 mm produced some increase in the average temperature of the components T_{avg}. This behavior was expected considering that now the surface of both top and bottom heat exchangers has been reduced to 30 percent of its former value. The mean value of the component averaged temperatures over the nine heaters for a power of 0.1 W was 14.5° C, 1.5° C higher than the average temperature obtained with 30 mm width. For a dissipation level of 3.0 W, the mean value of the components' averaged temperature over the nine heaters was 51° C, 4.0° C higher than the average observed for the 30 mm width. The T_{avg} value increased from the bottom to the top row, as was also found for w = 30 mm.

Analyzing individual components on the bottom row (components 1, 4, and 7), minimum temperatures were found on the bottom surfaces.

Plots of Nu1 versus Ra_f are illustrated in Figure 4.3. The correlation obtained for this chamber width was:

$$Nu1 = 0.073\, Ra_f^{0.28} \text{ in the range } 3 * 10^8 < Ra_f < 10^{10}$$

$$\text{and } 15 < Pr < 30.2 \qquad (4.3)$$

This correlation indicates the expected decrease in Nu1 for the same Ra_f, when compared with Equation 4.1 for w = 30 mm.

C. TEMPERATURE FLUCTUATIONS IN STEADY STATE

Oscillations in component surface temperatures following achievement of nominally steady conditions were measured in the dissipation range of 0.1 W to 3.0 W. Three thermocouples were scanned at a rate of approximately three times per second for a period of 200 seconds. Plots of surface temperature variations were made in order to display the long-time temperature fluctuations and compare with results of Liu, et al. [Ref. 11] and Benedict [Ref. 13]. Figure 4.4 is a vertical arrangement diagram which portrays the location of the scanned thermocouples.

1. Surface Temperature Fluctuations for a w = 30 mm

Temperature oscillations for this chamber width are illustrated in Figures 4.5 through 4.7. It was observed that at all power

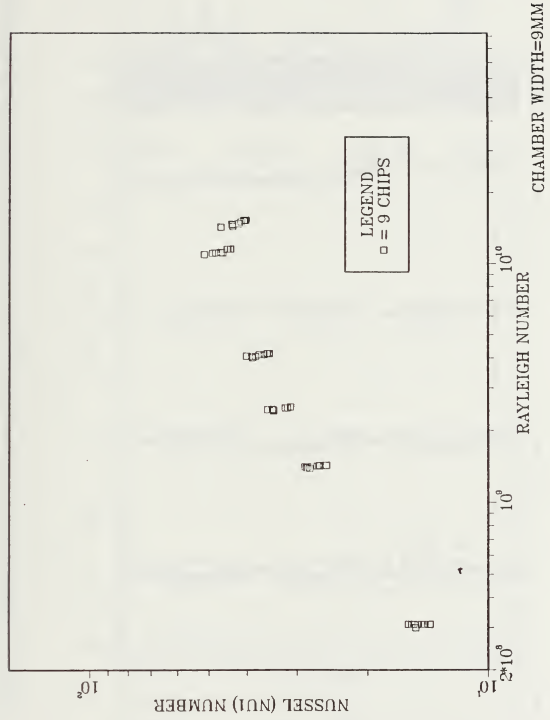


Figure 4.3 **Plot of Nu1 vs. Ra_f for a Chamber Width = 9 mm**

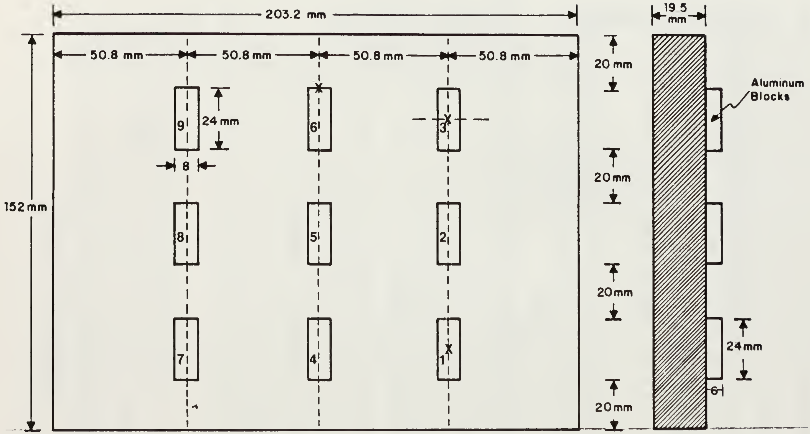


Figure 4.4 **Location of Thermocouples Scanned for Measurements of Fluctuations**

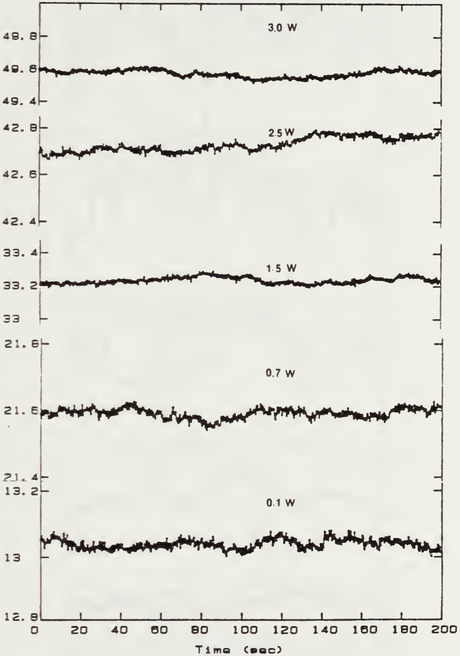


Figure 4.5 **Temperature Fluctuations for Thermocouple No. 0 at Different Power Levels**

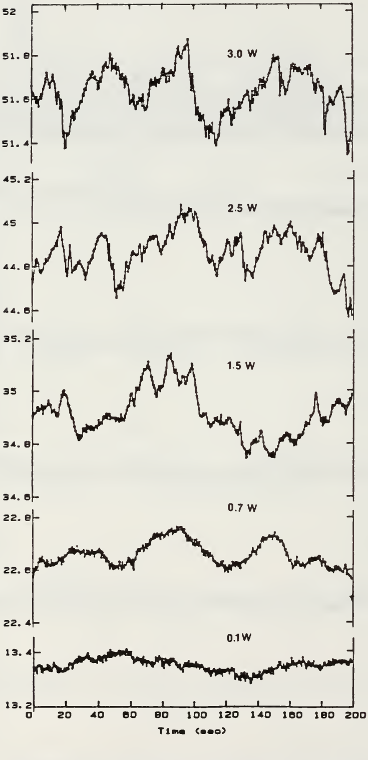


Figure 4.6 **Temperature Fluctuations for Thermocouple No. 12 at Different Power Levels**

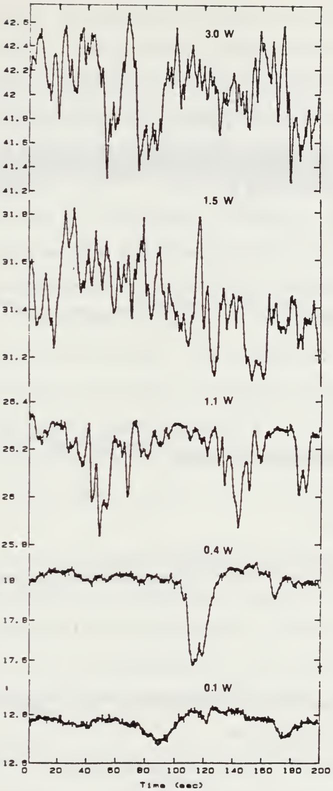


Figure 4.7 **Temperature Fluctuations for Thermocouple No. 31 at Different Power Levels**

levels considered, there were no temperature fluctuations on the components in the lower row. Benedict [Ref. 13] documented with heat transfer measurement and flow visualizations that the stagnant fluid layer above the bottom heat exchanger prevented the penetration of warmer fluid, resulting in conduction-dominated transport for the bottom row of components.

At 0.1 W, a spread in temperature of less than 0.5° C was observed between the six thermocouples that were scanned. Increasing the power level to 0.7 W, oscillation amplitudes with a mean of 0.7° C were observed in component 6. At 1.1 W, the amplitude increased to 0.8° C. Benedict [Ref. 13] found that a component at the same relative location and power level in a horizontal arrangement had almost no oscillations. At 2.5 W, oscillations of about 1.6° C were found. At 3.0 W, oscillations rose to almost 1.7° C at the same location. Benedict [Ref. 13] found at 3.1 W for the equivalent thermocouple an amplitude of 0.85° C.

2. Surface Temperature Fluctuations for w = 9 mm

Plots of temperature oscillations are illustrated in Figures 4.8 through 4.10. At 0.1 W, no fluctuations were found in any of the thermocouples scanned. At 0.4 W, fluctuations of 0.3° C were observed in the top row components. No fluctuations were observed in the middle and bottom row components.

Increasing the power dissipation level to 0.7 W, no fluctuations were observed in either the middle or the bottom rows, but

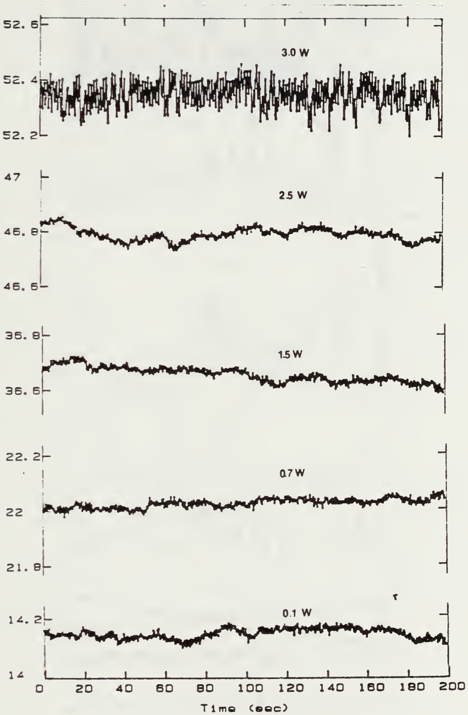


Figure 4.8 **Temperature Fluctuations for Thermocouple No. 0 at Different Power Levels**

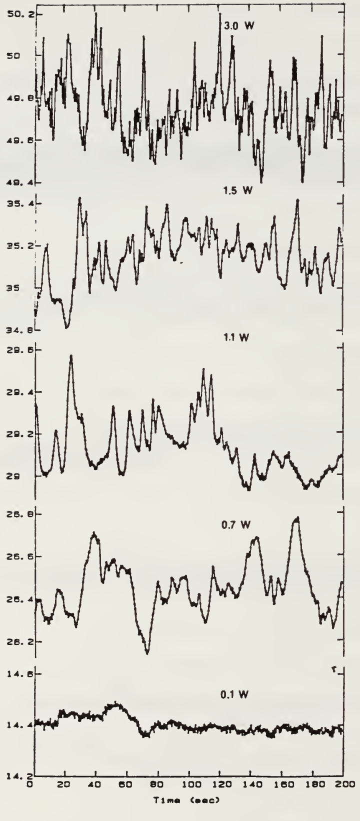


Figure 4.9 **Temperature Fluctuations for Thermocouple No. 12 at Different Power Levels**

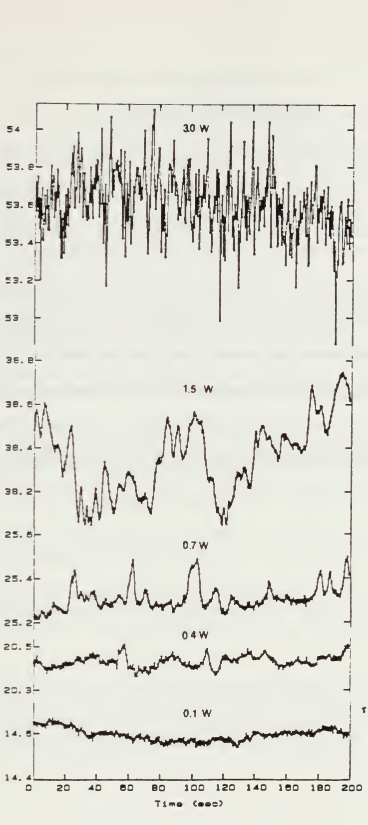


Figure 4.10 **Temperature Fluctuations for Thermocouple No. 31 at Different Power Levels**

fluctuations of 0.7° C were observed in the top row. At 1.1 W, fluctuations in the top-row components were about 0.9° C. No fluctuations were observed at the middle and bottom rows. At 1.5 W, fluctuations of 0.2° C appeared in the components in the middle row and reached values of 1.1° C in the top-row components. At 3.0 W, the highest power level utilized in the experiments, fluctuation amplitudes on the top-row components were recorded at 2.0° C. It is interesting to note that no significant increase in the amplitude of the fluctuations was observed when the chamber width was changed from 30 mm to 9 mm. Liu, et al. [Ref. 11] calculated temperature oscillations peak to valley of 8° C for the 9 mm chamber width. They attributed the increase in the oscillation amplitude to the fact that now the flow is highly confined.

V. RECOMMENDATIONS

The design of the present chamber can be improved in many ways to give more versatility in the following experiments. The recommended changes that can be made to software and hardware include:

- Placement of the blocks can be done by screwing or attaching them to the board in a different way to the one used until now, which is bonding the chips to the board with glue. This would allow the experimenter to change a defective heater or change the orientation of the chips for a different set of experiments, using the same board and the same equipment set-up.

- To avoid the flow of dielectric liquid to the back of the chamber through the gaps between the board and the chamber walls that can alter the heat transfer results or the flow visualization, a small diameter O-ring can be used. A groove should be engraved in the board to allow the O-ring installation.

- Temperature measurements within the fluid and on the board surfaces should also be performed.

- a Fast Fourier Transform algorithm should be developed to perform frequency analysis on the surface temperature fluctuations data. In addition, improvements in the plotting programs can be made.

- With the present set-up, different combinations of heaters could be powered, row-wise or column-wise or staggered, instead of the entire array. This variation might help better to explain the heat transfer and flow characteristics of the chamber.

APPENDIX A

SAMPLE CALCULATIONS

A. CONVERSION OF THERMOCOUPLE VOLTAGES TO TEMPERATURES

(Channels 0 to 60 and 71 to 76, in the data acquisition system)

$$T = D1 + D2 * Emf + D3 * Emf^2 + D4 * Emf^3 + D5 * Emf^4$$
$$+ D6 * Emf^5 + D7 * Emf^6 + D8 * Emf^7$$

where D1 to D9 are the calibration coefficients of the Omega thermocouples and are: 0.10086091, 25727.9, -767345.8, 7802-5596, -9247486589, 6.98E11, -2.66E13, and 3.94E14.

Calculating the temperature found in the thermocouple connected to channel 0 at 1.1 W gives:

$$Emf = 0.995E\text{-}3\ V$$
$$T = 24.48°\ C$$

B. CALCULATION OF HEATER POWER

Channels 61 to 70 in the data acquisition system are used to measure the supply voltage (61) and voltage to the heaters.

$$Power = Emf * (Volt - Emf)/Rp$$

Calculating the power dissipated by the heater #3:

$$\text{Power} = 3.408 * (4.085 - 3.408)/2.07$$

$$\text{Power} = 1.114 \text{ W}$$

C. CALCULATION OF THE DIMENSIONLESS PARAMETERS

1. Calculation of the Block Faces Areas

Dimensions of the aluminum blocks are: length 24 mm, width 8 mm, and thickness 6 mm.

$$A_{cen} = 24 \text{ mm} * 8 \text{ mm} = 192 \text{ mm}^2 = 1.92\text{E-4 m}^2$$

$$A_{lef} = 24 \text{ mm} * 6 \text{ mm} = 144 \text{ mm}^2 = 1.44\text{E-4 m}^2$$

$$A_{rig} = 24 \text{ mm} * 6 \text{ mm} = 144 \text{ mm}^2 = 1.44\text{E-4 m}^2$$

$$A_{top} = 6 \text{ mm} * 8 \text{ mm} = 48 \text{ mm}^2 = 4.8\text{E-5 m}^2$$

$$A_{bot} = 6 \text{ mm} * 8 \text{ mm} = 48 \text{ mm}^2 = 4.8\text{E-5 m}^2$$

$$A_{tot} = \Sigma A = 576 \text{ mm}^2 = 5.76\text{E-4 m}^2$$

$$T_{avg} = \Sigma(T(I) * A(I))/A_{tot}$$

Calculating for component 3 at 1.1 W:

$$T_{avg} = (27.67 * 1.92\text{E-4} + 25.73 * 4.8\text{E-5} + 26.08 * 1.44\text{E-4} + 26.69 * 4.8\text{E5}) \quad /5.76\text{E-4}$$

$$T_{avg} = 26.63° \text{ C}$$

2. Calculation of the Temperatures at the Back of the Components

Due to problems in the placement of the thermocouples that measure the temperature at the heaters, these temperatures were calculated with a calibration curve for w = 30 mm from data obtained in Benedict [Ref. 13]. This calibration cannot be applied to the case where the width of the chamber is very small. In such a case, when w = 9 mm, a one-dimensional conduction analysis was applied to find the back temperature.

The best fit for the calibration points was:

$$T(K) = 14.003957 * \text{Power} + 14.517501$$

So, for 1.1 W,

$$T = 29.92° \text{ C}$$

3. To Calculate the Conduction Losses Through the Circuit Card

$Q_{loss} = \Delta T/Rc = 1/N\ \Sigma(T(I) - Tb(J))/Rc$

$R_c = L/kA$

$R_c = 19.5E\text{-}3/(0.195 * 8E\text{-}3 * 24E\text{-}3) = 520.83\ K/W$

$L = 19.5E\text{-}3$ m

$k = 0.195$ W/m.K (plexiglass conductivity [Ref. 14])

$A = (24E\text{-}3 * 8E\text{-}3)\ m^2 = 1.92E\text{-}4\ m^2$

$Q_{loss} = (29.92 - 17.31)/520.83$

$= 0.024$ W

4. To Find the Average Sink Temperature

Channels 58, 59, and 60 in the bottom heat exchanger and channels 61, 72, and 73 in the top heat exchanger.

$$T_{sink} = 1/N\ (\Sigma T_{tc} + \Sigma T_{bc})$$

$$T_{sink} = (10.05 + 10.1 + 10.02 + 10.11 + 10.12 + 10.13)/6$$

$$T_{sink} = 10.08° \text{ C}$$

To find the net power dissipated by the heater, Q_{net}:

$$Q_{net} = \text{Power} - Q_{loss}$$

For 1.1 W and component 3:

$$Q_{net} = (1.1 - 0.024) \text{ W}$$

$$= 1.076 \text{ W}$$

To find the convection coefficient h (from Newton's law of cooling):

$$Q_{net} = h * A_{tot} * \Delta T$$

$$\Delta T = T_{avg} - T_{sink}$$

$$\Delta T = (26.63 - 10.08)° \text{ C}$$

$$T = 16.55° \text{ C}$$

$$h = Q_{net} /(A_{tot} * \Delta T)$$

5. For 1.1 W and Component 3

$$h = 1.09 /(16.55 * 5.76E\text{-}4)$$

$$h = 114.342 \text{ W/m}^2 \text{ K}$$

6. To Calculate the Thermal Conductivity of the FC-75

$$k = (0.65 - 7.8947E\text{-}4 * T_{film})/10$$

where $T_{film} = (T_{avg} + T_{sink})/2$.

At 1.1 W and chip 3:

$$T_{film} = (26.63 + 10.08)° \text{ C}/2$$

$$T_{film} = 18.35° \text{ C}$$

$$k = 0.0645 \text{ W/m K}$$

7. To Calculate the Vertical Length Based Nusselt Number, Nu1

$$Nu1 = h * L1/k$$

$$Nu1 = 114.342 * 24E\text{-}3/0.0645$$

$$Nu1 = 42.54$$

8. To Calculate the Ratio Area/Perimeter Based Nusselt Number, Nu2

$$L2 = \Sigma(A(i)/P(i))$$

$$L2 = (24 * 8)/64 + (2 * 8 * 6)/(2 * 14) + (2 * 24 * 6)/(2 * 60)$$

$$L2 = 11.229E\text{-}3 \text{ m}$$

$$L2 = 19.905$$

9. To Calculate the Density of the FC-75, ρ (Kg/m^3)

$$\rho = (1.825 - 0.00246 * T_{film}) * 1000$$

$$\rho = 1779.86 \ Kg/m^3$$

10. To Calculate the FC-75 Specific Heat, Cp (J/Kg K)

$$Cp = (.241111 + 3.7037E\text{-}4 * T_{film}) * 4180$$

$$Cp = 1036.25 \ J/Kg \ K$$

11. To Calculate the FC-75 Viscosity, ν(m^2/s)

$$\nu = (1.4074 - 2.964E\text{-}2 * T_{film} + 3.8018E\text{-}4 * T_{film}^2 - 2.7308E\text{-}6 * T_{film}^3 + 8.1679E\text{-}9 * T_{film}^4)E\text{-}6$$

$$\nu = .97557E\text{-}6 \ m^2/s$$

12. To Find the FC-75 Thermal Expansion Coefficient, β(K^{-1})

$$\beta = 0.00246/(1.825 - 0.00246 * T_{film})$$

For 1.1 W and component 3:

$$\beta = 1.382E\text{-}3 \ K^{-1}$$

13. To Calculate the FC-75 Thermal Diffusivity α(m^2/s)

$$\alpha = k / \rho * Cp$$

For 1.1 W and component 3:

$\alpha = 3.497E\text{-}8 \ m^2/s$

14. To Calculate the Grashof Number

$Gr = g * \beta * l^3 * \Delta T/\nu^2$

For 1.1 W and component 3:

Gr - 3255734.402

15. To Calculate the Prandtl Number

$Pr = \nu/\alpha$

$Pr = 27.89$

16. To Find the Temperature Based Rayleigh Number

$Ra = Gr * Pr$

For 1.1 W and component 3:

$Ra = 9.08E7$

17. To Calculate the Flux Based Rayleigh Number

$Ra_f = g * B * l^4 * Q_{net}/(k * \nu * \alpha * A_{tot})$

$Ra_f = 3.9E9$

APPENDIX B

UNCERTAINTY ANALYSIS

The uncertainty analysis was done using the method of Kline and McClintock, presented in Holman [Ref. 15]. The calculations will be done for the end values 0.1 W and 3.0 W, for a chamber width of 30 mm.

A. UNCERTAINTIES IN THE NET POWER ADDED TO THE FLUID

$$Q_{net} = Power - Q_{loss}$$

$$Power = emf(I) * (Volt - emf(I))/Rp$$

$$Power = f(emf(I), Volt, Rp)$$

$$\frac{\partial Power}{\partial emf(I)} = \frac{Volt - 2 \cdot emf(I)}{Rp}$$

$$\frac{\partial Power}{\partial Volt} = \frac{emf(I)}{Rp}$$

$$\frac{\partial Power}{\partial Rp} = -\frac{emf(I) \cdot (Volt - emf(I))}{Rp^2}$$

$$W_{power} = \left[\left(\frac{\partial_{power}}{\partial_{emf(I)}}\right)^2 W^2_{emf(I)} + \left(\frac{\partial_{power}}{\partial_{Volt}}\right)^2 W^2_{Volt} + \left(\frac{\partial_{power}}{\partial_{Rp}}\right)^2 W^2_{Rp}\right]^{\frac{1}{2}}$$

$$W_{emf} = 0.001 \text{ V}$$

(by Resolution in the reading and precision of measuring devices)

$$W_{Volt} = 0.001 \text{ V}$$

(by Resolution in the reading and precision of measuring devices)

$$W_{Rp} = 0.05 \ \Omega$$

(including the added resistances)

For 0.1 W and chip 3:

$$\text{emf(I)} = 1.022 \text{ V}$$

$$\text{Volt} = 1.225 \text{ V}$$

$$\text{Rp} = 2.06 \ \Omega$$

(measured resistance including resistances in the junctions, etc.)

$$\frac{\partial \text{Power}}{\partial \text{emf}(I)} = -0.397$$

$$\frac{\partial \text{Power}}{\partial \text{Volt}} = 0.496$$

$$\frac{\partial \text{Power}}{\partial \text{Rp}} = -0.0488$$

$$W_{power} = \left[(-0.397)^2 \cdot (0.001)^2 + (0.496)^2 \cdot (0.001)^2 + (-0.0488)^2 \cdot (0.05)^2\right]^{\frac{1}{2}}$$

$$W_{power} = 0.00252 \text{ W}$$

$$\frac{W_{power}}{\text{Power}} = \frac{0.00252 \text{ W}}{0.1 \text{ W}} = 2.5\%$$

$$Q_{loss} = \frac{\Delta T}{Rc}$$

where ΔT is the difference in temperature between the back surface of the chip and the back of the board.

$$Q = f(\Delta T,\ Rc)$$

$$\frac{\partial Q_{loss}}{\partial \Delta T} = \frac{1}{Rc} = \frac{Q_{loss}}{\partial Rc} = \frac{\Delta T}{Rc^2}$$

For 0.1 W and component 3:

$$\frac{\partial Q_{loss}}{\partial \Delta T} = \frac{1}{520.83 \text{ K/W}} = 0.00192$$

$$\frac{\partial Q_{loss}}{\partial Rc} = -\frac{0.12° \text{ K}}{(520.83)^2} = -4.424 \times 10^{-7}$$

$$WQ_{loss} = \left[\left(\frac{l}{Rc}\right)^2 W_{\Delta T} + \left(\frac{-\Delta T}{Rc^2}\right) W_{Rc}\right]$$

$$W_{\Delta T} = 10\% = 0.012° \text{ C}$$

$$W_{Rc} = 10\% = 52.083 \text{ K/W}$$

$$WQ_{loss} = \left[(0.00192)^2 \cdot 0.012^2 + \left(-4.424 \times 10^{-7}\right)^2 \cdot (52.083)^2\right]^{\frac{1}{2}}$$

$$WQ_{loss} = \left(5.352 \times 10^{-10}\right)^{\frac{1}{2}} = 3.258\text{E}{-5}$$

$$\frac{WQ_{loss}}{Q_{loss}} = 0.14 = 14\%$$ [1]

$$WQ_{net} = \left[\left(W_{power}\right)^2 + \left(WQ_{loss}\right)^2\right]^{\frac{1}{2}}$$

$$WQ_{net} = \left[(0.00252)^2 + \left(3.258 \times 10^{-5}\right)^2\right]^{\frac{1}{2}}$$

$$WQ_{net} = \pm 0.025 \text{ W}$$

$$\frac{WQ_{net}}{Q_{net}} = \pm 2.5\%$$

[1]The uncertainties in the losses are relatively big, but they do not have a large effect on the final undertaking.

For 3.0 W and component 3:

$$emf(I) = 5.647 \text{ V}$$

$$Volt = 6.762$$

$$Rp = 2.06\Omega$$

$$\frac{\partial Power}{\partial emf(I)} = -2.2$$

$$\frac{\partial Power}{\partial Volt} = 2.74$$

$$\frac{\partial Power}{\partial Rp} = 1.484$$

$$W_{power} = \left[(-2.2)^2 \cdot (0.001)^2 + (2.74)^2 \cdot (0.001)^2 + (1.484)^2 \cdot (0.05)^2\right]^{\frac{1}{2}}$$

$$W_{power} = 0.74 \text{ W}$$

$$\frac{W_{power}}{power} = \frac{0.074}{3.0} = \pm 2.5\%$$

$$\frac{\partial Q_{loss}}{\partial \Delta T} = \frac{1}{520.83} k/w = 0.00192$$

$$\frac{\partial Q_{loss}}{\partial Rc} = -\frac{21.68}{(520.83)^2} = -7.993E-5$$

$$WQ_{loss} = \left[(0.00192)^2 \cdot (2.168)^2 + (-7.992E-5)^2 \cdot (52.083)^2\right]^{\frac{1}{2}}$$

$$WQ_{loss} = 0.059 \text{ W}$$

$$\frac{WQ_{loss}}{Q_{loss}} = 14.14\%$$

$$WQnet = \left[(W_{power})^2 + (WQ_{loss})^2\right]^{\frac{1}{2}}$$

$$WQnet = \left[(0.074)^2 + (0.0059)^2\right]^{\frac{1}{2}}$$

$$WQ_{net} = \pm 0.0742 \text{ W}$$

$$\frac{WQ_{net}}{Q_{net}} = \pm 2.5\%$$

B. UNCERTAINTY IN RAYLEIGH AND NUSSELT NUMBERS

Starting with:

$$Q_{net} = hA_{tot} (T_{avg} - T_{sink})$$

$$h = \frac{Q_{net}}{A_{tot}(T_{avg} - T_{sin\,k})}$$

$$h = f(Q_{net}, A_{tot}, \Delta T)$$

$$\frac{\partial h}{\partial Q_{net}} = \frac{1}{A_{tot}(\Delta T)}$$

$$\frac{\partial h}{\partial A_{tot}} = \frac{Q_{net}}{A_{tot}(\Delta T)^2}$$

$$\frac{\partial h}{\partial \Delta T} = \frac{Q_{net}}{A_{tot}(\Delta T)^2}$$

for 0.1 W and component 3:

$$A_{tot} = 5.76 \times 10^{-4} m^2 \text{ (for all components)}$$

$$\frac{\partial h}{\partial Q_{net}} = \frac{1}{(5.76 \times 10^{-4})(3.02)} = 574.87$$

$$\frac{\partial h}{\partial A_{tot}} = -\frac{0.1}{(5.76 \times 10^{-4})(3.02)} = -99804.03$$

$$\frac{\partial h}{\partial \Delta T} = -\frac{-0.1}{(5.76 \times 10^{-4})(3.02)^2} = -19.035$$

$$Wh = \left[\left(\frac{\partial h}{\partial Q_{net}}\right)^2 WQ_{net}^2 + \left(\frac{\partial h}{\partial \Delta_{tot}}\right)^2 W_{A_{tot}}^2 + \left(\frac{\partial h}{\partial \Delta T}\right)^2 W_{\Delta T}^2\right]^{\frac{1}{2}}$$

$$W_{Q_{net}} = \pm 0.0025 \text{ W}$$

$$W_L = \pm 10^{-5} \text{ m}$$

$$W_A = \left[\left(10^{-5}\right)^2 + \left(10^{-5}\right)^2\right]^{\frac{1}{2}} = 1.41\text{E} -5 \text{ m}^2$$

$$W_{\Delta T} = \pm 1\% = 0.03° \text{ C}$$

$$W_h = \left[(574.87)^2 \cdot (0.0025)^2 + (99804)^2 \cdot (1.41\text{E}-5)^2 + (19.035)^2 \cdot (0.03)^2\right]^{\frac{1}{2}}$$

$$W_h = (2.065 + 0.019 + .3260)^{\frac{1}{2}}$$

$$= \pm 2.09 \text{ W/m}^2 \text{ K}$$

$$\frac{W_h}{h} = \frac{2.09}{57.487} = \pm 3.64\%$$

For 3.0 W and component 3:

$$\frac{\partial h}{\partial Q_{net}} = \frac{1}{(5.76 \times 10^{-4})(38.38)} = 45.52$$

$$\frac{\partial h}{\partial A_{tot}} = \frac{3.0}{\left(5.76 \times 10^{-4}\right)^2 (38.38)} = 235597.84$$

$$\frac{\partial h}{\partial \Delta T} = \frac{3.0}{(5.76 \times 10^{-4})(38.38)^2} = 3,536$$

$$W_h = \left[(45.52)^2 \cdot (0.0742)^2 + (235597.8)^2 \cdot (1.4\,\mathrm{E}-5)^2 + (3.54)^2 \cdot (.38)^2\right]^{\frac{1}{2}}$$

$$W_h = \pm 4.92 \text{ w/m}^2\text{ K}$$

$$\frac{W_h}{h} = \frac{4.92}{135.7} = 3.63\%$$

To find the uncertainty of Nusselt Number:

$$Nu = \frac{h_L}{k}$$

$$Nu = f(h, L, k)$$

$$\frac{\partial Nu}{\partial h} = \frac{L}{k}$$

$$\frac{\partial Nu}{\partial L} = \frac{h}{k}$$

$$\frac{\partial Nu}{\partial k} = -\frac{hL}{k^2}$$

Since the thermal properties of the FC-75 (dielectric liquid) are values that depend on film temperatures, it is considered that there are no uncertainties in these values.

$$K = (0.65 - 7.89474E-4 \cdot T_{film})/10$$

$$T_{film} = \frac{T_{avg} + T_{sin\,k}}{2}$$

For 0.1 W and component 3:

$$K = 0.064 \frac{W}{m\ K}$$

$$T_{film} = 11.51° \ C$$

$$\frac{\partial Nu}{\partial k} = \frac{24 \times 10^{-3} m}{0.064\ w/m\,K} = 0.374$$

$$\frac{\partial Nu}{\partial k} = \frac{57.487}{24 \times 10^{-3}} = 2395.29$$

$$\frac{\partial Nu}{\partial k} = \frac{57.487 \times 24 \times 10^{-3}}{(0.064)^2} = 336.84$$

$$WNu = \left[\left(\frac{\partial Nu}{\partial h}\right)^2 Wh^2 + \left(\frac{\partial Nu}{\partial L}\right)^2 W_L^2 + \left(\frac{\partial Nu}{\partial k}\right)^2 Wk^2\right]^{\frac{1}{2}}$$

$$WNu = \left[(0.374)^2 \cdot (2.09)^2 + (2395.29)^2 \cdot \left(10^{-5}\right)^2\right]^{\frac{1}{2}}$$

$$WNu = \pm 0.78$$

$$\frac{WNu}{Nu} = \frac{0.78}{21.55} = 0.036 = 3.6\%$$

For 3.0 W and component 3:

$$k_f = 0.0627 \frac{W}{mk}$$

$$T_{film} = 29.2° \text{ C}$$

$$\frac{\partial Nu}{\partial h} = \frac{24 \times 10^{-3} m}{0.0627} = 0.382$$

$$\frac{\partial Nu}{\partial L} = \frac{135.7}{24 \times 10^{-3}} = 5654.16$$

$$WNu = \left[(0.382)^2 \cdot (4.92)^2 + (5654.16)^2 \cdot \left(10^{-5}\right)^2 \right]^{\frac{1}{2}}$$

$$WNu = \pm 1.88$$

$$\frac{WNu}{Nu} = \frac{1.88}{51.94} = 3.62\%$$

$$Ra_f = Gr_f \cdot Pr$$

$$Gr_f = \frac{g \beta L^4 Q_{net}}{k_f \nu^2 A_{tot}}$$

$$Pr = \frac{\nu}{\alpha}$$

$$Gr_f = f\left(g, \beta, L^4, Q_{net}, k_f, \nu^2, A_{tot}\right)$$

Consider fluid properties without uncertainties.

$$\frac{\partial Gr_f}{\partial L^4} = \frac{g \beta Q_{net}}{k_f \nu^2 A_{tot}}$$

$$\frac{\partial Gr_f}{\partial Q_{net}} = \frac{g \beta L^4}{k_f \nu^2 A_{tot}}$$

$$\frac{\partial Gr_f}{\partial A_{tot}} = \frac{g \beta L^4 Q_{net}}{k_f \nu^2 A_{tot}^2}$$

For 0.1 W and component 3:

$$\beta = 0.00137 \ K^{-1}$$

$$k_f = 0.064 \frac{W}{m.k}$$

$$\nu = 1.11259E\text{-}6 \frac{m^2}{s}$$

$$\frac{\partial Gr_f}{\partial L^4} = 2.94E13$$

$$\frac{\partial Gr_f}{\partial Q_{net}} = 9.76E7$$

$$\frac{\partial Gr_f}{\partial A_{tot}} = -1.69E10$$

$$WGr_f = \left[\left(\frac{\partial Gr_f}{\partial L^4}\right)^2 W^2L^4 + \left(\frac{\partial Gr_f}{\partial Q_{net}}\right)^2 W^2Q_{net} + \left(\frac{\partial Gr_f}{\partial A_{tot}}\right)^2 WA_{tot}\right]^{\frac{1}{2}}$$

$$WGr_f = \begin{bmatrix} (2.94E13)^2 \cdot (5.5\ E{-10})^2 + (9.76E7)^2 \cdot (0.0025)^2 \\ + (1.69E10)^2 \cdot (4.8\ E{-7})^2 \end{bmatrix}^{\frac{1}{2}}$$

$$WGr_f = [2.6E8 + 5.9536E10 + 6.5E7]^{\frac{1}{2}}$$

$$W_{Gr_f} = \pm 243569$$

$$\frac{W_{Gr_f}}{Gr_f} = \frac{243569}{9.67E6} = 2.5\%$$

$$W_{Ra_f} = 2.5\%$$

For 3.0 W and component 3:

$$\beta = 0.014\ K^{-1}$$

$$\nu = 0.80402 \times 10^{-6} \frac{m^2}{s}$$

$$k_f = 0.0627 \frac{W}{m.K}$$

$$\frac{\partial Gr_f}{\partial L^4} = 17.6E15$$

$$\frac{\partial Gr_f}{\partial Q_{net}} = 19.5E7$$

$$\frac{\partial Gr_f}{\partial A_{tot}} = 1.0E12$$

$$WGr_f = \left[(17.6E15)^2 \cdot (5.5\,E{-}10)^2 + (19.5E7)^2 \cdot (0.0742)^2 + (1.0E12)^2 \cdot (4.8\,E{-}7)^2\right]^{\frac{1}{2}}$$

$$WGr_f = [9.3E13 + 2.09E14 + 2.38E11]^{\frac{1}{2}}$$

$$\frac{WGr_f}{Gr_f} = \frac{17405183}{584920180} = 2.9\%$$

$$W_{Ra_f} = 2.9\%$$

APPENDIX C

TABLES

TABLE 1

TEMPERATURE DATA FOR INPUT POWER 0.1 W BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08021455

AMBIENT TEMP : 24.3 C
VOLTMETER READING : 1.025 V
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	17.46E+00	17.48E+00	17.48E+00	17.47E+00	17.54E+00	18.04E+00
POWER (WATTS):	10.01E-02					
CHIP NO2:	17.40E+00	17.44E+00	17.47E+00	17.41E+00	17.47E+00	17.96E+00
POWER (WATTS):	10.00E-02					
CHIP NO3:	17.13E+00	17.08E+00	17.16E+00	17.22E+00	17.29E+00	17.61E+00
POWER (WATTS):	99.84E-03					
CHIP NO4:	17.57E+00	17.56E+00	17.44E+00	15.60E+00	17.48E+00	17.89E+00
POWER (WATTS):	98.84E-03					
CHIP NO5:	17.48E+00	17.62E+00	17.56E+00	17.51E+00	17.58E+00	17.92E+00
POWER (WATTS):	99.24E-03					
CHIP NO6:	22.68E+00	17.39E+00	17.43E+00	17.38E+00	17.55E+00	18.42E+00
POWER (WATTS):	99.12E-03					
CHIP NO7:	17.59E+00	17.62E+00	17.60E+00	17.55E+00	17.74E+00	18.32E+00
POWER (WATTS):	10.04E-02					
CHIP NO8:	17.58E+00	17.64E+00	17.67E+00	17.58E+00	17.60E+00	18.47E+00
POWER (WATTS):	10.07E-02					
CHIP NO9:	17.33E+00	17.15E+00	17.34E+00	17.30E+00	17.36E+00	17.82E+00
POWER (WATTS):	99.32E-03					

AVERAGE HEAT EXCHANGERS TEMPERATURES:

BOTTOM:	10.01E+00
TOP:	19.97E+00

BACK PLANE TEMPERATURES ARE :

T(55):	17.81E+00
T(56):	18.09E+00
T(57):	17.54E+00
T(72):	18.33E+00
T(73):	18.43E+00
T(74):	18.91E+00
T(75):	18.07E+00
T(76):	18.40E+00
T(77):	18.29E+00

TABLE 2

TEMPERATURE DATA FOR INPUT POWER 0.7 W BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08021717

AMBIENT TEMP : 24.4 C
VOLTMETER READING : 3.218 V
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	24.74E+00	24.02E+00	23.96E+00	24.00E+00	24.09E+00	27.01E+00
POWER (WATTS):		70.97E-02				
CHIP N02:	24.71E+00	23.81E+00	23.96E+00	23.54E+00	23.80E+00	26.56E+00
POWER (WATTS):		70.93E-02				
CHIP N03:	23.83E+00	23.69E+00	23.59E+00	23.55E+00	23.60E+00	25.11E+00
POWER (WATTS):		70.79E-02				
CHIP N04:	24.30E+00	23.71E+00	23.60E+00	20.65E+00	23.60E+00	25.74E+00
POWER (WATTS):		70.09E-02				
CHIP N05:	24.26E+00	23.46E+00	23.44E+00	23.37E+00	23.69E+00	25.46E+00
POWER (WATTS):		70.38E-02				
CHIP N06:	26.78E+00	24.05E+00	23.44E+00	23.51E+00	24.08E+00	27.57E+00
POWER (WATTS):		70.26E-02				
'IP N07:	24.96E+00	24.47E+00	24.02E+00	23.81E+00	24.14E+00	27.58E+00
POWER (WATTS):		71.19E-02				
CHIP N08:	24.27E+00	24.14E+00	24.07E+00	23.85E+00	23.79E+00	29.43E+00
POWER (WATTS):		71.40E-02				
CHIP N09:	23.90E+00	23.70E+00	23.62E+00	23.50E+00	23.44E+00	26.70E+00
POWER (WATTS):		70.84E-02				

AVERAGE HEAT EXCHANGERS TEMPERATURES:

BOTTOM:	10.00E+00
TOP:	20.00E+00

BACK PLANE TEMPERATURES ARE :

T(55):	20.83E+00
T(56):	21.22E+00
T(57):	20.72E+00
T(72):	21.38E+00
T(73):	21.10E+00
T(74):	21.50E+00
T(75):	21.03E+00
T(76):	21.18E+00
T(77):	21.23E+00

TABLE 3

TEMPERATURE DATA FOR INPUT POWER 1.5 W BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08030205

AMBIENT TEMP : 24.4 C
VOLTMETER READING : 4.7082 V
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	33.28E+00	31.29E+00	31.67E+00	31.63E+00	31.81E+00	37.53E+00
POWER (WATTS):	15.17E-01					
CHIP NO2:	33.22E+00	31.21E+00	31.50E+00	30.68E+00	31.25E+00	36.83E+00
POWER (WATTS):	15.16E-01					
CHIP NO3:	31.23E+00	31.26E+00	30.99E+00	30.76E+00	30.63E+00	34.16E+00
POWER (WATTS):	15.13E-01					
CHIP NO4:	33.06E+00	31.52E+00	31.54E+00	27.88E+00	31.60E+00	35.83E+00
POWER (WATTS):	14.98E-01					
CHIP NO5:	32.56E+00	30.25E+00	30.60E+00	30.44E+00	31.30E+00	34.65E+00
POWER (WATTS):	15.04E-01					
CHIP NO6:	20.87E+00	32.79E+00	30.75E+00	31.13E+00	32.43E+00	43.50E+00
POWER (WATTS):	15.01E-01					
CHIP NO7:	33.79E+00	32.54E-00	31.83E+00	31.29E+00	31.97E+00	38.83E+00
POWER (WATTS):	15.21E-01					
CHIP NO8:	32.46E+00	31.64E+00	31.72E+00	31.46E+00	31.25E+00	43.11E+00
POWER (WATTS):	15.26E-01					
CHIP NO9:	31.47E+00	31.25E+00	31.12E+00	30.80E+00	31.01E+00	37.41E+00
POWER (WATTS):	15.14E-01					

AVERAGE HEAT EXCHANGERS TEMPERATURES:

BOTTOM:	10.09E+00
TOP:	20.04E+00

BACK PLANE TEMPERATURES ARE :

T(55):	23.97E+00
T(56):	24.51E+00
T(57):	25.06E+00
T(72):	24.93E+00
T(73):	24.57E+00
T(74):	24.85E+00
T(75):	25.10E+00
T(76):	24.49E+00
T(77):	24.61E+00

TABLE 4

TEMPERATURE DATA FOR INPUT POWER 3.0 W
BOTTOM BOUNDARY AT 20° C

RESULTS ARE STORED IN FILE: 08041705

AMBIENT TEMP : 24.5 C
VOLTMETER READING : 6.601 V
HEAT EXCHANGER TEMP.: 10-20 C

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	49.47E+00	45.65E+00	46.44E+00	46.13E+00	45.76E+00	56.26E+00
POWER (WATTS):	29.74E-01					
CHIP NO2:	48.99E+00	45.37E+00	46.33E+00	44.51E+00	46.02E+00	56.02E+00
POWER (WATTS):	29.73E-01					
CHIP NO3:	44.62E+00	45.57E+00	45.04E+00	44.58E+00	44.60E+00	51.20E+00
POWER (WATTS):	29.68E-01					
CHIP NO4:	49.59E+00	46.17E+00	46.77E+00	42.62E+00	46.97E+00	54.89E+00
POWER (WATTS):	29.38E-01					
CHIP NO5:	48.69E+00	43.92E+00	45.19E+00	44.75E+00	46.43E+00	52.53E+00
POWER (WATTS):	29.51E-01					
CHIP NO6:	37.80E+00	48.64E+00	45.04E+00	45.78E+00	47.85E+00	68.62E+00
POWER (WATTS):	29.40E-01					
'IP NO7:	51.18E+00	48.27E+00	47.48E+00	46.51E+00	47.28E+00	58.60E+00
POWER (WATTS):	29.82E-01					
CHIP NO8:	48.09E+00	47.05E+00	47.09E+00	46.58E+00	45.99E+00	67.94E+00
POWER (WATTS):	29.91E-01					
CHIP NO9:	44.97E+00	45.78E+00	45.57E+00	45.11E+00	44.78E+00	58.25E+00
POWER (WATTS):	29.69E-01					

AVERAGE HEAT EXCHANGERS TEMPERATURES:
BOTTOM: 10.98E+00
TOP: 20.08E+00

BACK PLANE TEMPERATURES ARE :

T(55): 31.46E+00
T(56): 32.62E+00
T(57): 34.30E+00
T(72): 33.38E+00
T(73): 32.78E+00
T(74): 33.27E+00
T(75): 33.99E+00
T(76): 32.43E+00
T(77): 32.42E+00

TABLE 5

REDUCED DATA FOR INPUT POWER 0.1 W BOTTOM BOUNDARY AT 20° C

THE RAW Emf DATA ARE FROM THE FILE: 08021455
THE POWER SETTING PER CHIP WAS: 0.1 W

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	99.93E-03	74.63E-01	29.10E-01	13.42E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 139.72E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :134.16E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 406.58E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 458.54E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
2	99.84E-03	74.15E-01	29.26E-01	13.50E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 138.74E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :135.03E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 405.97E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 458.97E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
3	99.64E-03	71.59E-01	30.24E-01	13.99E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 133.57E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :139.86E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.97E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 459.86E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
4	98.64E-03	70.22E-01	30.52E-01	14.26E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 130.83E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :142.58E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 399.28E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 464.52E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
5	99.04E-03	75.15E-01	28.64E-01	13.32E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 140.78E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :133.23E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 403.22E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 462.64E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
6	98.92E-03	91.61E-01	23.49E-01	10.93E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 174.75E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :109.29E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 410.50E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 463.23E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
7	10.02E-02	75.85E-01	28.72E-01	13.20E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 142.18E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :132.01E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 408.40E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 457.14E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
8	10.05E-02	75.98E-01	28.75E-01	13.18E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 142.45E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :131.78E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 409.59E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 455.89E-05

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
9	99.72E-03	73.00E-01	29.68E-01	13.72E-01

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 136.42E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :137.15E-02
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 404.94E-04
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 459.52E-05

TABLE 6

REDUCED DATA FOR INPUT POWER 0.7 W
BOTTOM BOUNDARY AT 20° C

```
THE RAW Emf DATA ARE FROM THE FILE:    08021717
  THE POWER SETTING PER CHIP WAS:   0.7 WATTS

CHIP      QNET(W)          Tavg-Ts          Nu           %UNC IN Nu

1        70.20E-02       14.24E+00       10.76E+00       70.34E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  297.08E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :703.04E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  308.85E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  231.59E-04

2        70.16E-02       14.08E+00       10.88E+00       71.16E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  283.28E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :711.21E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  308.10E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  231.71E-04

3        70.03E-02       13.66E+00       11.18E+00       73.32E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  273.69E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :732.84E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  306.03E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  232.17E-04

4        69.32E-02       13.10E+00       11.54E+00       76.47E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  260.80E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :764.36E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  301.00E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  234.54E-04

5        69.61E-02       13.71E+00       11.08E+00       73.06E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  274.81E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :730.23E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  304.37E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  233.57E-04

6        69.49E-02       14.67E+00       10.34E+00       68.30E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  297.03E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :682.63E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  307.22E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  233.95E-04

7        70.42E-02       14.32E+00       10.73E+00       69.95E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  288.95E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :699.10E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  310.07E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  230.88E-04

8        70.63E-02       14.06E+00       10.96E+00       71.25E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  282.84E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :712.17E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  310.07E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  230.19E-04

9        70.07E-02       13.67E+00       11.18E+00       73.27E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  273.90E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :732.34E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  306.28E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  232.01E-04
```

TABLE 7

REDUCED DATA FOR INPUT POWER 1.5 W
BOTTOM BOUNDARY AT 20° C

THE RAW Emf DATA ARE FROM THE FILE: 08030205
THE POWER SETTING PER CHIP WAS: 1.5 WATTS

CHIP ONET(W) Tavg-Ts Nu %UNC IN Nu

1 15.00E-01 22.08E+00 14.90E+00 45.39E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 484.85E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :453.37E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 722.22E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.19E-04

2 14.99E-01 21.73E+00 15.13E+00 46.13E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 475.36E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :460.71E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 719.11E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.28E-04

3 14.96E-01 20.92E+00 15.68E+00 47.92E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 453.60E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :478.68E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 711.25E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.71E-04

4 14.81E-01 21.04E+00 15.43E+00 47.63E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 457.00E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :475.76E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 705.05E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 228.02E-04

5 14.87E-01 21.15E+00 15.42E+00 47.39E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 459.81E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :473.39E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 708.81E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.07E-04

6 14.84E-01 17.77E+00 18.26E+00 56.38E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 372.79E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :563.37E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 680.72E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.65E-04

7 15.04E-01 22.33E+00 14.78E+00 44.90E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 491.49E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :448.39E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 726.23E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 224.56E-04

8 15.09E-01 21.76E+00 15.20E+00 46.06E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 476.17E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :460.08E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 723.92E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 223.86E-04

9 14.97E-01 21.07E+00 15.58E+00 47.58E-02
TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 457.63E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :475.23E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 712.82E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.59E-04

TABLE 8

REDUCED DATA FOR INPUT POWER 3.0 W
BOTTOM BOUNDARY AT 20° C

```
              THE RAW Emf DATA ARE FROM THE FILE:    08041705
                 THE POWER SETTING PER CHIP WAS:   3.0 WATTS

CHIP      QNET(W)          Tavg-Ts           Nu            %UNC IN Nu

 1         29.42E-01       36.28E+00       17.97E+00       27.67E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  936.63E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :276.00E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  168.28E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  194.60E-04

 2         29.41E-01       35.68E+00       18.25E+00       28.13E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  915.94E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :280.60E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  167.20E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  194.65E-04

 3         29.36E-01       33.82E+00       19.20E+00       29.67E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  852.28E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :296.05E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  163.66E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  195.00E-04

 4         29.06E-01       35.66E+00       18.05E+00       28.14E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  915.27E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :280.75E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  165.19E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  196.99E-04

 5         29.19E-01       35.27E+00       18.32E+00       28.46E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  901.62E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :283.89E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  165.19E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  196.17E-04

 6         29.08E-01       32.37E+00       19.85E+00       30.99E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  804.05E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :309.31E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  159.62E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  196.89E-04

 7         29.50E-01       37.54E+00       17.42E+00       26.74E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  981.44E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :266.69E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  170.99E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  194.07E-04

 8         29.59E-01       36.23E+00       18.09E+00       27.71E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  934.88E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :276.38E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  169.15E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  193.51E-04

 9         29.37E-01       34.23E+00       18.98E+00       29.32E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  866.10E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :292.51E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  164.42E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  194.95E-04
```

TABLE 9

TEMPERATURE DATA FOR INPUT POWER 0.1 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08221255

AMBIENT TEMP WAS: 23.0 C
VOLTMETER READING WAS: 1.2134 V
BATH TEMP WAS: 10 C-INSUL

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	15.92E+00	15.85E+00	15.85E+00	15.82E+00	15.87E+00	16.36E+00
POWER (WATTS):	10.08E-02					
CHIP NO2:	15.92E+00	15.95E+00	15.98E+00	15.87E+00	15.95E+00	16.44E+00
POWER (WATTS):	10.07E-02					
CHIP NO3:	15.7[illegible]E+00	15.66E+00	15.78E+00	15.82E+00	15.86E+00	16.14E+00
POWER (WATTS):	10.05E-02					
CHIP NO4:	15.77E+00	15.93E+00	15.72E+00	15.64E+00	15.71E+00	16.12E+00
POWER (WATTS):	99.49E-03					
CHIP NO5:	15.77E+00	15.87E+00	15.84E+00	15.77E+00	15.85E+00	16.20E+00
POWER (WATTS):	99.89E-03					
CHIP NO6:	17.93E+00	15.73E+00	15.77E+00	15.71E+00	12.78E+00	16.59E+00
POWER (WATTS):	99.74E-03					
CHIP NO7:	15.75E+00	15.79E+00	15.75E+00	15.71E+00	15.84E+00	16.4[illegible]E+00
POWER (WATTS):	10.11E-02					
CHIP NO8:	15.85E+00	15.86E+00	15.91E+00	15.82E+00	15.83E+00	16.56E+00
POWER (WATTS):	10.14E-02					
CHIP NO9:	15.56E+00	15.49E+00	15.62E+00	15.59E+00	15.64E+00	16.15E+00
POWER (WATTS):	10.05E-02					

HEAT EXCHANGERS TEMPERATURES:

	RIGHT	LEFT
BOTTOM:	15.97E+00	15.97E+00
TOP:	10.20E+00	96.30E-01

BACK PLANE TEMPERATURES ARE :

T(55):	16.0[illegible]E+00
T(56):	16.41E+00
T(57):	16.0[illegible]E+00
T(72):	16.73E+00
T(73):	16.78E+00
T(74):	17.24E+00
T(75):	16.42E+00
T(76):	16.75E+00
T(77):	16.69E+00

TABLE 10

TEMPERATURE DATA FOR INPUT POWER 0.7 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08222257

AMBIENT TEMP WAS: 21.7 C
VOLTMETER READING WAS: 3.22 V
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	23.67E+00	22.36E+00	22.84E+00	22.84E+00	22.85E+00	25.39E+00
POWER (WATTS):	70.88E-02					
CHIP NO2:	23.52E+00	22.57E+00	22.76E+00	22.30E+00	22.68E+00	25.39E+00
POWER (WATTS):	70.83E-02					
CHIP NO3:	22.90E+00	22.62E+00	22.51E+00	22.47E+00	22.24E+00	24.00E+00
POWER (WATTS):	70.69E-02					
CHIP NO4:	23.46E+00	22.91E+00	22.73E+00	22.17E+00	22.67E+00	24.75E+00
POWER (WATTS):	69.99E-02					
CHIP NO5:	23.20E+00	22.20E+00	22.27E+00	22.14E+00	22.60E+00	24.21E+00
POWER (WATTS):	70.28E-02					
CHIP NO6:	26.26E+00	22.78E+00	22.23E+00	22.30E+00	18.88E+00	26.38E+00
POWER (WATTS):	70.15E-02					
C P NO7:	23.85E+00	23.15E+00	22.80E+00	22.60E+00	22.93E+00	25.70E+00
POWER (WATTS):	71.09E-02					
CHIP NO8:	23.17E+00	22.97E+00	22.85E+00	22.70E+00	22.60E+00	26.66E+00
POWER (WATTS):	71.30E-02					
CHIP NO9:	22.70E+00	22.48E+00	22.43E+00	22.26E+00	22.24E+00	25.53E+00
POWER (WATTS):	70.72E-02					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	LEFT
BOTTOM:	17.35E+00	17.36E+00
TOP:	10.28E+00	97.63E-01

BACK PLANE TEMPERATURES ARE :

T(55):	19.34E+00
T(56):	19.81E+00
T(57):	19.74E+00
T(72):	20.01E+00
T(73):	71.30E-01
T(74):	19.99E+00
T(75):	19.59E+00
T(76):	19.76E+00
T(77):	19.88E+00

TABLE 11

TEMPERATURE DATA FOR INPUT POWER 1.1 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08231010

AMBIENT TEMP WAS: 21.33 C
VOLTMETER READING WAS: 4.00 V
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	28.35E+00	26.73E+00	27.12E+00	27.11E+00	27.13E+00	30.82E+00
POWER (WATTS):	10.96E-01					
CHIP NO2:	28.16E+00	26.70E+00	26.93E+00	26.29E+00	26.90E+00	30.97E+00
POWER (WATTS):	10.95E-01					
CHIP NO3:	26.96E+00	26.97E+00	26.70E+00	26.57E+00	26.26E+00	28.94E+00
POWER (WATTS):	10.93E-01					
CHIP NO4:	28.21E+00	27.02E+00	27.14E+00	26.29E+00	27.07E+00	30.17E+00
POWER (WATTS):	10.82E-01					
CHIP NO5:	27.75E+00	26.13E+00	26.25E+00	26.09E+00	26.86E+00	29.20E+00
POWER (WATTS):	10.87E-01					
CHIP NO6:	27.17E+00	27.20E+00	26.33E+00	26.45E+00	25.80E+00	32.61E+00
POWER (WATTS):	10.84E-01					
CHIP NO7:	28.65E+00	27.60E+00	27.07E+00	26.77E+00	27.15E+00	31.29E+00
POWER (WATTS):	10.99E-01					
CHIP NO8:	27.65E+00	26.99E+00	27.08E+00	26.92E+00	26.57E+00	32.87E+00
POWER (WATTS):	11.02E-01					
CHIP NO9:	26.81E+00	26.65E+00	26.59E+00	26.36E+00	26.23E+00	31.29E+00
POWER (WATTS):	10.93E-01					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	LEFT
BOTTOM:	18.43E+00	18.43E+00
TOP:	10.21E+00	97.25E-01

BACK PLANE TEMPERATURES ARE :

T(55): 21.49E+00
T(56): 22.00E+00
T(57): 22.27E+00
T(72): 22.32E+00
T(73): 21.94E+00
T(74): 22.22E+00
T(75): 22.04E+00
T(76): 21.97E+00
T(77): 22.12E+00

TABLE 12

TEMPERATURE DATA FOR INPUT POWER 3.0 W BOTTOM BOUNDARY INSULATED

THESE RESULTS ARE STORED IN FILE: 08231310

AMBIENT TEMP WAS: 23 C
VOLTMETER READING WAS: 4.00 V
BATH TEMP WAS: 10 C-INS

ALL TEMPERATURES ARE IN DEGREES CELCIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	54.28E+00	49.66E+00	50.72E+00	50.63E+00	50.34E+00	59.54E+00
POWER (WATTS):	30.12E-01					
CHIP NO2:	53.84E+00	49.73E+00	50.52E+00	48.65E+00	50.06E+00	60.06E+00
POWER (WATTS):	30.11E-01					
CHIP NO3:	50.25E+00	50.25E+00	49.56E+00	49.03E+00	47.98E+00	55.22E+00
POWER (WATTS):	30.06E-01					
CHIP NO4:	53.66E+00	49.90E+00	50.54E+00	48.37E+00	50.35E+00	58.19E+00
POWER (WATTS):	29.77E-01					
CHIP NO5:	52.76E+00	47.84E+00	48.71E+00	48.29E+00	49.81E+00	55.75E+00
POWER (WATTS):	29.89E-01					
CHIP NO6:	55.76E+00	51.99E+00	48.65E+00	49.14E+00	50.78E+00	70.28E+00
POWER (WATTS):	29.78E-01					
CHIP NO7:	55.44E+00	51.67E+00	50.76E+00	50.15E+00	50.57E+00	60.78E+00
POWER (WATTS):	30.21E-01					
CHIP NO8:	52.46E+00	51.07E+00	51.00E+00	50.88E+00	50.31E+00	67.37E+00
POWER (WATTS):	30.30E-01					
CHIP NO9:	50.77E+00	50.34E+00	49.91E+00	49.40E+00	49.60E+00	61.43E+00
POWER (WATTS):	30.06E-01					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	LEFT
BOTTOM:	21.94E+00	21.96E+00
TOP:	11.02E+00	98.81E-01

BACK PLANE TEMPERATURES ARE :

T(55):	32.74E+00
T(56):	34.26E+00
T(57):	36.45E+00
T(72):	35.41E+00
T(73):	34.76E+00
T(74):	35.18E+00
T(75):	35.96E+00
T(76):	34.28E+00
T(77):	34.30E+00

TABLE 13

REDUCED DATA FOR INPUT POWER 0.1 W
BOTTOM BOUNDARY INSULATED

THE RAW Emf DATA ARE FROM THE FILE: 08221255
THE POWER SETTING PER CHIP WAS: 0.1 WATTS

```
CHIP      QNET(W)        Tavg-Ts         Nu           %UNC IN Nu

1       10.06E-02      59.19E-01      35.91E-01      16.93E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  108.69E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :169.28E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  401.14E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  394.13E-05

2       10.05E-02      60.09E-01      36.31E-01      16.67E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  110.46E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :166.74E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  401.11E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  394.58E-05

3       10.03E-02      58.46E-01      37.24E-01      17.14E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  107.28E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :171.38E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  399.54E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  395.38E-05

4       99.33E-03      58.11E-01      37.11E-01      17.24E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  106.58E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :172.43E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  395.51E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  399.24E-05

5       99.73E-03      58.84E-01      36.79E-01      17.03E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  108.02E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :170.27E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  397.44E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  397.65E-05

6       99.58E-03      63.05E-01      34.29E-01      15.89E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  116.29E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :158.90E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  398.81E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  398.24E-05

7       10.09E-02      58.34E-01      37.56E-01      17.17E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  107.04E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :171.73E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  402.00E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  392.90E-05

8       10.12E-02      59.41E-01      36.98E-01      16.87E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  109.12E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :168.66E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  403.56E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  391.87E-05

9       10.04E-02      56.68E-01      38.43E-01      17.68E-01
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  103.80E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :176.77E-02
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  398.95E-04
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  395.13E-05
```

TABLE 14

REDUCED DATA FOR INPUT POWER 0.7 W
BOTTOM BOUNDARY INSULATED

```
            THE RAW Emf DATA ARE FROM THE FILE:    08222257
               THE POWER SETTING PER CHIP WAS:   0.7 WATTS

CHIP      QNET(W)          Tavg-Ts           Nu            %UNC IN Nu

1         70.13E-02       13.10E+00       11.67E+00       76.47E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  261.03E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :764.35E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  304.66E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  234.56E-04

2         70.07E-02       12.85E+00       11.89E+00       77.95E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  255.36E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :779.20E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  303.54E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  234.75E-04

3         69.94E-02       12.59E+00       12.11E+00       79.57E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  249.47E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :795.34E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  302.04E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  235.21E-04

4         69.24E-02       12.82E+00       11.78E+00       78.16E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  254.59E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :781.28E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  299.83E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  237.56E-04

5         69.53E-02       12.54E+00       12.08E+00       79.88E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  248.36E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :798.47E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  300.13E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  236.58E-04

6         69.40E-02       13.34E+00       11.35E+00       75.14E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  266.31E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :751.07E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  302.30E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  237.02E-04

7         70.34E-02       13.12E+00       11.70E+00       76.40E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  261.31E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :763.62E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  305.62E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  233.86E-04

8         70.55E-02       12.88E+00       11.95E+00       77.82E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  255.86E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :777.86E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  305.69E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  233.16E-04

9         69.97E-02       12.44E+00       12.26E+00       80.54E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  246.04E-03
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :805.10E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  301.64E-03
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  235.11E-04
```

TABLE 15

REDUCED DATA FOR INPUT POWER 1.1 W
BOTTOM BOUNDARY INSULATED

THE RAW Emf DATA ARE FROM THE FILE: 08231010
THE POWER SETTING PER CHIP WAS: 1.1 WATTS

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
1	10.84E-01	17.53E+00	13.52E+00	57.17E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 365.80E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :571.25E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 494.53E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 226.98E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
2	10.83E-01	17.19E+00	13.77E+00	58.29E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 357.49E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :582.43E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 492.30E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.14E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
3	10.81E-01	16.77E+00	14.09E+00	59.75E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 347.17E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :597.04E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 489.01E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.58E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
4	10.70E-01	17.30E+00	13.52E+00	57.93E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 360.14E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :578.80E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 487.09E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 229.85E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
5	10.75E-01	16.78E+00	14.00E+00	59.71E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 347.42E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :596.67E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 486.30E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 228.88E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
6	10.73E-01	16.70E+00	14.03E+00	60.00E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 345.45E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :599.56E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 484.82E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 229.37E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
7	10.87E-01	17.61E+00	13.50E+00	56.91E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 367.76E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :568.68E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 496.47E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 226.30E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
8	10.90E-01	17.22E+00	13.85E+00	58.21E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 358.03E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :581.69E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 495.81E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 225.59E-04

CHIP	QNET(W)	Tavg-Ts	Nu	%UNC IN Nu
9	10.81E-01	16.61E+00	14.23E+00	60.32E-02

TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS: 343.28E-03
% UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :602.77E-03
FLUX BASED RAYLEIGH NUMBER * E-8 IS: 488.34E-03
% UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS: 227.49E-04

TABLE 16

REDUCED DATA FOR INPUT POWER 3.0 W BOTTOM BOUNDARY INSULATED

```
            THE RAW Emf DATA ARE FROM THE FILE:    08231310
               THE POWER SETTING PER CHIP WAS:   3.0 WATTS

CHIP      QNET(W)          Tavg-Ts          Nu            %UNC IN Nu

1         29.78E-01        41.31E+00        16.01E+00     24.31E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  110.90E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :242.30E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  177.54E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  202.57E-04

2         29.77E-01        40.60E+00        16.28E+00     24.74E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  108.25E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :246.54E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  176.18E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  202.65E-04

3         29.72E-01        39.13E+00        16.84E+00     25.66E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  102.84E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :255.82E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  173.21E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  203.01E-04

4         29.42E-01        40.51E+00        16.12E+00     24.79E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  107.92E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :247.08E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  173.98E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  205.02E-04

5         29.55E-01        39.52E+00        16.59E+00     25.41E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  104.27E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :253.28E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  172.94E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  204.15E-04

6         29.44E-01        41.15E+00        15.89E+00     24.42E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  110.27E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :243.29E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  175.19E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  204.93E-04

7         29.87E-01        41.77E+00        15.89E+00     24.05E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  112.63E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :239.64E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  178.94E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  201.94E-04

8         29.96E-01        40.95E+00        16.25E+00     24.53E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  109.55E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :244.43E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  177.96E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  201.34E-04

9         29.72E-01        39.63E+00        16.64E+00     25.34E-02
     TEMPERATURE BASED RAYLEIGH NUMBER * E-7 IS:  104.65E-02
     % UNCERTAINTY IN THE TEMPERATURE BASED RAYLEIGH NUMBER IS :252.60E-03
     FLUX BASED RAYLEIGH NUMBER * E-8 IS:  174.11E-02
     % UNCERTAINTY IN FLUX BASED RAYLEIGH NUMBER IS:  203.00E-04
```

TABLE 17

TEMPERATURE DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10161810

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 24.33
BATH TEMP : 10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	12.806	12.761	12.736	12.771	12.616	15.431
POWER (WATTS):	.0983					
CHIP N02:	12.954	12.894	12.591	12.861	12.816	15.438
POWER (WATTS):	.099					
CHIP N03:	13.099	12.956	00.000	12.986	13.076	15.451
POWER (WATTS):	.0996					
CHIP N04:	12.764	12.731	12.536	12.574	12.484	15.441
POWER (WATTS):	.0990					
CHIP N05:	12.831	12.894	12.836	12.824	12.801	15.446
POWER (WATTS):	.0993					
CHIP N06:	13.019	12.914	12.979	11.858	12.746	15.448
POWER (WATTS):	.0995					
CHIP N07:	12.689	12.686	12.706	12.684	12.559	15.445
POWER (WATTS):	.0992					
CHIP N08:	13.039	12.941	12.966	00.000	12.901	15.442
POWER (WATTS):	.0990					
CHIP N09:	13.256	13.114	12.834	13.144	13.144	15.445
POWER (WATTS):	.0992					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.967	10.012	09.997
TOP:	10.037	00.000	10.042

BACK PLANE TEMPERATURES :
T(55): 12.656
T(56): 12.961
T(57): 12.709
T(74): 13.131
T(75): 13.561
T(76): 13.671
T(77): 13.366

SOURCE VOLTAGE: 1.225

VOLTAGE TO THE HEATERS :
CHIP #1: .972
CHIP #2: 1.027
CHIP #3: 1.022
CHIP #4: 1.024
CHIP #5: .968
CHIP #6: 1.022
CHIP #7: 1.023
CHIP #8: 1.023
CHIP #9: 1.023

TABLE 18

TEMPERATURE DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10170950

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 24.78
BATH TEMP : 10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	21.48	21.22	21.08	21.31	20.01	24.28
POWER (WATTS):	.708					
CHIP N02:	22.18	21.50	18.45	21.41	20.88	24.34
POWER (WATTS):	.712					
CHIP N03:	22.65	21.48	00.00	21.56	21.98	24.44
POWER (WATTS):	.719					
CHIP N04:	21.68	21.26	20.78	21.12	20.37	24.39
POWER (WATTS):	.715					
CHIP N05:	21.93	21.19	21.53	21.74	21.48	24.42
POWER (WATTS):	.718					
CHIP N06:	22.75	21.81	22.07	20.73	20.12	24.48
POWER (WATTS):	.721					
CHIP N07:	21.14	20.83	21.34	20.95	19.34	24.44
POWER (WATTS):	.719					
CHIP N08:	22.00	21.42	21.32	00.00	20.87	24.43
POWER (WATTS):	.718					
CHIP N09:	22.65	20.64	18.15	22.02	21.83	24.42
POWER (WATTS):	.717					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.922	10.017	09.972
TOP:	09.977	00.000	10.060

BACK PLANE TEMPERATURES :
T(55): 15.191
T(56): 15.611
T(57): 14.265
T(74): 15.651
T(75): 16.079
T(76): 16.521
T(77): 15.350

SOURCE VOLTAGE: 3.288

VOLTAGE TO THE HEATERS :
CHIP #1: 2.610
CHIP #2: 2.756
CHIP #3: 2.743
CHIP #4: 2.747
CHIP #5: 2.597
CHIP #6: 2.741
CHIP #7: 2.743
CHIP #8: 2.744
CHIP #9: 2.745

TABLE 19

TEMPERATURE DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10171720

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 25.94
BATH TEMP : 10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	26.38	25.79	25.94	26.17	24.21	29.857
POWER (WATTS):	1.092					
CHIP NO2:	27.34	26.00	22.01	26.17	25.62	29.96
POWER (WATTS):	1.099					
CHIP NO3:	27.67	25.73	00.00	26.08	26.69	30.11
POWER (WATTS):	1.1093					
CHIP NO4:	26.74	26.07	25.51	26.00	24.85	30.02
POWER (WATTS):	1.103					
CHIP NO5:	29.78	25.86	26.40	26.71	26.35	30.08
POWER (WATTS):	1.107					
CHIP NO6:	27.51	25.54	26.74	25.65	24.17	30.16
POWER (WATTS):	1.113					
CHIP NO7:	25.80	25.40	26.18	25.63	22.98	30.10
POWER (WATTS):	1.109					
CHIP NO8:	27.06	25.80	26.15	00.00	25.29	30.11
POWER (WATTS):	1.109					
CHIP NO9:	27.79	24.71	21.36	26.94	26.60	30.11
POWER (WATTS):	1.110					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.924	10.015	09.987
TOP:	10.010	00.000	10.068

BACK PLANE TEMPERATURES :
T(55): 16.88
T(56): 17.48
T(57): 15.70
T(74): 17.57
T(75): 18.00
T(76): 18.49
T(77): 17.08

SOURCE VOLTAGE: 4.085

-VOLTAGE TO THE HEATERS :
CHIP #1: 3.244
CHIP #2: 3.424
CHIP #3: 3.408
CHIP #4: 3.413
CHIP #5: 3.228
CHIP #6: 3.406
CHIP #7: 3.408
CHIP #8: 3.408
CHIP #9: 3.408

TABLE 20

TEMPERATURE DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10181020

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 23.94
BATH TEMP : 10 C-10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	33.07	32.50	32.62	32.72	29.91	35.55
POWER (WATTS):	1.484					
CHIP N02:	34.32	32.62	27.17	32.75	31.80	35.68
POWER (WATTS):	1.493					
CHIP N03:	34.63	32.10	00.00	32.62	33.39	35.89
POWER (WATTS):	1.5077					
CHIP N04:	33.56	32.40	31.90	32.49	30.83	35.79
POWER (WATTS):	1.501					
CHIP N05:	33.39	32.19	32.67	33.16	32.64	35.87
POWER (WATTS):	1.506					
CHIP N06:	34.02	31.20	33.07	32.41	29.59	35.97
POWER (WATTS):	1.513					
CHIP N07:	32.02	30.79	32.47	31.73	27.98	35.89
POWER (WATTS):	1.508					
CHIP N08:	33.89	32.28	32.71	00.00	31.39	35.89
POWER (WATTS):	1.507					
CHIP N09:	34.69	31.22	26.04	33.41	33.00	35.88
POWER (WATTS):	1.507					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.027	10.098	10.073
TOP:	10.108	00.000	10.126

BACK PLANE TEMPERATURES :

T(55):	19.59
T(56):	20.25
T(57):	17.80
T(74):	21.09
T(75):	20.76
T(76):	21.47
T(77):	19.69

SOURCE VOLTAGE: 4.767

VOLTAGE TO THE HEATERS :

CHIP #1:	3.787
CHIP #2:	3.997
CHIP #3:	3.979
CHIP #4:	3.983
CHIP #5:	3.767
CHIP #6:	3.975
CHIP #7:	3.979
CHIP #8:	3.979
CHIP #9:	3.979

THESE RESULTS ARE NOW STORED ON DISK 'FASTSCAN

FILE: 30MM10R

TABLE 21

TEMPERATURE DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10182338

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 23.17
BATH TEMP : 10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	42.47	41.80	41.39	42.04	37.20	49.73
POWER (WATTS):	2.461					
CHIP NO2:	44.31	40.93	41.68	41.68	40.14	49.93
POWER (WATTS):	2.475					
CHIP NO3:	44.77	41.10	00.00	41.43	42.66	50.28
POWER (WATTS):	2.4985					
CHIP NO4:	42.78	40.79	40.47	41.00	38.73	50.08
POWER (WATTS):	2.485					
CHIP NO5:	42.58	42.08	41.60	42.36	41.83	50.20
POWER (WATTS):	2.494					
CHIP NO6:	42.77	38.65	41.30	41.37	35.79	50.41
POWER (WATTS):	2.507					
CHIP NO7:	40.63	39.59	41.08	40.51	34.17	50.25
POWER (WATTS):	2.497					
CHIP NO8:	42.02	39.95	40.79	00.00	37.88	50.27
POWER (WATTS):	2.498					
CHIP NO9:	42.77	37.10	41.32	41.32	40.60	50.24
POWER (WATTS):	2.496					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.020	10.110	10.065
TOP:	09.748	00.000	10.015

BACK PLANE TEMPERATURES :
T(55): 21.28
T(56): 22.30
T(57): 19.47
T(74): 23.34
T(75): 22.77
T(76): 23.81
T(77): 21.70

SOURCE VOLTAGE: 6.142

VOLTAGE TO THE HEATERS :
CHIP #1: 4.881
CHIP #2: 5.152
CHIP #3: 5.128
CHIP #4: 5.135
CHIP #5: 4.859
CHIP #6: 5.124
CHIP #7: 5.129
CHIP #8: 5.129
CHIP #9: 5.129

TABLE 22

TEMPERATURE DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 30 mm

RESULTS ARE STORED IN FILE: 10232224

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 22.83
BATH TEMP : 10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	50.66	49.62	49.07	49.97	43.61	57.87
POWER (WATTS):	3.022					
CHIP NO2:	52.71	47.72	49.42	49.42	46.37	58.10
POWER (WATTS):	3.038					
CHIP NO3:	52.51	48.65	00.00	47.22	49.87	58.53
POWER (WATTS):	3.0672					
CHIP NO4:	51.15	47.96	48.59	48.79	46.00	58.30
POWER (WATTS):	3.051					
CHIP NO5:	50.48	48.36	49.36	50.54	48.61	58.47
POWER (WATTS):	3.063					
CHIP NO6:	51.67	42.15	48.38	47.63	46.09	58.70
POWER (WATTS):	3.079					
CHIP NO7:	48.27	46.25	48.70	48.07	39.78	58.52
POWER (WATTS):	3.066					
CHIP NO8:	49.10	45.58	48.05	00.00	44.02	58.53
POWER (WATTS):	3.067					
CHIP NO9:	50.71	41.39	43.01	43.01	45.34	58.49
POWER (WATTS):	3.064					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	10.057	10.166	10.176
TOP:	10.073	00.000	10.163

BACK PLANE TEMPERATURES :
T(55): 24.75
T(56): 26.51
T(57): 22.64
T(74): 28.00
T(75): 26.95
T(76): 28.63
T(77): 25.41

SOURCE VOLTAGE: 6.807

VOLTAGE TO THE HEATERS :
CHIP #1: 5.411
CHIP #2: 5.712
CHIP #3: 5.685
CHIP #4: 5.692
CHIP #5: 5.385
CHIP #6: 5.680
CHIP #7: 5.685
CHIP #8: 5.685
CHIP #9: 5.686

TABLE 23

REDUCED DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:     10161810
THE POWER SETTING PER CHIP WAS:   0.1 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP   QNET(W)  Tavg-Ts       Nu1        Nu2

 1        .10      2.76      23.19      10.85
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 12.861
  SINK TEMPERATURE: 10.104

 2        .10      2.82      22.77      10.66
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 12.925
  SINK TEMPERATURE: 10.104

 3        .10      3.04      21.32       9.98
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 13.144
  SINK TEMPERATURE: 10.104

 4        .10      2.63      24.48      11.46
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 12.734
  SINK TEMPERATURE: 10.104

 5        .10      2.83      22.82      10.68
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 12.934
  SINK TEMPERATURE: 10.104

 6        .10      2.68      24.11      11.28
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 12.788
  SINK TEMPERATURE: 10.104

 7        .10      2.68      24.10      11.28
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 12.782
  SINK TEMPERATURE: 10.104

 8        .10      2.99      21.58      10.10
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 13.089
  SINK TEMPERATURE: 10.104

 9        .10      3.10      20.84       9.75
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 13.202
  SINK TEMPERATURE: 10.104
```

TABLE 24

REDUCED DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10170950
THE POWER SETTING PER CHIP WAS:   0.7 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1        .70      11.22      40.87      19.12
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.41
  AVERAGE TEMPERATURE: 21.294
  SINK TEMPERATURE: 10.073

 2        .71      10.92      42.23      19.76
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.42
  AVERAGE TEMPERATURE: 20.990
  SINK TEMPERATURE: 10.073

 3        .71      12.11      38.48      18.00
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.48
  AVERAGE TEMPERATURE: 22.185
  SINK TEMPERATURE: 10.073

 4        .71      11.20      41.37      19.36
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.44
  AVERAGE TEMPERATURE: 21.273
  SINK TEMPERATURE: 10.073

 5        .71      11.71      39.73      18.59
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.46
  AVERAGE TEMPERATURE: 21.783
  SINK TEMPERATURE: 10.073

 6        .72      11.81      39.61      18.53
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.48
  AVERAGE TEMPERATURE: 21.878
  SINK TEMPERATURE: 10.073

 7        .71      10.99      42.38      19.83
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.45
  AVERAGE TEMPERATURE: 21.066
  SINK TEMPERATURE: 10.073

 8        .71      11.61      40.07      18.75
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.46
  AVERAGE TEMPERATURE: 21.685
  SINK TEMPERATURE: 10.073

 9        .71      11.16      41.64      19.48
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.44
  AVERAGE TEMPERATURE: 21.235
  SINK TEMPERATURE: 10.073
```

TABLE 25

REDUCED DATA FOR INPUT POWER 1.1 W CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10171720
THE POWER SETTING PER CHIP WAS:   1.1 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1        1.08      16.00      44.33      20.74
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     3.93
  AVERAGE TEMPERATURE: 26.089
  SINK TEMPERATURE: 10.085

 2        1.09      15.48      46.12      21.58
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     3.94
  AVERAGE TEMPERATURE: 25.562
  SINK TEMPERATURE: 10.085

 3        1.10      16.83      42.84      20.04
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     4.03
  AVERAGE TEMPERATURE: 26.917
  SINK TEMPERATURE: 10.085

 4        1.09      16.05      44.67      20.90
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     3.98
  AVERAGE TEMPERATURE: 26.136
  SINK TEMPERATURE: 10.085

 5        1.10      17.57      40.98      19.17
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     4.06
  AVERAGE TEMPERATURE: 27.657
  SINK TEMPERATURE: 10.085

 6        1.10      16.42      44.03      20.60
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     4.03
  AVERAGE TEMPERATURE: 26.509
  SINK TEMPERATURE: 10.085

 7        1.10      15.60      46.18      21.60
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     3.98
  AVERAGE TEMPERATURE: 25.688
  SINK TEMPERATURE: 10.085

 8        1.10      16.43      43.88      20.53
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     4.02
  AVERAGE TEMPERATURE: 26.519
  SINK TEMPERATURE: 10.085

 9        1.10      15.63      46.12      21.58
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     3.98
  AVERAGE TEMPERATURE: 25.717
  SINK TEMPERATURE: 10.085
```

TABLE 26

REDUCED DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:     10211130
THE POWER SETTING PER CHIP WAS:   1.5 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1        1.52     22.39     44.65     20.89
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    5.94
  AVERAGE TEMPERATURE: 32.569
  SINK TEMPERATURE: 10.180

 2        1.53     21.80     46.10     21.57
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    5.94
  AVERAGE TEMPERATURE: 31.978
  SINK TEMPERATURE: 10.180

 3        1.54     24.07     42.22     19.75
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    6.15
  AVERAGE TEMPERATURE: 34.252
  SINK TEMPERATURE: 10.180

 4        1.54     22.27     45.37     21.23
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    6.00
  AVERAGE TEMPERATURE: 32.450
  SINK TEMPERATURE: 10.180

 5        1.54     23.39     43.35     20.28
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    6.09
  AVERAGE TEMPERATURE: 33.574
  SINK TEMPERATURE: 10.180

 6        1.55     22.61     45.06     21.08
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    6.07
  AVERAGE TEMPERATURE: 32.788
  SINK TEMPERATURE: 10.180

 7        1.54     21.66     46.86     21.92
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    5.99
  AVERAGE TEMPERATURE: 31.837
  SINK TEMPERATURE: 10.180

 8        1.54     22.30     45.54     21.30
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    6.03
  AVERAGE TEMPERATURE: 32.482
  SINK TEMPERATURE: 10.180

 9        1.54     20.60     49.26     23.05
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    5.92
  AVERAGE TEMPERATURE: 30.782
  SINK TEMPERATURE: 10.180
```

TABLE 27

REDUCED DATA FOR INPUT POWER 2.5 W CHAMBER WIDTH = 30 mm

THE RAW Emf DATA ARE FROM THE FILE: 10182338
THE POWER SETTING PER CHIP WAS: 2.5 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	2.44	31.61	51.08	23.90

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.54
AVERAGE TEMPERATURE: 41.698
SINK TEMPERATURE: 10.087

2	2.45	30.24	53.65	25.10

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.44
AVERAGE TEMPERATURE: 40.331
SINK TEMPERATURE: 10.087

3	2.48	33.03	49.69	23.25

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.86
AVERAGE TEMPERATURE: 43.113
SINK TEMPERATURE: 10.087

4	2.46	31.27	52.14	24.39

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.60
AVERAGE TEMPERATURE: 41.356
SINK TEMPERATURE: 10.087

5	2.47	32.19	50.86	23.79

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.74
AVERAGE TEMPERATURE: 42.277
SINK TEMPERATURE: 10.087

6	2.49	31.14	52.84	24.72

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.68
AVERAGE TEMPERATURE: 41.225
SINK TEMPERATURE: 10.087

7	2.48	30.10	54.39	25.44

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.52
AVERAGE TEMPERATURE: 40.189
SINK TEMPERATURE: 10.087

8	2.48	30.94	52.97	24.78

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.62
AVERAGE TEMPERATURE: 41.023
SINK TEMPERATURE: 10.087

9	2.48	28.94	56.51	26.44

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 10.39
AVERAGE TEMPERATURE: 39.028
SINK TEMPERATURE: 10.087

TABLE 28

REDUCED DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 30 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    10191310
THE POWER SETTING PER CHIP WAS:   3.0 W
THE DISTANCE TO THE FRONT WALL WAS 30 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1       2.96      38.29      51.36      24.03
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.73
   AVERAGE TEMPERATURE: 48.440
   SINK TEMPERATURE: 10.154

 2       2.98      36.50      54.14      25.33
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.56
   AVERAGE TEMPERATURE: 46.657
   SINK TEMPERATURE: 10.154

 3       3.01      38.80      51.50      24.10
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    14.03
   AVERAGE TEMPERATURE: 48.959
   SINK TEMPERATURE: 10.154

 4       2.99      38.03      52.27      24.46
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.85
   AVERAGE TEMPERATURE: 48.185
   SINK TEMPERATURE: 10.154

 5       3.00      38.62      51.66      24.17
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.98
   AVERAGE TEMPERATURE: 48.777
   SINK TEMPERATURE: 10.154

 6       3.02      36.60      54.74      25.61
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.76
   AVERAGE TEMPERATURE: 46.755
   SINK TEMPERATURE: 10.154

 7       3.01      36.49      54.71      25.60
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.69
   AVERAGE TEMPERATURE: 46.642
   SINK TEMPERATURE: 10.154

 8       3.01      36.62      54.55      25.52
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.72
   AVERAGE TEMPERATURE: 46.771
   SINK TEMPERATURE: 10.154

 9       3.01      33.27      59.88      28.01
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:    13.23
   AVERAGE TEMPERATURE: 43.421
   SINK TEMPERATURE: 10.154
```

TABLE 29

TEMPERATURE DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 9 mm

RESULTS ARE STORED IN FILE: 11050029

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 22.78
BATH TEMP : 10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	14.34	14.25	14.16	14.24	14.08	14.40
POWER (WATTS):	.097					
CHIP NO2:	14.48	14.33	14.32	14.32	14.22	14.54
POWER (WATTS):	.098					
CHIP NO3:	14.58	14.53	14.49	14.48	14.54	14.64
POWER (WATTS):	.0989					
CHIP NO4:	14.39	14.25	14.10	14.12	14.02	14.45
POWER (WATTS):	.099					
CHIP NO5:	14.43	15.89	14.33	14.37	14.26	14.49
POWER (WATTS):	.099					
CHIP NO6:	14.65	14.37	00.00	14.24	14.58	14.71
POWER (WATTS):	.099					
CHIP NO7:	14.13	14.14	14.19	14.17	14.08	14.19
POWER (WATTS):	.099					
CHIP NO8:	14.59	14.41	14.42	00.00	14.24	14.65
POWER (WATTS):	.099					
CHIP NO9:	14.71	14.28	16.01	16.01	14.45	14.77
POWER (WATTS):	.099					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.914	09.967	09.965
TOP:	10.011	00.000	10.392

BACK PLANE TEMPERATURES :
T(55): 12.97
T(56): 13.12
T(74): 13.52
T(75): 13.83
T(76): 13.99
T(77): 13.25

SOURCE VOLTAGE: 1.219

VOLTAGE TO THE HEATERS :
CHIP #1: .967
CHIP #2: 1.021
CHIP #3: 1.016
CHIP #4: 1.017
CHIP #5: .962
CHIP #6: 1.015
CHIP #7: 1.015
CHIP #8: 1.015
CHIP #9: 1.016

TABLE 30

TEMPERATURE DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 9 mm

RESULTS ARE STORED IN FILE: 11062057

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 20.61
BATH TEMP : 10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	23.48	23.27	22.85	23.21	21.49	23.88
POWER (WATTS):	.696					
CHIP N02:	24.85	23.75	23.74	23.74	23.07	25.26
POWER (WATTS):	.701					
CHIP N03:	24.78	24.57	24.32	23.70	24.51	25.19
POWER (WATTS):	.7050					
CHIP N04:	23.92	22.97	22.82	22.78	21.97	24.32
POWER (WATTS):	.703					
CHIP N05:	24.77	23.82	24.12	24.42	23.69	25.17
POWER (WATTS):	.705					
CHIP N06:	25.92	23.76	00.00	23.15	25.35	26.33
POWER (WATTS):	.709					
CHIP N07:	23.12	22.57	23.13	22.84	21.02	23.53
POWER (WATTS):	.707					
CHIP N08:	24.84	23.90	23.94	00.00	22.83	25.25
POWER (WATTS):	.707					
CHIP N09:	25.78	22.75	19.26	23.34	24.30	26.19
POWER (WATTS):	.706					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.972	10.070	10.088
TOP:	10.047	00.000	10.137

BACK PLANE TEMPERATURES :
T(55): 15.17
T(56): 15.45
T(74): 15.92
T(75): 15.99
T(76): 16.29
T(77): 15.68

SOURCE VOLTAGE: 3.259

VOLTAGE TO THE HEATERS :
CHIP #1: 2.587
CHIP #2: 2.731
CHIP #3: 2.720
CHIP #4: 2.722
CHIP #5: 2.575
CHIP #6: 2.717
CHIP #7: 2.718
CHIP #8: 2.718
CHIP #9: 2.720

TABLE 31

TEMPERATURE DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 9 mm

RESULTS ARE STORED IN FILE: 11022255

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 21.11
BATH TEMP : 10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	28.92	28.61	28.26	28.57	25.77	29.87
POWER (WATTS):	1.093					
CHIP NO2:	31.27	29.86	29.60	29.60	28.52	29.97
POWER (WATTS):	1.100					
CHIP NO3:	30.49	30.42	30.02	28.65	30.37	30.08
POWER (WATTS):	1.1071					
CHIP NO4:	29.63	28.45	28.11	27.89	26.78	30.04
POWER (WATTS):	1.104					
CHIP NO5:	31.16	29.79	30.20	30.63	29.54	30.08
POWER (WATTS):	1.107					
CHIP NO6:	31.91	28.89	00.00	28.72	31.17	30.18
POWER (WATTS):	1.114					
CHIP NO7:	28.48	27.51	28.46	28.34	25.07	30.15
POWER (WATTS):	1.112					
CHIP NO8:	31.20	30.08	30.00	00.00	28.01	30.14
POWER (WATTS):	1.111					
CHIP NO9:	32.68	28.26	31.03	31.03	30.57	30.11
POWER (WATTS):	1.110					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.839	10.128	10.241
TOP:	09.863	00.000	09.952

BACK PLANE TEMPERATURES :
T(55): 17.38
T(56): 17.58
T(74): 18.00
T(75): 18.02
T(76): 18.41
T(77): 17.63

SOURCE VOLTAGE: 4.086

VOLTAGE TO THE HEATERS :
CHIP #1: 3.244
CHIP #2: 3.425
CHIP #3: 3.411
CHIP #4: 3.413
CHIP #5: 3.229
CHIP #6: 3.406
CHIP #7: 3.407
CHIP #8: 3.408
CHIP #9: 3.409

TABLE 32

TEMPERATURE DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 9 mm

RESULTS ARE STORED IN FILE: 11091225

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 21.83
BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	36.71	36.38	35.78	36.25	32.76	37.56
POWER (WATTS): 1.489						
CHIP NO2:	38.97	36.79	37.06	37.06	35.88	39.83
POWER (WATTS): 1.497						
CHIP NO3:	38.33	37.92	37.67	34.98	37.83	39.20
POWER (WATTS): 1.5093						
CHIP NO4:	37.06	35.37	35.16	34.59	33.41	37.92
POWER (WATTS): 1.504						
CHIP NO5:	38.29	36.57	37.19	37.75	36.20	39.16
POWER (WATTS): 1.508						
CHIP NO6:	39.40	35.38	00.00	34.97	38.23	40.27
POWER (WATTS): 1.516						
CHIP NO7:	34.94	33.67	35.04	34.46	30.18	35.81
POWER (WATTS): 1.512						
CHIP NO8:	38.18	35.83	36.98	00.00	34.50	39.05
POWER (WATTS): 1.512						
CHIP NO9:	39.71	34.80	28.60	36.52	36.89	40.58
POWER (WATTS): 1.511						

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.828	09.977	10.040
TOP:	10.007	00.000	10.295

BACK PLANE TEMPERATURES :
T(55): 20.82
T(56): 21.73
T(74): 22.48
T(75): 22.33
T(76): 22.64
T(77): 21.31

SOURCE VOLTAGE: 4.771

VOLTAGE TO THE HEATERS :
CHIP #1: 3.789
CHIP #2: 4.000
CHIP #3: 3.983
CHIP #4: 3.987
CHIP #5: 3.772
CHIP #6: 3.979
CHIP #7: 3.981
CHIP #8: 3.982
CHIP #9: 3.983

TABLE 33

TEMPERATURE DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 9 mm

RESULTS ARE STORED IN FILE: 11082020

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 21.28
BATH TEMP : 10 C

TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP NO1:	46.62	45.93	45.41	46.08	40.22	48.05
POWER (WATTS):	2.504					
CHIP NO2:	50.04	46.15	47.23	47.23	43.85	51.48
POWER (WATTS):	2.520					
CHIP NO3:	48.91	48.75	48.04	45.63	48.30	50.37
POWER (WATTS):	2.5388					
CHIP NO4:	47.00	43.52	44.22	42.84	41.35	48.45
POWER (WATTS):	2.531					
CHIP NO5:	48.77	46.61	47.23	48.29	45.89	50.23
POWER (WATTS):	2.538					
CHIP NO6:	49.99	44.34	00.00	44.08	48.13	51.45
-POWER (WATTS):	2.552					
CHIP NO7:	43.36	41.13	43.65	42.69	35.63	44.82
POWER (WATTS):	2.544					
CHIP NO8:	48.86	45.42	47.09	00.00	43.17	50.32
POWER (WATTS):	2.544					
CHIP NO9:	49.89	42.54	34.29	45.52	45.93	51.35
POWER (WATTS):	2.541					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.859	10.037	10.110
TOP:	09.803	00.000	10.073

BACK PLANE TEMPERATURES :
T(55): 22.95
T(56): 24.01
T(74): 24.80
T(75): 24.59
T(76): 24.97
T(77): 23.67

SOURCE VOLTAGE: 6.193

VOLTAGE TO THE HEATERS :
CHIP #1: 4.921
CHIP #2: 5.193
CHIP #3: 5.172
CHIP #4: 5.176
CHIP #5: 4.897
CHIP #6: 5.165
CHIP #7: 5.169
CHIP #8: 5.169
CHIP #9: 5.171

TABLE 34

TEMPERATURE DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 9 mm

RESULTS ARE STORED IN FILE: 11072058

EXPERIMENT CARRIED OUT AT
AMBIENT TEMP (CELSIUS) OF: 21.00
BATH TEMP : 10 C
TEMPERATURE READINGS IN DEGREES CELSIUS

	CENTER	TOP	RIGHT	LEFT	BOTTOM	BACK
CHIP N01:	55.97	54.46	55.08	55.59	45.61	57.66
POWER (WATTS):	2.938					
CHIP N02:	61.12	57.34	58.19	58.19	54.57	62.82
POWER (WATTS):	2.957					
CHIP N03:	58.47	58.54	57.89	55.35	58.30	60.18
POWER (WATTS):	2.9774					
CHIP N04:	57.35	53.88	54.52	54.33	49.46	59.05
POWER (WATTS):	2.969					
CHIP N05:	58.98	57.68	58.44	59.12	56.79	60.69
POWER (WATTS):	2.978					
CHIP N06:	61.17	55.49	00.00	55.89	59.33	62.89
POWER (WATTS):	2.993					
CHIP N07:	52.97	51.59	53.54	53.26	43.41	54.68
POWER (WATTS):	2.984					
CHIP N08:	60.57	57.20	59.10	00.00	54.97	62.28
POWER (WATTS):	2.985					
CHIP N09:	60.45	53.52	46.33	56.95	56.66	62.17
POWER (WATTS):	2.984					

HEAT EXCHANGERS TEMPERATURES:	RIGHT	CENTER	LEFT
BOTTOM:	09.783	10.022	10.176
TOP:	09.816	00.000	10.063

BACK PLANE TEMPERATURES :
T(55): 32.35
T(56): 34.45
T(74): 35.59
T(75): 35.08
T(76): 35.20
T(77): 33.52

SOURCE VOLTAGE: 6.715

VOLTAGE TO THE HEATERS :
CHIP #1: 5.339
CHIP #2: 5.633
CHIP #3: 5.611
CHIP #4: 5.615
CHIP #5: 5.314
CHIP #6: 5.603
CHIP #7: 5.608
CHIP #8: 5.607
CHIP #9: 5.608

TABLE 35

REDUCED DATA FOR INPUT POWER 0.1 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:     11050029
THE POWER SETTING PER CHIP WAS:   0.1 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1         .10       4.10      15.19       7.11
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .30
  AVERAGE TEMPERATURE: 14.242
  SINK TEMPERATURE: 10.139

 2         .10       4.08      15.38       7.19
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.221
  SINK TEMPERATURE: 10.139

 3         .10       4.39      14.43       6.75
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.525
  SINK TEMPERATURE: 10.139

 4         .10       4.07      15.54       7.27
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.208
  SINK TEMPERATURE: 10.139

 5         .10       4.36      14.52       6.80
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.497
  SINK TEMPERATURE: 10.139

 6         .10       4.33      14.70       6.88
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.473
  SINK TEMPERATURE: 10.139

 7         .10       4.01      15.86       7.42
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.153
  SINK TEMPERATURE: 10.139

 8         .10       4.33      14.67       6.86
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.471
  SINK TEMPERATURE: 10.139

 9         .10       4.52      14.00       6.55
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:      .31
  AVERAGE TEMPERATURE: 14.660
  SINK TEMPERATURE: 10.139
```

TABLE 36

REDUCED DATA FOR INPUT POWER 0.7 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:     11062057
THE POWER SETTING PER CHIP WAS:   0.7 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts       Nu1        Nu2

 1         .68      13.03      34.38      16.08
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.41
  AVERAGE TEMPERATURE: 23.174
  SINK TEMPERATURE: 10.145

 2         .69      13.11      34.42      16.10
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.43
  AVERAGE TEMPERATURE: 23.251
  SINK TEMPERATURE: 10.145

 3         .69      14.31      31.75      14.86
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.48
  AVERAGE TEMPERATURE: 24.456
  SINK TEMPERATURE: 10.145

 4         .69      13.07      34.63      16.20
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.44
  AVERAGE TEMPERATURE: 23.219
  SINK TEMPERATURE: 10.145

 5         .69      14.31      31.75      14.86
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.48
  AVERAGE TEMPERATURE: 24.451
  SINK TEMPERATURE: 10.145

 6         .70      14.65      31.20      14.60
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.50
  AVERAGE TEMPERATURE: 24.794
  SINK TEMPERATURE: 10.145

 7         .70      12.79      35.62      16.66
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.44
  AVERAGE TEMPERATURE: 22.933
  SINK TEMPERATURE: 10.145

 8         .70      14.17      32.16      15.04
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.48
  AVERAGE TEMPERATURE: 24.313
  SINK TEMPERATURE: 10.145

 9         .69      13.12      34.64      16.21
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:     2.45
  AVERAGE TEMPERATURE: 23.266
  SINK TEMPERATURE: 10.145
```

TABLE 37

REDUCED DATA FOR INPUT POWER 1.1 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11022255
THE POWER SETTING PER CHIP WAS:   1.1 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts      Nu1       Nu2

 1       1.08      18.18     38.87     18.19
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.02
  AVERAGE TEMPERATURE: 28.377
  SINK TEMPERATURE: 10.193

 2       1.08      18.63     38.19     17.87
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.07
  AVERAGE TEMPERATURE: 28.825
  SINK TEMPERATURE: 10.193

 3       1.09      19.71     36.38     17.02
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.14
  AVERAGE TEMPERATURE: 29.898
  SINK TEMPERATURE: 10.193

 4       1.09      18.29     39.06     18.28
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.07
  AVERAGE TEMPERATURE: 28.480
  SINK TEMPERATURE: 10.193

 5       1.09      20.35     35.26     16.49
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.17
  AVERAGE TEMPERATURE: 30.538
  SINK TEMPERATURE: 10.193

 6       1.10      20.24     35.66     16.68
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.19
  AVERAGE TEMPERATURE: 30.429
  SINK TEMPERATURE: 10.193

 7       1.10      17.88     40.23     18.82
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.08
  AVERAGE TEMPERATURE: 28.076
  SINK TEMPERATURE: 10.193

 8       1.10      20.13     35.76     16.73
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.18
  AVERAGE TEMPERATURE: 30.321
  SINK TEMPERATURE: 10.193

 9       1.09      19.19     37.43     17.51
  FLUX BASED RAYLEIGH NUMBER * E-9 IS:    4.13
  AVERAGE TEMPERATURE: 29.382
  SINK TEMPERATURE: 10.193
```

TABLE 38

REDUCED DATA FOR INPUT POWER 1.5 W
CHAMBER WIDTH = 9 mm

THE RAW Emf DATA ARE FROM THE FILE: 11091225
THE POWER SETTING PER CHIP WAS: 1.5 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
1	1.47	25.92	37.30	17.45

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.96
AVERAGE TEMPERATURE: 36.108
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
2	1.47	25.87	37.60	17.59

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.00
AVERAGE TEMPERATURE: 36.053
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
3	1.49	27.17	36.12	16.90

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.13
AVERAGE TEMPERATURE: 37.353
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
4	1.48	25.44	38.39	17.96

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.99
AVERAGE TEMPERATURE: 35.625
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
5	1.49	27.48	35.69	16.70

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.15
AVERAGE TEMPERATURE: 37.664
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
6	1.49	27.26	36.16	16.92

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.17
AVERAGE TEMPERATURE: 37.450
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
7	1.49	24.25	40.46	18.93

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 5.95
AVERAGE TEMPERATURE: 34.440
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
8	1.49	27.02	36.36	17.01

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.13
AVERAGE TEMPERATURE: 37.211
SINK TEMPERATURE: 10.186

CHIP	QNET(W)	Tavg-Ts	Nu1	Nu2
9	1.49	25.41	38.61	18.07

FLUX BASED RAYLEIGH NUMBER * E-9 IS: 6.02
AVERAGE TEMPERATURE: 35.592
SINK TEMPERATURE: 10.186

TABLE 39

REDUCED DATA FOR INPUT POWER 2.5 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11082020
THE POWER SETTING PER CHIP WAS:   2.5 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1       2.47     35.42     46.27     21.65
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.15
   AVERAGE TEMPERATURE: 45.692
   SINK TEMPERATURE: 10.271

 2       2.49     35.23     46.82     21.90
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.20
   AVERAGE TEMPERATURE: 45.503
   SINK TEMPERATURE: 10.271

 3       2.50     37.64     44.23     20.69
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.58
   AVERAGE TEMPERATURE: 47.908
   SINK TEMPERATURE: 10.271

 4       2.50     34.33     48.22     22.56
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.14
   AVERAGE TEMPERATURE: 44.605
   SINK TEMPERATURE: 10.271

 5       2.50     37.68     44.17     20.66
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.58
   AVERAGE TEMPERATURE: 47.946
   SINK TEMPERATURE: 10.271

 6       2.52     37.02     45.18     21.14
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.56
   AVERAGE TEMPERATURE: 47.287
   SINK TEMPERATURE: 10.271

 7       2.51     32.27     51.53     24.11
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   10.96
   AVERAGE TEMPERATURE: 42.536
   SINK TEMPERATURE: 10.271

 8       2.51     37.08     44.97     21.04
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.53
   AVERAGE TEMPERATURE: 47.355
   SINK TEMPERATURE: 10.271

 9       2.51     33.79     49.19     23.01
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   11.12
   AVERAGE TEMPERATURE: 44.057
   SINK TEMPERATURE: 10.271
```

TABLE 40

REDUCED DATA FOR INPUT POWER 3.0 W
CHAMBER WIDTH = 9 mm

```
THE RAW Emf DATA ARE FROM THE FILE:    11072058
THE POWER SETTING PER CHIP WAS:   3.0 W
THE DISTANCE TO THE FRONT WALL WAS 9 MM

CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2

 1        2.90     44.40     43.64     20.42
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.41
   AVERAGE TEMPERATURE: 54.762
   SINK TEMPERATURE: 10.362

 2        2.92     46.34     42.14     19.72
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.79
   AVERAGE TEMPERATURE: 56.697
   SINK TEMPERATURE: 10.362

 3        2.94     47.28     41.61     19.47
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.04
   AVERAGE TEMPERATURE: 57.639
   SINK TEMPERATURE: 10.362

 4        2.93     44.68     43.84     20.51
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.61
   AVERAGE TEMPERATURE: 55.040
   SINK TEMPERATURE: 10.362

 5        2.94     48.33     40.74     19.06
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.20
   AVERAGE TEMPERATURE: 58.691
   SINK TEMPERATURE: 10.362

 6        2.96     48.31     40.97     19.17
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.28
   AVERAGE TEMPERATURE: 58.676
   SINK TEMPERATURE: 10.362

 7        2.95     42.01     46.78     21.89
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.29
   AVERAGE TEMPERATURE: 52.372
   SINK TEMPERATURE: 10.362

 8        2.95     48.82     40.44     18.92
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   15.31
   AVERAGE TEMPERATURE: 59.183
   SINK TEMPERATURE: 10.362

 9        2.95     44.89     43.86     20.52
   FLUX BASED RAYLEIGH NUMBER * E-9 IS:   14.71
   AVERAGE TEMPERATURE: 55.253
   SINK TEMPERATURE: 10.362
```

APPENDIX D

SOFTWARE LISTING

```
!       !**********************
10      ! PROGRAM  CalcDiel    *
20      !**********************
21      !
23      ! EDITED BY LT E. TORRES. FROM ORIGINALS OF
30      ! PAMUK [REF.12] AND BENEDICT [REF. 13]
31      !
40      !****************************************
50      ! THIS PROGRAM ANALYSES THE DATA READ FROM *
60      ! A DATA FILE DESIGNATED BY THE OPERATOR.IT*
70      ! REDUCES THE DATA TO CALCULATIONS OF NET  *
80      ! POWER. RAYLEIGH NUMBER AND NUSELT NUMBER.*
90      !****************************************
91      !
93      ! VARIABLES USED ARE :
94      ! EMF : VOLTAGE FROM THE THERMOCOUPLES.
95      ! POWER : POWER DISSIPATED BY THE HEATERS.
96      ! T(I)  : TEMPERATURE CONVERTED FROM THERMOCOU-
97      !         PLES VOLTAGE.
98      ! TAVG  : IS THE AVERAGE TEMPERATURE OF THE
99      !         CHIP. IT IS OBTAINED MULTIPLYING
100     !         THE TEMPERATURE FOUND IN EACH FACE
101     !         BY THE AREA AND DIVIDING BY THE TO-
102     !         TAL AREA.
104     ! Ts    : CHIP BACK SURFACE TEMPERATURE.
105     ! Tfilm: FILM TEMPERATURE OF THE FC-75.
106     ! QNET : ELECTRIC POWER MINUS CONDUCTION LOSSES.
107     ! TSINK: AVERAGE OF THE 6 THERMOCOUPLES IN
108     !        THE UPPER AND LOWER HEAT-EXCHANGERS.
109     ! NU1 : VERTICAL LENGTH BASED NUSSELT NUMBER
110     ! NU2 : AREA-PERIMETER BASED NUSSELT NUMBER.
111     ! OTHER VARIABLES ARE SELF EXPLANATORIES.
113     !**********************************************
114     !
115     COM /Co/ D(7)
116     !
120     DIM Emf(76),Power(9),T(76),Tavg(9),Ts(9)
130     DIM Tfilm(9),Qnet(9),H(9),K(9),Rho(9),Cp(9)
140     DIM N(9),Nu(9),Ra(9),Delt(9),Alfa(9),Pr(9)
150     DIM Gr(9),Beta(9),Dpow(9),Dts(9),Rp(8)
160     !
170     ! CORRELATION FACTORS TO CONVERT Emf TO DEGREES CELSIUS.
180     DATA 0.10086091.25727.9.-767345.8.78025596.
190     DATA -9247486589.6.98E11.-2.66E13.3.94E14
191     DATA 2.50.2.06.2.08.2.08.2.50.2.08.2.08.2.08.2.08
200     !
210     READ D(*)
211     READ Rp(*)
220     !
260     PRINTER IS 701
270     BEEP
280     BEEP
290     !
300     INPUT "ENTER THE NAME OF THE FILE CONTAINING DATA".Oldfile$
301     !
310     PRINT USING "10X.""THE RAW Emf DATA ARE FROM THE FILE:     "".10A":Oldfile$
311     !
320     INPUT "ENTER THE POWER SETTING ".Power$
330     !
```

```
340  PRINT USING "9X,"" THE POWER SETTING PER CHIP WAS:    "",10A";Power$
341  !
343  PRINT USING "10X,""THE DISTANCE TO THE FRONT WALL WAS 9 MM """
344  !
350  PRINT
370  !
380  BEEP
390  BEEP
400  ASSIGN @File TO Oldfile$
401  ENTER @File;Emf(*)
410  !
420  !*********************************
430  ! CONVERT Emf TO DEGREES CELSIUS  *
431  !*********************************
432  !
440  FOR I=0 TO 60
450  Sum=0
460  FOR J=0 TO 7
470  Sum=Sum+D(J)*Emf(I)^J
480  NEXT J
490  T(I)=Sum
500  NEXT I
502  FOR I=71 TO 76
503  Sum=0
504  FOR J=0 TO 7
506  Sum=Sum+D(J)*Emf(I)^J
508  NEXT J
509  T(I)=Sum
510  NEXT I
511  !
513  !************************
520  ! CONVERT Emf TO POWER   *
521  !************************
522  !
530  J=1
540  Volt=Emf(61)
550  FOR I=62 TO 70
560  Power(J)=Emf(I)*(Volt-Emf(I))/Rp(I-62)
580  J=J+1
590  NEXT I
591  !
600  !**************************
610  ! AREA OF THE BLOCK FACES  *
611  !**************************
612  !
620  Acen=1.92E-4
630  Alef=1.44E-4
640  Arig=1.44E-4
650  Atop=4.8E-5
660  Abot=4.8E-5
670  Atot=5.76E-4
671  !
680  !*****************************************************
690  !CALCULATE THE AVERAGE TEMPERATURES OF THE BLOCK FACES  *
691  !IF A THERMOCOUPLE IS FOUND OPENED,IT SHOULD BE TAKEN OFF.*
700  !*****************************************************
701  !
710  Tavg(1)=(T(0)*Acen+T(1)*Atop+T(2)*Arig+T(3)*Alef+T(4)*Abot)/Atot
720  Tavg(2)=(T(6)*Acen+T(7)*Atop+T(8)*Arig+T(9)*Alef+T(10)*Abot)/Atot
```

```
740   Tavg(4)=(T(18)*Acen+T(19)*Atop+T(20)*Arig+T(21)*Alef+T(22)*Abot)/Atot
750   Tavg(5)=(T(24)*Acen+T(25)*Atop+T(26)*Arig+T(27)*Alef+T(28)*Abot)/Atot
760   Tavg(6)=(T(30)*Acen+T(31)*Atop+T(33)*Alef+T(34)*Abot)/(Atot-Alef)
770   Tavg(7)=(T(36)*Acen+T(37)*Atop+T(38)*Arig+T(39)*Alef+T(40)*Abot)/Atot
780   Tavg(8)=(T(42)*Acen+T(43)*Atop+T(44)*Arig+T(46)*Abot)/(Atot-Alef)
790   Tavg(9)=(T(48)*Acen+T(49)*Atop+T(50)*Arig+T(51)*Alef+T(52)*Abot)/Atot
800   !*******************************************************
850   ! RESISTANCE OF PLEXIGLASS. FOUND WITH A CONDUCTIVITY OF *
852   ! 0.195 W/m.K AND A LENGTH OF 19.5 MM.
853   !
860   Rc=520.83
880   !
881   !*******************************
890   ! CHIP BACK SURFACE TEMPERATURES *
891   !*******************************
900   Ts(1)=T(5)
910   Ts(2)=T(11)
920   Ts(3)=T(17)
930   Ts(4)=T(23)
940   Ts(5)=T(29)
950   Ts(6)=T(35)
960   Ts(7)=T(41)
970   Ts(8)=T(47)
980   Ts(9)=T(53)
990   Tssum=0
1000  FOR J=1 TO 9
1010  Tssum=Tssum+Ts(J)
1020  NEXT J
1030  !
1040  Tsavg=Tssum/9
1041  !
1050  !******************************
1060  ! CONDUCTION LOSS CALCULATION. *
1061  !******************************
1062  !
1070  Qloss3=(T(17)-T(75))/Rc
1080  Qloss5=(T(29)-T(55))/Rc
1090  Qloss7=(T(41)-T(54))/Rc
1100  Qloss=(Qloss3+Qloss5+Qloss7)/3
1110  !
1120  !**************************************
1130  ! AVERAGE SINK TEMPERATURE CALCULATION *
1131  !**************************************
1132  !
1140  Tsink=(T(57)+T(58)+T(59)+T(60)+T(71)+T(72))/6
1150  !
1152  ! TWO CHARACTERISTIC LENGTHS.WILL BE USED TOCALCULATE NUSSELT NUMBERS :
1153  ! L1 BASED IN THE VERTICAL DIMENSION OF THE CHIP (24.MM)
1154  ! AND L2 BASED IN  THE SUMATION OF THE AREASDIVIDED BY THE PERIMETER.
1155  !
1160  L1=2.40E-2
1161  L2=(2.*(6.*24./60.)+2.*(8.*6./28.)+8.*24./54.)*.001
1170  !************************************************************************
1171  !
1173  !*******************************
1174  ! TO PRINT THE OUTPUT HEADINGS. *
1175  !*******************************
1176  !
1180 PRINT USING "9X,""CHIP   QNET(W)  Tavg-Ts      Nu1        Nu2    "",10A"
1200 PRINT
1210  !**************************************
```

```
1220  ! CALCULATION OF NET POWER. Nu AND  Ra. *
1230  !***************************************
1231  !
1240  FOR J=1 TO 9
1250  !
1260  ! CALCULATION OF Qnet
1270  Qnet(J)=Power(J)-Qloss
1290  !
1300  ! CALCULATION OF Tfilm
1310  Tfilm(J)=(Tavg(J)+Tsink)/2
1330  !
1340  ! CALCULATION OF A DELTA TEMPERATURE
1350  Delt(J)=Tavg(J)-Tsink
1370  !
1380  ! CALCULATION OF CONVECTION COEFFICIENT
1390  H(J)=Qnet(J)/(Atot*Delt(J))
1410  !
1420  ! CALCULATION OF FC-75 THERMAL CONDUCTIVITY.
1430  K(J)=(.65-7.89474E-4*Tfilm(J))/10
1440  !
1450  ! CALCULATION OF FC-75 DENSITY
1460  Rho(J)=(1.825-.00246*Tfilm(J))*1000
1470  !
1480  ! CALCULATION OF FC-75 SPECIFIC HEAT
1490  Cp(J)=(.241111+3.7037E-4*Tfilm(J))*4180
1500  !
1510  ! CALCULATION OF FC-75 VISCOSITY
1520  N(J)=1.4074-2.964E-2*Tfilm(J)+3.8018E-4*Tfilm(J)^2-2.7308E-6*Tfilm(J)^3+8.
1679E-9*Tfilm(J)^4
1530  N(J)=N(J)*1.E-6
1540  !
1550  ! CALCULATION OF THE COEFFICIENT OF THERMAL
1551  ! EXPANSION [BETA]
1560  Beta(J)=.00246/(1.825-.00246*Tfilm(J))
1570  !
1580  ! CALCULATION OF ALPHA
1590  Alfa(J)=K(J)/(Rho(J)*Cp(J))
1600  !
1610  ! CALCULATION OF PRANDTL NUMBER.
1620  Pr(J)=N(J)/Alfa(J)
1630  !
1640  ! CALCULATION OF NUSSELT NUMBERS
1650  Nu1(J)=H(J)*L1/K(J)
1651  Nu2(J)=H(J)*L2/K(J)
1670  !
1710  ! CALCULATION OF GRASHOF NUMBER.
1720  Gr(J)=9.81*Beta(J)*(L1^3)*Delt(J)/N(J)^2
1740  !
1750  ! CALCULATION OF RAYLEIGH NUMBER.
1760  Ra(J)=Gr(J)*Pr(J)*1.E-7
1780  !
1794  ! CALCULATION OF FLUX BASED RAYLEIGH NUMBER
1810  Raf(J)=((9.81*Beta(J)*L1^4*Qnet(J))/(K(J)*N(J)*Alfa(J)*Atot))*1.E-9
1830  !
1870  !*************************************************************
1880  PRINT USING "10X,D,1X,5(5X,DD.DD,)";J,Qnet(J),Delt(J),Nu1(J),Nu2(J)
1890  !
1930  PRINT USING "12X,""FLUX BASED RAYLEIGH NUMBER * E-9 IS:  "",DDD.DD";Raf(J)
1940  PRINT USING "12X,""AVERAGE TEMPERATURE:"",DDD.DDD";Tavg(J)
1941  PRINT USING "12X,""SINK TEMPERATURE:"",DDD.DDD";Tsink
1950  PRINT
```

```
1960  NEXT J
1970  ASSIGN @File TO *
1980  END
```

```
1      !+++++++++++++++++++
10     ! PROGRAM FASTSCAN  +
11     !++++++++++++++++++++++++++++++++++++++++++++++++++
30     !PROGRAM TO SCAN THE THREE UPPERMOST THERMOCOUPLES.
40     ! IT SCANS 3 CHANNELS FOR TEMPERATURE VARIATION MEASUREMENTS.
41     ! CHANNELS ARE 13,31 AND 49
50     !+++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
60     Ipass=599
70     Pass=0
71     N=0
80     DIM T1(599),V1(2),Y1(599)
81     DIM T2(599),V2(2),Y2(599)
82     DIM T3(599),V3(2),Y3(599)
90     CLEAR 709
100    CLEAR 722
101    !++++++++++++++++++++++++++++++++++++++++++++++++
102    ! THE THREE FILE NAMES THAT ARE REQUIRED FOLLOWING
103    ! ARE TO STORE THE READINGS FROM THREE THERMOCOUPLES.
104    !++++++++++++++++++++++++++++++++++++++++++++++++++
106    BEEP
107    PRINTER IS 701
108    BEEP
109    INPUT "ENTER THE FIRST FILE NAME:  ",Newfile1$
110    INPUT "ENTER THE SECOND FILE NAME: ",Newfile2$
111    INPUT "ENTER THE THIRD FILE NAME: ",Newfile3$
112    INPUT "ENTER THE VOLTMETER READING: ",V$
113    PRINT USING "15X,"" RESULTS ARE STORED ON DISK 'FASTSCAN' "",10A"
114    PRINT
116    PRINT USING "25X,""FILE: "",10A";Newfile1$
117    PRINT
118    PRINT USING "25X,""FILE: "",10A";Newfile2$
119    PRINT
120    PRINT USING "25X,""FILE: "",10A";Newfile3$
121    PRINT
123    WAIT 1
124    BEEP
125    OUTPUT 709;"AE1"
130    WAIT 2
131    BEEP
140    OUTPUT 722;"T4 F1 R1 P0 Z0 1STI S01 1STN"
141    !
143    !+++++++++++++++++++
144    ! LOOP NUMBER ONE  +
145    !++++++++++++++++++++++++++++
146    ! START SCANNING CHANNEL # 13  +
147    !++++++++++++++++++++++++++++
150    OUTPUT 709;"AF13 AL13"
160    OUTPUT 709;"AS"
170    BEEP
175    Timedate1=TIMEDATE
180    FOR Jj=0 TO Ipass
200    OUTPUT 722;"T3"
210    ENTER 722;V1(*)
220    T1(Pass)=V1(1)
250    Pass=Pass+1
251    N=N+1
260    NEXT Jj
261    Timedate2=TIMEDATE
263    Time2=Timedate2-Timedate1
```

```
264   Pass=0
266   !*********************
267   ! LOOP NUMBER TWO     *
269   !******************************
271   ! START SCANNING CHANNEL 31    *
272   !******************************
273   !
275   OUTPUT 709:"AF31 AL31"
276   OUTPUT 709:"AS"
277   BEEP
278   BEEP
279   FOR Jj=0 TO Ipass
280   OUTPUT 722:"T3"
281   ENTER 722:V2(*)
282   T2(Pass)=V2(1)
283   Pass=Pass+1
284   NEXT Jj
285   OUTPUT 722:"AC31"
286   Pass=0
287   !
289   !***********************
290   ! LOOP NUMBER THREE     *
291   !***************************
292   ! START SCANNING CHANNEL 49 *
294   !***************************
295   !
297   OUTPUT 709:"AF49 AL49"
298   OUTPUT 709:"AS"
299   BEEP
300   BEEP
301   BEEP
302   FOR Jj=0 TO Ipass
303   OUTPUT 722:"T3"
304   ENTER 722:V3(*)
305   T3(Pass)=V3(1)
306   Pass=Pass+1
307   NEXT Jj
308   !
309   ! END LOOPS
310   !
311   PRINT USING "15X,""THE TOTAL TIME ELAPSED (SECONDS) :"",2X,(DDD.DD)":Total
time]
312   PRINT
313   PRINT USING "15X,""THE TOTAL NUMBER OF SCANS :   "",2X, DDDD.D,2X ":N
314   PRINT
315   PRINT USING "15X,""THE VOLTMETER READING :   "",10A,":V$
316   PRINTER IS 1
317   BEEP
318   !*****************************
319   ! TRANSFER FIRST SCAN DATA     *
320   !*******************************************
322   ! TRANSFERING THE SCAN DATA FROM CHANNEL 13
323   ! TO THE FILE. THIS FILE WILL BE USED , WITH
324   ! THE PROGRAM "PLOT", TO MAKE A PLOT OF TEM-
325   ! PERATURE VS TIME.
326   !*******************************************
328   CREATE BDAT Newfile13,20
329   ASSIGN @File TO Newfile13
330   OUTPUT @File:T1(*)
331   FOR Ii=0 TO Ipass
332   T1(Ii)=.10086091+25727.9*T1(Ii)-767345.8*T1(Ii)^2+78002556*T1(Ii)^3
```

```
340   NEXT I1
341   !********************************
342   ! TRANSFER SECOND SCAN DATA      *
344   !********************************
345   !TRANSFERING DATA FROM CHANNEL 31*
346   !TO THE FILE                     *
347   !********************************
349   CREATE BDAT Newfile2$,20
350   ASSIGN @File TO Newfile2$
351   OUTPUT @File;T2(*)
352   FOR I1=0 TO Ipass
353   T2(I1)=.10086091+25727.9*T2(I1)-767345.8*T2(I1)^2+78002556*T2(I1)^3
354   NEXT I1
355   !
357   !*******************************
358   ! TRANSFER THIRD SCAN DATA      *
359   !*********************************
360   ! TRANSFERING DATA FROM CHANNEL 31 *
361   ! TO THE FILE.
362   !*********************************
363   !
364   CREATE BDAT Newfile3$,20
365   ASSIGN @File TO Newfile3$
366   OUTPUT @File;T3(*)
367   FOR I1=0 TO Ipass
368   T3(I1)=.10086091+25727.9*T3(I1)-767345.8*T3(I1)^2+78002556*T3(I1)^3
369   NEXT I1
390   STOP
400   END
```

```
10   !  FILE NAME: PLOT
20   !
40   !
50   ! THIS PROGRAM PLOTS THE DATA ACQUIRED BY
60   ! PROGRAM "FASTSCAN".
70   !
80    PRINTER IS 705
90    BEEP
100   Xmin=0
110   Xmax=200
120   BEEP
130   INPUT "ENTER MINIMUM AND MAXIMUM Y-VALUES".Ymin.Ymax
140   BEEP
150   Xstep=20
160   BEEP
170   Ystep=.2
180   BEEP
190   PRINT "IN:SP1:IP 2000.2000.8000.7000:"
200   PRINT "SC 0.100.0.100:TL 2.0:"
210   Sfx=100/(Xmax-Xmin)
220   Sfy=100/(Ymax-Ymin)
230   PRINT "PU 0,0 PD"
240   FOR Xa=Xmin TO Xmax STEP Xstep
250   X=(Xa-Xmin)*Sfx
260   PRINT "PA":X.".0: XT:"
270   NEXT Xa
280   PRINT "PA 100.0:PU:"
290   PRINT "PU PA 0.0 PD"
300   FOR Ya=Ymin TO Ymax STEP Ystep
310   Y=(Ya-Ymin)*Sfy
320   PRINT "PA 0,":Y."YT"
330   NEXT Ya
340   PRINT "PA 0.100 TL 0 2"
350   FOR Xa=Xmin TO Xmax STEP Xstep
360   X=(Xa-Xmin)*Sfx
370   PRINT "PA":X.".100: XT"
380   NEXT Xa
390   PRINT "PA 100.100 PU PA 100.0 PD"
400   FOR Ya=Ymin TO Ymax STEP Ystep
410   Y=(Ya-Ymin)*Sfy
420   PRINT "PD PA 100.".Y."YT"
430   NEXT Ya
440   PRINT "PA 100.100 PU"
450   PRINT "PA 0.-2 SR 1.5.2"
460   FOR Xa=Xmin TO Xmax STEP Xstep
470   X=(Xa-Xmin)*Sfx
480   PRINT "PA":X.".0:"
490   PRINT "CP -2.-1:LB":Xa:""
500   NEXT Xa
510   PRINT "PU PA 0.0"
520   FOR Ya=Ymin TO Ymax STEP Ystep
530   IF ABS(Ya)<1.E-5 THEN Ya=0
540   Y=(Ya-Ymin)*Sfy
550   PRINT "PA 0.":Y.""
560   PRINT "CP -5.-.25:LB";Ya:""
570   NEXT Ya
580   BEEP
590   Idl=0
600   IF Idl=0 THEN
```

```
620   Xlabel$="Time (sec)"
630   BEEP
640   Ylabel$="Temperature (C)"
650   PRINT "SR 1.5.2:PU PA 50.-10 CP":-LEN(Xlabel$)/2:"0:LB":Xlabel$:""
660   PRINT "PA -11.50 CP 0.":-LEN(Ylabel$)/2+5/6:"DI 0.1:LB":Ylabel$:""
670   END IF
680   PRINT "CP 0.0"
690   BEEP
700   INPUT "ENTER THE NAME OF THE DATA FILE".D_file$
710   ASSIGN @File TO D_file$
720   BEEP
730   Md=0
740   BEEP
750   Npairs=600
760   BEEP
770   PRINTER IS 1
780   Sym=1
790   PRINTER IS 705
800   PRINT "PU DI"
810   IF Sym=1 THEN PRINT "SM."
820   IF Sym=2 THEN PRINT "SM+"
830   IF Sym=3 THEN PRINT "SMo"
840   IF Md>1 THEN
850   FOR I=1 TO (Md-1)
860   ENTER @File:Xa.Ya
870   NEXT I
880   END IF
890   FOR Xa=0 TO 199 STEP .3333333
900   ENTER @File:Ya
910   Ya=.10086091+25727.9*Ya-767345.8*Ya^2+78002556*Ya^3
920   X=(Xa-Xmin)*Sfx
930   Y=(Ya-Ymin)*Sfy
940   IF Sym>3 THEN PRINT "SM"
950   IF Sym<4 THEN PRINT "SR 1.4.2.4"
960   PRINT "PA".X.Y."PD"
970   IF Sym>3 THEN PRINT "SR 1.2.1.6"
980   IF Sym=4 THEN PRINT "UC2.4.99.0.-8.-4.0.0.8.4.0.:"
990   IF Sym=5 THEN PRINT "UC3.0.99.-3.-6.-3.6.3.6.3.-6:"
1000  IF Sym=6 THEN PRINT "UC0.5.3.99.3.-8.-6.0.3.8:"
1010  IF Sym=7 THEN PRINT "UC0.-5.3.99.-3.8.6.0.-3.-8:"
1020  NEXT Xa
1021  PRINT "PU"
1030  BEEP
1040  ASSIGN @File TO *
1050  END
```

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Apartado Aereo 2845
Cartagena Colombia

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