

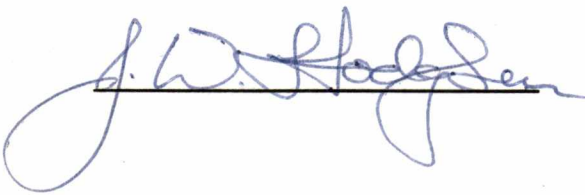
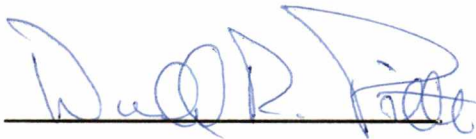
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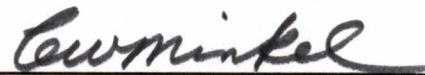


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THE ASPECT RATIO EFFECT ON IMMERSION COOLING OF DISCRETE
FLUSH-HEATERS IN AN ENCLOSURE COOLED FROM THE TOP

A Thesis

Presented for the

Master of Sciences

Degree

The University of Tennessee, Knoxville

Ricardo Jose Carmona

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ABSTRACT

The width effect on natural convection heat transfer due to discrete flush-heated sections of equal height in an enclosure cooled from the top was experimentally investigated. Five heated sections were uniformly distributed along a vertical side wall, where the height of the unheated sections was equal to that of the heated sections. All other vertical surfaces and the bottom plate were insulated. The experiments were conducted for six values of cavity width resulting in a variation in the cavity height-to-width ratio (aspect ratio) of 3.67 to 12.22. Ethylene glycol and FC-75 (a dielectric fluid) were used as the convective media. The flow visualization results with ethylene glycol revealed a fairly inactive core flow at low power inputs and small cavity width. Higher values of the power input and cavity width transformed a well structured core flow into a time dependent one with higher horizontal velocities toward the "hot" wall. For all the cavity widths, it was found that the heat transfer results for all the heated sections could be unified and presented by a single correlation through use of a local height as the length scale. This correlation includes an explicit relation for the aspect ratio effect on local Nusselt number. The local height of a given heated section was measured from the bottom of the cavity to the mid-height of that section. The data indicated that an increase in the cavity width results in an increase in the heat transfer coefficients of the heated sections. A comparison between ethylene glycol and FC-75 revealed no appreciable Prandtl number effect which is in agreement with a previously reported prediction. A heat transfer coefficient for the top surface was defined based on the total convective heat

flux at this surface and an average temperature difference between the heated sections and the top plate. The result shows that for a given heat flux at the top, the highest heat transfer coefficient on this surface can be obtained with the lowest cavity width.

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CHAPTER 1

INTRODUCTION

The evolution in miniaturization of electronic components, which unquestionably started with the invention of the transistor in 1947, has not come to an end yet. The desire to decrease time of electronic signals as well as the interest in having higher performance from printed circuits and solid state devices has resulted in the design of more densely packed electronic components. As a consequence, heat removal requirements have risen not only because power dissipation has increased but also because of the lower temperature requirements of integrated circuits. Techniques such as using higher velocities to enhance forced convection of the electronic arrays have become less satisfactory due to excessive acoustical noise generated. Natural convection, on the other hand, has taken a new dimension with the acceptance of liquid immersion cooling as a mean of maintaining thermal control of electronic devices.

In today's electronic industry it is a common practice to mount arrays of heat dissipating components on a flat plate and then encase the assembly in a cabinet resulting in a configuration which may be modeled as a vertical cavity with discrete heat sources. The present problem falls in the category of immersion cooling of an array of electronic cards where the cooling is provided by a large condenser placed on the top of a vertical cavity providing a constant temperature top plate in the enclosure thus formed.

LITERATURE REVIEW

Under some circumstances, the problem of cooling the arrays of heat dissipating components may be modeled simply as a flat plate with distributed heat sources. In fact, numerous studies of natural convection along a vertical plate have been conducted. These studies had considered a wide variation of heating conditions and other effects including : uniform isoflux and isothermal boundary conditions; two dimensional heat transfer with one or more isolated strip heat sources or line thermal sources; considerations of leading edge and wake effects; and three-dimensional, flush-mounted or protruding heat sources with in-line or staggered array orientation. Boundary layer equations were numerically solved by Sparrow and Faghri [25] for the case of two in-line, isothermal heaters flush-mounted on a vertical plate for natural convection in air. Jaluria [9] also analytically studied natural convection in air due to multiple in-line, flush-mounted heaters on a vertical plate and in a follow-up paper [10] reported finite-difference solutions of the more general equations for the case of two in-line heaters.

Park and Bergles [24] conducted experimental studies of free convection from in-line and staggered arrays of flush-mounted and protruding heaters in a flat plate with water and R-113 as the working fluids. They reported that the heat transfer coefficient for the widest single flush-mounted heater studied (~70 mm) in R-113 was 20% higher than that of a uniformly heated vertical plate. Another of their major findings was that for the case of three flush-mounted heaters, the heat transfer coefficients for the middle and the top heaters are lower than those for the bottom heater, and the difference decreases with increasing distance between the heaters.

The modeling of the electronic cooling problem as a vertical channel with a variety of thermal boundary conditions has also been considered by a number of investigators (a number of them are cited in the bibliography). Ortega and Moffat [22] and Moffat and Ortega [20] have experimentally investigated convective heat transfer from an array of cubical elements mounted on an insulated plane wall of an open ended channel. They concluded that when a shrouding wall is placed in front of the array, the heat transfer is significantly affected if the ratio of the gap width to the protrusion height is in the range of 1 to 4.

As stated earlier some electronic packaging problems, depending on the end conditions, may be modeled as an enclosure such as the Liquid Encapsulated Module proposed by Oktay [21]. Chu, Churchill, and Patterson [5] were among the first investigators to conduct experimental and numerical studies of laminar natural convection from a flush-mounted heat source on an insulated vertical wall of an air-filled rectangular cavity. Their calculations and experiments were for aspect ratios (height-to-width ratio) from 0.4 to 5.0 and a range of Grashof numbers up to 10^5 . However, as pointed out by Turner and Flack [27], their range of Grashof numbers was considerably low for actual electronic cooling applications. Turner and Flack experimentally expanded the numerical study made by Chu et al. to Grashof numbers as high as 9×10^6 .

A numerical study conducted by Kuhn and Oosthuizen [15] on three-dimensional, transient natural convection flow in a rectangular enclosure with localized heating had demonstrated that the proximity of the heater elements to the horizontal walls (especially the top wall) has a strong effect on the heat transfer

coefficient while the side walls have negligible effects. Ozoe [23] presented a two-dimensional numerical study of natural convection in a square cavity with nine point sources of uniform heat flux. He reported results for the two cases of cooling from the top and cooling from the side. Keeping in mind that the side and the top areas were kept the same size, the conclusion was that cooling from the top was more effective and resulted in lower temperatures. Other studies deserving credit for their contribution to natural convection heat transfer in rectangular enclosures with protruding heaters are due to Kelleher, Knock and Yang [12]; Lee, Liu, Yang and Kelleher [16]; and Liu, Yang and Kelleher [18]. Liu et al. [18] reported numerical analysis for the case of three-dimensional, natural convection cooling of an array of heated protrusions in a enclosure filled with fluorinert FC-75. The wall opposing the protruding elements was insulated while the top and bottom were isothermal. Similarly as Ozoe [23] did, they concluded that the top sink surface is responsible for about all the heat dissipated from the enclosure. Thus, the cooling of the bottom surface may not be required in packaging considerations.

Sparrow, Vemury and Kadle [26] have indicated that in order to facilitate the design of digital computers, sophisticated computer programs are already in existence to trace the heat flow through complex paths. The imminent problem in the computer simulation is the unavailability of heat transfer coefficients which may be appropriate to the complex geometries typically encountered in a computer cooling passage. Liu et al. [18] pointed out that no studies dealing with the cooling of arrays of chips in a closed enclosure were available for comparison with their numerical results. The only experimental data for multiple in-line heaters in an enclosure have

been reported by Keyhani, Prasad and Cox [13]; Chen, Keyhani and Pitts [4]; and Keyhani, Prasad, Shen, and Wong [14]. Keyhani et al. [13] studied natural convection of ethylene-glycol in a tall cavity with a height-to-width ratio (aspect ratio) of 16.5. Their experimental set-up consisted of an isothermal vertical wall facing an adiabatic vertical wall containing eleven flush-mounted, alternatively unheated and heated sections of equal height. Their heat transfer data and flow visualization photographs indicate that stratification is the primary factor influencing the temperature of the heated sections. They indicated that this behavior persisted for all power inputs where the secondary flow cells covered a large vertical portion of the cavity. It was also reported that the local Nusselt numbers were nearly the same as those reported by Park and Bergles [24] for a single wide (~70 mm) flush-mounted heater on a vertical plate. The work done by Chen, Keyhani and Pitts [4] reported heat transfer data and flow visualization photographs in a vertical cavity with an aspect ratio of 7.26. The cavity was cooled from the top, and one of the vertical protruding non-conductive walls contained ten equal alternatively unheated and heated sections of equal height. All other surfaces were insulated. Water and ethylene glycol were used as the working fluids. Their experimental results indicated that the bottom heater, except for high Rayleigh number data, had the highest heat transfer coefficient. However, in the case of high Rayleigh numbers, the top heater had the highest heat transfer coefficient. From the flow visualization experiments with ethylene glycol, they concluded that the primary flow within the enclosure was very strong and made the main contribution to the heat transfer. They also reported that a secondary circulating flow existed in the gaps between protrusions.

MOTIVATION

Review of the relevant literature has lead to the conclusion that experimental information is extremely scarce for the design and analysis of the thermal performance of electronic packages when the geometric considerations require that the problem be modeled as an enclosure. This lack of experimental data for validation of numerical studies was pointed out by Liu et al. [18]. Furthermore, the desirability of the modular approach (such as liquid encapsulated module proposed by Oktay [21]) to electronic packaging was raised by Lee and Hsu [17].

Johnson [11] suggested that new techniques should be investigated only after one has demonstrated that the efficiency of natural convection to dissipate heat from electronic circuits is relatively low when compared with forced convection air cooling. The fact that natural convection in immersion cooling with dielectric liquids provides much higher heat transfer coefficients than forced convection air cooling [8] increased the inquisitive desire to investigate liquid immersion cooling of simulated microelectronic components. The aim of this work was to expand the limited understanding of natural convection in fluid-filled enclosures with multiple heaters by experimentally studying the cavity width effects (while keeping the cavity height constant) on the heat transfer coefficients and the flow regimes.

OBJECTIVES

There still exist numerous unanswered questions with regard to natural convection cooling in packaged microelectronic components. Given an enclosure with a set of fixed geometric parameters H , D , L_1 , and L_2 (please see Fig. 1-1 for the

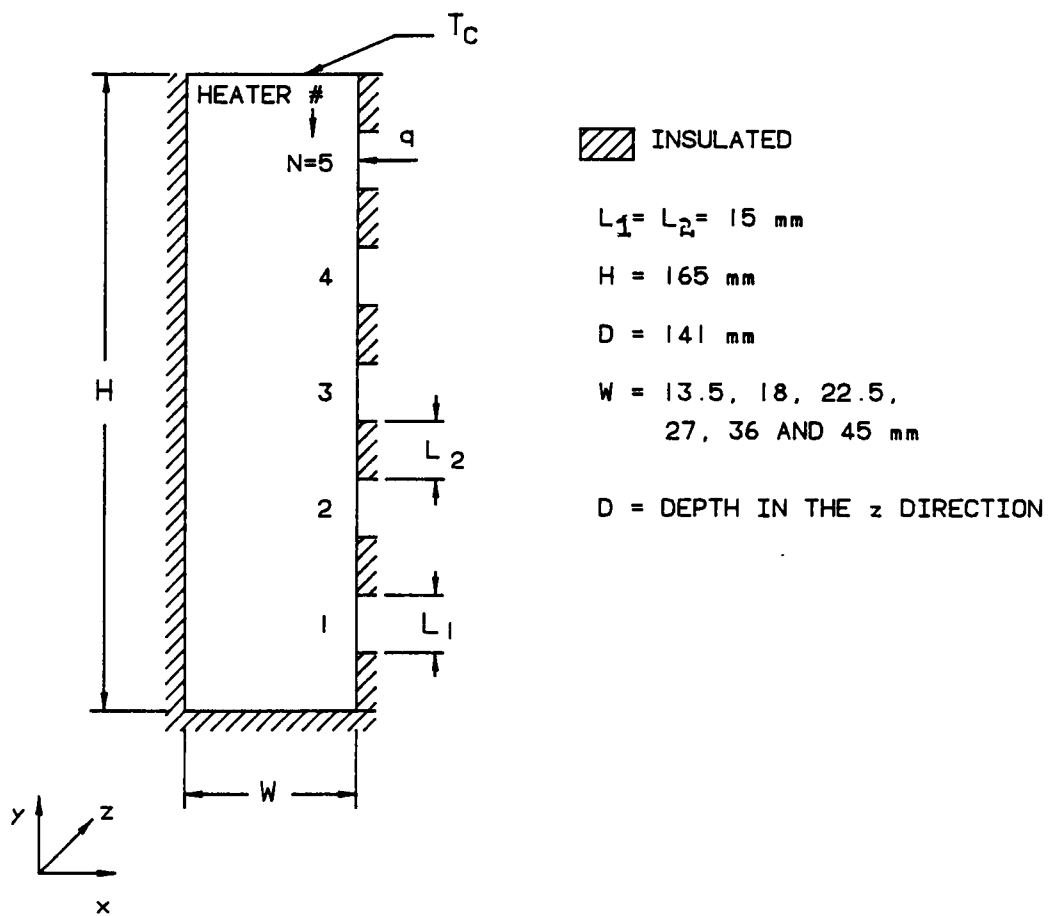


Fig. 1-1 Schematic of the enclosure.

geometric nomenclature) such that they are in the mid-range of values acceptable to the electronic industry, then the focus was set on the following objectives:

- (i) Determination of the effects of the variation of cavity width on the heat transfer and flow regimes.
- (ii) Determination of the local heat transfer coefficient of each element in the array and its dependence on the rate of power dissipation.
- (iii) Classification of the flow regimes encountered and determination of the conditions under which turbulent flow may initiate.
- (iv) Correlation of non-dimensional parameters such as the Nusselt number in terms of Rayleigh number to quantify the cavity aspect ratio effect on the convective heat transfer from each heated section.

CHAPTER 2

EXPERIMENTAL APPARATUS

The dimensional parameters of the experimental apparatus were selected to cover a wide range of actual dimensions currently used in the electronic packaging industry. The test cell consisted of a liquid filled, rectangular enclosure isothermally cooled from the top. Five identical rows of isoflux heated strips were flush-mounted on one vertical side wall. These heated strips were distributed such that identical rows of unheated and heated sections were obtained. All other surfaces of the cavity were insulated. The schematic of the enclosure and the details of the experimental apparatus are given in Figs. 1-1 and 2-1, respectively. Data were collected at steady state with ethylene glycol ($64 < Pr < 138$) and Fluorinert FC-75 ($22 < Pr < 25$) as the working fluids. The actual test section height and depth were 165 mm and 141 mm, respectively.

OUTER ENCLOSURE

In order to have sufficient space for a wide variation in the width of the actual enclosure under study, an outer rectangular box with inner dimensions of $H=171.35$ mm, $D=141$ mm and $W=139.7$ mm was made of 25.4 mm thick plexiglass sheet. The two vertical walls of this outer enclosure were placed in two 25.4 mm deep grooves cut on the surface of the bottom horizontal wall. The vertical end-walls of the box (z-direction) were made out of 6.35 mm thick, ground plate glass. These plates

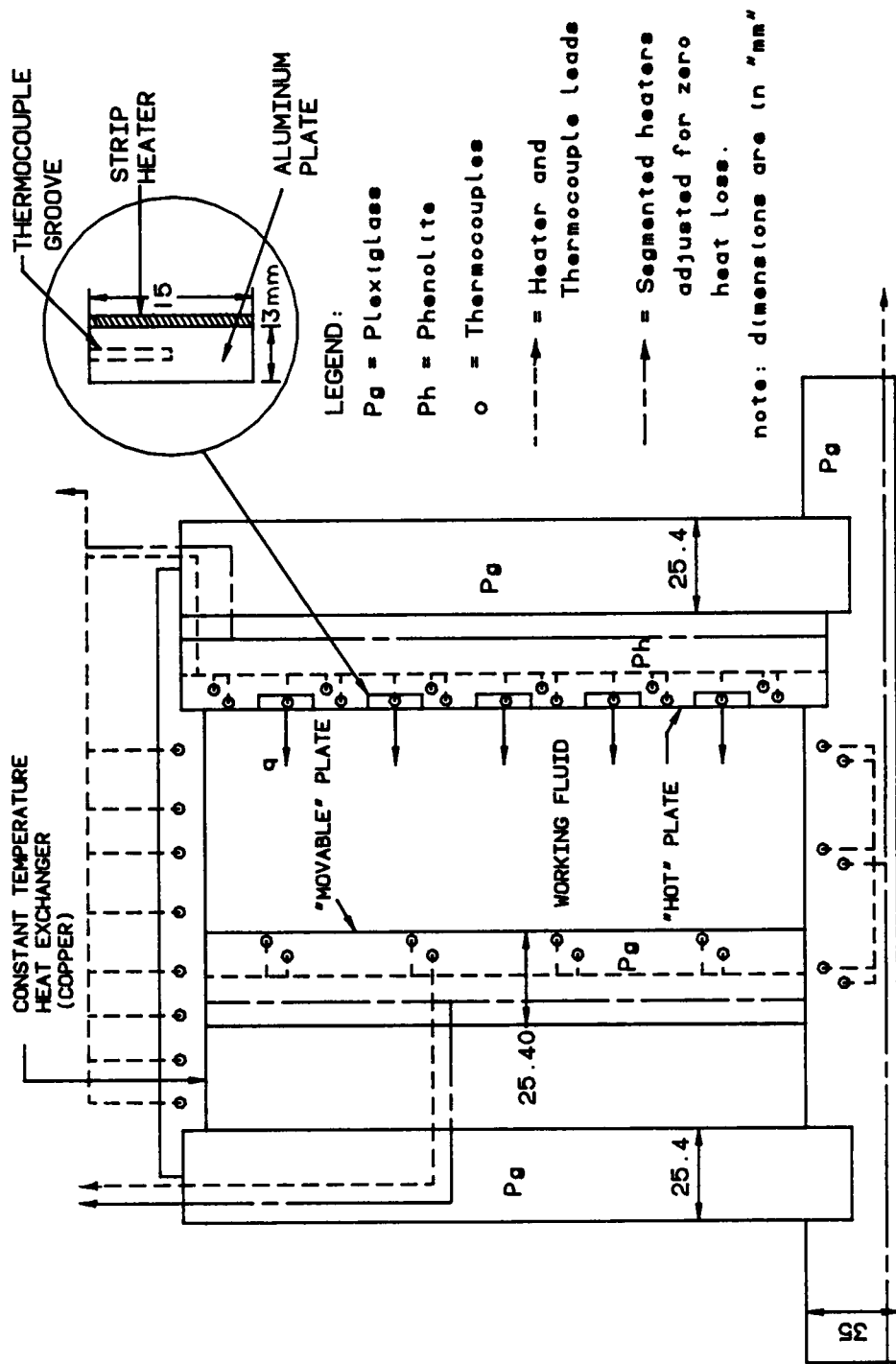


Fig. 2-1 Details of the experimental apparatus.

were bolted to the outer plexiglass box with aluminum frames. To make the cavity leak proof, a continuous groove was cut at the edges of the outer enclosure walls to accomodate a 3.18 mm silicone O-ring which was sandwiched between the outer plexiglass enclosure and the glass plates.

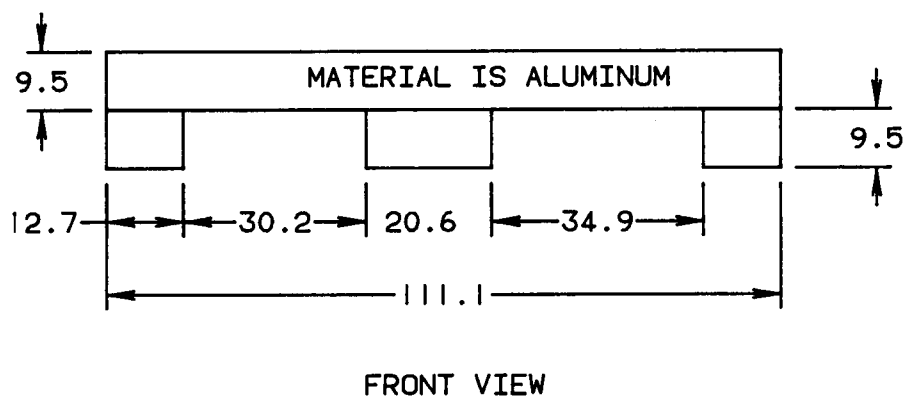
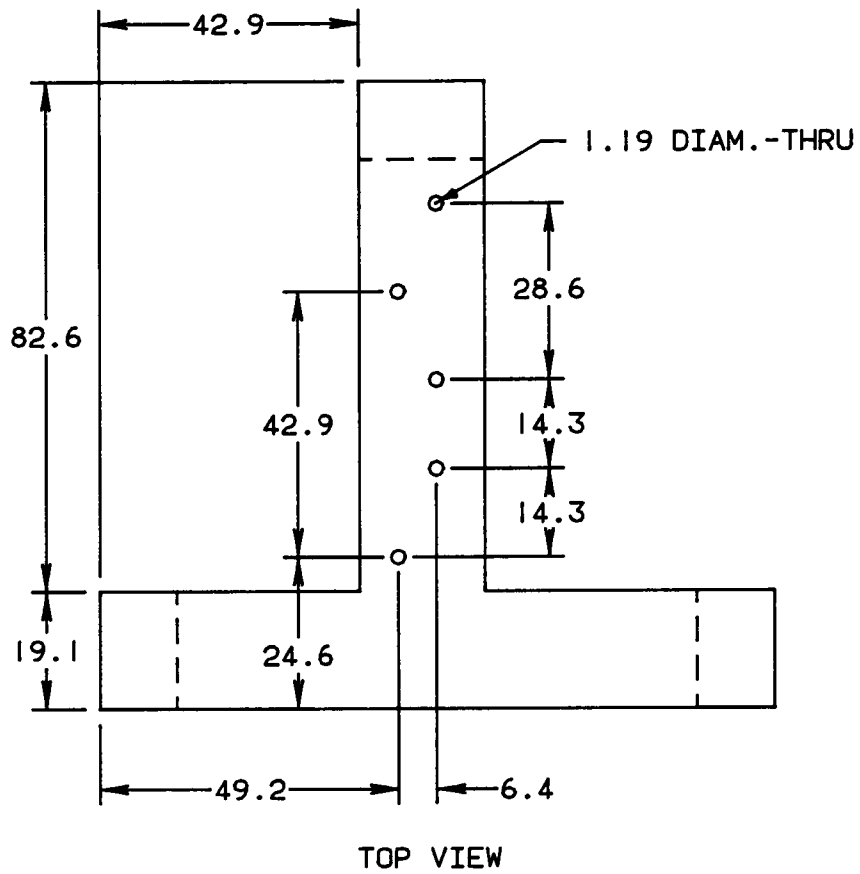
CONSTANT TEMPERATURE PLATE

The top surface covering the cavity was a copper heat exchanger plate. Two 6.35 mm thick, rectangular pieces of copper formed this heat exchanger. The top piece measured 153.7 mm by 190.5 mm. Two edges were cut in this piece to allow the extraction of thermocouples and heater leads. The bottom piece, which fitted tightly in the actual experimental enclosure, had dimensions of 110.5 mm by 140.9 mm and covered 6.35 mm of the inside enclosure height. A 3.18 mm deep semicircular groove was milled on the surface of each copper plate in the form of a sinusoidal wave line. The groove in one plate was the mirror image of the other and they met to form a channel when the plates were silver-soldered together. Supply and return hoses were connected from this heat exchanger to a LaudaTM constant temperature bath circulator which maintained the cooling water within ± 0.15 °C. Seven 30 AWG, type T, (copper-constantan) thermocouples were placed in wells which were within 1 mm of the bottom surface of the plate to verify that the copper heat exchanger was maintained at a constant temperature. Eight holes of 3.97 mm diameter were drilled through the top plate so that sealed probes could be inserted into the enclosure to measure the core flow temperature. The probes were formed by inserting a 30 AWG (type T) thermocouple lead into a stainless steel tube which had a diameter of 1.20

mm and a length of 305 mm. One end of the hollow tube was, therefore, equipped with a point measuring thermocouple, while the other end served as an exit for the thermocouple lead. In order to have control on the vertical positioning of the probes, a guiding device (Fig. 2-2) was constructed out of a 10 mm thick aluminum plate. Guiding holes with the same diameter of the stainless steel tube were drilled through this device, and set screws were provided on the sides to hold the probes in the measuring position. A stainless steel pointing sheet was welded at the upper end of each probe to be used as reference point in vertical length measurement.

THE MOVABLE VERTICAL WALL

The actual experimental enclosure was formed by placing a "movable" vertical plate and a "hot" plate inside the rectangular box enclosure formed by the outer plexiglass plates and the two glass end-walls (please see Fig. 2-1 for details). The "movable" vertical plate measured 141 mm by 165 mm. These were, in fact, the actual dimensions of the experimental cavity. In order to minimize heat losses, the movable vertical wall was instrumented with four silicone-rubber thermofoil heaters which were sandwiched between 6.35 mm thick and 19.1 mm thick plexiglass plates. The thicker plate was instrumented with differential thermopiles to determine the temperature gradients. The heaters were glued to the surface of the plate with MincoTM #6 adhesive heat sink compound; the same compound was used to hold the two composing plates together. The heaters were placed such that a seven mm gap was available on the "movable" wall. This gap was used to introduce a thin plane of light during flow visualization experiments. A 3.18-mm deep groove was milled on the



Note: dlm. in mm

Fig. 2-2 Thermocouple probe holder.

19.1 mm thick plate to facilitate channeling of the thermocouple leads out of the cavity . All the thermocouple leads were secured in their channel grooves with a 8-hour cure time epoxy. A 3.18-mm O-ring was placed on the edge of the movable plate to maintain it firmly inside the experimental enclosure. With this movable plate the actual test cell width could be varied from 0 to 88 mm.

THE "HOT" WALL

The heated phenolic wall was 177.7 mm high and 141 mm wide. Of this total height, 6.35 mm fitted into a slot cut at the bottom plate and another 6.35 mm fitted into an existing gap between the constant temperature heat exchanger and one of the vertical walls of the outer enclosure. The complete "hot" wall was formed by bolting together two 12.7 mm thick phenolic sheets. One sheet was instrumented with "guard" heaters similar to those of the "movable" plexiglass plate. Five slots with dimensions of 15 by 141 by 3.425 mm deep were cut in the face of the frontal phenolic sheet. Silicon rubber thermofoil heaters with a thickness of 0.25 mm were placed in each slot and covered with heat sink compound to enhance heat transfer. Aluminum plates with the same dimensions as the slots, but with a thickness of 3.125 mm, were placed over the strip heaters. Each aluminum plate was instrumented with at least one 30 AWG thermocouple (type T) which was inserted in a well drilled on the side of the aluminum plate. These thermocouples were located at the mid-height of the aluminum plates and at the midspan of the cavity. Each unheated section of the phenolic plate was also instrumented with 30 AWG thermocouples for temperature measurements. These temperatures were used to obtain an estimate of the substrate

conduction effects. The thermocouple and heater leads were routed through holes made in the phenolite plate and then directed out of the cavity through channels milled on the back of the plate. The face of the hot wall was sanded to produce a smooth-flat surface between the aluminum plates and the phenolite wall. The bottom horizontal wall was also instrumented with "guard" heaters and differential thermopiles to measure and control the heat losses.

POWER AND DATA ACQUISITION SYSTEMS

A SorenceTM power panel containing a voltage regulator, a step-down transformer, and five variacs was used to measure and control the voltage and current inputs in five different circuits (the arrangement and location of each circuit are presented in appendix C). The units of this panel were compatible with an existing data acquisition package consisting of a Hewlett-Packard control unit (HP 3497A), a digital voltmeter (HP 3456A), an extender (HP 3498A) and a system voltmeter (HP 3437A). The data acquisition unit was used to collect the voltage supplied to each circuit from the power panel and the emf outputs from all the thermocouples. A total of 60 copper-constantan thermocouples were distributed in the experimental apparatus (the thermocouple locations are indicated in the figures presented in appendix B). The reference ice point temperature was provided with a Kaye InstrumentTM unit. All digital information collected was fed to a Hewlett-PackardTM 9817A desktop computer for subsequent data reduction and analysis. This personal computer includes a HP 9133D Winchester disk with 14.8 Mb of storage capacity.

CHAPTER 3

EXPERIMENTAL PROCEDURE

HEAT TRANSFER MEASUREMENTS

The first step in conducting the experiments involved setting the cavity width by using positioning gauge blocks made out of plexiglass plates. Once the cavity width was set, the enclosure was filled with the working fluid and then the voltage input to the heated sections was adjusted to the desired power input. Each experiment started with a low power input of 2 Watts per element. For subsequent runs the power input was increased until a local maximum temperature close to 80 °C was reached. After setting the voltage input to each heated section, the system was allowed to expand for checking possible fluid leakage and no initial attempt to control the heat losses was tried. One hour later, the temperature gradients were measured on the back of the "hot" wall, the vertical "movable" plate and on the bottom horizontal wall by using the existing thermopiles to calculate the heat losses from each wall. The input voltage to each "guard" heater was now turned on and adjusted such that the outputs of the differential thermopiles were reduced to a level where the heat losses from each wall was below 2 percent of the total power input. Experimental data were collected and analysed on an hourly basis until consecutive local Nusselt numbers changed less than 1 percent. The stored data included thirteen surface temperature readings on the "hot" wall (heated and unheated sections), temperature gradients at the back of the "hot" wall, the "movable" wall and the bottom horizontal wall, seven surface temperature readings on the top sink surface, the surface glass temperature as well as the ambient

temperature. For most of the experiments conducted, a quasi-steady state was reached in less than four hours. The voltage input as well as the open-circuit current were also recorded to verify later the actual experimental stability of each circuit resistance. Measurements of the fluid core temperature were performed only after all of the surface temperature data were collected.

FLOW VISUALIZATION

The final stage in conducting the experiments was to obtain photographs of the flow structure. The flow visualization experiments were conducted with ethylene glycol after all information for each cavity width and power input was permanently recorded.

A thin plane of light was projected through a transparent gap on the "movable" wall to illuminate the midspan section of the test enclosure. A slide projector (KodakTM Carousel AV900) served as the light source. A 3 mm wide vertical slit was cut on a black painted slide which was inserted into the projector to reduce excess lighting and produce the necessary plane of focused light. Aluminum powder (5 to 20 μm in size) provided the tracer particles. The powder was poured down into the working fluid through the available holes in the top sink surface. Ten to fifteen minutes were required for the powder particles to assume the flow motion. Still photographs were taken with an XG-A MinoltaTM camera having a 50 mm macro lens. The camera was equipped with a shutter release cable and was supported on a tripod to prevent any camera movement during exposure. Kodak TMAX film (ASA 100) was used. The best photographic results were obtained when an aperture of f8 was used. The shutter speeds used ranged from 5 to 50 seconds.

DATA REDUCTION

The Nusselt number and modified Rayleigh number used in the presentation of the data were calculated by

$$Nu = h[\text{length scale}]/k \quad (1)$$

$$Ra^* = g\beta q[\text{length scale}]^4 / k\nu\alpha \quad (2)$$

Three length scales of local height (Nu_y , Ra_y^*), heater height (Nu_{L_1} , $Ra_{L_1}^*$) and cavity width ($Nu_{W,T}$, $Ra_{W,T}^*$) are used in the presentation of the results.

When using the length scales of L_1 and y , the local values of the thermophysical properties for ethylene glycol and fluorinert (FC-75) were evaluated at the average temperature,

$$T_f = (T_h + T_c)/2 \quad (3)$$

where T_h is the local mid-height temperature of a given heater and T_c is the constant sink temperature. Kelleher et al. (1987) and Lee et al. (1987) suggest the use of this simple arithmetic mean temperature for evaluating the thermophysical properties. The local convective heat transfer coefficient h (of a given heated section) is defined as

$$h = (Q - Q_l - Q_{sc}) / A_h (T_h - T_c) \quad (4)$$

where $(T_h - T_c)$ is the excess local temperature between each heater and the cold plate, Q is the power input to each heater, Q_l is the heat loss per heater to the laboratory environment by conduction through the enclosure walls, Q_{sc} is the substrate conduction heat dissipated to the fluid from the unheated phenolite surfaces, and A_h is the heater surface area. A two dimensional unit cell conduction heat transfer model was numerically solved to calculate the heat convected to the fluid through the unheated phenolic sections. The unit cell modeling heaters 2, 3 and 4 represented the details of the phenolite plate from the midheight of an unheated section to the

midheight of the next unheated section. Hence, this unit cell comprised half the vertical length of two unheated regions which were adjacent to the full vertical length of a heated section (with a line source 3 mm from the surface). In order to model the asymmetrical unheated sections of heaters 1 and 5, a simple alteration was done on the unit cell, just mentioned, to include the full vertical length of one of the unheated sections. The measured temperatures were used to specify the boundary conditions of the unit cell. It was found that the convection heat transfer to the fluid through substrate conduction ranged from about 2 to 20 percent of the power input per heater for glycol and 16 to 38 percent for experiments conducted with FC-75. The FC-75 requires a higher substrate correction due to its lower thermal conductivity (~ 0.063 W/m K) than that of ethylene glycol (~ 0.25 W/m K).

For the results presented using the length scale W , the thermophysical properties were evaluated at an overall film average temperature of

$$\bar{T}_f = (\bar{T}_h + T_c)/2 \quad (5)$$

where $\bar{T}_h$ is the average temperature of the heaters. The heat transfer coefficient for this scaling is defined as

$$h_T = (Q_{To} - Q_{l,To})/A_T(\bar{T}_h - T_c) \quad (6)$$

Where Q_{To} is the total power input, $Q_{l,To}$ is the total heat loss to the laboratory environment and A_T is the top sink surface. It should be noted that the convective energy at the top surface includes the energy convected from the unheated sections.

The standard deviation of the correlations presented in this report was calculated by using :

$$\sigma^2 = (\sum (Nu_{y,i} - \bar{Nu}_y)^2) / (n-1) \quad (7)$$

where n is the total number of data points (based on the "y" length scale), $Nu_{y,i}$ is the experimental local Nusselt number and $\bar{Nu}_y$ is the mean of the experimental local Nusselt number.

CHAPTER 4

RESULTS AND DISCUSSION OF RESULTS

The experiments with ethylene glycol were conducted for cavity width values of 13.5, 18, 22.5, 27, 36 and 45 mm, and for nominal power inputs ranging from 2 to 18 watts per heater. The data presented for FC-75 were collected for a cavity width of 18 mm and nominal power inputs of 2 and 4 watts per heater. It should be noted that the absence of a freeboard height above the dielectric fluid level (to keep the vapor in place) results in a rather high rate of evaporation. Due to other constraints on the design of the apparatus, no provisions were made to provide a freeboard height above the liquid level. Thus, a rather high rate of evaporation occurred during the experiments. The objective of the experiments conducted with FC-75 was to verify that the ethylene glycol results are applicable to immersion cooling as reported by Keyhani et al. (1988b). Considering the fact that FC-75 is rather expensive, the experiments were limited to two power levels which were sufficient to achieve the stated objective.

The experiments conducted with ethylene glycol as convective medium covered a range of local modified Rayleigh numbers Ra_y^* from 4.1×10^6 to 1.37×10^{11} . This corresponds to a local Prandtl number variation between 137.8 and 63.7. The range of modified Rayleigh numbers covered with FC-75 was from 1.02×10^9 to 5.24×10^{12} , with a corresponding local Prandtl number variation between 24.88 and

22.03.

FLOW VISUALIZATION

Photographs of the flow patterns for the entire enclosure are shown in Figs. 4-1, 4-2, 4-3 and 4-4. A primary flow traveling along the vertical side walls of the cavity in a counterclockwise sense constitutes the main mechanism for the transport of energy to the top surface. The following general observations can be made from a detailed study of the flow visualization results for all the cavity widths. At low power inputs a very well structured core flow is evident (Figs. 4-1 and 4-4). As the power input is increased the following two events take place : (i) the bottom of the core flow moves upward (Figs. 4-1 and 4-4); and (ii) a stable and structured core flow at a lower power input is transformed into a time dependent one (Figs. 4-1 to 4-4).

The cavity width effect on the flow structure can be summarized as following :

(i) For $W > 13.5$ mm, a large secondary flow cell (counterclockwise motion) at the top portion of the cavity is observed (Figs. 4-1 to 4-4). As the power input is increased the center of rotation of this cell moves toward the upper right-hand corner of the cavity ("hot" wall), thus, causing the creation of a tertiary cell (clockwise motion) in the upper left-hand corner of the cavity (Fig. 4-4). (ii) It is observed that, for a given power input, an increase in the cavity width results in a much stronger horizontal movement of the fluid in a larger lower portion of the cavity (please see the photographs for $Q=2$ watts, and cavity width of 13.5, 27 and 45 mm). The combined effects of increasing power input and cavity width are : (i) a transition from a fairly inactive core to one where secondary and tertiary cells are created at

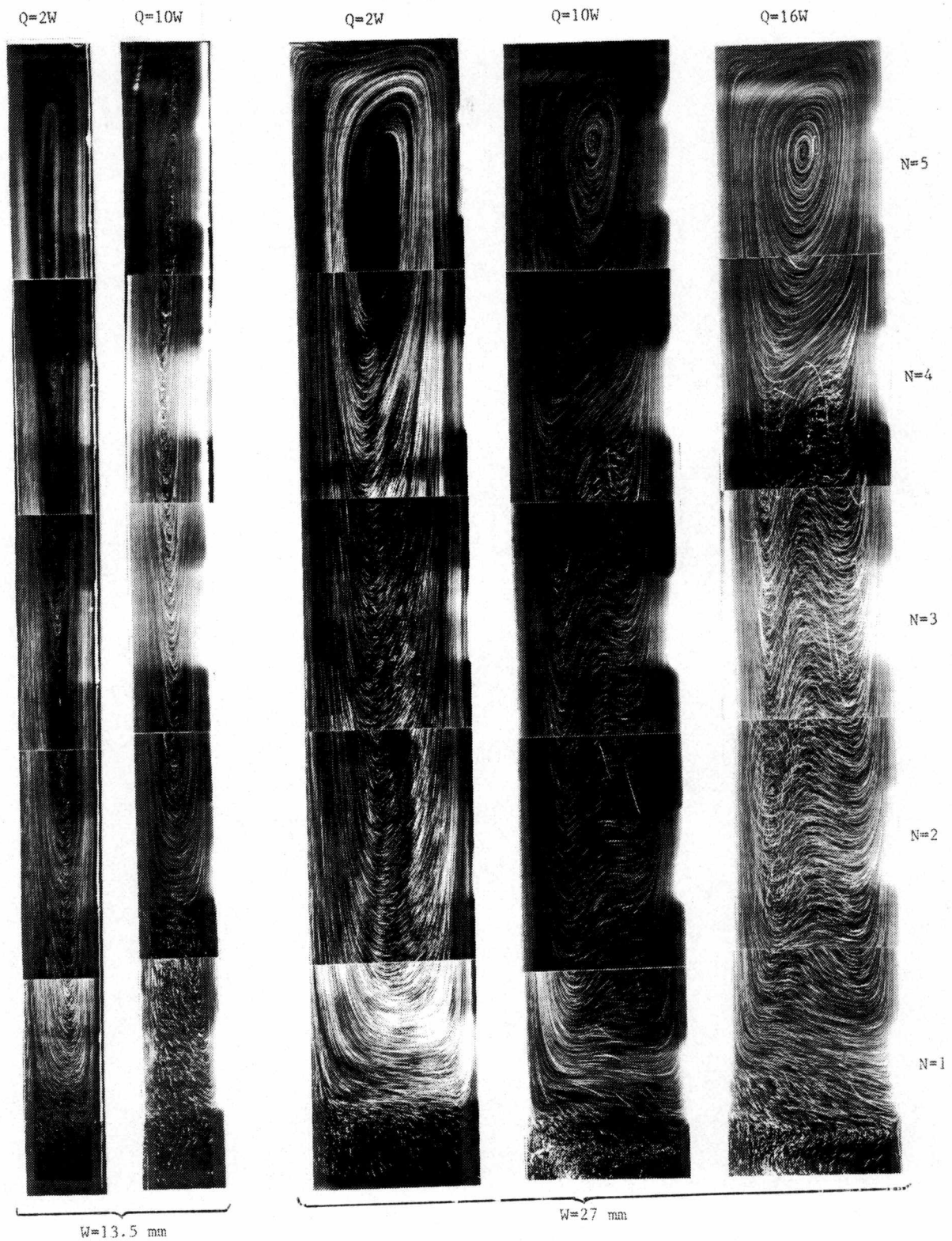


Fig. 4-1 Streak photographs for the entire cavity, (a) $W = 13.5$ mm, (b) $W = 27$ mm.

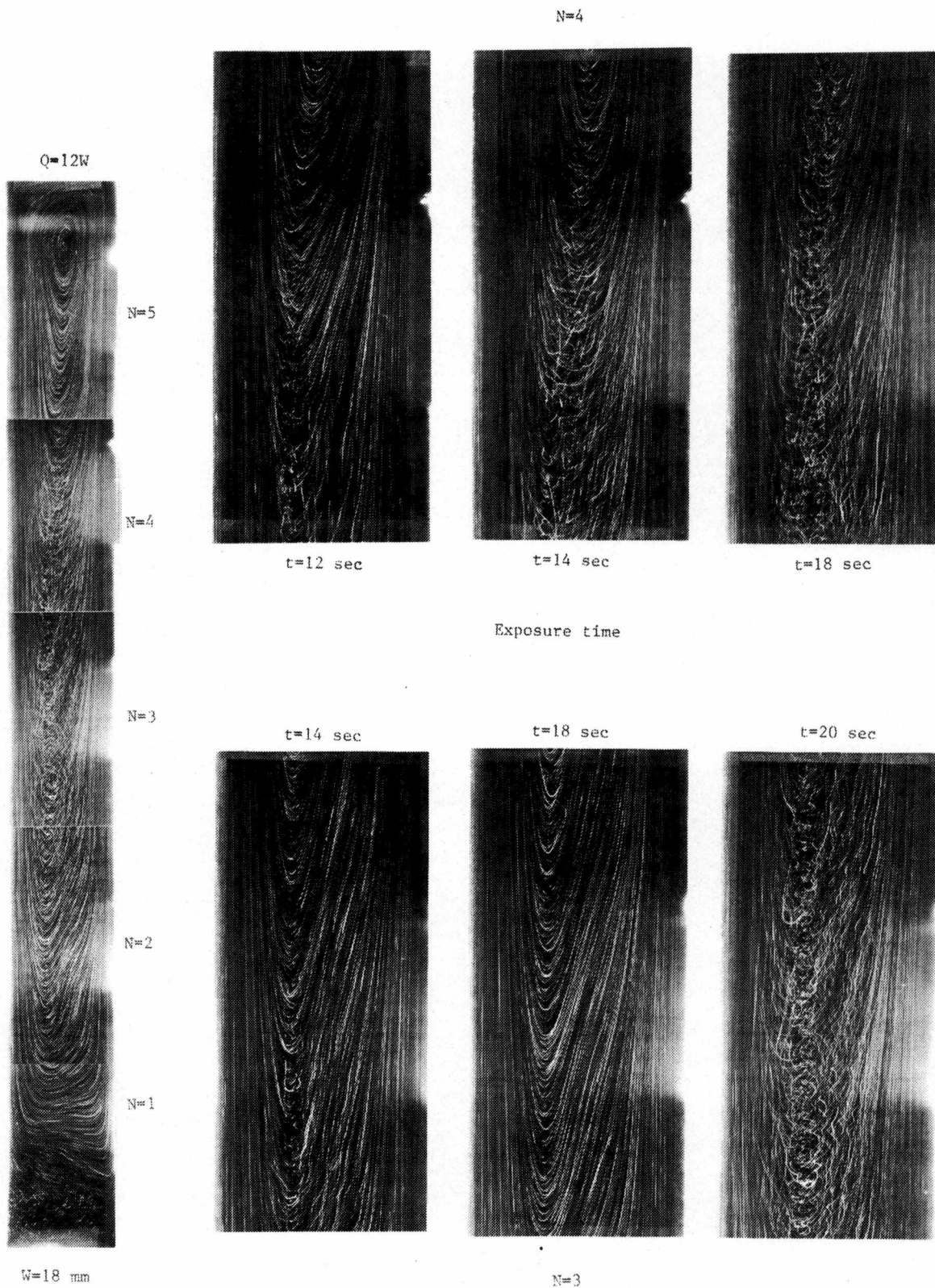


Fig. 4-2 Streak photographs of the time dependent core flow at heaters 3 and 4 for $W = 18$ mm and $Q = 12$ Watts.

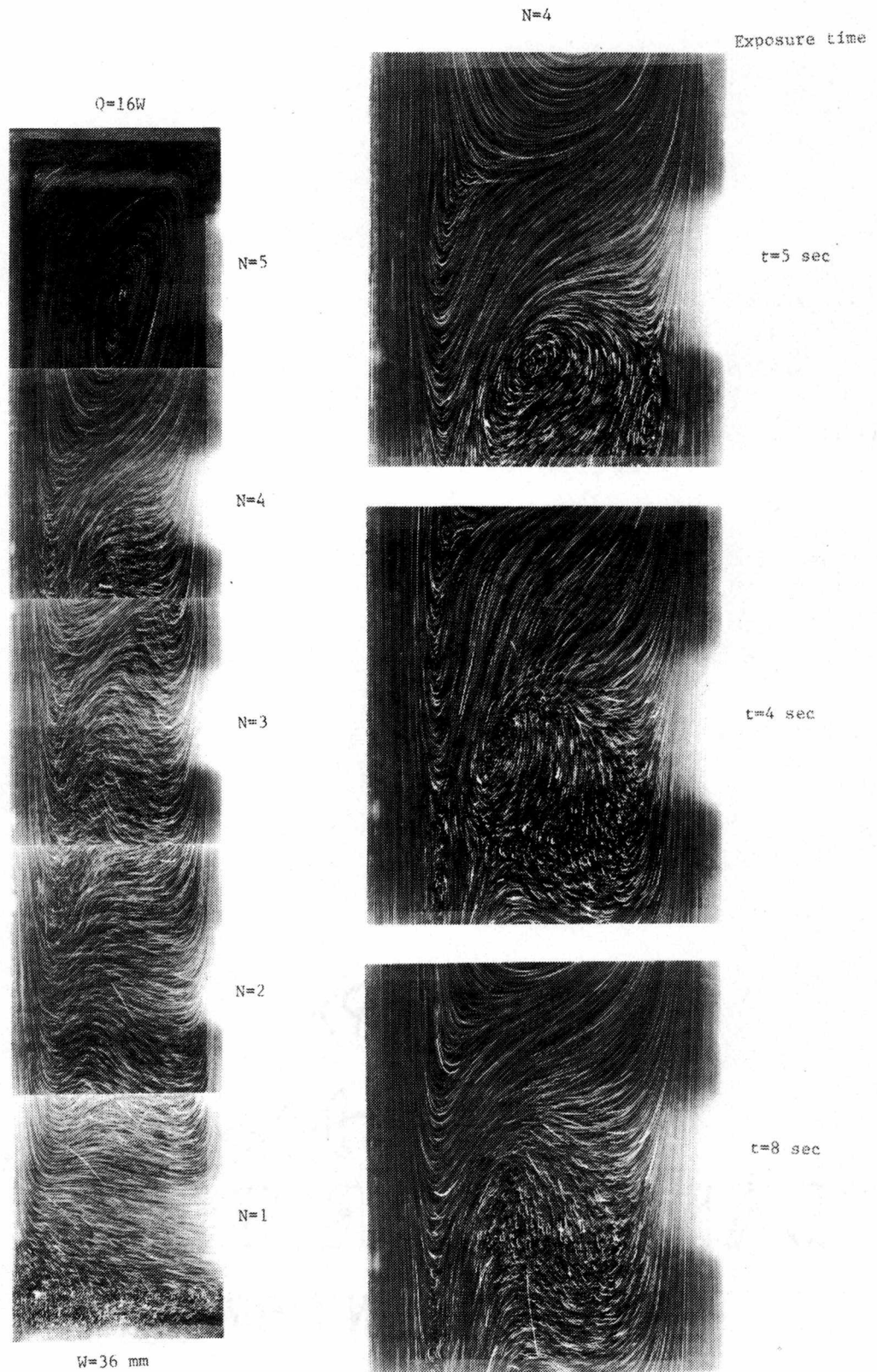


Fig. 4-3 Streak photographs of the time dependent core flow below heater 5 ($N = 4$) for $W = 36$ mm and $Q = 16$ Watts.

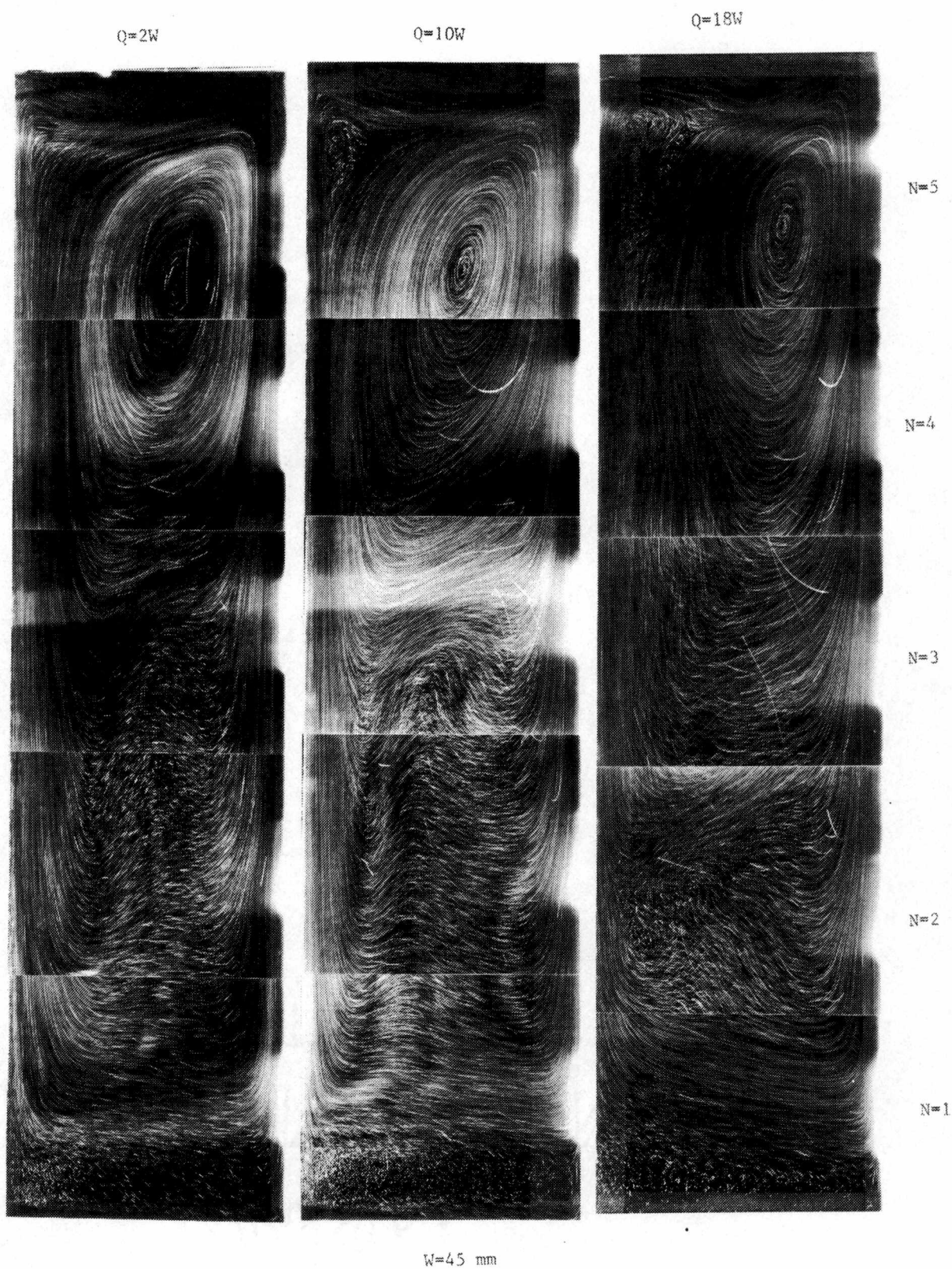


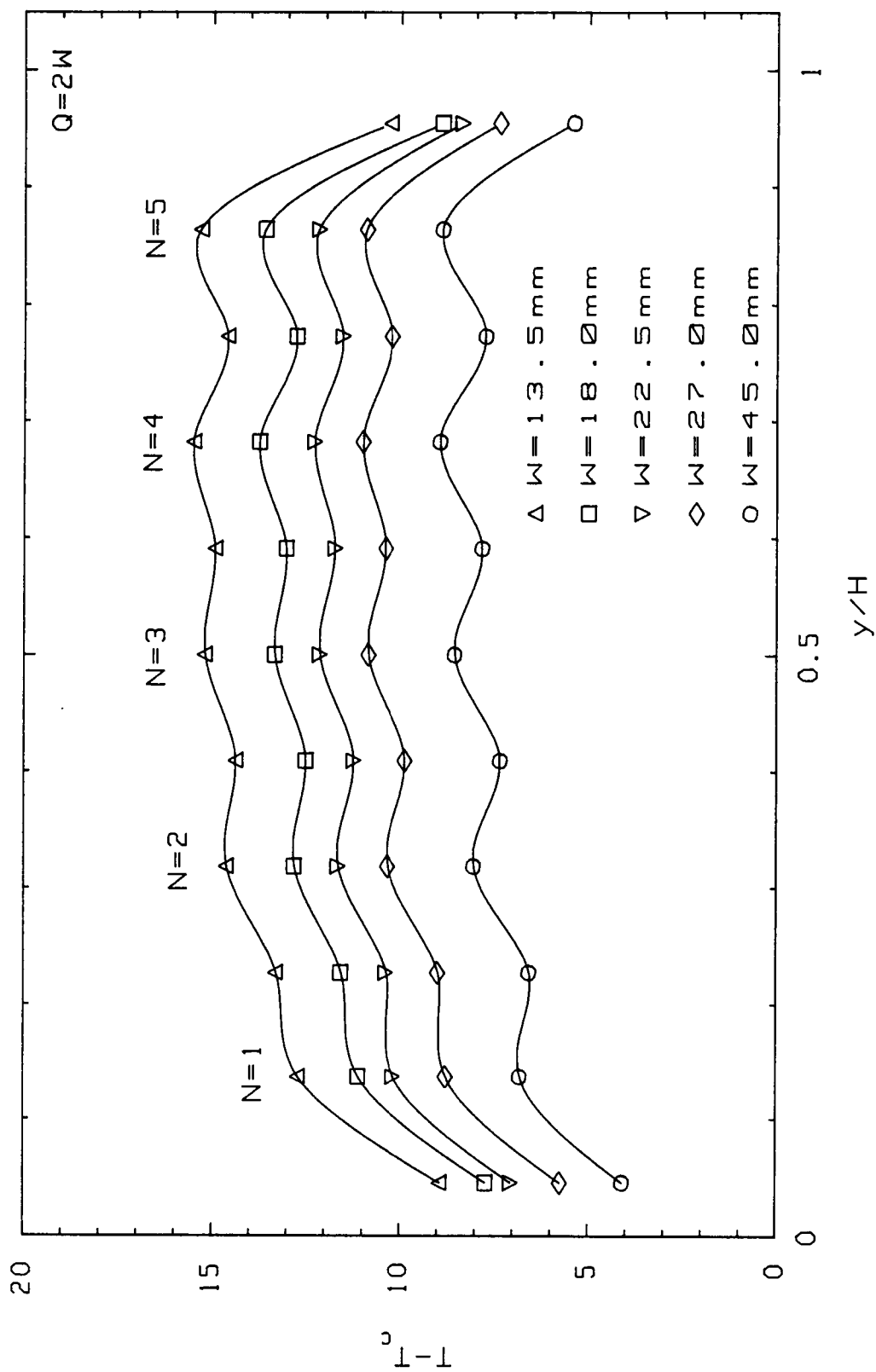
Fig. 4-4 Streak photographs for the entire cavity for $W = 45$ mm.

the top of the cavity; and (ii) development of a time dependent core flow (below the secondary and tertiary cells), with increasing horizontal velocities toward the "hot" wall.

Sample photographs of the time dependent core flow are shown in Figs. 4-2 and 4-3. Figure 4-2 shows the core flow adjacent to heaters 3 and 4 for the case of 12 watts per heater and cavity width of 18 mm. The time sequence of the close-up photographs taken is from left to right in the figure. Figure 4-3 shows the core flow adjacent to heater 4 for the case of 16 watts per heater and cavity width of 36 mm. The time sequence of the close-up photographs shown in this figure is from top to bottom. The exposure time of each photograph is noted in the figures. Sporadic extension and subsequent shrinkage of the secondary flow cell adjacent to heater 5 into the region of heater 4 can be seen in Fig. 4-2. The photographs of the core flow adjacent to heater 3 ($N = 3$) indicate a sporadic formation and subsequent vanishing of a secondary flow cell in this region. At a higher power input and a larger cavity width, one can observe sporadic formation and subsequent vanishing of a tertiary flow cell below the top secondary cell next to heater 4 (Fig.4-3).

TEMPERATURE DISTRIBUTION

The temperature distributions ($T-T_c$) along the hot wall (unheated and heated sections) for various cavity widths and power inputs with ethylene glycol as the working fluid are presented in Figs. 4-5, 4-6, 4-7 and 4-8. The locations of the heated sections are indicated via the heater number (N) in the graphs. Figures 4-5



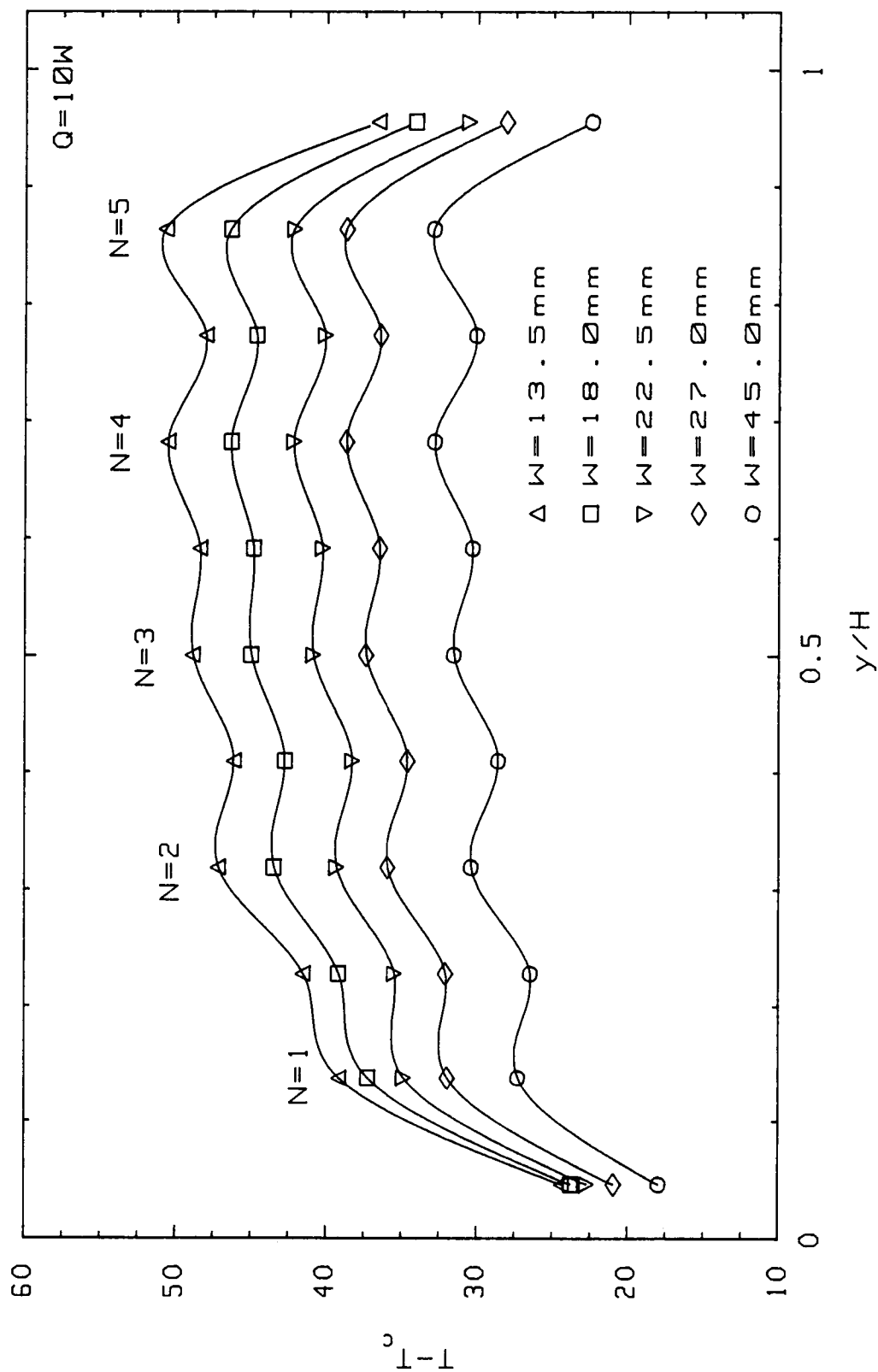


Fig. 4-6 Cavity width effect on the temperature profile along the "hot" wall, $Q = 10W$.

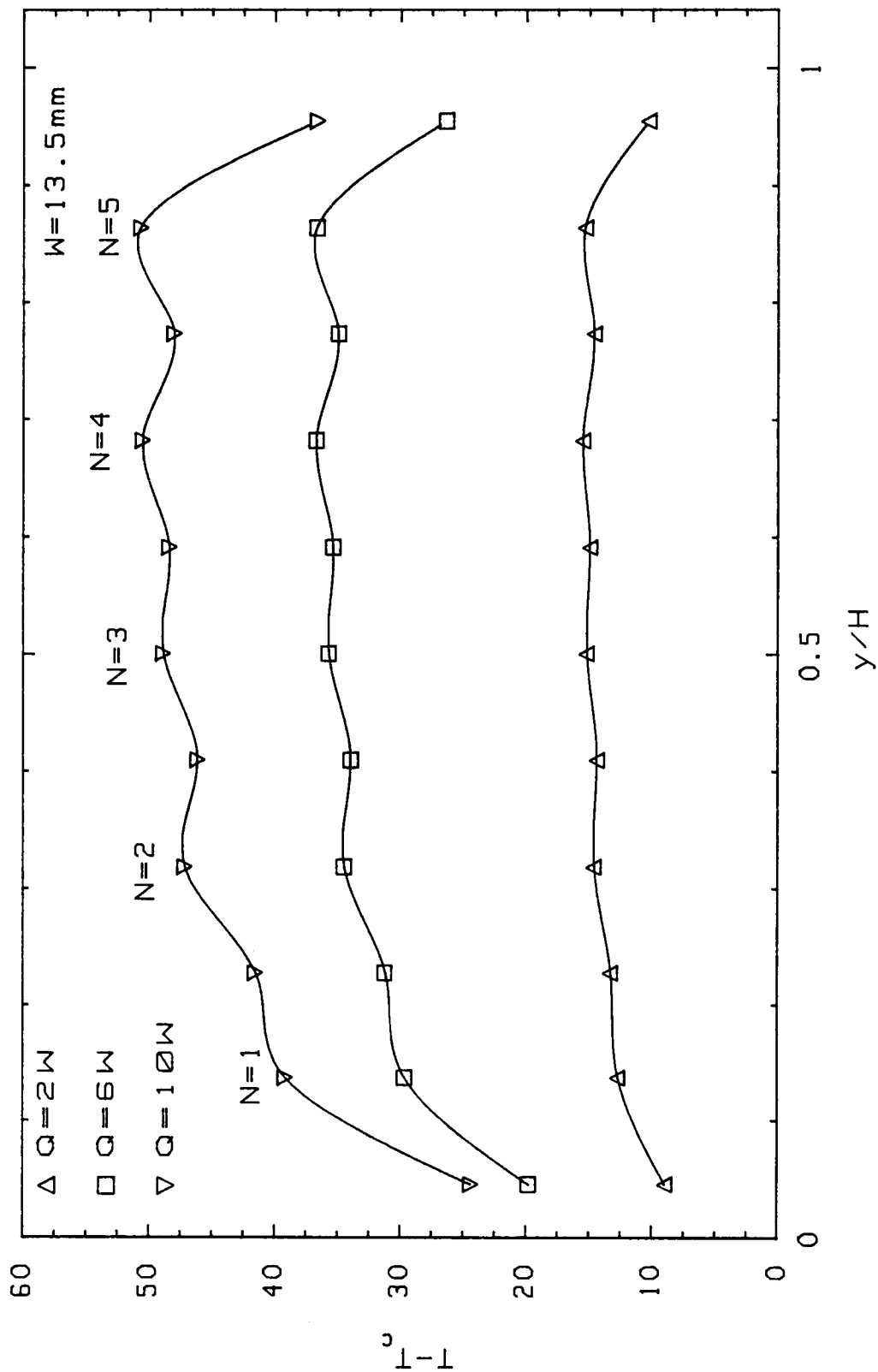


Fig. 4-7 Power input effect on the temperature profile along the "hot" wall, $W = 13.5$ mm.

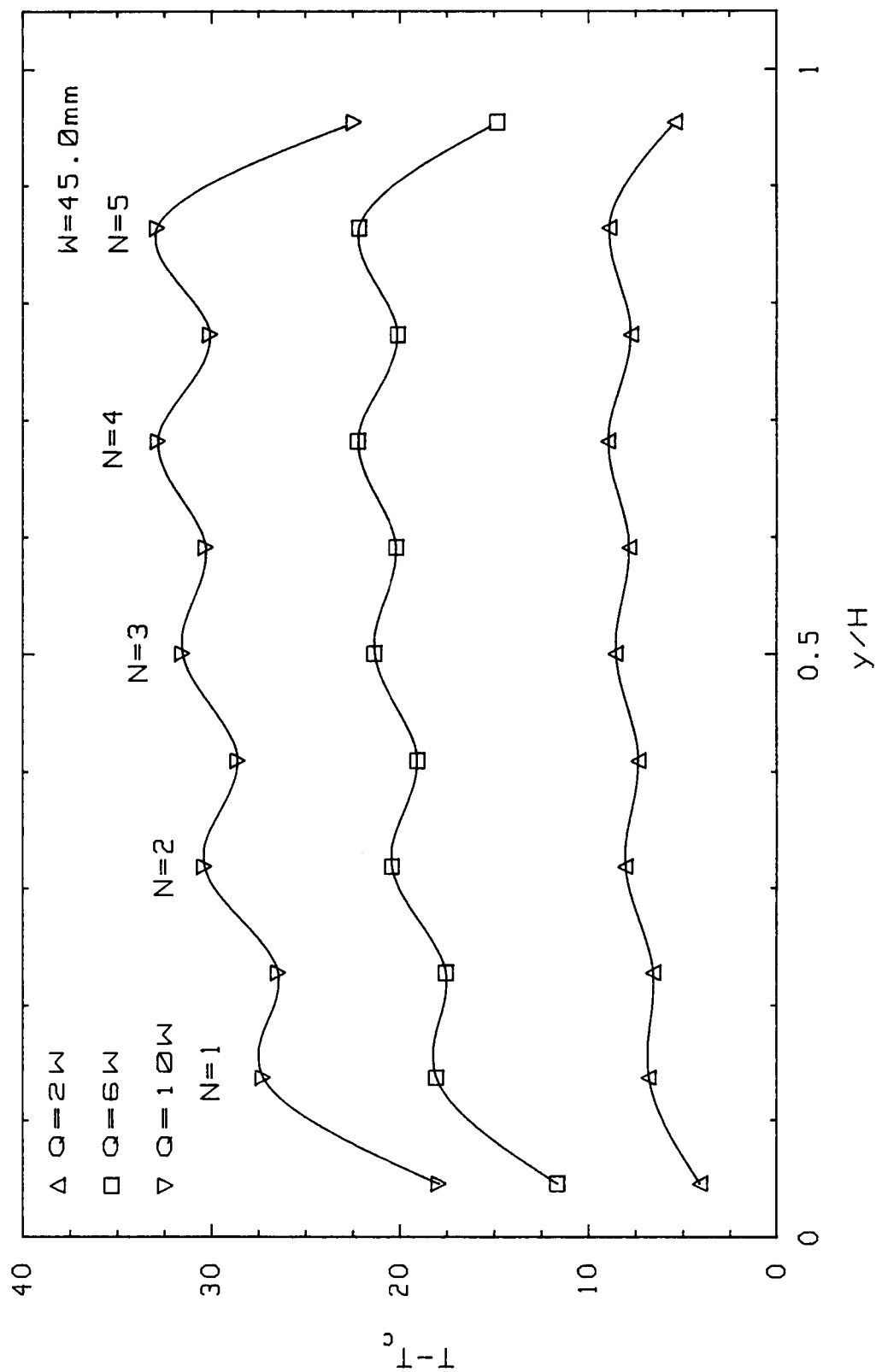


Fig. 4-8 Power input effect on the temperature profile along the "hot" wall, $W = 45.0$ mm.

and 4-6 show the effect of the variation in the cavity width on the temperature profile, while Figs. 4-7 and 4-8 demonstrate the dependence of the profile on the power input.

It should be emphasized that the magnitude of the $(T-T_c)$ of the unheated sections does not imply substantial rate of transfer of energy to the fluid from these regions. Indeed, the conduction solutions of the substrate show that the highest rate of convection heat transfer from the unheated regions occurs in the section with the lowest temperature. Thus, the highest substrate conduction corrections are applied to heaters 1 and 5, respectively.

The lowest temperature for the heated sections occurs at heater 1, while the highest value fluctuates between heaters 4 and 5. The difference between the temperature of the heaters 4 and 5, however, is less than 0.2 °C. Although there is a steady increase in the temperature of the heated sections from heater 1 to 4, the magnitude of the temperature rise is not substantial. The data suggest that the temperature of the heated sections, for each power input and cavity width, can be represented with an average value $\bar{T}_h \pm 5$ percent. Based on the temperature difference, the data can be approximated with an average value $(\bar{T}_h - T_c) \pm 18$ percent. The variation of the maximum temperature difference from the average value, however, is less than 8 percent. A rather small difference between the maximum observed temperature and the average value can have important practical applications in design and analysis of cooling problems with multiple heated sections.

The sensitivity of the "hot" wall temperature distribution to variation in the power input for a fixed cavity width is also illustrated in Figs. 4-7 and 4-8. For $W = 13.5$ mm, the maximum rises in $T_h - T_c$ above those of heater 1 for $Q = 2$ and 10 watts are 22% and 29.5%, respectively. Therefore, the rate of rise in the temperature of the heated sections increases with power input. A reverse trend is observed for $W = 45$ mm. At this cavity width, the maximum rises in $T_h - T_c$ above those of heater 1 for $Q = 2$ and 10 watts are 31.5% and 20.6%, respectively. It should be noted that the maximum rise in the $T_h - T_c$ above that of heater 1 is nearly constant for $W = 18$ mm (23.8% at $Q=2$ watts and 24.5% at $Q=10$ watts). Thus, the reversal in the trend begins with $W = 22.5$ mm. As discussed earlier a simultaneous increase in the power input and cavity width results in a more active core flow as well as formation of a tertiary cell at the top of the cavity. Thus, for $W = 45$ mm and $Q = 10$ watts one observes a relatively smaller rise in the temperature of the heated sections above that of heater 1.

The temperature profiles at $x/W = 0.167, 0.186, 0.583$ and 1 (the "hot" wall) are presented in Figs. 4-9 and 4-10 for a power input of 12 watts per heater and cavity widths of 18 and 36 mm. For both cavity widths, the fluid temperature, with the exception of the end regions, is nearly constant. Excluding the end regions, the fluid temperature $T - T_c$ for $W = 18$ mm and 36 mm can be approximated as 32.58 ± 0.5 °C and 23.36 ± 0.5 °C, respectively. A measure of comparison of the core flow

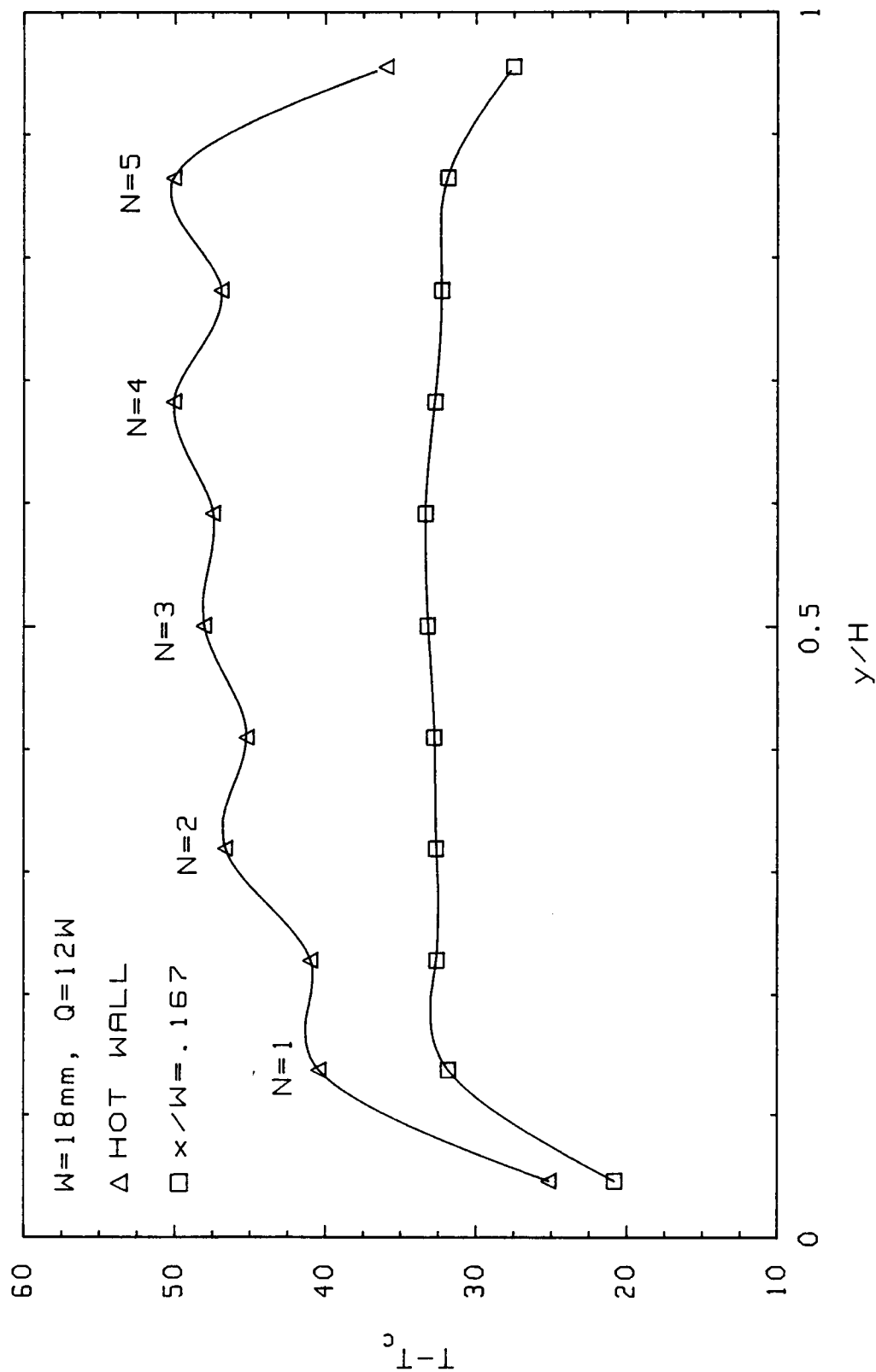


Fig. 4-9 Core flow temperature distribution, W=18 mm and Q=12 watts.

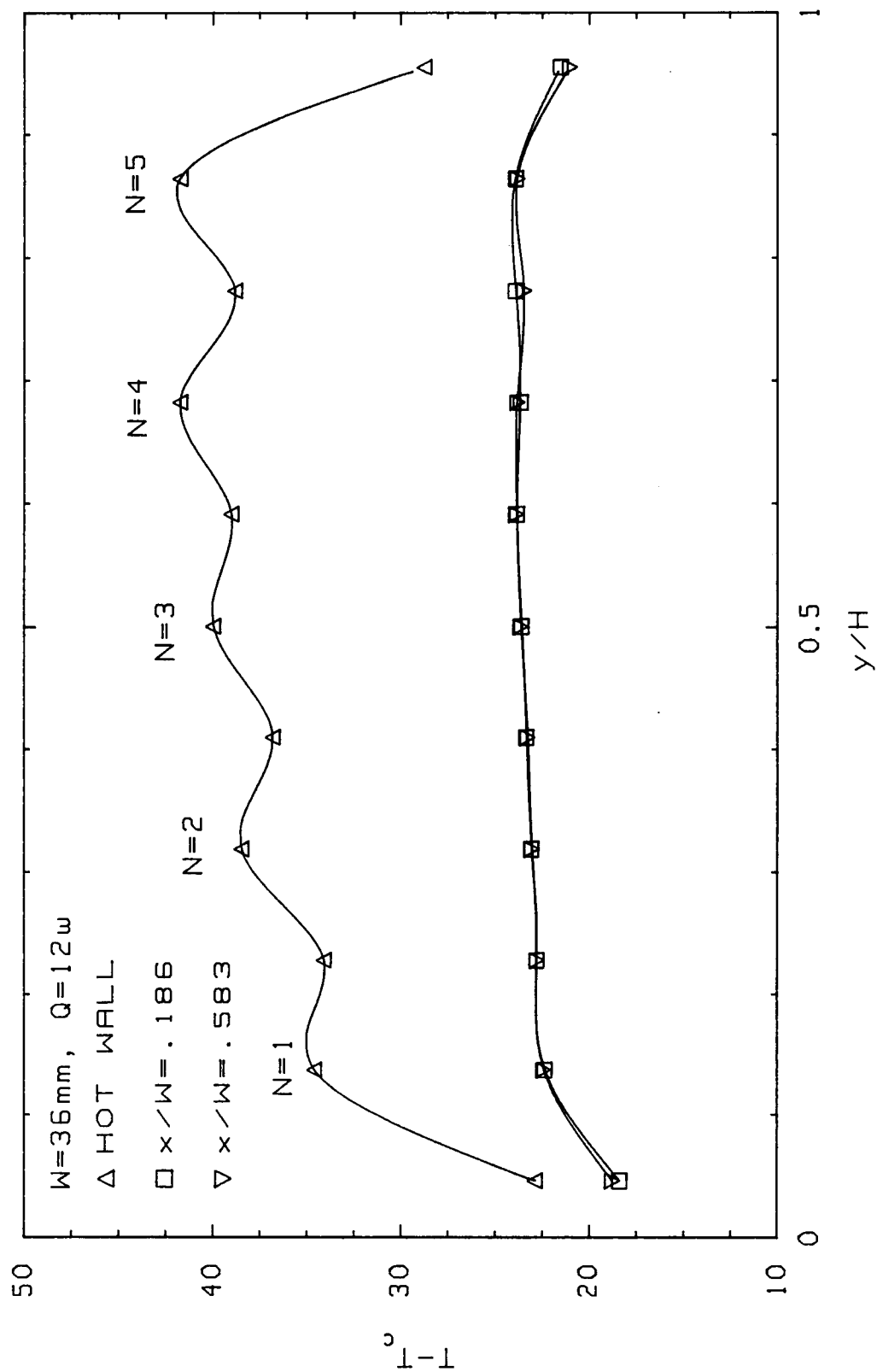


Fig. 4-10 Core flow temperature distribution, $W=36$ mm and $Q=12$ watts.

at these two cavity widths is the ratio of the average core-fluid temperature to that of the heated sections. The ratios of the average core-fluid temperature (excluding the end regions) to that of the heated sections for $W = 18$ mm and 36 mm are 0.69 and 0.594, respectively. The higher cavity width has resulted in a relatively "cooler" core-fluid temperature. It may be noted that the fluid temperature distributions at $x/W = 0.186$ and 0.583 (Fig. 4-10) are nearly identical. This behavior is attributed to the insulated boundary condition at $x=0$.

The temperature distributions along the "hot" wall with FC-75 as the working fluid for $W = 18$ mm and power inputs of 2 and 4 watts per heater are shown in Fig. 4-11. It should be mentioned that the thermophysical properties group of $(g\beta)/(\alpha\nu)$ for FC-75 at 25 °C is 105 times larger than that of ethylene glycol. Thus, the FC-75 temperature profiles shown in Fig. 4-11 are for substantially higher Rayleigh numbers than those given in Figs. 4-5 and 4-6 for glycol. The general trend of the temperature variation for FC-75 is similar to that discussed for glycol data. The heated section temperatures can be represented with an average value $\bar{T}_h \pm 12$ percent (7% higher deviation than the glycol data). However, the deviation of the maximum temperature from the average value is only 5.2%. Based on the temperature difference, the data can be approximated with an average value $(\bar{T}_h - T_c) \pm 29\%$ (11% higher deviation than the glycol data). The maximum rises in $T_h - T_c$ above those of heater 1 for $Q = 2$ and 4 watts are 60% and 51%, respectively.

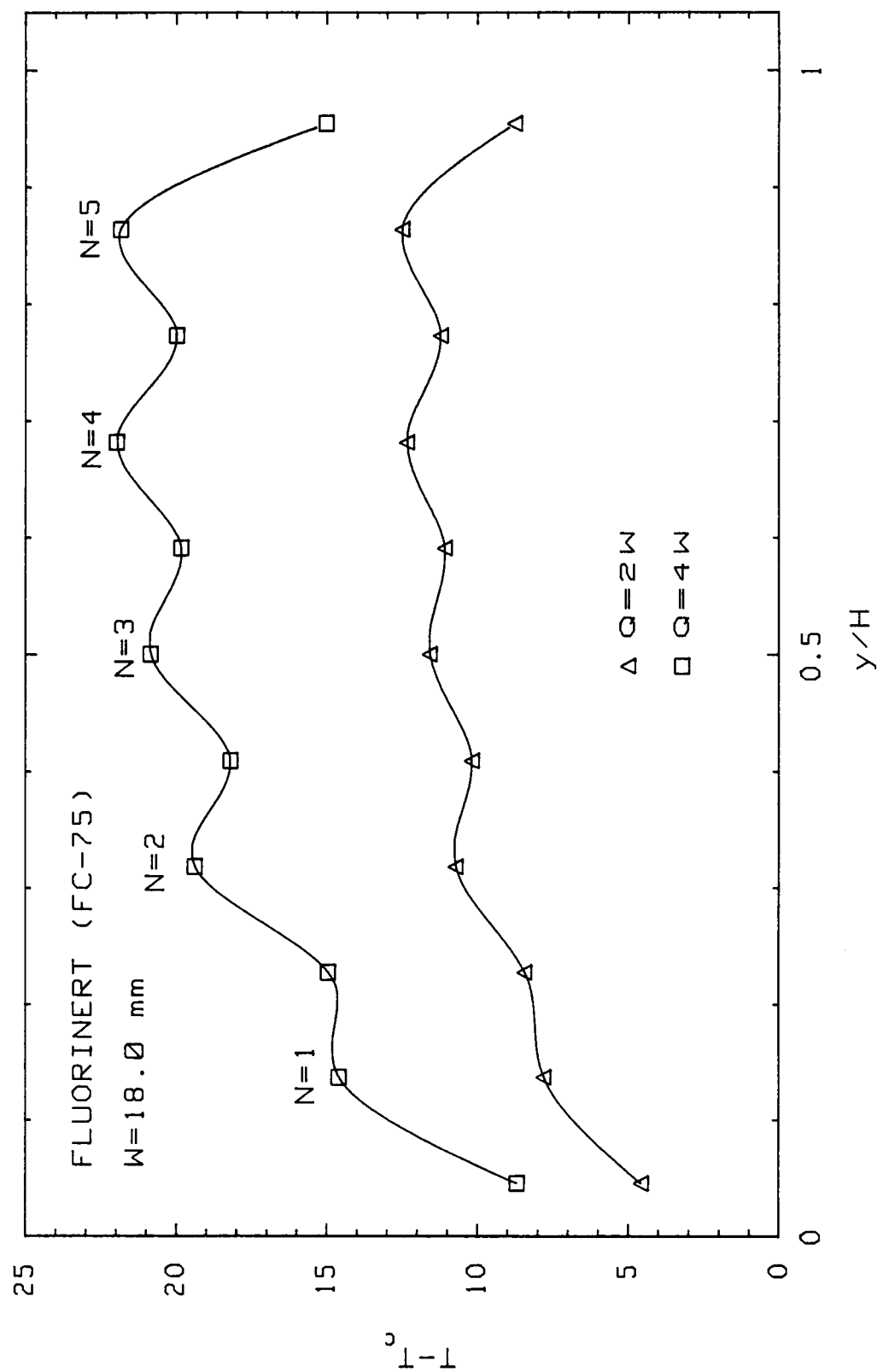


Fig. 4-11 Temperature profile along the "hot" wall with FC-75 as the working fluid.

HEAT TRANSFER

The Nusselt numbers Nu_{L1} for heaters 1 to 5 for cavity widths of 13.5 and 45 mm are presented in Figs. 4-12 and 4-13. As can be seen from both figures, heater 1 has the highest heat transfer coefficient, while heater 5 has the lowest. For the case when $W = 13.5$ mm (Fig. 4-12), the difference between the Nusselt numbers of heaters 1 and 2 is rather small at low Ra_{L1}^* values and increases with Ra_{L1}^* . A reverse trend is observed in Figure 4-13 for $W = 45$ mm. This behavior is due to the changes in the flow patterns caused by variations in the power input and cavity width (discussed earlier).

The presentation of the Nusselt numbers in terms of Nu_{L1} for all of the heated sections and cavity widths would require several graphs and thirty correlations. Chen et al. [4] have shown that the choice of length scale of local height y substantially simplifies the task of the presentation and discussion of the results. The present data based on the length scale of y are presented in Fig. 4-14. It is interesting to note that for each cavity width, the plot of the $\log_e(Nu_y)$ versus $\log_e(Ra_y^*)$ for all the heated sections forms a straight line. Moreover, the data for each cavity width has been correlated with a standard deviation of less than 0.83. It is obvious that the task of analysis of cooling problems is substantially simplified when one can unify the data via local height scaling. The local Nusselt number of the heated sections Nu_y for each cavity width is correlated in terms of its respective local modified Rayleigh number

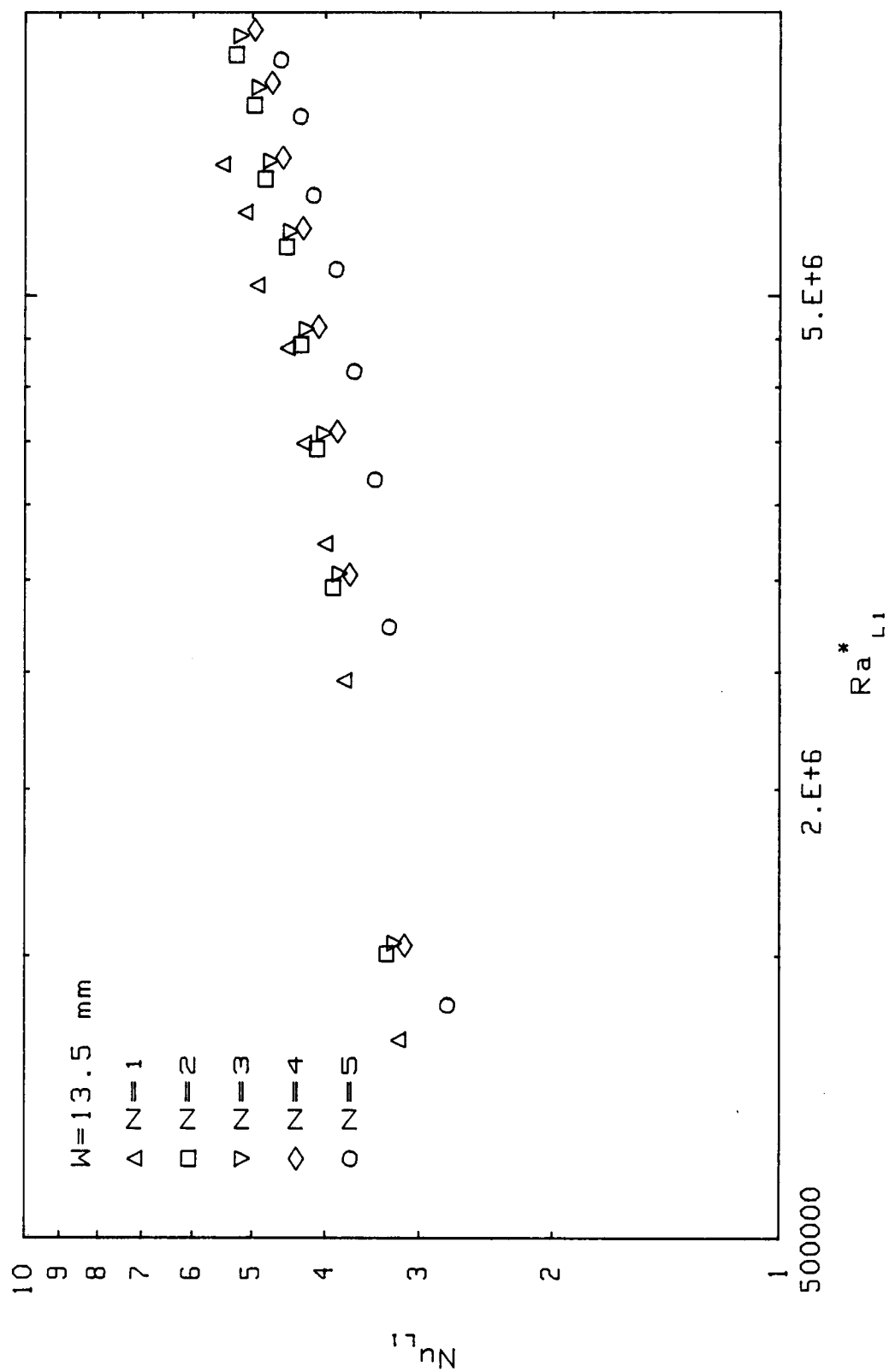


Fig. 4-12 Heated section Nusselt numbers (Nu_{L1}) as a function of Ra_{L1}^* for $W=13.5$ mm.

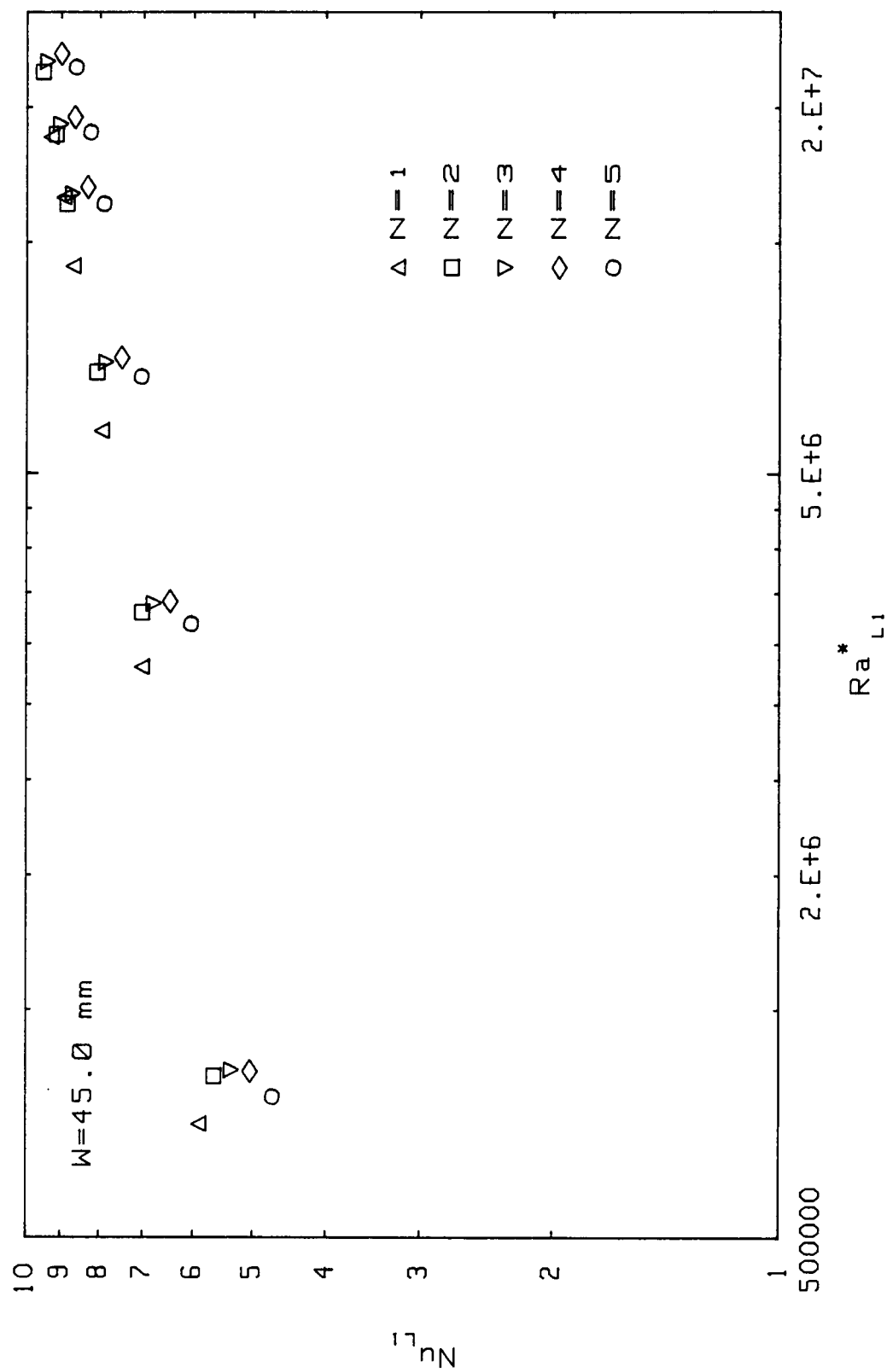


Fig. 4-13 Heated section Nusselt number (Nu_{L1}) as a function of Ra_{L1}^* for $W = 45.0$ mm.

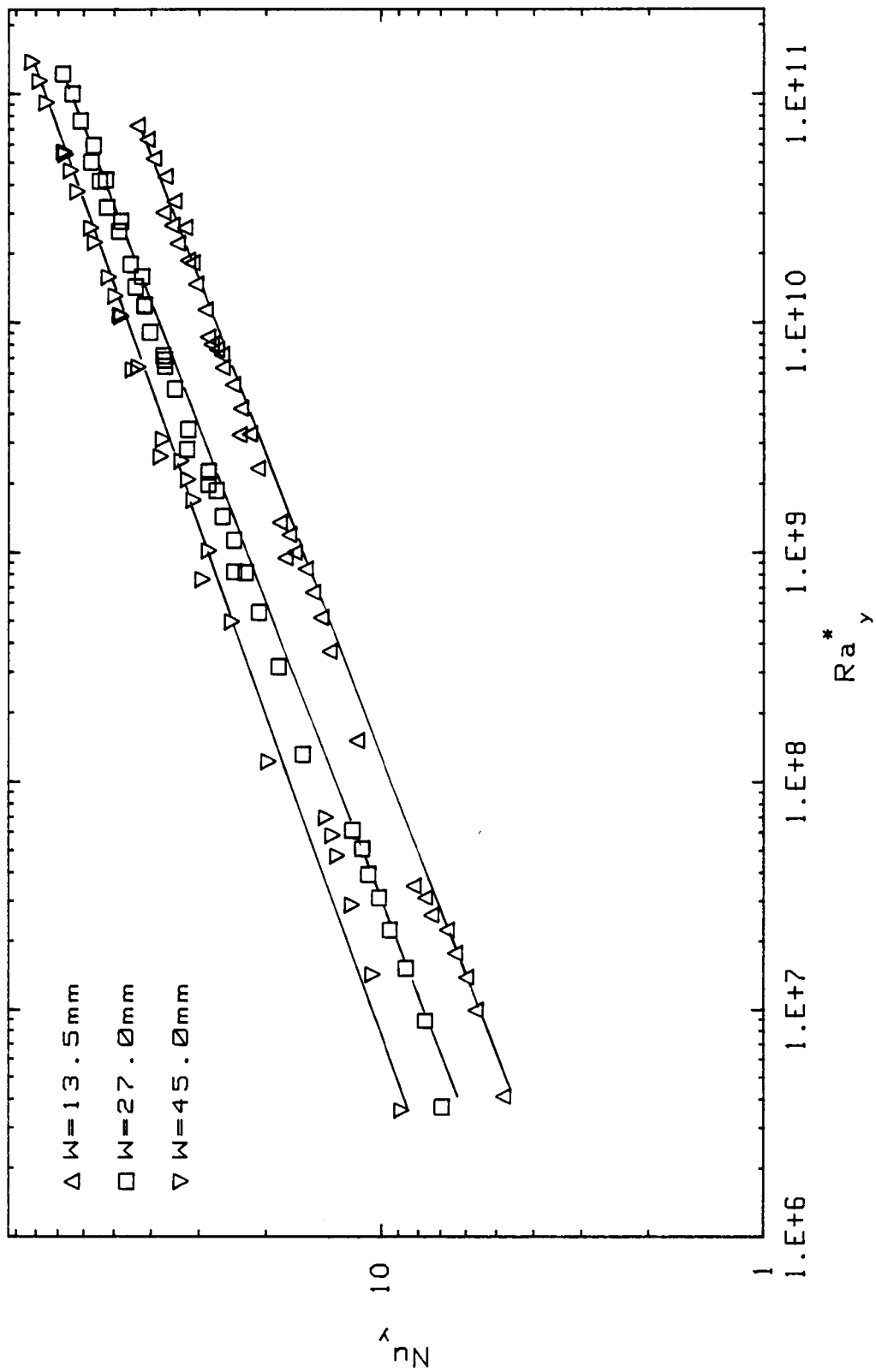


Fig. 4-14 Local Nusselt number (Nu_y) as a function of modified Rayleigh number (Ra_y^*), ethylene glycol.

Ra_y^* in the form of

$$Nu_y = C(Ra_y^*)^m \quad (8)$$

and the constants C , exponents m , and the standard errors are tabulated in Table C-12 (appendix C). These correlations are indicated in figures 4-14 and 4-15 by the solid lines. They represent the data with an average deviation of less than 4.6 percent.

All the experimental data collected with ethylene glycol and FC-75 for the six cavity widths can be correlated into the following general equation :

$$Nu_y = 0.437(A)^{-0.416} Ra_y^{*0.227} \quad , \quad 3.67 < A < 12.22 \quad (9)$$

Equation (9) predicts the experimental data with an average deviation of 4.6 percent.

The effect of increasing the cavity width on the heat transfer coefficient can clearly be seen in Fig. 4-14. As expected, the increase in W , i. e., heat sink surface, results in higher heat transfer coefficients for all the heaters. The data indicates that at $Ra_y^* = 10^9$ an increase in W from 13.5 to 45 mm results in a 66% higher heat transfer coefficient. The ethylene glycol and FC-75 data for $W = 18$ mm are presented in a separate plot in Fig. 4-15. A single correlation as given in Table C-12 (appendix C) represents the two fluid data with an average deviation of 4.6 percent. This agreement obviously indicates a negligible Prandtl number effect for the range covered ($23 < Pr < 124$). Keyhani et al. [14] conducted experimental and numerical studies of natural convection in a vertical cavity with an isothermal vertical wall and three flush-mounted heated sections on the opposing vertical wall. Based on the

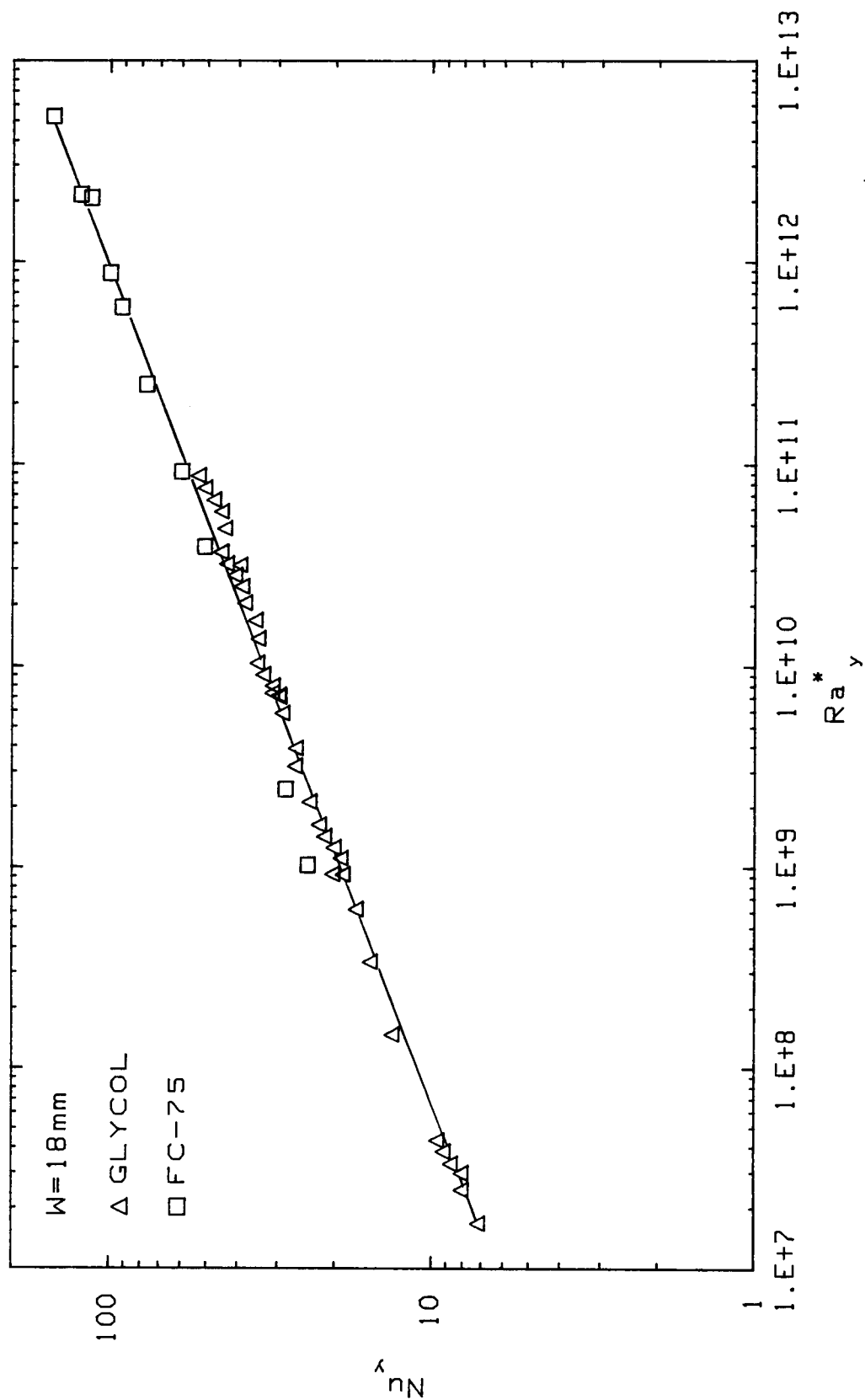


Fig. 4-15 Local Nusselt number (Nu_y) as a function of modified Rayleigh number (Ra_y^*), ethylene glycol and FC-75.

numerical results, they reported that although the flow structure varies significantly when the Prandtl number is reduced from 25 to 1, the variations are negligible when Pr is increased from 25 to 166.

The total energy convected from the heated and unheated sections is transferred to the top sink surface. The heat transfer coefficient h_T at the top surface as defined by equation (6) is plotted against the total convective heat flux at the top surface q_T in Fig. 4-16. This figure shows that h_T increases with decreasing cavity width. It should be noted that for a given power input the highest fluid velocity was observed at the smallest cavity width during the flow visualization experiments. Liu et al. [18] reported a similar finding in their numerical study dealing with convection cooling of heated protrusions in a cavity. The FC-75 data for $W = 18$ mm are even higher than the glycol data for $W=13.5$ mm. This is due to the fact that the corresponding $Ra_{W,T}^*$ for the FC-75 data are more than 300 times larger than those for glycol data. The non-dimensional ($Nu_{W,T} = h_T W/k$ versus $Ra_{W,T}^* = (g\beta/\alpha\nu)W^3(q_T W/k)$) version of the data in Fig. 4-16 are presented in Fig. 14-17. It appears that the data for all the cavity widths converge into a single line at low $Ra_{W,T}^*$ values. It is evident that for all cavity widths as the $Ra_{W,T}^*$ is decreased a change in flow regime is taking place. This may be an indication of transition to a conduction dominated flow regime. For a given fluid, the data at low $Ra_{W,T}^*$ suggests

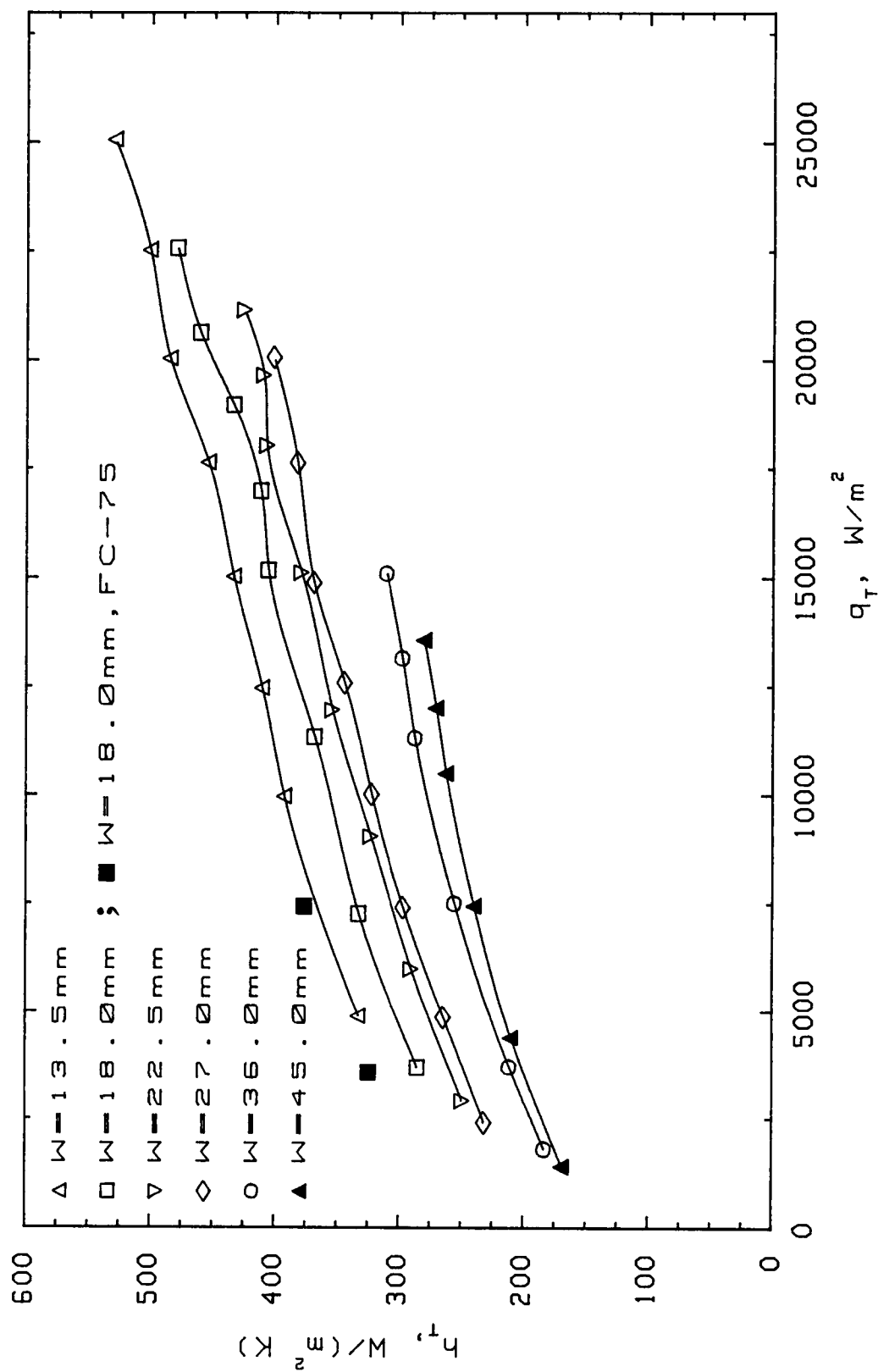


Fig. 4-16 Heat transfer coefficient (based on the top heat sink surface) as a function of the heat flux at the top surface.

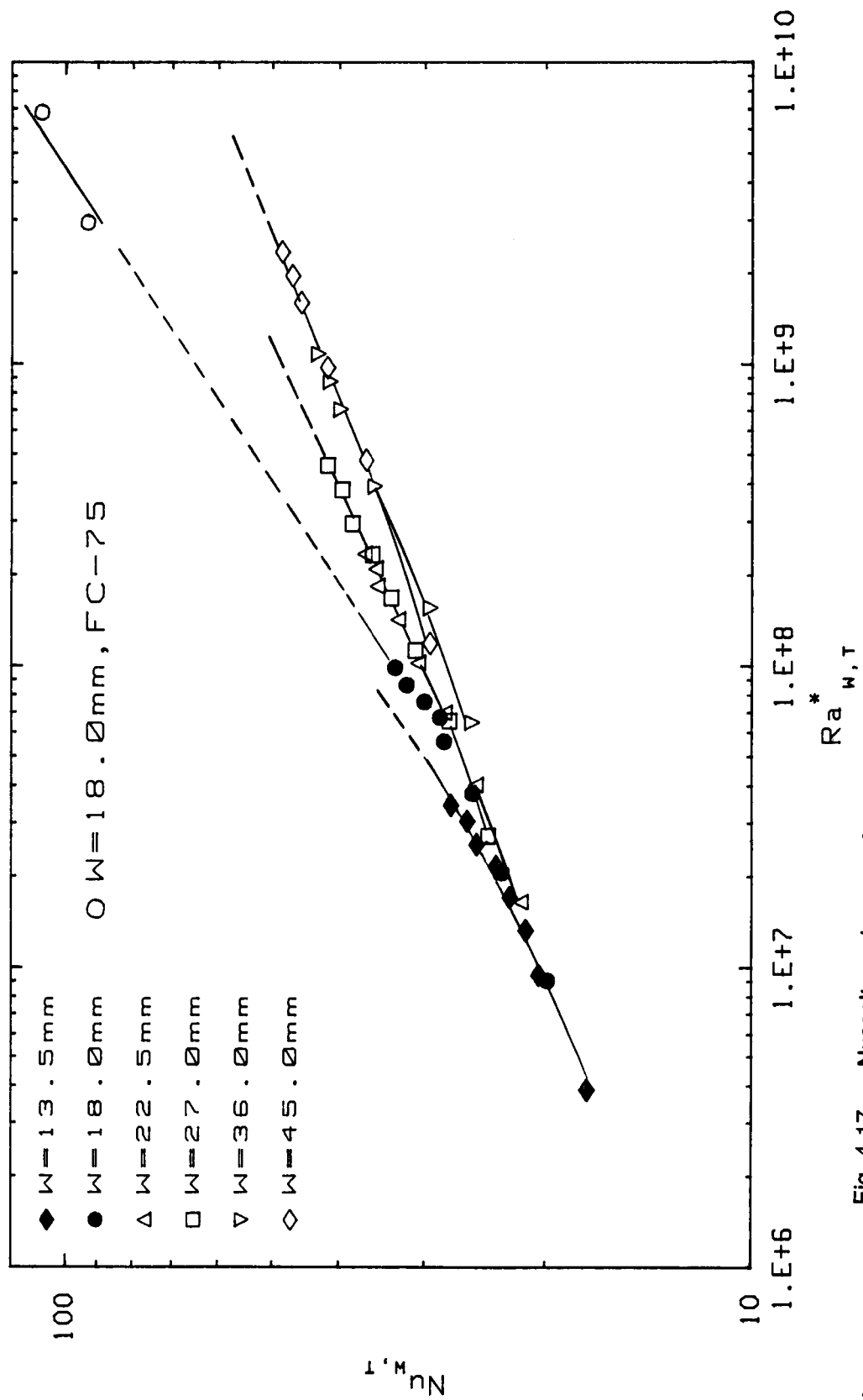


Fig. 4-17 Nusselt number as a function of modified Rayleigh number (based on the top heat sink surface).

that for a fixed modified Rayleigh number one obtains the same value for $h_T W$ product for the present range of aspect ratios. Thus, a decrease in W is off-set by a corresponding increase in h_T . However, as the $Ra_{W,T}^*$ is increased the data for each W diverge. The slope of $\log_e(Nu_{W,T})$ versus $\log_e(Ra_{W,T}^*)$ on the plot increases with decreasing W . At high $Ra_{W,T}^*$ the data indicate that for a given fluid and $Ra_{W,T}^*$ a decrease in W results in higher value for $h_T W$ product. Thus a decrease in W is compensated for via a proportionately higher increase in the h_T . Unfortunately, sufficient data are not available at either end of the $Ra_{W,T}^*$ range in order to report any correlations.

Figure 4-18 demonstrates the effect of increasing the cavity width on the average temperature of the heaters (recall $Q_T = h_T W D [T_h - T_c]$). Note that for a fixed power input a decrease in the cavity width results in a decrease in the " $h_T W$ " product, hence, the average temperature of the heaters increase. For an actual power input of 10 watts per heater a decrease in the cavity width from 45 to 27 mm results in a 17% increases in the temperature difference between the average temperature of the heaters and the temperature of the sink; a further decrease in the cavity width to 13.5 mm results in a additional 31% increase in the average temperature of the heaters.

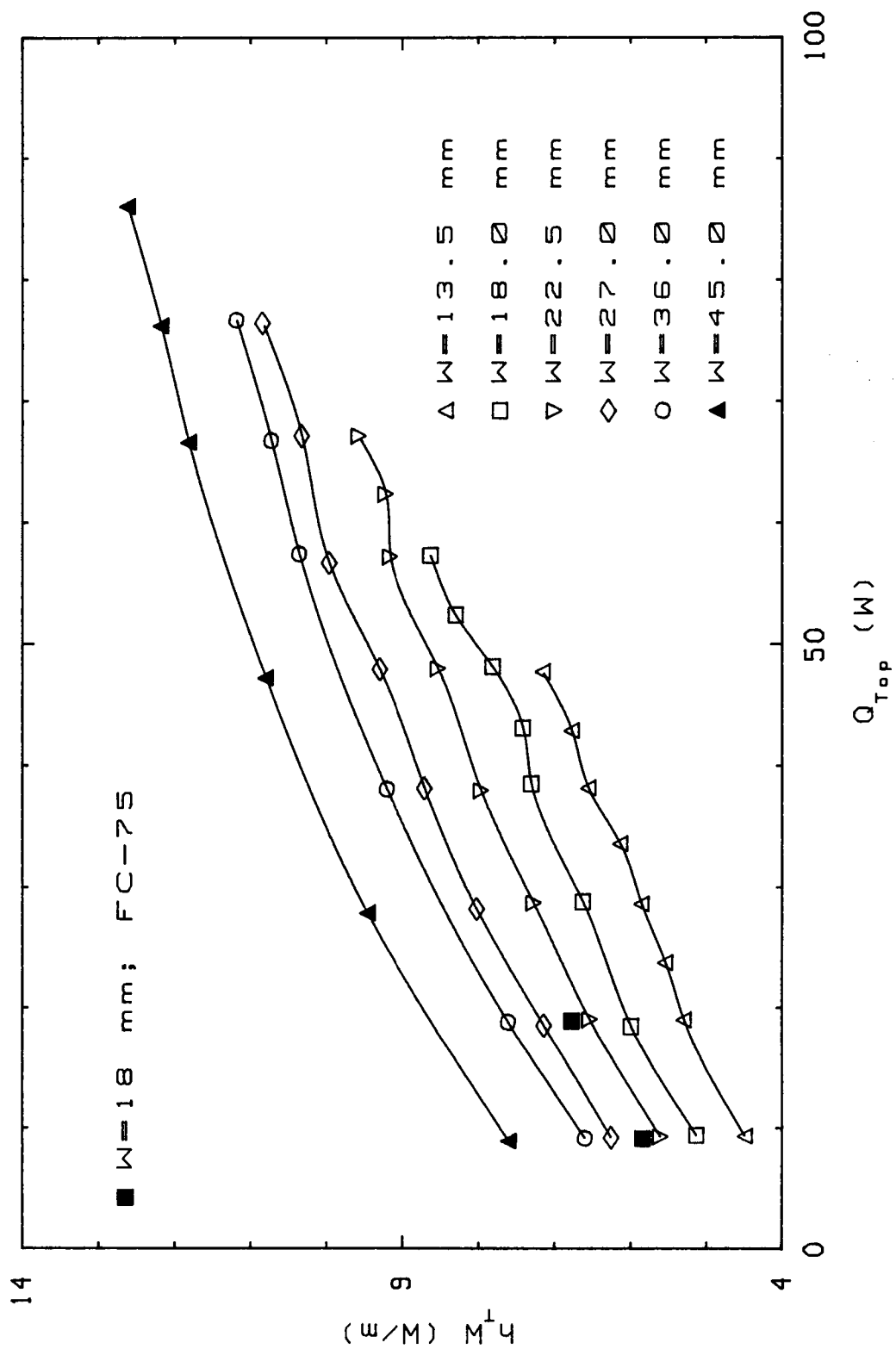


Fig. 4-18 Heat transfer coefficient at the top sink surface (h_T) times the cavity width as a function of the total heat dissipated to the top surface.

UNCERTAINTY ANALYSIS

The thermocouple outputs were measured to $\pm 0.1 \mu\text{V}$ which rendered a sensitivity of 0.0025°C . A reasonable limit of the accuracy of the temperature measurement is $\pm 0.15^\circ\text{C}$. This limit contains errors associated with reference junction compensation ($\pm 0.01^\circ\text{C}$), temperature difference along terminals, thermal offset, voltage to temperature conversion error, and DVM accuracy. Measurements of the voltage input to each heater circuit were done with a sensitivity of 1mV and an accuracy of 0.1 percent. The input voltage and current to each circuit were measured for each run to verify the experimental stability of each circuit resistance. A maximum uncertainty of ± 2.0 percent was obtained when comparing the original resistance accurately measured before the experiments with the calculated average experimental resistance. The uncertainty associated with the length scale for the enclosure width was $\pm 0.25\text{ mm}$. The thermophysical properties of ethylene glycol and fluorinert (FC-75) were assigned an uncertainty of ± 2 percent. This judgment was based on the observed variations in the reported values in the literature for glycol. It should be noted that the manufacturer of the FC-75 does not report any uncertainty for the thermophysical properties of this fluid.

The uncertainty in the Nusselt and modified Rayleigh numbers has been found to be strongly dependent on the power input. Low power input results in higher uncertainties due to small temperature differences. As the power input is increased, the uncertainty in the experimental data is decreased. The estimated uncertainties in the Nusselt and modified Rayleigh numbers for glycol are 3.1 to 10.0 and 4.2 to 10.9

percent, respectively. Likewise, for fluorinert the corresponding percentages are 5.3 to 10.2 and 7.8 to 11.6.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Immersion cooling of discrete flush-mounted heaters placed in a vertical side wall of an enclosure cooled from the top caused the formation of a bicellular flow structure for aspect ratio (H/W) lower than 12.22 and power inputs lower than 10 watts per heater. The strong primary cell traveling along the vertical side walls of the cavity constituted the main mechanism for the transport of energy to the top sink surface while the secondary cell (rotating in the same sense as the primary cell) covered 2/5 of the top portion of the enclosure leaving a large lower region of considerable flow inactivity. For aspect ratios lower than 9.17 and power inputs higher than 11 watts per heater, a well structured core flow was transformed into a time dependent one with higher horizontal velocities toward the "hot" wall in a large lower portion of the cavity. Hence, heat transfer was enhanced for all the discrete heaters.

It was experimentally shown that variations in the Prandtl number from 23 to 124 have negligible effects on the Nusselt number. This corroborates the previous numerical predictions done by Keyhani et al. [14]. Hence, present findings reinforce the idea that experimental results obtained with ethylene glycol can be used to predict performance of a dielectric liquid ($Pr \approx 25$).

It was demonstrated that the local length scale "y" simplifies the task of analysis of the electronic cooling problem because all the experimental data (for both ethylene glycol and fluorinert) can be incorporated into a single correlation (equation (9)) in which an explicit relation for the aspect ratio effect on local Nusselt number is included. Since this equation covers a wide range of aspect ratios and is valid for the covered range of experimental Prandtl number, its use is recommended to satisfy the industrial need of determining local convective heat transfer coefficients. Users should be warned, however, that the applicability of equation (9) is restricted to the range of geometric parameters considered.

The modified Rayleigh number based on the heat flux at the top sink surface and the length scale of cavity width is an appropriate parameter for the determination of any change in the flow regime. Unfortunately, due to the maximum temperature limitations imposed on each strip heater, the present data set is not sufficient to present a complete description of flow regimes at either end of the $Ra_{W,T}^*$ range. The available data for all the cavity widths studied suggest that at $Ra_{W,T}^* < 2 \times 10^7$ a change in regime occurs which may well be the transition to a conduction dominated flow regime. The results indicate that for a given heat flux at the top, the highest heat transfer coefficient at this surface could be obtained with the lowest cavity width.

In order to present a complete picture of the different flow regimes, further research should be conducted with an experimental apparatus at least twice the size of the present test cell. With such a facility, one could cover experimentally the high end

region of $Ra_{w,T}^*$ without being encumbered by the need for high temperatures to achieve the fully turbulent regime. Additional research should be also performed on studying the effects of varying the heater protruding height in an enclosure with the same boundary conditions as the present problem.

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APPENDIXES

APPENDIX A

LIST OF SYMBOLS AND ABBREVIATIONS

NOMENCLATURE

A	aspect ratio, H/W
A_h	surface area of heater, m^2
A_T	surface area of top sink surface, m^2
C	isobaric specific heat, $J/kg\cdot K$
D	Depth of the enclosure in the z direction, m
g	acceleration due to gravity, m/s^2
h	local heat transfer coefficient $q/(T_h-T_c)$, $W/m^2\cdot K$
h_T	heat transfer coefficient at the top sink surface $q_T/(T_h-T_c)$, $W/m^2\cdot K$
H	height of the enclosure, m
k	thermal conductivity, $W/m\cdot K$
L_1	height of the heated section, m
L_2	height of the unheated section, m
N	heater row number (starting from the bottom)
Nu	Nusselt number, $h[\text{length scale}]/k$
$Nu_{W,T}$	Nusselt number
Pr	Prandtl number, ν/α
q	convective heat flux per heater section, $(Q-Q_l-Q_{sc})/A_h$, W/m^2
q_T	total convective heat flux to the sink surface, $(Q_{T0}-Q_{l,T0})/A_T$
Q	power input per heater section, W

Q	heat loss per heater section, W
$Q_{l,To}$	total heat loss from the enclosure to the environment, W
Q_{sc}	substrate conduction heat transfer per heated section, W
Q_{To}	total power input, W
Ra	Rayleigh number, $g\beta(T_h - T_c)[\text{length scale}]^3/\alpha\nu$
Ra^*	modified Rayleigh number, $NuRa$
$Ra_{W,T}^*$	modified Rayleigh number based on the top sink surface, $g\beta q_T W^4/k\nu\alpha$
T	temperature, K
t	exposure time of photographs, seconds
x, y, z	Cartesian coordinates, m
W	width of the cavity, m

GREEK SYMBOLS

α	thermal diffusivity, $k/\rho C$, m^2/s
ρ	density, kg/m^3
ν	kinematic viscosity, m^2/s
σ	standard deviation

SUBSCRIPTS

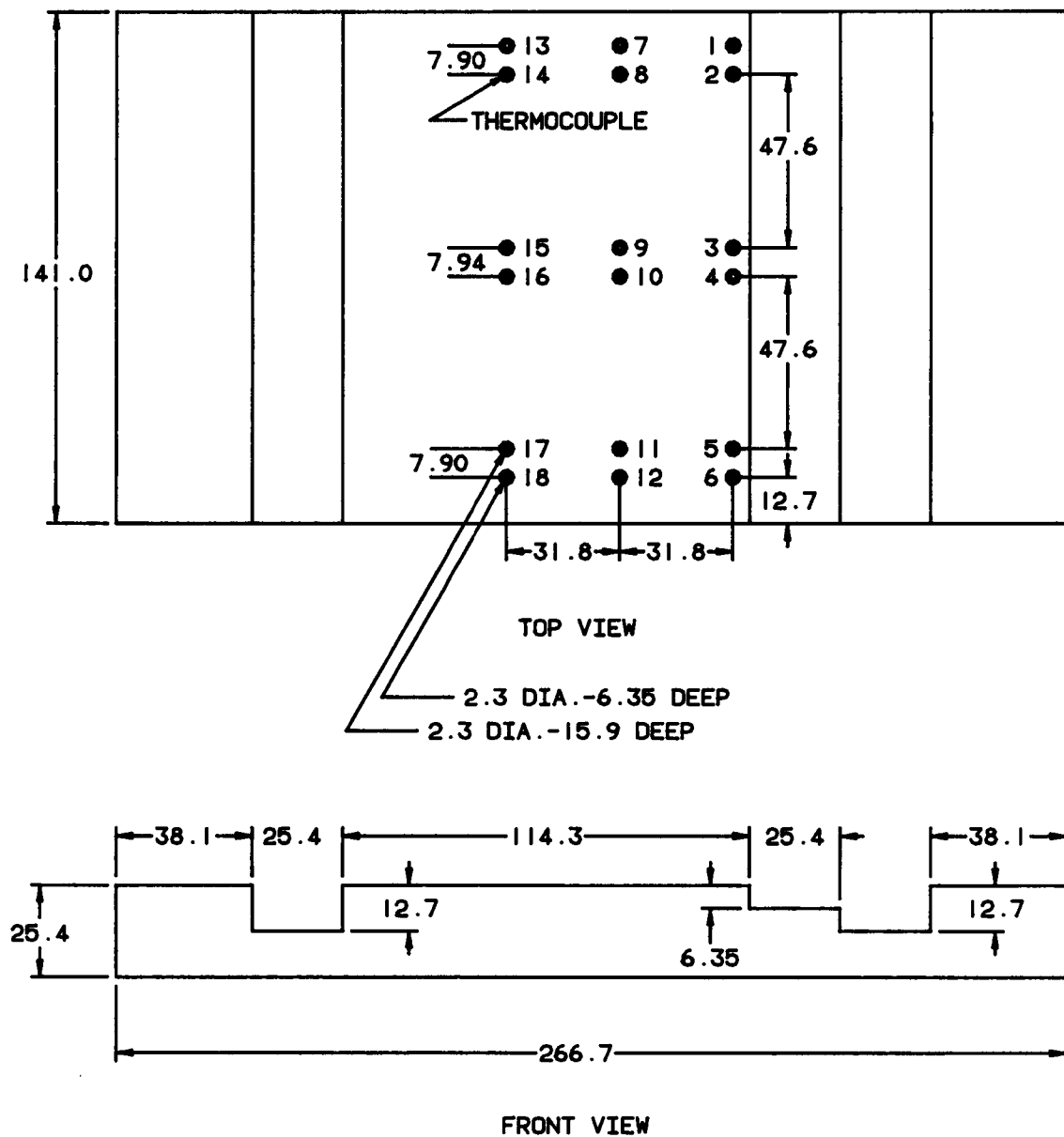
c	cold wall
h	heated section
L_1	vertical length scale of a heated section.
y	based on the local height, measured from the bottom of the cavity to the mid-height of a heated or unheated section.

SUPERSCRIPTS

—	average value
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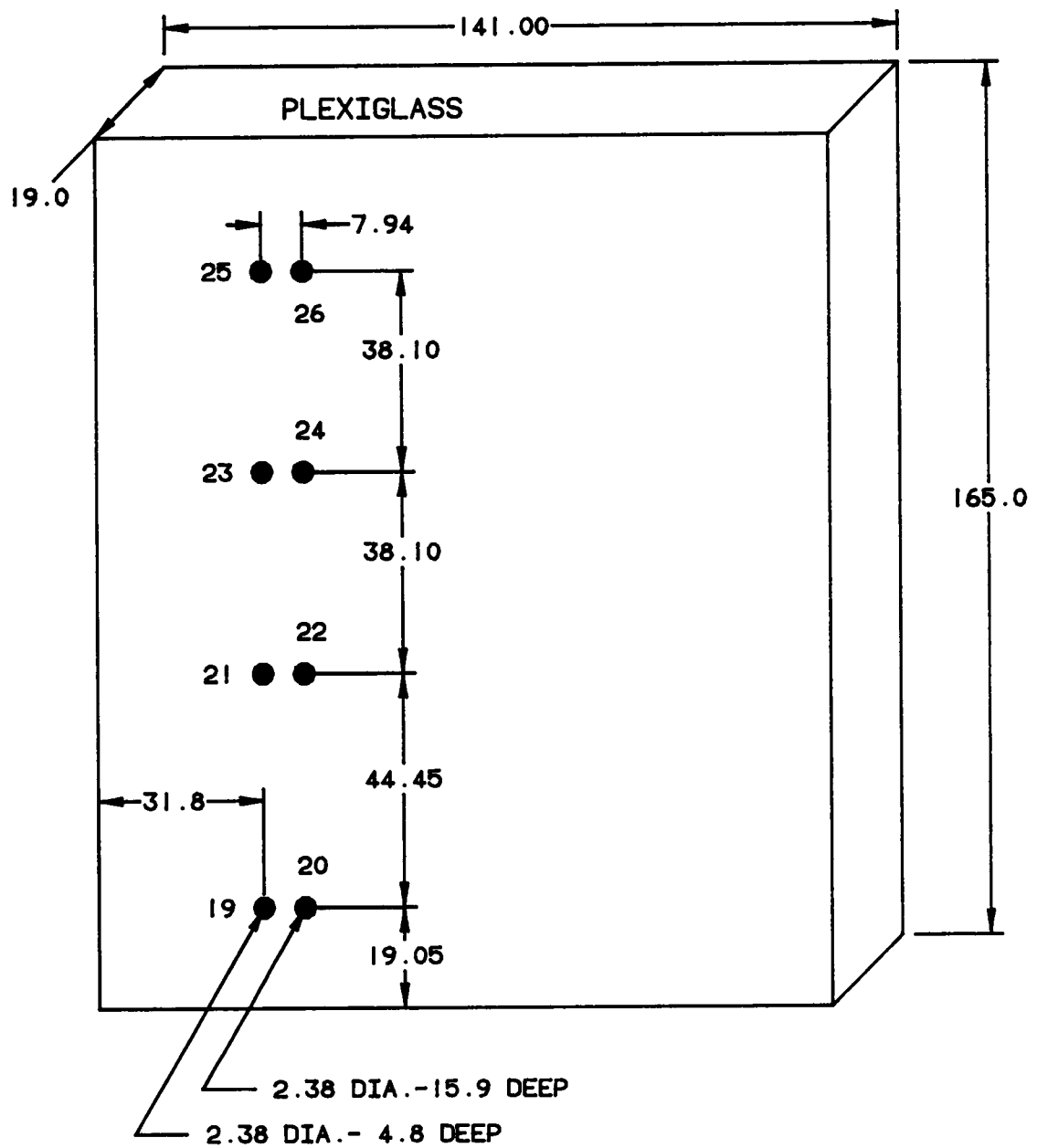
APPENDIX B

DETAILS OF EXPERIMENTAL APPARATUS



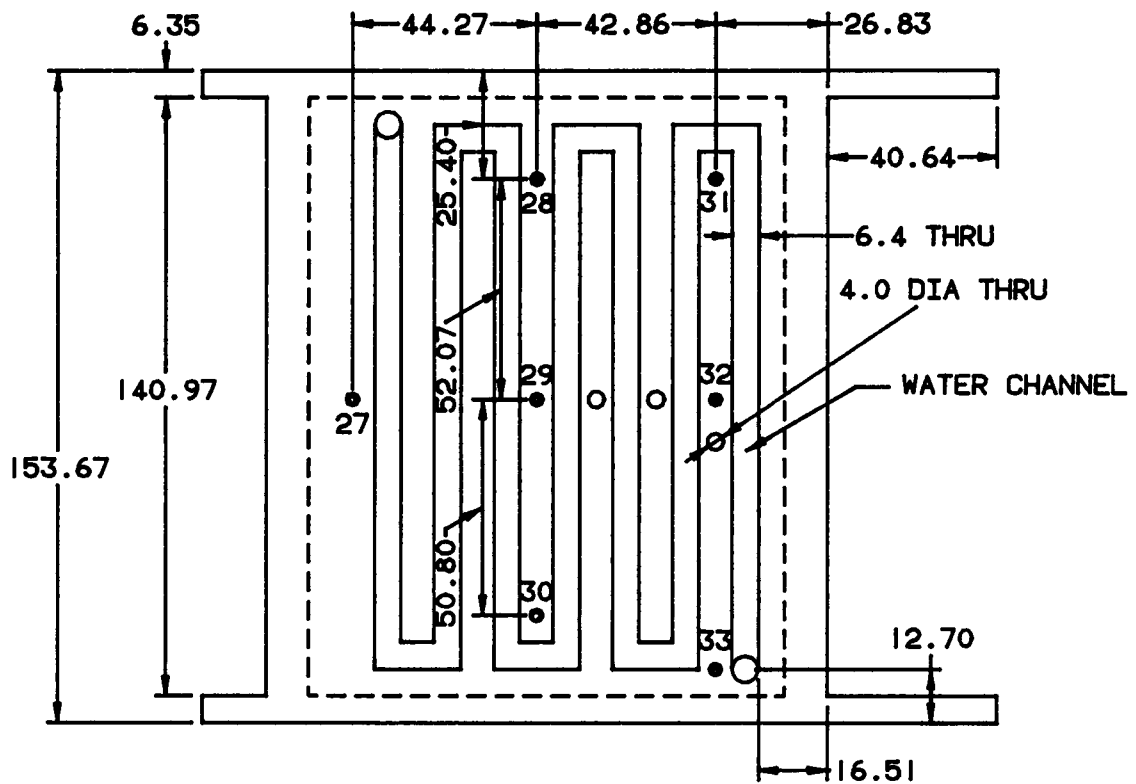
Note: dim. in mm.

Fig. B-1 Location of differential thermopiles imbedded in the bottom horizontal plexiglass plate.

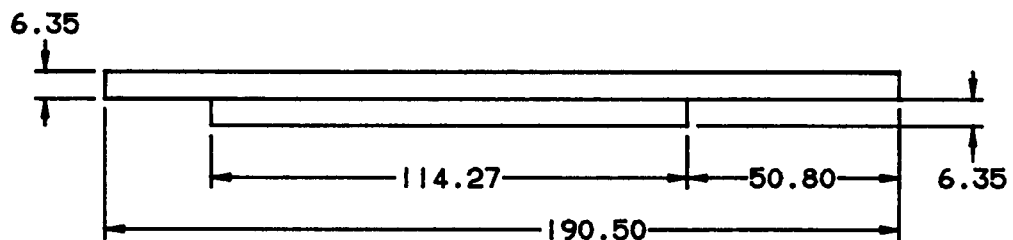


Note: dim. in mm

Fig. B-2 Location of differential thermopiles imbedded in the vertical "movable" wall.



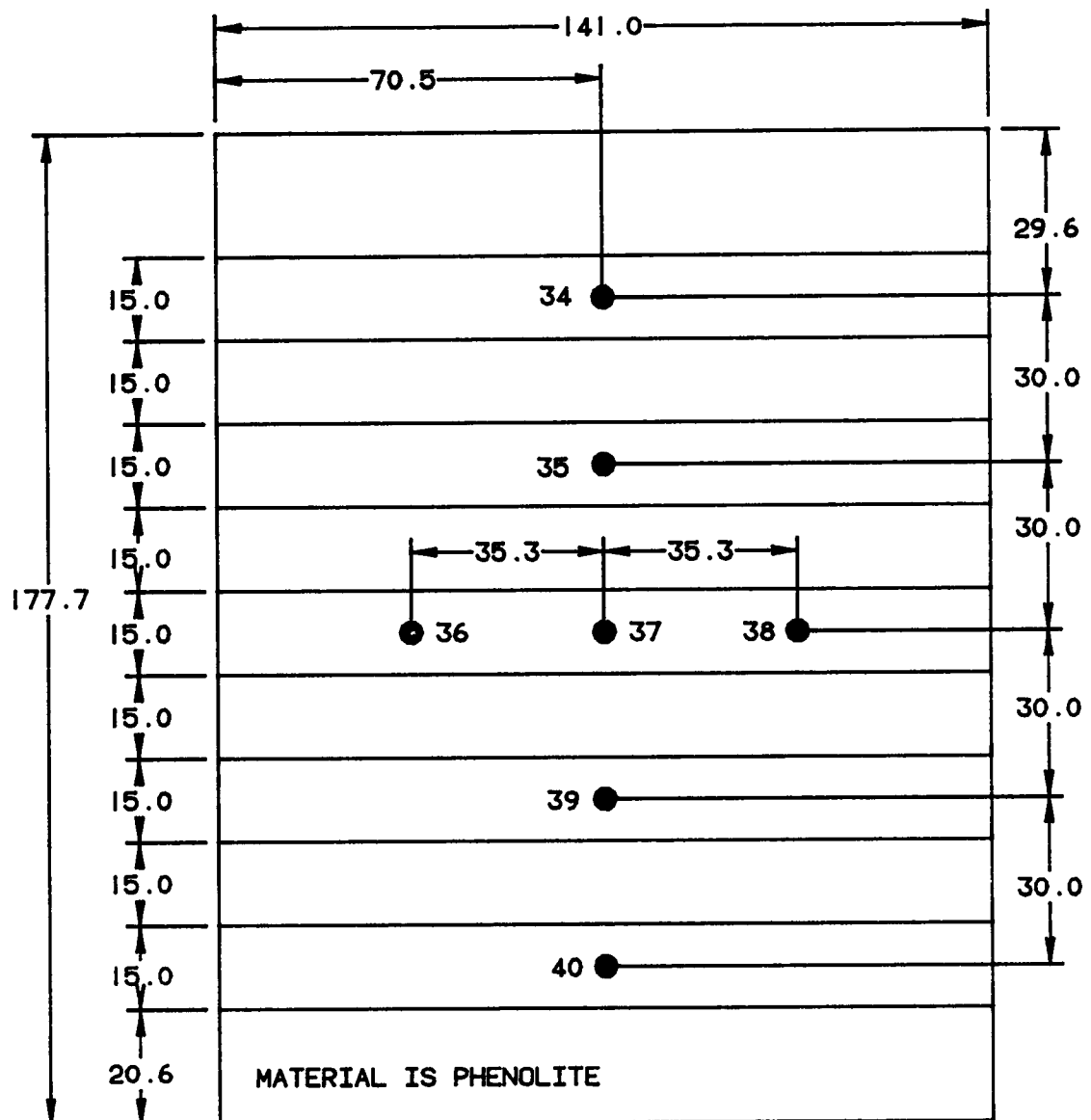
TOP VIEW
(MATERIAL IS COPPER)



FRONT VIEW

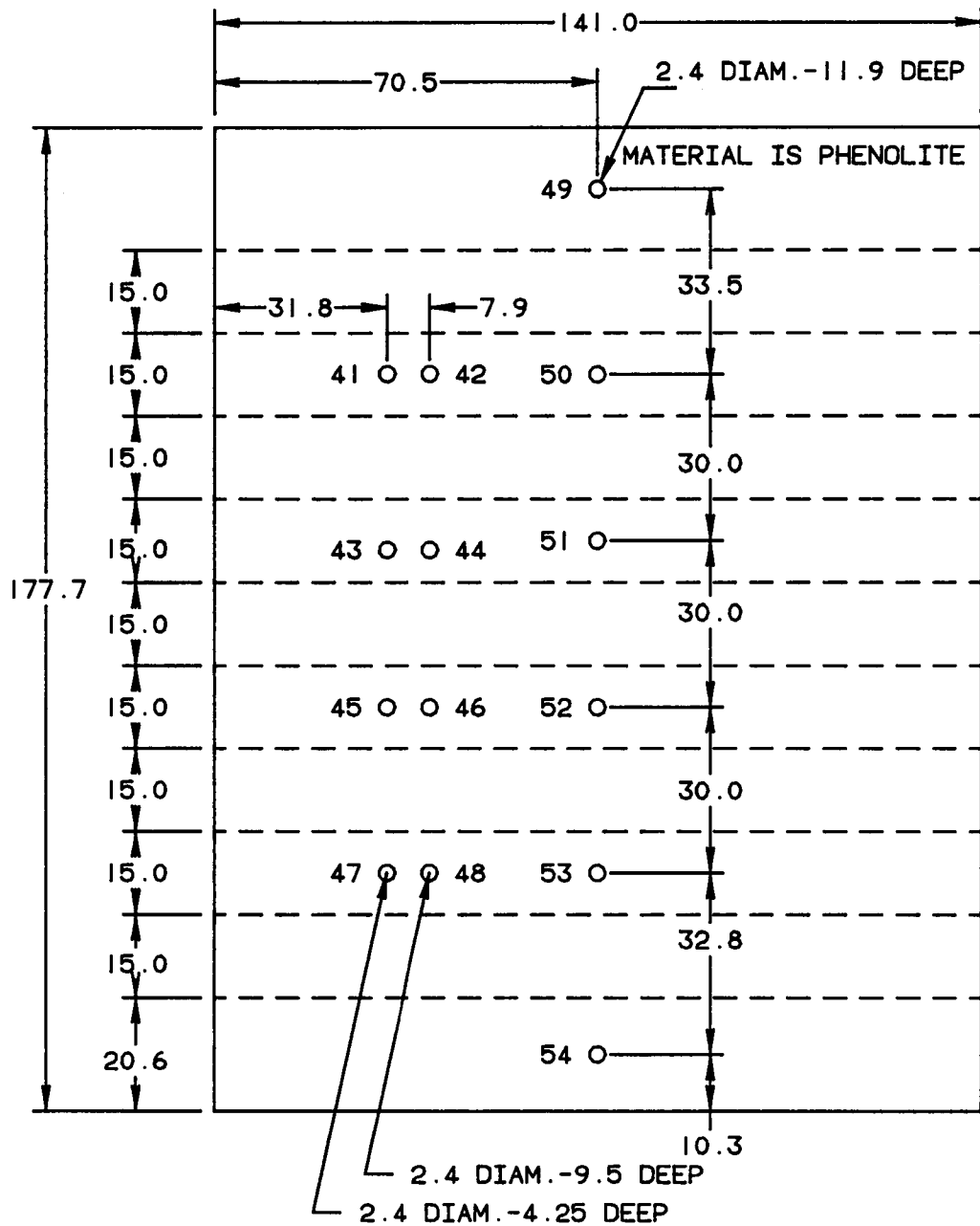
Note : dim. in mm

Fig. B-3 Location of thermocouples imbeded in the copper heat exchanger.



Note: dlm. in mm

Fig. B-4 Location of thermocouples in the "hot" wall (heated sections).



Note: dlm. in mm

Fig. B-5 Location of thermocouples at the back of the "hot" wall (thermocouples positioned at the center of the wall measure temperatures of insulated sections)

APPENDIX C

TABLES

Table C-1 List of Items Used and their Manufacturers.

ITEM	MANUFACTURER
35 mm camera Single Lens Reflex	Minolta XG-A
AC Regulator ACR 3000	Sorence Power Supplies
Carousel AV 900 slide Projector	Kodak
Personal Computer	Hewlett-Packard 9000/217
Data Acquisition/Control Unit (200 channels)	Hewlett-Packard 3497A
Digital Voltmeter	Hewlett-Packard 3456A
Channel Extender	Hewlett-Packard 3498A
Graphics Plotter	Hewlett-Packard 7470A
Ice-Point Reference	Kaye Instrument Model K-140/4
Think Jet Printer	Hewlett-Packard
Whinchester Disk	Hewlett-Packard 9133D

Table C-2 Measuring Instruments Used, their Ranges and Accuracy.

ITEM	MANUFACTURER	RANGE	ACCURACY
Ammeter	Keithley Instruments (Model 177 DMM)	20 μ A to 2000 mA	0.2% Rdg. +1 D
Constant Temperature Bath	MGW (Lauda) (M T - 6)	-20 to 120 $^{\circ}$ C	$\pm$ 0.15 $^{\circ}$ C
Voltmeter	Keithley Instruments (Model 177 DMM)	20 mV to 1000 V	5% Rdg. +15 D

Table C-3 Channel Number and its Corresponding Thermocouple Number.

THERMOCOUPLE NO. ON DRAWINGS (APPENDIX B)	CHANNEL NO.	REMARKS
--	0	Ice-Point
1 } 3 } 5 }	1	Bottom Plate Temperature
2 } 4 } 6 }	2	" " "
7 } 9 } 11 }	3	" " "
8 } 10 } 12 }	4	" " "
13 } 15 } 17 }	5	" " "
14 } 16 } 18 }	6	" " "
19 } 21 }	7	Temperature of Moving Wall
20 } 22 }	8	" " "

Note : braces indicate thermocouples in a single channel connected in parallel.

Table C-3 (continued)

THERMOCOUPLES NO. ON DRAWINGS (APPENDIX B)	CHANNEL NO.	REMARKS
23 } 25 }	9	Temperature of Moving Wall
24 } 26 }	10	" " "
27	11	Top Sink Surface Temperature
28	12	" " "
29	13	" " "
30	14	" " "
31	15	" " "
32	16	" " "
33	17	" " "
34	18	Heater # 5
35	19	Heater # 4
--	20	Ice-Point
36	21	To Check Symmetry
37	22	Heater # 3
38	23	To Check Symmetry
39	24	Heater # 2

Table C-3 (continued)

THERMOCOUPLES NO. ON DRAWINGS (APPENDIX B)	CHANNEL NO.	REMARKS
40	25	Heater # 1
41 } 43 }	26	Back of "Hot" Wall
42 } 44 }	27	" " "
45 } 47 }	28	" " "
46 } 48 }	29	" " "
49	30	Unheated Section (above heater # 5)
50	31	Unheated Section (above heater # 4)
51	32	Unheated Section (above heater # 3)
52	33	Unheated Section (above heater # 2)
53	34	Unheated Section (above heater # 1)
54	35	Unheated Section (below heater # 1)
--	100	Ice- Point

Table C-3 (continued)

THERMOCOUPLES NO. ON DRAWINGS (APPENDIX B)	CHANNEL NO.	REMARKS
---	101	Surface Glass Temp.
---	102	Ambient Temp.
---	103	Probe at x = 15.0 mm
---	104	Probe at x = 29.3 mm
---	105	Probe at x = 43.6 mm

Table C-4 Measured Resistance of each Strip Heater (June 15, 1988).

HEATER NO.	LOCATION	RESISTANCE MEASURED (Ω)
1	Bottom Plate	565.5
2	" " "	561.1
3	" " "	568.3
4	Movable Wall	435.4
5	" " "	434.4
6	" " "	429.8
7	" " "	438.5
8	Back of "Hot" Wall	431.1
9	" " "	433.7
10	" " "	430.5
11	" " "	429.4
12	Aluminum Heaters	39.73
13	" " "	39.95
14	" " "	39.52
15	" " "	39.62
16	" " "	39.21

Table C-5 Circuit Number and Its Measured Resistance (June 20, 1988).

CIRCUIT NO.	ARRANGED IN	RESISTANCE (Ω)	REMARK
1 (Heaters 15, 16)	Series	78.83	Heated Sections 1 & 2
2 (Heaters 12, 13, 14)	Series	119.2	Heated Sections 3, 4, 5
3 (Heaters 8, 9, 10, 11)	Parallel	107.81	"Guard" Heaters (Back of "Hot" Wall)
4 (Heaters 4, 5, 6, 7)	Parallel	108.63	"Guard" Heaters (Movable" Wall)
5 (Heaters 1, 2, 3)	Parallel	188.42	"Guard" Heaters (Bottom Plate)

Table C-6 Average Resistance and Its Respective Standard Deviation for Various Circuits (W = 13.5 mm)

CIRCUIT NO.	AVERAGE RESISTANCE (Ω)	STANDARD DEVIATION	UNCERTAINTY (%) (Compared with Measurements done on June 20, 1988)
1	80.39	0.34	1.98
2	120.87	0.32	0.98
3	108.68	0.77	0.90
4	109.32	0.37	0.64

Table C-7 Average Resistance and Its Respective Standard Deviation for Various Circuits (W = 45.0 mm)

CIRCUIT NO.	AVERAGE RESISTANCE (Ω)	STANDARD DEVIATION	UNCERTAINTY (%) (Compared with Measurements done on June 20, 1988)
1	80.61	0.28	1.75
2	121.19	0.44	1.67
3	109.30	0.26	1.38
4	110.01	0.44	1.27

Table C-8 Percentage Energy Convected per Heater for Power Inputs of
2 and 10 watts (W = 13.5 mm; Ethylene Glycol)

HEATED SECTION (N)	% ENERGY CONVECTED FROM HEATER, (Q-Q _L -Q _{SC})/(Q-Q _L)	
	Q = 2 Watts	Q = 10 Watts
1	80.0	83.0
2	95.5	96.0
3	96.9	98.1
4	95.8	97.2
5	83.1	90.1

Table C-9 Percentage Energy Convected per Heater for Power Inputs of
2 and 18 watts (W = 45.0 mm; Ethylene Glycol)

HEATED SECTION (N)	% ENERGY CONVECTED FROM HEATER, $(Q - Q_L - Q_{SC}) / (Q - Q_L)$	
	Q = 2 Watts	Q = 18 Watts
1	83.0	86.0
2	93.6	97.6
3	94.4	98.8
4	93.3	98.4
5	86.4	94.4

Table C-10 Percentage Energy Convected per Heater for Power Inputs of
2 and 12 watts (W = 18.0 mm; Ethylene Glycol)

HEATED SECTION (N)	% ENERGY CONVECTED FROM HEATER, $(Q-Q_L-Q_{SC})/(Q-Q_L)$	
	Q = 2 Watts	Q = 12 Watts
1	80.4	83.4
2	95.2	96.3
3	95.6	98.2
4	95.4	97.4
5	83.6	90.7

Table C-11 Percentage Energy Convected per Heater for Power Inputs of
2 and 4 watts (W = 18.0 mm; Fluorinert, FC-75)

HEATED SECTION (N)	% ENERGY CONVECTED FROM HEATER, $(Q-Q_L-Q_{SC})/(Q-Q_L)$	
	Q = 2 Watts	Q = 4 Watts
1	62.0	65.0
2	76.6	77.9
3	79.6	81.8
4	80.8	84.7
5	73.9	80.7

Table C-12 Heat transfer Correlation Coefficients for each Cavity Width
(equation (8)).

W (mm)	C	m	σ	Applicable range (min < Ra _y < max)
13.5	0.156	0.226	0.657	4.1E6 - 7.23E10
18.0	0.154	0.234	0.830	4.1E6 - 5.24E12
22.5	0.180	0.230	0.682	3.8E6 - 1.07E11
27.0	0.210	0.228	0.676	3.7E6 - 1.22E11
36.0	0.229	0.226	0.684	3.7E6 - 1.22E11
45.0	0.276	0.223	0.677	3.6E6 - 1.40E11

APPENDIX D
DATA, RAW AND REDUCED

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 2.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.77
20	-25.47
100	-24.77

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	27.19
2	28.07
3	26.09
4	26.75
5	25.34
6	25.56

CHANNEL # TEMPERATURE AT MOVING WALL

7	35.11
8	35.54
9	35.79
10	36.09

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	40.11
27	40.39
28	39.58
29	39.65

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.94
12	25.96
13	25.97
14	25.93
15	25.98
16	26.02
17	25.93

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	41.28
19	41.47
22	41.16
24	40.58
25	38.67

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	40.96
23	40.79

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	36.23
31	40.56
32	40.89
33	40.33
34	39.26
35	34.89

AVERAGE COLD PLATE TEMPERATURE: 25.96
SURFACE GLASS TEMPERATURE : 32.33
AMBIENT TEMPERATURE : 21.80

HEAT LOSS FROM BOTTOM WALL IS	.04 WATTS	.44 %
HEAT LOSS FROM MOVING WALL IS	.19 WATTS	1.93 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.29 WATTS	2.86 %
HEAT LOSS TO AIR THROUGH END GLASSES	.18 WATTS	1.81 %
TOTAL HEAT INPUT IS :	10.02 WATTS	
TOTAL HEAT LOSS IS :	.70 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	221.80	17.75	78.83	80.01	4.00
2	222.60	26.81	119.20	120.43	6.03
3	126.90	13.75	107.81	108.37	1.75
4	204.90	22.28	108.63	108.75	4.57
5	2.98	.59	188.42	199.38	0.00

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 2.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	4.789	+4.105E+06	+8.572E+05	55.036
.0525	11.588	+1.506E+08	+1.300E+07	57.102
.0825	17.784	+9.428E+08	+5.302E+07	55.776
.1125	23.494	+3.240E+09	+1.379E+08	54.038
.1425	26.124	+7.211E+09	+2.760E+08	47.435

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	2.873	+5.320E+05	+1.852E+05	121.604
.0525	2.980	+6.585E+05	+2.210E+05	117.411
.0825	2.910	+6.760E+05	+2.323E+05	116.182
.1125	2.819	+6.719E+05	+2.383E+05	115.542
.1425	2.475	+5.808E+05	+2.347E+05	115.926

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	3.193	+6.669E+03	+8.109E+05
.0525	3.311	+8.549E+03	+1.004E+06
.0825	3.234	+8.868E+03	+1.030E+06
.1125	3.133	+8.863E+03	+1.024E+06
.1425	2.750	+7.637E+03	+8.853E+05

Ra(w)ave= +6.904E+05
Nu(w)ave 2.81

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
17.369	+3.855E+06	332.845	+4.883E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 80.00
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.48
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.95
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.81
% ENERGY CONTRIBUTED BY HEATER 5 IS 83.11

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 4.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.23
20	-26.09
100	-25.39

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	29.63
2	30.65
3	27.76
4	28.50
5	26.75
6	26.86

CHANNEL # TEMPERATURE AT MOVING WALL

7	41.02
8	41.92
9	42.30
10	42.85

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	50.46
27	50.79
28	49.33
29	49.35

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.48
12	25.52
13	25.51
14	25.48
15	25.61
16	25.65
17	25.57

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	52.14
19	52.26
22	51.75
24	50.80
25	47.63

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	51.45
23	51.14

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	44.30
31	51.04
32	51.42
33	50.43
34	48.64
35	40.98

AVERAGE COLD PLATE TEMPERATURE: 25.55
SURFACE GLASS TEMPERATURE : 38.59
AMBIENT TEMPERATURE : 21.58

HEAT LOSS FROM BOTTOM WALL IS	.05 WATTS	.25 %
HEAT LOSS FROM MOVING WALL IS	.39 WATTS	1.93 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.28 WATTS	1.41 %
HEAT LOSS TO AIR THROUGH END GLASSES	.33 WATTS	1.64 %
TOTAL HEAT INPUT IS :	19.86 WATTS	
TOTAL HEAT LOSS IS :	1.05 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	313.00	24.97	78.83	79.78	7.91
2	312.00	37.74	119.20	120.95	11.95
3	164.50	17.84	107.81	108.46	2.95
4	274.00	29.93	108.63	109.23	8.25
5	5.98	1.18	188.42	197.83	.01

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 4.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	5.661	+9.904E+06	+1.750E+06	65.200
.0525	13.665	+3.679E+08	+2.692E+07	67.505
.0825	21.041	+2.320E+09	+1.102E+08	66.162
.1125	27.833	+8.004E+09	+2.876E+08	64.190
.1425	31.242	+1.814E+10	+5.807E+08	56.882

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	3.397	+1.284E+06	+3.779E+05	104.342
.0525	3.514	+1.609E+06	+4.578E+05	98.807
.0825	3.443	+1.663E+06	+4.831E+05	97.236
.1125	3.340	+1.660E+06	+4.969E+05	96.407
.1425	2.960	+1.461E+06	+4.938E+05	96.596

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	3.774	+1.875E+04	+1.956E+06
.0525	3.904	+2.481E+04	+2.452E+06
.0825	3.826	+2.607E+04	+2.535E+06
.1125	3.711	+2.624E+04	+2.530E+06
.1425	3.289	+2.306E+04	+2.227E+06

Ra(w)ave= +1.686E+06
Nu(w)ave 3.33

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
20.427	+9.413E+06	392.446	+9.957E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 80.75
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.63
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.24
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.18
% ENERGY CONTRIBUTED BY HEATER 5 IS 84.86

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 5.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.20
20	-24.79
100	-24.41

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	30.73
2	31.99
3	28.71
4	29.73
5	27.60
6	27.86

CHANNEL # TEMPERATURE AT MOVING WALL

7	45.48
8	46.60
9	47.35
10	47.88

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	56.21
27	56.59
28	54.63
29	54.71

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.34
12	26.36
13	26.40
14	26.35
15	26.54
16	26.58
17	26.46

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	58.52
19	58.61
22	57.68
24	56.47
25	52.57

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	57.32
23	56.96

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	48.96
31	56.98
32	57.35
33	56.07
34	53.84
35	44.27

AVERAGE COLD PLATE TEMPERATURE: 26.43
SURFACE GLASS TEMPERATURE : 41.61
AMBIENT TEMPERATURE : 21.09

HEAT LOSS FROM BOTTOM WALL IS	.06 WATTS	.25 %
HEAT LOSS FROM MOVING WALL IS	.44 WATTS	1.75 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.37 WATTS	1.49 %
HEAT LOSS TO AIR THROUGH END GLASSES	.41 WATTS	1.66 %
TOTAL HEAT INPUT IS :	25.27 WATTS	
TOTAL HEAT LOSS IS :	1.29 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	349.10	27.97	78.83	80.12	9.92
2	354.70	42.77	119.20	120.57	15.34
3	186.20	20.16	107.81	108.26	3.77
4	306.00	33.40	108.63	109.15	10.27
5	7.26	1.45	188.42	199.33	.01

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 5.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	6.001	+1.380E+07	+2.299E+06	69.222
.0525	14.360	+5.156E+08	+3.590E+07	71.063
.0825	22.066	+3.265E+09	+1.480E+08	69.510
.1125	28.906	+1.134E+10	+3.924E+08	66.791
.1425	32.667	+2.594E+10	+7.941E+08	59.589

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	3.601	+1.788E+06	+4.966E+05	94.501
.0525	3.693	+2.254E+06	+6.104E+05	88.661
.0825	3.611	+2.341E+06	+6.483E+05	86.951
.1125	3.469	+2.352E+06	+6.781E+05	85.675
.1425	3.095	+2.090E+06	+6.752E+05	85.797

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.001	+2.884E+04	+2.725E+06
.0525	4.103	+3.875E+04	+3.436E+06
.0825	4.012	+4.103E+04	+3.568E+06
.1125	3.854	+4.184E+04	+3.585E+06
.1425	3.439	+3.712E+04	+3.185E+06

Ra(w)ave= +2.368E+06
Nu(w)ave 3.49

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
21.332	+1.322E+07	410.555	+1.246E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.13
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.70
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.39
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.36
% ENERGY CONTRIBUTED BY HEATER 5 IS 85.73

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 6.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.19
20	-25.79
100	-25.11

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	31.43
2	32.72
3	29.19
4	30.18
5	27.96
6	28.25

CHANNEL # TEMPERATURE AT MOVING WALL

7	48.42
8	49.61
9	51.38
10	51.54

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	60.29
27	60.75
28	58.30
29	58.48

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.10
12	26.15
13	26.14
14	26.12
15	26.34
16	26.41
17	26.37

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	62.88
19	62.93
22	61.95
24	60.71
25	55.88

CAVITY WIDTH

13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	61.55
23	61.18

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	52.59
31	61.17
32	61.58
33	60.17
34	57.46
35	46.02

AVERAGE COLD PLATE TEMPERATURE: 26.23

SURFACE GLASS TEMPERATURE : 45.45

AMBIENT TEMPERATURE : 22.90

HEAT LOSS FROM BOTTOM WALL IS	.06 WATTS	.21 %
HEAT LOSS FROM MOVING WALL IS	.36 WATTS	1.20 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.52 WATTS	1.73 %
HEAT LOSS TO AIR THROUGH END GLASSES	.46 WATTS	1.55 %
TOTAL HEAT INPUT IS :	29.88 WATTS	
TOTAL HEAT LOSS IS :	1.41 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	382.30	30.71	78.83	80.33	11.96
2	383.00	46.22	119.20	120.67	17.92
3	173.50	18.92	107.81	109.07	3.32
4	341.40	37.29	108.63	109.23	12.80
5	8.89	1.77	188.42	199.42	.02

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 6.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	6.406	+1.763E+07	+2.752E+06	73.951
.0525	15.084	+6.652E+08	+4.410E+07	74.721
.0825	23.297	+4.214E+09	+1.809E+08	73.464
.1125	30.594	+1.465E+10	+4.790E+08	70.766
.1425	34.815	+3.381E+10	+9.711E+08	63.575

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	3.844	+2.284E+06	+5.944E+05	89.798
.0525	3.879	+2.908E+06	+7.498E+05	83.152
.0825	3.812	+3.022E+06	+7.926E+05	81.571
.1125	3.671	+3.039E+06	+8.277E+05	80.344
.1425	3.298	+2.723E+06	+8.257E+05	80.411

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.271	+3.877E+04	+3.482E+06
.0525	4.310	+5.331E+04	+4.433E+06
.0825	4.236	+5.646E+04	+4.605E+06
.1125	4.079	+5.764E+04	+4.631E+06
.1425	3.665	+5.162E+04	+4.151E+06

Ra(w)ave= +3.046E+06
Nu(w)ave 3.70

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
22.513	+1.700E+07	433.713	+1.502E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.50
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.77
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.54
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.55
% ENERGY CONTRIBUTED BY HEATER 5 IS 86.61

CAVITY WIDTH	13.50 mm
POWER INPUT PER ELEMENT	7.00 W

CHANNEL #	REFERENCE TEMPERATURE (ICE POINT)
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0	-25.53
20	-25.13
100	-24.71

CHANNEL #	TEMPERATURE AT BOTTOM WALL
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1	32.19
2	33.55
3	29.83
4	30.89
5	28.60
6	28.91

CHANNEL #	TEMPERATURE AT MOVING WALL
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7	51.20
8	52.76
9	54.93
10	55.19

CHANNEL #	TEMPERATURE AT BACK OF HOT WALL
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26	65.22
27	65.56
28	62.90
29	62.99

CHANNEL #	TOP SINK SURFACE TEMPERATURE
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11	26.37
12	26.47
13	26.45
14	26.40
15	26.67
16	26.72
17	26.61

CHANNEL #	TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)
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18	67.59
19	67.60
22	66.47
24	65.24
25	59.75

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	66.00
23	65.56

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	56.15
31	65.99
32	66.37
33	64.78
34	61.78
35	48.55

AVERAGE COLD PLATE TEMPERATURE: 26.53
 SURFACE GLASS TEMPERATURE : 46.61
 AMBIENT TEMPERATURE : 21.22

HEAT LOSS FROM BOTTOM WALL IS	.07 WATTS	.19 %
HEAT LOSS FROM MOVING WALL IS	.48 WATTS	1.38 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.35 WATTS	1.01 %
HEAT LOSS TO AIR THROUGH END GLASSES	.54 WATTS	1.54 %
TOTAL HEAT INPUT IS :	35.10 WATTS	
TOTAL HEAT LOSS IS :	1.44 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	415.70	33.38	78.83	80.31	14.14
2	414.20	49.99	119.20	120.69	20.97
3	206.80	22.35	107.81	108.07	4.63
4	370.60	40.42	108.63	109.08	15.04
5	11.17	2.22	188.42	199.20	.03

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 7.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	6.732	+2.227E+07	+3.308E+06	77.797
.0525	15.758	+8.437E+08	+5.354E+07	78.157
.0825	24.452	+5.345E+09	+2.186E+08	77.203
.1125	32.097	+1.862E+10	+5.802E+08	74.337
.1425	36.782	+4.335E+10	+1.178E+09	67.254

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	4.039	+2.886E+06	+7.146E+05	84.022
.0525	4.052	+3.689E+06	+9.103E+05	77.235
.0825	4.001	+3.832E+06	+9.577E+05	75.830
.1125	3.852	+3.862E+06	+1.003E+06	74.569
.1425	3.485	+3.492E+06	+1.002E+06	74.586

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.488	+5.236E+04	+4.399E+06
.0525	4.502	+7.279E+04	+5.622E+06
.0825	4.446	+7.702E+04	+5.841E+06
.1125	4.280	+7.893E+04	+5.886E+06
.1425	3.872	+7.135E+04	+5.322E+06

Ra(w)ave= +3.856E+06
Nu(w)ave 3.89

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
23.554	+2.152E+07	454.325	+1.763E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.88
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.84
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.68
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.73
% ENERGY CONTRIBUTED BY HEATER 5 IS 87.48

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 8.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.57
20	-26.21
100	-25.36

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.23
2	33.51
3	29.94
4	30.93
5	28.78
6	29.08

CHANNEL # TEMPERATURE AT MOVING WALL

7	51.67
8	53.54
9	56.11
10	56.61

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	67.31
27	67.84
28	64.51
29	64.69

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.31
12	26.35
13	26.34
14	26.35
15	26.64
16	26.69
17	26.70

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	70.45
19	70.44
22	69.23
24	67.68
25	61.00

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	68.71
23	68.27

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	57.97
31	68.26
32	68.65
33	66.87
34	63.30
35	48.54

AVERAGE COLD PLATE TEMPERATURE: 26.48
SURFACE GLASS TEMPERATURE : 48.95
AMBIENT TEMPERATURE : 21.51

HEAT LOSS FROM BOTTOM WALL IS	.06 WATTS	.16 %
HEAT LOSS FROM MOVING WALL IS	.63 WATTS	1.57 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.58 WATTS	1.46 %
HEAT LOSS TO AIR THROUGH END GLASSES	.59 WATTS	1.48 %
TOTAL HEAT INPUT IS :	39.89 WATTS	
TOTAL HEAT LOSS IS :	1.86 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	441.00	35.48	78.83	80.45	15.97
2	442.00	53.40	119.20	120.82	23.93
3	200.80	21.72	107.81	108.17	4.38
4	368.80	40.30	108.63	109.27	14.95
5	14.55	2.61	188.42	179.10	.04

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 8.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	7.395	+2.593E+07	+3.506E+06	85.494
.0525	16.830	+9.958E+08	+5.917E+07	83.525
.0825	25.984	+6.342E+09	+2.441E+08	82.098
.1125	34.128	+2.212E+10	+6.482E+08	79.099
.1425	39.403	+5.192E+10	+1.318E+09	72.098

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	4.437	+3.360E+06	+7.573E+05	82.458
.0525	4.328	+4.354E+06	+1.006E+06	74.534
.0825	4.252	+4.547E+06	+1.069E+06	72.864
.1125	4.095	+4.587E+06	+1.120E+06	71.608
.1425	3.733	+4.183E+06	+1.120E+06	71.598

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.930	+6.211E+04	+5.122E+06
.0525	4.808	+8.904E+04	+6.636E+06
.0825	4.724	+9.511E+04	+6.930E+06
.1125	4.550	+9.764E+04	+6.992E+06
.1425	4.148	+8.904E+04	+6.375E+06

Ra(w)ave= +4.548E+06
Nu(w)ave 4.17

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
25.148	+2.538E+07	485.382	+2.003E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.25
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.92
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.83
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.91
% ENERGY CONTRIBUTED BY HEATER 5 IS 88.35

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 9.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.11
20	-25.71
100	-25.22

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.36
2	34.62
3	30.90
4	31.92
5	29.69
6	29.99

CHANNEL # TEMPERATURE AT MOVING WALL

7	53.88
8	56.15
9	58.85
10	59.64

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	71.57
27	72.13
28	68.12
29	68.35

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.53
12	26.64
13	26.61
14	26.58
15	26.93
16	26.97
17	26.86

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	74.64
19	74.56
22	73.13
24	71.53
25	64.25

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	72.54
23	72.08

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	61.62
31	72.64
32	72.92
33	70.84
34	66.81
35	50.68

AVERAGE COLD PLATE TEMPERATURE: 26.73
SURFACE GLASS TEMPERATURE : 50.34
AMBIENT TEMPERATURE : 21.92

HEAT LOSS FROM BOTTOM WALL IS	.06 WATTS	.14 %
HEAT LOSS FROM MOVING WALL IS	.81 WATTS	1.81 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.64 WATTS	1.43 %
HEAT LOSS TO AIR THROUGH END GLASSES	.62 WATTS	1.37 %
TOTAL HEAT INPUT IS :	44.98 WATTS	
TOTAL HEAT LOSS IS :	2.14 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	465.60	37.65	78.83	80.87	17.98
2	468.00	56.73	119.20	121.22	27.00
3	205.20	22.43	107.81	109.30	4.67
4	386.40	42.47	108.63	109.92	16.61
5	14.87	2.96	188.42	198.99	.05

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 9.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	7.673	+3.096E+07	+4.035E+06	88.786
.0525	17.387	+1.192E+09	+6.853E+07	86.385
.0825	26.921	+7.592E+09	+2.820E+08	85.146
.1125	35.281	+2.656E+10	+7.529E+08	81.862
.1425	40.991	+6.291E+10	+1.535E+09	75.090

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	4.604	+4.012E+06	+8.715E+05	78.152
.0525	4.471	+5.210E+06	+1.165E+06	70.250
.0825	4.405	+5.444E+06	+1.236E+06	68.692
.1125	4.234	+5.508E+06	+1.301E+06	67.341
.1425	3.883	+5.068E+06	+1.305E+06	67.260

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.116	+7.825E+04	+6.115E+06
.0525	4.968	+1.130E+05	+7.940E+06
.0825	4.895	+1.208E+05	+8.297E+06
.1125	4.704	+1.247E+05	+8.395E+06
.1425	4.315	+1.148E+05	+7.724E+06

Ra(w)ave= +5.438E+06
Nu(w)ave 4.32

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
25.960	+3.035E+07	501.589	+2.252E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.63
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.99
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.97
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.10
% ENERGY CONTRIBUTED BY HEATER 5 IS 89.23

CAVITY WIDTH 13.50 mm
POWER INPUT PER ELEMENT 10.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.72
20	-26.28
100	-25.60

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.86
2	34.18
3	30.52
4	31.45
5	29.34
6	29.68

CHANNEL # TEMPERATURE AT MOVING WALL

7	54.14
8	56.87
9	60.03
10	60.84

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	73.32
27	73.94
28	69.53
29	69.68

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.83
12	25.92
13	25.92
14	25.94
15	26.34
16	26.42
17	26.43

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	76.80
19	76.64
22	74.99
24	73.27
25	65.24

CAVITY WIDTH 13.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	74.51
23	73.72

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	62.71
31	74.14
32	74.51
33	72.24
34	67.62
35	50.46

AVERAGE COLD PLATE TEMPERATURE: 26.11
SURFACE GLASS TEMPERATURE : 52.34
AMBIENT TEMPERATURE : 21.54

HEAT LOSS FROM BOTTOM WALL IS	.07 WATTS	.13 %
HEAT LOSS FROM MOVING WALL IS	.94 WATTS	1.88 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.63 WATTS	1.25 %
HEAT LOSS TO AIR THROUGH END GLASSES	.68 WATTS	1.36 %
TOTAL HEAT INPUT IS :	50.07 WATTS	
TOTAL HEAT LOSS IS :	2.31 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	489.70	39.59	78.83	80.85	19.89
2	493.50	59.98	119.20	121.54	30.18
3	185.73	20.52	107.81	110.51	3.91
4	395.00	43.41	108.63	109.89	17.34
5	0.00	0.00	188.42	330.67	0.00

RESULTS FOR ASPECT RATIO = 12.222
POWER INPUT PER ELEMENT = 10.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	8.223	+3.480E+07	+4.232E+06	95.158
.0525	18.389	+1.349E+09	+7.335E+07	91.387
.0825	28.464	+8.615E+09	+3.027E+08	90.056
.1125	37.210	+3.024E+10	+8.127E+08	86.371
.1425	43.516	+7.226E+10	+1.661E+09	79.747

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	4.934	+4.511E+06	+9.142E+05	77.713
.0525	4.729	+5.897E+06	+1.247E+06	69.149
.0825	4.658	+6.177E+06	+1.326E+06	67.508
.1125	4.465	+6.271E+06	+1.404E+06	65.997
.1425	4.123	+5.821E+06	+1.412E+06	65.855

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.482	+8.847E+04	+6.875E+06
.0525	5.254	+1.300E+05	+8.988E+06
.0825	5.175	+1.395E+05	+9.414E+06
.1125	4.961	+1.448E+05	+9.557E+06
.1425	4.581	+1.347E+05	+8.872E+06

Ra(w)ave= +6.155E+06
Nu(w)ave 4.58

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
27.419	+3.434E+07	529.933	+2.505E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.00
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.06
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.12
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.28
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.10

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 2.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.79
20	-26.43
100	-25.60

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	27.28
2	28.05
3	26.40
4	27.06
5	25.74
6	25.89

CHANNEL # TEMPERATURE AT MOVING WALL

7	34.01
8	34.31
9	34.54
10	34.75

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	38.66
27	38.91
28	38.19
29	38.21

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.25
12	26.24
13	26.26
14	26.27
15	26.35
16	26.36
17	26.38

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	39.90
19	40.05
22	39.64
24	39.11
25	37.41

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	39.46
23	39.30

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	35.20
31	39.06
32	39.33
33	38.80
34	37.87
35	34.01

AVERAGE COLD PLATE TEMPERATURE: 26.30

SURFACE GLASS TEMPERATURE : 32.05

AMBIENT TEMPERATURE : 21.40

HEAT LOSS FROM BOTTOM WALL IS	.05 WATTS	.51 %
HEAT LOSS FROM MOVING WALL IS	.14 WATTS	1.36 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.22 WATTS	2.25 %
HEAT LOSS TO AIR THROUGH END GLASSES	.25 WATTS	2.45 %
TOTAL HEAT INPUT IS :	10.04 WATTS	
TOTAL HEAT LOSS IS :	.66 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	221.80	17.78	78.83	80.17	4.01
2	221.70	26.81	119.20	120.94	6.03
3	119.40	12.98	107.81	108.68	1.56
4	192.10	21.04	108.63	109.53	4.08
5	8.91	1.78	188.42	199.58	.02

PROBE MEASUREMENTS

y/H	x= 3.00 mm
.9545	33.99
.8636	35.01
.7727	34.98
.6818	35.14
.5909	35.31
.5000	35.18
.4091	35.13
.3182	35.19
.2273	35.12
.1364	34.87
.0455	33.01

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 2.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	5.538	+4.075E+06	+7.359E+05	63.628
.0525	13.261	+1.478E+08	+1.114E+07	65.326
.0825	20.306	+9.231E+08	+4.546E+07	63.666
.1125	26.537	+3.179E+09	+1.198E+08	61.019
.1425	29.773	+7.146E+09	+2.400E+08	54.045

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	4.430	+1.669E+06	+3.768E+05	123.699
.0525	4.547	+2.042E+06	+4.491E+05	119.868
.0825	4.430	+2.092E+06	+4.721E+05	118.724
.1125	4.246	+2.084E+06	+4.907E+05	117.826
.1425	3.761	+1.819E+06	+4.837E+05	118.160

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	3.692	+6.508E+03	+8.050E+05
.0525	3.789	+8.214E+03	+9.846E+05
.0825	3.692	+8.497E+03	+1.009E+06
.1125	3.538	+8.528E+03	+1.005E+06
.1425	3.134	+7.425E+03	+8.773E+05

Ra(w)ave= +2.149E+06
Nu(w)ave 4.28

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
19.831	+9.000E+06	284.941	+3.681E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 80.43
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.22
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.58
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.45
% ENERGY CONTRIBUTED BY HEATER 5 IS 83.59

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 4.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.86
20	-26.44
100	-25.81

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	29.50
2	30.49
3	28.02
4	28.09
5	27.09
6	27.22

CHANNEL # TEMPERATURE AT MOVING WALL

7	37.39
8	38.64
9	38.05
10	39.07

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	46.24
27	46.74
28	45.38
29	45.63

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.67
12	25.66
13	25.69
14	25.70
15	25.90
16	25.94
17	25.91

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	46.72
19	46.63
22	46.12
24	47.33
25	44.91

CAVITY WIDTH

16.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	47.81
23	47.57

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	41.40
31	46.90
32	47.27
33	46.45
34	45.01
35	39.06

AVERAGE COLD PLATE TEMPERATURE: 25.70
 SURFACE GLASS TEMPERATURE : 35.84
 AMBIENT TEMPERATURE : 23.04

HEAT LOSS FROM BOTTOM WALL IS	.07 WATTS	.33 %
HEAT LOSS FROM MOVING WALL IS	.60 WATTS	3.00 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.62 WATTS	3.09 %
HEAT LOSS TO AIR THROUGH END GLASSES	.31 WATTS	1.54 %
TOTAL HEAT INPUT IS :	20.01 WATTS	
TOTAL HEAT LOSS IS :	1.59 WATTS	

CIRCUIT#	MEASURED CURRENT (AMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	311.90	25.11	78.83	80.51	8.00
2	312.60	37.64	119.20	120.97	12.01
3	112.08	12.22	107.81	109.00	1.38
4	213.60	23.40	108.63	109.56	5.04
5	0.00	0.00	188.42	330.00	0.00

PROBE MEASUREMENTS

y/H	x= 3.00 mm
.9545	38.43
.8636	40.09
.7727	40.76
.6818	40.76
.5909	40.86
.5000	40.78
.4091	40.70
.3182	40.62
.2273	40.58
.1364	40.37
.0455	37.74

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 4.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	6.373	+9.227E+06	+1.448E+06	73.357
.0525	15.542	+3.366E+08	+2.166E+07	76.716
.0825	23.915	+2.114E+09	+8.841E+07	75.134
.1125	31.257	+7.323E+09	+2.343E+08	72.028
.1425	35.286	+1.669E+10	+4.729E+08	64.191

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	5.099	+3.779E+06	+7.412E+05	108.975
.0525	5.329	+4.651E+06	+8.728E+05	104.460
.0825	5.218	+4.791E+06	+9.183E+05	103.030
.1125	5.001	+4.799E+06	+9.596E+05	101.781
.1425	4.457	+4.248E+06	+9.531E+05	101.974

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.249	+1.672E+04	+1.823E+06
.0525	4.441	+2.147E+04	+2.243E+06
.0825	4.348	+2.243E+04	+2.311E+06
.1125	4.168	+2.274E+04	+2.314E+06
.1425	3.714	+2.009E+04	+2.049E+06

Ra(w)ave= +4.897E+06
Nu(w)ave 5.02

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
23.112	+2.051E+07	332.755	+7.253E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.03
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.43
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.91
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.85
% ENERGY CONTRIBUTED BY HEATER 5 IS 85.01

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 6.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-24.68
20	-24.28
100	-23.78

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	30.23
2	31.51
3	28.28
4	29.44
5	27.08
6	27.33

CHANNEL # TEMPERATURE AT MOVING WALL

7	44.59
8	45.49
9	46.41
10	46.79

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	56.13
27	56.41
28	54.45
29	54.52

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.67
12	25.71
13	25.71
14	25.68
15	25.96
16	26.02
17	25.93

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	58.33
19	58.41
22	57.48
24	56.22
25	52.52

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	57.08
23	56.70

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	49.15
31	56.84
32	57.12
33	55.73
34	53.54
35	43.89

AVERAGE COLD PLATE TEMPERATURE: 25.81
SURFACE GLASS TEMPERATURE : 40.80
AMBIENT TEMPERATURE : 21.16

HEAT LOSS FROM BOTTOM WALL IS	.09 WATTS	.29 %
HEAT LOSS FROM MOVING WALL IS	.34 WATTS	1.13 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.30 WATTS	.99 %
HEAT LOSS TO AIR THROUGH END GLASSES	.52 WATTS	1.74 %
TOTAL HEAT INPUT IS :	29.87 WATTS	
TOTAL HEAT LOSS IS :	1.25 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	378.40	30.45	78.83	80.46	11.76
2	385.20	46.46	119.20	120.60	18.11
3	178.30	19.28	107.81	108.13	3.45
4	307.00	33.46	108.63	108.99	10.31
5	11.91	2.37	188.42	199.19	.03

PROBE MEASUREMENTS

y/H	x= 3.00 mm
.9545	43.98
.8636	47.37
.7727	47.43
.6818	47.40
.5909	47.77
.5000	47.57
.4091	47.36
.3182	47.32
.2273	47.29
.1364	46.96
.0455	41.63

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 6.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	7.168	+1.664E+07	+2.322E+06	82.669
.0525	17.196	+6.158E+08	+3.581E+07	85.078
.0825	26.373	+3.899E+09	+1.479E+08	83.058
.1125	34.576	+1.355E+10	+3.920E+08	79.873
.1425	39.424	+3.129E+10	+7.938E+08	71.898

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	5.734	+6.816E+06	+1.189E+06	95.560
.0525	5.896	+8.509E+06	+1.443E+06	89.913
.0825	5.754	+8.836E+06	+1.536E+06	88.101
.1125	5.532	+8.882E+06	+1.606E+06	86.803
.1425	4.980	+7.967E+06	+1.600E+06	86.908

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.779	+3.440E+04	+3.287E+06
.0525	4.913	+4.564E+04	+4.103E+06
.0825	4.795	+4.837E+04	+4.261E+06
.1125	4.610	+4.935E+04	+4.284E+06
.1425	4.150	+4.421E+04	+3.842E+06

Ra(w)ave= +8.956E+06
Nu(w)ave 5.58

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
25.505	+3.750E+07	368.072	+1.133E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.63
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.64
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.24
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.25
% ENERGY CONTRIBUTED BY HEATER 5 IS 86.44

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 8.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.66
20	-25.28
100	-24.87

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	31.58
2	32.70
3	29.48
4	30.59
5	28.35
6	28.53

CHANNEL # TEMPERATURE AT MOVING WALL

7	48.16
8	49.39
9	51.03
10	51.37

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	62.68
27	62.99
28	60.23
29	60.39

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.46
12	25.56
13	25.52
14	25.43
15	25.86
16	25.94
17	25.91

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	65.27
19	65.33
22	64.20
24	62.74
25	57.66

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	63.68
23	63.23

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	54.40
31	63.57
32	63.80
33	62.04
34	59.16
35	46.56

AVERAGE COLD PLATE TEMPERATURE: 25.68
SURFACE GLASS TEMPERATURE : 44.29
AMBIENT TEMPERATURE : 21.07

HEAT LOSS FROM BOTTOM WALL IS	.08 WATTS	.19 %
HEAT LOSS FROM MOVING WALL IS	.42 WATTS	1.05 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.39 WATTS	.97 %
HEAT LOSS TO AIR THROUGH END GLASSES	.64 WATTS	1.61 %
TOTAL HEAT INPUT IS :	39.86 WATTS	
TOTAL HEAT LOSS IS :	1.52 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	439.80	35.35	78.83	80.37	15.85
2	443.10	53.49	119.20	120.72	24.01
3	186.00	20.15	107.81	108.31	3.76
4	339.90	37.11	108.63	109.19	12.68
5	14.83	2.96	188.42	199.25	.05

PROBE MEASUREMENTS

y/H x= 3.00 mm

.9545	49.47
.8636	52.51
.7727	52.23
.6818	51.82
.5909	52.52
.5000	52.23
.4091	51.77
.3182	51.69
.2273	51.65
.1364	51.04
.0455	42.76

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 8.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	8.059	+2.443E+07	+3.031E+06	93.070
.0525	18.892	+9.174E+08	+4.856E+07	93.619
.0825	29.060	+5.829E+09	+2.006E+08	91.677
.1125	38.128	+2.032E+10	+5.331E+08	88.234
.1425	43.968	+4.752E+10	+1.081E+09	80.327

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	6.448	+1.001E+07	+1.552E+06	88.041
.0525	6.477	+1.268E+07	+1.957E+06	81.275
.0825	6.340	+1.321E+07	+2.083E+06	79.472
.1125	6.100	+1.332E+07	+2.183E+06	78.126
.1425	5.554	+1.210E+07	+2.178E+06	78.193

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.373	+5.481E+04	+4.826E+06
.0525	5.398	+7.522E+04	+6.113E+06
.0825	5.284	+8.016E+04	+6.370E+06
.1125	5.084	+8.222E+04	+6.424E+06
.1425	4.628	+7.462E+04	+5.834E+06

Ra(w)ave= +1.330E+07
Nu(w)ave 6.18

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
28.072	+5.566E+07	405.780	+1.516E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.23
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.85
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.57
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.65
% ENERGY CONTRIBUTED BY HEATER 5 IS 87.86

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 9.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.90
20	-26.54
100	-25.78

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.06
2	34.43
3	30.59
4	31.84
5	29.24
6	29.49

CHANNEL # TEMPERATURE AT MOVING WALL

7	50.41
8	52.21
9	53.71
10	54.31

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	67.08
27	67.51
28	64.42
29	64.61

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.82
12	25.90
13	25.88
14	25.86
15	26.28
16	26.38
17	26.36

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	69.59
19	69.61
22	68.35
24	66.93
25	61.90

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	67.74
23	67.33

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	57.96
31	67.86
32	68.12
33	66.22
34	63.25
35	49.82

AVERAGE COLD PLATE TEMPERATURE: 26.07

SURFACE GLASS TEMPERATURE : 46.44

AMBIENT TEMPERATURE : 21.94

HEAT LOSS FROM BOTTOM WALL IS	.09 WATTS	.20 %
HEAT LOSS FROM MOVING WALL IS	.64 WATTS	1.41 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.51 WATTS	1.14 %
HEAT LOSS TO AIR THROUGH END GLASSES	.69 WATTS	1.53 %
TOTAL HEAT INPUT IS :	45.20 WATTS	
TOTAL HEAT LOSS IS :	1.93 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	468.10	37.67	78.83	80.48	18.01
2	471.10	56.93	119.20	120.85	27.19
3	197.10	21.33	107.81	108.23	4.22
4	357.70	39.14	108.63	109.43	14.11
5	14.88	2.97	188.42	199.43	.05

PROBE MEASUREMENTS

y/H x= 3.00 mm

.9545	52.66
.8636	55.07
.7727	54.70
.6818	54.68
.5909	55.28
.5000	55.05
.4091	54.73
.3182	54.67
.2273	54.74
.1364	54.32
.0455	46.05

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 9.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	8.073	+2.962E+07	+3.668E+06	93.340
.0525	19.179	+1.105E+09	+5.763E+07	95.156
.0825	29.657	+7.016E+09	+2.366E+08	93.671
.1125	38.905	+2.451E+10	+6.299E+08	90.140
.1425	45.088	+5.768E+10	+1.279E+09	82.473

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	6.459	+1.213E+07	+1.878E+06	81.844
.0525	6.576	+1.527E+07	+2.323E+06	75.829
.0825	6.471	+1.590E+07	+2.457E+06	74.261
.1125	6.225	+1.606E+07	+2.580E+06	72.909
.1425	5.695	+1.468E+07	+2.578E+06	72.928

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.382	+7.148E+04	+5.850E+06
.0525	5.480	+9.713E+04	+7.365E+06
.0825	5.392	+1.032E+05	+7.667E+06
.1125	5.187	+1.062E+05	+7.745E+06
.1425	4.746	+9.710E+04	+7.081E+06

Ra(w)ave= +1.601E+07
Nu(w)ave 6.28

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
28.460	+6.702E+07	411.881	+1.697E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.53
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.96
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.73
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.85
% ENERGY CONTRIBUTED BY HEATER 5 IS 88.58

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 10.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-24.81
20	-24.42
100	-24.08

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	31.94
2	33.14
3	29.64
4	30.80
5	28.41
6	28.70

CHANNEL # TEMPERATURE AT MOVING WALL

7	50.65
8	52.43
9	54.47
10	55.09

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	68.92
27	69.26
28	65.67
29	65.88

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	24.90
12	25.03
13	24.98
14	24.93
15	25.38
16	25.50
17	25.39

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	71.52
19	71.50
22	70.14
24	68.61
25	62.38

CAVITY WIDTH

18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	69.48
23	69.05

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	59.25
31	69.80
32	69.98
33	67.88
34	64.33
35	48.90

AVERAGE COLD PLATE TEMPERATURE: 25.16

SURFACE GLASS TEMPERATURE : 46.62

AMBIENT TEMPERATURE : 20.73

HEAT LOSS FROM BOTTOM WALL IS	.08 WATTS	.16 %
HEAT LOSS FROM MOVING WALL IS	.64 WATTS	1.28 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.45 WATTS	.90 %
HEAT LOSS TO AIR THROUGH END GLASSES	.74 WATTS	1.47 %
TOTAL HEAT INPUT IS :	50.09 WATTS	
TOTAL HEAT LOSS IS :	1.90 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	495.40	39.79	78.83	80.31	20.08
2	494.70	59.81	119.20	120.90	30.01
3	206.60	22.22	107.81	107.53	4.58
4	365.70	39.96	108.63	109.27	14.70
5	14.88	2.97	188.42	199.35	.05

PROBE MEASUREMENTS

y/H	x= 3.00 mm
.9545	51.89
.8636	54.87
.7727	56.16
.6818	55.83
.5909	56.16
.5000	55.86
.4091	55.77
.3182	55.63
.2273	55.56
.1364	54.68
.0455	44.12

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 10.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	8.709	+3.296E+07	+3.785E+06	100.679
.0525	20.159	+1.250E+09	+6.202E+07	100.039
.0825	31.168	+7.954E+09	+2.552E+08	98.465
.1125	40.889	+2.783E+10	+6.806E+08	94.761
.1425	47.627	+6.593E+10	+1.384E+09	87.140

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	6.967	+1.350E+07	+1.938E+06	82.385
.0525	6.912	+1.728E+07	+2.499E+06	74.976
.0825	6.800	+1.802E+07	+2.651E+06	73.306
.1125	6.542	+1.824E+07	+2.788E+06	71.884
.1425	6.016	+1.678E+07	+2.790E+06	71.860

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.806	+7.903E+04	+6.511E+06
.0525	5.760	+1.111E+05	+8.331E+06
.0825	5.667	+1.186E+05	+8.692E+06
.1125	5.452	+1.224E+05	+8.795E+06
.1425	5.013	+1.126E+05	+8.095E+06

Ra(w)ave= +1.806E+07
Nu(w)ave 6.65

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
29.979	+7.558E+07	433.933	+1.895E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.83
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.06
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.90
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.05
% ENERGY CONTRIBUTED BY HEATER 5 IS 89.29

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 11.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.03
20	-27.66
100	-27.23

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.90
2	35.18
3	31.41
4	32.60
5	30.19
6	30.41

CHANNEL # TEMPERATURE AT MOVING WALL

7	50.89
8	53.36
9	54.76
10	55.78

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	70.01
27	70.67
28	66.61
29	67.05

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.78
12	25.80
13	25.84
14	25.88
15	26.37
16	26.50
17	26.42

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	73.68
19	73.67
22	71.89
24	70.33
25	64.62

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	71.28
23	70.63

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	60.31
31	70.75
32	71.23
33	69.06
34	65.16
35	50.62

AVERAGE COLD PLATE TEMPERATURE: 26.08
 SURFACE GLASS TEMPERATURE : 48.35
 AMBIENT TEMPERATURE : 21.93

HEAT LOSS FROM BOTTOM WALL IS	.08 WATTS	.15 %
HEAT LOSS FROM MOVING WALL IS	.92 WATTS	1.68 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.89 WATTS	1.62 %
HEAT LOSS TO AIR THROUGH END GLASSES	.75 WATTS	1.37 %
TOTAL HEAT INPUT IS :	55.38 WATTS	
TOTAL HEAT LOSS IS :	2.65 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	512.70	41.42	78.83	80.79	21.76
2	521.20	63.30	119.20	121.45	33.62
3	134.75	14.80	107.81	109.81	2.03
4	351.80	38.56	108.63	109.60	13.69
5	0.00	0.00	188.42	330.00	0.00

PROBE MEASUREMENTS

y/H x= 3.00 mm

.9545	52.93
.8636	56.09
.7727	56.99
.6818	57.20
.5909	57.82
.5000	57.55
.4091	57.22
.3182	57.10
.2273	56.97
.1364	56.31
.0455	46.35

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 11.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	9.182	+3.787E+07	+4.125E+06	106.229
.0525	21.555	+1.418E+09	+6.580E+07	107.037
.0825	33.349	+9.027E+09	+2.707E+08	105.428
.1125	43.396	+3.178E+10	+7.323E+08	100.652
.1425	50.859	+7.572E+10	+1.489E+09	93.127

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	7.345	+1.551E+07	+2.112E+06	78.480
.0525	7.390	+1.960E+07	+2.652E+06	72.132
.0825	7.276	+2.046E+07	+2.811E+06	70.539
.1125	6.943	+2.083E+07	+2.999E+06	68.793
.1425	6.424	+1.928E+07	+3.001E+06	68.782

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.121	+9.533E+04	+7.481E+06
.0525	6.158	+1.310E+05	+9.451E+06
.0825	6.063	+1.399E+05	+9.865E+06
.1125	5.786	+1.460E+05	+1.004E+07
.1425	5.354	+1.352E+05	+9.296E+06

Ra(w)ave= +2.055E+07
Nu(w)ave 7.08

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
31.817	+8.601E+07	460.886	+2.063E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.13
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.17
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.06
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.25
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.00

CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 12.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.68
20	-27.14
100	-26.51

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.66
2	35.35
3	31.60
4	32.79
5	30.34
6	30.66

CHANNEL # TEMPERATURE AT MOVING WALL

7	52.97
8	55.50
9	57.75
10	58.45

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	72.43
27	73.12
28	68.80
29	69.33

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.02
12	26.03
13	26.09
14	26.08
15	26.67
16	26.79
17	26.73

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	76.43
19	76.41
22	74.41
24	73.00
25	66.77

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	73.68
23	73.13

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	62.30
31	73.26
32	73.82
33	71.55
34	67.31
35	51.49

AVERAGE COLD PLATE TEMPERATURE: 26.34
 SURFACE GLASS TEMPERATURE : 49.29
 AMBIENT TEMPERATURE : 22.41

HEAT LOSS FROM BOTTOM WALL IS	.11 WATTS	.19 %
HEAT LOSS FROM MOVING WALL IS	.86 WATTS	1.43 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.99 WATTS	1.66 %
HEAT LOSS TO AIR THROUGH END GLASSES	.77 WATTS	1.28 %
TOTAL HEAT INPUT IS :	60.01 WATTS	
TOTAL HEAT LOSS IS :	2.73 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	536.60	43.34	78.83	80.76	23.82
2	540.80	65.67	119.20	121.44	36.18
3	135.42	14.40	107.81	106.32	1.92
4	378.40	41.50	108.63	109.68	15.86
5	0.00	0.00	188.42	496.00	0.00

PROBE MEASUREMENTS

y/H	x= 3.00 mm
.9545	53.83
.8636	58.20
.7727	58.61
.6818	59.04
.5909	59.69
.5000	59.54
.4091	59.11
.3182	58.99
.2273	58.94
.1364	58.18
.0455	47.14

RESULTS FOR ASPECT RATIO = 9.167
POWER INPUT PER ELEMENT = 12.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	9.603	+4.318E+07	+4.496E+06	111.178
.0525	22.371	+1.622E+09	+7.252E+07	111.175
.0825	34.798	+1.030E+10	+2.961E+08	110.088
.1125	45.178	+3.638E+10	+8.052E+08	104.865
.1425	53.250	+8.719E+10	+1.637E+09	97.581

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	7.683	+1.769E+07	+2.302E+06	75.700
.0525	7.670	+2.242E+07	+2.923E+06	69.191
.0825	7.592	+2.335E+07	+3.075E+06	67.836
.1125	7.228	+2.384E+07	+3.298E+06	66.000
.1425	6.726	+2.220E+07	+3.300E+06	65.984

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.402	+1.127E+05	+8.529E+06
.0525	6.392	+1.562E+05	+1.081E+07
.0825	6.327	+1.660E+05	+1.126E+07
.1125	6.024	+1.742E+05	+1.150E+07
.1425	5.605	+1.622E+05	+1.070E+07

Ra(w)ave= +2.344E+07
Nu(w)ave 7.38

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
33.077	+9.811E+07	479.482	+2.256E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.43
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.27
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.23
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.45
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.71

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 2.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.18
20	-25.05
100	-24.59

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	26.57
2	27.21
3	25.70
4	26.36
5	25.01
6	25.14

CHANNEL # TEMPERATURE AT MOVING WALL

7	31.81
8	32.15
9	32.27
10	32.48

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	36.56
27	36.81
28	36.04
29	36.17

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.45
12	25.46
13	25.44
14	25.43
15	25.51
16	25.52
17	25.47

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	37.64
19	37.74
22	37.61
24	37.11
25	35.65

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	37.43
23	37.29

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	33.83
31	37.00
32	37.20
33	36.70
34	35.84
35	32.50

AVERAGE COLD PLATE TEMPERATURE: 25.47
 SURFACE GLASS TEMPERATURE : 30.52
 AMBIENT TEMPERATURE : 21.31

HEAT LOSS FROM BOTTOM WALL IS	.05 WATTS	.54 %
HEAT LOSS FROM MOVING WALL IS	.15 WATTS	1.50 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.32 WATTS	3.16 %
HEAT LOSS TO AIR THROUGH END GLASSES	.26 WATTS	2.56 %
TOTAL HEAT INPUT IS :	10.00 WATTS	
TOTAL HEAT LOSS IS :	.78 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	221.30	17.77	78.83	80.32	4.01
2	222.50	26.73	119.20	120.13	5.99
3	103.00	11.10	107.81	107.80	1.14
4	168.70	18.36	108.63	108.82	3.10
5	5.97	1.19	188.42	198.97	.01

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	32.54
.8636	33.32
.7727	33.75
.6818	33.75
.5909	33.69
.5000	33.58
.4091	33.41
.3182	33.33
.2273	33.26
.1364	33.10
.0455	31.64

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 2.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	6.003	+3.846E+06	+6.407E+05	68.923
.0525	14.374	+1.378E+08	+9.584E+06	70.758
.0825	21.959	+8.594E+08	+3.914E+07	68.796
.1125	29.257	+2.945E+09	+1.006E+08	67.219
.1425	33.054	+6.688E+09	+2.023E+08	59.953

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	6.003	+3.846E+06	+6.407E+05	129.878
.0525	6.160	+4.648E+06	+7.544E+05	126.339
.0825	5.989	+4.755E+06	+7.939E+05	125.182
.1125	5.851	+4.712E+06	+8.052E+05	124.858
.1425	5.219	+4.157E+06	+7.964E+05	125.109

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.002	+5.849E+03	+7.597E+05
.0525	4.107	+7.267E+03	+9.181E+05
.0825	3.993	+7.503E+03	+9.392E+05
.1125	3.901	+7.454E+03	+9.307E+05
.1425	3.479	+6.563E+03	+8.211E+05

Ra(w)ave= +4.898E+06
Nu(w)ave 5.84

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
21.672	+1.641E+07	248.921	+2.908E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 80.86
% ENERGY CONTRIBUTED BY HEATER 2 IS 94.95
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.22
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.09
% ENERGY CONTRIBUTED BY HEATER 5 IS 84.06

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 4.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.51
20	-25.39
100	-25.08

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	28.28
2	29.30
3	26.98
4	27.92
5	25.91
6	26.12

CHANNEL # TEMPERATURE AT MOVING WALL

7	37.36
8	37.87
9	38.08
10	38.32

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	45.49
27	45.77
28	44.56
29	44.67

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.49
12	25.51
13	25.49
14	25.48
15	25.67
16	25.71
17	25.66

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	47.12
19	47.23
22	46.81
24	46.02
25	43.72

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	46.53
23	46.26

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	40.92
31	46.07
32	46.31
33	45.41
34	44.04
35	38.08

AVERAGE COLD PLATE TEMPERATURE: 25.57
 SURFACE GLASS TEMPERATURE : 35.12
 AMBIENT TEMPERATURE : 21.62

HEAT LOSS FROM BOTTOM WALL IS	.09 WATTS	.43 %
HEAT LOSS FROM MOVING WALL IS	.20 WATTS	1.01 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.32 WATTS	1.61 %
HEAT LOSS TO AIR THROUGH END GLASSES	.41 WATTS	2.05 %
TOTAL HEAT INPUT IS :	19.94 WATTS	
TOTAL HEAT LOSS IS :	1.02 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	311.50	25.05	78.83	80.43	7.96
2	312.30	37.79	119.20	120.99	11.98
3	138.20	15.06	107.81	108.98	2.10
4	229.70	25.13	108.63	109.41	5.81
5	5.96	1.19	188.42	199.23	.01

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	38.74
.8636	39.60
.7727	39.50
.6818	39.77
.5909	40.02
.5000	39.98
.4091	39.83
.3182	39.55
.2273	39.37
.1364	39.18
.0455	36.56

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 4.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	6.999	+9.365E+06	+1.338E+06	80.535
.0525	16.900	+3.377E+08	+1.998E+07	83.384
.0825	25.947	+2.121E+09	+8.175E+07	81.486
.1125	34.341	+7.315E+09	+2.130E+08	79.096
.1425	39.412	+1.694E+10	+4.299E+08	71.665

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	6.999	+9.365E+06	+1.338E+06	111.727
.0525	7.243	+1.139E+07	+1.573E+06	107.274
.0825	7.076	+1.174E+07	+1.658E+06	105.790
.1125	6.868	+1.170E+07	+1.704E+06	105.020
.1425	6.223	+1.053E+07	+1.692E+06	105.218

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.666	+1.656E+04	+1.850E+06
.0525	4.828	+2.098E+04	+2.250E+06
.0825	4.718	+2.191E+04	+2.318E+06
.1125	4.579	+2.201E+04	+2.312E+06
.1425	4.149	+1.977E+04	+2.080E+06

Ra(w)ave= +1.197E+07
Nu(w)ave 6.88

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
25.217	+4.011E+07	290.333	+5.983E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.86
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.47
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.92
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.93
% ENERGY CONTRIBUTED BY HEATER 5 IS 86.49

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 6.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-24.75
20	-24.33
100	-23.96

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	30.00
2	31.25
3	28.17
4	29.43
5	26.97
6	27.19

CHANNEL # TEMPERATURE AT MOVING WALL

7	41.86
8	42.66
9	43.05
10	43.45

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	53.21
27	53.47
28	51.81
29	51.91

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.68
12	25.70
13	25.73
14	25.69
15	25.98
16	26.06
17	25.98

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	55.26
19	55.35
22	54.47
24	53.45
25	50.41

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	54.04
23	53.71

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	46.96
31	53.85
32	54.12
33	52.85
34	51.03
35	42.74

AVERAGE COLD PLATE TEMPERATURE: 25.83
 SURFACE GLASS TEMPERATURE : 39.21
 AMBIENT TEMPERATURE : 20.22

HEAT LOSS FROM BOTTOM WALL IS	.10 WATTS	.35 %
HEAT LOSS FROM MOVING WALL IS	.32 WATTS	1.06 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.29 WATTS	.98 %
HEAT LOSS TO AIR THROUGH END GLASSES	.63 WATTS	2.09 %
TOTAL HEAT INPUT IS :	29.96 WATTS	
TOTAL HEAT LOSS IS :	1.34 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	382.60	30.72	78.83	80.29	11.97
2	384.30	46.30	119.20	120.49	17.99
3	164.90	17.85	107.81	108.24	2.95
4	275.20	30.06	108.63	109.22	8.32
5	8.89	1.78	188.42	199.95	.02

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	42.94
.8636	44.54
.7727	44.81
.6818	45.11
.5909	45.12
.5000	45.10
.4091	44.74
.3182	44.54
.2273	44.39
.1364	44.13
.0455	40.29

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 6.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	7.836	+1.613E+07	+2.059E+06	90.328
.0525	18.902	+5.860E+08	+3.100E+07	93.448
.0825	29.099	+3.696E+09	+1.270E+08	91.575
.1125	38.123	+1.285E+10	+3.370E+08	88.000
.1425	44.089	+3.006E+10	+6.817E+08	80.344

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	7.836	+1.613E+07	+2.059E+06	98.986
.0525	8.101	+1.977E+07	+2.440E+06	94.072
.0825	7.936	+2.045E+07	+2.576E+06	92.496
.1125	7.625	+2.056E+07	+2.696E+06	91.169
.1425	6.961	+1.868E+07	+2.684E+06	91.307

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.224	+3.219E+04	+3.187E+06
.0525	5.400	+4.151E+04	+3.905E+06
.0825	5.291	+4.366E+04	+4.039E+06
.1125	5.083	+4.454E+04	+4.061E+06
.1425	4.641	+4.042E+04	+3.690E+06

Ra(w)ave= +2.078E+07
Nu(w)ave 7.69

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
28.008	+6.961E+07	323.125	+9.033E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.36
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.72
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.28
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.36
% ENERGY CONTRIBUTED BY HEATER 5 IS 87.70

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 8.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.10
20	-26.68
100	-26.14

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.29
2	33.62
3	30.15
4	31.43
5	28.80
6	28.96

CHANNEL # TEMPERATURE AT MOVING WALL

7	43.63
8	45.34
9	44.97
10	46.12

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	58.71
27	59.12
28	56.75
29	57.03

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.72
12	25.73
13	25.78
14	25.79
15	26.17
16	26.23
17	26.16

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	61.47
19	61.57
22	60.31
24	59.31
25	55.83

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	59.67
23	59.34

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	51.19
31	59.31
32	59.64
33	58.14
34	55.79
35	46.18

AVERAGE COLD PLATE TEMPERATURE: 25.94
SURFACE GLASS TEMPERATURE : 42.00
AMBIENT TEMPERATURE : 22.27

HEAT LOSS FROM BOTTOM WALL IS	.11 WATTS	.28 %
HEAT LOSS FROM MOVING WALL IS	.76 WATTS	1.91 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.57 WATTS	1.42 %
HEAT LOSS TO AIR THROUGH END GLASSES	.66 WATTS	1.64 %
TOTAL HEAT INPUT IS :	40.03 WATTS	
TOTAL HEAT LOSS IS :	2.10 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	440.20	35.50	78.83	80.65	15.99
2	440.80	53.54	119.20	121.45	24.04
3	126.27	13.67	107.81	108.30	1.73
4	275.60	30.18	108.63	109.52	8.39
5	0.00	0.00	188.42	330.00	0.00

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	43.81
.8636	48.01
.7727	48.40
.6818	48.79
.5909	48.85
.5000	48.87
.4091	48.88
.3182	48.62
.2273	48.32
.1364	47.97
.0455	43.12

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 8.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	8.561	+2.362E+07	+2.759E+06	98.826
.0525	20.713	+8.594E+08	+4.149E+07	102.560
.0825	32.133	+5.419E+09	+1.687E+08	101.277
.1125	41.892	+1.896E+10	+4.526E+08	96.857
.1425	48.881	+4.477E+10	+9.158E+08	89.220

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	8.561	+2.362E+07	+2.759E+06	90.293
.0525	8.877	+2.899E+07	+3.266E+06	85.399
.0825	8.764	+2.998E+07	+3.421E+06	84.059
.1125	8.378	+3.033E+07	+3.621E+06	82.427
.1425	7.718	+2.782E+07	+3.605E+06	82.550

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.708	+5.167E+04	+4.666E+06
.0525	5.918	+6.706E+04	+5.727E+06
.0825	5.842	+7.046E+04	+5.923E+06
.1125	5.586	+7.270E+04	+5.992E+06
.1425	5.145	+6.658E+04	+5.496E+06

Ra(w)ave= +3.041E+07
Nu(w)ave 8.46

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
30.628	+1.019E+08	353.905	+1.195E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.86
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.98
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.63
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.78
% ENERGY CONTRIBUTED BY HEATER 5 IS 88.91

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 10.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.41
20	-25.03
100	-24.41

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	31.88
2	33.35
3	29.58
4	30.99
5	28.19
6	28.49

CHANNEL # TEMPERATURE AT MOVING WALL

7	48.50
8	49.91
9	51.22
10	51.53

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	65.07
27	65.46
28	62.35
29	62.70

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.63
12	25.70
13	25.68
14	25.72
15	26.18
16	26.28
17	26.20

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	68.06
19	68.08
22	66.77
24	65.20
25	60.73

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	66.05
23	65.71

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	56.48
31	66.00
32	66.15
33	64.18
34	61.36
35	48.53

AVERAGE COLD PLATE TEMPERATURE: 25.91
 SURFACE GLASS TEMPERATURE : 45.36
 AMBIENT TEMPERATURE : 20.26

HEAT LOSS FROM BOTTOM WALL IS	.12 WATTS	.25 %
HEAT LOSS FROM MOVING WALL IS	.46 WATTS	.91 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.61 WATTS	1.21 %
HEAT LOSS TO AIR THROUGH END GLASSES	.88 WATTS	1.77 %
TOTAL HEAT INPUT IS :	50.23 WATTS	
TOTAL HEAT LOSS IS :	2.07 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	490.00	39.53	78.83	80.68	19.83
2	496.20	60.20	119.20	121.31	30.40
3	174.40	18.95	107.81	108.64	3.33
4	342.70	37.58	108.63	109.66	13.00
5	13.71	2.77	188.42	202.30	.04

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	47.31
.8636	52.40
.7727	52.61
.6818	53.31
.5909	53.60
.5000	53.14
.4091	53.19
.3182	52.75
.2273	52.45
.1364	52.04
.0455	45.36

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 10.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	9.339	+3.258E+07	+3.489E+06	107.939
.0525	22.268	+1.198E+09	+5.378E+07	110.429
.0825	34.246	+7.621E+09	+2.225E+08	108.116
.1125	44.879	+2.667E+10	+5.943E+08	103.938
.1425	52.734	+6.364E+10	+1.207E+09	96.416

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	9.339	+3.258E+07	+3.489E+06	83.541
.0525	9.544	+4.040E+07	+4.234E+06	77.994
.0825	9.340	+4.216E+07	+4.514E+06	76.181
.1125	8.976	+4.268E+07	+4.754E+06	74.725
.1425	8.326	+3.955E+07	+4.750E+06	74.750

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.226	+7.704E+04	+6.436E+06
.0525	6.362	+1.023E+05	+7.981E+06
.0825	6.227	+1.093E+05	+8.328E+06
.1125	5.984	+1.128E+05	+8.430E+06
.1425	5.551	+1.045E+05	+7.813E+06

Ra(w)ave= +4.238E+07
Nu(w)ave 9.10

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
32.754	+1.419E+08	379.052	+1.511E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.36
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.23
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.98
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.20
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.12

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 12.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.87
20	-27.44
100	-26.66

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.59
2	35.08
3	31.12
4	32.48
5	29.62
6	29.86

CHANNEL # TEMPERATURE AT MOVING WALL

7	49.46
8	51.87
9	52.60
10	53.66

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	69.47
27	70.08
28	66.31
29	66.83

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.88
12	25.96
13	25.96
14	25.95
15	26.57
16	26.69
17	26.60

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	73.04
19	73.06
22	71.24
24	69.95
25	65.10

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	70.52
23	69.93

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	59.62
31	70.11
32	70.67
33	68.56
34	64.96
35	51.11

AVERAGE COLD PLATE TEMPERATURE: 26.23
 SURFACE GLASS TEMPERATURE : 47.08
 AMBIENT TEMPERATURE : 22.51

HEAT LOSS FROM BOTTOM WALL IS	.12 WATTS	.21 %
HEAT LOSS FROM MOVING WALL IS	.92 WATTS	1.54 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.93 WATTS	1.55 %
HEAT LOSS TO AIR THROUGH END GLASSES	.86 WATTS	1.43 %
TOTAL HEAT INPUT IS :	60.08 WATTS	
TOTAL HEAT LOSS IS :	2.84 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	536.60	43.37	78.83	80.83	23.86
2	540.50	65.71	119.20	121.57	36.22
3	131.05	14.41	107.81	109.92	1.92
4	340.00	37.33	108.63	109.81	12.83
5	0.00	0.00	188.42	414.17	0.00

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	49.74
.8636	55.14
.7727	55.38
.6818	55.77
.5909	56.07
.5000	56.07
.4091	56.16
.3182	56.04
.2273	55.70
.1364	55.13
.0455	47.15

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 12.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	10.026	+4.213E+07	+4.202E+06	116.016
.0525	23.902	+1.548E+09	+6.477E+07	118.689
.0825	37.167	+9.810E+09	+2.640E+08	117.482
.1125	48.336	+3.460E+10	+7.158E+08	112.096
.1425	57.306	+8.329E+10	+1.453E+09	104.919

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	10.026	+4.213E+07	+4.202E+06	77.747
.0525	10.244	+5.223E+07	+5.099E+06	72.382
.0825	10.136	+5.427E+07	+5.354E+06	71.049
.1125	9.667	+5.536E+07	+5.726E+06	69.239
.1425	9.048	+5.177E+07	+5.721E+06	69.260

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.684	+1.070E+05	+8.322E+06
.0525	6.829	+1.425E+05	+1.032E+07
.0825	6.758	+1.509E+05	+1.072E+07
.1125	6.445	+1.579E+05	+1.093E+07
.1425	6.032	+1.476E+05	+1.023E+07

Ra(w)ave= +5.459E+07
Nu(w)ave 9.82

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
35.142	+1.828E+08	407.216	+1.802E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.86
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.49
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.33
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.62
% ENERGY CONTRIBUTED BY HEATER 5 IS 91.33

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 13.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-22.62
20	-22.25
100	-21.69

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.46
2	34.28
3	29.59
4	31.31
5	27.95
6	28.33

CHANNEL # TEMPERATURE AT MOVING WALL

7	51.87
8	54.28
9	55.88
10	56.55

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	74.03
27	74.36
28	70.24
29	70.68

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.56
12	25.64
13	25.65
14	25.60
15	26.22
16	26.41
17	26.28

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	76.62
19	76.50
22	74.83
24	73.26
25	67.95

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	73.88
23	73.55

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	63.54
31	74.77
32	74.78
33	72.33
34	68.98
35	53.23

AVERAGE COLD PLATE TEMPERATURE: 25.91
 SURFACE GLASS TEMPERATURE : 49.20
 AMBIENT TEMPERATURE : 19.60

HEAT LOSS FROM BOTTOM WALL IS	.15 WATTS	.23 %
HEAT LOSS FROM MOVING WALL IS	.82 WATTS	1.26 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.62 WATTS	.96 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.09 WATTS	1.67 %
TOTAL HEAT INPUT IS :	65.16 WATTS	
TOTAL HEAT LOSS IS :	2.67 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	561.20	45.19	78.83	80.53	25.91
2	565.70	68.40	119.20	120.92	39.25
3	206.10	22.47	107.81	109.03	4.68
4	379.00	41.51	108.63	109.52	15.86
5	14.88	2.97	188.42	199.40	.05

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	56.71
.8636	59.12
.7727	58.52
.6818	58.75
.5909	58.99
.5000	58.90
.4091	58.64
.3182	58.23
.2273	57.87
.1364	57.35
.0455	48.20

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 13.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	10.129	+4.792E+07	+4.731E+06	117.286
.0525	24.074	+1.767E+09	+7.342E+07	119.633
.0825	37.320	+1.124E+10	+3.013E+08	118.066
.1125	48.850	+3.955E+10	+8.097E+08	113.380
.1425	58.011	+9.584E+10	+1.652E+09	106.300

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	10.129	+4.792E+07	+4.731E+06	74.866
.0525	10.317	+5.963E+07	+5.779E+06	69.358
.0825	10.178	+6.221E+07	+6.112E+06	67.853
.1125	9.770	+6.328E+07	+6.477E+06	66.308
.1425	9.160	+5.957E+07	+6.503E+06	66.204

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.753	+1.264E+05	+9.466E+06
.0525	6.878	+1.698E+05	+1.178E+07
.0825	6.785	+1.811E+05	+1.229E+07
.1125	6.513	+1.885E+05	+1.250E+07
.1425	6.106	+1.777E+05	+1.177E+07

Ra(w)ave= +6.226E+07
Nu(w)ave 9.91

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
35.349	+2.085E+08	409.935	+1.965E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 84.11
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.62
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.51
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.83
% ENERGY CONTRIBUTED BY HEATER 5 IS 91.93

CAVITY WIDTH 22.50 mm
POWER INPUT PER ELEMENT 14.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.58
20	-28.15
100	-27.44

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	35.49
2	37.13
3	32.77
4	34.26
5	31.23
6	31.49

CHANNEL # TEMPERATURE AT MOVING WALL

7	53.23
8	55.90
9	57.52
10	58.18

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	75.60
27	76.09
28	71.60
29	72.21

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.94
12	26.05
13	26.06
14	26.06
15	26.75
16	26.94
17	26.83

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	78.97
19	78.91
22	76.87
24	75.41
25	70.12

CAVITY WIDTH 22.50 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	76.05
23	75.42

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	64.79
31	76.09
32	76.43
33	74.07
34	70.15
35	54.82

AVERAGE COLD PLATE TEMPERATURE: 26.38
 SURFACE GLASS TEMPERATURE : 50.82
 AMBIENT TEMPERATURE : 22.99

HEAT LOSS FROM BOTTOM WALL IS	.14 WATTS	.19 %
HEAT LOSS FROM MOVING WALL IS	.88 WATTS	1.26 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.89 WATTS	1.28 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.00 WATTS	1.43 %
TOTAL HEAT INPUT IS :	70.09 WATTS	
TOTAL HEAT LOSS IS :	2.92 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	578.90	46.77	78.83	80.79	27.75
2	583.00	71.04	119.20	121.85	42.34
3	148.60	16.36	107.81	110.09	2.48
4	379.40	41.67	108.63	109.82	15.98
5	0.00	0.00	188.42	310.62	0.00

PROBE MEASUREMENTS

y/H	x= 7.50 mm
.9545	55.74
.8636	59.12
.7727	60.21
.6818	60.71
.5909	60.20
.5000	59.81
.4091	60.18
.3182	59.96
.2273	59.57
.1364	58.94
.0455	50.30

RESULTS FOR ASPECT RATIO = 7.333
POWER INPUT PER ELEMENT = 14.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	10.441	+5.353E+07	+5.127E+06	120.977
.0525	24.972	+1.974E+09	+7.904E+07	124.178
.0825	38.820	+1.252E+10	+3.226E+08	122.891
.1125	50.486	+4.424E+10	+8.764E+08	117.265
.1425	59.757	+1.066E+11	+1.785E+09	109.579

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	10.441	+5.353E+07	+5.127E+06	72.046
.0525	10.702	+6.658E+07	+6.222E+06	66.874
.0825	10.587	+6.929E+07	+6.545E+06	65.553
.1125	10.097	+7.079E+07	+7.011E+06	63.781
.1425	9.435	+6.628E+07	+7.025E+06	63.730

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.960	+1.468E+05	+1.057E+07
.0525	7.135	+1.967E+05	+1.315E+07
.0825	7.058	+2.088E+05	+1.369E+07
.1125	6.732	+2.192E+05	+1.398E+07
.1425	6.290	+2.054E+05	+1.309E+07

Ra(w)ave= +6.968E+07
Nu(w)ave 10.25

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
36.675	+2.334E+08	425.611	+2.115E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.86
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.49
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.33
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.62
% ENERGY CONTRIBUTED BY HEATER 5 IS 91.33

CAVITY WIDTH 27.00 mm
POWER INPUT PER ELEMENT 2.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-24.41
20	-24.26
100	-23.60

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	25.33
2	25.95
3	24.60
4	25.30
5	24.05
6	24.21

CHANNEL # TEMPERATURE AT MOVING WALL

7	30.00
8	30.42
9	30.53
10	30.86

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	34.96
27	35.20
28	34.40
29	34.48

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.11
12	25.13
13	25.12
14	25.12
15	25.19
16	25.22
17	25.20

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	36.06
19	36.16
22	36.01
24	35.49
25	33.94

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	35.84
23	35.70

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	32.52
31	35.39
32	35.54
33	35.03
34	34.15
35	30.89

AVERAGE COLD PLATE TEMPERATURE: 25.16
 SURFACE GLASS TEMPERATURE : 29.17
 AMBIENT TEMPERATURE : 19.45

HEAT LOSS FROM BOTTOM WALL IS	.06 WATTS	.62 %
HEAT LOSS FROM MOVING WALL IS	.20 WATTS	1.99 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.27 WATTS	2.70 %
HEAT LOSS TO AIR THROUGH END GLASSES	.33 WATTS	3.28 %
TOTAL HEAT INPUT IS :	10.00 WATTS	
TOTAL HEAT LOSS IS :	.86 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	219.70	17.75	78.83	80.79	4.00
2	221.90	26.76	119.20	120.59	6.01
3	95.56	10.55	107.81	110.37	1.03
4	149.01	16.49	108.63	110.68	2.50
5	5.93	1.18	188.42	199.48	.01

PROBE MEASUREMENTS

y/H	x= 12.00 mm
.9545	31.15
.8636	31.95
.7727	32.03
.6818	32.00
.5909	31.94
.5000	32.00
.4091	31.97
.3182	31.88
.2273	31.72
.1364	31.45
.0455	30.04

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 2.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	6.934	+3.681E+06	+5.308E+05	79.573
.0525	16.015	+1.311E+08	+8.183E+06	78.796
.0825	24.252	+8.172E+08	+3.370E+07	75.942
.1125	32.239	+2.801E+09	+8.688E+07	74.036
.1425	36.768	+6.423E+09	+1.747E+08	66.658

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	8.321	+7.632E+06	+9.172E+05	134.996
.0525	8.236	+9.168E+06	+1.113E+06	131.055
.0825	7.937	+9.375E+06	+1.181E+06	129.769
.1125	7.737	+9.293E+06	+1.201E+06	129.403
.1425	6.967	+8.278E+06	+1.188E+06	129.639

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.623	+5.386E+03	+7.270E+05
.0525	4.576	+6.664E+03	+8.733E+05
.0825	4.409	+6.882E+03	+8.931E+05
.1125	4.299	+6.841E+03	+8.852E+05
.1425	3.870	+6.083E+03	+7.886E+05

Ra(w)ave= +9.691E+06
Nu(w)ave 7.84

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
24.188	+2.706E+07	231.408	+2.401E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.29
% ENERGY CONTRIBUTED BY HEATER 2 IS 94.69
% ENERGY CONTRIBUTED BY HEATER 3 IS 95.85
% ENERGY CONTRIBUTED BY HEATER 4 IS 94.73
% ENERGY CONTRIBUTED BY HEATER 5 IS 84.54

CAVITY WIDTH 27.00 mm
POWER INPUT PER ELEMENT 4.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.93
20	-27.53
100	-27.01

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	29.40
2	30.14
3	28.13
4	29.02
5	27.30
6	27.34

CHANNEL # TEMPERATURE AT MOVING WALL

7	33.55
8	34.85
9	33.90
10	35.02

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	43.04
27	43.40
28	42.22
29	42.39

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.65
12	25.67
13	25.69
14	25.69
15	25.88
16	25.92
17	25.87

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	45.14
19	45.27
22	44.56
24	43.83
25	41.86

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	44.27
23	44.04

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	39.03
31	43.62
32	43.80
33	43.00
34	41.81
35	37.05

AVERAGE COLD PLATE TEMPERATURE: 25.77
 SURFACE GLASS TEMPERATURE : 34.11
 AMBIENT TEMPERATURE : 23.31

HEAT LOSS FROM BOTTOM WALL IS	.07 WATTS	.37 %
HEAT LOSS FROM MOVING WALL IS	.64 WATTS	3.20 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.43 WATTS	2.16 %
HEAT LOSS TO AIR THROUGH END GLASSES	.37 WATTS	1.87 %
TOTAL HEAT INPUT IS :	20.04 WATTS	
TOTAL HEAT LOSS IS :	1.52 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	312.10	25.12	78.83	80.47	8.00
2	312.90	37.88	119.20	121.05	12.03
3	100.64	10.96	107.81	108.94	1.12
4	157.65	17.42	108.63	110.47	2.79
5	0.00	0.00	188.42	332.67	0.00

PROBE MEASUREMENTS

y/H	x = 12.00 mm
.9545	36.19
.8636	37.44
.7727	37.68
.6818	37.73
.5909	37.69
.5000	37.60
.4091	37.50
.3182	37.33
.2273	37.13
.1364	36.87
.0455	35.04

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 4.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	7.675	+8.824E+06	+1.150E+06	88.275
.0525	18.535	+3.154E+08	+1.702E+07	91.406
.0825	28.362	+1.975E+09	+6.962E+07	89.024
.1125	36.843	+6.843E+09	+1.857E+08	84.820
.1425	42.264	+1.581E+10	+3.740E+08	76.815

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	9.211	+1.830E+07	+1.987E+06	115.126
.0525	9.532	+2.206E+07	+2.315E+06	111.119
.0825	9.282	+2.265E+07	+2.441E+06	109.694
.1125	8.842	+2.270E+07	+2.567E+06	108.315
.1425	8.008	+2.037E+07	+2.544E+06	108.568

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.117	+1.514E+04	+1.743E+06
.0525	5.296	+1.892E+04	+2.102E+06
.0825	5.157	+1.967E+04	+2.158E+06
.1125	4.912	+1.997E+04	+2.163E+06
.1425	4.449	+1.787E+04	+1.941E+06

Ra(w)ave= +2.336E+07
Nu(w)ave 8.97

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
27.563	+6.523E+07	264.321	+4.855E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 81.71
% ENERGY CONTRIBUTED BY HEATER 2 IS 94.98
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.22
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.16
% ENERGY CONTRIBUTED BY HEATER 5 IS 85.60

CAVITY WIDTH	27.00 mm
POWER INPUT PER ELEMENT	6.00 W

CHANNEL #	REFERENCE TEMPERATURE (ICE POINT)
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0	-28.03
20	-27.61
100	-26.93

CHANNEL #	TEMPERATURE AT BOTTOM WALL
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1	30.41
2	31.48
3	28.88
4	29.90
5	27.67
6	27.78

CHANNEL #	TEMPERATURE AT MOVING WALL
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7	36.67
8	38.34
9	37.18
10	38.61

CHANNEL #	TEMPERATURE AT BACK OF HOT WALL
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26	49.82
27	50.13
28	48.52
29	48.66

CHANNEL #	TOP SINK SURFACE TEMPERATURE
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11	25.67
12	25.72
13	25.70
14	25.72
15	26.02
16	26.07
17	26.05

CHANNEL #	TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)
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18	52.14
19	52.25
22	51.26
24	50.34
25	47.77

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	50.85
23	50.56

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	44.16
31	50.31
32	50.49
33	49.36
34	47.74
35	40.94

AVERAGE COLD PLATE TEMPERATURE: 25.85

SURFACE GLASS TEMPERATURE : 37.17

AMBIENT TEMPERATURE : 22.47

HEAT LOSS FROM BOTTOM WALL IS .11 WATTS .36 %

HEAT LOSS FROM MOVING WALL IS .82 WATTS 2.74 %

HEAT LOSS THROUGH THE BACK OF HOT WALL .37 WATTS 1.22 %

HEAT LOSS TO AIR THROUGH END GLASSES .55 WATTS 1.82 %

TOTAL HEAT INPUT IS : 30.00 WATTS

TOTAL HEAT LOSS IS : 1.84 WATTS

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	381.00	30.65	78.83	80.45	11.92
2	382.60	46.42	119.20	121.33	18.08
3	120.80	13.27	107.81	109.89	1.63
4	193.20	21.32	108.63	110.37	4.19
5	0.00	0.00	188.42	330.00	0.00

PROBE MEASUREMENTS

y/H	x = 12.00 mm
.9545	38.90
.8636	41.45
.7727	41.84
.6818	42.06
.5909	41.97
.5000	41.79
.4091	41.68
.3182	41.51
.2273	41.26
.1364	40.91
.0455	38.28

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 6.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	8.617	+1.509E+07	+1.751E+06	99.259
.0525	20.856	+5.430E+08	+2.603E+07	103.028
.0825	32.014	+3.412E+09	+1.066E+08	100.663
.1125	41.590	+1.188E+10	+2.856E+08	95.926
.1425	47.956	+2.766E+10	+5.769E+08	87.319

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	10.341	+3.128E+07	+3.025E+06	103.542
.0525	10.726	+3.798E+07	+3.541E+06	99.074
.0825	10.477	+3.914E+07	+3.736E+06	97.538
.1125	9.982	+3.941E+07	+3.948E+06	95.942
.1425	9.086	+3.565E+07	+3.924E+06	96.121

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.745	+2.878E+04	+2.980E+06
.0525	5.959	+3.652E+04	+3.618E+06
.0825	5.821	+3.823E+04	+3.729E+06
.1125	5.545	+3.913E+04	+3.754E+06
.1425	5.048	+3.534E+04	+3.396E+06

Ra(w)ave= +4.017E+07
Nu(w)ave 10.12

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
30.916	+1.121E+08	296.996	+7.396E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.14
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.27
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.59
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.60
% ENERGY CONTRIBUTED BY HEATER 5 IS 86.66

CAVITY WIDTH 27.00 mm
POWER INPUT PER ELEMENT 8.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.65
20	-26.28
100	-25.59

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	30.38
2	31.55
3	28.54
4	29.82
5	27.48
6	27.66

CHANNEL # TEMPERATURE AT MOVING WALL

7	41.35
8	42.53
9	42.46
10	43.32

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	55.46
27	55.85
28	53.66
29	53.89

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.36
12	25.41
13	25.41
14	25.41
15	25.79
16	25.84
17	25.82

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	58.39
19	58.47
22	57.39
24	56.16
25	52.58

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	56.81
23	56.54

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	48.96
31	56.35
32	56.53
33	55.00
34	52.86
35	43.30

AVERAGE COLD PLATE TEMPERATURE: 25.58
SURFACE GLASS TEMPERATURE : 39.79
AMBIENT TEMPERATURE : 20.98

HEAT LOSS FROM BOTTOM WALL IS	.12 WATTS	.29 %
HEAT LOSS FROM MOVING WALL IS	.54 WATTS	1.36 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.51 WATTS	1.27 %
HEAT LOSS TO AIR THROUGH END GLASSES	.74 WATTS	1.86 %
TOTAL HEAT INPUT IS :	39.86 WATTS	
TOTAL HEAT LOSS IS :	1.91 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	440.50	35.41	78.83	80.38	15.91
2	442.60	53.44	119.20	120.73	23.95
3	139.70	15.13	107.81	108.30	2.12
4	266.80	29.10	108.63	109.08	7.80
5	8.89	1.77	188.42	199.36	.02

PROBE MEASUREMENTS

y/H	x = 12.00 mm
.9545	43.81
.8636	45.56
.7727	45.64
.6818	45.64
.5909	45.77
.5000	45.64
.4091	45.56
.3182	45.38
.2273	45.13
.1364	44.70
.0455	39.94

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 8.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	9.503	+2.223E+07	+2.339E+06	109.588
.0525	22.630	+8.110E+08	+3.584E+07	111.951
.0825	34.677	+5.123E+09	+1.477E+08	109.204
.1125	45.287	+1.787E+10	+3.945E+08	104.614
.1425	52.531	+4.194E+10	+7.984E+08	95.798

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	11.403	+4.610E+07	+4.043E+06	95.847
.0525	11.638	+5.673E+07	+4.874E+06	90.342
.0825	11.349	+5.877E+07	+5.179E+06	88.559
.1125	10.869	+5.928E+07	+5.454E+06	87.037
.1425	9.953	+5.406E+07	+5.431E+06	87.158

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.335	+4.582E+04	+4.391E+06
.0525	6.466	+5.982E+04	+5.404E+06
.0825	6.305	+6.322E+04	+5.599E+06
.1125	6.038	+6.488E+04	+5.647E+06
.1425	5.530	+5.908E+04	+5.149E+06

Ra(w)ave= +5.983E+07
Nu(w)ave 11.04

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
33.526	+1.670E+08	322.537	+1.001E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.57
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.55
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.96
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.04
% ENERGY CONTRIBUTED BY HEATER 5 IS 87.71

CAVITY WIDTH 27.00 mm
POWER INPUT PER ELEMENT 10.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-29.21
20	-28.76
100	-28.33

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.89
2	34.03
3	30.90
4	32.06
5	29.63
6	29.81

CHANNEL # TEMPERATURE AT MOVING WALL

7	44.75
8	46.18
9	46.16
10	47.02

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	61.20
27	61.61
28	58.78
29	59.14

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.56
12	25.62
13	25.62
14	25.60
15	26.12
16	26.20
17	26.11

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	64.52
19	64.52
22	63.21
24	61.75
25	57.77

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	62.47
23	62.26

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	53.91
31	62.26
32	62.29
33	60.43
34	57.89
35	46.73

AVERAGE COLD PLATE TEMPERATURE: 25.83
 SURFACE GLASS TEMPERATURE : 44.01
 AMBIENT TEMPERATURE : 24.68

HEAT LOSS FROM BOTTOM WALL IS	.11 WATTS	.23 %
HEAT LOSS FROM MOVING WALL IS	.61 WATTS	1.21 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.63 WATTS	1.27 %
HEAT LOSS TO AIR THROUGH END GLASSES	.77 WATTS	1.53 %
TOTAL HEAT INPUT IS :	49.42 WATTS	
TOTAL HEAT LOSS IS :	2.12 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	488.40	39.26	78.83	80.38	19.55
2	493.50	59.67	119.20	120.91	29.87
3	133.80	14.45	107.81	107.97	1.94
4	285.00	31.07	108.63	109.02	8.89
5	9.57	1.91	188.42	199.87	.02

PROBE MEASUREMENTS

y/H	x= 12.00 mm
.9545	44.88
.8636	48.92
.7727	49.77
.6818	49.29
.5909	49.63
.5000	49.68
.4091	49.44
.3182	49.22
.2273	48.95
.1364	48.52
.0455	43.12

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 10.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	10.136	+3.082E+07	+3.041E+06	117.056
.0525	24.260	+1.126E+09	+4.642E+07	120.199
.0825	37.183	+7.141E+09	+1.920E+08	117.279
.1125	48.543	+2.499E+10	+5.148E+08	112.318
.1425	56.582	+5.919E+10	+1.046E+09	103.356

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	12.163	+6.391E+07	+5.255E+06	87.665
.0525	12.477	+7.878E+07	+6.315E+06	82.333
.0825	12.169	+8.192E+07	+6.732E+06	80.490
.1125	11.650	+8.291E+07	+7.117E+06	78.897
.1425	10.721	+7.628E+07	+7.115E+06	78.903

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.757	+6.945E+04	+6.088E+06
.0525	6.932	+9.115E+04	+7.505E+06
.0825	6.761	+9.695E+04	+7.804E+06
.1125	6.472	+1.001E+05	+7.898E+06
.1425	5.956	+9.210E+04	+7.267E+06

Ra(w)ave= +8.305E+07
Nu(w)ave 11.84

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
35.740	+2.318E+08	344.364	+1.258E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.00
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.84
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.33
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.48
% ENERGY CONTRIBUTED BY HEATER 5 IS 88.77

CAVITY WIDTH 27.00 mm
 POWER INPUT PER ELEMENT 12.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.84
20	-26.41
100	-25.75

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.71
2	34.15
3	30.42
4	31.85
5	28.95
6	29.14

CHANNEL # TEMPERATURE AT MOVING WALL

7	43.49
8	46.29
9	44.75
10	46.94

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	65.06
27	65.59
28	62.08
29	62.66

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.68
12	25.75
13	25.78
14	25.78
15	26.35
16	26.47
17	26.43

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	68.79
19	68.75
22	66.96
24	65.76
25	61.56

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	66.24
23	65.65

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	56.30
31	65.78
32	66.13
33	64.16
34	60.92
35	48.81

AVERAGE COLD PLATE TEMPERATURE: 26.04
 SURFACE GLASS TEMPERATURE : 44.66
 AMBIENT TEMPERATURE : 21.20

HEAT LOSS FROM BOTTOM WALL IS	.14 WATTS	.24 %
HEAT LOSS FROM MOVING WALL IS	1.33 WATTS	2.21 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.91 WATTS	1.51 %
HEAT LOSS TO AIR THROUGH END GLASSES	.98 WATTS	1.63 %
TOTAL HEAT INPUT IS :	59.82 WATTS	
TOTAL HEAT LOSS IS :	3.35 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	537.00	43.37	78.83	80.77	23.87
2	538.90	65.46	119.20	121.48	35.95
3	98.82	10.84	107.81	109.65	1.09
4	257.30	28.19	108.63	109.54	7.31
5	0.00	0.00	188.42	333.33	0.00

PROBE MEASUREMENTS

y/H	x = 12.00 mm
.9545	48.99
.8636	51.64
.7727	51.51
.6818	51.65
.5909	51.59
.5000	51.74
.4091	51.59
.3182	51.33
.2273	50.98
.1364	50.53
.0455	44.72

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 12.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	10.824	+3.914E+07	+3.616E+06	125.134
.0525	25.996	+1.429E+09	+5.498E+07	128.940
.0825	40.297	+9.024E+09	+2.239E+08	127.228
.1125	52.195	+3.182E+10	+6.096E+08	120.906
.1425	61.219	+7.596E+10	+1.241E+09	111.956

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	12.989	+8.117E+07	+6.249E+06	82.307
.0525	13.369	+9.998E+07	+7.478E+06	77.197
.0825	13.188	+1.035E+08	+7.850E+06	75.835
.1125	12.527	+1.056E+08	+8.427E+06	73.856
.1425	11.599	+9.790E+07	+8.440E+06	73.813

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.216	+9.394E+04	+7.732E+06
.0525	7.427	+1.234E+05	+9.524E+06
.0825	7.327	+1.300E+05	+9.861E+06
.1125	6.959	+1.362E+05	+1.006E+07
.1425	6.444	+1.264E+05	+9.326E+06

Ra(w)ave= +1.050E+08
Nu(w)ave 12.73

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
38.249	+2.932E+08	368.941	+1.488E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.43
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.13
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.70
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.92
% ENERGY CONTRIBUTED BY HEATER 5 IS 89.83

CAVITY WIDTH 27.00 mm
POWER INPUT PER ELEMENT 14.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.47
20	-27.06
100	-26.36

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	34.40
2	35.92
3	31.81
4	33.42
5	30.23
6	30.47

CHANNEL # TEMPERATURE AT MOVING WALL

7	49.35
8	51.50
9	51.88
10	52.88

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	71.32
27	71.83
28	67.82
29	68.37

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.70
12	25.81
13	25.80
14	25.76
15	26.47
16	26.59
17	26.48

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	74.83
19	74.74
22	73.00
24	71.48
25	66.83

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	71.97
23	71.65

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	61.18
31	72.25
32	72.44
33	69.97
34	66.78
35	52.61

AVERAGE COLD PLATE TEMPERATURE: 26.09
 SURFACE GLASS TEMPERATURE : 47.79
 AMBIENT TEMPERATURE : 22.75

HEAT LOSS FROM BOTTOM WALL IS	.15 WATTS	.22 %
HEAT LOSS FROM MOVING WALL IS	.84 WATTS	1.20 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.87 WATTS	1.24 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.06 WATTS	1.51 %
TOTAL HEAT INPUT IS :	69.72 WATTS	
TOTAL HEAT LOSS IS :	2.91 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	581.50	46.87	78.83	80.60	27.86
2	583.90	70.64	119.20	120.97	41.86
3	151.60	16.31	107.81	107.57	2.47
4	332.60	36.28	108.63	109.08	12.12
5	8.59	1.72	188.42	199.92	.02

PROBE MEASUREMENTS

y/H	x= 12.00 mm
.9545	54.46
.8636	55.88
.7727	56.36
.6818	56.17
.5909	56.11
.5000	55.97
.4091	55.74
.3182	55.49
.2273	55.16
.1364	54.66
.0455	47.73

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 14.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	11.220	+5.069E+07	+4.518E+06	129.888
.0525	26.988	+1.854E+09	+6.870E+07	134.060
.0825	41.718	+1.176E+10	+2.820E+08	131.923
.1125	54.432	+4.141E+10	+7.608E+08	126.284
.1425	64.249	+9.965E+10	+1.551E+09	117.681

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	13.464	+1.051E+08	+7.807E+06	75.916
.0525	13.880	+1.297E+08	+9.344E+06	70.951
.0825	13.653	+1.349E+08	+9.884E+06	69.431
.1125	13.064	+1.374E+08	+1.052E+07	67.766
.1425	12.173	+1.284E+08	+1.055E+07	67.684

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.480	+1.319E+05	+1.001E+07
.0525	7.711	+1.741E+05	+1.235E+07
.0825	7.585	+1.851E+05	+1.285E+07
.1125	7.258	+1.931E+05	+1.309E+07
.1425	6.763	+1.808E+05	+1.223E+07

Ra(w)ave= +1.360E+08
Nu(w)ave 13.25

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
39.579	+3.795E+08	382.347	+1.762E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.86
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.42
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.07
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.36
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.89

CAVITY WIDTH 27.00 mm
POWER INPUT PER ELEMENT 16.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.80
20	-26.58
100	-25.95

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	34.63
2	36.15
3	31.72
4	33.29
5	30.07
6	30.28

CHANNEL # TEMPERATURE AT MOVING WALL

7	48.99
8	52.02
9	51.23
10	53.30

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	75.58
27	76.13
28	71.58
29	72.17

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.68
12	25.77
13	25.76
14	25.70
15	26.53
16	26.69
17	26.54

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	78.99
19	78.87
22	76.96
24	75.41
25	70.01

CAVITY WIDTH 27.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	75.95
23	75.38

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	64.31
31	76.31
32	76.74
33	73.91
34	70.18
35	54.39

AVERAGE COLD PLATE TEMPERATURE: 26.10

SURFACE GLASS TEMPERATURE : 49.78

AMBIENT TEMPERATURE : 22.12

HEAT LOSS FROM BOTTOM WALL IS	.15 WATTS	.19 %
HEAT LOSS FROM MOVING WALL IS	1.35 WATTS	1.69 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.94 WATTS	1.17 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.20 WATTS	1.49 %
TOTAL HEAT INPUT IS :	79.96 WATTS	
TOTAL HEAT LOSS IS :	3.64 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	621.20	50.11	78.83	80.67	31.86
2	624.90	75.72	119.20	121.18	48.11
3	150.80	15.55	107.81	103.11	2.24
4	320.70	35.02	108.63	109.20	11.29
5	4.19	.79	188.42	189.19	0.00

PROBE MEASUREMENTS

y/H x= 12.00 mm

.9545	55.24
.8636	58.63
.7727	58.99
.6818	58.81
.5909	58.87
.5000	58.56
.4091	58.30
.3182	57.95
.2273	57.55
.1364	56.95
.0455	48.44

RESULTS FOR ASPECT RATIO = 6.111
POWER INPUT PER ELEMENT = 16.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	11.901	+6.089E+07	+5.116E+06	137.888
.0525	28.331	+2.243E+09	+7.916E+07	140.872
.0825	43.922	+1.423E+10	+3.241E+08	139.034
.1125	57.324	+5.022E+10	+8.761E+08	133.135
.1425	68.101	+1.218E+11	+1.788E+09	124.870

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	14.281	+1.263E+08	+8.841E+06	72.455
.0525	14.570	+1.569E+08	+1.077E+07	67.134
.0825	14.374	+1.633E+08	+1.136E+07	65.725
.1125	13.758	+1.666E+08	+1.211E+07	64.060
.1425	12.903	+1.569E+08	+1.216E+07	63.952

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.934	+1.660E+05	+1.203E+07
.0525	8.095	+2.226E+05	+1.494E+07
.0825	7.986	+2.367E+05	+1.555E+07
.1125	7.643	+2.478E+05	+1.587E+07
.1425	7.168	+2.338E+05	+1.495E+07

Ra(w)ave= +1.638E+08
Nu(w)ave 13.98

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
41.527	+4.571E+08	401.573	+2.006E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 84.29
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.70
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.44
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.79
% ENERGY CONTRIBUTED BY HEATER 5 IS 91.94

CAVITY WIDTH 36.00 mm
POWER INPUT PER ELEMENT 2.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.89
20	-26.44
100	-25.81

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	26.40
2	26.95
3	25.83
4	26.45
5	25.30
6	25.45

CHANNEL # TEMPERATURE AT MOVING WALL

7	29.34
8	29.96
9	29.74
10	30.24

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	34.86
27	35.09
28	34.37
29	34.44

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.68
12	25.71
13	25.71
14	25.71
15	25.79
16	25.78
17	25.81

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	36.14
19	36.25
22	35.82
24	35.36
25	34.01

CAVITY WIDTH 36.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	35.63
23	35.53

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	32.36
31	35.23
32	35.39
33	34.87
34	34.08
35	31.22

AVERAGE COLD PLATE TEMPERATURE: 25.74
 SURFACE GLASS TEMPERATURE : 29.26
 AMBIENT TEMPERATURE : 22.11

HEAT LOSS FROM BOTTOM WALL IS	.08 WATTS	.78 %
HEAT LOSS FROM MOVING WALL IS	.30 WATTS	2.98 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.24 WATTS	2.42 %
HEAT LOSS TO AIR THROUGH END GLASSES	.30 WATTS	2.99 %
TOTAL HEAT INPUT IS :	10.05 WATTS	
TOTAL HEAT LOSS IS :	.92 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	222.60	17.80	78.83	79.96	4.02
2	222.80	26.81	119.20	120.33	6.03
3	85.28	9.28	107.81	108.80	.80
4	115.35	12.71	108.63	110.16	1.49
5	0.00	0.00	188.42	332.67	0.00

PROBE MEASUREMENTS

y/H	x= 6.71	x=21.00 (mm)
.9545	30.04	31.09
.8636	31.27	31.58
.7727	31.31	31.63
.6818	31.42	31.61
.5909	31.51	31.61
.5000	31.43	31.52
.4091	31.29	31.46
.3182	31.15	31.35
.2273	31.09	31.22
.1364	30.97	31.01
.0455	29.99	29.93

RESULTS FOR ASPECT RATIO = 4.583
POWER INPUT PER ELEMENT = 2.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	7.395	+3.745E+06	+5.064E+05	84.870
.0525	16.994	+1.307E+08	+7.691E+06	83.623
.0825	25.754	+8.122E+08	+3.154E+07	80.654
.1125	33.284	+2.799E+09	+8.409E+07	76.448
.1425	38.762	+6.539E+09	+1.687E+08	70.285

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	11.831	+2.454E+07	+2.074E+06	133.302
.0525	11.653	+2.890E+07	+2.480E+06	129.914
.0825	11.238	+2.945E+07	+2.620E+06	128.801
.1125	10.651	+2.935E+07	+2.756E+06	127.759
.1425	9.793	+2.664E+07	+2.720E+06	128.032

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	4.930	+5.549E+03	+7.397E+05
.0525	4.855	+6.704E+03	+8.709E+05
.0825	4.683	+6.891E+03	+8.876E+05
.1125	4.438	+6.924E+03	+8.846E+05
.1425	4.080	+6.270E+03	+8.028E+05

Ra(w)ave= +3.078E+07
Nu(w)ave 11.03

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
25.512	+6.445E+07	183.081	+1.789E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.14
% ENERGY CONTRIBUTED BY HEATER 2 IS 94.17
% ENERGY CONTRIBUTED BY HEATER 3 IS 95.11
% ENERGY CONTRIBUTED BY HEATER 4 IS 94.00
% ENERGY CONTRIBUTED BY HEATER 5 IS 85.50

CAVITY WIDTH 36.00 mm
POWER INPUT PER ELEMENT 4.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.44
20	-27.98
100	-27.34

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	28.87
2	29.69
3	27.96
4	28.88
5	27.14
6	27.32

CHANNEL # TEMPERATURE AT MOVING WALL

7	33.71
8	34.42
9	34.13
10	34.63

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	42.30
27	42.62
28	41.50
29	41.64

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.78
12	25.81
13	25.81
14	25.83
15	25.98
16	26.01
17	26.00

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	44.37
19	44.50
22	43.76
24	43.06
25	41.15

CAVITY WIDTH 36.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	43.43
23	43.25

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	38.14
31	42.85
32	43.07
33	42.19
34	41.02
35	36.37

AVERAGE COLD PLATE TEMPERATURE: 25.89
 SURFACE GLASS TEMPERATURE : 33.12
 AMBIENT TEMPERATURE : 23.19

HEAT LOSS FROM BOTTOM WALL IS	.12 WATTS	.58 %
HEAT LOSS FROM MOVING WALL IS	.32 WATTS	1.61 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.37 WATTS	1.85 %
HEAT LOSS TO AIR THROUGH END GLASSES	.45 WATTS	2.24 %
TOTAL HEAT INPUT IS :	20.12 WATTS	
TOTAL HEAT LOSS IS :	1.26 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	313.90	25.20	78.83	80.30	8.06
2	315.20	37.92	119.20	120.31	12.06
3	96.35	10.53	107.81	109.30	1.03
4	168.30	18.58	108.63	110.39	3.18
5	0.00	0.00	188.42	332.67	0.00

PROBE MEASUREMENTS

y/H	x= 6.71	x=21.00 (mm)
.9545	34.45	35.42
.8636	35.74	36.41
.7727	35.74	36.48
.6818	36.38	36.50
.5909	36.20	36.41
.5000	36.08	36.31
.4091	35.98	36.17
.3182	35.86	36.05
.2273	35.78	35.90
.1364	35.61	35.63
.0455	34.12	34.12

RESULTS FOR ASPECT RATIO = 4.583
POWER INPUT PER ELEMENT = 4.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	8.296	+8.944E+06	+1.078E+06	95.402
.0525	19.701	+3.147E+08	+1.598E+07	97.141
.0825	30.060	+1.966E+09	+6.539E+07	94.337
.1125	38.926	+6.816E+09	+1.751E+08	89.603
.1425	45.472	+1.602E+10	+3.524E+08	82.632

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	13.274	+5.861E+07	+4.416E+06	116.361
.0525	13.509	+6.959E+07	+5.151E+06	112.422
.0825	13.117	+7.127E+07	+5.433E+06	111.018
.1125	12.456	+7.148E+07	+5.738E+06	109.562
.1425	11.488	+6.527E+07	+5.681E+06	109.829

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.531	+1.518E+04	+1.767E+06
.0525	5.629	+1.866E+04	+2.097E+06
.0825	5.465	+1.935E+04	+2.148E+06
.1125	5.190	+1.966E+04	+2.154E+06
.1425	4.787	+1.791E+04	+1.967E+06

Ra(w)ave= +7.400E+07
Nu(w)ave 12.77

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
29.377	+1.550E+08	211.256	+3.693E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 82.57
% ENERGY CONTRIBUTED BY HEATER 2 IS 94.59
% ENERGY CONTRIBUTED BY HEATER 3 IS 95.62
% ENERGY CONTRIBUTED BY HEATER 4 IS 94.59
% ENERGY CONTRIBUTED BY HEATER 5 IS 86.59

CAVITY WIDTH 36.00 mm
POWER INPUT PER ELEMENT 8.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.14
20	-27.75
100	-27.30

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	32.00
2	33.12
3	30.36
4	31.76
5	29.20
6	29.36

CHANNEL # TEMPERATURE AT MOVING WALL

7	39.51
8	40.62
9	40.16
10	40.84

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	53.97
27	54.38
28	52.38
29	52.63

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.81
12	25.87
13	25.86
14	25.87
15	26.23
16	26.29
17	26.25

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	57.05
19	57.10
22	55.86
24	54.74
25	51.84

CAVITY WIDTH

36.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	55.29
23	54.98

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	47.21
31	54.77
32	54.97
33	53.42
34	51.52
35	43.75

AVERAGE COLD PLATE TEMPERATURE: 26.03

SURFACE GLASS TEMPERATURE : 38.84

AMBIENT TEMPERATURE : 22.88

HEAT LOSS FROM BOTTOM WALL IS	.17 WATTS	.42 %
HEAT LOSS FROM MOVING WALL IS	.47 WATTS	1.19 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.53 WATTS	1.34 %
HEAT LOSS TO AIR THROUGH END GLASSES	.81 WATTS	2.02 %
TOTAL HEAT INPUT IS :	39.90 WATTS	
TOTAL HEAT LOSS IS :	1.98 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. . RESIST. (OHMS)	POWER (W)
1	441.00	35.43	78.83	80.34	15.92
2	443.00	53.46	119.20	120.68	23.98
3	114.90	12.41	107.81	107.96	1.43
4	231.00	25.19	108.63	109.06	5.84
5	0.00	0.00	188.42	330.00	0.00

PROBE MEASUREMENTS

y/H	x= 6.71	x=21.00 (mm)
.9545	41.21	42.51
.8636	43.57	43.81
.7727	43.65	43.91
.6818	43.69	43.81
.5909	43.61	43.75
.5000	43.50	43.54
.4091	43.15	43.31
.3182	42.98	43.11
.2273	42.81	42.84
.1364	42.53	42.51
.0455	39.83	39.67

RESULTS FOR ASPECT RATIO = 4.583
POWER INPUT PER ELEMENT = 8.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	10.026	+2.230E+07	+2.225E+06	115.610
.0525	24.032	+7.952E+08	+3.309E+07	118.857
.0825	36.790	+5.004E+09	+1.360E+08	115.823
.1125	47.729	+1.751E+10	+3.669E+08	110.228
.1425	56.133	+4.175E+10	+7.438E+08	102.344

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	16.041	+1.462E+08	+9.112E+06	96.317
.0525	16.479	+1.758E+08	+1.067E+07	91.784
.0825	16.054	+1.814E+08	+1.130E+07	90.119
.1125	15.273	+1.836E+08	+1.202E+07	88.335
.1425	14.181	+1.701E+08	+1.199E+07	88.404

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	6.684	+4.574E+04	+4.406E+06
.0525	6.866	+5.773E+04	+5.299E+06
.0825	6.689	+6.068E+04	+5.468E+06
.1125	6.364	+6.265E+04	+5.534E+06
.1425	5.909	+5.798E+04	+5.126E+06

Ra(w)ave= +1.861E+08
Nu(w)ave 15.61

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
35.444	+3.896E+08	255.681	+7.489E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.43
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.44
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.63
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.77
% ENERGY CONTRIBUTED BY HEATER 5 IS 88.79

CAVITY WIDTH 36.00 mm
POWER INPUT PER ELEMENT 12.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.33
20	-27.90
100	-27.19

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.54
2	35.03
3	31.54
4	33.16
5	30.10
6	30.36

CHANNEL # TEMPERATURE AT MOVING WALL

7	44.20
8	45.91
9	45.37
10	46.36

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	64.50
27	64.88
28	61.86
29	62.23

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.16
12	26.22
13	26.21
14	26.22
15	26.77
16	26.86
17	26.80

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	68.19
19	68.20
22	66.44
24	64.92
25	61.05

CAVITY WIDTH 36.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	65.57
23	65.17

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	55.19
31	65.27
32	65.47
33	63.25
34	60.54
35	49.32

AVERAGE COLD PLATE TEMPERATURE: 26.46
 SURFACE GLASS TEMPERATURE : 43.37
 AMBIENT TEMPERATURE : 23.04

HEAT LOSS FROM BOTTOM WALL IS	.21 WATTS	.35 %
HEAT LOSS FROM MOVING WALL IS	.72 WATTS	1.19 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.62 WATTS	1.03 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.09 WATTS	1.82 %
TOTAL HEAT INPUT IS :	60.42 WATTS	
TOTAL HEAT LOSS IS :	2.63 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	539.00	43.39	78.83	80.49	23.88
2	545.50	66.00	119.20	120.99	36.54
3	125.90	13.62	107.81	108.20	1.72
4	269.30	29.38	106.63	109.08	7.94
5	0.00	0.00	188.42	330.00	0.00

PROBE MEASUREMENTS

y/H	x= 6.71	x=21.00 (mm)
.9545	47.47	47.97
.8636	50.26	50.36
.7727	49.93	50.38
.6818	50.26	50.10
.5909	50.33	50.30
.5000	50.10	50.06
.4091	49.75	49.81
.3182	49.52	49.54
.2273	49.22	49.25
.1364	48.88	48.81
.0455	45.22	44.83

RESULTS FOR ASPECT RATIO = 4.583
POWER INPUT PER ELEMENT = 12.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	11.377	+3.999E+07	+3.515E+06	131.527
.0525	27.244	+1.440E+09	+5.287E+07	135.112
.0825	41.748	+9.122E+09	+2.185E+08	131.808
.1125	54.128	+3.217E+10	+5.944E+08	125.380
.1425	64.350	+7.771E+10	+1.208E+09	117.676

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	18.204	+2.621E+08	+1.440E+07	82.421
.0525	18.681	+3.185E+08	+1.705E+07	77.679
.0825	18.217	+3.307E+08	+1.815E+07	75.932
.1125	17.321	+3.374E+08	+1.948E+07	73.994
.1425	16.257	+3.165E+08	+1.947E+07	74.004

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.585	+9.584E+04	+7.900E+06
.0525	7.784	+1.236E+05	+9.599E+06
.0825	7.591	+1.313E+05	+9.968E+06
.1125	7.217	+1.374E+05	+1.017E+07
.1425	6.774	+1.289E+05	+9.540E+06

Ra(w)ave= +3.353E+08
Nu(w)ave 17.74

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
39.758	+7.018E+08	287.608	+1.130E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 84.29
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.28
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.64
% ENERGY CONTRIBUTED BY HEATER 4 IS 96.96
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.98

CAVITY WIDTH 36.00 mm
POWER INPUT PER ELEMENT 14.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.24
20	-27.88
100	-27.46

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	35.25
2	36.72
3	32.75
4	34.59
5	31.26
6	31.41

CHANNEL # TEMPERATURE AT MOVING WALL

7	46.12
8	48.30
9	47.59
10	48.89

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	69.32
27	69.91
28	66.13
29	66.68

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.77
12	25.86
13	25.85
14	25.85
15	26.52
16	26.60
17	26.57

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	72.70
19	72.75
22	70.81
24	69.61
25	65.32

CAVITY WIDTH 36.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	70.00
23	69.34

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	58.82
31	69.89
32	70.50
33	68.08
34	64.78
35	52.46

AVERAGE COLD PLATE TEMPERATURE: 26.15
 SURFACE GLASS TEMPERATURE : 45.47
 AMBIENT TEMPERATURE : 22.82

HEAT LOSS FROM BOTTOM WALL IS	.22 WATTS	.31 %
HEAT LOSS FROM MOVING WALL IS	.92 WATTS	1.32 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.93 WATTS	1.33 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.24 WATTS	1.78 %
TOTAL HEAT INPUT IS :	70.30 WATTS	
TOTAL HEAT LOSS IS :	3.32 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	584.10	47.02	78.83	80.51	28.05
2	586.50	70.97	119.20	121.00	42.25
3	116.63	12.83	107.81	110.00	1.53
4	284.90	31.11	108.63	109.19	8.91
5	0.00	0.00	188.42	330.67	0.00

PROBE MEASUREMENTS

y/H	x= 6.71	x=21.00 (mm)
.9545	49.07	51.56
.8636	52.54	52.93
.7727	52.66	52.87
.6818	53.04	52.88
.5909	52.98	52.93
.5000	52.81	52.78
.4091	52.49	52.58
.3182	52.27	52.34
.2273	52.11	52.05
.1364	51.65	51.64
.0455	46.90	46.74

RESULTS FOR ASPECT RATIO = 4.583
POWER INPUT PER ELEMENT = 14.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	11.722	+4.976E+07	+4.245E+06	135.653
.0525	28.110	+1.799E+09	+6.399E+07	139.565
.0825	43.615	+1.134E+10	+2.599E+08	137.847
.1125	56.620	+4.010E+10	+7.081E+08	131.294
.1425	67.768	+9.735E+10	+1.437E+09	124.060

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	18.756	+3.261E+08	+1.739E+07	77.585
.0525	19.275	+3.977E+08	+2.063E+07	72.820
.0825	19.032	+4.110E+08	+2.159E+07	71.572
.1125	18.118	+4.204E+08	+2.320E+07	69.623
.1425	17.120	+3.966E+08	+2.316E+07	69.671

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.815	+1.267E+05	+9.829E+06
.0525	8.031	+1.646E+05	+1.199E+07
.0825	7.930	+1.731E+05	+1.239E+07
.1125	7.549	+1.820E+05	+1.267E+07
.1425	7.133	+1.716E+05	+1.195E+07

Ra(w)ave= +4.153E+08
Nu(w)ave 18.46

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
41.140	+8.694E+08	297.927	+1.314E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 84.71
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.71
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.15
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.55
% ENERGY CONTRIBUTED BY HEATER 5 IS 92.07

CAVITY WIDTH 36.00 mm
POWER INPUT PER ELEMENT 16.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-30.45
20	-29.97
100	-29.78

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	36.64
2	38.33
3	34.07
4	35.82
5	32.26
6	32.47

CHANNEL # TEMPERATURE AT MOVING WALL

7	48.21
8	50.77
9	50.04
10	51.47

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	74.56
27	74.98
28	70.69
29	71.28

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	26.02
12	26.12
13	26.12
14	26.10
15	26.86
16	26.98
17	26.90

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	77.75
19	77.66
22	75.58
24	74.29
25	69.73

CAVITY WIDTH 36.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	74.60
23	73.99

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	62.97
31	74.90
32	75.47
33	72.79
34	69.22
35	55.42

AVERAGE COLD PLATE TEMPERATURE: 26.44
 SURFACE GLASS TEMPERATURE : 48.54
 AMBIENT TEMPERATURE : 25.17

HEAT LOSS FROM BOTTOM WALL IS	.23 WATTS	.29 %
HEAT LOSS FROM MOVING WALL IS	1.06 WATTS	1.32 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.83 WATTS	1.04 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.29 WATTS	1.61 %
TOTAL HEAT INPUT IS :	80.15 WATTS	
TOTAL HEAT LOSS IS :	3.41 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	623.60	50.24	78.83	80.56	32.02
2	625.60	75.75	119.20	121.08	48.14
3	129.60	13.99	107.81	107.98	1.82
4	295.90	32.24	108.63	108.94	9.57
5	0.00	0.00	188.42	329.33	0.00

PROBE MEASUREMENTS

y/H	x= 6.71	x=21.00 (mm)
.9545	52.52	54.25
.8636	55.51	55.87
.7727	55.60	55.85
.6818	55.95	56.07
.5909	55.70	56.01
.5000	55.70	55.85
.4091	55.69	55.75
.3182	55.48	55.50
.2273	55.28	55.21
.1364	54.87	54.80
.0455	49.10	49.37

RESULTS FOR ASPECT RATIO = 4.583
POWER INPUT PER ELEMENT = 16.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	12.232	+6.175E+07	+5.048E+06	141.722
.0525	29.418	+2.234E+09	+7.594E+07	146.249
.0825	45.706	+1.410E+10	+3.084E+08	144.644
.1125	59.452	+4.994E+10	+8.400E+08	138.047
.1425	71.373	+1.222E+11	+1.712E+09	130.841

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	19.571	+4.047E+08	+2.068E+07	72.389
.0525	20.173	+4.939E+08	+2.449E+07	67.855
.0825	19.944	+5.111E+08	+2.563E+07	66.658
.1125	19.025	+5.237E+08	+2.753E+07	64.802
.1425	18.031	+4.978E+08	+2.761E+07	64.727

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	8.155	+1.685E+05	+1.220E+07
.0525	8.405	+2.194E+05	+1.489E+07
.0825	8.310	+2.311E+05	+1.541E+07
.1125	7.927	+2.436E+05	+1.578E+07
.1425	7.513	+2.318E+05	+1.500E+07

Ra(w)ave= +5.140E+08
Nu(w)ave 19.35

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
42.849	+1.076E+09	310.710	+1.509E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 85.14
% ENERGY CONTRIBUTED BY HEATER 2 IS 97.13
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.66
% ENERGY CONTRIBUTED BY HEATER 4 IS 98.14
% ENERGY CONTRIBUTED BY HEATER 5 IS 93.17

CAVITY WIDTH 45.00 mm
POWER INPUT PER ELEMENT 2.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-26.43
20	-25.99
100	-25.36

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	25.62
2	26.08
3	25.22
4	25.78
5	24.84
6	25.01

CHANNEL # TEMPERATURE AT MOVING WALL

7	27.77
8	28.44
9	28.16
10	28.72

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	32.83
27	33.16
28	32.27
29	32.48

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.67
12	25.57
13	25.56
14	25.58
15	25.64
16	25.62
17	25.65

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	34.50
19	34.56
22	34.17
24	33.66
25	32.43

CAVITY WIDTH 45.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	34.02
23	33.88

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	31.02
31	33.35
32	33.44
33	32.95
34	32.18
35	29.69

AVERAGE COLD PLATE TEMPERATURE: 25.61
 SURFACE GLASS TEMPERATURE : 28.07
 AMBIENT TEMPERATURE : 21.97

HEAT LOSS FROM BOTTOM WALL IS	.09 WATTS	.86 %
HEAT LOSS FROM MOVING WALL IS	.33 WATTS	3.27 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.44 WATTS	4.43 %
HEAT LOSS TO AIR THROUGH END GLASSES	.31 WATTS	3.07 %
TOTAL HEAT INPUT IS :	9.94 WATTS	
TOTAL HEAT LOSS IS :	1.16 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	219.50	17.57	78.83	80.04	3.92
2	222.60	26.81	119.20	120.42	6.03
3	40.01	4.36	107.81	109.02	.18
4	87.54	9.65	108.63	110.27	.86
5	0.00	0.00	188.42	334.00	0.00

PROBE MEASUREMENTS

y/H	x= 1.43	x=15.71	x=30.00 (mm)
.9545	28.30	29.37	29.81
.8636	28.91	30.00	30.10
.7727	29.21	30.12	30.16
.6818	29.38	30.13	30.16
.5909	29.40	30.12	30.10
.5000	29.48	30.08	30.03
.4091	29.49	29.98	29.93
.3182	29.50	29.91	29.86
.2273	29.44	29.74	29.72
.1364	29.29	29.48	29.49
.0455	28.41	28.51	28.55

RESULTS FOR ASPECT RATIO = 3.667
POWER INPUT PER ELEMENT = 2.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	8.827	+3.558E+06	+4.030E+05	101.269
.0525	19.676	+1.219E+08	+6.197E+06	96.771
.0825	29.296	+7.571E+08	+2.584E+07	91.702
.1125	37.735	+2.608E+09	+6.911E+07	86.629
.1425	44.623	+6.213E+09	+1.392E+08	80.874

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	17.654	+5.692E+07	+3.224E+06	137.776
.0525	16.865	+6.582E+07	+3.903E+06	134.545
.0825	15.979	+6.702E+07	+4.194E+06	133.232
.1125	15.094	+6.676E+07	+4.423E+06	132.229
.1425	14.091	+6.179E+07	+4.385E+06	132.393

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	5.885	+5.101E+03	+7.028E+05
.0525	5.622	+6.039E+03	+8.126E+05
.0825	5.326	+6.210E+03	+8.274E+05
.1125	5.031	+6.233E+03	+8.242E+05
.1425	4.697	+5.762E+03	+7.628E+05

Ra(w)ave= +7.058E+07
Nu(w)ave 15.94

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
29.418	+1.182E+08	168.811	+1.393E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.00
% ENERGY CONTRIBUTED BY HEATER 2 IS 93.64
% ENERGY CONTRIBUTED BY HEATER 3 IS 94.38
% ENERGY CONTRIBUTED BY HEATER 4 IS 93.28
% ENERGY CONTRIBUTED BY HEATER 5 IS 86.45

CAVITY WIDTH 45.00 mm
POWER INPUT PER ELEMENT 6.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-25.54
20	-25.07
100	-24.52

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	28.50
2	29.46
3	27.51
4	28.64
5	26.69
6	27.01

CHANNEL # TEMPERATURE AT MOVING WALL

7	32.68
8	34.12
9	33.13
10	34.31

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	45.15
27	45.59
28	43.88
29	44.20

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.66
12	25.73
13	25.72
14	25.73
15	25.95
16	25.99
17	25.99

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	47.99
19	48.06
22	47.19
24	46.25
25	43.90

CAVITY WIDTH 45.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	46.83
23	46.46

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	40.65
31	45.93
32	46.01
33	44.89
34	43.38
35	37.47

AVERAGE COLD PLATE TEMPERATURE: 25.83
 SURFACE GLASS TEMPERATURE : 33.36
 AMBIENT TEMPERATURE : 21.38

HEAT LOSS FROM BOTTOM WALL IS	.17 WATTS	.58 %
HEAT LOSS FROM MOVING WALL IS	.69 WATTS	2.31 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.62 WATTS	2.06 %
HEAT LOSS TO AIR THROUGH END GLASSES	.71 WATTS	2.36 %
TOTAL HEAT INPUT IS :	29.88 WATTS	
TOTAL HEAT LOSS IS :	2.20 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	381.70	30.73	78.83	80.52	11.98
2	381.80	46.19	119.20	121.06	17.90
3	78.92	8.64	107.81	109.51	.69
4	143.43	15.83	108.63	110.40	2.31
5	0.00	0.00	188.42	334.00	0.00

PROBE MEASUREMENTS

y/H	x= 1.43	x=15.71	x=30.00 (mm)
.9545	33.97	35.90	36.26
.8636	35.54	37.37	37.40
.7727	35.99	37.42	37.50
.6818	36.02	37.47	37.52
.5909	36.20	37.46	37.36
.5000	36.14	37.26	37.24
.4091	36.20	37.12	37.09
.3182	36.18	36.97	36.92
.2273	36.14	36.74	36.70
.1364	36.00	36.40	36.38
.0455	34.33	34.47	34.45

RESULTS FOR ASPECT RATIO = 3.667
POWER INPUT PER ELEMENT = 6.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	10.532	+1.415E+07	+1.343E+06	121.194
.0525	24.558	+4.947E+08	+2.014E+07	121.186
.0825	37.227	+3.097E+09	+8.319E+07	116.931
.1125	48.304	+1.077E+10	+2.230E+08	111.289
.1425	57.370	+2.590E+10	+4.515E+08	104.348

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	21.064	+2.264E+08	+1.075E+07	110.866
.0525	21.050	+2.670E+08	+1.269E+07	106.362
.0825	20.306	+2.741E+08	+1.350E+07	104.631
.1125	19.322	+2.758E+08	+1.427E+07	103.071
.1425	18.117	+2.576E+08	+1.422E+07	103.180

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.021	+2.521E+04	+2.795E+06
.0525	7.017	+3.099E+04	+3.297E+06
.0825	6.769	+3.235E+04	+3.384E+06
.1125	6.441	+3.303E+04	+3.404E+06
.1425	6.039	+3.082E+04	+3.180E+06

Ra(w)ave= +2.845E+08
Nu(w)ave 19.97

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
36.499	+4.765E+08	210.155	+4.382E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 83.75
% ENERGY CONTRIBUTED BY HEATER 2 IS 94.62
% ENERGY CONTRIBUTED BY HEATER 3 IS 95.50
% ENERGY CONTRIBUTED BY HEATER 4 IS 94.58
% ENERGY CONTRIBUTED BY HEATER 5 IS 88.44

CAVITY WIDTH 45.00 mm
POWER INPUT PER ELEMENT 10.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.61
20	-27.20
100	-26.51

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	31.56
2	32.79
3	30.11
4	31.53
5	29.00
6	29.35

CHANNEL # TEMPERATURE AT MOVING WALL

7	36.71
8	38.85
9	37.19
10	39.05

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	55.47
27	55.90
28	53.59
29	53.85

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.71
12	25.81
13	25.81
14	25.81
15	26.20
16	26.28
17	26.24

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	58.86
19	58.81
22	57.52
24	56.36
25	53.24

CAVITY WIDTH

45.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	56.85
23	56.36

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	48.40
31	56.05
32	56.28
33	54.57
34	52.42
35	43.91

AVERAGE COLD PLATE TEMPERATURE: 25.98
 SURFACE GLASS TEMPERATURE : 38.42
 AMBIENT TEMPERATURE : 22.64

HEAT LOSS FROM BOTTOM WALL IS	.22 WATTS	.44 %
HEAT LOSS FROM MOVING WALL IS	1.06 WATTS	2.12 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.56 WATTS	1.13 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.00 WATTS	1.99 %
TOTAL HEAT INPUT IS :	49.80 WATTS	
TOTAL HEAT LOSS IS :	2.84 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	490.50	39.55	78.83	80.63	19.84
2	494.10	59.76	119.20	120.94	29.96
3	74.96	8.23	107.81	109.73	.63
4	173.71	19.22	108.63	110.65	3.40
5	0.00	0.00	188.42	333.33	0.00

PROBE MEASUREMENTS

y/H	x= 1.43	x=15.71	x=30.00 (mm)
.9545	38.94	41.49	42.25
.8636	40.87	43.11	43.16
.7727	41.62	43.14	43.20
.6818	41.91	43.28	43.28
.5909	41.59	43.26	43.19
.5000	41.74	43.00	43.00
.4091	41.69	42.86	42.85
.3182	41.52	42.63	42.64
.2273	41.49	42.43	42.42
.1364	41.37	41.99	42.03
.0455	39.41	39.45	39.42

RESULTS FOR ASPECT RATIO = 3.667
POWER INPUT PER ELEMENT = 10.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	11.919	+2.869E+07	+2.407E+06	137.493
.0525	28.213	+1.015E+09	+3.597E+07	139.595
.0825	43.148	+6.377E+09	+1.478E+08	135.896
.1125	56.072	+2.235E+10	+3.987E+08	129.551
.1425	66.894	+5.431E+10	+8.119E+08	122.018

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	23.838	+4.591E+08	+1.926E+07	94.156
.0525	24.183	+5.477E+08	+2.265E+07	89.466
.0825	23.535	+5.645E+08	+2.398E+07	87.807
.1125	22.429	+5.723E+08	+2.551E+07	86.018
.1425	21.124	+5.401E+08	+2.557E+07	85.958

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	7.946	+6.019E+04	+5.667E+06
.0525	8.061	+7.558E+04	+6.762E+06
.0825	7.845	+7.937E+04	+6.969E+06
.1125	7.476	+8.213E+04	+7.065E+06
.1425	7.041	+7.757E+04	+6.668E+06

Ra(w)ave= +5.789E+08
Nu(w)ave 23.02

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
41.555	+9.695E+08	239.909	+7.432E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 84.50
% ENERGY CONTRIBUTED BY HEATER 2 IS 95.60
% ENERGY CONTRIBUTED BY HEATER 3 IS 96.63
% ENERGY CONTRIBUTED BY HEATER 4 IS 95.88
% ENERGY CONTRIBUTED BY HEATER 5 IS 90.42

CAVITY WIDTH 45.00 mm
POWER INPUT PER ELEMENT 14.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.45
20	-27.02
100	-26.56

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	33.31
2	34.84
3	31.48
4	33.17
5	30.19
6	30.67

CHANNEL # TEMPERATURE AT MOVING WALL

7	41.69
8	44.04
9	42.56
10	44.48

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	64.96
27	65.39
28	62.17
29	62.63

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.81
12	25.91
13	25.92
14	25.93
15	26.46
16	26.58
17	26.52

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	68.34
19	68.34
22	66.67
24	65.54
25	61.62

CAVITY WIDTH 45.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	65.81
23	65.21

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	55.44
31	65.44
32	66.14
33	63.87
34	60.65
35	49.18

AVERAGE COLD PLATE TEMPERATURE: 26.16
 SURFACE GLASS TEMPERATURE : 42.72
 AMBIENT TEMPERATURE : 22.69

HEAT LOSS FROM BOTTOM WALL IS	.27 WATTS	.38 %
HEAT LOSS FROM MOVING WALL IS	1.13 WATTS	1.62 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.73 WATTS	1.04 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.34 WATTS	1.91 %
TOTAL HEAT INPUT IS :	69.78 WATTS	
TOTAL HEAT LOSS IS :	3.47 WATTS	

CIRCUIT#	MEASURED CURRENT (AMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	579.60	46.81	78.83	80.76	27.80
2	582.70	70.74	119.20	121.40	41.98
3	88.93	9.72	107.81	109.36	.88
4	229.80	25.18	108.63	109.59	5.84
5	0.00	0.00	188.42	333.33	0.00

PROBE MEASUREMENTS

y/H	x= 1.43	x=15.71	x=30.00 (mm)
.9545	44.32	46.27	45.66
.8636	45.82	48.44	48.41
.7727	46.60	48.45	48.42
.6818	47.09	48.54	48.55
.5909	47.04	48.57	48.57
.5000	46.99	48.59	48.53
.4091	47.06	48.48	48.40
.3182	47.05	48.25	48.22
.2273	47.07	47.98	47.98
.1364	46.79	47.47	47.46
.0455	43.09	43.31	43.69

RESULTS FOR ASPECT RATIO = 3.667
POWER INPUT PER ELEMENT = 14.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	13.015	+4.712E+07	+3.620E+06	150.474
.0525	30.952	+1.684E+09	+5.440E+07	153.518
.0825	47.837	+1.058E+10	+2.211E+08	151.031
.1125	62.257	+3.731E+10	+5.993E+08	144.203
.1425	74.998	+9.133E+10	+1.218E+09	137.143

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	26.031	+7.539E+08	+2.896E+07	82.073
.0525	26.531	+9.089E+08	+3.426E+07	77.313
.0825	26.093	+9.363E+08	+3.588E+07	76.017
.1125	24.903	+9.551E+08	+3.835E+07	74.164
.1425	23.684	+9.082E+08	+3.835E+07	74.169

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	8.677	+1.134E+05	+9.307E+06
.0525	8.844	+1.451E+05	+1.122E+07
.0825	8.698	+1.521E+05	+1.156E+07
.1125	8.301	+1.590E+05	+1.179E+07
.1425	7.895	+1.512E+05	+1.121E+07

Ra(w)ave= +9.498E+08
Nu(w)ave 25.45

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
45.365	+1.591E+09	262.542	+1.049E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 85.25
% ENERGY CONTRIBUTED BY HEATER 2 IS 96.58
% ENERGY CONTRIBUTED BY HEATER 3 IS 97.75
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.18
% ENERGY CONTRIBUTED BY HEATER 5 IS 92.41

CAVITY WIDTH 45.00 mm
POWER INPUT PER ELEMENT 16.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.38
20	-27.00
100	-26.25

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	34.51
2	36.08
3	32.39
4	34.25
5	31.00
6	31.53

CHANNEL # TEMPERATURE AT MOVING WALL

7	44.47
8	46.82
9	45.63
10	47.43

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	69.56
27	70.11
28	66.00
29	66.68

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.80
12	25.95
13	25.95
14	25.95
15	26.60
16	26.73
17	26.64

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	72.96
19	72.90
22	71.14
24	69.99
25	65.81

CAVITY WIDTH 45.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	70.20
23	69.57

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	59.44
31	70.13
32	70.57
33	68.13
34	64.63
35	51.90

AVERAGE COLD PLATE TEMPERATURE: 26.23

SURFACE GLASS TEMPERATURE : 44.42

AMBIENT TEMPERATURE : 22.51

HEAT LOSS FROM BOTTOM WALL IS .29 WATTS .36 %

HEAT LOSS FROM MOVING WALL IS 1.10 WATTS 1.38 %

HEAT LOSS THROUGH THE BACK OF HOT WALL 1.01 WATTS 1.26 %

HEAT LOSS TO AIR THROUGH END GLASSES 1.49 WATTS 1.87 %

TOTAL HEAT INPUT IS : 79.86 WATTS

TOTAL HEAT LOSS IS : 3.89 WATTS

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	620.90	50.17	78.83	60.80	31.93
2	621.40	75.59	119.20	121.64	47.93
3	96.34	10.51	107.81	109.14	1.03
4	258.00	28.29	108.63	109.66	7.37
5	0.00	0.00	188.42	333.33	0.00

PROBE MEASUREMENTS

y/H	x= 1.43	x=15.71	x=30.00 (mm)
.9545	44.36	49.21	50.38
.8636	47.56	51.15	51.16
.7727	49.00	51.32	51.24
.6818	49.26	51.38	51.32
.5909	49.62	51.33	51.36
.5000	49.74	51.36	51.27
.4091	48.70	51.26	51.16
.3182	48.19	51.07	51.01
.2273	48.84	50.81	50.77
.1364	49.16	50.36	50.34
.0455	44.31	45.60	45.89

RESULTS FOR ASPECT RATIO = 3.667
POWER INPUT PER ELEMENT = 16.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	13.385	+5.793E+07	+4.328E+06	154.913
.0525	31.990	+2.075E+09	+6.488E+07	158.849
.0825	49.595	+1.304E+10	+2.629E+08	156.763
.1125	64.731	+4.606E+10	+7.115E+08	150.113
.1425	78.171	+1.133E+11	+1.450E+09	143.119

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	26.769	+9.268E+08	+3.462E+07	76.916
.0525	27.420	+1.120E+09	+4.086E+07	72.333
.0825	27.052	+1.154E+09	+4.267E+07	71.150
.1125	25.892	+1.179E+09	+4.554E+07	69.394
.1425	24.686	+1.127E+09	+4.565E+07	69.329

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	8.923	+1.488E+05	+1.144E+07
.0525	9.140	+1.912E+05	+1.383E+07
.0825	9.017	+2.003E+05	+1.425E+07
.1125	8.631	+2.098E+05	+1.456E+07
.1425	8.229	+2.007E+05	+1.391E+07

Ra(w)ave= +1.164E+09
Nu(w)ave 26.36

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
46.708	+1.950E+09	270.627	+1.200E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 85.63
% ENERGY CONTRIBUTED BY HEATER 2 IS 97.07
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.31
% ENERGY CONTRIBUTED BY HEATER 4 IS 97.83
% ENERGY CONTRIBUTED BY HEATER 5 IS 93.41

CAVITY WIDTH 45.00 mm
POWER INPUT PER ELEMENT 18.00 W

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-27.71
20	-27.39
100	-26.56

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	35.74
2	37.07
3	33.03
4	35.01
5	31.56
6	32.14

CHANNEL # TEMPERATURE AT MOVING WALL

7	46.99
8	49.33
9	48.61
10	50.21

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	74.15
27	74.58
28	69.73
29	70.50

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	25.78
12	25.93
13	25.91
14	25.94
15	26.63
16	26.77
17	26.67

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	77.23
19	77.09
22	75.22
24	73.93
25	69.39

CAVITY WIDTH 45.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	74.16
23	73.51

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	62.89
31	74.59
32	74.93
33	72.13
34	68.37
35	54.47

AVERAGE COLD PLATE TEMPERATURE: 26.23

SURFACE GLASS TEMPERATURE : 46.74

AMBIENT TEMPERATURE : 22.38

HEAT LOSS FROM BOTTOM WALL IS	.28 WATTS	.31 %
HEAT LOSS FROM MOVING WALL IS	1.04 WATTS	1.16 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.98 WATTS	1.08 %
HEAT LOSS TO AIR THROUGH END GLASSES	1.70 WATTS	1.89 %
TOTAL HEAT INPUT IS :	90.00 WATTS	
TOTAL HEAT LOSS IS :	4.00 WATTS	

CIRCUIT#	MEASURED CURRENT (MAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	657.30	53.17	78.83	80.90	35.87
2	660.10	80.33	119.20	121.69	54.13
3	115.80	12.63	107.81	109.04	1.48
4	284.60	31.17	108.63	109.50	8.94
5	0.00	0.00	188.42	330.67	0.00

PROBE MEASUREMENTS

y/H	x= 1.43	x=15.71	x=30.00 (mm)
.9545	46.35	51.48	52.65
.8636	49.56	53.65	53.43
.7727	51.14	53.84	53.65
.6818	51.61	53.77	53.67
.5909	51.90	53.76	53.71
.5000	52.06	53.73	53.68
.4091	52.12	53.68	53.57
.3182	52.24	53.47	53.39
.2273	52.28	53.23	53.16
.1364	52.07	52.66	52.72
.0455	47.44	47.47	47.36

RESULTS FOR ASPECT RATIO = 3.667
POWER INPUT PER ELEMENT = 18.00 Watts

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m^2)
.0225	13.916	+6.946E+07	+4.991E+06	161.217
.0525	33.288	+2.499E+09	+7.507E+07	165.464
.0825	51.603	+1.573E+10	+3.049E+08	163.281
.1125	67.477	+5.566E+10	+8.249E+08	156.649
.1425	81.702	+1.376E+11	+1.684E+09	149.748

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	27.833	+1.111E+09	+3.993E+07	72.965
.0525	28.533	+1.349E+09	+4.727E+07	68.395
.0825	28.147	+1.393E+09	+4.948E+07	67.185
.1125	26.991	+1.425E+09	+5.279E+07	65.487
.1425	25.801	+1.369E+09	+5.304E+07	65.363

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	9.278	+1.880E+05	+1.372E+07
.0525	9.511	+2.435E+05	+1.665E+07
.0825	9.382	+2.559E+05	+1.719E+07
.1125	8.997	+2.686E+05	+1.759E+07
.1425	8.600	+2.585E+05	+1.690E+07

Ra(w)ave= +1.396E+09
Nu(w)ave 27.46

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m^2)	HEAT FLUX (W/m^2)
48.341	+2.338E+09	280.379	+1.355E+04

% ENERGY CONTRIBUTED BY HEATER 1 IS 86.00
% ENERGY CONTRIBUTED BY HEATER 2 IS 97.56
% ENERGY CONTRIBUTED BY HEATER 3 IS 98.87
% ENERGY CONTRIBUTED BY HEATER 4 IS 98.48
% ENERGY CONTRIBUTED BY HEATER 5 IS 94.40

RESULTS FOR FLUORINERT FC-75
 CAVITY WIDTH 18.00 mm
 POWER INPUT PER ELEMENT 2.00 W
 ALL TEMPERATURES ARE IN DEGREE CENTIGRADE

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-28.01
20	-27.49
100	-27.06

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	23.39
2	23.62
3	23.06
4	23.24
5	22.95
6	23.08

CHANNEL # TEMPERATURE AT MOVING WALL

7	25.50
8	26.34
9	26.40
10	27.37

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	33.10
27	33.32
28	31.12
29	31.37

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	22.17
12	22.21
13	22.22
14	22.22
15	22.31
16	22.34
17	22.34

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	34.76
19	34.60
22	33.84
24	32.98
25	30.06

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	33.71
23	33.49

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	31.02
31	33.48
32	33.34
33	32.44
34	30.70
35	26.82

AVERAGE COLD PLATE TEMPERATURE: 22.26
SURFACE GLASS TEMPERATURE : 26.22
AMBIENT TEMPERATURE : 22.25

HEAT LOSS FROM BOTTOM WALL IS	.02 WATTS	.15 %
HEAT LOSS FROM MOVING WALL IS	.48 WATTS	4.82 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.39 WATTS	3.86 %
HEAT LOSS TO AIR THROUGH END GLASSES	.07 WATTS	.72 %
TOTAL HEAT INPUT IS :	10.04 WATTS	
TOTAL HEAT LOSS IS :	.96 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	221.40	17.74	78.83	80.13	3.99
2	223.20	26.86	119.20	120.32	6.05
3	.01	.01	107.81	1787.20	0.00
4	.01	.03	108.63	5898.20	0.00
5	.01	0.00	188.42	98.40	0.00

LIQUID USED : FC-75

RESULTS FOR ASPECT RATIO = 9.167

POWER INPUT PER ELEMENT = 2.00 WATTS

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	24.160	+1.021E+09	+4.226E+07	67.578
.0525	50.792	+3.856E+10	+7.591E+08	60.776
.0825	76.910	+2.468E+11	+3.209E+09	58.531
.1125	99.910	+8.733E+11	+8.741E+09	55.732
.1425	114.345	+2.060E+12	+1.802E+10	50.351

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	19.328	+4.182E+08	+2.164E+07	24.884
.0525	17.414	+5.328E+08	+3.059E+07	24.312
.0825	16.780	+5.593E+08	+3.333E+07	24.147
.1125	15.986	+5.724E+08	+3.580E+07	24.002
.1425	14.444	+5.245E+08	+3.632E+07	23.972

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	16.107	+8.105E+06	+2.017E+08
.0525	14.512	+1.057E+07	+2.569E+08
.0825	13.984	+1.117E+07	+2.697E+08
.1125	13.321	+1.150E+07	+2.760E+08
.1425	12.036	+1.055E+07	+2.530E+08

Ra(W)ave= +6.979E+08

Nu(W)ave= 16.79

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
92.925	+2.908E+09	324.253	+3.563E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 62.00
 % ENERGY CONTRIBUTED BY HEATER 2 IS 76.57
 % ENERGY CONTRIBUTED BY HEATER 3 IS 79.66
 % ENERGY CONTRIBUTED BY HEATER 4 IS 80.86
 % ENERGY CONTRIBUTED BY HEATER 5 IS 73.98

RESULTS FOR FLUORINERT FC-75
CAVITY WIDTH 18.00 mm
POWER INPUT PER ELEMENT 4.00 W
ALL TEMPERATURES ARE IN DEGREE CENTIGRADE

CHANNEL # REFERENCE TEMPERATURE (ICE POINT)

0	-30.27
20	-29.73
100	-29.38

CHANNEL # TEMPERATURE AT BOTTOM WALL

1	26.45
2	26.93
3	26.15
4	26.33
5	25.82
6	26.01

CHANNEL # TEMPERATURE AT MOVING WALL

7	31.76
8	32.30
9	33.23
10	34.17

CHANNEL # TEMPERATURE AT BACK OF HOT WALL

26	42.78
27	43.03
28	39.07
29	39.47

CHANNEL # TOP SINK SURFACE TEMPERATURE

11	23.06
12	23.01
13	23.01
14	23.02
15	23.23
16	23.27
17	23.24

CHANNEL # TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)

18	44.96
19	45.09
22	43.97
24	42.50
25	37.72

CAVITY WIDTH 18.00 mm (CONTINUED)

CHANNEL # TEMPERATURES TO CHECK SYMMETRY

21	43.74
23	43.36

CHANNEL # TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)

30	38.13
31	43.10
32	42.95
33	41.31
34	38.07
35	31.80

AVERAGE COLD PLATE TEMPERATURE: 23.12
SURFACE GLASS TEMPERATURE : 32.72
AMBIENT TEMPERATURE : 23.34

HEAT LOSS FROM BOTTOM WALL IS	.03 WATTS	.16 %
HEAT LOSS FROM MOVING WALL IS	.39 WATTS	1.97 %
HEAT LOSS THROUGH THE BACK OF HOT WALL	.54 WATTS	2.69 %
HEAT LOSS TO AIR THROUGH END GLASSES	.21 WATTS	1.04 %
TOTAL HEAT INPUT IS :	20.03 WATTS	
TOTAL HEAT LOSS IS :	1.17 WATTS	

CIRCUIT#	MEASURED CURRENT (mAMPS)	MEASURED VOLTAGE (VOLTS)	ORIGINAL RESIST. (OHMS)	EXP. RESIST. (OHMS)	POWER (W)
1	311.60	25.06	78.83	80.41	7.96
2	313.50	37.92	119.20	120.97	12.07
3	66.70	9.67	107.81	144.96	.87
4	134.00	14.82	108.63	110.57	2.02
5	.01	0.00	188.42	55.33	0.00

LIQUID USED : FC-75

RESULTS FOR ASPECT RATIO = 9.167

POWER INPUT PER ELEMENT = 4.00 WATTS

Y(m)	Nu(y)	Ra*(y)	Ra(y)	h (W/K-m ²)
.0225	28.346	+2.438E+09	+8.600E+07	78.862
.0525	59.963	+9.105E+10	+1.519E+09	71.282
.0825	91.957	+5.912E+11	+6.429E+09	69.499
.1125	123.356	+2.141E+12	+1.736E+10	68.320
.1425	149.642	+5.243E+12	+3.504E+10	65.436

Y(m)	Nu(w)	Ra*(w)	Ra(w)	Pr
.0225	22.677	+9.985E+08	+4.403E+07	23.270
.0525	20.559	+1.258E+09	+6.120E+07	22.440
.0825	20.063	+1.340E+09	+6.677E+07	22.195
.1125	19.737	+1.403E+09	+7.110E+07	22.011
.1425	18.902	+1.335E+09	+7.062E+07	22.031

Y(m)	Nu(L1)	Gr(L1)	Ra(L1)
.0225	18.897	+2.069E+07	+4.815E+08
.0525	17.132	+2.704E+07	+6.068E+08
.0825	16.720	+2.911E+07	+6.460E+08
.1125	16.448	+3.075E+07	+6.768E+08
.1425	15.752	+2.922E+07	+6.437E+08

Ra(W)ave= +1.619E+09
Nu(W)ave= 20.39

Nu(W,T)	Ra*(W,T)	h(top) (W/K-m ²)	HEAT FLUX (W/m ²)
108.479	+6.747E+09	376.036	+7.419E+03

% ENERGY CONTRIBUTED BY HEATER 1 IS 65.00
% ENERGY CONTRIBUTED BY HEATER 2 IS 77.99
% ENERGY CONTRIBUTED BY HEATER 3 IS 81.81
% ENERGY CONTRIBUTED BY HEATER 4 IS 84.74
% ENERGY CONTRIBUTED BY HEATER 5 IS 80.70

APPENDIX E

EQUATIONS FOR EVALUATION OF PROPERTIES

```

1      !***** ETHYLENE GLYCOL PROPERTIES *****
2      !
4      DIM Tx(3),Dd(3)
10     T=18
20     FOR I=10 TO 60
1352    T=T+1
1353    Rho=1130.75-.6297915*T-5.013587E-5*T^2+6.448046E-7*T^3-9.115537E-9*T^4
1354    Tk=T+273.15
1360    K=.2175195+1.3439E-4*Tk
1380    Cp=4186.8*(5.548E-3+3.35083E-3*Tk-7.224E-6*Tk^2+8.04367E-9*Tk^3)
1390    Nu=EXP(-2.813092-5.196844E-2*T+1.746046E-4*T^2+8.043671E-7*T^3)
1410    Vs=1/(Rho*.1E-3)
1420    Mu=(.04445*EXP(2234/Tk))+5.578276E-7*EXP(5570/Tk))/SQR(Vs)
1430    Mu=Mu/10000
1431    Mu=(Mu+Nu)/2
1440    B=6.65E-4
1450    Alf=K/(Rho*Cp)
1460    Kvis=Mu/Rho
1770 END

```

```

1345 !***** PROPERTIES OF FLUORINERT (FC-75)*****
1346 !
1347 !
1351 FOR T=10 TO 60
1353    Rho=1825-2.46*T
1360    K=.065-(7.89475E-5)*T
1380    Cp=4186.73*(.241111+(3.7037E-4)*T)
1440    B=.00246/(1.825-.00246*T)
1450    Alf=K/(Rho*Cp)
1451    A0=1.4074
1452    A1=-2.964E-2
1453    A2=3.8018E-4
1454    A3=-2.7308E-6
1455    A4=8.1679E-9
1460    Kvis=1.E-6*(A0+A1*T+A2*(T^2)+A3*(T^3)+A4*(T^4))
1781 END

```

APPENDIX F
PROGRAM LISTING

```

C*****
C
C          PROGRAMMER:    RICARDO CARMONA
C
C    THIS PROGRAM CALCULATES THE PERCENT HEAT LOSS THROUGH SUBSTRATE
C    (e.i.:THROUGH UNHEATED SECTION OF PHENOLITE ELEMENT)
C
C*****

```

```

INTEGER L1,L2,L3,L4,L5,L6,IA,IDGT,IER,M2
INTEGER M1,M,N,N1,N2,I,J,K,Z2,Z3
REAL DX1,DX2,DY,C1,C2,C3,C4,S1,S2,TAVE1,TAVE2,TPB,TPU,TAL
REAL W,AR,PIN,P1,Q1,Q2,Q3,Q4,BAL,LEQT1F,KA,KP
REAL PER1,PER2,PER3,PER4,QCR1,QCR2,QCR3,QCR4,QLOSS
DIMENSION A(221,221),C(221,1),WAREA(221),T(238,1)

```

```

OPEN(60,NAME='RICHI.DAT',STATUS='NEW')

```

```

PRINT*,'WHAT IS THE CAVITY WIDTH OF THE ENCLOSURE (mm)?'
PRINT*,' '
READ(5,*) W
PRINT*,'WHAT IS THE POWER INPUT TO EACH ALUMINUM PLATE (Watts)?'
PRINT*,' '
READ(5,*) PIN
PRINT*,'TEMPERATURE OF UNHEATED SECTION @ LOWER REGION?'
PRINT*,' '
READ(5,*) TPB
PRINT*,'TEMPERATURE OF THE ALUMINUM PLATE @ CENTRAL REGION?'
PRINT*,' '
READ(5,*) TAL
PRINT*,'TEMPERATURE OF UNHEATED SECTION @ UPPER REGION?'
PRINT*,' '
READ(5,*) TPU

```

```

P1=PIN/141.
KA=170.0
KP=0.33
DX1= 1.00
DX2= 0.975
DY = 1.875

```

```

C1 = DX1/DY
C2 = DY/DX1
C3 = DX2/DY
C4 = DY/DX2
S1 = C1 + C2
S2 = C3 + C4
M1 = 3.00/DX1
M = M1 + (9.75/DX2)
N1 = (7.50/DY) + 1
N2 = (22.5/DY) + 1
N = (30.0/DY) + 1

```

```

Z2 = 1
Z3 = N*M
P4 = P3*P3
IA = 221
IDGT = 2
IER = 2
AR = 165/W

```

```

1      WRITE(60,1) DX1
      FORMAT(/,3X,'THE INITIAL "X" INCREAMENT IS  :',10X,F6.3,1X,'(mm)',/)
2      WRITE(60,2) DX2
      FORMAT(/,3X,'THE SECOND "X" INCREAMENT IS  :',10X,F6.3,1X,'(mm)',/)
3      WRITE(60,3) DY
      FORMAT(/,3X,'THE "Y" INCREAMENT IS  :',17X,F6.4,1X,'(mm)',/)
4      WRITE(60,4) AR
      FORMAT(/,3X,'THE ASPECT RATIO OF THE CAVITY IS :',7X,F6.3,1X,/)
5      WRITE(60,5) PIN
      FORMAT(/,3X,'POWER INPUT TO EACH ALUMINUM PLATE IS:',3X,F6.2,
F      'WATTS',/)

C
C      ***** REGION 2 *****
C
C      REGION CLOSE TO KNOWN SURFACE TEMPERATURE
      J=1
      I=1
      K=(J+(I-1)*M)
      A(K,K+1)=KP*C2/2.0
      A(K,K+M)=KP*C1
      A(K,K)=--KP*S1
      C(K,1)--TPB*KP*C2/2.0

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE (DX1 RANGE)
      I=1
      DO 20 J=2,(M1-1)
          K=(J+(I-1)*M)
          A(K,K-1)=KP*C2/2.0
          A(K,K+1)=A(K,K-1)
          A(K,K+M)=KP*C1
          A(K,K)=--KP*S1
          C(K,1)=0.00
20     CONTINUE

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE (@ DX1 LINE)
      I=1
      J=M1
      K=(J+(I-1)*M)
      A(K,K-1)=KP*C2/2.0
      A(K,K+1)=KP*C4/2.0
      A(K,K+M)=KP*(C1+C3)/2.0
      A(K,K)=--KP*(S1+S2)/2.0
      C(K,1)=0.00

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE (DX2 RANGE)
      I=1
      DO 30 J=(M1+1),(M-1)
          K=(J+(I-1)*M)
          A(K,K-1)=KP*C4/2.0
          A(K,K+1)=A(K,K-1)
          A(K,K+M)=KP*C3
          A(K,K)=--KP*S2
          C(K,1)=0.00
30     CONTINUE

C      ***** REGION 3 *****

      I=1
      J=M
      K=(J+(I-1)*M)
      A(K,K-1)=KP*C4/2.0
      A(K,K+1)=0.00
      A(K,K+M)=KP*C3/2.0
      A(K,K)=--KP*S2/2.0
      C(K,1)=0.00

```

C ***** REGION 5 (INSIDE PHENOLITE REGION) *****

C REGION CLOSE TO KNOWN SURFACE TEMPERATURE

J=1

DO 40 I=2, (N1-1)

K=(J+(I-1)*M)

A(K,K+1)=KP*C2

A(K,K-M)=KP*C1

A(K,K+M)=A(K,K-M)

A(K,K)=--2*KP*(S1)

C(K,1)=--TPB*KP*C2

40 CONTINUE

C UPPER REGION

J=1

DO 50 I=(N2+1), (N-1)

K=(J+(I-1)*M)

A(K,K+1)=KP*C2

A(K,K-M)=KP*C1

A(K,K+M)=A(K,K-M)

A(K,K)=--2*KP*(S1)

C(K,1)=--TPU*KP*C2

50 CONTINUE

C PHENOLITE REGION INSIDE DX1 REGION

DO 51 I=2, (N1-1)

DO 52 J=2, (M1-1)

K=(J+(I-1)*M)

A(K,K-1)=KP*C2

A(K,K+1)=KP*C2

A(K,K-M)=KP*C1

A(K,K+M)=KP*C1

A(K,K) =--2.0*KP*S1

C(K,1) = 0.00

52 CONTINUE

51 CONTINUE

C UPPER REGION

DO 53 I=(N2+1), (N-1)

DO 54 J=2, (M1-1)

K=(J+(I-1)*M)

A(K,K-1)=KP*C2

A(K,K+1)=KP*C2

A(K,K-M)=KP*C1

A(K,K+M)=KP*C1

A(K,K) =--2.0*KP*S1

C(K,1) = 0.00

54 CONTINUE

53 CONTINUE

C PHENOLITE REGION AT M1 LINE

J=M1

DO 55 I=2, (N1-1)

K=(J+(I-1)*M)

A(K,K-1)=KP*C2

A(K,K+1)=KP*C4

A(K,K-M)=KP*(C1+C3)/2.0

A(K,K+M)=A(K,K-M)

A(K,K) =--KP*(S1+S2)

C(K,1) =0.00

55 CONTINUE

```

C      UPPER REGION
      J=M1
      DO 56 I=(N2+1),(N-1)
        K=(J+(I-1)*M)
        A(K,K-1)=KP*C2
        A(K,K+1)=KP*C4
        A(K,K-M)=KP*(C1+C3)/2.0
        A(K,K+M)=A(K,K-M)
        A(K,K)  =-KP*(S1+S2)
        C(K,1)  = 0.00
56     CONTINUE

C      PHENOLITE REGION INSIDE DX2 LIMIT

      DO 57 J=(M1+1),(M-1)
      DO 58 I=2,(N-1)
        K=(J+(I-1)*M)
        A(K,K-1)=KP*C4
        A(K,K+1)=KP*C4
        A(K,K-M)=KP*C3
        A(K,K+M)=KP*C3
        A(K,K)  =-2*KP*S2
        C(K,1)  = 0.00
58     CONTINUE
57     CONTINUE

C      ***** REGION 6 *****

      J=M
      DO 70 I=2,(N-1)
        K=(J+(I-1)*M)
        A(K,K-1)=KP*C4
        A(K,K-M)=KP*C3/2.0
        A(K,K+M)=A(K,K-1)
        A(K,K)  =-KP*S2
        C(K,1)  =0.00
70     CONTINUE

C      ***** REGION 8 *****

C      REGION CLOSE TO KNOWN TEMPERATURE SURFACE
      J=1
      I=N1
      K=(J+(I-1)*M)
      A(K,K+1)=(KA+KP)*C2/2.0
      A(K,K-M)=KP*C1
      A(K,K+M)=KA*C1
      A(K,K)  =-(KP+KA)*S1
      C(K,1)  =-(KA+KP)*C2*TAL/2.0

C      REGION AWAY FROM KNOWN TEMPERATURE SURFACE
      I=N1
      DO 71 J=2,(M1-1)
        K=(J+(I-1)*M)
        A(K,K-1)=(KA+KP)*C2/2.0
        A(K,K+1)=A(K,K-1)
        A(K,K-M)=KP*C1
        A(K,K+M)=KA*C1
        A(K,K)  =-(KA+KP)*S1
        C(K,1)  =0.00
71     CONTINUE

C      ***** REGION 9 *****

```

```

J=M1
I=N1
K=(J+(I-1)*M)
A(K,K-1)=(KA+KP)*C2/2.0
A(K,K+1)=KP*C4
A(K,K-M)=KP*(C1+C3)/2.0
A(K,K+M)=KA*C1/2.0 + KP*C3/2.0
A(K,K)  =-(KA+KP)*S1/2.0 - KP*S2
C(K,1)  =-P1*DY/2.0

C      ***** REGION 11 *****

C      REGION CLOSE TO KNOWN SURFACE TEMPERATURE
J=1
DO 72 I=(N1+1),(N2-1)
    K=(J+(I-1)*M)
    A(K,K+1)=KA*C2
    A(K,K-M)=KA*C1
    A(K,K+M)=KA*C1
    A(K,K)  =-2.0*KA*S1
    A(K,1)  =-KA*TAL*C2
72 CONTINUE

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE
DO 73 I=(N1+1),(N2-1)
DO 74 J=2,(M1-1)
    K=(J+(I-1)*M)
    A(K,K-1)=KA*C2
    A(K,K+1)=KA*C2
    A(K,K-M)=KA*C1
    A(K,K+M)=KA*C1
    A(K,K)  =-2.0*KA*S1
    C(K,1)  =0.00
74 CONTINUE
73 CONTINUE

C      ***** REGION 12 *****

J=M1
DO 75 I=(N1+1),(N2-1)
    K=(J+(I-1)*M)
    A(K,K-1)=KA*C2
    A(K,K+1)=KP*C4
    A(K,K-M)=KA*C1/2.0 + KP*C3/2.0
    A(K,K+M)=A(K,K-M)
    A(K,K)  =-KA*S1-KP*S2
    C(K,1)  =-P1*DY
75 CONTINUE

C      ***** REGION 14 *****

C      REGION CLOSE TO KNOWN TEMPERATURE SURFACE
J=1
I=N2
K=(J+(I-1)*M)
A(K,K+1)=(KA+KP)*C2/2.0
A(K,K-M)=KA*C1
A(K,K+M)=KP*C1
A(K,K)  =-(KA+KP)*S1
C(K,1)  =-(KA+KP)*TAL*C2/2.0

```

```

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE
      I=N2
      DO 76 J=2,M1-1
        K=(J+(I-1)*M)
        A(K,K-1)=(KA+KP)*C2/2.0
        A(K,K+1)=A(K,K-1)
        A(K,K-M)=KA*C1
        A(K,K+M)=KP*C1
        A(K,K)  =-(KA+KP)*S1
        C(K,1)  =0.00
76     CONTINUE

C      ***** REGION 15 *****

      J=M1
      I=N2
      K=(J+(I-1)*M)
      A(K,K-1)=(KA+KP)*C2/2.0
      A(K,K+1)=KP*C4
      A(K,K-M)=KA*C1/2.0 + KP*C3/2.0
      A(K,K+M)=KP*(C1+C3)/2.0
      A(K,K)  =-((KA+KP)*S1/2.0) - (KP*S2)
      C(K,1)  =-P1*DY/2.0

C      ***** REGION 18 *****

C      REGION CLOSE TO KNOWN SURFACE TEMPERATURE
      I=N
      J=1
      K=(J+(I-1)*M)
      A(K,K+1)=KP*C2/2.0
      A(K,K-M)=KP*C1
      A(K,K)  =-KP*S1
      C(K,1)  =-KP*TPU*C2/2.0

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE (WITHIN DX1 RANGE)
      I=N
      DO 77 J=2,(M1-1)
        K=(J+(I-1)*M)
        A(K,K-1)=KP*C2/2.0
        A(K,K+1)=A(K,K-1)
        A(K,K-M)=KP*C1
        A(K,K)  =-KP*S1
        C(K,1)  =0.00
77     CONTINUE

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE (@ MI LINE)
      I=N
      J=M1
      K=(J+(I-1)*M)
      A(K,K-1)=KP*C2/2.0
      A(K,K+1)=KP*C4/2.0
      A(K,K-M)=KP*(C1+C3)/2.0
      A(K,K)  =-KP*(S1+S2)/2.0
      C(K,1)  =0.00

C      REGION AWAY FROM KNOWN SURFACE TEMPERATURE (WITHIN DX2 RANGE)
      I=N
      DO 80 J=(M1+1),(M-1)
        K=(J+(I-1)*M)
        A(K,K-1)=KP*C4/2.0

```

```

      A(K,K+1)=A(K,K-1)
      A(K,K-M)=KP*C3
      A(K,K)  =-KP*S2
      C(K,1)  =0.00
80    CONTINUE

C      ***** REGION 19 *****

      I=N
      J=M
      K=(J+(I-1)*M)
      A(K,K-1)=KP*C4/2.0
      A(K,K-M)=KP*C3/2.0
      A(K,K)  =-KP*S2/2.0
      C(K,1)  =0.00

C      CALLING THE "INVERSE MATRIX" SUBROUTINE

      CALL LEQT1F(A,Z2,Z3,IA,C,IDGT,WAREA,IER)

C      CONSIDERING NOW THAT WE HAVE THE ANSWER OF T(C) BACK FROM THE
C      LIBRARY SUBROUTINE

C      SETTING THE CONSTANT TEMPERATURE SURFACE OF THE UPPER PHENOLITE
C      REGION

      M2=M+1
      J=1
      DO 110 I=1,(N1-1)
        K=(J+(I-1)*M2)
        T(K,1)=TPU
110    CONTINUE

C      SETTING THE CONSTANT TEMPERATURE SURFACE OF THE ALUMINUM REGION

      J=1
      DO 115 I=N1,N2
        K=(J+(I-1)*M2)
        T(K,1)=TAL
115    CONTINUE

C      SETTING THE CONSTANT TEMPERATURE SURFACE OF THE LOWER PHENOLITE
C      REGION

      J=1
      DO 120 I=(N2+1),N
        K=(J+(I-1)*M2)
        T(K,1)=TPB
120    CONTINUE

      J=1
      L2=M*(N-1)+1
      L3=N*M
      DO 130 I=1,N
        J=J+1
        DO 140 L1=L2,L3

```

```

          T(J,1)=C(L1,1)
          J=J+1
140      CONTINUE
          L3=L2-1
          L2=L2-M
130      CONTINUE

C          PERFORMING AN ENERGY BALANCE USING CONDUCTION METHOD
C          HEAT LOSS FROM REGION 1 (BOTTOM UNHEATED SECTION)

          K=1
          K1=K+1
          QCR1=KP*C2*(C(K,1)-TPB)/2.0

C          HEAT LOSS FROM REGION 4

          J=1
          DO 150 I=2,(N1-1)
              K=(J+(I-1)*M)
              QCR1=QCR1+KP*C2*(C(K,1)-TPB)
150      CONTINUE

C          HEAT LOSS FROM REGION 7

          I=N1
          J=1
          K=(J+(I-1)*M)
          QCR2=(KA+KP)*C2*(C(K,1)-TAL)/2.0

C          HEAT LOSS FROM REGION 10

          DO 160 I=(N1+1),(N2-1)
              K=(J+(I-1)*M)
              QCR2=QCR2+KA*C2*(C(K,1)-TAL)
160      CONTINUE

C          HEAT LOSS FROM REGION 13

          I=N2
          J=1
          K=(J+(I-1)*M)
          QCR2=QCR2+(KA+KP)*C2*(C(K,1)-TAL)/2.0

C          HEAT LOSS FROM REGION 16

          QCR3=0.00
          J=1
          DO 170 I=(N2+1),(N-1)
              K=(J+(I-1)*M)
              QCR3=QCR3+KP*C2*(C(K,1)-TPU)
170      CONTINUE

C          HEAT LOSS FROM REGION 17

          I=N
          J=1
          K=(J+(I-1)*M)
          QCR3=QCR3+KP*C2*(C(K,1)-TPU)/2.00

C          HEAT LOSS FROM REGION 3

          J=M

```

```

      I=1
      K=(J+(I-1)*M)
      QCR4=KP*C4*(C(K-1,1)-C(K,1))/2.00

C      HEAT LOSS FROM REGION 6

      J=M
      DO 180 I=2,(N-1)
        K=(J+(I-1)*M)
        QCR4=QCR4+KP*C4*(C(K-1,1)-C(K,1))
180    CONTINUE

C      HEAT LOSS AT REGION 19

      J=M
      I=N
      K=(J+(I-1)*M)
      QCR4=QCR4+KP*C4*(C(K-1,1)-C(K,1))/2.00

      QCR1=QCR1*0.141
      QCR2=QCR2*0.141
      QCR3=QCR3*0.141
      QCR4=QCR4*0.141
      QLOSS=(QCR1+QCR2+QCR3+QCR4)

      IF (QCR1 .LE. 0) THEN
        PER1 = -(QCR1/PIN)*100
      ELSE
        PER1 = (QCR1/PIN)*100
      END IF
      IF (QCR2 .LE. 0) THEN
        PER2 = -(QCR2/PIN)*100
      ELSE
        PER2 = (QCR2/PIN)*100
      END IF
      IF (QCR3 .LE. 0) THEN
        PER3 = -(QCR3/PIN)*100
      ELSE
        PER3 = (QCR3/PIN)*100
      END IF
      IF (QCR4 .LE. 0) THEN
        PER4 = -(QCR4/PIN)*100
      ELSE
        PER4 = (QCR4/PIN)*100
      END IF

200    WRITE(60,200)QCR1,PER1
      F    FORMAT(/,10X,'HEAT BY CONDUCTION AT REGION I :',4X,F10.5,1X,'WATTS'
        ,',',1X,F6.2,'%')
      WRITE(60,210)QCR2,PER2
210    F    FORMAT(/,10X,'HEAT BY CONDUCTION AT REGION II:',4X,F10.5,1X,'WATTS'
        ,',',1X,F6.2,'%')
      WRITE(60,220)QCR3,PER3
220    F    FORMAT(/,10X,'HEAT BY CONDUCTION AT REGION III:',3X,F10.5,1X,
        'WATTS',',',1X,F6.2,'%')
      WRITE(60,230)QCR4,PER4
230    F    FORMAT(/,10X,'HEAT BY CONDUCTION AT REGION IV :',4X,F10.5,1X,
        'WATTS',',',1X,F6.2,'%')
      BAL=(QLOSS/PIN)*100
      WRITE(60,231)BAL
231    F    FORMAT(/,10X,'BALANCE OBTAINED BY CONDUCTION :',
        2X,F10.2,1X,'%')

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C      WRITING THE TEMPERATURE FIELD

      WRITE(60,240)
240     FORMAT('1',58X,'TEMPERATURE OF NODES')
      WRITE(60,242)
242     FORMAT(60X,'( CENTIGRADES )',////)

      M2=M+1
      L2=1
      L3=M2
      DO 250 I=1,N
      DO 260 J=L2,L3
          WRITE(60,270) C(J,1)
270         FORMAT(/,1X,13(F5.2,1X))
260     CONTINUE
      L2=L3+1
      L3=L3+M2
250     CONTINUE

      STOP
      END

```

```

1  PRINT "      IT IS ",TIME$(TIMEDATE)
10  ! *** PROGRAM NAME : COLECT
20  ! THIS PROGRAM IS USED TO ACQUIRE AND TO STORE
30  ! TEMPERATURE INFORMATION ASSOCIATED WITH THE CAVITY
40  ! WHICH SIMULATES MICROELECTRONICS ELEMENTS SUMERGED
50  ! IN LIQUID COOLANT (GLYCOL)-FLUSH MOUNTED CASE-
60  !
61  ! *****
62  !           DECLARATION OF VARIABLES
63  !   Tp = ALL THE DIFFERENT TEMPERATURES INSIDE THE CAVITY
64  !   V(I)= VOLTAGE INPUT TO FIVE DIFFERENT CIRCUITS
65  !   R   = TOTAL RESISTANCE OF EACH CIRCUIT
66  !   Th  = TEMPERATURE AT CENTER OF EACH ALUMINUM PLATE
67  !   Tun = TEMPERATURE AT CENTER OF EACH UNHEATED SECTION
68  !   AR  = ASPECT RATIO
69  !   W   = CAVITY WIDTH
70  !   H   = CAVITY HEIGHT
71  !   Ptot= TOTAL POWER INPUT
72  !   Qft = RATIO OF HEAT LOSS THROUGH THE BACK OF HOT WALL TO
73  !         TOTAL POWER INPUT
74  !   Qmt = RATIO OF HEAT LOSS THROUGH THE MOVING WALL TO TOTAL
75  !         POWER INPUT
76  !   Qbt = RATIO OF HEAT LOSS THROUGH THE BOTTOM WALL TO TOTAL
77  !         POWER INPUT
78  !   Tc  = AVERAGE TEMPERATURE OF HEAT EXCHANGER
79  !   Ta  = AMBIENT TEMPERATURE
80  !   Tg  = SURFACE GLASS TEMPERATURE
81  !   Tprobe = TEMPERATURES ASSOCIATED WITH THE PROBES
82  !
83  ! *****
85  OPTION BASE 1
86  DIM Tp(39),E(39),V(5),R(5),Th(5),Tun(6),Eprobe(3,11),Tprobe(3,11)
87  DIM Cur(5),P(5),Rm(5)
90  ! THIS SECTION OF THE PROGRAM IS USED TO ACQUIRE THE VOLTAGE
100 ! INFORMATION FROM THE THERMOCOUPLES. IT MEASURES CHANNELS
110 ! 0 TO 35 ,CHANNELS 100 TO 105 & VOLTAGE INPUT #99. (CHANNELS 0,20,80 AND
111 ! 100 ARE REFERENCE TEMPERATURE)
130 ! 709 AND 722 ARE THE TWO DEVICES USED IN DATA ACQUISITION.
140 ! NEXT : THE ICE POINT VOLTAGE WILL BE SUBSTRACTED FROM ALL
150 ! THE MEASURED VOLTAGES.
151 INPUT "HORIZONTAL DISTANCE FROM HOT WALL TO MOVING WALL (mm)?",W
152 INPUT "POWER DESIRED PER ALUMINUM PLATE",Po
153 PRINT
154 H=165
155 Ar=H/W
157 V1=SQR(78.83*2*Po)
158 V2=SQR(119.2*3*Po)
162 PRINT "      HORIZONTAL DISTANCE IS ";W;" mm"

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163 PRINT
164 PRINT USING "28A,40.3D";" ASPECT RATIO IS " ,Ar
165 PRINT
166 PRINT USING "22A,40.2D,8A";" SET VARIAC #1 TO " ,V1," VOLTS"
167 PRINT
168 PRINT USING "22A,40.2D,8A";" SET VARIAC #2 TO " ,V2," VOLTS"
169 INPUT "DO YOU WANT TO COLECT TEMPERATURE DATA (Y/N)?",S10$
170 IF S10$="N" THEN GOTO 578
172 CLEAR 709
173 CLEAR 722
180 OUTPUT 722;"H6ST6S0F1FL1Z1R1"
190 FOR I=0 TO 19
200 OUTPUT 709;"AC";I
210 ENTER 722 USING "*,K";E(I+1)
220 NEXT I
221 FOR I=20 TO 35
222 OUTPUT 709;"AC";I
223 ENTER 722 USING "*,K";E(I+1)
224 NEXT I
225 J1=37
226 FOR I=100 TO 102
227 OUTPUT 709;"AC";I
228 ENTER 722 USING "*,K";E(J1)
229 J1=J1+1
230 NEXT I
232 R0=E(1)
240 R20=E(21)
241 R100=E(37)
250 FOR I=2 TO 20
260 E(I)=E(I)-R0
270 NEXT I
280 FOR I=22 TO 36
290 E(I)=E(I)-R20
300 NEXT I
301 FOR I=38 TO 39
302 E(I)=E(I)-R100
303 NEXT I
310 ! THE SUBROUTINE TO CONVERT Emf TO TEMPERATURE IS CALLED
320 ! Temp = 0.1 SETS THE TEMPERATURE TO 0.1 IF THE READING
330 ! IS BAD.
350 FOR I=1 TO 39
360 Em=E(I)
370 Tem=.1
380 CALL Eat(Em,Tem)
381 Tp(I)=Tem
400 NEXT I
401 PRINT "
402 PRINT " REFERENCE TEMPERATURE (ICE POINT) "

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```

403 PRINT "
404 I=1
405 J=I-1
407 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
408 I=21
409 J=I-1
411 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
412 I=37
413 J=100
415 PRINT USING "8X,3D,8X,4D.2D";J,Tp(I)
416 PRINT "
417 PRINT "    TEMPERATURE AT BOTTOM WALL "
418 PRINT "
419 FOR I=2 TO 7
420     J=I-1
422     PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
423 NEXT I
424 PRINT "
425 PRINT "    TEMPERATURE AT MOVING WALL
426 PRINT "
427 FOR I=8 TO 11
428     J=I-1
430     PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
431 NEXT I
432 PRINT "
433 PRINT "    TEMPERATURE AT BACK OF HOT WALL "
434 PRINT "
435 FOR I=27 TO 30
436     J=I-1
438     PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
439 NEXT I
440 PRINT "    CONSTANT TEMPERATURE WALL (HEAT EXCHANGER) "
441 FOR I=12 TO 18
442     J=I-1
444     PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
445 NEXT I
450 PRINT "
460 PRINT "    TEMPERATURES OF THE ALUMINUM PLATES (TOP TO BOTTOM)"
470 I=19
471 J=I-1
473 Th(5)=Tp(I)
480 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
490 I=20
491 J=I-1
493 Th(4)=Tp(I)
500 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
501 I=23
502 J=I-1
504 Th(3)=Tp(I)

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```

505 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
512 FOR I=25 TO 26
513 J=I-1
515 Th(2)=Tp(25)
516 Th(1)=Tp(26)
517 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
518 NEXT I
519 PRINT " "
520 PRINT " TEMPERATURES TO CHECK SIMMETRY AT CENTER OF HOT WALL "
521 PRINT " "
522 I=22
523 J=I-1
525 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
526 I=24
527 J=I-1
529 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
540 PRINT " "
550 PRINT " TEMPERATURE OF UNHEATED SECTIONS (TOP TO BOTTOM)"
560 PRINT " "
561 K=6
562 FOR I=31 TO 36
563 J=I-1
565 Tun(K)=Tp(I)
566 PRINT USING "8X,2D,8X,4D.2D";J,Tp(I)
567 K=K-1
568 NEXT I
569 !CALCULATING AN AVERAGE TEMPERATURE FOR THE CONSTANT TEMPERATURE PLATE
570 !
571 Tc=(Tp(12)+Tp(13)+Tp(14)+Tp(15)+Tp(16)+Tp(17)+Tp(18))/7
572 !
573 PRINT
574 PRINT USING "8X,32A,4D.2D";"AVERAGE COLD PLATE TEMPERATURE: ",Tc
575 PRINT USING "8X,32A,4D.2D";"SURFACE GLASS TEMPERATURE : ",Tp(38)
576 PRINT USING "8X,32A,4D.2D";"AMBIENT TEMPERATURE : ",Tp(39)
577 PRINT
578 ! ALUMINUM PLATE RESISTANCE (2 IN SERIES)
579 R(1)=78.83
580 ! ALUMINUM PLATE RESISTANCE (3 IN SERIES)
581 R(2)=119.20
582 ! GUARD HEATER RESISTANCE (BACK OF HOT WALL - 4 IN PARALLEL)
583 R(3)=107.81
584 ! MOVING WALL GUARD HEATERS RESISTANCE (4 IN PARALLEL)
585 R(4)=108.63
586 ! GUARD HEATER RESISTANCE (BOTTOM WALL- 4 IN PARALLEL)
587 R(5)=188.42
589 !
599 CLEAR 709
609 CLEAR 722

```

```

610 OUTPUT 722;"H6ST6FL1R1Z1F2"
611 FOR I=36 TO 39
612     J=I-35
613     OUTPUT 709;"AC";I
614     WAIT 1
615     ENTER 722 USING "$,K";V(J)
616 NEXT I
617 I=99
618 J=5
619 OUTPUT 709;"AC";I
620 WAIT 1
621 ENTER 722 USING "$,K";V(J)
622 IF S10$="N" THEN GOTO 833
624 ! CHECKING THE TEMPERATURE GRADIENT AT THE BOTTOM WALL
625 !
626 Ab=(.140970*W)/1000
627 Kb=.25
628 D1b=.009525
629 IF W>33 THEN
630     Dtb1=Tp(3)-Tp(2)
631     Dtb2=Tp(5)-Tp(4)
632     IF Dtb1<0 OR Dtb2<0 THEN
634         Dtb=(Dtb1+Dtb2)/2
635         Dtb=ABS(Dtb)
636         Qb1=Kb*Ab*Dtb/D1b
637         V0=V(5)-SQR(R(5)*Qb1)
638         PRINT
639         PRINT " !!!WARNING!!! -REDUCE OUTSIDE VARIAC TO ";V0;" VOLTS"
640         PRINT
641         END IF
657     IF Dtb1>0 AND Dtb2>0 THEN
658         Dtb=(Dtb1+Dtb2)/2
659     END IF
661     END IF
662     IF W<33 THEN
663         Dtb=Tp(3)-Tp(2)
664         IF Dtb<0 THEN
665             Dtb=ABS(Dtb)
666             Qb1=Kb*Ab*Dtb/D1b
667             V0=V(5)-SQR(R(5)*Qb1/3)
668             PRINT
669             PRINT " !!!WARNING !!!-REDUCE OUTSIDE VARIAC TO ";V0;" VOLTS"
670             PRINT
671             END IF
672             IF Dtb1>0 THEN
673                 Dtb=Dtb1
674             END IF
681     END IF

```

```

682      !
683      ! CHECKING THE TEMPERATURE GRADIENT AT THE    MOVING WALL
684      !
685      Dtm1=Tp(9)-Tp(8)
686      Dtm2=Tp(11)-Tp(10)
687      Am=.023598
688      Km=.25
689      Dlm=.0111125
690      !
691      IF Dtm1<0 OR Dtm2<0 THEN
692          Dtm=(Dtm2+Dtm1)/2
693          Dtm=ABS(Dtm)
694          Qm1=Km*Am*Dtm/Dlm
695          V4=V(4)-SQRT(R(4)*Qm1)
696          PRINT
697          PRINT "!!!WARNING!!!-REDUCE VARIAC #4 TO ";V4;" VOLTS"
698          PRINT
699      END IF
700      IF Dtm1>0 AND Dtm2>0 THEN
701          Dtm=(Dtm1+Dtm2)/2
702      END IF
703      !
704      ! CHECKING THE TEMPERATURE GRADIENTS AT THE BACK OF THE HOT WALL
705      !
706      Dtf1=Tp(28)-Tp(27)
707      Dtf2=Tp(30)-Tp(29)
708      Af=.023598
709      Kf=.33
710      Dlf=.0047625
711      !
712      IF Dtf1<0 OR Dtf2<0 THEN
713          Dtf=(Dtf1+Dtf2)/2
714          Dtf=ABS(Dtf)
715          Qf1=Kf*Af*Dtf/Dlf
716          V3=V(3)-SQRT(R(3)*Qf1)
717          PRINT
718          PRINT "!!!WARNING!!!-REDUCE VARIAC #3 TO ";V3;" VOLTS"
719          PRINT
720      END IF
721      IF Dtf1>0 AND Dtf2>0 THEN
722          Dtf=(Dtf1+Dtf2)/2
723      END IF
724      IF Dtb1<0 OR Dtb2<0 OR Dtm1<0 OR Dtm2<0 OR Dtf1<0 OR Dtf2<0 THEN GOTO 1002
725      !*****CALCULATING HEAT LOSS FROM THE BOTTOM *****
726      !
727      Qb=Kb*Ab*Dtb/Dlb
728      !
729      !*****CALCULATING HEAT LOSSES FROM HOT WALL *****

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764      !
765      Qf=Kf*Af*Dtf/Dlf
766      !
767      !*****CALCULATING HEAT LOSSES FROM THE MOVING WALL*****
768      !
769      Qm=Km*Am*Dtm/Dlm
770      !
771      !*****CALCULATING HEAT LOSSES THROUGH THE END GLASSES*****
772      !
773      !AIR PROPERTIES TAKEN FROM CIRCULAR # 564 PUBLISHED BY NATIONAL BUREAU
774      !OF STANDARDS
775      !
776      L=.165
777      Wg=W/1000
778      Tg=Tp(38)
779      Ta=Tp(39)
780      Tair=(Tg+Ta)/2
781      Tk=Tair+273.15
782      Tk1=6.325E-6*(Tk^1.5)
783      G=-12/Tk
784      Tk2=245.4*(10^6)
785      Kair=418.3709*Tk1/(Tk+Tk2)
786      Betha=1/Tk
787      Cpair=981.5714+.085714*Tk
788      Den=352.5/Tk
789      Dynvis=1.458E-6*(Tk^1.5)/(Tk+110.4)
790      Kinvis=Dynvis/Den
791      Alf=Kair/(Den*Cpair)
792      Pr=Kinvis/Alf
793      Cl=(9.81*Betha/(Kinvis^2))*(L^3)
794      Grair=Cl*(Tg-Ta)
795      Rair=Pr*Grair
796      Nair=.68+((.670*(Rair^.25))/((1+((.492/Pr)^(9/16))))^(4/9))
797      Hair=(Nair*Kair)/L
798      Qair=2*(Hair*Wg*L*(Tg-Ta))
799      !
800      Ptot=5*Po
801      Perc1=(Qb/Ptot)*100
802      Perc2=(Qm/Ptot)*100
803      Perc3=(Qf/Ptot)*100
804      Perc4=(Qair/Ptot)*100
805      PRINT
806      PRINT USING "8X,29A,11X,4D.2D,6A,4D.2D,2A"; "HEAT LOSS FROM BOTTOM WALL IS"
807      ,Qb," WATTS ;",Perc1," %"
808      PRINT
809      PRINT USING "8X,29A,11X,4D.2D,6A,4D.2D,2A"; "HEAT LOSS FROM MOVING WALL IS"
810      ,Qm," WATTS ;",Perc2," %"
811      PRINT

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816 PRINT USING "8X,38A,2X,4D.2D,6A,4D.2D,2A"; "HEAT LOSS THROUGH THE BACK OF H
OT WALL", Qf, " WATTS "; ",Perc3," %"
817 PRINT
818 PRINT USING "8X,36A,4X,4D.2D,6A,4D.2D,2A"; "HEAT LOSS TO AIR THROUGH END GL
ASSES", Qair, " WATTS "; ",Perc4," %"
819 PRINT
820 PRINT USING "8X,10A,4D.2D"; "Nu(air) = ", Nair
821 PRINT USING "8X,10A,4D.2D"; "hc(air) = ", Hair
822 PRINT USING "8X,10A,SD.3DE"; "Ra(air) = ", Rair
823 PRINT
824 !*****CALCULATING THE TOTAL POWER INPUT AND COMPARING
825 !           IT WITH THE TOTAL HEAT LOSS*****!
826 !
827 Hlos=Qb+Qm+Qf+Qair
828 Perc=(Hlos/Ptot)*100
829 PRINT
830 PRINT USING "8X,26A,4D.2D,6A"; "TOTAL HEAT INPUT IS      : ", Ptot, " WATTS"
831 PRINT USING "8X,26A,4D.2D,6A"; "TOTAL HEAT LOSS IS      : ", Hlos, " WATTS"
832 PRINT USING "8X,26A,4D.2D,6A"; "PERCENT HEAT LOSS IS    : ", Perc, " % "
833 PRINT
834 !
835 !THE PROGRAM NOW PROCEED TO REQUEST THE CURRENT AT THE FIVE DIFFERENT
836 !CIRCUITS. THIS CURRENT WILL BE MEASURED BY USING A "KEITHLEY" AMPMETER
837 !
838 INPUT "DO YOU WANT TO INPUT THE CURRENT FOR EACH CIRCUIT (Y/N)?", S6$
839 IF S6$="N" THEN GOTO 897
840 !
841 FOR J=1 TO 5
842     IF J=1 THEN
843         INPUT " TYPE MEASURED CURRENT (mA) AT CIRCUIT # 1", Cur(1)
844     END IF
845     IF J=2 THEN
846         INPUT " TYPE MEASURED CURRENT (mA) AT CIRCUIT # 2", Cur(2)
847     END IF
848     IF J=3 THEN
849         INPUT " TYPE MEASURED CURRENT (mA) AT CIRCUIT # 3", Cur(3)
850     END IF
851     IF J=4 THEN
852         INPUT " TYPE MEASURED CURRENT (mA) AT CIRCUIT # 4", Cur(4)
853     END IF
854     IF J=5 THEN
855         INPUT " TYPE MEASURED CURRENT (mA) AT CIRCUIT # 5", Cur(5)
856     END IF
857 NEXT J
858 PRINT
859 PRINT "          MEASURED      MEASURED      ORIGINAL      EXP.      POWER"
860 PRINT "          CURRENT      VOLTAGE      RESIST.      RESIST."
861 PRINT "          (mAMPS)      (VOLTS)      (OHMS)      (OHMS)      (W)"

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862 PRINT
863 FOR I=1 TO 5
864     Rm(I)=(V(I)*1000)/Cur(I)
870     P(I)=V(I)^2/R(I)
880     PRINT USING "4X,10,2X,50.2D,5X,40.2D,7X,40.2D,7X,40.2D,4X,40.2D":I,Cur
(I),V(I),R(I),Rm(I),P(I)
890 NEXT I
891 !
892 PRINT "!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!!"
893 !
894 ! IF TEMPERATURE GRADIENT (WHICH ARE BEING CHECKED ABOVE) ARE OK
895 ! THEN CALCULATE HOW MUCH MORE HEAT INPUT IS NEEDED TO DECREASES LOSSES
897 !
904 V0=SQR(R(5)*Qb)*1.05+V(5)
906 PRINT "PLEASE ADJUST OUTSIDE VARIAC TO ";V0;" VOLTS "
907 PRINT
917 V3=SQR(R(3)*Qf)*1.05+V(3)
919 PRINT "PLEASE ADJUST VARIAC #3 TO ";V3;" VOLTS"
920 PRINT
930 V4=SQR(R(4)*Qm)*1.05+V(4)
931 PRINT "PLEASE ADJUST VARIAC #4 TO ";V4;" VOLTS"
933 PRINT
934 IF S1$="N" THEN GOTO 942
936 INPUT "TO WRITE THE DATA INTO THE FILE 'RICH12_DAT' ENTER NUMBER,OTHERWISE
ENTER 0",R1
937 IF R1>0 THEN CALL Write(R1,Ptot,W,Tc,Tp(*),Hlos,P(*),V(*),Cur(*))
938 !
939 ! THIS PORTION OF THE PROGRAM COLLECTS THE TEMPERATURES ASSOCIATED WITH
940 ! THE PROBES AND STORE IT IN THE FILE 'PROB_DAT'
941 !
942 INPUT "DO YOU WANT TO TAKE PROBE MEASUREMENTS (Y/N)",S1$
943 IF S1$="N" THEN GOTO 1002
944 INPUT "HOW MANY PROBES ARE INSIDE THE CAVITY ",N
945 IF N=0 THEN GOTO 1002
946 !
947 CLEAR 709
948 CLEAR 722
953 FOR J=1 TO 11
954     INPUT "IF YOU ARE READY TO TAKE NEXT PROBE MEASUREMENT ENTER 'Y'",S2$
955     WAIT 5
956     OUTPUT 722;"H6ST6S0F1FL1Z1R1"
957     I=100
958     OUTPUT 709;"AC":I
959     ENTER 722 USING "$,K":E(37)
960     R100=E(37)
962     FOR I=1 TO N
963         OUTPUT 709;"AC":102+I
964         ENTER 722 USING "$,K":Eprobe(I,J)

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965     NEXT I
966     FOR I=1 TO N
967         Tem=.1
968         Em=Eprobe(I,J)-R100
969         CALL Eat(Em,Tem)
970         Tprobe(I,J)=Tem
971     NEXT I
972 NEXT J
973 PRINT
974 PRINT
975 PRINT "                PROBE MEASUREMENTS                "
976 PRINT
977 PRINT
978 IF N=1 THEN
979     PRINT "                1                "
980 END IF
981 IF N=2 THEN
982     PRINT "                1                2 "
983 END IF
984 IF N=3 THEN
985     PRINT "                1                2                3"
986 END IF
987 PRINT
988 FOR J=1 TO 11
989     IF N=1 THEN
990         PRINT USING "25X,2D,6X,4D.2D";J,Tprobe(1,J)
991     END IF
992     IF N=2 THEN
993         PRINT USING "8X,2D,11X,4D.2D,16X,4D.2D";J,Tprobe(1,J),Tprobe(2,J)
994     END IF
995     IF N=3 THEN
996         PRINT USING "8X,2D,5X,4D.2D,12X,4D.2D,14X,4D.2D";J,Tprobe(1,J),Tprobe(
2,J),Tprobe(3,J)
997     END IF
998 NEXT J
999     !
1000     INPUT "TO WRITE THE PROBES DATA INTO 'PROBE_DAT' ENTER RUN NUMBER,OTHE
RWISE ENTER 0",R3
1001     IF R3>0 THEN CALL Write2(R3,Po,W,Tc,Tprobe(*),N)
1002 PRINT "RUN COMPLETED"
1003 END
1004 !
1005 !
1006 ! ***** TEMPERATURE CONVERSION SUBROUTINE *****
1007 SUB Eat(Em,Tem)
1008 DIM A(8)
1009 INTEGER J,K,I,I1
1010 Emf=Em

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1011 Emf=Emf*1000.*1000.
1012 Delta=.0001
1013 A(1)=3.8740773840E+1
1020 A(2)=3.3190198092E-2
1030 A(3)=2.0714183645E-4
1040 A(4)=-2.1945834823E-6
1050 A(5)=1.1031900550E-8
1060 A(6)=-3.0927581898E-11
1070 A(7)=4.5653337165E-14
1080 A(8)=-2.7616878040E-17
1090 T=25.
1100 FOR K=1 TO 10
1110 B=0.
1120 C=0.
1130 FOR J=2 TO 9
1140 I=10-J
1150 B=(B+A(I))*T
1160 C=C+I*A(I)
1170 Tdelta=(B-Emf)/C
1180 NEXT J
1190 T=T-Tdelta
1200 Err=ABS(Tdelta)
1210 IF Err<Delta THEN
1220 Temp=T
1230 Tem=Temp
1240 GOTO 1280
1250 ELSE
1260 END IF
1270 NEXT K
1280 SUBEND
1290 !
1300 ! SUBROUTINE USED TO STORE TEMPERATURE,HEAT LOSS,POWER INPUT AND CURRENT
1310 !
1320 SUB Write(R1,Ptot,W,Tc,Tp(*),Hlos,P(*),V(*),Cur(*))
1330 !
1340 ! NEXT STATEMENT IS USED TO SELECT THE CORRECT RECORDS TO STORE THE DATA
1350 ASSIGN @Path_1 TO "RICH12_DAT"
1360 OUTPUT @Path_1,R1
1370 OUTPUT @Path_1;R1
1380 OUTPUT @Path_1;Ptot,W,Tc,Hlos
1390 OUTPUT @Path_1;P(*),V(*),Cur(*)
1400 OUTPUT @Path_1;Tp(*)
1440 PRINT " DATA ADDED TO RICH12_DAT UNDER RUN NUMBER :",R1
1450 SUBEND
1460 !
1470 ! SUBROUTINE TO WRITE THE PROBE TEMPERATURE DATA
1480 !
1490 SUB Write2(R3,Po,W,Tc,Tprobe(*),N)

```

```

1500 ASSIGN @Path_1 TO "PROB_DAT"
1510 OUTPUT @Path_1,R3
1520 OUTPUT @Path_1;R3
1530 OUTPUT @Path_1;Ptot,W,Tc,N
1540 FOR J=1 TO 11
1550     IF N=1 THEN
1560         OUTPUT @Path_1;Tprobe(1,J)
1570     END IF
1580     IF N=2 THEN
1590         OUTPUT @Path_1;Tprobe(1,J),Tprobe(2,J)
1600     END IF
1610     IF N=3 THEN
1620         OUTPUT @Path_1;Tprobe(1,J),Tprobe(2,J),Tprobe(3,J)
1630     END IF
1640 NEXT J
1650 PRINT
1660 PRINT "PROBE MEASUREMENTS HAVE BEEN ADDED TO PROB_DAT UNDER RUN #",R3
1670 SUBEND

```

```

10  !***** PROGRAM NAME "REDUCE"*****
20  ! THIS PROGRAM READ DATA FROM "RICH12_DAT", REDUCES DATA BASED ON Y&W
21  ! AND STORE DAT INTO "REDU2_DAT" OR "GLY_DAT". Y IS LOCAL HEIGHT.
40  !*****DIMENSION STATEMENTS*****
50  OPTION BASE 1
51  DIM Th(S),T(S),V(S),Rho(S),K(S),Cp(S),Mu(S),Alf(S),Y(S),Tun(6),Tk(S)
52  DIM Pr(S),Kvis(S),Grw(S),Raw(S),Nuw(S),C(S),Tf(S),Ray(S),Nuy(S),Gry(S)
62  DIM Nu11(S),Gr11(S),Ra11(S),Rasy(S),Rasw(S),Tp(39),P(S),Cur(S),Cc(S)
63  DIM R1(44)
72  !
82  !          DECLARATION OF VARIABLES
390 ! Ah IS AREA OF EACH HEATER
391 ! Rasy=LOCAL MODIFIED RAYLEIGH NUMBER BASED ON HEAT FLUX CONVECTED
392 ! Ray =LOCAL RAYLEIGH NUMBER BASED ON LOCAL TEMPERATURE DIFFERENCE
393 ! Y = LOCAL HEIGHT TO THE CENTER OF EACH HEATER
394 ! Rasw=LOCAL MODIFIED RAYLEIGH NUMBER BASED ON HEAT FLUX CONVECTED
395 ! Raw =LOCAL RAYLEIGH NUMBER BASED ON LOCAL TEMPERATURE DIFFERENCE
396 ! W = CAVITY WIDTH
400 Ah=.002126004
410 Y(1)=.0225
420 FOR I=2 TO 5
430 Y(I)=Y(I-1)+.03
440 NEXT I
450 L1=.015
720 !***** SELECTION OF REQUIRED DATA*****
721 !
722 ! REARRANGING THE OLD RUN NUMBER IN ONE OF INCREASING POWER INPUT
723 ! AND CAVITY WIDTH
725 R1(1)=1
726 R1(2)=2
727 R1(3)=8
728 R1(4)=3
729 R1(5)=7
730 R1(6)=4
731 R1(7)=6
732 R1(8)=5
733 R1(9)=9
734 R1(10)=10
735 R1(11)=11
736 R1(12)=12
737 R1(13)=16
738 R1(14)=13
739 R1(15)=15
740 R1(16)=14
741 R1(17)=17
742 R1(18)=18
743 R1(19)=19
744 R1(20)=20

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745 R1(21)=21
746 R1(22)=22
747 R1(23)=24
748 R1(24)=23
749 R1(25)=25
750 R1(26)=26
751 R1(27)=27
752 R1(28)=28
753 R1(29)=29
754 R1(30)=30
755 R1(31)=31
756 R1(32)=32
757 R1(33)=33
758 R1(34)=34
759 R1(35)=35
760 R1(36)=36
761 R1(37)=38
762 R1(38)=37
763 R1(39)=39
764 R1(40)=40
765 R1(41)=41
766 R1(42)=42
767 R1(43)=43
768 R1(44)=44
769 INPUT "WHAT IS THE DESIRED RUN NUMBER ?",R2
770 ASSIGN @Path_1 TO "RICH12_DAT"
771 ENTER @Path_1,R1(R2)
772 ENTER @Path_1;R1(R2)
773 ENTER @Path_1;Ptot,W,Tc,Hlos
774 ENTER @Path_1;P(*),V(*),Cur(*)
775 ENTER @Path_1;Tp(*)
776 !
777 !READING THE RESPECTIVE CORRECTION CONSTANT FOR SUBSTRATE
778 !CONDUCTION
780 ASSIGN @Path_1 TO "CONSTA_DAT"
781 ENTER @Path_1,R2
782 ENTER @Path_1;R2
783 ENTER @Path_1;Cc(1),Cc(2),Cc(3),Cc(4),Cc(5)
785 Qt=Ptot-Hlos
786 Qc=Qt/(5*Ah)
787 Ar=165/W
788 Th(5)=Tp(19)
789 Th(4)=Tp(20)
795 Th(3)=Tp(23)
805 Th(2)=Tp(25)
815 Th(1)=Tp(26)
816 J=1
825 FOR I=31 TO 36

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835     Tun(J)=Tp(I)
845     J=J+1
855 NEXT I
1270 !***** CALCULATING PROPERTIES IN THIS SECTION *****
1280 ! EVALUATE FILM TEMPERATURE (TF) ACCORDING TO PAPER BY ZHONG,YANG AND
1281 ! LLOYD-"VARIABLE PROPERTY EFFECTS IN LAMINAR NATURAL CONVECTION IN A
1282 ! SQUARE ENCLOSURE"
1283 PRINT USING "8X,27A,1X,40.3D";"RESULTS FOR ASPECT RATIO = ",Ar
1284 P1=Ptot/S
1285 PRINT USING "8X,27A,1X,40.2D,1X,5A";"POWER INPUT PER ELEMENT = ",P1,"Watt
s"
1287 PRINT
1290 W=W/1000
1319 PRINT
1320 FOR I=1 TO 5
1326 Tf(I)=(Th(I)+Tc)/2
1327 NEXT I
1329 !
1345 ! PROPERTIES OF GLYCOL
1346 !
1347 Ave1=0.
1348 Ave2=0.
1349 Ave3=0.
1351 FOR I=1 TO 5
1352     T(I)=Tf(I)
1353 Rho(I)=1130.75-.6297915*T(I)-5.013587E-5*T(I)^2+6.448046E-7*T(I)^3-9.11553
7E-9*T(I)^4
1354     Tk(I)=T(I)+273.15
1356     K(I)=.2175195+1.3439E-4*Tk(I)
1380     Cp(I)=4186.8*(5.548E-3+3.35083E-3*Tk(I)-7.224E-6*Tk(I)^2+8.04367E-9*Tk
(I)^3)
1390     Nu=EXP(-2.813092-5.195844E-2*T(I)+1.746046E-4*T(I)^2+8.043671E-7*T(I)^
3)
1410     Vs(I)=1/(Rho(I)*1.E-3)
1420     Mu(I)=(.04445*EXP(2234/Tk(I))+5.578276E-7*EXP(5570/Tk(I)))/SQR(Vs(I))
1430     Mu(I)=Mu(I)/10000
1431     Mu(I)=(Mu(I)+Nu)/2
1440     B=6.65E-4
1450     Alf(I)=K(I)/(Rho(I)*Cp(I))
1460     Kvis(I)=Mu(I)/Rho(I)
1464 !*****CALCULATE DIMENTIONLESS NUBER*****
1470     Pr(I)=Kvis(I)/Alf(I)
1480     C(I)=9.81*B/(Kvis(I)^2)
1511     Hc(I)=(Qc/(Th(I)-Tc))*Cc(I)
1514     Grw(I)=(C(I)*W^4*Qc/K(I))*Cc(I)
1515     Rasw(I)=Pr(I)*Grw(I)
1517     Nuw(I)=(Hc(I)*W/K(I))
1518     Raw(I)=(Rasw(I)/Nuw(I))
1520     Null(I)=(Hc(I)*L1/K(I))

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1521      Gr11(I)=(C(I)*L1^4*Qc/K(I))*Cc(I)
1522      Ra11(I)=Pr(I)*Gr11(I)
1524      Gry(I)=(C(I)*Y(I)^4*Qc/K(I))*Cc(I)
1525      Rasy(I)=Pr(I)*Gry(I)
1526      Nuy(I)=(Hc(I)*Y(I)/K(I))
1527      Ray(I)=Rasy(I)/Nuy(I)
1528      !
1529      ! CALCULATING AVERAGE PROPERTY VALUES TO EVALUATE AVERAGE NUSSELT
1530      ! NUMBER AND AVERAGE RAYLEIGH NUMBER
1531      !
1532      Ave1=Ave1+(B/(K(I)*Kvis(I)*Alf(I)))
1533      Ave2=Ave2+Hc(I)
1534      Ave3=Ave3+K(I)
1535 NEXT I
1545      Ave1=Ave1/5
1555      Ave2=Ave2/5
1565      Ave3=Ave3/5
1575      Rave=9.81*Ave1*W^4*Qc
1585      Nuave=Ave2*W/Ave3
1732 PRINT "          Y(m)          Nu(y)          Ra*(y)          Ra(y)          h (W/
K-m^2)"
1733 FOR I=1 TO 5
1734 PRINT USING "8X,1D.4D,4X,4D.3D,6X,SD.3DE,6X,SD.3DE,6X,3D.3D";Y(I),Nuy(I),Ra
sy(I),Ray(I),Hc(I)
1735 NEXT I
1736 PRINT
1737 PRINT
1739 PRINT "          Y(m)          Nu(w)          Ra*(w)          Ra(w)          Pr
"
1740 FOR I=1 TO 5
1741 PRINT USING "8X,1D.4D,4X,4D.3D,6X,SD.3DE,6X,SD.3DE,6X,3D.3D";Y(I),Nu(I),Ra
sw(I),Raw(I),Pr(I)
1742 NEXT I
1743 PRINT
1744 PRINT
1746 PRINT "          Y(m)          Nu(L1)          Gr(L1)          Ra(L1)"
1747 Nut=0.
1749 FOR I=1 TO 5
1750 PRINT USING "8X,1D.4D,4X,4D.3D,6X,SD.3DE,6X,SD.3DE";Y(I),Nu11(I),Gr11(I),Ra
11(I)
1753 NEXT I
1758 !
1759 ! PRINTING AVERAGE VALUES
1760 !
1762 PRINT
1763 PRINT USING "10X,10A,1X,SD.3DE";"Ra(w)ave= ",Rave
1764 PRINT USING "10X,11A,1X,4D.2D";"Nu(w)ave ",Nuave
1774 Tave=0
1779 FOR J=1 TO 5

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1780 Tave=Tave+Th(J)
1782 NEXT J
1792 Tave=Tave/S
1802 Tf(1)=(Tave+Tc)/2
1816 !
1833 ! PROPERTIES OF GLYCOL (EVALUATED AT TAVE)
1834 !
1836 D=141/1000
1837 Qc=Qt/(W*D)
1840 T(1)=Tf(1)
1841 Rho(1)=1130.75-.6297915*T(1)-5.013587E-5*T(1)^2+6.448046E-7*T(1)^3-9.11553
7E-9*T(1)^4
1842 Tk(1)=T(1)+273.15
1848 K(1)=.2175195+1.3439E-4*Tk(1)
1868 Cp(1)=4186.8*(5.548E-3+3.35083E-3*Tk(1)-7.224E-6*Tk(1)^2+8.04367E-9*Tk
(1)^3)
1878 Nu=EXP(-2.813092-5.196844E-2*T(1)+1.746046E-4*T(1)^2+8.043671E-7*T(1)^
3)
1898 Vs(1)=1/(Rho(1)*1.E-3)
1908 Mu(1)=(.04445*EXP(2234/Tk(1))+5.578276E-7*EXP(5570/Tk(1)))/SQR(Vs(1))
1918 Mu(1)=Mu(1)/10000
1919 Mu(1)=(Mu(1)+Nu)/2
1928 B=6.65E-4
1938 Alf(1)=K(1)/(Rho(1)*Cp(1))
1948 Kvis(1)=Mu(1)/Rho(1)
1952 !*****CALCULATE DIMENTIONLESS NUBER*****
1953 I=1
1958 Pr(I)=Kvis(I)/Alf(I)
1968 C(I)=9.81*B/(Kvis(I)^2)
1999 Hc(I)=Qc/(Tave-Tc)
2002 Grw(I)=C(I)*W^4*Qc/K(I)
2003 Rasw(I)=Pr(I)*Grw(I)
2005 Nuw(I)=Hc(I)*W/K(I)
2006 Raw(I)=Rasw(I)/Nuw(I)
2225 PRINT
2228 PRINT "          Nu(W,T)          Ra*(W,T)          h(top)          HEAT FLUX"
2229 PRINT "                                (W/K-m^2)          (W/m^2)"
2230 PRINT
2232 PRINT USING "8X,40.30,6X,50.30E,6X,40.30,6X,50.30E";Nuw(I),Rasw(I),Hc(I),Qc
2233 PRINT
2234 PRINT
2235 FOR I=1 TO 5
2236 Cc(I)=100*Cc(I)
2237 PRINT USING "8X,30A,1X,10,1X,2A,1X,30.20";"% ENERGY CONTRIBUTED BY HEATER";
I;"IS";Cc(I)
2238 NEXT I
2239 END

```

```

10  !***** PROGRAM NAME "LEAST SQUARE FITTING" *****
****
20  ! THIS PROGRAM CALL THE TOTAL DATA STORED IN "NU_DAT" FILE AND BY
30  ! LEAST SQUARE METHOD FIND A CORRELATION FOR EACH CAVITY WIDTH
40  !          Nu(Y)=C*(W/H)^(M)*Ra*(Y)^N
50  !
60  OPTION BASE 1
70  DIM R(220),N(220),W(220)
80  ASSIGN @Path_1 TO "NU_DAT"
90  FOR I=1 TO 220
100     ENTER @Path_1;R(I),N(I),W(I)
110  NEXT I
111  ! NOTE W(I)=H/W ALREADY
120  A1=0
150  A2=0
160  A3=0
170  A4=0
171  A5=0
172  A6=0
173  A7=0
174  A8=0
180  Ym=0
181  K1=220
190  FOR I=1 TO 220
200     A1=A1+LOG(W(I))
210     A2=A2+LOG(R(I))
220     A3=A3+LOG(N(I))
230     A4=A4+(LOG(W(I)))^2
231     A5=A5+LOG(R(I))*LOG(W(I))
232     A6=A6+LOG(N(I))*LOG(W(I))
233     A7=A7+(LOG(R(I)))^2
234     A8=A8+LOG(N(I))*LOG(R(I))
240     Ym=Ym+N(I)
250  NEXT I
260  Ym=Ym/220
270  D=220*(A4*A7-A5*A5)-A1*(A1*A7-A2*A5)+A2*(A1*A5-A2*A4)
280  C=EXP((A3*(A4*A7-A5*A5)-A1*(A6*A7-A5*A8)+A2*(A5*A6-A4*A8))/D)
281  M=(220*(A6*A7-A5*A8)-A3*(A1*A7-A2*A5)+A2*(A1*A8-A2*A6))/D
282  N1=(A3-M*A1-220*LOG(C))/A2
320  PRINT USING "14X,15A,1X,2D.4D";"CONSTANT (C) = ",C
330  PRINT USING "14X,15A,1X,2D.3D";"EX.CONST.(M) = ",M
331  PRINT USING "14X,15A,1X,2D.3D";"EX.CONST.(N) = ",N1
340  PRINT
350  PRINT
360  PRINT
370  PRINT
380  PRINT "          Ra*(y)          H/W          Nu(y)          APPROX.          E
RROR(X)"

```

```

390 PRINT
400 Ave=0
401 Sy=0
402 Sxy=0
403 Sy2=0
410 FOR I=1 TO 220
420     Approx=C*((W(I))^M)*(R(I)^N1)
430     Err=ABS((N(I)-Approx)/N(I))*100
440     Ave=Ave+Err
441     Sy=Sy+((N(I)-Ym)^2)
442     Sxy=Sxy+((N(I)-Approx)^2)
443     Sy2=Sy2+((LOG(N(I))-LOG(Ym))^2)
445     IF I=41 THEN
446         PRINT USING "0,%"
447     END IF
448     IF I=81 THEN
449         PRINT USING "0,%"
450     END IF
451     IF I=121 THEN
452         PRINT USING "0,%"
453     END IF
454     IF I=161 THEN
455         PRINT USING "0,%"
456     END IF
457     IF I=191 THEN
458         PRINT USING "0,%"
459     END IF
460     PRINT USING "8X,50.30E,5X,20.20,7X,40.40,5X,40.40,8X,30.20":R(I),W(I),
N(I),Approx,Err
461 NEXT I
470 PRINT
480 PRINT
490 Ave=Ave/220
491 Sy=(Sy/(K1-1))^.5
492 Sxy=(Sxy/(K1-2))^.5
493 Sy2=(Sy2/(K1-1))^.5
495 R2=(1-(Sxy^2)/(Sy^2))^.5
500 PRINT USING "14X,15A,1X,30.20,1X,1A": "AVERAGE ERROR =" ,Ave,"%"
501 PRINT USING "14X,15A,1X,30.40,1X,1A": "CORRE. COEFFI. =" ,R2
503 PRINT USING "14X,15A,1X,30.40,1X,1A": "STANDART DEV. =" ,Sy2
510 END

```

VITA

Ricardo Jose Carmona was born in Barcelona, Venezuela, on September 28, 1962. At the early age of 9 he began to attend the conservatory of music in that city and later became a clarinet player for the Juvenile Symphonic Orquestra of the state of Anzoategui when he was only 12. Parallel with his music education he graduated from the Catholic Pio XII high school in the city of Puerto La Cruz in June 1980. During this period he was also a member of the American Boy Scout Association.

Eager to explore new horizons, he decided to come to the U.S.A in summer of 1982 and after a year of intensive training in the English language he entered the University of Tennessee. He received a Bachelor of Science in Mechanical Engineering from this university in the winter of 1987. In the fall of 1987 he accepted a teaching assistantship to pursue a Master's degree. This degree was conferred in May 1989.

The author is a member of Tau Beta Pi and the American Society of Mechanical Engineers. Mr Carmona will continue studying toward a Doctor of Philosophy degree with a major concentration in convection heat transfer.