EXPERIMENTS ON FREE CONVECTION HEAT TRANSFER TO WATER IN RECTANGULAR VERTICAL GAPS OPEN AT THE UPPER SIDE

By B. V. Krishna Murthy and H. A. Havemann
(*Department of Internal Combustion Engineering, Indian Institute of Science, Bangalore-3*)

Received March 1, 1957

Summary

Experiments have been conducted to study the effect of the gap width on the rate of heat transfer by free convection to water in a rectangular gap between parallel, and relatively short plates open at the upper side.

The results show that as the width of the gap decreases the rate of heat transfer decreases and for very small widths conductive heat transfer is predominant whilst the free convection heat transfer becomes almost negligible.

They are presented in graphical form indicating the interdependence of the Nusselt number on the product of Prandtl and Garshof number.

1. Introduction

The heat transfer from vertical plates to air has been investigated by a number of investigators.[1-4] Similarly, the heat transfer from vertical parallel plates to the enclosed liquids between them has also been studied.[5]

The heat transfer to a rectangular body of water enclosed, with the exception of the upper side which communicated with a cooled section, between short vertical copper plates facing each other and kept at the same temperature has been studied in the following, whereby the effect of the distance between the plates has particularly been investigated. Thus, the bottom of the gap between the plates was kept closed and a flow pattern established characterized by two loops as shown in Fig. 1.

2. Experimental Arrangement

It consisted of two wooden blocks in which the copper plates were embedded. Behind these plates two rectangular copper boxes were fixed, which contained the heater coils. They were connected to a variac with which the voltage could be controlled, and thus the 'Bath temperature'. The two wooden blocks were separated along the circumference by U-type wooden pieces which determined the distance between the plates. The top of the gap thus formed opened into a cylindrical wooden compartment, in which two copper U-tubes were placed through which water was passed, to remove the heat. The details are shown in Fig. 1 and by

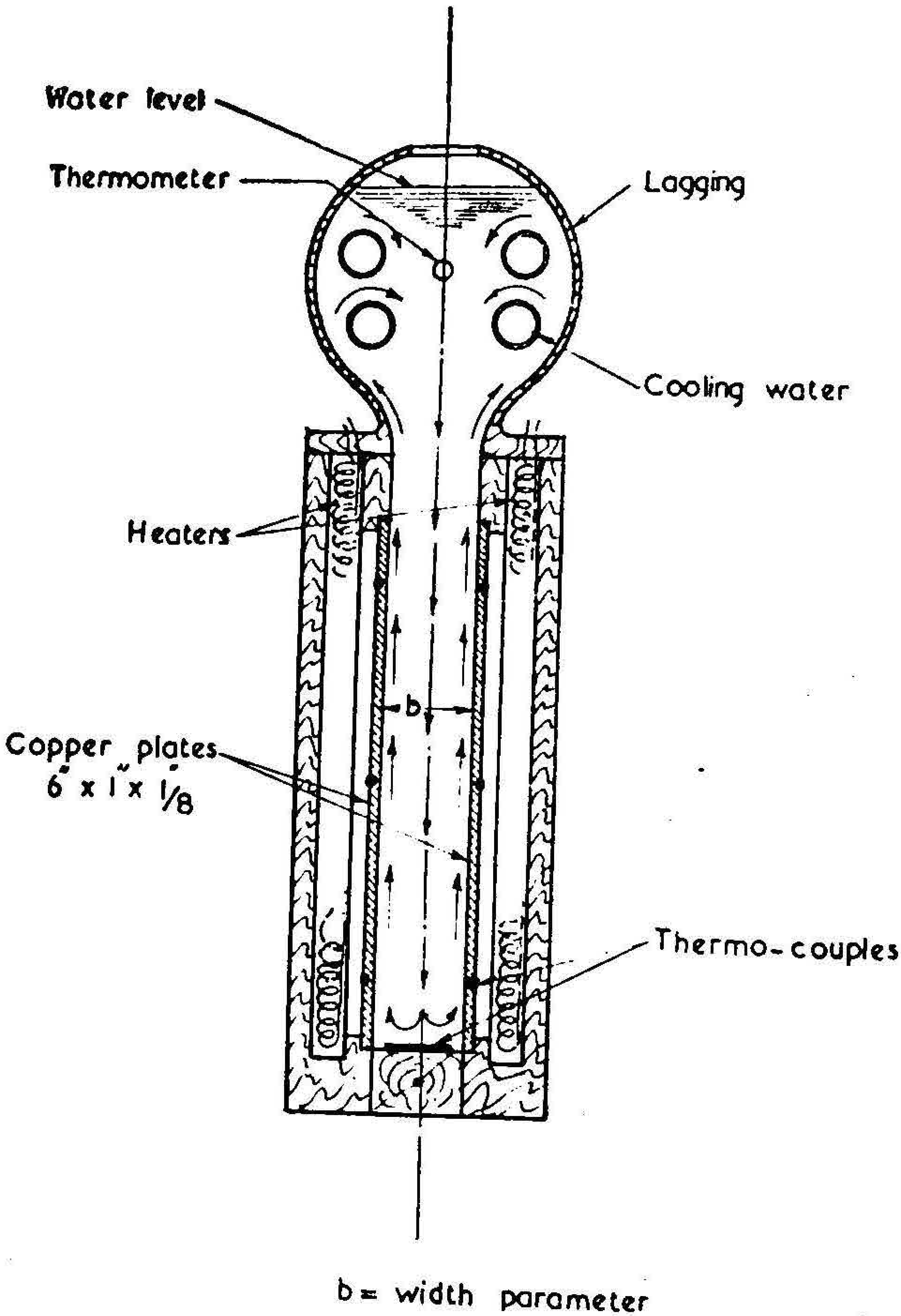


FIG. 1. Apparatus for studying heat transfer by convection from parallel plates to fluids.

Plate IX. The copper plates measured $6'' \times 1'' \times \frac{1}{8}''$ (150 mm. × 25 mm. × 3·10 mm.). Three copper-constantan thermocouples were inserted at the back of each of these plates as shown in Fig. 1. Into the cooling tubes also, copper-contantan thermocouples were inserted for measuring the inlet and outlet water temperatures. The quantity of cooling water was measured which was supplied from an overhead tank and through a control valve.

A copper-constantan thermocouple probe was introduced from the top into the apparatus to check for any temperature gradient along the central plane between the plates. In the case of the $\frac{1}{4}''$ and $\frac{1}{8}''$ wide gaps another thermocouple was introduced in a horizontal plane at the mid-height of the plates to measure the 'Bath temperature'. The thermal e.m.f.s were measured on a precision potentiometer with an accuracy of $\pm 0{\cdot}01$ mv.

The heat removed by the cooling tubes was supplied by the top section of the gap which in the case of the two smallest distances was $1'' \times \frac{1}{4}''$ and $1'' \times \frac{1}{8}''$. As this area was very small and the investigations were confined to the study of free convection without change of state higher temperature differences were difficult to realise without boiling, and thus were not attempted.

3. Experimental Procedure

The apparatus was filled with distilled water upto the top. The heater was switched on and the cooling water adjusted to give a steady 'Bath temperature' which was maintained for at least an hour before readings were taken. The desired 'Bath temperature' could be obtained by adjusting the quantity of cooling water in the system, or by varying the voltage on the heater coils. The readings were recorded at different times of the day and also on different days to check their accuracy. A series of experiments was conducted with the following gap widths:

$$1'',\ \tfrac{3}{4}'',\ \tfrac{1}{2}'',\ \tfrac{1}{4}'' \text{ and } \tfrac{1}{8}''.$$

In all the above cases except in $\frac{1}{4}''$ and $\frac{1}{8}''$ the non-dimensional groups N_{Gr}, N_{Nu}, and N_{Pr} were determined, and also the heat transfer coefficient h.

4. Experimental Results

They are expressed in terms of the following non-dimensional groups:

$$\text{Nusselt Number} = \frac{hD}{k} = N_{Nu}$$

$$\text{Prandtl Number} = \frac{\mu C_p}{k} = N_{Pr}$$

$$\text{Grashof Number} = N_{Gr} = \frac{D^3 \rho^2 \beta g \Delta t}{\mu^2}$$

where

h = Film coefficient of heat transfer of water $B\,hr^{-1} ft^{-2}\,F^{-1}$.

D = Height of the plate *ft*.

k = Thermal conductivity of water $B\,hr^{-1} ft^{-1} F^{-1}$.

μ = Dynamic viscosity of water $lb\,ft^{-2}\,hr^{-1}$.

C_p = Specific heat of water $B lb_m^{-1} F^{-1}$.

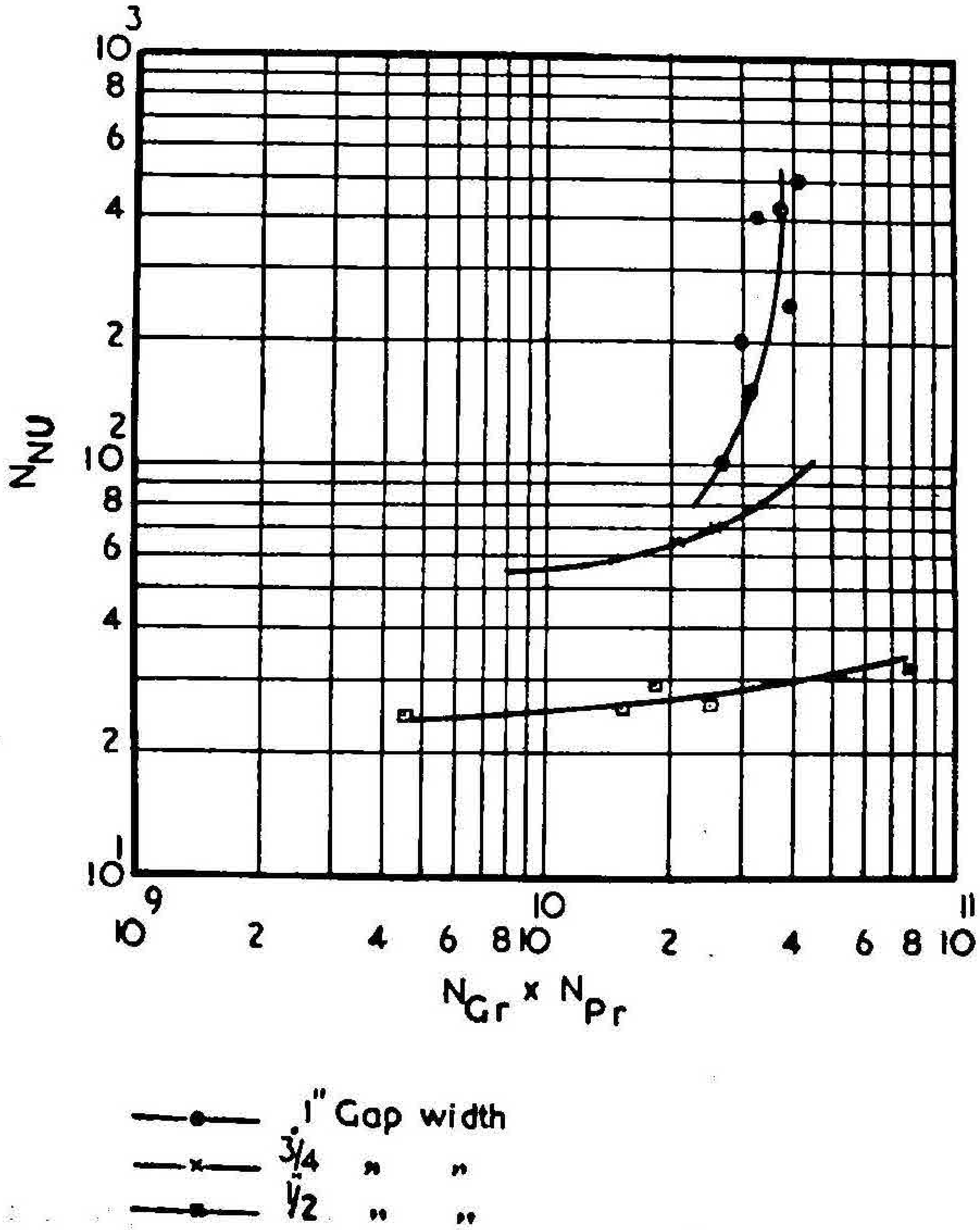
ρ = Density of water $lb_m ft^{-3}$.

Δt = Difference in temperature between the plate and the centre of bath F.

g = Acceleration due to gravity $ft. hr.^{-2}$

$$\beta = \frac{1}{\text{Bath temperature } (abs.)} F^{-1}$$

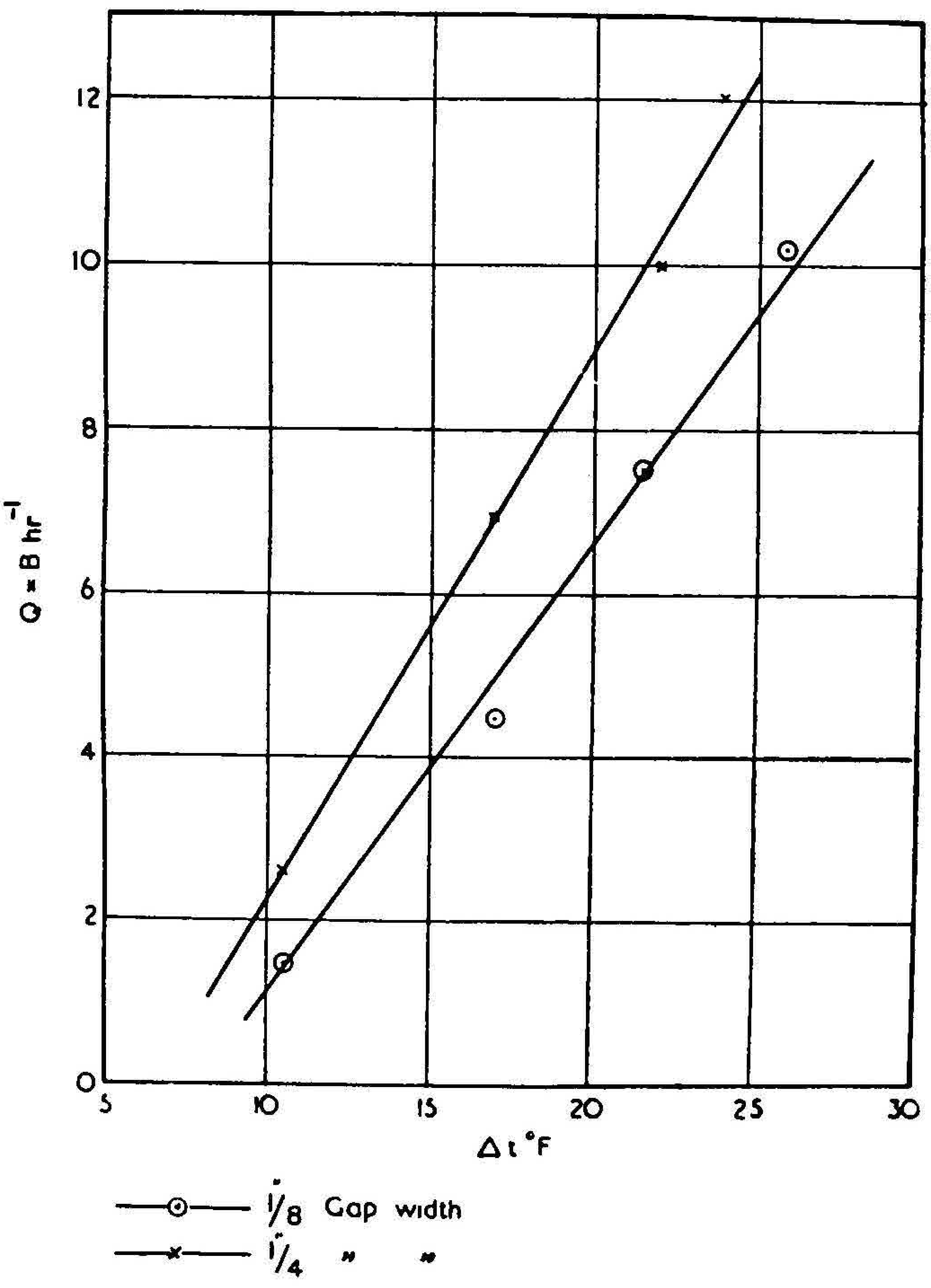
C_p, μ, ρ and k were calculated at the mean film temperature. The variation of the N_{Nu} with the product of the $(N_{Gr} \times N_{Pr})$ has been plotted in Graph 1, for the



GRAPH I

three gap widths 1", ¾", ½". For the ¼" and ⅛" widths the variation of h with Δt has been plotted, Graph 2. The thermocouple probes showed that the temperature at the mid-plane between the plates was the same from bottom to top for the 1",

$\frac{3}{4}''$, $1\frac{1}{2}''$ gap widths. In case of the $\frac{1}{4}''$ and $\frac{1}{8}''$ widths the temperatures in the gap centres were very much higher than those at the top chamber.



GRAPH II

5. DISCUSSION OF RESULTS, AND CONCLUSIONS

It is seen from the above graphs that for gap widths from $1''$ to $\frac{1}{2}''$ the heat flow is predominantly by convection, and for the other widths, $\frac{1}{4}''$ and $\frac{1}{8}''$, the heat transfer is mainly by conduction. The fact that the temperature at the mid-zone between the plates was higher than that at the top chamber indicates that convection currents are not predominant any more for smaller gap widths, and that heat transfer occurs by conduction. The variation of the Nusselt number with $(N_{Gr} \times N_{Pr})$ is quite pronounced for 1" width, and gradually decreases for ½" gap width. This may be due to the fact that the convection currents are more predominant in the case of larger distances between the plates.

The results outlined above indicate that for the given configuration maximum heat removal occurs if the gap width is large. As the gap width decreases the rate of heat transfer by convection decreases and heat transfer by conduction increases. At the smallest gap width (⅛") heat is transferred only due to pure conduction.

6. FUTURE WORK

A photographic study of the flow pattern in the gap fitted with transparent side walls would yield more precise information as to where the mode of heat transfer changes.

Longer plates with wider widths and higher heat fluxes would give more information regarding the transition from one mode of heat transfer to the other, and its dependence on parameters of the configuration considered.

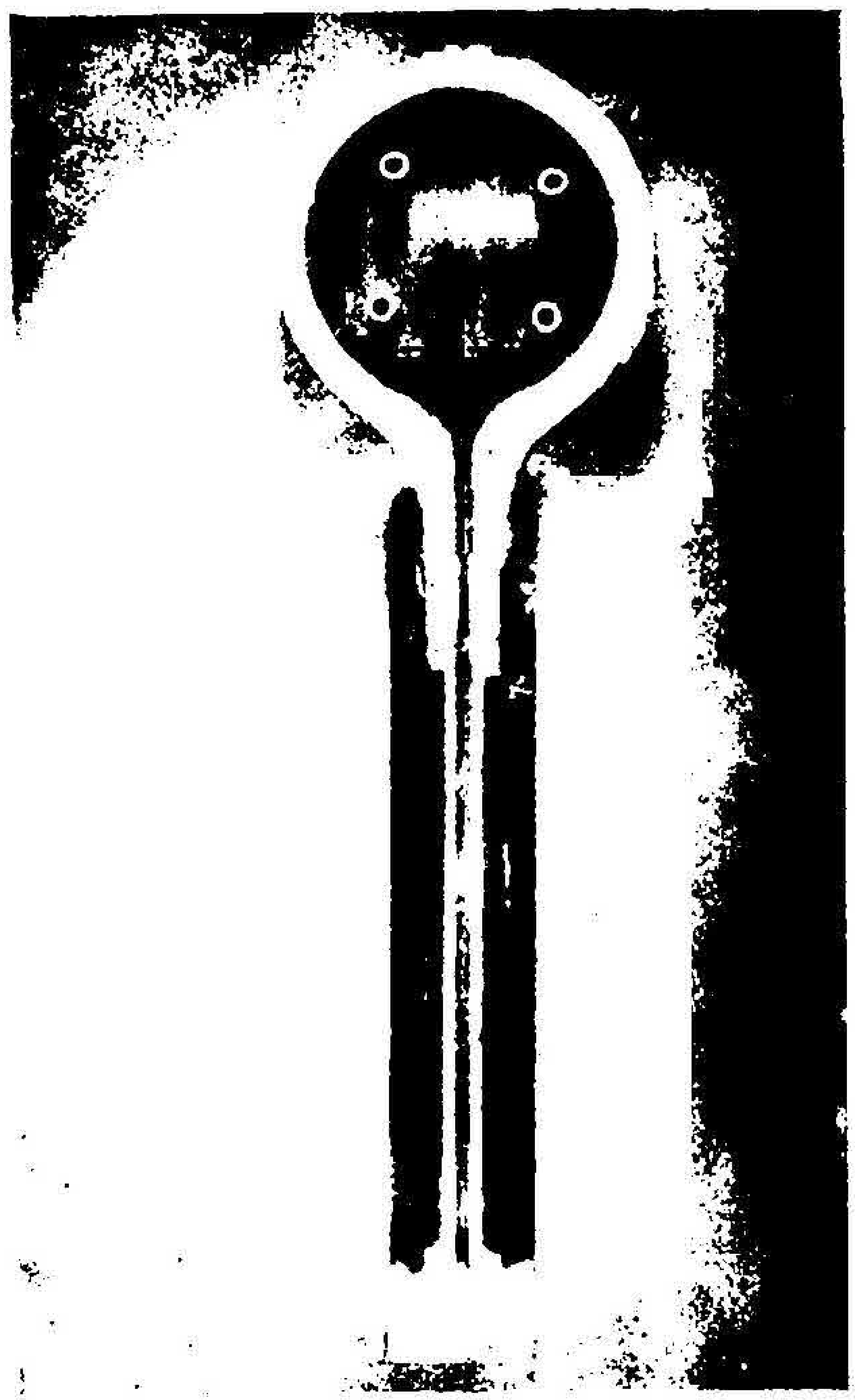
7. ACKNOWLEDGEMENTS

The authors wish to thank the Department of Atomic Energy, Government of India, under whose auspices the investigations were carried out, for permitting the paper to be published.

Thanks are also due to the Department of Internal Combustion Engineering, Indian Institute of Science, Bangalore, for having providec the necessary facilities throughout the investigations.

8. REFERENCES

1. Bosworth, R. C. L. .. *Heat Transfer Phenomena*, John Wiley & Son, Inc., New York, 1952.
2. Chandra, K. .. *Proc. Roy. Soc.*, 1938, **A 164**, 231–42.
3. McAdams, W. H. .. *Heat Transmission*, McGraw-Hill, New York, 1942.
4. Mull, W. and Reiher, H. .. *Beiheft zum Gesundheit Ingeneiur, Reihe* 1, *Heft.* 28, 1930
5. Yablonski, V. S. and Yablonskaya, V. P. *Dokl. Akad. Nauk. U.S.S.R.*, 1948, **59**, 1575–77.



Cross section of the Apparatus with
$\frac{1}{8}''$ gap width