Effect of discrete heating on natural convection heat transfer on square plate

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Abstract

Experimental and numerical analysis is presented for steady state natural convection from discrete heating inside a two dimensional square copper plate. The study has been made for different heater length and location. The left side wall is heated discretely at an interval of 12.5 mm keeping remaining portion unheated portion adiabatic. The experimental study is performed on an experimental setup designed in order to assuming, with a good approximation, those adopted natural convection hypotheses on a heated horizontal flat plate. The finite volume method is used to solve the dimensionless governing equations. The temperature distribution are presented at different heater length and location which reveals, Nusselt number increases when heater is located at mid height from base distributing heat uniformly setting up proper convection currents as compared to other positions and with increase in heater length temperature increases at hot wall. The results obtained from experiment are found to be in good agreement with numerical results and previous researchers.

Index Terms— *Natural convection, discrete heating, heat transfer enhancement.*

I. INTRODUCTION

With advances in science and technology, modern machines are operated by electronic instruments with use of integrated circuit board which in turn chips are mounted on circuit board. These chips act as a source of heat located at discrete points on board. Location of these discrete points plays a vital role in heat transfer by natural convection.

Most of the literatures available worked on numerical analysis with least work on experimental analysis as given by lino et.al[1] presented experimental and numerical study of flat vertical plate with constant heat flux resulted in correlation of local nusselt number as a fuction of Rayleigh number mohamad et.al[2] numerically studied natural convection through horizontal enclosure heated discretely by varying Rayleigh number and aspect ratio efforts has been carried on size and arrangement of heat source and sink the result is well documented by deng[3]. The heat transfer and fluid flow charecteristics was greatly influenced by material properties tang ei al.[4] conducted 2D numerical study on porous rectangular enclosure with saturated fluid and Brinkman extended Darcy model was used to formulate fluid flow in the cavity. younghe ghae[5] investigated on vertical porous annulus the governing fluid flow equation was solved by an implicit finite volume method for a wide range of Rayleigh Darcy number for different heat source length and location. The placing of the discrete heat source is significant when the heat source is placed in an enclosure which is well presented in M. sankar[6] were heat source was varied along the inner wall of rectangular porous enclosure while the outer wall is maintained lower temperature the numerical result reveals that the maximum temperature decreases with Rayleigh number. Some other researchers carried their work on parameters such as porosity of the media, aspect ratio of the enclosure and Darcy number the variation of these parameters greatly influence the average Nusselt number investigated by j m lopeze et al.[7].

The present study experimentally and numerically investigates the effect of discrete heat source length and location on a rectangular flat plate with fixed aspect ratio and the variation of Nusselt number. Numerical analysis is performed using commercially available CFD software ANSYS FLUENT to solve the governing differential equation. The experimental results are in good agreement with numerical result.

II. EXPERIMENTAL SETUP

Experiment was build to evaluate effect of discrete heating on flat horizontal plate for natural convection heat transfer mode. The atmospheric air is used as convective fluid and resistance type of heater is employed for heat source on left side wall while the upper portion is exposed to convective currents, the unheated portion and bottom wall are kept adiabatic with proper insulation as shown in the fig. 1 the exposed surface of the plate is put in non dimensional aspect ratio (l/b) equal to 1, the thickness of the plate is 6mm available commercially. The mechanical and thermal properties of the copper plate and air are standard values from [8]. The heater is of resistance type made up of mica sheet and nichrome wire, wound to mica sheet fig.2. The two terminals of the heater are shouldered and given to power supply with proper electric circuits as shown in fig. 1.

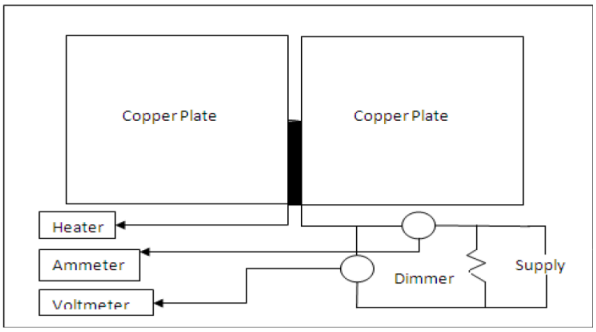


Fig. 1- Experimental setup with electric connection.

The ammeter and voltmeter are arranged in serial and parallel respectively to record current and voltage across heater, dimmer stat is used to regulate current through the circuit. The preparation of heater is shown in fig. 2

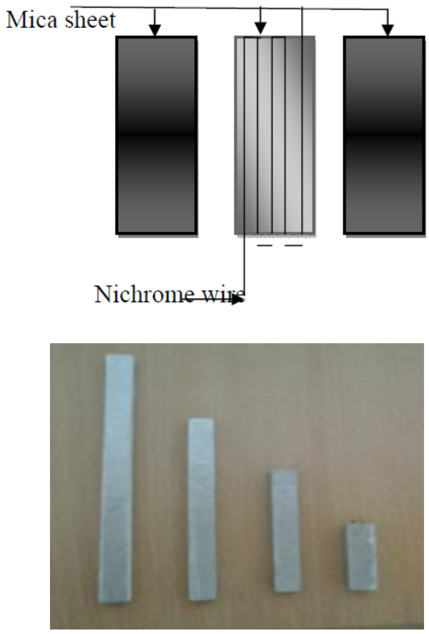


Fig. 2- Heater arrangement and lengths.

Heater lengths and location are chosen to be 25, 50, 75 and 100 mm given in terms of non dimensional number [8]. The insulation is provided with glass wool with minimum losses in downstream, the unheated side walls are made adiabatic with Bakelite sheet. A graduated scale is provided towards left side to locate the heater. The energy input is through electric supply by carefully recording ammeter and voltmeter reading, the radiations emitted by the plate is captured in IR camera to measure the temperature distribution on the pate, keeping the emissivity of the plate uniform. The measured values are in good agreement with CFD software results.

III. DATA REDUCTION

in the present work the energy input to the specimen is by electric supply which is calculated by Q=VI where V is voltage, I is current. The loss of energy is minimum and is neglected, the only mode of energy transfer is by convection through exposed top surface calculated as

$$Q = V\,I = h\,A\,(T_s - T_a)\ ,\ Nu = hL/k,\ q = ½(Q/A)$$

Q is heat input in Watt, h is heat transfer coefficient in W/m^2K, A is exposed surface area, T_s & T_a are surface and ambient air temperature in Kelvin, L is characteristic length in m and k is thermal conductivity in W/m-K.

IV. RESULT AND DISCUSSION

Experimental and numerical study is carried out on a copper plate exposed to natural convection on the top surface with different heater length and location. These heaters are located on left side of the plate. An attempt is made to study the natural convection heat transfer and temperature distribution on a plate with discrete heating on the side walls as carried by other researches with uniform heating. Numerical analysis carried out based on experimental results all the parameters and boundary condition are given to the numerical analysis is same. The CFD model of the plate with meshing is shown in fig. 3 using tetrahedron element

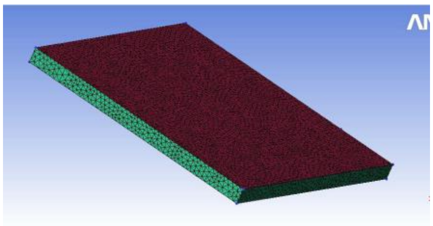
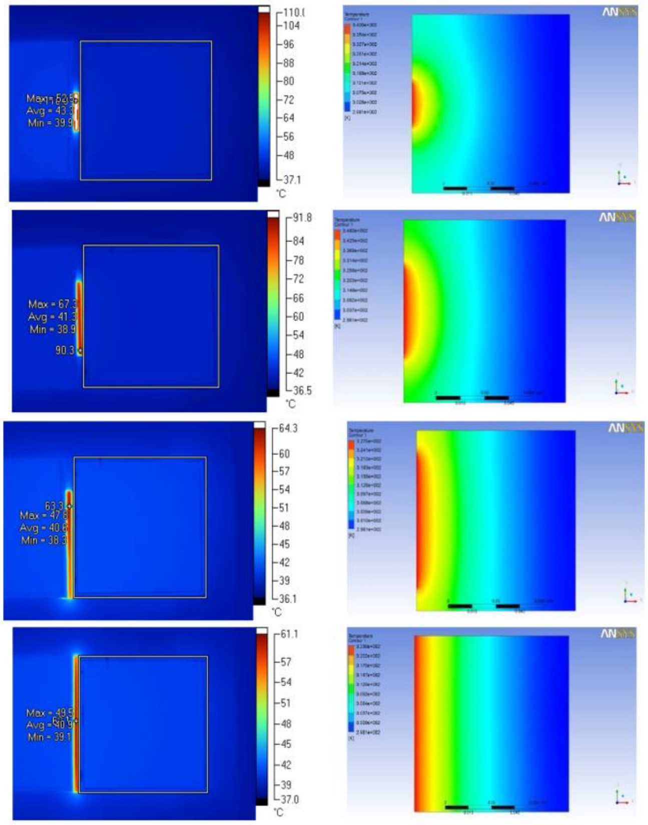


Fig. 3- meshed model of the plate.

The study is performed considering two cases i) effect of heater length ii) effect of heater location. In the first part heater length is varied for fixed heater location in second part for different heater lengths the location is varied along the left wall.

i)the study of variation of heater length on the flat plate is important when the plate is heated uniformly or discretely as the heater length is increased from 25mm to 100mm the maximum temperature on the plate increases inducing strong convection currents at a heater length of 100mm it will be acting as uniform heat source, the isothermal lines are parallel to each other as compared 25, 50 and 75 mm heater lengths were isothermal lines are curved with reducing temperature away from heater, corresponding temperature profiles are shown in fig.-4 in comparison with experimental data.



(a) (b)

Fig.4- effect of heater length 25, 50, 75 and 100mm for mid height heater location (a) experimental result (b) CFD result

ii) The effect of the heater location in natural convection in a square copper plate. How the heat distribution is carried by varying the heater location from base of the side walls by reference of middle position of the heater. When the heater is kept at base of the side walls and increasing the location with reference to the middle height of the plate. These results are comparing with analysis results for different heater lengths the location is again varied from 12.5 to 87.5mm in a interval of 12.5 mm as shown in fig. 5

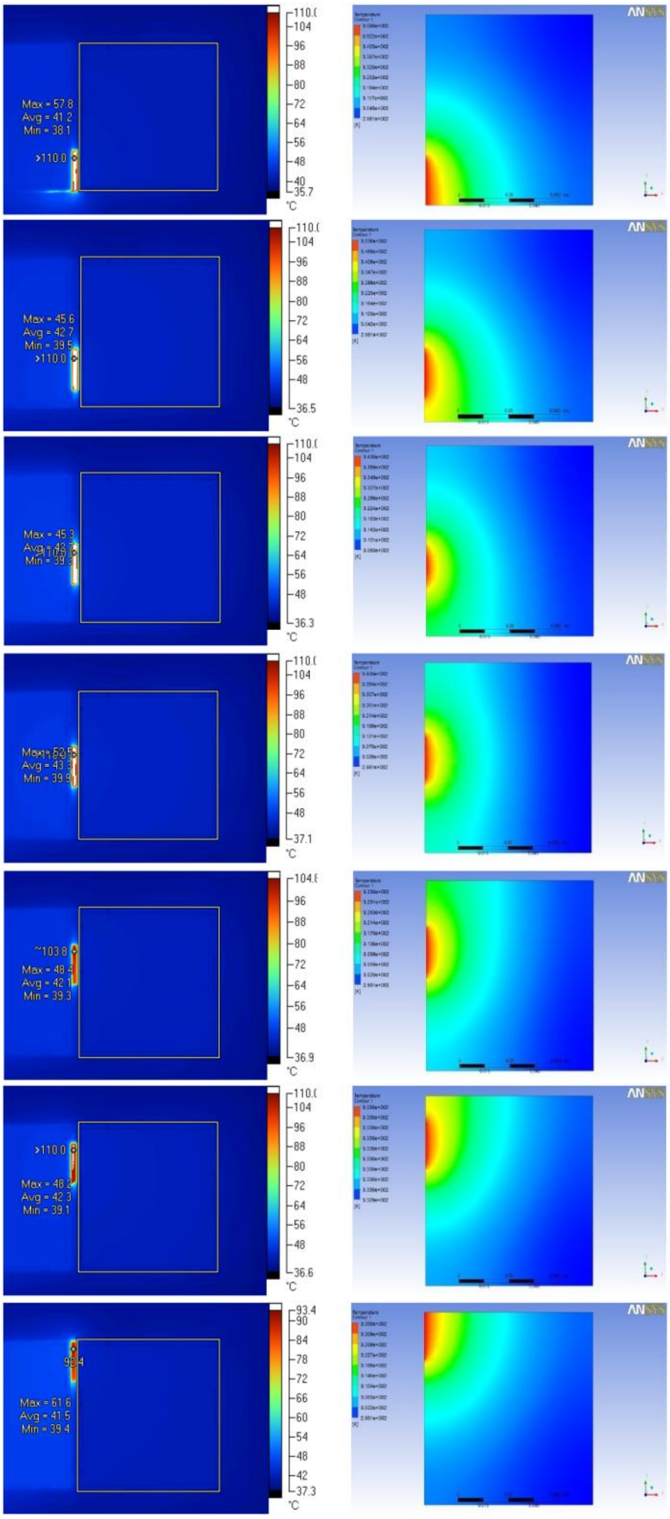
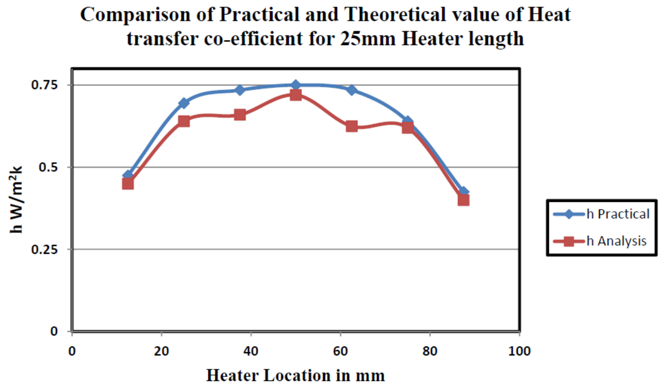


Fig.5- effect of heater location 12.5, 25, 37.5, 50, 62.5, 75 and 87.5 mm from the base for fixed heater length
(a) Experimental result (b) CFD result

In this part of the study, the effect of heater location on the flow and temperature distributions and the corresponding heat transfer is discussed by fixing the values of L = 25mm depicts the effect of heater location on the development of the isotherms for seven different locations of the heater. A highly stratified medium with almost parallel, horizontal flow in the core results when the heat source is located at the bottom portion of the outer wall. As the heat source moves towards the top wall, the main vortex reduces in size and shift towards the cold wall. Further, the relative strength of the flow as indicated by the maximum absolute stream function reduces as the heat source move upwards. In fact, the closer the heat source is to the bottom wall, the higher the magnitude for the stream function that is achieved. These predictions are consistent with those reported for natural convection in a square solid with a single is isoflux heat source mounted on the left wall. As the heater moves upwards, depicts the effects of the heat source for different heater location. However, this trend changes. Another important observation that can be made from Fig. is the location of maximum average heat transfer coefficient for different values of heater location. The heat transfer coefficient attains the maximum value when the heat source is placed at L = 25mm.This indicates that the location of the heat source plays a crucial role in determining the removal of heat from the heater. The effect of heater location on the isotherm pattern reveals a strong flow circulation in the solid when the heat source is placed close to the bottom wall. But, a careful observation of Fig. 5 reveals that the heat transfer is maximum when the isoflux heater is placed around the mid-height of the enclosure rather than placing the heater near the bottom portion of the outer wall. This may be explained due to the fact that the rising fluid cannot wipe the entire surface of the heater, when the heat source is placed very near to the bottom or top wall of the enclosure. Therefore, the optimal heat source location for maximum heat transfer not only depends on the circulation intensity, but also depends on the shape of the buoyancy driven flow. The graph below shows the comparison between experimental and numerical result in terms heat transfer coefficient



From the graph it reveals that when heater is located lower half of the inner wall heat transfer rate goes on increases and attains maximum value at its mid height, after that it decreases following a symmetry profile at its mid height. The nature of graph remains same for other heater length and locations.

V. CONCLUSION

The present experimental and numerical investigation exhibits many interesting results concerning the effect of discrete heating on the natural convective heat transfer in a horizontal solid medium. An isoflux discrete heater is placed at the inner wall of the annular cavity, while the outer wall is kept at a adiabatic. Our efforts have been focused on the size and location effects of the heater. The heat transfer characteristics for a wide range of parameters of the problem. The size and location of the heat source have different effects on the rate of heat transfer. That is, the solid enclosure is significantly affected by the buoyancy driven flow when the discrete heater is either larger or occupies a lower position in the cavity. However, the rate of heat transfer is found to be higher when the heater is small or placed at mid-height of the cavity. For a fixed heater length, the maximum heat transfer rate changes with location of the heater. For high heat transfer coefficient the rate of heat transfer is higher when the heater is located at the middle of the inner wall, and as the value of heat transfer rate decreases, this location shifts towards the lower end of the inner wall. The maximum temperature increases with an increase in the heat source length, while it increases with an increase in the heat transfer coefficient.

VI. NOMENCLATURE

A exposed surface area to air (m^2)
L length of the plate (m)
B breadth of the plate (m)
l/b aspect ratio
h heat transfer coefficient (W/m^2K)
k thermal conductivity (W/mK)
q heat flux (W/m^2)
T_s,T_a surface and ambient air temperature (K)
Nu Nusselt number (hL/k)

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