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Natural Convection Cooling of an Array of Flush Mounted Discrete Heaters Inside a 3D Cavity

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Abstract. An investigation of natural convective flow and heat transfer inside a three dimensional rectangular cavity containing an array of discrete heat sources is carried out. The array consists of a row and columnwise regular arrangement of identical square shaped isoflux discrete heaters and is flush mounted on a vertical wall of the cavity. A symmetrical isothermal sink condition is maintained by cooling the cavity uniformly from either the opposite wall or the side walls or the top and bottom walls. The other walls of the cavity are maintained adiabatic. A finite volume method based on the SIMPLE algorithm and the power law scheme is used to solve the conservation equations. The parametric study covers the influence of pertinent parameters such as the Rayleigh number, the Prandtl number, side aspect ratio of the cavity and cavity heater ratio. A detailed fluid flow and heat transfer characteristics for the three cases are reported in terms of isothermal and velocity vector plots and Nusselt numbers. In general it is found that the overall heat transfer rate within the cavity for $Ra=10^7$ is maximum when the side aspect ratio of the cavity lies between 1.5 and 2. A more complex and peculiar flow pattern is observed in the presence of top and bottom cold walls which in turn introduces hot spots on the adiabatic walls. Their location and size are highly sensitive to the side aspect ratio of the cavity and hence offers more effective ways for passive heat removal.

AMS subject classifications: 76R05, 76D55, 76M12, 80A20

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1 Introduction

The study of natural convective flows is an evergreen area of research due to its widespread applications in cooling of nuclear reactors, crystal growth, double glazing, home heating, cryogenic storage, building thermal design, furnace design, solar energy collector, cooling of electronic equipments and so on. The coupling of temperature and velocity equations through the buoyancy force term makes the study quite intricate. As active cooling involving forced convection is associated with noise and requires additional power consumption, passive cooling driven by natural convection is suitable in many engineering applications. A large body of literature associated with natural convective flows in cavities of various shapes subjected to a variety of boundary conditions was discussed by Ostrach [1] in his review article. Due to major developments in electronic industry in the past few decades the number of components in modern electronic equipments and their heat emission have increased exponentially. Hence a proper thermal control of electronic components is essential and one of its principal objectives is to maintain the component temperature well below the manufacturer's maximum allowable limit. For a good overview of electronic equipment cooling problems one can refer [2,3].

In the past few decades, there have been several studies on two dimensional natural convection in cavities with a single or multiple discrete heat sources attached on one of their walls. Chu et al. [4] studied the effect of aspect ratio, boundary conditions, heater size and heater location on the two dimensional natural convection in an air filled rectangular cavity. A heater was mounted on a vertical wall with an opposing cold wall. They found an effective way of cooling in terms of the location of heat source and found some complicated as well as interesting flow patterns in the presence of horizontal cold walls. These results were later verified experimentally by Turner and Flack [5] for constant fluid properties. Ho and Chang [6] conducted both numerical and experimental investigations of free convective heat transfer inside a vertical rectangular cavity with four non-protruding discrete heaters mounted on a side wall. They analyzed the effects of cavity aspect ratio and the the modified Rayleigh number based on the heater size. It was found that the effect of cavity aspect ratio on the Nusselt number of the heaters diminish with increase of the Rayleigh number. Later Liu and Phan-Thien [7] considered three protruding isoflux discrete heaters attached to a cavity side wall. They concluded that an optimum thermal performance can be obtained when the center-to-center distances between the heaters follow a geometric series, especially when the geometric ratio is the golden mean. Time dependent natural convection in a rectangular enclosure with three discrete heaters was carried out by Bae and Hyun [8]. It was found that the temperature of the heat sources in the transient state exceed those of the steady state. Ben Nasr et al. [9] investigated two dimensional natural convection in a cavity induced by localized heating of a right bottom placed heater and cooled ceiling. They concluded that the Nusselt number strongly depend on the position of the heater as well as the Rayleigh number. Chen and Chen [10] considered natural convection in a square enclosure with