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Numerical study on effect of vent locations on natural convection in an enclosure with an internal heat source☆

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ABSTRACT

Natural convection is a widely studied phenomenon because of the extensive applications in cooling of large scale electrical and electronic equipments. The current study involves study of effect of vent locations on natural convection in enclosures with partial openings having an internal heat source. It involves the numerical simulation of 2D steady state natural convection in enclosure of different aspect ratios ($H/W = 1$, 2 and 3) for lower Rayleigh numbers ($Ra_h = 10^3$, 10^4 and 10^5). Four different configurations have been considered based on the number and position of vents — same side (SS), diagonal side (DS), one inlet two outlets (1I2O) and two inlets one inlet (2I1O). The mass flow rate driven through the enclosure and the average Nusselt number over the heater surface for all the four configurations have been compared. It is found that the 2I1O configuration yielded better heat transfer rates of the four considered. It was found that the mass flow rates and Nu increased with increase in Ra_h and decrease in the aspect ratio.

1. Introduction

Heat generation by virtue of resistance to electricity is a common phenomenon, encountered in many day to day cases such as electrical and electronic appliances. Though beneficial applications of this phenomenon are present, heat generation in electrical/electronic devices proves to be harmful to the efficiency as well as life of the component. In these cases, cooling of the heat generating component is a significant necessity. Appropriate cooling of the component can yield better performance for a longer period of time. To facilitate electronic cooling, vents and exhaust fans are provided on the cabinet walls of processing units in computers. But usage of blowers consumes greater investment, space in bigger geometries such as switch gear cabinets. For feasibility concerns over a wide range of applications, cooling by natural convection process will prove to yield better results in terms of investment, installation and maintenance. When cooled by this manner, inflow and outflow of the coolant fluid (mostly air) play a vital role, which is facilitated by the presence of vents. In this scenario, study of natural convection in an enclosure with vents and an internal heat source becomes a case of great significance. The study would be useful in design of cabinets for commercial electronics and electrical systems which has efficient heat transfer characteristics.

The study of natural convection in two dimensional enclosures has been carried out extensively for decades. Earliest work in simulation of laminar natural convection in square enclosures is reported by De Vahl Davis [1] and De Vahl Davis and Jones [2]. They obtained the solution of the equations describing two-dimensional laminar natural convection in a square cavity with differentially heated side walls. Barakos et al. [3] simulate natural convection enclosure problems for laminar and turbulent regimes. They modelled turbulent flows using $k - \varepsilon$ model with and without wall functions. Buoyancy driven flows in 2D enclosures with internal heat sources as well as partial openings have been dealt with in papers [4–9]. Cocco Mariani and da Silva [4] simulated natural convection in an enclosure with partial opening. The enclosure has internal uniform heat source (occupying 1% of the enclosure volume) and differential wall temperatures. They studied effect of heat source position and aspect ratio for a Rayleigh number range of 10^3 to 10^6. Bilgen and co-workers [5–9] numerically studied natural convection in partially open square enclosures. In their study constant heat flux was specified on the wall. They analysed effect of opening size, position of opening, inclination, number of slots and Rayleigh number. Ishizuka and Kitamura [10] numerically studied the natural convection in electronic cabinets solving three dimensional Navier Stokes equations along with the energy equation. The effect of distance between heat source and vent in the cabinet was studied. They found that the numerical solutions were in satisfactory agreement with the measured data. Kitamura and Ishizuka [11] carried out a numerical simulation of natural convection in an enclosure and validated their results through experiments. The method adopted by them for promoting the cooling capacity in the enclosure was by inclining

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Nomenclature

DS	diagonal side configuration
h	height of the heater
h_v	height of the vent
H	height of the enclosure
Nu	average Nusselt number on the heater
Nu_s	local Nusselt number
Ra_h	Rayleigh number based on h_v
s	coordinate chosen along the heater surface
SS	same side configuration
T_{max}	maximum temperature of air
T_∞	ambient temperature of air (300 K)
u, v	x and y component velocities
w	width of the heater
W	width of the enclosure
θ	non-dimensional temperature
1I2O	one inlet two outlet configuration
2I1O	two inlet one outlet configuration

the electronics casing which they called Chimney effect. The effect of casing inclination on the temperature rise across the casing was studied numerically and experimentally. They concluded that the simulation results were in good agreement to the experimental data.

Based on the literature survey done, to the best of the authors' knowledge, the effect of position of vents in 2D enclosures on natural convection heat transfer has not been studied. The current study involves the study of this effect using FLUENT 6.3. The effect of vent positions on natural convection in an enclosure with an internal heat source is studied for Rayleigh number varying from 10^3 to 10^5 and aspect ratios of the enclosure varying from 1 to 3.

2. Problem and mathematical model

2.1. Problem definition

The problem domain is a rectangular room space which has a 2D enclosure with vents open for air flow and one copper heater placed at its bottom centre as shown in Fig. 1 (heater is shown shaded). Though the domain of interest is only the enclosure, the region outside the enclosure has also been considered to simulate the heat transfer rates at the enclosure walls more physically as shown in Fig. 2. The conduction resistance of the wall of the enclosure is neglected.

Based on the location of vents, four different configurations of the enclosure are considered: same side vents, diagonal vents, one inlet with two outlet vents and, two inlet vents with one outlet vent. These configurations are labelled as SS, DS, 1I2O and 2I1O respectively. Schematic of these configurations is shown in Fig. 1. The vent height (h_v) is 10% of the enclosure height. Similarly, the heater height (h) and width (w) are taken to be 10% of height (H) and width (W) of the enclosure respectively. The study is done for three different aspect ratios (H/W) of the enclosure $H/W = 1$, 2 and 3 and three Rayleigh numbers $Ra_h = 10^3$, 10^4 and 10^5.

2.2. Mathematical model

The continuity, momentum and energy equations for a steady laminar flow of an incompressible fluid in its two dimensional form given by Eqs. (1) to (4) are considered with the following assumptions: fluid is a Newtonian fluid, no viscous dissipation, gravity acts in the y direction, thermophysical properties of heater and air are assumed to be constant

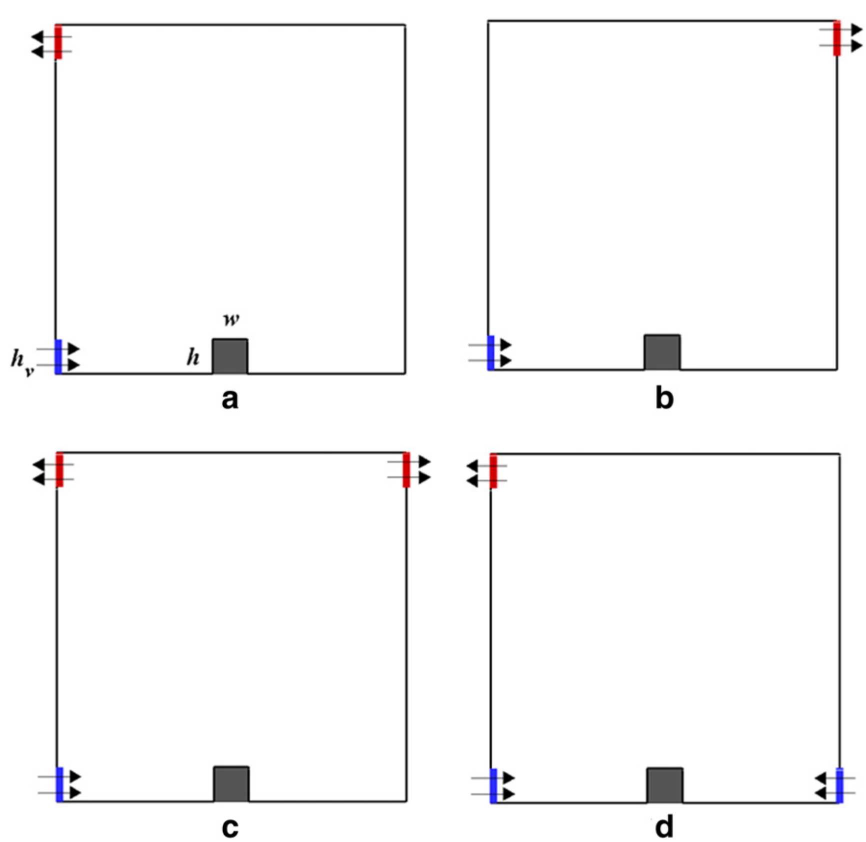

Fig. 1. Configurations of enclosures based on vent locations. (a) SS (b) DS (c) 1I2O (d) 2I1O.