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Natural convection in differentially heated and partially divided square cavities with internal heat generation

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Abstract

Heat transfer in a differentially heated, partitioned, square cavity containing heat generating fluid has been studied numerically. The vertical walls were isothermal, horizontal walls adiabatic and an isothermal partition at the reference temperature was attached to the bottom wall. Results have been obtained for various geometrical parameters specifying the height, thickness and position of the partition and for Rayleigh numbers characterizing internal and external heating from 10^3 to 10^6. Depending on the ratio of the internal and external Rayleigh numbers, two distinct regimes have been observed and studied with various geometrical parameters. Flow and temperature fields for these cases have been produced; average and local Nusselt numbers at hot and cold walls have been calculated. It is found that the flow field was modified considerably with partial dividers and heat transfer was generally reduced particularly when the ratio of internal and external Rayleigh numbers was from 10^1 to 10^2.

Keywords: Natural convection; Internal heat generation; Partitioned cavity

1. Introduction

Considerable attention is given to the study of natural convection in enclosures which are filled with volumetric heat generating fluids. The application areas are in nuclear reactor design, post-accident heat removal in nuclear reactors, geophysics and underground storage of nuclear waste and energy storage systems, among others (e.g., Baker et al., 1976; McKenzie et al., 1974).

Literature review shows various studies have been published on the mechanism of natural convection in heated enclosure containing heat generating fluids with different geometrical parameters and boundary conditions: an experimental study with equal boundary temperatures (Kulacki and Goldstein, 1972), similar to the previous study but inclined enclosures (Lee and Goldstein, 1988), a numerical study similar to that in Lee and Goldstein (1988) but with different aspect ratios (Acharya and Goldstein, 1985), a numerical study of a fluid layer with insulated side and bottom walls and rigid or free top surface (Emara and Kulacki, 1979), a numerical study with insulated side walls, heated bottom, cooled top walls (Rahman and Sharif, 2003), numerical studies with differentially heated with insulated bottom and top walls (Fusegi et al., 1992a) and with different aspect ratios (Fusegi et al., 1992b).

We will briefly review the numerical studies mentioned above. Acharya and Goldstein (1985) studied for Ra_{I} from 10^4 to 10^7 and Ra_{E} from 10^3 to 10^6, and cavity inclination angle from 30° to 90°, the latter corresponding to adiabatic bottom and top in vertical position. They found that the flow pattern changed with $Ra_{\mathrm{E}}/Ra_{\mathrm{I}}$: when this ratio was large, the flow was downward at hot and cold wall, and when small, the flow was upward at the hot wall and

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Nomenclature

A	aspect ratio L/H	T	dimensionless temperature
c	partition position, m	T_c	cold temperature, reference temperature, °C
g	acceleration due to gravity, m/s^2	T_h	hot temperature, °C
h	partition height, m	u', v'	velocity, m/s
H	height of enclosure, m	w	partition thickness
k	heat conduction coefficient, W/mK	x, y	dimensionless coordinates
L	length of enclosure, m		
Nu	Nusselt number	*Greek symbols*	
Q	rate of internal heat generation per unit volume	α	thermal diffusivity, m^2/s
p	pressure, N/m^2	β	coefficient of thermal expansion of fluid, 1/K
Pr	Prandtl number	ν	kinematic viscosity, m^2/s
Ra_I	internal Rayleigh number	ϕ	general variable
Ra_E	external Rayleigh number		

downward at the cold wall. Rahman and Sharif (2003) studied numerically the case in inclined rectangular cavities with heated bottom and cooled top walls and insulated sides. Ra_I and Ra_E were 2×10^5 and the aspect ratio from 0.25 to 4. They found that for $Ra_E/Ra_I > 1$, the convective flow and heat transfer was almost the same as that in a cavity without internal heat generating fluid and they observed similar results as in Acharya and Goldstein (1985).

Following the experimental studies by Kawara et al. (1990) with a differentially heated square cavity containing a heat generating fluid of $Pr = 5.85$, Fusegi et al. (1992a,b) numerically studied the same problem at high external and internal Rayleigh numbers, Ra_E set at 5×10^7 and Ra_I varied from 10^9 to 10^{10}. They found a broad agreement with the experimental results and identified similar patterns as reported in Acharya and Goldstein (1985).

There is a renewed interest in energy conservation and energy storage systems using fundamental principles of heat transfer in enclosures with volumetric heat generating fluids. The presence of a partial divider in a differentially heated enclosures containing heat generating fluid adds an additional dynamic to overall convection characteristics, which we will study in the present work. Both Ra_I and Ra_E will be varied from 10^3 to 10^6 and various partial divider geometry and position will be used. We will carry out a numerical study and analyze the results to examine the flow patterns and heat transfer. Thus, we will provide additional basic design information.

2. Problem definition

Schematic of the problem with coordinate system and boundary conditions is shown in Fig. 1. It is a square enclosure with isothermal vertical walls at T_h and T_c, and adiabatic horizontal walls. It is filled with a uniform heat generating fluid with volumetric rate of Q. An isothermal solid partition of h by w at T_c is placed at a distance c from the origin as shown in the figure.

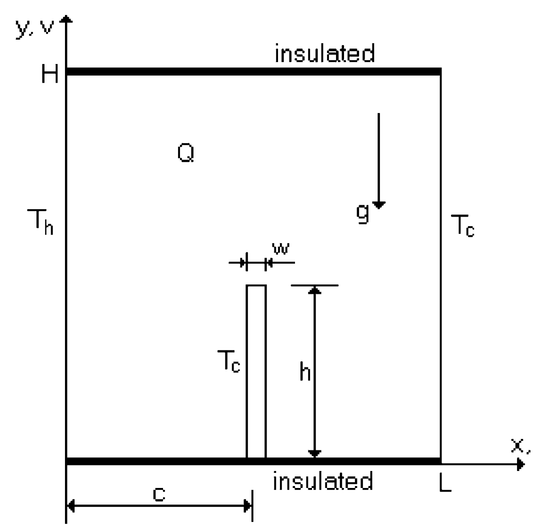

Fig. 1. Problem definition, the coordinate system and boundary conditions.

3. Governing equations

We assume that the fluid is Newtonian and incompressible, the flow is laminar, and the effect of viscous dissipation is negligible. Further, the gravity acts in the vertical direction, fluid properties are constant and fluid density variations are neglected except in the buoyancy term, and radiation heat transfer is negligible. With these assumptions the non-dimensional governing equations are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{1}$$

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{\partial P}{\partial x} + Pr\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{\partial P}{\partial y} + Pr\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + \frac{Ra_E}{Pr}T \tag{3}$$

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) + \frac{Ra_I}{Ra_E Pr} \tag{4}$$