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Numerical Analysis on Natural Convection Inside a Square Enclosure having Porous Partition

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Abstract**: Theoretical analysis has been conducted on the performance of buoyancy motivated heat and fluid movement within a square inclusion having porous partition occupied with air. For investigating the flow behaviour inside the inclusion, numerous pertinent parameters such as stream function, isotherm, Nusselt number (Nu) along the conducting wall have been determined while varying partition width (from 0.1 to 0.3) and Darcy number (from 10^{-3} to 10^{-1}). Ansys, fluent software is used to determine the solution of governing differential equations. The significant finding of the work that heat allocation rate enhances with Da and reduces with partition width.

Keywords: Natural Convection, Porous Partition, Darcy Number, Nusselt Number, Stream Function.

I. INTRODUCTION

Dealing with heat transfer for high energy density systems is a challenging task especially with external cooling device cannot be installed. Many applications need excess energy need to get removed for a better working of the system like cooling of nuclear reactor's core [1], microprocessor of high-end computational device, gas insulated electrical transmission systems, discharging processes, etc. Techniques in transferring heat in an efficient manner in these areas is an ongoing area of research and development amongst industry and academia. These techniques include using of nanofluids, applying magnetic field [2], using rotatory cylinder wall, applying discrete wall heating [3], use of porous material or media [4], use of boiling [5]. Therefore a details study natural convection inside square enclosure having porous partition at middle of enclosure.

During asymmetrically heated channel with square nibs, Saad et al. [6] computationally examined the properties of heat allocation through natural convection and concluded that the size of protrusions greatly affects the quantity, size, and development of vortex structures within the channel. The impact of nonuniform heating on natural convection inside an enclosure had been documented by Mullick et al. [7-8], who also look at how heat transit behavior differs noticeably depending on the wall's nonuniformity in thermal state. When developing engineering applications such as nuclear reactors and electrical gadgets that generate bulk heat in the system, one of the foremost goalmouths is heat dissipation. Exploration is being done to simulate the movement of heat within a cavity that is regularly heated and/or cooled from below in order to regulate the thermal footprint of temperature-sensitive structures, such as chemical reactors. Few works are available where natural convection inside enclosure with porous media and nano fluid are critically discussed [9-11].

In the current work, natural convection inside enclosure having porous partition filled with air (Pr=0.71) has been critically investigated with the help of stream function, isotherms and Nusselt number which is generally essential for many engineering applications such as cooling of high energy system, crude oil production, cooling system of electronic devices etc. The parameters varied for the presents work is width of the partition (0.1 to 0.3) and Darcy number ($10^{-3} \leq$ Da $\leq 10^{-1}$), by keeping Rayleigh number (Ra=10^6) constant.

II. MATHEMATICAL FORMULATION

In the current work, natural convection inside enclosure having porous partition filled with air has been critically investigated with the assistance of isotherms, stream function and Nusselt number. The parameters diverse for the presents work is width of the partition (0.1 to 0.3) and Darcy number (10^{-4} to 10^{-1}) while keeping Rayleigh number (10^6) and Prandtl number (Pr=0.71) constant. Figure 1 illustrates the representation of the recent problem with boundary condition where uniform heating and cooling are applied from bottom wall and side walls respectively.

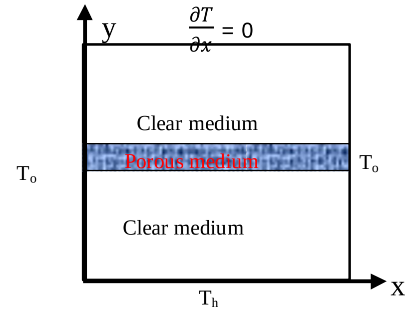


Fig. 1 The problem domain with boundary condition

To abridge the problem statement, ensuing norms are made:

(i) The fluid in the porous bed is incompressible, laminar, and Newtonian.
(ii) Effects of viscous dispersion are disregarded.
(iii) All physical characteristics are taken to be persistent, with the omission of density in the body force tenure. The following is how density fluctuations brought on by temperature variations are taken into account using the Boussinesq approximation: ρ = ρ [1 − β(T − T)]. Here, β is the isobaric factor of expansion and ρ is the density at a reference temperature
0 o 0
T . o

Non-dimensional form of the foremost differential equations (equation 1 to equation 4) are stated below and which are unraveled by the assistance of Ansys, fluent software.

Continuity: $$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0 \qquad (1)$$

X-momentum

Clear medium: $$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \mathrm{Pr}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) \qquad (2)$$

Porous partition: $$U\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial Y} = -\frac{\partial P}{\partial X} + \mathrm{Pr}\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2}\right) - \frac{1}{Da}U \qquad (3)$$

Y-momentum:

Clear medium: $$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + Pr\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) - \frac{1}{Da}V + Ra * Pr * \theta \qquad (4)$$

Porous partition: $$U\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial Y} = -\frac{\partial P}{\partial Y} + Pr\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2}\right) + Ra * Pr * \theta \qquad (5)$$

Energy: $$U\frac{\partial \theta}{\partial X} + V\frac{\partial \theta}{\partial Y} = \left(\frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}\right) \qquad (6)$$

III. NUMERICAL SIMULATION PROCEDURE

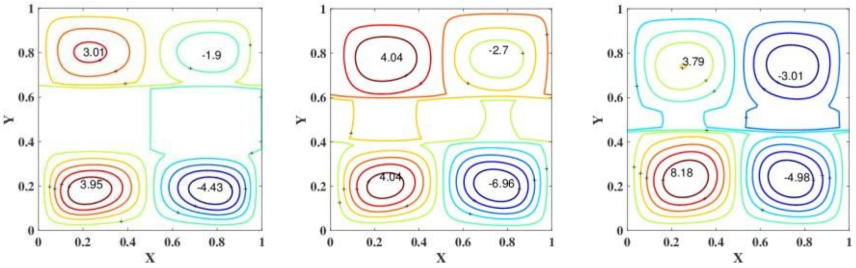
Ansys fluent, a commercial software is adopted to unravel the governing equations. SIMPLE procedure is implemented to couple the velocity and pressure term presence in the y-momentum equation. For each control volume in the computational domain, the FVM is implemented to unravel the governing differential equations, ensuring the conservation of mass, momentum, and energy. Furthermore, the behavior inside the porous matrix—which is crucial for examining heat transport in porous media— is modelled using a UDF. The user defined scalar (UDS) is used to solve the non-dimensional energy equation, allowing the nondimensional energy distribution to be calculated.

The code validation and grid independence study are done to validate and accurate solution of the current work. The optimum size of the grid is 0.01 for both the direction (ΔX and ΔY).

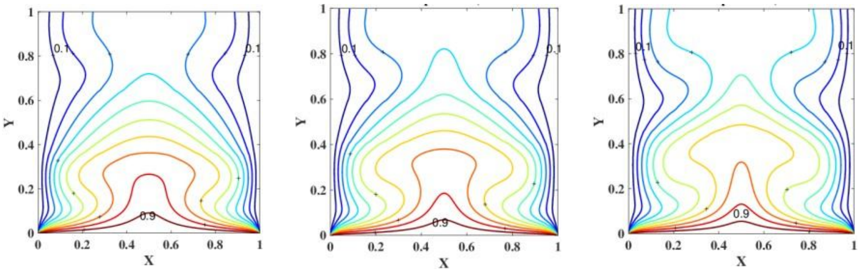
IV. RESULTS AND DISCUSSIONS

The key persistence of the current reconsideration is to analysis the consequences of extended surface applied to the lower wall on the thermo-fluid characteristics inside the contour. These features are significant for the designing of sensitive engineering devices. To estimate the impact of Da and partition depth (d/H), thermal characteristic, isotherms, stream function and Nusselt number are calculated and critically inspected in the ensuing section of the work.

A. Stream Function and Isotherms



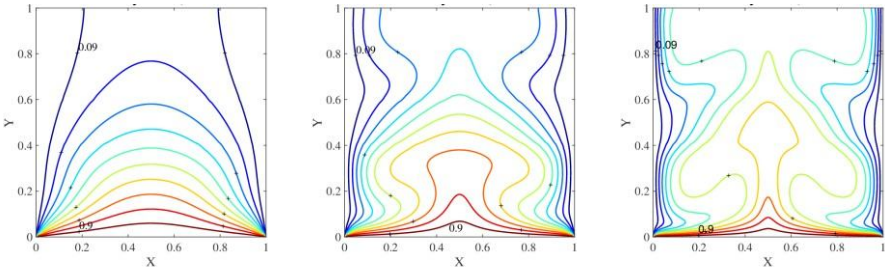
Stream function



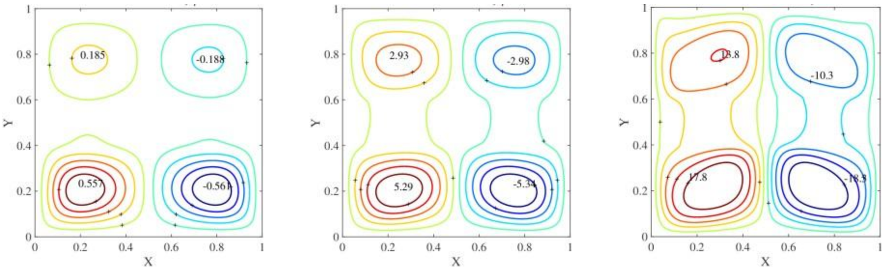
Isotherms

(a) (b) (c)

Fig. 2 Stream function and isotherms at (a) d/H=0.3, (b) d/H=0.2 and (c) d/H=0.1 at Ra=10^5 and Da=10^{-2}



Stream function



Isotherms

(a) (b) (c)

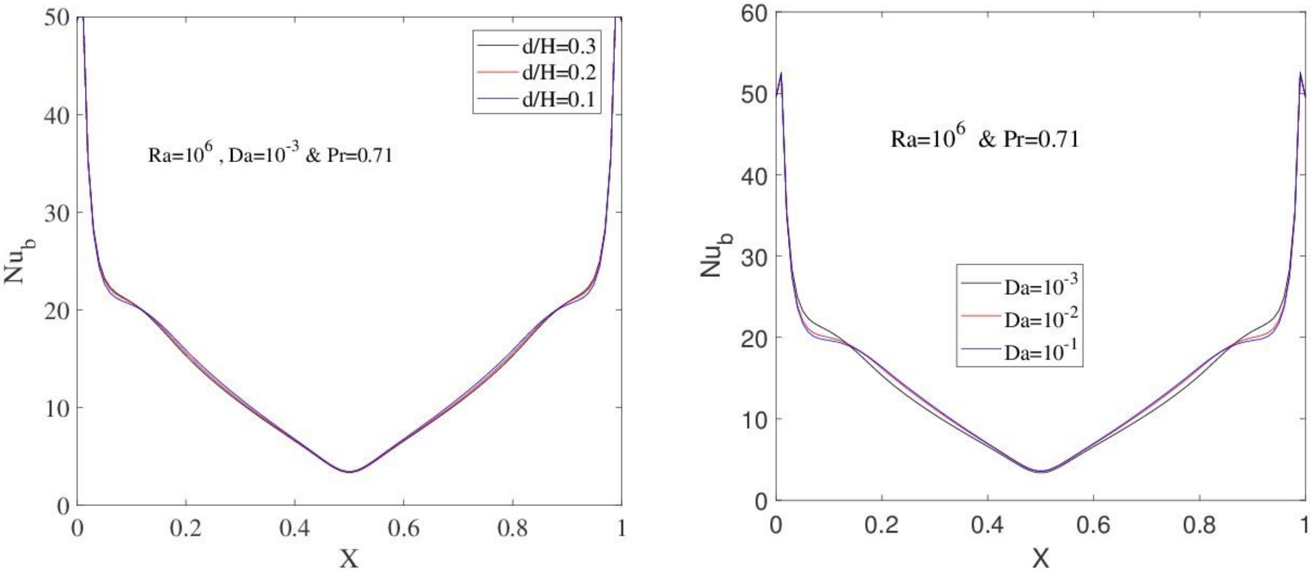
Fig. 3 Stream function and isotherms at (a) Da=10^{-3}, (b) Da=10^{-2} and (c) Da=10^{-1} at d/H=0.3, Ra=10^6

B. Local Heat Transfer Rate

During the studies on convection, exploring the significance of Nu is crucial as it represents the augmentation in heat flow through a layer of fluid owing to convection, as compared to conduction across the same fluid layer. In the present discussion, both local and average Nusselt numbers have been included. The mathematical expression for local Nusselt number can be given as:

$$Nu = \frac{\partial\theta}{\partial\eta} \qquad (7)$$

Where, η is the direction normal.



(a) (b)

Fig. 4 Local Nusselt number variation along the bottom wall (a) at different partition width and (b) at different Darcy number

V. CONCLUSIONS

Free convection indoors a square cavity with permeable partition, heated uniformly from the bottom, has been inspected in the contemporary learning. The following significant findings have been confirmed on the basis of stream function and isotherm patterns, and local Nusselt number obtained herein.

1) Heat allocation rate significantly reduces with d/H due to retardation of flow at the presence of porous matrix.
2) Further, thermal penetration and strength of the circulation augments with Da attributable to respective reduction of porous matrix retardation force to circulate any flow.
3) Local heat allocation rate is higher at corner of the lowermost wall by reason of large temperature incline at this segment of the cavity.

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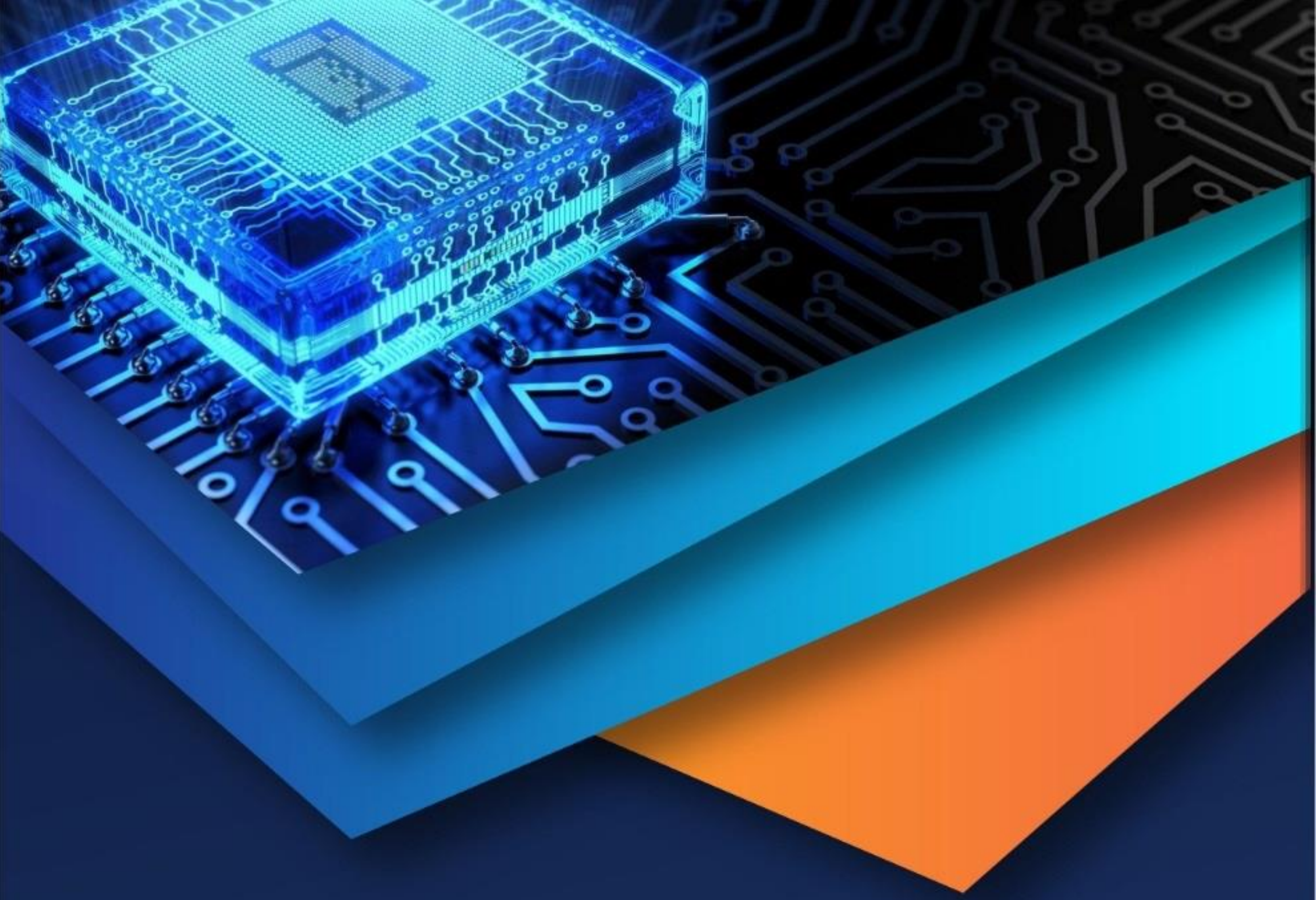

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