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Numerical Analysis Of Heat And Fluid Flow Through Porous Square Cavity

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Abstract

To examine the heat dissipation in a permeable chamber is carried out. A recent study of heat and fluid dissipation in permeable chamber is discussed in this article. This review focuses on the movement of warm and liquid in permeable cavities with geometrical forms such as circular, triangular and trapezoidal forms. It is accepted that the stream follows the Darcy law. This analysis addresses the traditional methodology for differential heating and discrete heating**.** This analysis examines the notion of thermal mixing in traditional and discrete heating. In this study, various heat transfers related phenomena such as natural convection, thermal mixing, and thermal equilibrium are discussed.

Keywords: *Porous cavities, Isotherms, Streamlines, Triangular enclosure, Trapezoidal enclosure, Discrete heating, Square duct, Ra (Rayleigh's Number), Rd (Radiation parameter), Aspect Ratio(W/H)*

1. Introduction

Porous medium is a medium that has a solid matrix with interconnected pores. Due to the presence of pores, it provides a way for a fluid to flow across a channel and it is also one which carry heat from one region to the other region [1]. In various thermal and industrial processes, natural convection plays an important role, such as electronic parts cooling, packaged bed reactors, chemical and material processing, food processing, production process casting, polymer processing and alloy casting. [2-6].

In the recent times considerably, numerous studies have been published on the porous cavities [7]. Natural convection in any medium plays an important role in transporting steam. Different heating techniques have been carried out by scientists. Differential heating techniques are one of them. Heat from the hot layer travels to the depth faster during this process, but it takes longer time to travel to the opposite cold wall. It includes isothermal heating from one side and isothermal cooling of other side. Thus, the thermal mixing is weak overall; there is a significant non-uniformity in the enclosure. This will lead poor thermal management of the enclosure. To avoid this, discrete heating technique is used where buoyancy flow is occurred within the cavity due to the separate heaters. This will lead to uniform thermal mixing and good thermal management of enclosure.

In numerous recent papers, heat and fluid stream in a square duct are discussed [8]. Abdulgaphur Athani and T. M Yunus Khan [9] studied the transfer of heat in the permeable square duct. The permeable chamberis inserted between internal and external surface of a square duct. When the square duct is subjected to left and right outer surfaces hot temperature and all other six sides to cold temperature, it was observed that isotherms and streamlines penetrate deeper when is diameter (represents the absence of porous medium in a square duct) is smaller. As diameter increases, the bottom section is occupied by least amount of heat when compare to other area. The velocity of fluid decreases with increase in hallows section.

Debayan Das and Tanmay Basak [9] investigated the function of discrete heating through the heatline method in order to achieve efficient thermal management in 4-sided figure (square) and 3-sided figure (triangular) enclosures. Heat line, isotherms and streamlines should be successful in evaluating the thermal management in multiple cavities. In contrast with the symmetrically distributed configuration of heat flow, the rate of asymmetric flow of heat is found to be more. It can be observed that because of the dispersed heat sources inside the enclosures, buoyancy flow is induced locally and that leads to the development of thermal mixing within the enclosures. Thus, thermal mixing in a discreetly warmed up cavity should be substantially higher relative to the differential heating method.

K.N. Seetharamu and K. Aparna [10] investigated dissipation of heat in a non square walled in area with permeable media. Because of the extended hot bottom surface, the primary use of selecting the trapezoidal cavity is to increment the warm exchange rate. It is very difficult to determine the flow inside these cavities, as boundary zone and the middle zone for a certain boundary condition never have the same effect. Using porous material underground, trapezoidal cavities are used to store heat, heat transfer absorbs for solar collectors in a solar trapezoidal cavity. A comparable pattern of reducing Nusselt number through the altitude of the hot surface is discussed in the heat dissipation behavior of a medium by several researchers [8-10].

Ameer Ahamad Nandalur, Sarfaraz Kamangar and Irfan Anjum Badruddin [11] investigated warm exchange in a permeable medium with the nearness of square strong pieces. Any solid inclusion within the permeable chamber powers the warm vitality to be exchanged over the strong whereas obstructing the liquid in solid-occupied area. Such situations under which combination of transfer of heat between solid and liquid in fluids is called conjugate heat transfer. It can be observed that the enlargement in block volume within a porous cavity decreases the flow of the fluid as well as the transfer of heat within the cavity. Transfer of heat from the warm surface increases, leading to the increase in ratio of thermal conductivity. It is also noted that transfer of heat increases with the rise in Ra number and Rd.

Suvash C.Saha and Y.T. Gu investigated natural convection in a three sided enclosure with fluid-saturated permeable chamber and internal heat generation [12]. The effects of the production of inside heat and the porosity of the channel on the laminar stream and dissipation of heat by natural convection on the 3-sided enclosure of which one of the tilted surfaces are non-isothermal. They used the solution of finite volume method to handle the buoyancy effects and applied the Boussinesq approximation. Increasing heat output in the fluid decreases the dT/dx near the channel. Due to this raising heat output, the intensity of the dominant vertex caused by buoyancy is decreased and a more, nearly equal double vertex arrangement grows. The heat transfer on surfaces is also improved by increasing the medium’s permeability for the parameter value of a fixed heat generation.

M A Theeb investigated the effect of W/H parameter on heat dissipation in a 4-sided square chamber filled with a permeable chamber [13]. In this article, various aspect ratio values are analyzed (W/H ratio). The impact on heat dissipation of modifying the W/H ratio of the four sided coordinate enclosure filled with a permeable chamber is numerically checked. It may be observed that the W/H ratio affects the average Nu number sum and increases the aspect ratio stream rate from 1:1 to 4:1.

2. Porous Geometry

A physical domain of a Square Porous region is depicted in Figure 1. Notice that, left side wall with uniformly varying boundary conditions, top and bottom walls are adiabatic and right wall is cold.

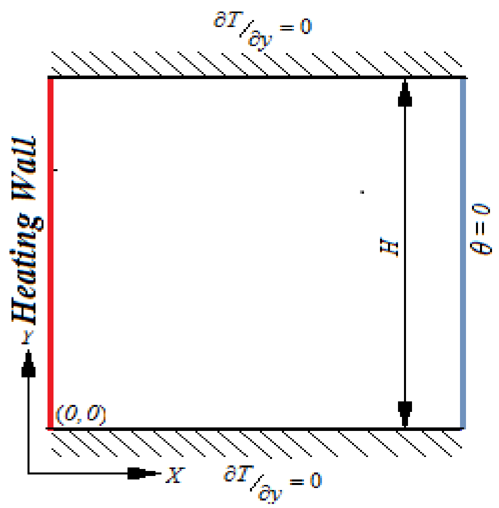


Fig. 1: Computational domain.

3. Governing Equations

Consider a permeable chamber saturated with the fluid. The governing equation in the Cartesian coordinate can be written as

The continuity equation

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

Darcy equation (Momentum equation)

$$u=\frac{-K}{\mu}\frac{\partial p}{\partial x} \tag{1.1}$$

The velocity in x direction by Darcy law velocity in horizontal direction

$$u = \frac{-K}{\mu}\frac{\partial p}{\partial x} \tag{1.2}$$

Velocity in vertical direction is given by

$$v = \frac{-K}{\mu}\left(\frac{\partial p}{\partial y} + \rho g\right) \tag{1.3}$$

The permeability K of porous medium can be described by Bejan

$$K = \frac{D_P^2 \phi^3}{180(1-\phi)^2} \tag{1.4}$$

The variation of density w.r.t temperature can be described by Boussinesq approximation as

$$\rho = \rho_\infty[1 - \beta_T (T - T_\infty)] \tag{1.5}$$

Momentum equation:

$$\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = \frac{Kg\beta_T}{\gamma}\frac{\partial T}{\partial x} \tag{1.6}$$

Energy equation;

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \tag{1.7}$$

The continuity equation (1) can be modified by introducing a stream function ψ as

$$u = \frac{\partial \psi}{\partial y} \tag{1.8}$$

$$v = -\frac{\partial \psi}{\partial x} \tag{1.9}$$

The following are the non-dimensional parameters for the fluid saturated permeable medium

Non-dimensional temperature $\theta = \left(\frac{T - T_C}{T_h - T_C}\right)$ (1.10a)

Non-dimensional Stream function $\psi = \frac{\psi}{\alpha}$ (1.10b)

Non-dimensional Height $Y = \frac{y}{L}$ (1.10c)

Non-dimensional Width $X = \frac{x}{L}$ (1.10d)

Modified Rayleigh number $Ra = \frac{g\beta_T \nabla TKL}{\nu\alpha}$ (1.10e)

4. Solution Methodology and Convergence Study

The computations are undertaken for 41 X 41 grid based on a grid refinement study. A Galerikin's Residual FEM is used for solution of the dimensionless governing equations. In order to determine the buoyant heat transfer parameters in the non square cavity, Eqn. (1.10e) is to be solved.

The grid independency against $\overline{Nu}$ for various mesh size of 11×11, 21×21 31×31, 41×41, 51×51 and 61× 61 of a porous square cavity for regular mesh with triangular element have been investigated using Finite Element Method. Table shows grid independence study of the average Nusslet numbers with *Ra =500* for left side is wall uniform heating. Average Nusselt number is increases from 11 X 11 to 31 X 31 and constant at 41 X 41,51 X 51,61 X 61 Grid size , hence 41 X 41grid is used for all further computations**.**

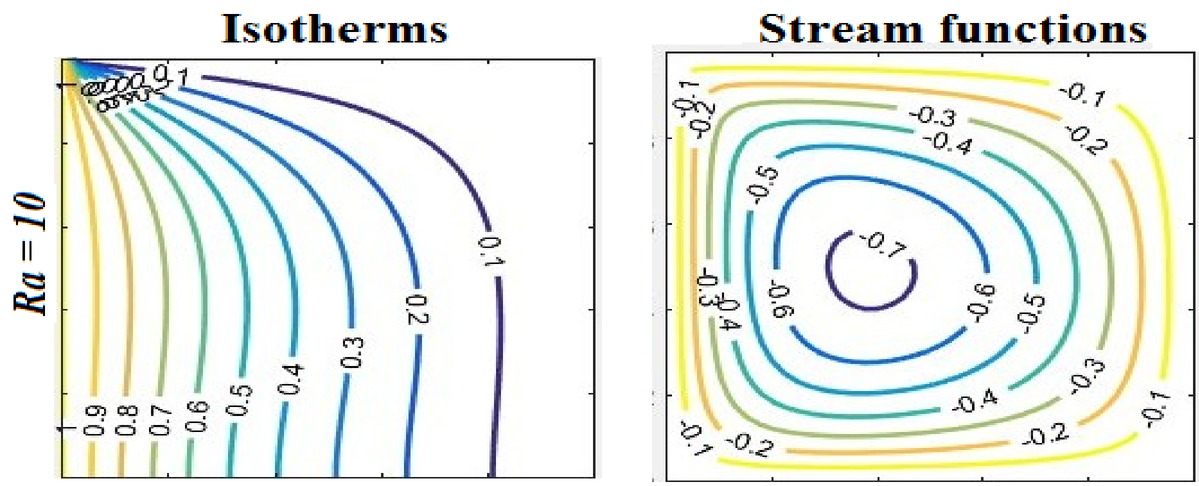
Grid independence Test	
Grid Dimension	Average Nusselt No($\overline{Nu}$)
11 X 11	6.2351
21 X 21	5.222
31 X 31	4.7252
41 X 41	4.4222
51 X 51	4.2114
61 X 61	4.2021

Table. 1: ***Mesh convergence study*****.**

4. Results and Discussion

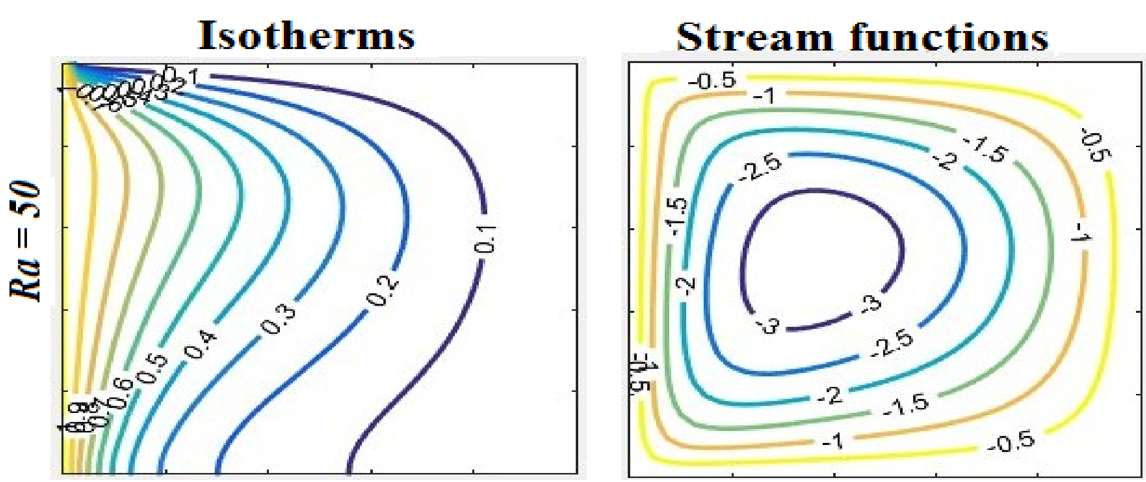
The results are plotted for the square geometry by giving the left side wall uniform heat and right side wall cooled and keeping top and bottom portion adiabatic. The plots (Isotherms and Stream function) are plotted with the help of MATLAB using above non-dimensional equation.

Case 1: For Ra 10



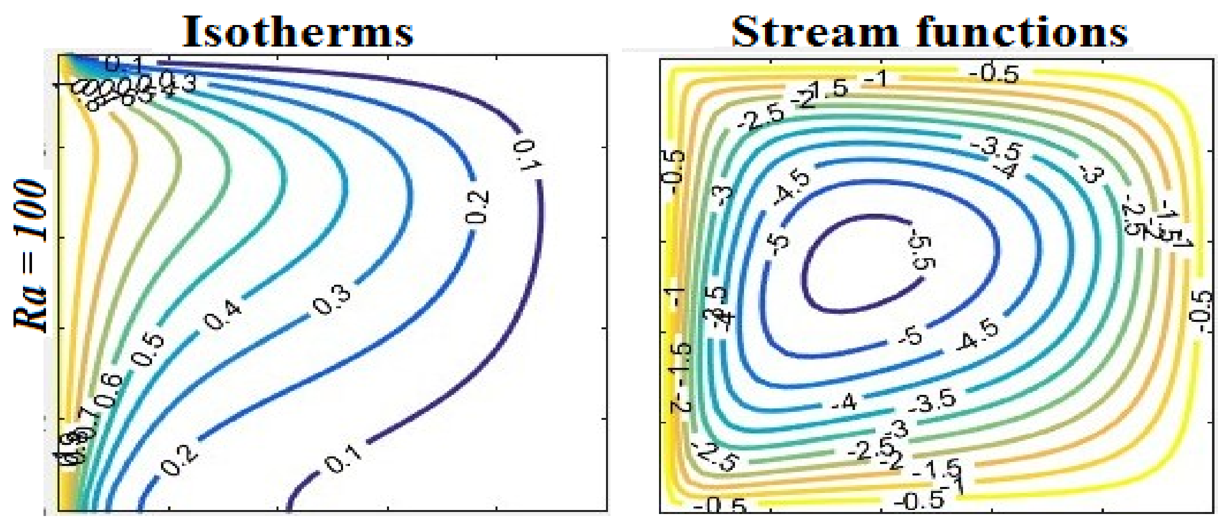
It can be seen from that graph that less amount of permeable chamber is engaged by high isotherm lines. The isotherms $\theta = 1$ is almost parallel to the vertical wall. The fluid rises up from bottom and streamlines goes downward in left side due to the uniform heat and cold surfaces in the left and right side walls respectively.

Case 2: For Ra 50



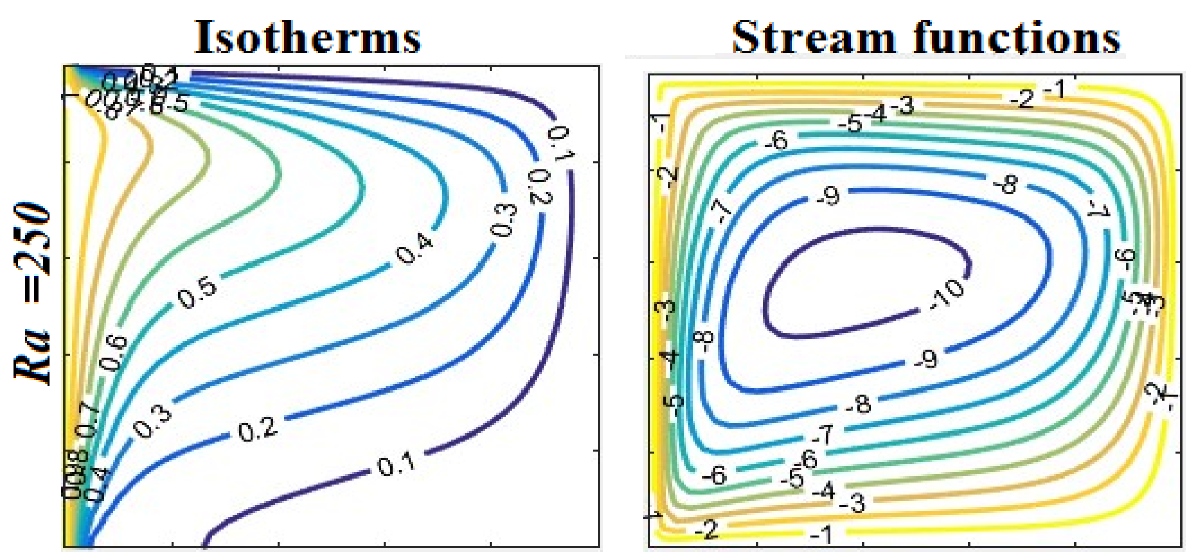
For Ra 50, we can seen that streamlines increases from 0.7 to 3 when compare to Ra 10. Here more amount of permeable chamber is engaged by high isotherm lines when compare to Ra 10.The isotherms $\theta = 1$ and 0.1 of hot and cold surface is almost parallel to the vertical wall.

Case 3: For Ra 100



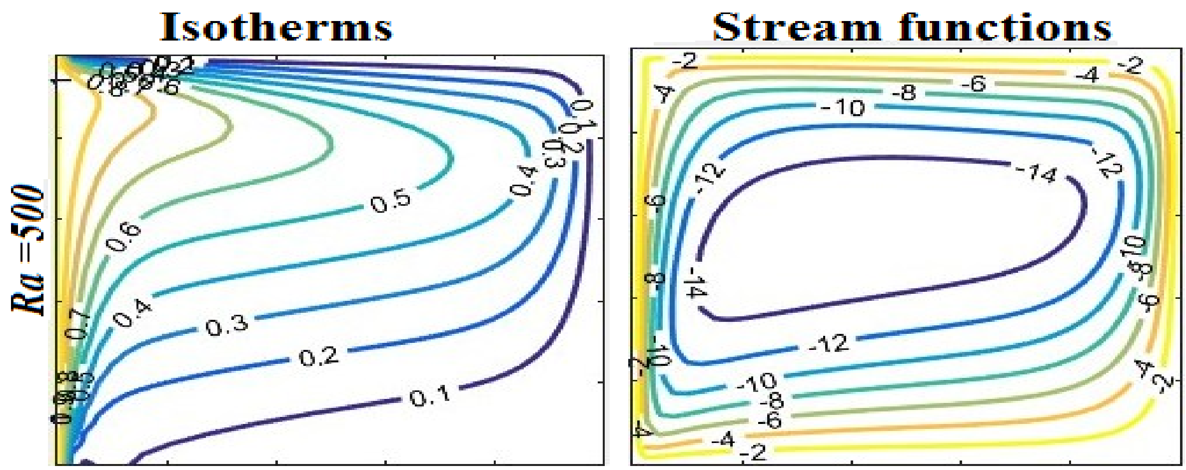
For Ra 100, we can seen that streamlines increases from 3 to 5.5 when compare to Ra 50. Here more amount of permeable chamber is engaged by high isotherms lines when compare to Ra 50.

Case 4: For Ra 250



For Ra 250, we can seen that streamlines increases from 5.5 to 10 when compare to Ra 100. Here more amount of permeable chamber is engaged by high isotherms lines when compare to Ra 100.

Case 5: For Ra 500



For Ra 500, we can seen that streamlines increases from 10 to 12 when compare to Ra 250. Here more amount of permeable cavity is engaged by high isotherms lines when compare to Ra 250. Due to the buoyancy force caused within the chamber (due to increase in Ra number) the stream function increases.

It can be seen that more area of porous medium is occupied by high temperature lines when the Ra number is increased from 10 to 500.As the Ra number increases more amount of permeable media is engaged by high isotherms lines. Maximum absolute value of streamlines increases from 0.7-14 when Ra number increase from 10-500. As the Ra number increases, the convection current caused by buoyancy force within the chamber, the value of stream function also increases. The isotherms between $\theta = 0.6$ to 0.2 we observe a smooth curve and surrounds the square geometry partially.

The plots of stream function and isotherms for various Rayleigh numbers varied from Ra = 10 to 500, when the left vertical surface is warmed uniformly and right surface is uniformly cooled .Due to the uniform heating and cooling of left and right walls we observe the fluid rise from bottom to the top portion of square geometry and fluid flows downwards in streamlines in the right side wall.

5. Conclusion

The purpose of this article is to provide a mini analysis for the various phenomena studied in the porous medium along with transfer of heat. It is assumed that transfer of heat in porous cavity is extensively analyzed; however it's still a wide range of space to study the characteristics of transfer of heat in porous cavity.

The prime investigation of the current study is to study the effect of Ra number on free convection in a square enclosure. The following conclusions have been noted from the present computations.

a) The lower values of local Nu number are achieved up to *Ra =100*.
b) The average Nu number increases monotonically with increase of *Ra* number.
c) The conduction domination mode is observed up to *Ra = 100*.

It is witnessed that the overall heat transfer rate increase with increase of Rayleigh number.

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6. Notes on Contributors

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