ANALYSIS OF THE NATURAL CONVECTION HEAT TRANSFER INSIDE SQUARE ENCLOSURE PARTIALLY DIVIDED BY NON-CONDUCTIVE PARTITIONS S

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ABSTRACT

This work focuses on the numerical analysis of natural convection in a saturated porous medium. A square enclosure is partially divided by adiabatic partitions. The vertical walls were isothermal, horizontal walls were set adiabatic and an adiabatic partitions were attached to the bottom and top walls. A finite difference method had been adopted for solving the governing equations. This paper reports the effect of length, position of the partition. The numerical results of heat transfer are presented for modified Rayleigh number Ra^ in the range (100 to 1000) and different position of the partition two cases were studied case one [$x_{p1}=1/4$, $x_{p2}=3/4$] and case two [$x_{p1}=3/4$, $x_{p2}=1/4$] the length of partition change in the range [0.2 , 0.4 , 0.6 , 0.8]. The results are represented by streamlines and isotherms lines to show the behavior of the flow and temperatures distribution. In addition to that, some graphics represent the relation between Nusselt and Rayleigh numbers with different length. Results shows that Nusselt number decreases with the increase in the length of partition for case one ($x_{p1}=1/4$, $x_{p2}=3/4$), and for case two ($x_{p1}=3/4$, $x_{p2}=1/4$) the Nusselt number increase until it reaches the maximum value when the length of the partitions between (0.5-0.6) and then decreases with the increase in partition length. Heat transfer quantity decreases according to local and length of partition when Rayleigh 1000 and ($x_{p1}=1/4$, $x_{p2}=3/4$, $y_p=0.8$) which leads to heat reduction approximately 97% while for case two ($x_{p1}=3/4$, $x_{p2}=1/4$, $y_p=0.8$) the quantity of heat reduction is observed to 81%.*

KEYWORDS:

Received: May 09, 2020; Accepted: May 29, 2020; Published: Jun 24, 2020; Paper Id.: IJMPERDAUG202014

NOMENCLATURE

Pr	Prandtl Number
$\hat{y}_p$	Dimensionless height from horizontal surface
L	Dimensionless length
L	Horizontal/ vertical dimension of enclosure
Ra^*	Rayleigh number
Nu	Nusselt number
u, v	Velocity in x, y –direction
θ	Dimensionless temperature
ρ	density
μ	Dynamic viscosity
g	Gravitational acceleration
K	Permeability
ψ	stream function

$\hat{\psi}$	Dimensionless stream function
α	Thermal diffusivity
β	Thermal expansion coefficient
Subscripts	
h,c	hot, cold
p	Partition

INTRODUCTION

Recently, numerous investigations have been focused on the heat transfer within a porous media in order to provide a deep understanding in this field, especially in the problems related to transport process phenomena. Many sensible applications like chemical catalytic process reactors, high performance insulation for buildings, packed sphere beds, grain storage, migration of wet through the air contained in fibrous insulations, solar energy collectors, and lots of alternative areas are classified as a transport inside a porous medium [1]. There is still plenty of literature on the convective flow in porous media. It is possible to find representative fieldwork in this. The influences of adiabatic fin attached to the bottom base of a triangular cavity packed with porous medium have been examined [2]. The enclosure's height and the base length were equal. The vertical surface of the enclosure was insulated and the lower surface was set isothermal and its temperature was higher than the inclined surface, higher than the temperature of the inclined surface temperature. The fin splits the heated bottom wall into two separated areas. The results showed that there is ability of using the fin to be a key feature for the fluid flow behavior and heat transfer processes. To investigate the influence of partial partitions fixed to the adiabatic horizontal walls on the natural convection inside enclosures, Bilgen [3] studied different parameters such as partitions number and position, cavity height to base ratio, dimensionless height (up to 15), and Rayleigh number. The results indicated that for Rayleigh number up to 10^8 , the flow regime was laminar thereafter turbulent. The results also showed that heat transfer significantly was reduced in the case of using two partitions instead of one, in the smaller aspect ratio, and when the location of partitions was farther away from the hot surface. A study has been conducted by Ali Hooshyar et al [4] to inspect the effect of position and height of rectangular block on mean Nusselt inside, a square enclosure contained a porous medium. The bottom and the top surfaces were insulated and the left vertical surface was set at a temperature greater than the right vertical surface temperature. The results of their study showed that the mean Nusselt number has a significant dependency on the location of the block body, and it also influences on the dimensionless time to achieve a steady state solution. The partition location effect also, has been examined by Paweena Khansila et al [5]. The partition was connected to the base of a square enclosure saturated with porous material. The top and the left wall were cold while the right and bottom wall was set to be adiabatic and the partition was set the non-uniform heated surface. They pointed out that when the ratio the partition length to the enclosure side length is less than half, the flow field intends to be a unicellular. They also denoted that the significant heat transfer and flow field with an increase of Darcy number. The effect of the position of two thin partitions which are considered fully insulated placed in the cavity on transient magneto hydrodynamic natural convection inside square cavity filled with a fluid-saturated porous medium with internal heat generation has been studied by Mat Salim Selamat et al [6]. The results showed that the angle of the magnetic field and the position of partitions play an influential role on the rate of heat transfer. Many parameters such as partition and thermal conductivity ratios, height, and modified Rayleigh number are under investigation in the study of the effect of two solid

vertical partitions on a conjugate natural convection inside a square cavity filled with a saturated fluid [7]. They examined three categories of thermal conductivity ratios which are: 1- 0.1-0.3, 2- 0.3-1, and 3- 0.5-2, with a modified Rayleigh number ranged between 100 and 1000. The results indicated that, the Nusselt number most certainly decreases when employing a solid partition within the enclosure. For partition length between 0 to 0.6, the sensitivity of the Nusselt number due to partition length appeared more significant than other case. Since in this extent, the drop in Nusselt number was more than other ranges, there after the drop still appeared but only very subtle. Also, the Nusselt number was correlated with the thermal conductivity ratio (thermal conductivity of solid to thermal conductivity of porous medium) .

Many studies have been performed to investigate the amount of heat transfer between two side walls with different temperatures [8-16]. The results obviously showed that the heat transfer rate decreases when partial partition is extant. Flow imaging by Nansteel and Greif [11,12] verified that a weak recirculation region in the upper gradient near the top wall is responsible for decreasing the heat transfer across the enclosure. The influence of a rectangular block on the Nusselt number of heated wall in a square cavity filled with porous media has been conducted [Ali]. Upper and lower surfaces were insulated and the left vertical surface was set at a constant temperature, but higher than the right vertical surface. The study covered for different cases depends on the block position which are: case 1 and case 2 - the block attached at the upper or lower edge with variable location regarding to the left heated wall, case 3 and case 4 - the block at the middle edge of upper or lower edge with a variable block length. The correlation of the mean Nusselt number with the no insulated case was presented in normalized form. The results indicated that the mean Nusselt number was significantly affected by the location of the block. It also showed that the dimensionless time required to achieve steady state was affected by block position. Al-Timemy [17] Studied numerically the effect of partitions fixed vertically on the bottom wall of the 2-D enclosure filled porous media. The results shows that the increase in number and length of the partitions reduce the heat transfer. Raed Ahmed Ali [18] Examined the effect of length and position of thin conductive partition on natural convection inside porous cavity. The results shows the Nusselt number were decreasing with an increase in partition length . Abbas S. Hussain, Ziad M. Al-Makhyoul and Ramiz I. Al-Aboshi [19] Investigated the effect of vertical partition inside square enclosure and inclination angle of one side of enclosure. The study shows that the Nusselt number decreased with an increase in partition length.

The goal of the current research is to inspect the influence of the adiabatic partitions attached to the top and the bottom walls of an enclosure on the natural convection heat transfer. Two different cases associated with the partition position are adopted in this study: $x_{p1}=1/4$, $x_{p2}=3/4$ and $x_{p1}=3/4$, $x_{p2}=1/4$. The effect of the partition length and position, and Ra^* number on fluid flow behaviour, temperatures distribution and Nu number are considered for each stated case.

Physical Model and Governing Equations

Figure 1: Diagram Shows Square Enclosure with Partitions attached to Insulated Walls.

A diagram of 2-D square enclosure system filled with a fluid-saturated porous medium and the proposed boundary conditions are shown in figure (1). Solid partitions are attached to the upper and lower horizontal surface. The temperature of the vertical left wall is maintained at temperature greater than the temperature of the right vertical wall, while the upper and the lower walls are insulated. The partition is assumed to be made from non-conductive material i.e "adiabatic partition".

2-D laminar flow of an incompressible fluid, some assumptions have to be deemed to apply governing equation as followings:

- Fluid and porous medium. properties are constant.
- Radiation heat exchange is insignificant.
- The cavity walls are impermeable.
- The Boussinesq approximation is considered and the viscous drag and inertia terms of momentum equations are negligible.

According to the above assumptions, the dominating equations for continuity, momentum and energy can be written as follows:

$$\rho = \rho_o (1 - \beta \Delta T) \text{-----1}$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \text{-----2}$$

$$\frac{\partial u}{\partial y} - \frac{\partial v}{\partial x} = -\frac{\rho \cdot g \beta K}{\mu} \frac{\partial T}{\partial x} \text{-----3}$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha_c \left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \text{-----4}$$

The above equations can be written in terms of the stream functions which are defined as

$$\left\{ u = -\frac{\partial \psi}{\partial y}, v = \frac{\partial \psi}{\partial x} \right\} \text{-----5}$$

and the governing equations can be written in dimensionless form as follows:

$$\frac{\partial^2 \hat{\psi}}{\partial \hat{x}^2} + \frac{\partial^2 \hat{\psi}}{\partial \hat{y}^2} = Ra^* \frac{\partial \theta}{\partial \hat{x}} \text{-----6}$$

$$\frac{\partial \hat{\psi}}{\partial \hat{x}} \frac{\partial \theta}{\partial \hat{y}} - \frac{\partial \hat{\psi}}{\partial \hat{y}} \frac{\partial \theta}{\partial \hat{x}} = \frac{\partial^2 \theta}{\partial \hat{x}^2} + \frac{\partial^2 \theta}{\partial \hat{y}^2} \text{-----7}$$

Dimensionless parameters are listed as

$$\left\{ \hat{x} = \frac{x}{L}, \hat{y} = \frac{y}{L}, A = \frac{H}{L}, \hat{\psi} = \frac{\psi}{\alpha}, \theta = \frac{T - T_c}{T_h - T_c} \right\} \text{----8}$$

Boundary conditions for the enclosure

$$\text{at } \hat{x} = 0, 1 \text{ any } \hat{y} \quad \hat{\psi} = 0 \text{-----9}$$

$$\text{at } \hat{x} = 0, \text{ any } \hat{y} \quad \theta = 1.0 \text{-----10}$$

$$\text{at } \hat{x} = 1, \text{ any } \hat{y} \quad \theta = 0.0 \text{-----11}$$

$$\text{at } \hat{y} = 0, 1 \text{ any } \hat{x} \quad \frac{\partial \theta}{\partial \hat{y}} = 0, \hat{\psi} = 0 \text{-----12}$$

For the partition

$$\text{at } \hat{x} = \hat{x}_p, 0 \leq \hat{y} \leq \hat{y}_p, \frac{\partial \theta}{\partial \hat{x}} = 0, \hat{\psi} = 0 \text{-----13}$$

$$\text{at } \hat{x} = \hat{x}_p + t_p, 0 \leq \hat{y} \leq \hat{y}_p, \frac{\partial \theta}{\partial \hat{x}} = 0, \hat{\psi} = 0 \text{---14}$$

$$\text{at } \hat{y} = \hat{y}_p, \hat{x}_p \leq \hat{x} \leq \hat{x}_p + t_p, \frac{\partial \theta}{\partial \hat{y}} = 0, \hat{\psi} = 0 \text{---15}$$

NUMERICAL METHOD

The finite difference method was used to solve the non-dimensional governing equations of this problem. The flow field of natural convection heat transfers in a square enclosure with non-conductive partition attached. The upper and lower insulated walls was assumed to be 2-D, steady state, and laminar flow.

The following equation can be used to obtain the heat transfer:

$$Q = \int_p \frac{\partial \theta}{\partial x} dy \text{-----16}$$

Equation (17) can be used to obtain the average Nusselt number along the walls of the enclosure which is defined as the ratio between convective heat transfers to conductive heat transfer and can be written as

$$Nu = \frac{Q_{convection}}{Q_{conduction}} \text{-----17}$$

RESULTS AND DISCUSSIONS

In this section, numerical results of isotherms and streamlines for various values of Rayleigh number, partitions dimensionless length, and position of upper and lower partitions $\{(x_{p1}=1/4, x_{p2}=3/4) \text{ \& } (x_{p1}=3/4, x_{p2}=1/4)\}$ are presented.

Figure (2) shows the flow structure and constant temperature lines for various values of Ra^* number when the upper and lower partition in distances of $3/4$ and $1/4$ respectively from hot wall and the dimensionless partition length of 0.6 with respect to the width of the cavity. In this figure, it can be seen that the increase in the Ra^* number leads to rise in the temperature gradient vicinity to the vertical surface and causes increased value of a stream_function. This can be attributed to increasing buoyancy force due to an increase in Ra^* number, which represents the key control in the free convection heat transfer. Also, it can be seen that when the Rayleigh number increases, the fluid flow becomes multicellular flow. This occurs because the partition restriction the fluid flow, therefore the fluid trap.

Figure 3 shows the effect the dimensionless partition length on the streamlines and isotherm lines when Rayleigh number equals 500. With an increase in both partitions from 0.2 to 0.8 and partition distance of lower one of $1/4$ and upper one of $3/4$, the temperature gradient along the vertical walls decreases. This is because the increase in partitions length cause restricting the fluid flow, which lead to decrease and hence the temperature gradient. Also the increasing partitions length makes fluid flow multi-cellular flow, and this occurs because the increase in partitions restricts the fluid flow and therefore the fluid trap.

Figure 4 illustrates the influence of Ra^* number on steady state contour plots for the flow structure and constant temperature lines for several values of Rayleigh number when the upper and lower partitions in distances ($1/4, 3/4$) from hot wall and in dimensionless partitions length equal (0.6). As shown from this figure, in general, the increase in the Ra^* number produces rise in temperature gradient alongside the vertical surface, also the value of stream function raised with the rise in the Rayleigh number.

Figure 5 shows the result of the boosting in the non-dimensional partitions length upon flow structure and constant temperature lines when Ra^* number equals 500. When the upper and lower partition in distances ($1/4, 3/4$) from hot wall, the increase in the non-dimensional partition length causes reduction in temperature gradient alongside the vertical surface because the increase in partition length impeded the fluid flow, so the temperature gradient diminutions consequently and the heat transfer by convection decreases.

Figure 6 depicts the relationship between the Nusselt number and dimensionless partition length for different value of Rayleigh number when the upper and lower partition distances ($3/4, 1/4$) from hot wall. The boosting in the Rayleigh number here for the equal value of partition length results in rising the Nusselt number, because the increase in the heat transfer by convection resulting by increasing in buoyancy force. Also, the increase in the non-dimensional

partition length will decrease the Nusselt number because an increase in partition length decreases the temperature gradient along the vertical wall, therefore the heat transfer decreases.

Figure 7 depicts the relationship between the Nusselt number and dimensionless partition length for different value of Rayleigh number when the upper and lower partition in distances (1/4, 3/4) from hot wall. As it shown in this figure boosting in the Ra^* number for the equal value of partition length cause boosting the Nusselt number, this is because an increase in the heat transfer by convection due to buoyancy force which rises the temperature gradient alongside the vertical wall. Also the increasing in the dimensionless partition length will increase the Nu number, because the increase in partition length decreases the space in front of the fluid flow. This phenomena lead to increasing flow velocity consequently temperature gradient vicinity, the vertical wall increases, therefore the heat transfer increased. Also the important point from these relations can be summarised that the critical length of the partitions is around 0.6, which can return Nusselt number when the Rayleigh number is in the range between 300 and 1000. After this critical value, the Nusselt number drops. This can be attributed to the flow restriction caused by length increase.

CONCLUSIONS

Heat transfer by free convection inside a square enclosure with adiabatic partitions attached on the top and bottom walls wall has been studied numerically. The results show the next conclusions:

- The heat transfer by free convection is improved with the increase in Ra^* number.
- The fluid flow become multicellular flow with an increase in partition length and Rayleigh number when ($x_{p1}=1/4$, $x_{p2}=3/4$).
- The Nu number and temperature gradient are increased as Ra^* number augment when ($x_{p1}=1/4$, $x_{p2}=3/4$) & ($x_{p1}=3/4$, $x_{p2}=1/4$).
- The Nusselt number and temperature gradient reduced with an increase in the length of partition when ($x_{p1}=1/4$, $x_{p2}=3/4$)
- The Nusselt number and temperature gradient increases and reach the maximum value at the range of length of partition between (0.5-0.6) and then decreases with an increase in the partition when ($x_{p1}=3/4$, $x_{p2}=1/4$).

Figure 2: A,B,C,D, the influence of Rayleigh number on Flow Structure and constant temperature lines Ra^* (300,500,700,1000) & partitions length equal 0.6.

Figure 3 A, B, C and D the Influence of the Dimensionless Partitions Length upon Flow Structure and constant Temperature Lines when Rayleigh Number Equals 500 , Partitions Length Equal (0.2,0.4,0.6,0.8)

Figure 4: A,B,C,D, the effect of Rayleigh number flow structure and constant temperature line Ra^* (300,500,700,1000) & partitions length equal 0.6.

Figure 5: A, B, C and D the Influence of the Dimensionless Partitions Length upon Flow Structure and constant Temperature lines when Rayleigh Number Equals 500, Partitions Length Equal (0.2,0.4,0.6,0.8)

Figure 6: Relationship between the Nusselt Number and Dimensionless Partition Length

for different value of Rayleigh Number.

Figure 7: Relationship between the Nusselt Number and Dimensionless Partition Length for Different Value of Rayleigh Number.

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