Partition Effect on Thermo Magnetic Natural Convection and Entropy Generation in Inclined Porous Cavity

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(Received August 2, 2014; accepted November 10, 2014)

ABSTRACT

In this study natural convection heat transfer fluid flow and entropy generation in a porous inclined cavity in the presence of uniform magnetic field is studied numerically. For control of heat transfer and entropy generation, one or two partitions are attached to horizontal walls. The left wall of enclosure is heated with a sinusoidal function and right wall is cooled isothermally. Horizontal walls of the enclosure are adiabatic. The governing equations are numerically solved in the domain by the control volume approach based on the SIMPLE technique. The influence of Hartmann number, inclination angle, partition height, irreversibility distribution ratio, and partition location is investigated on the flow and heat transfer characteristics and the entropy generation. The obtained results indicated that the partition, magnetic field and rotation of enclosure can be used as control elements for heat transfer, fluid flow and entropy generation in porous medium.

Keywords: MHD; Free convection; Partition; Porous media.

1. INTRODUCTION

Flow of an ambient fluid induced solely due to buoyancy occurs in several natural and engineering processes. Natural convection in partitioned rectangular porous cavity with various boundary conditions exists in many engineering application like: high performance insulation for buildings, chemical catalytic reactors, the underground spread of pollutants, solar power collectors, and geothermal energy systems.

Effect of non-uniform sinusoidal heated wall in an open square cavity with viscose fluid is studied numerically by Basak and Roy (2005). Other studies of the natural convection in enclosures with sinusoidal temperature boundary condition are due to Bilgen and Yedder (2007), Storesletten and Pop (1996), Saeid (2005) and Heidary et al. (2009). They studied natural convection in porous cavity with sinusoidal bottom wall temperature variation. Basak et al. (2006) investigated effects of sinusoidal boundary conditions in cavity filled with porous media without porosity. Control of natural convection can be done with boundary condition or adding divider for disturbing fluid flow. In last decades, most of the studies on partition or divider were taken as non-porous medium filled partitioned rectangular or square enclosures. Also Varol et al. (2007) investigated the effects of fin location on the bottom wall of a triangular enclosure filled with porous media. The study of an electrically conducting fluid in engineering applications is of considerable interest, especially in metallurgical and metal working processes or in separation of molten metals from nonmetallic inclusions by the application of a magnetic field.

The phase change problem occurs in casting, welding, melting purification of metals and in the formation of ice layers on the oceans as well as on aircraft surfaces. In that case the fluid experiences a Lorentz force and its effect is to reduce the flow velocities. This in turn affects the rate of heat and mass transfer. The homogeneity and quality of single crystals grown from doped semiconductor melts is of interest to the manufacturers of electronic chips. Hence there has been increased interest in the flows of electrically conducting fluid in cavities subjected to external magnetic field.

Natural convection flow in the presence of a magnetic field in enclosure heated from one side and cooled from the other side was considered by Ece and Büyük (2006), Jue (2006) and Pirmohammadi and Ghassemi (2009). Free convection in an open cavity by locating partition is

The effect of magnetic field on entropy generation at the onset of natural convection was studied by Magherbi et al. (2010). Mahmud and Fraser (2004) investigated the effect of magnetohydrodynamic free convection and entropy generation in a square porous cavity. To the best of our knowledge no comprehensive model has been published yet to study natural convection on controlling heat transfer and entropy generation by including rectangular partition in porous inclined cavity under magnetic field. In the present study, natural convection in an inclined cavity filled with a porous medium cooled from right wall and heated from the left is analyzed numerically, while flow field is under magnetic field. Also horizontal walls are assumed adiabatic. Because constant thermal boundary condition usually doesn’t occur in nature, the hot wall temperature is assumed to be non-uniform temperature distribution prescribed at the left wall. But the difference between uniform and non-uniform boundary conditions has not been studied in this paper. We have studied the effects of non-uniform boundary condition in our earlier paper (2009). The main objective of this study is to control flow pattern, heat transfer and entropy generation in the inclined porous enclosure under magnetic field with one or two partition attached to the horizontal wall. For simulating of porous media, Darcy-Brinkman model is assumed to hold.
2. MATHEMATICAL ANALYSIS

A schematic diagram of a two-dimensional inclined porous cavity under magnetic field is shown in Fig. 1. It is assumed that the right wall of the cavity is cooled to the constant temperature $T_C$ and the left wall is heated to the non-uniform temperature $(T_I - T_C) \sin(\pi Y / H) + T_C$, where $T_I > T_C$, and the horizontal walls are adiabatic. The interface between the partition and the porous media is set to adiabatic boundary.

In the porous medium, Darcy-Brinkman model is assumed to hold, and the fluid is assumed to be a normal Boussinesq fluid. With these assumptions, the continuity, momentum and energy equations for steady, two-dimensional flow in an isotropic and homogeneous porous medium under magnetic field are:

\[
\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0
\]

(1)

\[
\frac{1}{\Phi^2} \left( \frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = \frac{1}{\rho} \left( \frac{\partial P}{\partial x} + \Phi \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \right) - \frac{\rho g}{\nu} (u \sin \phi + v) + \frac{\sigma B^2}{\rho} \frac{v}{\Phi}
\]

(2)

\[
\frac{1}{\Phi^2} \left( \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y} \right) = \frac{1}{\rho} \left( \frac{\partial P}{\partial y} + \Phi \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \right) - \frac{\rho g}{\nu} (u \cos \phi - v) - \frac{\sigma B^2}{\rho} \frac{u}{\Phi}
\]

(3)

\[
\frac{\partial T}{\partial x} + \frac{\partial T}{\partial y} = \frac{1}{\rho C_p} \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right)
\]

(4)

where $u$ and $v$ are the seepage velocity components along $x$- and $y$- axes, $P$ is pressure, $T$ is the fluid temperature. Also $\nu$, $\kappa$, $\phi$, $\rho$ and $\sigma$ are kinematic viscosity, permeability, inclination angle, porosity and density, respectively. $B_0$ is the magnitude of magnetic field and $\Phi$ is the electrical conductivity. The non-dimensional forms of the governing equations (1) – (4) are:

\[
\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0
\]

(5)

\[
\frac{1}{\Phi^2} \left( \frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} \right) = \frac{1}{\rho} \left( \frac{\partial P}{\partial X} + \Phi \left( \frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 U}{\partial Y^2} \right) \right) - \frac{\rho g}{\nu} (U \sin \phi + V) + \frac{\sigma B^2}{\rho} \frac{V}{\Phi}
\]

(6)

\[
\frac{1}{\Phi^2} \left( \frac{\partial V}{\partial X} + \frac{\partial U}{\partial Y} \right) = \frac{1}{\rho} \left( \frac{\partial P}{\partial Y} + \Phi \left( \frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 V}{\partial Y^2} \right) \right) - \frac{\rho g}{\nu} (U \cos \phi - V) - \frac{\sigma B^2}{\rho} \frac{U}{\Phi}
\]

(7)

\[
U \frac{\partial \theta}{\partial X} + V \frac{\partial \theta}{\partial Y} = \frac{\partial^2 \theta}{\partial X^2} + \frac{\partial^2 \theta}{\partial Y^2}
\]

(8)

where non-dimensional variables are defined as follows:

\[
X = \frac{x}{H}, Y = \frac{y}{H}, U = \frac{uH}{\alpha}, V = \frac{vH}{\alpha}, \theta = \frac{T - T_C}{T_H - T_C}\]

(9)

\[
P = \frac{\rho H^2}{\alpha^2}, \text{Pr} = \frac{\nu}{\alpha}, Da = \frac{K}{H^2}, Ra = \frac{g \beta \Delta H^3}{\nu a}
\]

(10)

\[
\alpha = \frac{a_f}{\lambda}, \lambda = k_f / k_e, k_e = \Phi k_f + (1 - \Phi) k_i
\]

(11)

The effect of the electromagnetic field is introduced into the equations of motion (7) through Hartmann number (Ha). Ha is defined as:

\[
Ha = B_0 H \sqrt{\frac{\sigma}{\rho \nu}}
\]

(12)

It is noted that $\frac{1}{\Phi} Ha^2 \rho \nu V$ in equation (7) is achieved by simplifying the Lorentz force term ($J \times B$) using constant magnetic field. Boundary conditions as shown in Fig. 1 are:

Left wall $U(0,Y) = 0, V(0,Y) = 0$,

Right wall $U(1,Y) = 0, V(1,Y) = 0$,

Top wall $U(X,1) = 0, V(X,1) = 0$,

Bottom wall $U(X,0) = 0, V(X,0) = 0$,

On the Partition: $U(X,Y) = 0, V(X,Y) = 0$,

And:

Left wall $\theta(0,Y) = \sin(Y \pi)$,

Right wall $\theta(1,Y) = 0$,

Top wall $\partial \theta(X,1) / \partial Y = 0$,

Bottom wall $\partial \theta(X,0) / \partial Y = 0$,

On the Partition: $\partial \theta(X,Y) / \partial n = 0$;

The heat transfer coefficient in terms of the local Nusselt number ($Nu_x$) and average Nusselt number ($\bar{Nu}$) at the left wall are defined by:

\[
Nu_x = \left[ \frac{\partial \theta}{\partial X} \right]_{X=0}, \bar{Nu} = \int_0^1 Nu_x dY
\]

(13)

Also dimensionless temperature contours ($\theta$) and streamline contours ($\psi$) are depicted in result section. The stream function $\psi$ is defined as $\nu = -\partial \psi / \partial X$ and $u = \partial \psi / \partial Y$.

The volumetric entropy generation can be obtained from the equation (12):

\[
S_{\text{gen}} = \frac{k_f}{T_0} (\nabla T)^2 + \frac{\mu}{K_0} (u^2 + v^2) + \frac{\sigma B^2}{T_0^2} \nu \frac{2}{\Phi^2}
\]

(14)

where $u$ and $v$ are seepage velocity (Nield (1999)).

The dimensionless form of entropy generation rate $S_{\text{gen}}$ is termed as entropy generation number. Entropy generation number (OEG) is the ratio between the volumetric entropy generation rate $S_{\text{gen}}$ and a characteristic transfer rate $S_0$. The characteristic transfer rate for the present problem can be estimated from the following equation:

\[
S_0 = \frac{k_f (\Delta T)^2}{H^2 T_0^2}
\]

(15)

So the dimensionless overall entropy generation
(OEG) can be expressed as:

\[
OEG = \frac{S_{gen}}{S_0} = \left[ \frac{\partial \theta}{\partial X}^2 + \frac{\partial \theta}{\partial Y}^2 \right] + \varphi \left[ (U^2 + V^2) + (Ha^*)^2 \frac{V^2}{\sigma^2} \right]
\]  

(14)

Where

\[
(Ha^*)^2 = Da \cdot Ha^2; \quad Ha^* = B_0 \sqrt{\frac{\sigma K}{\mu}}
\]  

(15)

where \( Ha^* \) is Hartmann number in case of porous media.

The non-dimensional volumetric entropy generation due to heat transfer irreversibility (HTI) and fluid frictional irreversibility (FFI) can be obtained by the following equations:

\[
HTI = \frac{\left( \frac{\partial \theta}{\partial X} \right)^2 + \left( \frac{\partial \theta}{\partial Y} \right)^2}{2}
\]  

(16)

\[
FFI = \varphi \left[ (U^2 + V^2) + (Ha^*)^2 \frac{V^2}{\sigma^2} \right]
\]  

(17)

where \( \theta, U, V, X, Y \) are the dimensionless temperature, velocity components and Cartesian coordinates respectively and \( \Phi \) is irreversibility distribution ratio:

\[
\Phi = \frac{\mu T_0}{k_f} \left( \frac{\alpha^2}{K(\Delta T)^2} \right); \quad T_0 = \frac{T_H + T_C}{2}
\]  

(18)

The overall entropy generation (OEG) in the flow field can be obtained by:

\[
OEG = HTI + FFI
\]  

(19)

The Bejan number (Be) which describes the contribution of heat transfer entropy on overall entropy generation is defined by:

\[
Be = \frac{HTI}{HTI + FFI}
\]  

(20)

On the other hand, Bejan number (Be) is the ratio of HTI to the total entropy generation (OEG). Bejan number ranges from 0 to 1. Accordingly, Be = 1 is the limit at which the heat transfer irreversibility dominates, Be = 0 is the opposite limit at which the irreversibility is dominated by fluid friction effects, and Be = 0.5 is the case in which the heat transfer and fluid friction entropy generation rates are equal.

3. NUMERICAL PROCEDURES

This code uses Finite Volume method and the SIMPLE algorithm developed by Patankar and Spalding (1972) for discretizing the governing equations of flow and resolving the pressure-velocity coupling system. In addition, all the variables are stored in same nodes by using collocated grid. This method was suggested by Rhie and Chow (1983). Collocated grid has various advantages over the staggered grid, e.g. the control volumes for all variables coincide with the boundaries of the solution domain, facilitating the enforcement of boundary conditions, and giving a simplified data storage structure. The diffusion term of the equations is discretized using a central difference algorithm. As the convergence criterion, \(10^{-5}\) is chosen for all dependent variables, where the computation is terminated if

\[
\sum_{i,j} A_{ij}^{n+1} - A_{ij}^n \leq 10^{-5}
\]

Here \( A \) stands for either temperature or velocity components, and \( n \) denotes the iteration step.

Table 1 shows the grid-independency test in this study. Four grid sizes (32 × 32, 64 × 64, 100 × 100, and 128 × 128) are chosen for analysis. Average Nusselt number for all four grid sizes are monitored at \( Ra = 5 \times 10^6, Ha = 50, \varphi = 0^0 \) and in case of two partitions. The magnitude of average Nusselt number at 128 × 128 grids shows a very little difference with the result obtained at 100 × 100 grids (0.23%). So we chose a grid size of 100 × 100 for our calculation in this paper.

Table 2 Validations: comparison of average Nusselt number obtained from the present computation and that of the literature for a porous enclosure (cavity) at various \( Ra, Da = 10^{-2} \) and \( \varphi = 0.9 \).

<table>
<thead>
<tr>
<th>( Re )</th>
<th>Present study</th>
<th>Nithiarasu et al. (1997)</th>
<th>Deviation % (Abs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>103</td>
<td>1.019</td>
<td>1.02</td>
<td>0.10</td>
</tr>
<tr>
<td>104</td>
<td>1.684</td>
<td>1.7</td>
<td>0.95</td>
</tr>
<tr>
<td>105</td>
<td>4.117</td>
<td>4.19</td>
<td>1.77</td>
</tr>
<tr>
<td>5 \times 105</td>
<td>6.997</td>
<td>7.06</td>
<td>0.90</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

Schematic of the computational domain is shown in Figs. 1-(a) and (b). Fig. 1-(b) shows two types of partition location studied in this paper.

In order to assess the accuracy of our numerical procedure, we have tested our algorithm for the classical natural convection problem in porous and non-porous cavity with adiabatic top and bottom walls and differentially heated side walls. For the
side walls, we used $\Theta = 0$ and 1, where $\Theta = \frac{T - T_c}{T_H - T_C}$ in which the subscripts C and H refer to cold and hot walls, respectively. The comparison of streamline contours and isotherm lines obtained from the present code and those of Sarris et al. (2006) for natural convection through the enclosure under magnetic field (see Fig. 2(a)) are depicted at $Ra = 7 \times 10^3$, $Ha = 25$ and $Ra = 7 \times 10^5$, $Ha = 100$ in Figs. 2(b) and 2(c). The present numerical results show excellent accuracy with the literature.

For validation of the present algorithm in the case of natural convection in porous media, comparison of average Nu are performed with those of Nithiarasu et al. (1997) with Darcy-Brinkman model. These computations are performed at $Ra = 10^5$, $10^4$, $10^3$ and $5 \times 10^3$ and at $Da = 10^2$ and $\Phi = 0.9$. As it can be seen from Table 1, there is very good agreement between present results and data available in the literature. There are many porous enclosure problems with magnetic effect, but most of them are based on Darcy model; in our study, the simulation of porous media is based on Darcy-Brinkman model. We could find no paper about porous enclosure problems with magnetic effect which is based on Darcy-Brinkman law. So we validated our computation for two above cases. For comprise the results of computer code with the results of literature in porous enclosure problems with magnetic effect, we validated results of present code against results of Mahmud and Fraser (2004): Consider a square porous enclosure with differentially heated side walls. Darcy’s law is assumed to hold and magnetic force is acting along the direction of the gravity. Figure 3 shows the comparison of our computation and Mahmud and Fraser (2004) in $Ra^* = 100$ and $Ha^* = 0$, 5 and 10.
Fig. 3. Validations; comparison of present code with the results obtained from Mahmud and Fraser (2004) at Ra* = 100 and Ha* = 0, 5 and 10 in cavity.

Where Ra* is the product of Ra and Da and also Ha* is the product of Ha and Da. The comparison shows excellent accuracy of our computer code in which porous media comply from Darcy law.

Entropy generation is investigated for this problem and effect of different parameters on entropy generation is studied. In order to assess the accuracy of our numerical procedure for calculation of entropy generation, validation results can be seen in Fig.4.

Figure 1 shows the computational domain used in this study. As noted in this figure, the computational domain contains of porous inclined cavity with one/two rectangular partitions attached to adiabatic walls (see figure 1-(b)); where C1 and C2 are partition center distance from the hot wall. In this study C1 and C2 are considered 0.5H and 0.25H respectively. Also W and L are considered 0.2H and 0.3H respectively.

The present computations have been carried out within the range of Hartmann number Ha: 0 ≤ Ha ≤ 150, inclination angle φ: 0 ≤ φ ≤ 135°, the partition height L: 0 ≤ L ≤ 0.4H, and partition location are performed to individually investigate the influence of each of these parameters. Darcy number (Da) and porosity (Φ) of porous domain is considered 10^{-4} and 0.9, respectively. Prandtl number (Pr) is considered unity.
The irreversibility distribution ratio is taken equal to $10^{-3}$ in all calculations as given in Varol et al. (2008). Anyhow we have studied the effect of the irreversibility distribution ratio on overall entropy generation and Bejan number as shown in Fig. 5 for $\varphi = 0.01, 0.001, 0.005$ and $0.0001$. As seen in this figure, as $\varphi$ increases, overall entropy generation increases, but Bejan number decreases. As shown in this figure, at low and moderate Ra, with magnetic force, conduction dominates. Most of the contribution on overall entropy generation comes from the heat transfer irreversibility. So, Bejan number shows a value closer to 1 and the variation of OEG with increasing Ra is insignificant in low Ra. A significant contribution on OEG comes from the fluid friction irreversibility (FFI) at higher Ra due to high convection current.

Figure 6 depicts the variation of average Nusselt number versus height of partition $L$: $0 \leq L \leq 0.4H$ and at various Hartmann number: $Ha = 0, 50, 100$. In this case, one partition was attached to bottom wall of cavity (see Fig. 1-(b)). It is observed that as $L$ increases, the Nusselt number decreases which indicates that the convection heat transfer has been damped and this is due to the blockage effect. In each $Ha$, by locating of partition with $L = 0.4H$, average Nu can decrease by 20%.

Also from this figure, it was concluded that the magnetic field considerably decreases the average Nusselt number and as the Hartmann number increases, heat transfer from vertical walls decreases. So flow extremity due to thermo magnetic natural convection decreases. In $Ha = 100$, as partition height increases, average Nu can decrease by 25%.

Figures 7-(a) and (b) show left wall average Nusselt number versus inclination angle in $Ra = 5 \times 10^6$ for various Hartmann number: $Ha = 0, 50, 100$ and 150 with 1 and 2 partitions attached to horizontal wall (see Fig. 1-(b)).

These figures show that as the Hartmann number increases, heat transfer from vertical walls decreases. So flow extremity due to thermo magnetic natural convection decreases. That is, the application of a longitudinal magnetic field results in a force opposite to the flow direction that tends to drag the flow and as strength of the magnetic field is increased, convection is suppressed and the heat transfer in the enclosure decreases. As seen from these figures, with increase of inclination angle, Nu number firstly increases, but after $30^\circ$, it starts to decrease and also after $\varphi = 105^\circ$ Nu increases. In inclination angle about $\varphi = 90^\circ$, average Nu for one and two partitions has different trends (see figures 7-(a) and (b)). In case of two partitions, Nu has lowest value. But in case of one partition, Nu is oscillated and afterwards that increases to $\varphi = 135^\circ$. In this case, Nu in $\varphi = 90^\circ$ has local maximum. Also it's showed that in various $Ha$, average Nu versus inclination angle has same trend (see figures 7-(a) and (b) again).

Figure 8 shows overall entropy generation, heat transfer entropy generation and Bejan number in various inclination angle for various Ha and Ra = 5 × 10^6 with 1 and 2 partitions attached to horizontal walls. As seen these figures, as Ha increases, because the convection term becomes less effective, so heat transfer entropy generation (HTI) decreases. Therefore overall entropy generation (OEG) decreases too. Increasing in the value of Ha has a tendency to slowdown the fluid movement inside the cavity, thus Bejan number enhances. These figures show that overall entropy generation and heat transfer entropy generation diagram has same trend with the average Nusselt number diagram except in Φ = 90⁰ for one partition. In each inclination angle, as Nu increases, heat transfer entropy generation enhances and therefore overall entropy generation (OEG) increases. But Bejan number diagram has reverse trend with entropy generation diagram. As noted in Fig. 7, in inclination angle between 30⁰ and 45⁰, OEG and HTI diagram has maximum value in case of one and two partitions. The minimum value of OEG and HTI diagram is in inclination angle about 105⁰ for one partition and about 90⁰ for two partitions. Also in inclination angle about 60⁰, Bejan number diagram has minimum value in case of one and two partitions. The maximum value of Bejan number diagram is in inclination angle about 105⁰ for one partition, while it is about 90⁰ for the case of two partitions. In the other hand, in inclination angles which OEG and HTI diagram has lowest value, most of the contribution on overall entropy generation comes from the heat transfer irreversibility. So, Bejan number shows a higher value and in these angles, Be has maximum value.

But in local maximum of OEG and HTI diagram, OEG and HTI curves have more difference, so the effect of fluid friction entropy generation increases and Be decreases.

Isotherms and streamlines contours for Ra = 5 × 10^6 with 1 and 2 partitions attached to horizontal walls depicted in Figs. 9 and 10 for Ha = 0 and 150. It is shown that as Ha increases the convection term becomes less effective. As shown these figures, in inclination angle equal to 90° with 1 partition, two vertices are formed but with 2 partitions and also in other angles, one primary vortex is appeared in the enclosure. Also it is observed that in Φ = 0°, 45° and 135° in the middle of left wall and in the top of right wall thermal boundary layer is formed but in Φ = 90° for one partition, this boundary layer is diminished.

With comparing of figures 7 to 10 in Φ = 90°, it could be seen that with 1 partition the average Nusselt number diagram has local maximum, because in this case, the number of stream line loops in stream line contours changes to two loops and the average Nusselt number increases suddenly. But overall entropy generation in this case has low value and Bejan number in this angle has high value. So when we need local maximum in heat transfer, addition of the partition and rotating of cavity to 90° would be best method.

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Fig. 8. The effect of inclination angle on overall entropy generation (OEG), heat transfer irreversibility (HTI) and Bejan number (Be), Ra = 5 × 10^6, (a) - one partition attached to bottom wall, (b) - two partitions attached to horizontal walls.


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Fig. 9. Streamline contours for $\varphi = 0^\circ$, $45^\circ$, $90^\circ$ and $135^\circ$ in counterclockwise direction for $Ra = 5 \times 10^6$ for $Ha = 0$ and $150$; (a) - one partition attached to bottom wall, (b) - two partitions attached to horizontal walls.


Ha = 150 Ha = 0

(a) Isotherm Contours, One partition attached to bottom wall

φ = 90°
φ = 0°
φ = 135°
φ = 45°

(b) Isotherm Contours, Two partitions attached to horizontal walls

φ = 90°
φ = 0°
φ = 135°
φ = 45°

Fig. 10. Isotherm contours for φ = 0°, 45°, 90° and 135° in counterclockwise direction for Ra = 5×10⁶ for Ha = 0 and 150; (a) - one partition attached to bottom wall, (b) - two partitions attached to horizontal walls.

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