

## The Natural Convective Heat Transfer in Rectangular Enclosure Containing Two Inclined Partitions

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**Abstract:** The effect of putting two inclined partitions inside a rectangular enclosure on natural convection heat transfer rate was studied in this work. The problem was simulated in (ANSYS FLUENT) and solved numerically. The vertical walls were heated differentially to produce a constant Ra of  $(3 \times 10^5)$ . The continuity equation, momentum equations, Navier-Stokes and energy equations were used in solution. The results are represented as contours of isotherms and streamlines. The results show that the maximum heat transfer rate occur at  $(45^\circ)$  for each partition. It is more than the non-partitioned case by 1.15%. The minimum heat transfer rate occur at  $(90^\circ)$  for each partition. It is less than the non-partitioned case by 53%.

**Key words:** enclosure, inclined, partition

### 1. Introduction

It is very important to study the natural convection heat transfer inside rectangular enclosure, because of its wide use in many engineering applications such as solar energy systems, cooling of the electronic circuits, nuclear reactors cooling and many other applications. Furthermore, many researchers studied the effect of a various types of partitions inside the enclosure on the natural convection heat transfer rate.

Lakhal, E. K. *et. al.* [1] studied numerically the natural convection heat transfer in inclined enclosure with perfectly conducting fins attached to heated wall. It is found that heat transfer is affected by number of fins, inclination angle and height of fins.

Bilgen, E. [2] studied numerically a differentially heated square cavity, which was provided with a thin fin on the active wall. Mass, momentum and energy equations were solved numerically for natural heat transfer inside the cavity. The fin was assumed to be conductive. It was found that fin length and position affect the natural convection heat transfer. The heat transfer rate was minimum, when the fin was at the center or near the center. Also, fin conductivity has a significant influence on heat transfer rate.

BEN-NAKHI, Abdullatif [3] studied the problem of steady, laminar, natural convective flow of a viscous fluid in an inclined enclosure with partitions. A transverse temperature gradient was applied on the two opposing regular walls of the inclined enclosure, while the other walls were maintained adiabatic. Two adiabatic partitions are installed at the lower wall of enclosure. The results show that the heat transfer and the flow characteristics depended strongly on the partition height, Rayleigh number and the inclination angle.

Ben-Nakhi Abdullatif and Ali J. Chamkha. [4] studied numerically the steady laminar conjugate natural convection in a square enclosure with an inclined thin fin. The inclined fin is attached to the left vertical thin side of the enclosure while the other three sides are considered to have finite and equal thicknesses. The left wall of the enclosure to which the fin is attached is assumed heated while the external sides of the other three surfaces of the enclosure are cooled. The presence of an inclined thin fin reduces the average Nusselt

number. It was possible to control heat transfer through an enclosure by proper selection of both fin inclination angle and length.

GHASSEMI M. *et. al.* [5] investigated the effect of inclination angle on flow field and heat transfer in a differentially heated square cavity with two insulated baffles attached to its isothermal walls. The walls that make angle with horizontal are adiabatic. The governing equations were solved using finite volume method. It is found that the length and position of baffles and inclination angle of cavity affect the flow field and heat transfer rate. The presence of baffles decreases heat transfer rate. The heat transfer rate decreases as baffle length and inclination angle decrease.

Sarkar Aryan *et. al.* [6] investigated the natural convection in partitioned enclosure and its control by choosing the location and size of partition. The vertical walls of square enclosure were isothermal, whereas, the horizontal walls were assumed to be insulated. The partitions were also considered to be insulated. The test model had two partitions on each horizontal wall to study the effect of partition size on natural convection. An alternative partition on lower or upper horizontal walls was used to study the effect of partition location on natural convection. The results show that the increase of partition height causes low heat transfer. When the partition on the top walls shifts towards the hot wall, heat transfer was increased. Similar features were observed as the partition on the base move towards the cold wall.

Alhazmy Majed M. [7] investigated numerically a new approach to suppress the convection currents inside a cavity by inserting dividers (partitions). The partitions divide the cavity into several triangles producing a string of small convection cells. The mass, momentum and energy equations are solved for partitioned square cavity. The partitions are conductive and its ends are in perfect contact with the walls. The vertical walls are assumed to be isothermals and the horizontal walls are assumed to be insulated. The results show that the heat flux transported across the partitioned cavity depends on the number of partitions and their conductivity. The heat flux through the cavity, decreases as the number of partitions increases.

Amin Habibzadeh *et. al.* [8] investigated the natural convection heat transfer in partitioned square cavity. The vertical left and right walls are considered as the hot and cold walls, respectively. The partition was put at lower edge and assumed to be adiabatic. The influence of position of partition and its height were studied. The working fluid was  $Al_2O_3$  water nanofluid, which was considered a newtonian incompressible fluid. It is found that the heat transfer rate increases as the partition approaches the cold wall. The results show that increases in height of the partition causes decreases in heat transfer rate, and the average Nusselt number is maximum when the partition is located at the center of lower wall.

Yousefi T. *et. al.* [9] studied free convection heat transfer in a partitioned cavity. The partition is assumed to be adiabatic and its angle ranging from  $0^\circ$  (horizontal) to  $90^\circ$  (vertical). The horizontal walls of cavity are adiabatic while the vertical walls are differentially heated. The results show that the inclination angle of the partition has a significant effect on heat transfer rate. The maximum and minimum heat transfer occurs at the angle of  $45^\circ$  and  $15^\circ$ , respectively.

Ahmed Abdul Ameer Abdul Raheem and Hussain Y. Mahmood [10] investigated experimentally the laminar natural convection heat transfer in a rectangular enclosure fitted with a vertical partition. The partition was oriented parallel to the two vertical differentially heated walls, while other walls were insulated. One of the parameters which were considered in experiments was partition inclination. It is found that the effect of inclination of partition towards the cold wall differs from its effect towards the hot wall. In general, the inclination angle has a clear effect on heat transfer rate.

An enclosure having two baffles was the test model of Mushatet, Khudheyer S. [11] who investigated numerically the turbulent natural convection inside his test model. The two baffles were considered as conducting material. A finite volume method was used to solve Navier-Stokes using (SIMPLE) algorithm. The results show that the heat transfer rate increases as the angle of inclination increase, that is due to increasing of horizontal and vertical velocities inside the enclosure. Also the number of vortices and their shapes and elongation were affected with the angle of inclination, baffles height and distance between baffles.

Ghazian Osameh *et. al.* [12] investigated experimentally the natural convection heat transfer in a partially partitioned enclosure. The top and bottom walls were isolated while one of the vertical walls was heated isothermally. The partitions were assumed to be adiabatic and are attached to the heated wall with angles changing from 30° to 150°. The results show that the inclination angle of partition affects significantly the heat transfer rate.

The aim of this work is to study the effect of two inclined partitions on the heat transfer rate inside a rectangular enclosure. The idea of this work was taken from Yousefi T. *et. al.* [9], dividing the single partition to two equal length partitions. Also, the dimensions of cavity are the same as in Yousefi T. *et. al.* [9].

## 2. Analysis

The sketch in fig.(1) shows the geometry of the problem of this work. The problem is a rectangular enclosure with two partitions. Each partition is to be tilted by different angle about its midpoint. The two partitions have equal lengths of ( $l$ ) and width of ( $w$ ) for each one. The side length of enclosure is ( $H$ ), the tilt angle for the upper partition is  $\theta_{up}$  and the tilt angle for the lower partition is  $\theta_{lo}$ . In this work, ( $H$ ) was fixed to be (0.05 m).

The working fluid was assumed to be Newtonian having constant physical properties except for the density that is assumed to be temperature dependent according to the Boussinesq approximation. Other assumptions include two dimensional steady incompressible laminar flow. Heat transfers from the hot wall to the cold wall by natural convection through the working fluid which is air (in this work). The governing equations for the conservation of mass momentum and energy are those of Navier-Stokes along with the energy equation which are:

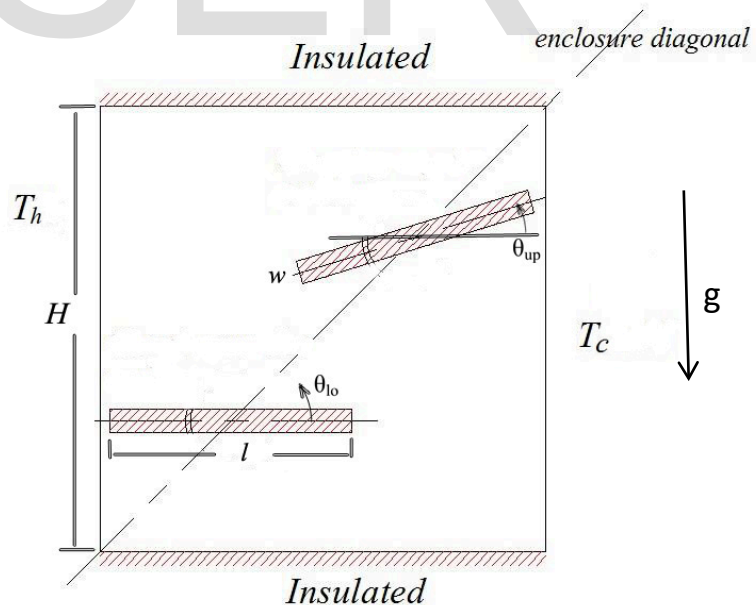


Fig.(1) Physical model and boundary conditions

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

$$u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\mu}{\rho} \left( \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) \quad (2)$$

$$u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \frac{\mu}{\rho} \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) \quad (3)$$

$$u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = \alpha \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) + \frac{\dot{q}}{\rho c_p} \quad (4)$$

The parameter assessed was Rayleigh number:

$$Ra = \frac{g \cdot \beta \cdot (T_h - T_c) \cdot l^3}{\nu \cdot \alpha} \quad (5)$$

The temperature values of vertical walls were selected to obtain a constant Rayleigh number of  $(3 \times 10^5)$ .

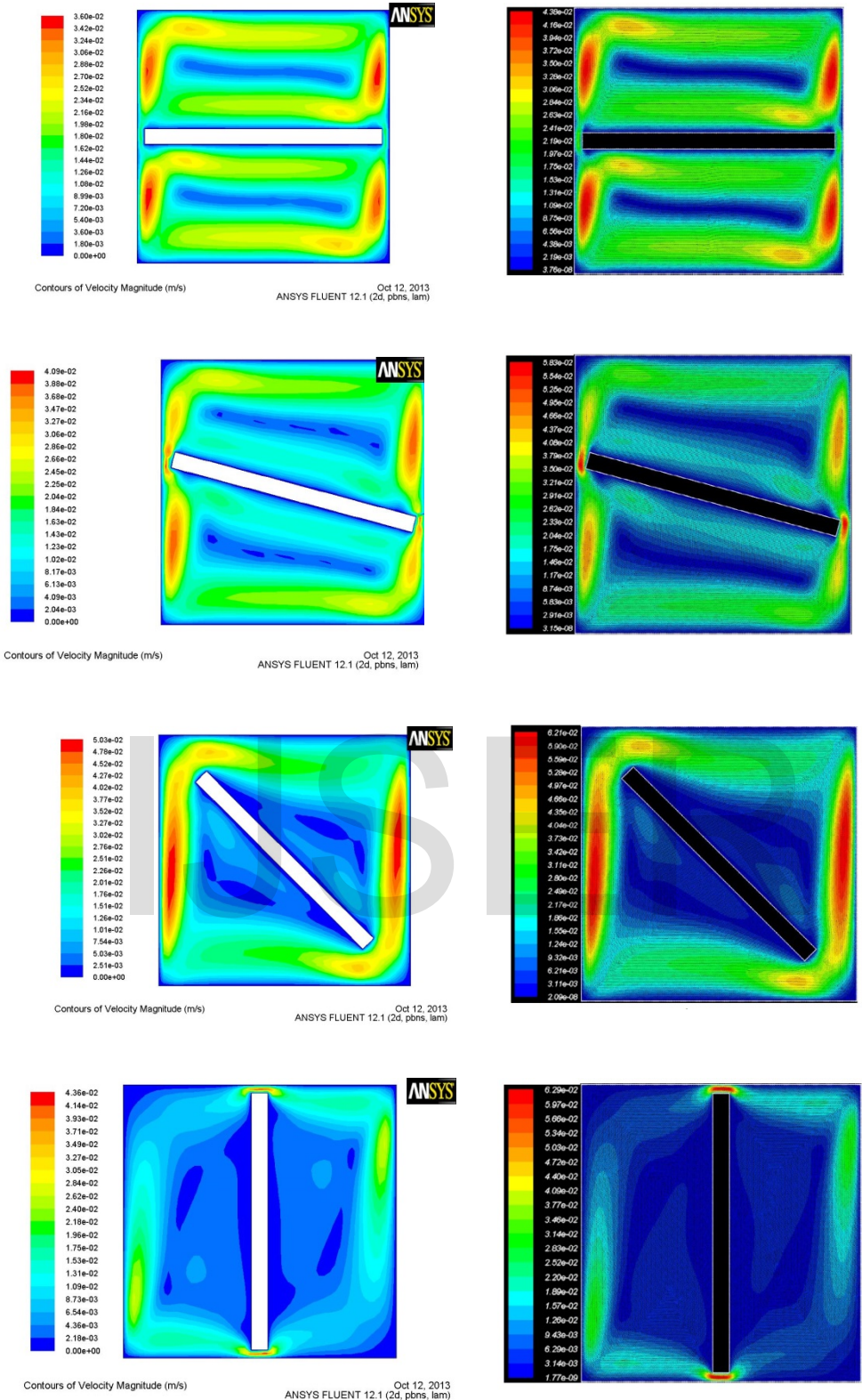
### 3. Boundary conditions

Fig.(1) also, shows the boundary conditions. There are no slip conditions on the walls of the enclosure. The vertical walls were assumed to be isothermal such that the left wall was at  $T_h$  and the right wall  $T_c$ . Horizontal walls were insulated while partitions were assumed to be adiabatic. Partitions were fixed on the diagonal of enclosure as shown in fig (1).

Equations (1) to (4) with their respective boundary conditions are solved by (ANSYS FLUENT) CFD software. The solution of the model will give the temperature and velocity fields hence total heat flux across the cavity and flow streamlines.

### 4. Algorithm validation

The solution algorithm has been validated by considering the experimental results of Yousefi T. *et. al.* [9]. The velocity contours (which was obtained experimentally) of Yousefi T. *et. al.* [9] at  $Ra$  of  $(3 \times 10^5)$  for different inclined angles was repeated numerically using the software (ANSYS FLUENT). As shown in fig.(2), there is great agreement between both results.



Numerical (ANSYS FLUENT)

Yousefi T. *et. al.* [9]

Fig.(2) Algorithm validation

## 5. Results

The principle of this study was to keep one of the partitions (upper partition at first) at a specified angle between ( $0^{\circ}$ - $165^{\circ}$ ) then changing the inclined angle of other partition in range between ( $0^{\circ}$ - $165^{\circ}$ ). The same steps are repeated alternately between upper and lower partitions.

From fig.(3-a), it can be noticed that the working fluid is continuously moving from hot wall to cold wall. The fluid passes through both gaps in upper right zone and lower left zone. In spite of the smallness of those gaps, there are no vortices except two weak vortices in the mid zone.

The isotherms are skewed lines which are illustrated in fig.(3-b). Since the isotherms lines are collective near both hot and cold walls, the heat transfer is shown to be by natural convection.

Fig.(3-c) shows some detained fluid in the upper left zone forming a main vortex. This causes a slow motion near the cold wall and non-uniform behavior.

Isotherms in fig.(3-d) show some zones containing straight and parallel lines which indicate conduction heat transfer at these zones.

Fig.(3-e) shows the stream lines for the angle of ( $90^{\circ}$ ) for both partitions. That position causes formation of two main vortices in the upper left side and lower right side respectively.

The previous case leads to make heat transfer more difficult because of weakness of heat transfer between vortices. That means less heat transfer from hot wall to cold wall.

It can be seen many parallel isothermal lines in fig.(3-f) mainly, at the center of enclosure. In addition, there are some parallel isotherms in the upper right and lower left corners. This illustrates that there is a great amount of heat transfer by conduction.

Fig.(3-g) exhibits a main vortex formed at the lower right side (lower point of cold wall). That vortex detains the working fluid at that zone. For this reason, the fluid finds it difficult to reach to the hot wall, which leads to irregular on a slow movement towards cold wall.

Isotherms in fig.(3-h) curves has some parallel sections which indicate a percent of heat is transferring by conduction.

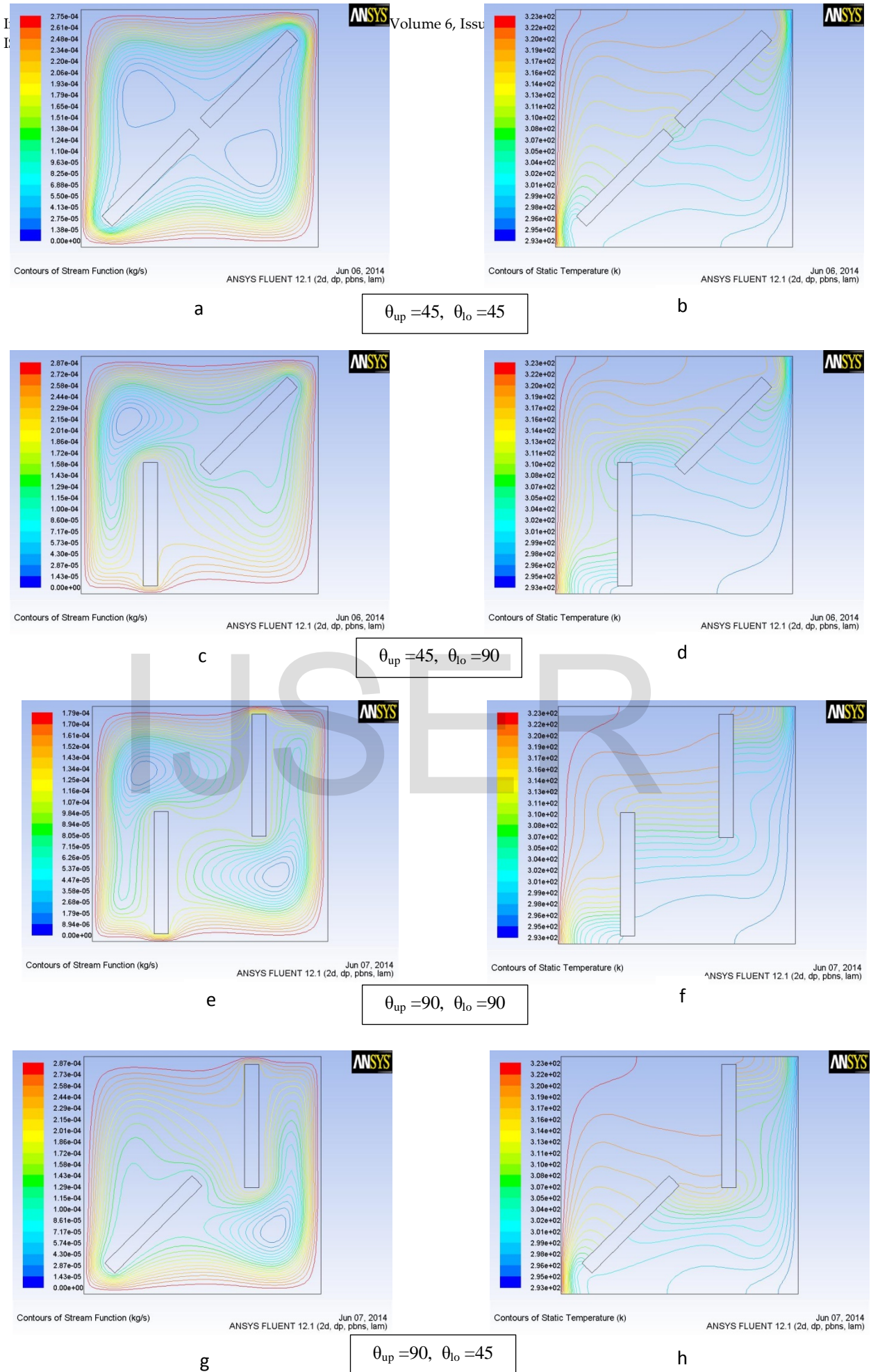


Fig. (3) Streamlines and isotherms of partitioned case

### 6. Discussion

The greatest amount of heat transfers when the position of each partition is (45°). That is because availability of one main vortex occupied whole enclosure space. That vortex formed due to natural convection currents which lead to transferring heat from hot wall to cold wall.

A smallest amount of heat transferred when the inclined angle of each partition is (90°). This position causes the formation of two main vortices which lead to minimize heat transferred from hot wall to cold wall.

The comparison between partitioned case with non-partitioned case (non-partitioned case shown in fig.(4)) reveals that the heat transfer rate in the partitioned case of (45° for each partition) is a little bit more than the heat transfer rate in non-partition case. That is because, the gaps in upper right corner and lower left corner help to increase the velocity of air. The increase of air flow velocity leads to increase the heat transfer rate. The heat transfer rate in all other partitioned cases is less than its value in non-partitioned case.

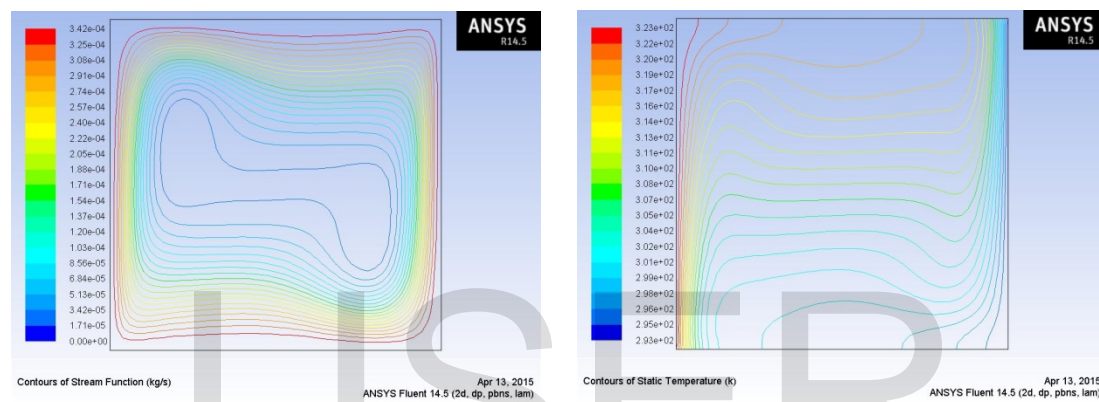


Fig. (4) Non partitions case

The effect of changing inclination angle of both partitions is shown in fig.(5), the heat transfer curves seems as if it is sinusoidal curves. It is clear that curve of lowest heat transfer occur when the angle of one of partitions is (90°) for all angles of other partition. The curve of highest heat transfer occurs when the angle of one of the partitions is (45°) for all angles of other partition.

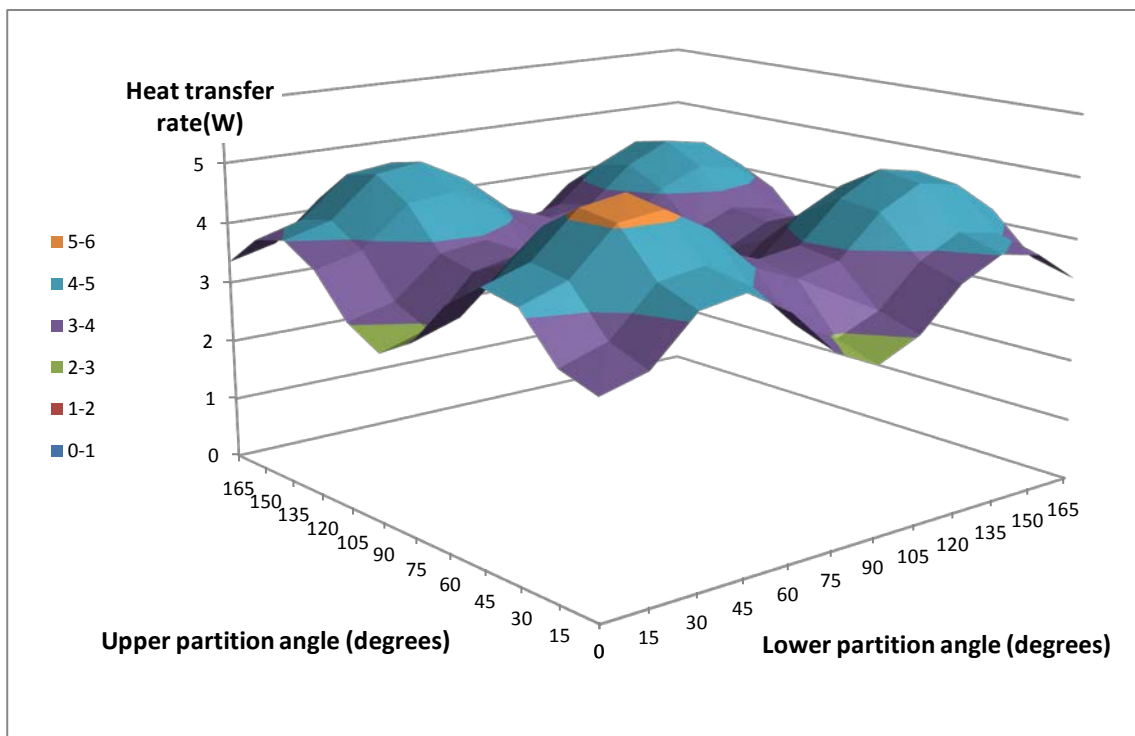


Fig. (5) Effect of inclination angles of partitions on heat transfer rate



## 7. Conclusion

The effect of two inclined partitions on the natural convective heat transfer rate inside a rectangular enclosure was studied. The conclusions were outlined in the following:

- \* The maximum heat transfer rate occurs at a position of inclined angle of ( $45^\circ$ ) for each partition. It is higher than even non-partitioned case by 1.15%.
- \* The heat transfer rate decreases in other positions of partitions.
- \* The minimum heat transfer rate occurs at the position of inclined angle of ( $90^\circ$ ) for each partition. It is less than its value at non-partitioned case by 53%.
- \* The heat transfer rate can be controlled by changing the inclined angle of partitions.

This work is a very small contribution to the field of studying the effect of availability of obstacles and baffles on convection heat transfer inside cavities and enclosures. This field is one of engineering fields which may serve and enrich a lot of industrial and thermal engineering application.

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