

# Numerical Analysis on Natural Convection in a Square Enclosure with Thin Baffles on Vertical walls at Different Positions

Sanat Kumar<sup>1</sup> H C Thakur<sup>2</sup> Prashant Gill<sup>3</sup>  
Department of Mechanical Engineering  
Gautam Buddha University  
Greater Noida, India

**Abstract**— Natural convection is the mode of heat transfer which occurs due to the existence of temperature gradient. It didn't require any external agent such as fan, pump and blower; it not only saves energy but avoids unwanted noise. Enclosure is a square segment which is a regular geometry, found in a number of applications such as a fully filled duct pipes, electronic systems, computer technologies, air conditioning applications, lubrication system, solar collector, a sheet metal covered store, a solar air heater and a compact plate heat exchanger etc.

The current study investigates laminar natural convection in a square enclosure with isothermal vertical walls along with two thin baffles at different positions on them and with adiabatic base and top of the enclosure. The domain is filled with air. This two-dimensional study focuses attention to understand changes in flow and temperature field development due to variation in position of baffles for each cases of Rayleigh number varies. The flow behaviour and thermal characteristics have been investigated in different cases through streamlines and isotherms respectively. Complete domain has been chosen for analysis. Asymmetric solutions are also observed for some of the cases. These results are confirmed by development of the corresponding convection loops and also by the variation of Average Nusselt number. Finally, the thesis report summarizes the effects of different parameters on rate of heat transfer.

**Keywords**—Natural Convection; Square enclosure; Baffles; Laminar flow; Nusselt Number; Rayleigh Number

## I. INTRODUCTION

Convection is that the mode of warmth energy transfer between a solid and fluid interface. Convection phenomenon occurs when a temperature difference exists between solid surface and fluid flowing on it. It is affected by the circulation or mixing of the fluid which may be gas or liquid. So it is the combined problem of conduction with fluid flow and mixing. The convective heat transfer is importance to the problems in industrial application. The flow of liquid or a gas through a device called heat exchanger, two phase flow within the boilers and condensers, cooling of electronic chips, heat removal from the condenser of refrigerator are some common examples of convective heat transfer.

## II. LITERATURE REVIEW AND OBJECTIVE

### A. Literature Review

A large number of research work focused on the analysis of buoyancy driven flow in regular enclosures. In which, Wu et al. [1] studied the laminar natural convection effect of top and bottom wall temperatures in an air-filled square cavity. Varol et al. [2] studied the effect of inclination angle on the natural convection in composite walled enclosure. The conductive heat transfer phenomenon investigated through each part of a composite wall for different solid wall thicknesses and thermal conductivities. Alam et al. [3] investigated numerically in rectangular enclosure with the partially heating and cooling of the vertical wall. Jabbar et al. [4] studied the effect of baffles inside square enclosure for different lengths of baffles at two positions and found that baffles helps in increasing and decreasing the rate of heat transfer. Tzeng et al. [5] completes its work by applying an operative and competent method, called Numerical Simulation-Aided Parametric Analysis (NSAPA), it is used develop simple and accurate correlation formulae for a natural convective flow system in roof top triangular enclosure. Kent [6] analyzed the natural convection in the isosceles triangular enclosure with cold base and hot inclined walls. Junqueira et al. [7] observed the phenomenon of steady natural convection flow in heterogeneous rectangular enclosure filled with a fluid and containing uniformly dispersed, conducting, fixed and disconnected solid blocks. The aspect ratio of enclosure is varying from 0.25 to 4, the Rayleigh number is taken from 105 to 108, and the value of Prandtl number is unity. Natural convection phenomenon is confirmed with the average Nusselt number.

Research for past few years has shifted its focus study natural convection in enclosure having different shaped internal objects or within it. It represents many practical problem applications. The presence of different shapes of objects inside the enclosure has significant effects on the patterns of fluid flow and heat transfer characteristics [8-11]. Cesini et al. [8] studied the case in which a single cylinder is inside the rectangular enclosure, effect of Rayleigh number and geometry on heat transfer is considered. Nakhi and Chamkha [9] works to predict numerical analysis of natural convective fluid flow in a square enclosure which contains an inclined heated thin fin of indiscriminate length attached to the hot wall is considered. Result confirm that average Nusselt

number of the heated wall including the fin affected significantly with the Rayleigh number and the thin-fin inclination angle and length. Baranwal and Chhabra [11] explored the effect of Prandtl number on the laminar natural convection heat transfer with Newtonian fluids inside square enclosure consisting of two cylinders i.e. one hot circular cylinder and other cold circular cylinder. Regular geometries are modified to achieve higher heat transfer rate so irregular domains are developed and analyzed [12-18].

**B. Objective**

The objective of the current study is to analyze natural convection inside square enclosure and effect of positions baffles on rate of heat transfer with varying Rayleigh number in enclosure at laminar conditions. To conduct research with saturated condition so steady state is considered.

**III. PROBLEM FORMATION AND RESEARCH METHODOLOGY**

The study domain is a two dimensional square cavity enclosure for dimensions ( $L^2=30*30 \text{ cm}^2$ ) with partial partitions as shown in Figure 1. It is an enclosure confined by isothermal sides on both left and right directions. The adiabatic surfaces are at two horizontal directions. The square cavity is partly heated, the right and the left isothermal walls are at  $T_H$  and  $T_C$  Respectively, while horizontal walls are isolated. Thinly insulated baffles are attached to the sidewalls at a height  $h$  from horizontal walls. Two different baffle configurations are considered. Within the first case, the baffle in the hot side is at higher position from baffle in cold side, and position of the upper baffle from the ceiling enclosure and lower location of the baffle from the bottom enclosure is the same. In the second case, the cold wall contained the top baffle and hot wall contains the bottom baffle with air as a working fluid in this study.

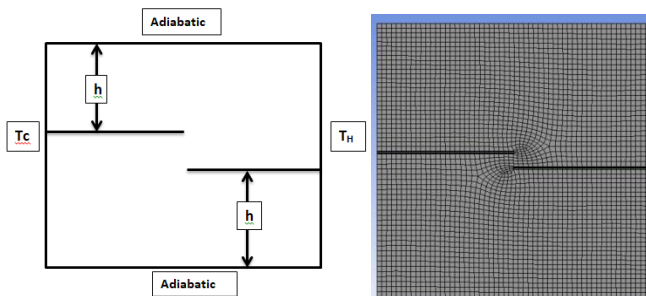


Figure 1: Physical model of geometry and Typical Meshing.

The problem is solved using the ANSYS (Fluent) 2021R1 student version software. The momentum and heat transfer for the problem involving convection and diffusion are governed by the Navier-Stokes partial differential equations which are available in text books on heat transfer and fluid dynamics. For this problem, the flow is assumed to be two dimensional, steady, laminar and incompressible. Viscous dissipation is neglected and thermo- physical properties are assumed to be constant, except for density in the buoyancy term where Boussinesq approximation is applied.

Table 1: Basic dimensions of baffles and range of temperatures used in work.

Model Arrangement		
Thickness of Baffles	0.3cm	0.3cm
$h$	(14,12,10,8,6,4,2)cm	(14,12,10,8,6,4,2)cm
$T_H$	(313, 333, 353, 373)K	
$T_C$	300K	
$Ra$	( $3.004 \times 10^6$ , $6.741 \times 10^6$ , $9.635 \times 10^6$ , $1.1875 \times 10^7$ )	
$L (l + \bar{l})$	30 (15+15) cm	

With these assumptions, the governing equations are represented in the following form:

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

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

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \nu \left( \frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + g\beta(T_h - T_c) \tag{3}$$

$$\frac{\partial T}{\partial t} + u \frac{\partial T}{\partial x} + v \frac{\partial T}{\partial y} = k \left( \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} \right) \tag{4}$$

$$Ra = \frac{g\beta(T_h - T_c)L^3}{\nu\alpha}, Pr = \frac{\nu}{\alpha} \tag{5}$$

Boundary conditions associated with the above governing equations are given by On the left vertical wall,  $u=0, v=0$  and  $T=T_L=T_C$  and On the right vertical wall,  $u=0, v=0$  and  $T=T_H$ . The above set of governing equations along with the corresponding boundary conditions is solved by finite volume method (FVM) in commercially available software, ANSYS (Fluent). The SIMPLE algorithm proposed by Jabbar [4], has been used for pressure velocity coupling while momentum and energy equations are discretized by second order upwind technique. The obtained solutions are calculated in terms of overall Nusselt number.

**A. Flow Pattern And Temperature Distribution**

Numerical experiments are carried out to study the phenomena of natural convection in a square enclosure. The numerical results for the flow and thermal fields at various Rayleigh number and location of baffles are observed through the streamlines and isotherms respectively.

In case 1 when the upper baffle is linked to a hot wall (see Figure 2). The free convection currents manifest a primary

cell consisting of three regions according to intensity, which leads to circulatory movement of the fluid resulting from buoyancy effects and it extending th These contours of streamlines shows the flow of air inside the enclosure as in Figure 2 as the gap between both baffles increases there is intense rise in fluid velocity between them. The stagnation zones are at the end of baffles, but they are of different intensity, and first decreasing and then increasing as the gap between baffles increases. At ( $h= 14$  cm) of the baffle on a hot and cold wall, the strong vortex started above and below the baffles and shafted between the middle of baffles of the enclosure. As the gap between the obstruction or baffles increases ( $h= 12$  cm) the vortex begins to converge in the gap between baffles. In the area at the middle of each baffle and adiabatic wall, the strength of convection decreases as the size of this area decreases, therefore it results to compose vortexes. While at ( $h= 10, h= 8$  cm) the vortex takes the same shape and dimension, where it gives an interpolated image within the space to be distribute for the streamlines. Then the strong vortex converges in the middle of enclosure as the gap between the obstacle increases from ( $h= 6$  cm) to ( $h= 4$  cm). As a result, the strength of convection increases between two baffles but it deceases between baffles and adiabatic walls. The difference in zone space of the Confined fluid and the most value of absolute stream task to be done with increasing Rayleigh number so that the internal roll inside the vortex evolves and earns strength and will be deformed. When Rayleigh number increases, the streamline is more effective towards the horizontal walls, this shows that the flow moves quicker as more intensified for the natural convection.

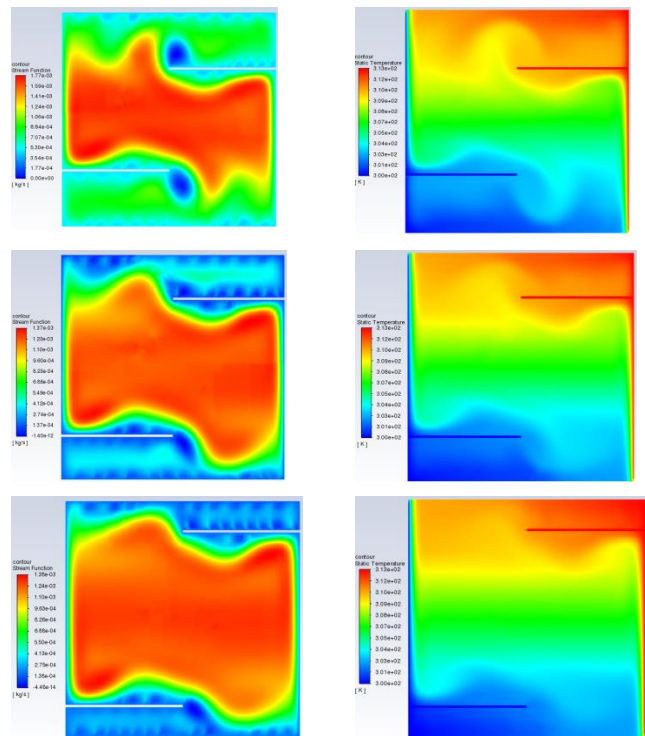
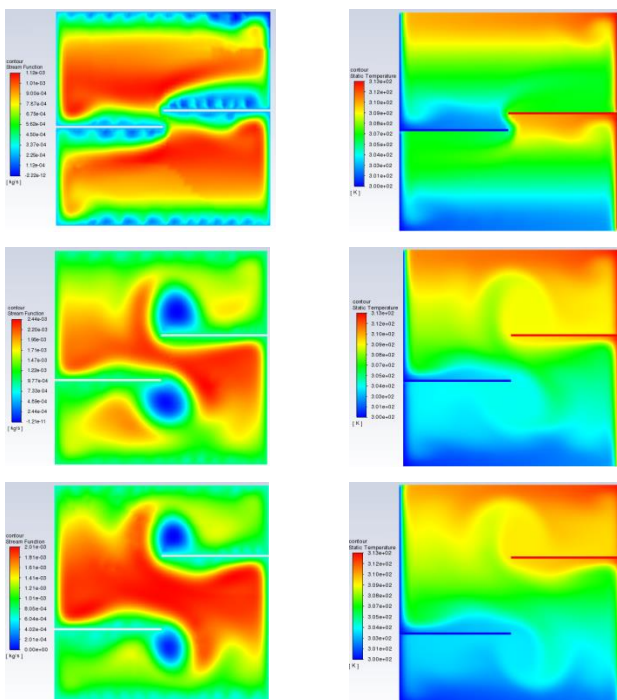


Figure 2: Streamlines(left) and Isotherms(right) at  $Ra= 3.004 \times 10^6$

Figure 2 represents the isotherms(right) of case 1, when the baffle connected to hot wall is at upper position and the baffle connected to the cold wall is at lower position, the low heat transfer areas are the low isotherms concentration regions (epitome the region lower to both baffles at the bottom of enclosure). The red zone above and blue zone at bottom in the contour shows that the natural convection is taking place efficiently due to density difference of air i.e. buoyancy. As if we change the aspect ratio of enclosure then the convection loops will be formed that denotes the natural convection. It is also noticed that as the height of baffle attached to hot wall increases versus decrease the barrier height tied to the cold wall i.e. as the gap between the baffles increases, in the top portion along the top wall, isotherms are dense that mentions high rate of heat transfer at this zone. This can observe highly for different heights from ( $h=14$  cm) to ( $h=4$  cm), also isotherm be more congested and the thermal boundary layer becomes more intensive along the middle zone, and also in the bottom area below the baffles. An else trait of this temperature style is that the streamlines become more crowded nearer to the side wall when the rising of  $Ra$  for both  $h$  values, since the intensity of the natural convection increases.

In case 2, when the baffle attached to the hot wall is below the baffle attached to the cold wall given in Figure 3. It is observed that there is a separation of fluid into two vortexes i.e. one above the baffle attached to hot wall and the other below the baffle attached cold wall and both baffles incarcerating the fluid in its bore i.e. between bottom confined fluid and top confined fluid. The regions between the baffle or restriction on hot wall and the bottom adiabatic wall as well as the region confined between baffle or restriction on cold wall and the top horizontal adiabatic wall forms two vortexes as shown in Figure 3 ( $h= 14$ ) that confirms the continuity, one



turned in the direction of bottom horizontal wall and other turned in the direction of top horizontal wall. It is due to the powerful natural convection in the top and bottom portion of enclosure. The separation of two vortices is due to the fluid stagnated between both baffles.

As the separation between both baffles i.e. one attached to hot wall and other attached to cold wall increases then the stagnated vortex formed by the fluid between both baffles begins to increase as shown in Figure 3 from ( $h=14$  cm) to ( $h=10$  cm) and then divides into two vortices, one towards baffle attached to hot wall and other towards the baffle attached to cold wall as shown in Figure 3 from ( $h=8$  cm) to ( $h=4$  cm). It has been observed from the contours of stream lines that they are almost symmetric in nature. As streamlines shows three vortices, as the separation between the baffles increases then upper and lower vortex are approaching towards each other and forms one bigger vortex in middle of the baffles of enclosure as shown in Figure 3 ( $h=8$ ) to ( $h=4$ ). At low Rayleigh number weak vortices are created and as we increases the Rayleigh number these vortices are begins to reinforce and strong vortices are begin to appear.

The temperature isotherms in three regions on increasing Rayleigh number and separation between the baffles. Due to the buoyancy effect in the square cavity the fluid in contact with hot vertical wall moves up or towards the top adiabatic wall and the fluid in contact with cold vertical wall moves down or towards bottom adiabatic wall. This confirms the effect of powerful natural convection inside the square enclosure or cavity. As the hot wall baffle moves downwards and cold wall baffle moves upward then both cold and hot regions respectively begin to reduce at those locations and begins to distribute in the middle region of the enclosure or region between both baffles.

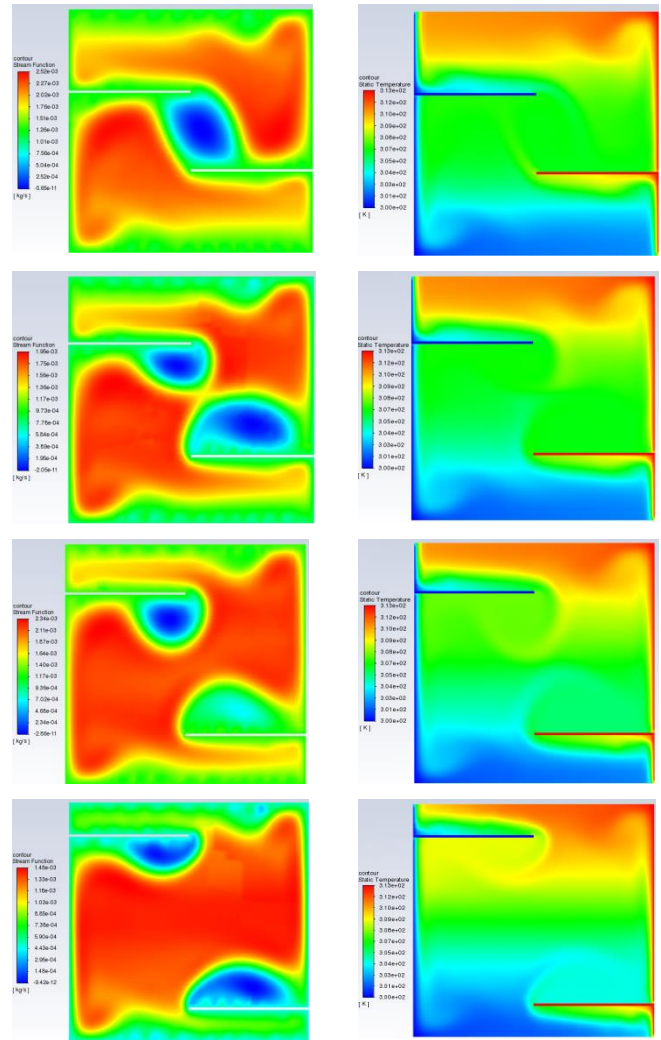
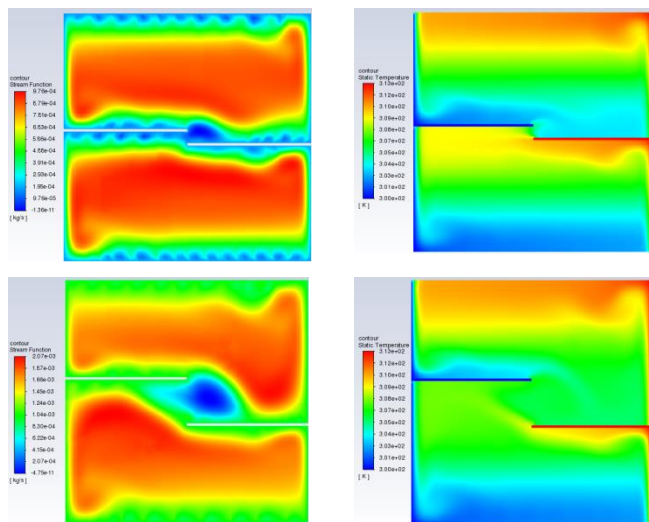


Figure 3: Streamlines(left) and Isotherms(right) at  $Ra= 3.004 \times 10^6$



#### IV. RESULT AND DISCUSSION

The comparative analysis of the rate of heat transfer in case 1 and case 2. As we increases the Rayleigh number then Nusselt number also increases in both cases but increase in case 2 is larger than increase in case 1. This shows that for case 2 in which baffle attached to hot wall is below the baffle attached to cold wall has much efficient convection due to effective turbulence created by the baffles in that condition and increase in Nusselt number then in case 1 in which baffle connected to cold wall lies below the baffle connected to hot wall.

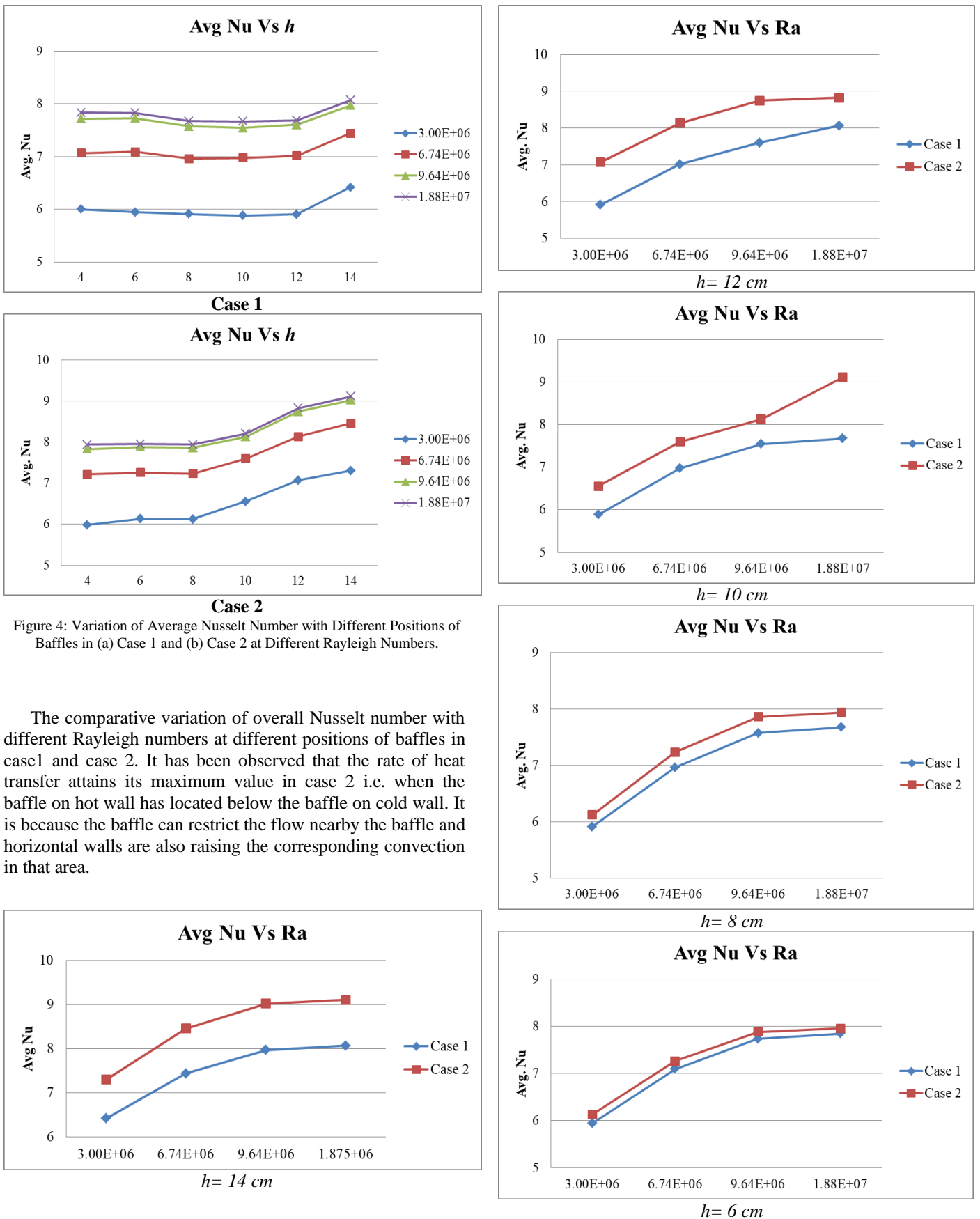


Figure 4: Variation of Average Nusselt Number with Different Positions of Baffles in (a) Case 1 and (b) Case 2 at Different Rayleigh Numbers.

The comparative variation of overall Nusselt number with different Rayleigh numbers at different positions of baffles in case1 and case 2. It has been observed that the rate of heat transfer attains its maximum value in case 2 i.e. when the baffle on hot wall has located below the baffle on cold wall. It is because the baffle can restrict the flow nearby the baffle and horizontal walls are also raising the corresponding convection in that area.

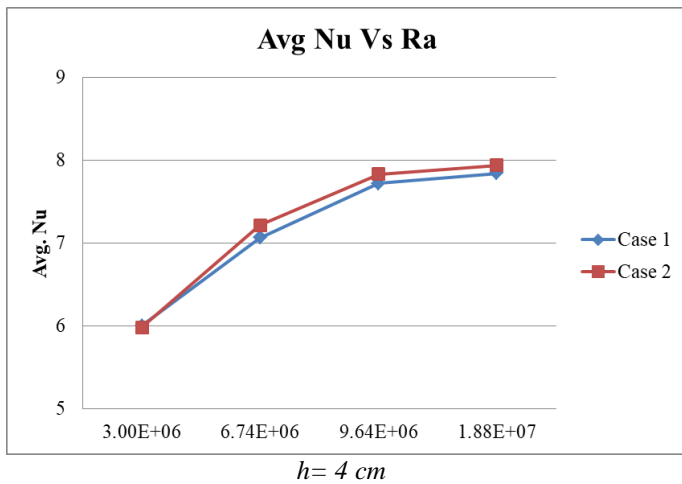


Figure 5: Variation of Average Nusselt number with different Rayleigh number at different locations for Case 1 and Case 2.

### V. CONCLUSION

Enclosures are used in a wide range of engineering applications such as sheet metal covered store, living, rooms, solar collector, lubrication systems, cold storages, solar air heaters, electronic cooling units, computer systems, heat exchangers, air conditioning, duct pipes, etc. This type of analysis has practically applied in the electronic systems in which electronic circuit plate inside Central Processing Units in hot condition in which the heating circuit is almost vertical. This study studies the steady state behaviour of natural convection and variation of heat transfer with variation in Rayleigh number with variation in position of baffles. The advantage of simulation is that it tells about the best position of baffle which provide maximum and minimum heat transfer rate with the variation in Rayleigh number.

Numerical steady state study of natural convection for two baffles in a square enclosure has been performed in detail. Flow pattern and Isotherms have been drawn of horizontal baffles for different positions and Rayleigh number which are varying from ( $h=14$  to  $h=4$ ) and ( $3.004 \times 10^6$  to  $1.875 \times 10^7$ ) respectively.

In study state analysis it has been observed that the average Nusselt number increases on increasing Rayleigh number and when the separation between the baffles increases then average Nusselt number decreases and when the separation between baffles decreases the average Nusselt number increases for all cases.

### NOMENCLATURE

$H/L$	Aspect Ratio	--
$g$	Gravitational acceleration	$[m/s^2]$
$Ra$	Rayleigh Number	--
$K$	Thermal Conductivity	$[W/m-K]$
$Nu$	Overall Nusselt Number	--
$Pr$	Prandtl Number	--
$h$	Height of Baffle top and bottom wall	cm
$L$	Length of Enclosure	cm

$l$	Length of baffles	cm
$T_H$	Higher Temperature of Cold vertical wall	$^{\circ}C$
$T_C$	Lower Temperature of Hot vertical wall	$^{\circ}C$
$u, v$	Velocity component at x direction and y direction	m/s
$T$	Temperature	$^{\circ}C$
$\alpha$	Thermal Diffusivity of fluid	--
$\beta$	Coefficient of volumetric expansion of fluid	--
$\nu$	Kinematic viscosity of fluid	--

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