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Study of Natural Convection Inside Corrugated Enclosure Containing Heated Thin Rectangle Plate

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ABSTRACT: A numerical investigation of heat transfer has been done in a corrugated cavity with heated thin plate which located at different vertical locations and different angles. The enclosure with five corrugated numbers ,and its wall temperature (Tc), and the insert body surface maintained at a constant temperature (Th). A two-dimensional solution for steady laminar flow is obtained by solving governing equations by (ANSYS 16.0). The present natural convection study is carried out based on the values: Rayleigh number ($10^4 - 10^6$), sinusoidal cylinder base radius ratio to plate length ($0.25 \le l/R \le 0.5$), and the inclination angles varied ($0 - 90^0$). The results indicate that at high (Ra) number and the ratio l/R =0.5, have significant effects fluid flow strength (i.e $\overline{NU}_m$ increases by 0.536%), Also the internal body must move downward when the heated plate at angle 90^0 with vertical direction to maximum increase in fluid flow strength.

KEYWORDS: Natural Convection, Laminar Flow, Isothermal cylinders, Rayleigh Number, Finite Volume, Simple Method, corrugated cavity.

INTRODUCTION

There is an infinite number of heat transfer problems and one of those natural convection problems in the cavity through a differentially heated, which has received considerable attention in recent years this problem either enhancement or depression of heat transfer mechanism. This attention because of the main principle of this phenomenon and it has multiple applications has clearly significance in industrial applications such as the field of thermal engineering, heat exchangers, electronic device cooling, and storage of radio–active wastes, drying technologies, etc. The fluid field and heat flow of natural convection in cavity was investigated in numerous numerical and experimental studies ,this studies was aims either enhancing or depressing the heat ,some investigators have deal the convection inside an enclosure that includes a fixed on the sidewall a single or set of fins in different locations or using a cylinder (stationary or rotating), square ,rectangle ,etc .While the other approach focusing in the modified the enclosure with changing its characteristics. A group researcher investigated numerically heat transfer flow by using Control Volume based Finite element Method [1].

A free space between circular cavity and a hot surface cylinder filled by nano fluids in the effects of magnetic field. The governing equations are solved for laminar, two dimensional, incompressible. The results are shown in the forms of flow lines, isotherms plots and for a wide range of Rayleigh numbers, Hartmann number, undulations number of hot cylinder , and volume fraction of nanoparticle. They have found that the behavior of the system critically depends on parameter including nanoparticle volume fraction, the result show that the $\overline{Nu}$ is strongly dependent and functionally increased with undulations number volume fraction of nanoparticle. A group researcher made analysis of heat flow in enclosure profile circular ,and its wall assumed cold and having a hot corrugated inner cylinder [2]. In this work ,the free region between the fitted internal sinusoidal cylinder and externally enclosure filled by air as working fluid . The equations that described the flow behavior and heat mechanism. The solutions done for achieved for wide range of Ra, amplitude of corrugations and inner cylinder undulations number of the sinusoidal. The examined show the number of formation vortex and its size are sensitively of Ra , undulations and the amplitude.

Shohel et al. An numerically studies have been finalized to analyzed the effect of(Gr) on the natural convection problem inside the enclosure (i.e flow and heat transfer), in this problem the vertical walls of enclosure assumed isothermally, and wavy-walled bounded by two adiabatic straight walls [3, 4]. Made a study, in triangular enclosure by assume the problem laminar and natural convective at steady state heat flow .Heat transfer studied around concentric cylinder insert inside the cavity and the equations solved by (FVM).The simulation covered different parameters :Ra, aspect ratio , and wide range of inclination angles. The results displayed when the aspect ratio stay constant ,the geometry and slop angle there are no sensitively effects on the heat transfer rate. A thin thickness fin and baffle placed in major enclosure horizontally to hot vertical left side wall for different shapes of enclosures (i.e) a rectangular and square were computed respectively [5,6].

This investigation proved there is a decreasing in average value of Sherwood number ,and its function of aspect ratio, also they found $\overline{Nu}$ rising as functional of (Ra). Some researcher examined the flow and heat transfer within spherical containers the effect of isothermal and insulated baffles with thin thickness on pseudo natural convection at steady-state case, also observed [7]. A studied experimentally flow and heat transfer inside concentric annuli which fixed horizontally ,for both two cases forced and free convection heat transfer process described for laminar air flow with thermally developing and fully developed [8]. They were obtained the (Nu) is significantly larger for developing if compared with the results for fully developed flow of the annulus .The aim of the this paper is to analyzing a three cases of (Ra) for a heat transfer problem inside a sinusoidal cavity ,having one hot baffle in rectangular geometry .Also the baffle (l/R) ratio, Squeeze angle and its position effects on the characteristic of the fluid flow and the rate of heat transfer are calculated.

PROBLEM DESCRIPTION AND ASSUMPTIONS

A representation of the system coordinates for three different cases of physical model is shown in figure (1, A, B and C). It consists of corrugated cavity containing rectangular hot plate, the enclosure external walls were set at cold temperature (Tc), whereas the thin body fixed at (Th). The non-slip was assumed as boundary conditions for velocity on it is surface, The gap between the sinusoidal enclosure and the inert plate filled by fluid (Pr=7.0) . Assumed that the fluid properties are to be constant density (i.e incompressible) fluid independent on change of pressure and dependent on temperature changes only. In this paper, three locations of insert rectangular plate (i.e) up, center and down and the solution done for Raight number varying ($10^4 \leq Ra \leq 10^6$). The assumptions that adopted here for simplification were the problem at steady state and laminar flow, and by using Boussinesq approximation for estimate the varity of fluid density the circular cavity outer radius has (R) and the hot plate length (0.25L, 0.35 L and 0.5L). The vertical distance between the center of the corrugated cavity plate center point is: δ 0.15L)

$$T_h = \frac{Ra * \alpha * \nu}{g * \beta * H^3} + T_c \qquad (1)$$

equal to (9).

MATHEMATICAL ANALYSIS AND NUMERICAL SOLUTION

So that, the form of governing equations in a two-dimensional space coordinates, velocity, temperature, and pressure are defined: [9].

Equations

Continuity Equation

$$\frac{\partial(\rho U)}{\partial X}+\frac{\partial(\rho V)}{\partial Y}=0 \tag{2}$$

The Two-Dimensional Momentum Equation (x and y directions):

$$\frac{\partial(\rho U^2)}{\partial X}+\frac{\partial(\rho UV)}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{\partial}{\partial X}\left(\mu\frac{\partial U}{\partial X}\right)+\frac{\partial}{\partial Y}\left(\mu\frac{\partial U}{\partial Y}\right) \tag{3}$$

$$\frac{\partial(\rho UV)}{\partial X}+\frac{\partial(\rho V^2)}{\partial Y}=\rho g_y-\frac{\partial P}{\partial Y}+\frac{\partial}{\partial X}\left(\mu\frac{\partial V}{\partial X}\right)+\frac{\partial}{\partial Y}\left(\mu\frac{\partial V}{\partial Y}\right) \tag{4}$$

Finally the energy equation after simplifications:

$$\frac{\partial}{\partial X}\left(\rho UC_pT\right)+\frac{\partial}{\partial Y}\left(\rho VC_pT\right)=\frac{\partial}{\partial X}\left(k\frac{\partial T}{\partial X}\right)+\frac{\partial}{\partial Y}\left(k\frac{\partial T}{\partial Y}\right) \tag{5}$$

The (u,v) velocity compoents in (x,y) corrdinates, and the symolbes (T ,P) refers to temperature and deriving pressure, the descbition of residual quantities listed in the nomenclature. The equations are solved using (Ansys Workbench Fluent) which used finite element techniques.

The dimensionless parameters

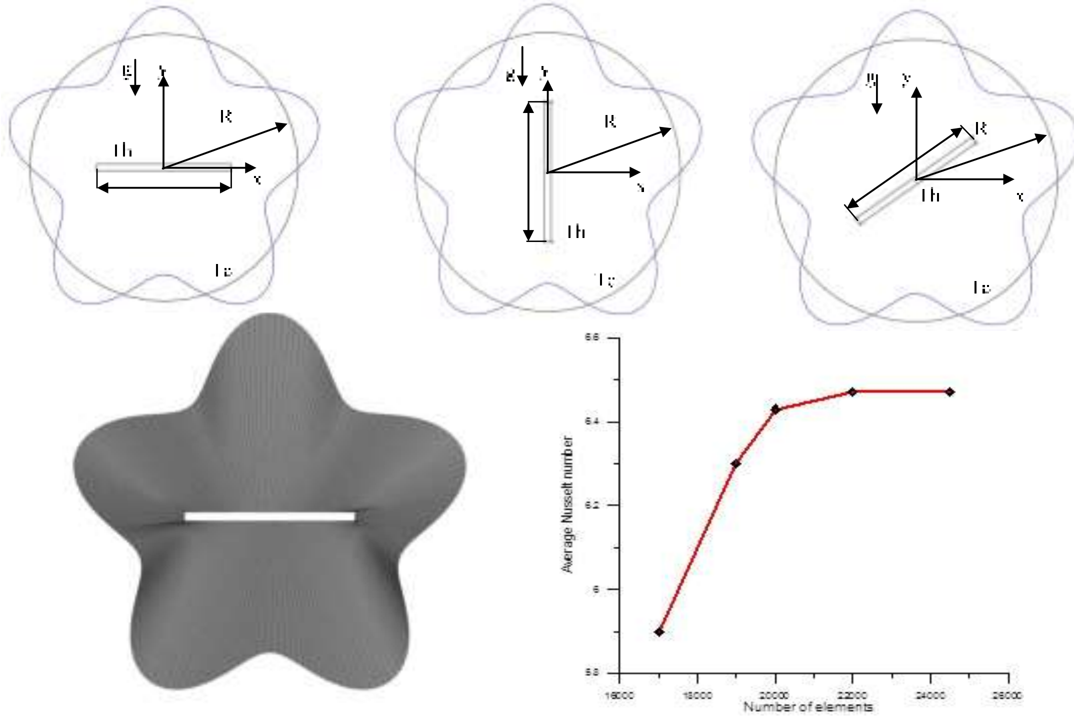
$$Ra=\frac{g\beta(T_h-T_c)H^3}{\alpha\vartheta},\ Pr=\frac{\vartheta}{\alpha} \tag{6}$$

By using the equation listed below to calculate the local and average Nusselt number in enclouser around the heated surface:

$$Nu=\left.\frac{\partial T}{\partial n}\right|_{inner\ wall},\ \overline{Nu}=\frac{1}{l}\int_0^l Nu\,dl \tag{7}$$

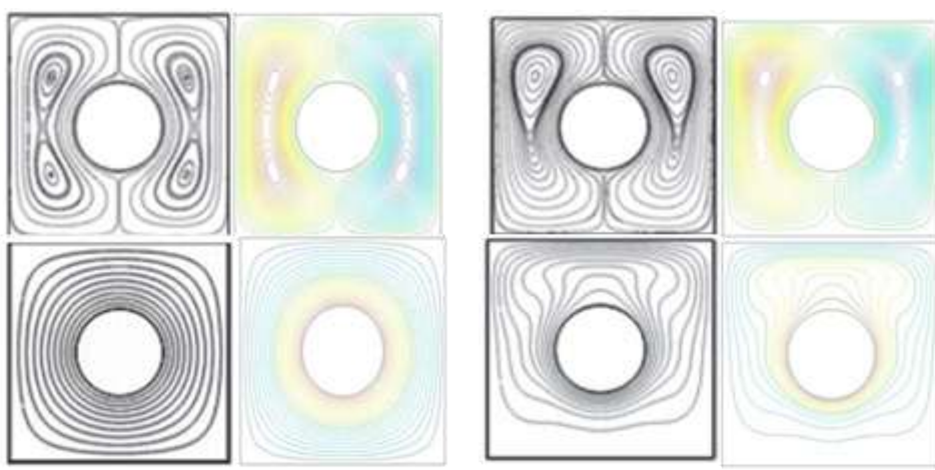
NUMERICAL METHOD TWO DIMENSIONAL

Figure(2,A) denotes the computational domain mesh generation ,and grid for obtained the results around the thin surface inside the cavity gird generation with different numbers as shown in figure. The domain edge sizing (type number of division=90) and face mapped meshing quadrilaterals method with internal number of division (135).A fine grid based on finite element technique have been achieved to solve the govering equations that obey to sets of boundary conditions, and after five tested of grid generation to attain a good solution was with 24480 nodes and 24300 elements the five try shown in figure , estimated results for horizontal plate position (i.e tilted angle $\theta=0^o$) and at $Ra=10^6$. In activation window setup program Fluent Launcher ,with optional double precision, solution methods velocity pressure coupling simplec scheme and by setup for gradient a least squares cell, to complete the solution the driving pressure order set as second order , while the solve for both momentum and energy was by putting second order upwind run order . the results valid of setup code and compared the average Nusselt number with results performed by Kim et al.[9], by assume natural convention heat flow the temperature difference in this study between the the cold walls of enclosure and hot cylinder with circular profile was tested as shown in figure which appears a high agreement between the results :the comparison is dependent on the $Ra = 10^5$, Pr=0.7 .Figure (2B) manifest independence of mesh from unchangeable of average Nusselt number , the convergence was check based on $\overline{Nu}$ at the on the horizontal hot surface (Ra=105,$\theta = 0^o, Pr = 7.0$)



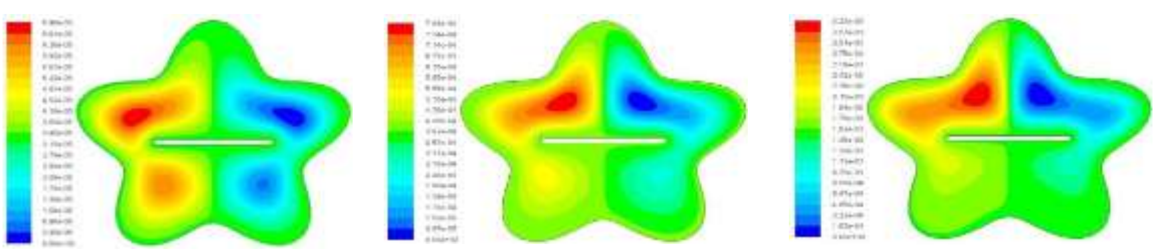
A **B**

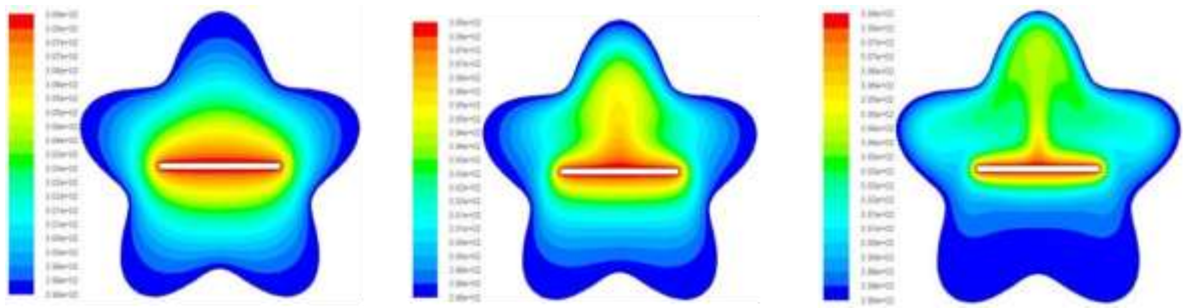
Figure 1. A-Mesh Generation **B-**Convergence of $\overline{Nu}$ On The Horizontal Hot Surface **(Ra=10^5θ,**$= 0^o, Pr = 7.0$)



$\overline{Nu} = 4.95$ $\overline{Nu} = 4.961$ $\overline{Nu} = 7.71$ $\overline{Nu} = 7.53$

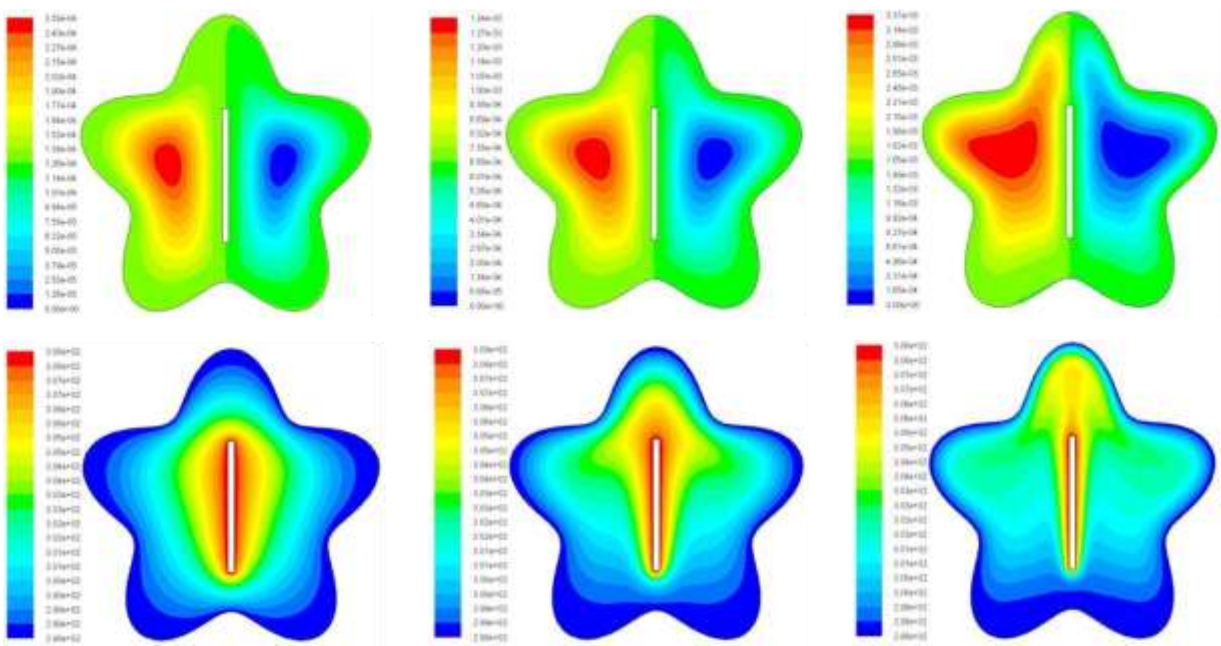
Figure 2. Streamline Up , isothermal line Down For Comparison the present solution of and heat transfer For present studyRight and Kim etal.[9]Left . For Ra=10^3 and 10^5 ,Pr=0.7





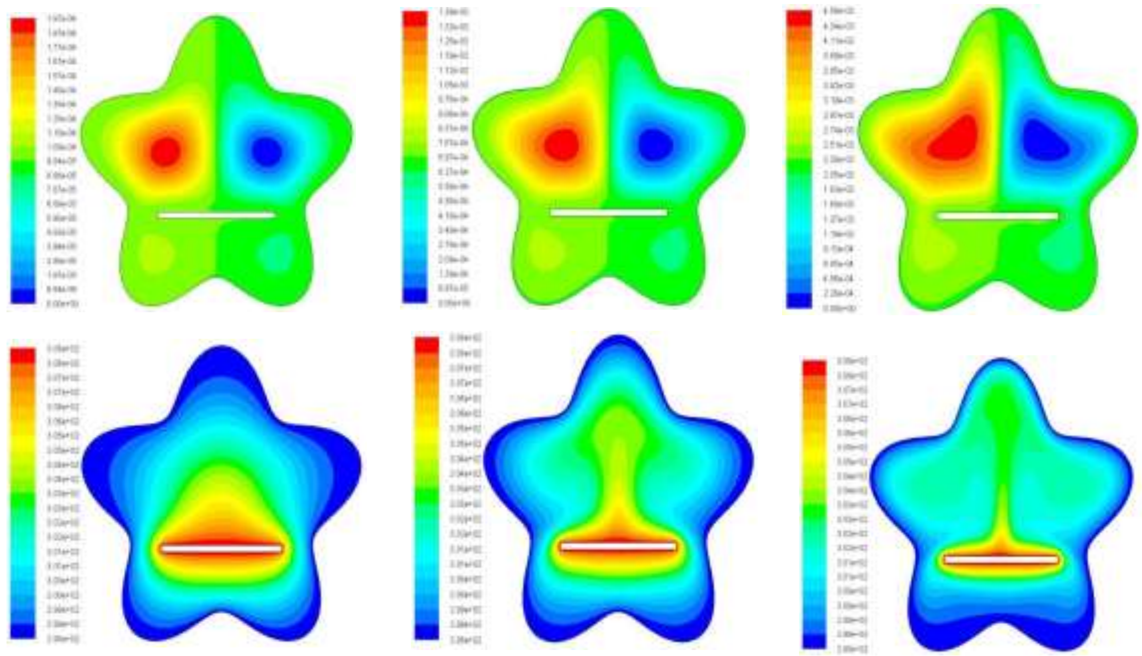
A B C

Figure 3. Stream Functions Up & Isotherms Lines Down For =0° ,Horizontal Plate From Left To Right Ra= $10^4-10^5-10^6$



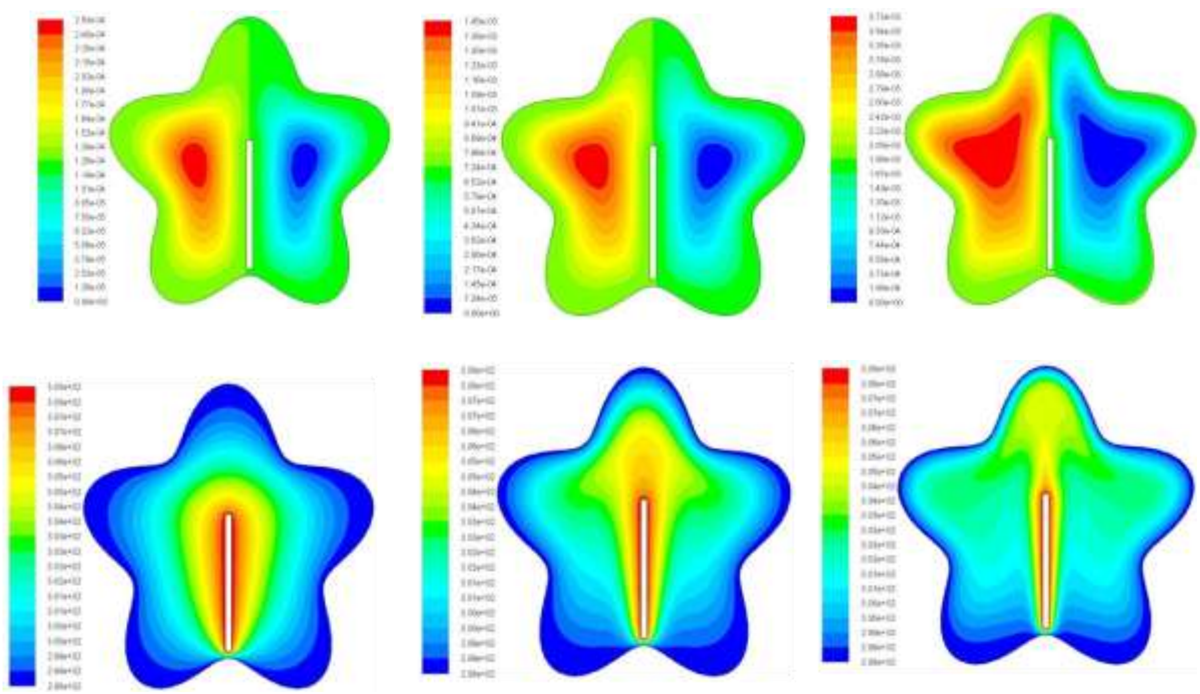
A B C

Figure 4. Stream Functions Up & Isotherms Lines Down For =90° ,Vertical Plate From Left To Right Ra= $10^4-10^5-10^6$



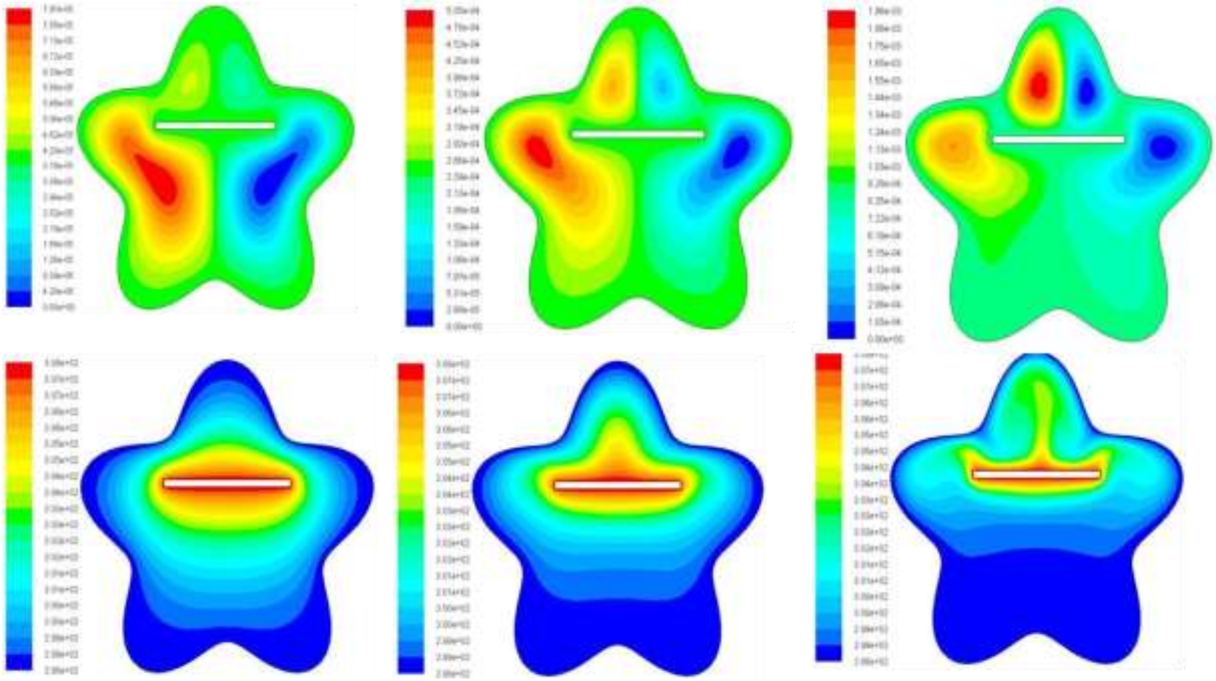
A B C

Figure 5. Stream Functions Up & Isotherms Lines Down For =0° ,Horizontal Plate From Left To Right Ra= $10^4 - 10^5 - 10^6$



A B C

Figure 6. Stream Functions Up & Isotherms Lines Down For =90°, Vertical Plate Down from Left To Right Ra= $10^4 - 10^5 - 10^6$



A B C

Figure 7. Stream Functions Up & Isotherms Lines Down For =0° ,Horizontal Plate From Left To Right Ra= $10^4 - 10^5 - 10^6$

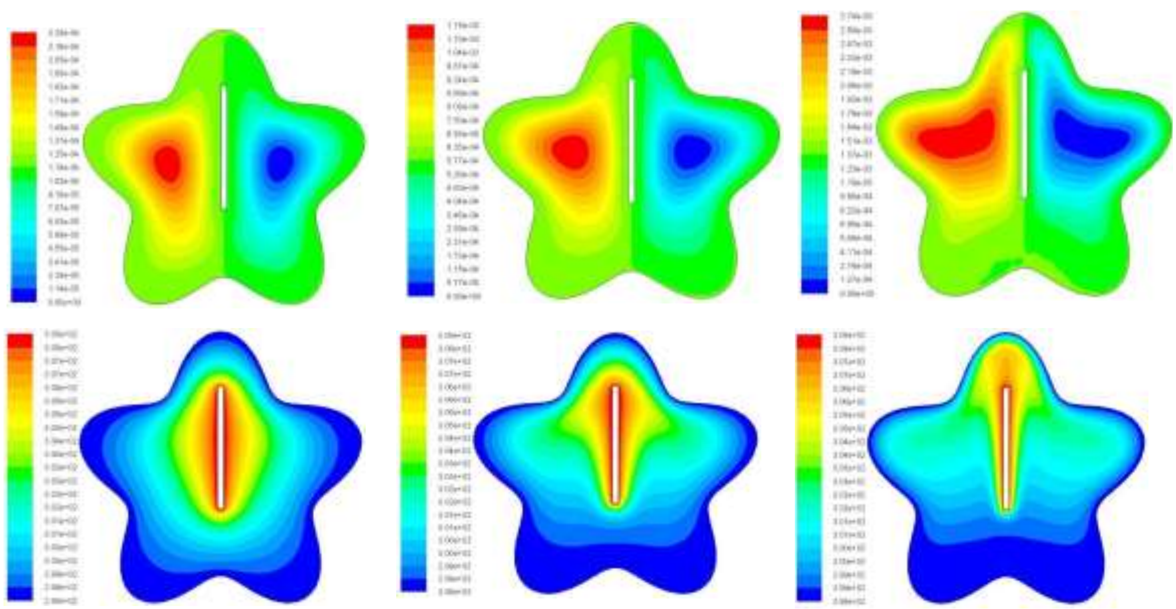
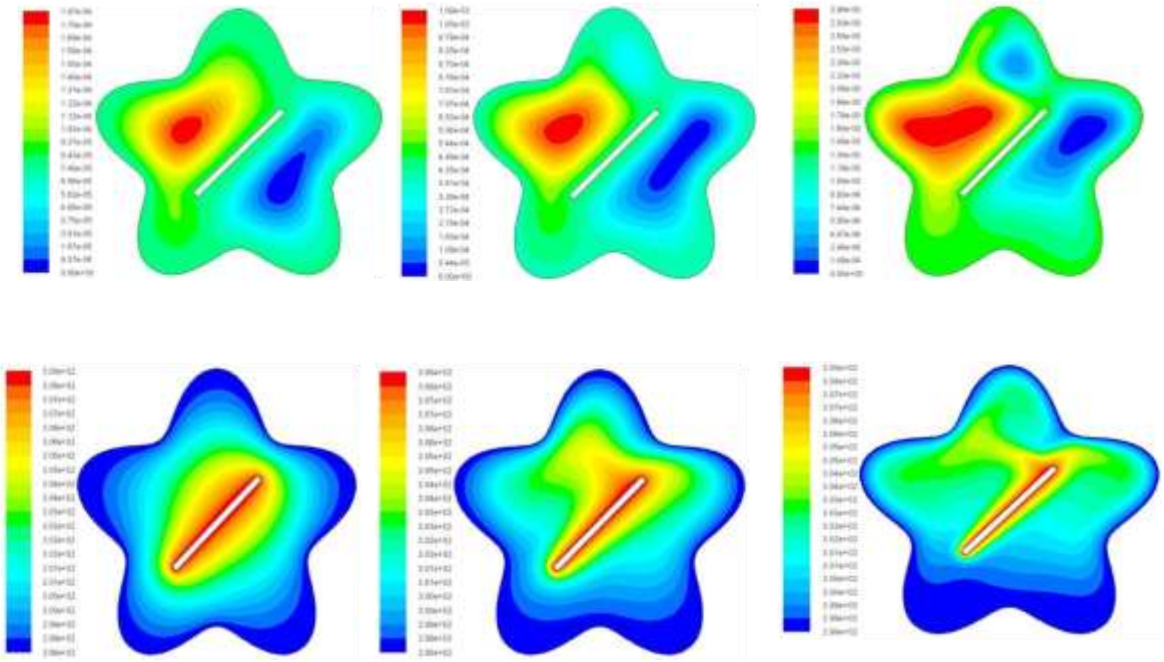
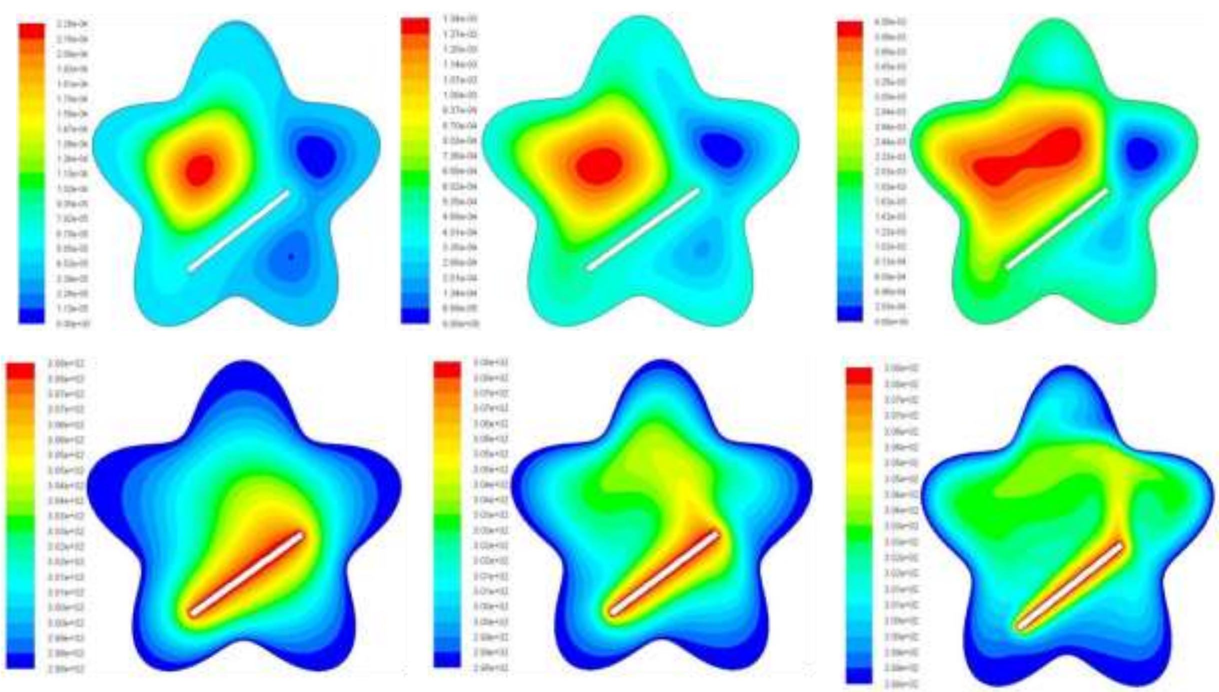


Figure 8. Stream functions up & Isotherms lines down For =90° , Up Plate From Left to Right Ra= $10^4 - 10^5 - 10^6$



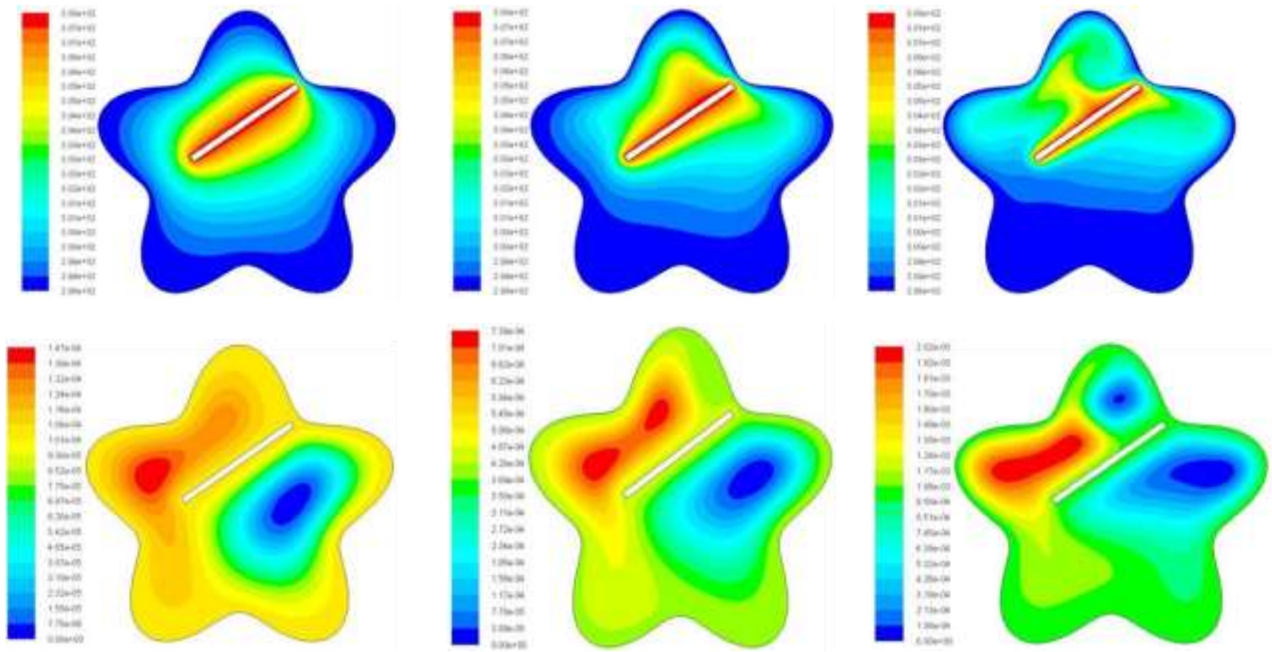
A B C

Figure 9. Stream functions up & Isotherms lines down for =45° Central Plate from Left to Right Ra= $10^4 - 10^5 - 10^6$



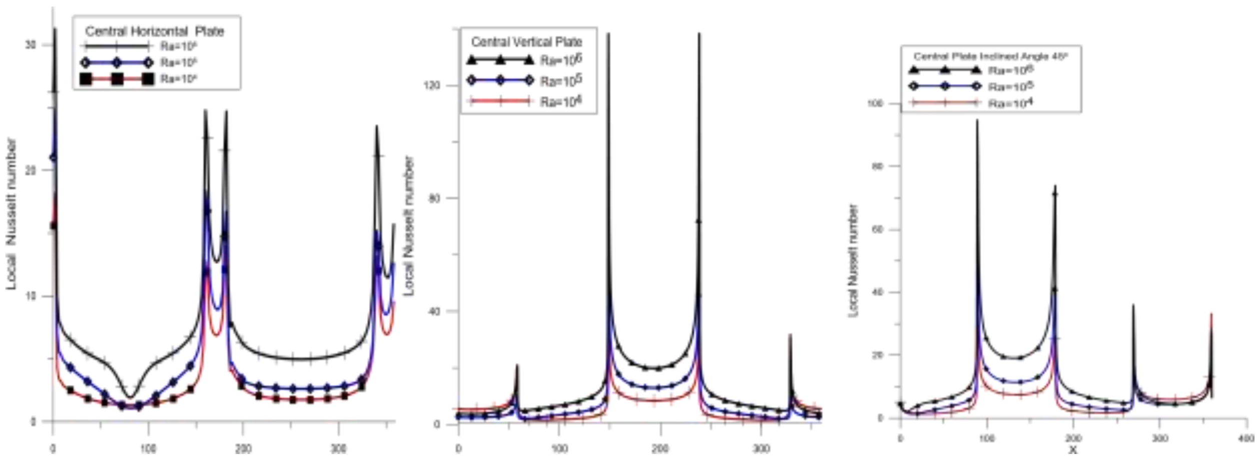
A B C

Figure 10. Stream functions up & Isotherms lines down for =45° Down Plate from Left to Right Ra= $10^4 - 10^5 - 10^6$



A B C

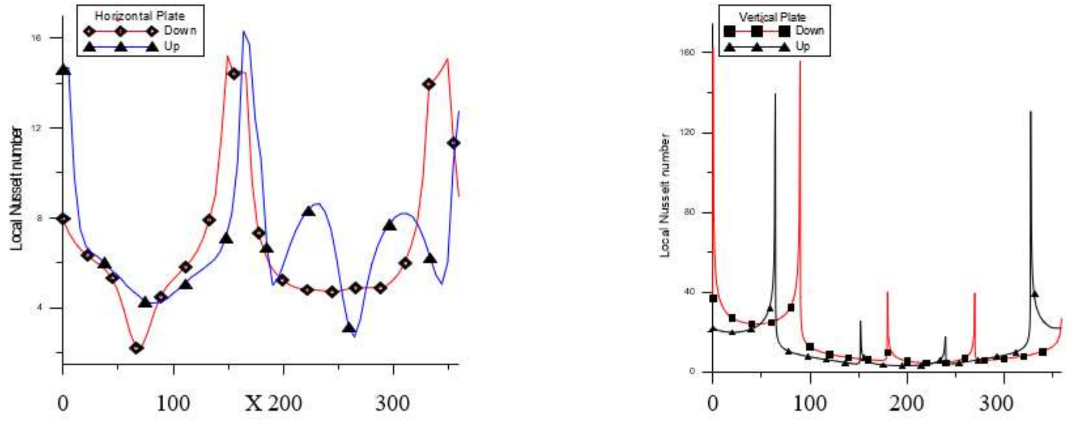
Figure 11. Stream functions up & Isotherms lines down for =45° Up Position from Left to Right Ra= $10^4 - 10^5 - 10^6$



X X

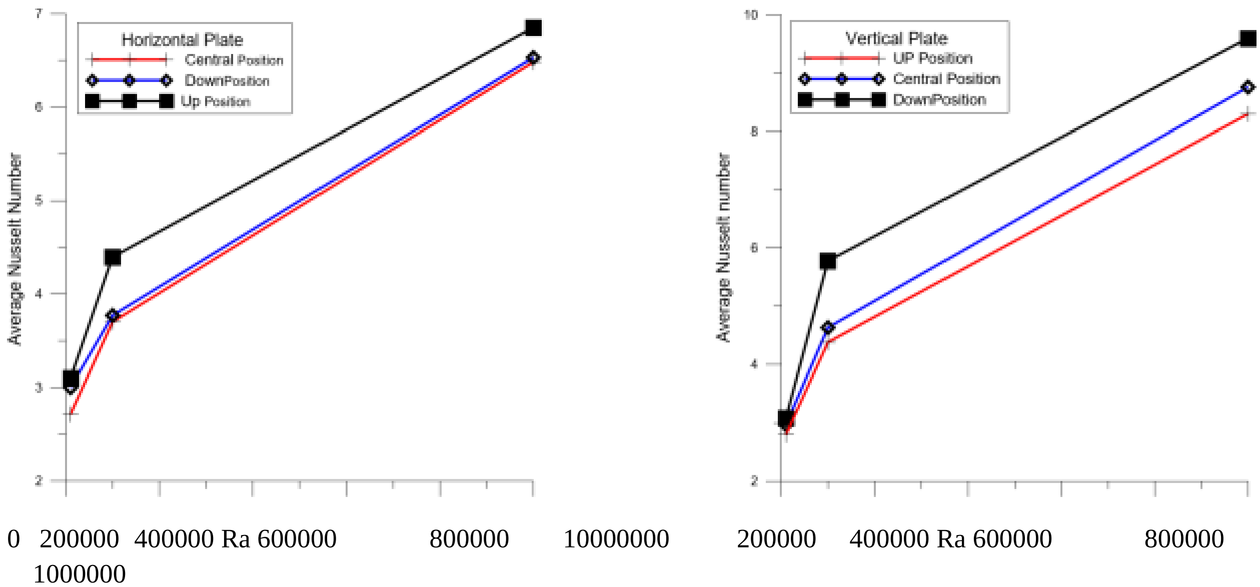
A-Central Horizontal Plate $(\theta = 0^o)$ B- Central Vertical Plate $(\theta = 90^o)$ C- Central Inclined Plate $(\theta = 45^o)$

Figure 12. Variation of Local Nusselt Number with Rayliegh number



A-Central Horizontal Plate ($\theta = 0^o$) B- Central Vertical Plate X ($\theta = 90^o$)

Figure 13. Variation of Local Nusselt Number Plate Location For Rayliegh number (10^6)



A-Central Horizontal Plate ($\theta = 0^o$) B- Central Vertical Plate ($\theta = 90^o$)

Figure 14. Variation of Average Nusselt Number With Rayliegh number

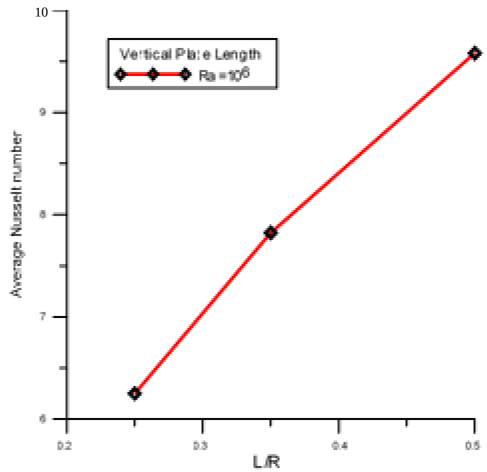


Figure 15. Variation of Average Nusselt Number With l/R Ratio.

RESULTS AND DISCUSSION

Flow and Temperature Fields

The predicted results for heat flow of natural convection represented by local and average Nusselt number inside a sinusoidal cylinder enclosure with constant wall temperature (Tc) and containing one thin baffle placed in different locations and inclination angle (i.e center, down and up) of cavity .By assuming hot wall temperature (Th) of the inserted body ,the streamline and temperature contours for varying Rayliegh number (Ra=$10^4, 10^5, 10^6$), baffle body is located near the top, bottom the wall of the cavity ,in which the results of right and left are not mentioned here for the sake of brevity. This work is performed for three values of the thin plate dimensionless length (l/R) (0.25,0.35 and 0.5) with inclination angle by($\theta = 0^o, 45^o, 90^o$) ,all results are computed and local and average Nusselt number will be reported and discussed. Figures (4,A,B,C) show the effects of ascending Rayliegh number from left to right on the flow field and the temperature contours in the first raw when $\theta = 0^o$, l/R =0.5 due of the existence of hot baffle partition inside the cold wall cavity high difference in temperature occurs ,hence the buoyant force will be effects on flow mechanism inside the cavity , the recirculating vortices with different strength about the central vertical direction are formed for all values of(Ra) , as shown in figure .The main flow consists of quad vortex shape and symmetrical . It is clear that an increases in the stream function value as increasing in Rayliegh number due to increase in velocity of flow and then increasing in the natural heat transfer.

Consequently, The light fluid moves upward in gap between the hot inner body and the grove of sinusoidal cavity ,and due to the corrugation of cavity the stream line will be appear denser due to a small available area there specially when (Ra=10^6) due to the domination of natural mechanism .For case of vertical hot body this corresponding with position at $(\theta = 90^o)$ as its advertiser Figures (5,A,B,C) , the circulation behavior of the flow indications two symmetric rotating vortex and with two inner eddies distributed across the rectangular body inside each one of the right and left and as (Ra) increases became different strength eddies . As (Ra=10^4) the heat transfer became governing by heat conduction mechanism ,with small cores of two vortices while a stretched flow contours as (Ra=10^5) with large cores if compared to (Ra=10^6) , slightly vortex ascended as increasing(Ra). The isotherms are symmetric in left and right of plate in distributed for all cases $(\theta = 0^o - 90^o)$ and the up and down situations, for (Ra=10^4) represented a pure conduction case future more, very weak of buoyancy-driven convection intensity ,hence this justifies the appearance in very thick thermal boundary layer does not exist of the plume . As higher Rayleigh number increased divergences if compared with the pure conduction different behavior for temperatures counters and becomes crowded packed specially near to the walls and intense at higher surface region .

When (Ra) reach its , largest value the crowding of the temperature lines near the upper walls separation the thermal boundary layers has been detected. This lines separate along the heated wall from its upper region to arrangement in a thermal plume which will impinging to the upper arc of cavity also the thermal boundary layer becomes more thinner and more thin when the convection effects dominated and this dependent on increasing of $Ra \leq 10^6$. It is worth mentioning $(\theta = 90^o)$, the temperature gradient becomes with high steeper and the temperatures line approximately filling all enclosure and that evident to enactment of average Nusselt number, especially as Rayliegh number reaches $(\mathrm{Ra} = 10^6)$ .The effects of (Ra) on the flow lines are existing in Figures (6,7,8,and 9) for (10_4, 10_5 and 10_6) respectively at down and upper plate for both horizontal and vertical locations . As increasing Rayliegh number as mentioned pervious leads to increase in value of stream lines due to increasing flow strength. It's clearly in horizontal below position Figures (6 A,B, and C) the flow circulation behavior with two smallest identical eddies distribution which appears in left and right sides of hot plate upper surface and having one vortex inside each one with small cores and largest and stretch for ($10^4 \leq Ra \leq 10^6$) respectively, due to a larger space area there . It is also remarkable, the maximum values of flow stream function recorded for vertical plate arrangements specially down partitions the main flow consist of two eddies distributed in left and right of plate and each one fills and taking the form of existing space the flow is affected considerably and forced to recirculation in sinusoidal grooves this indicated an enhanced in heat flow with extended to the bottom Figures (7 A,B, and C) .

As thin body fixed above of enclosure while horizontal position □□□□0□) Figures (8 A,B, and C) , different behavior occurs in which flow motion will separated in to four vortices , classified in two types , right hand half and left hand half sides with un-identically rotation vortex appears upper and blower the surface, the upper bi-cellar vortex looking small size with very small cores with high strength when $(\mathrm{Ra} = 10^6)$ coincides with high fluid strength , due to the little amount of fluid confined there with very smallest area. All temptress profile their presence is limited in the available small area and crowded , in addition the thermal boundary layer is repeated (i.e thicker and more thinner when$(\mathrm{Ra} = 10^4 - 10^6$) respectively. With regard to Figures (9 A,B, and C) with briefly there is a decreases average Nusselt number corresponding to upper vertical situation position. When the plate squeezed at center point by inclination angle □□□□45□) as shown in Figures (9 A,B, and C) , simulation were completed to study effect of (Ra) ,the intensity of flow motion becomes very low as (Ra) at minimum values ,due to the heat flow mechanism is dominant by conduction , in this situation the distribution of flow lines under and above the hot body will be around symmetric ,When ($\mathrm{Ra} = 10^6$) the bifurcation from two-cell vortices to the triple –cell vortex occurs at□□□□□45□), the newest cell will circulated in space of grove above the plate due to enhancing convection (i.e buoyancy induced).

For situation of □□□□45□) and this inclination about the center of cavity , thermal boundary layers concentrated in upper edge of plate for all values of (Ra) which appear thicker from upper side and gradually thinner from the other , and diminishes in symmetric . Figure (9 C) referring to starts of plume significant effect convection in heat transfer , this leads to the thermal boundary layers on plate surface more thinner. When the tilted hot plate displaced by (0.15L) in down direction as illustrated in Figures (10 A,B, and C) three circulation will filling the space between the plate and groves as shown in Figure (10 A), the cell in left hot fluid is lifted up and the other two cell in right side refer to cold air try to move in towards upper direction to fill the grove and then expanded there. The other type of vortices will be starts to appears as Ra exceed 10^4 and reaches to 10^6in this case secondary flow will be generated. Completely different in behavior of fluid flow and isothermal lines when tilted plate putted at upper location corresponding to Figures (11 A,B, and C) , as (Ra =10^4), the main flow having two types of vortices, one formed upper plate with anti-clockwise direction, its try to taken the cavity-plate space profile, the other one vortex under the hot body with a clockwise direction is a large and enclosed the lasting region , as in Figure (11 C) the above one will split in two vortices. the isothermal lines for the above cases have the greater distribution especially for up inclination condition concentrated near the center of slop plate corresponding to Ra=10^6, the lines shifted to mid points due to protuberance of walls and high effects on natural convection.

Heat Transfer and Nusselt Number

Local and average Nusselt number a rounds the rectangular hot is defined the local heat transfer in figures (12,13,14, and 15), the local Nusselt number graphs represented for five cases (i.e horizontal and vertical centered plate , horizontal and vertical up and down, and for tilted case). As expected the maximum value of NuL, reported as a hot plate occupied down position and in vertical situation , as depicted in figure , also the local Nusselt number reaches a maximum valves at the edge of hot plate and sharply decreases started whenever when moves away from the leading edge towards the middle of rectangular hot body and becomes lowers their the distribution of the (NuL) for tilted case .It's clearly the NuL becomes highest values left edge due to the temperature gradient become maximum at the left hot plate edge side . The average Nussel number as shown in figure (15) jumped when the ratio of plate length and enclosure radius increasing and this as expected due to the increasing of surface area of heat transfer also when the plate length by (50%) the closed area between the plate and corrugated of cavity will be decreases and the flow forced to move in narrow regions and will obligate to separate from bi-cell to triple-cell and with top value of (Ra) the secondary flow will appears.

CONCLUSIONS

A numerical calculation is performed for natural convection at steady state heat transfer problem for sinusoidal cylinder cavity with in inclined heated thin rectangular plate and this study indicated many conclusions: -

1. With the increase of (Ra), local Nusselt number increased in all situations.
2. The plate itself behaves like an obstruction and affects the flow field considerably , and average Nusselt number is changing more significant (increasing or decreasing) by its position and the inclination angle .
3. The maximum value of the $\overline{Nu}$when ($\theta = 90^0$)and the heated baffle in down situation.
4. As the ratio (l/R)of a thin plate is increases the value of , namely, heat transfer increases (i.e when (l/R) increses by 0.25 $\overline{Nu_L}$ increses by 0.536%).

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