Double Diffusive Convection in an Inclined Rectangular Cavity

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Abstract — *The natural convection which is caused by combined effect of temperature buoyancy and concentration buoyancy is studied analytically in an inclined tall rectangular cavity with uniform heat flux and mass flux along the vertical sides. The analytical part is true to the boundary layer regime where the heat transfer and mass transfer rates are governed by convection. An Oseen-linearized solution is for tall rectangular cavity filled with the combination characterized by Lewis number Le which is equal to one and arbitrary buoyancy ratios. The influence of the angle of inclination for different Rayleigh number Ra, on velocity and temperature distributions is determined. It is found that Nusselt number Nu and Sherwood number Sh increases the angle of inclination, passes through an apex and then begins to fall down. The effect of inclination on Nu and Sh is more identified as the Ra is increased. The apex of the Nu and Sh occurs at a lesser inclination angle when Ra is raised. The effect of Le is recorded by a similarity solution valid for Le beyond one in heat transfer driven flow, and for Le less than one in mass transfer driven flow.*

Keywords — *Convection, rectangular enclosure, inclination angle, cavity.*

I. INTRODUCTION

The subject of this study is formed by what emerges as a new class of flows driven by buoyancy in closed inclined cavities, namely, the natural circulation driven by density variations caused by the combined presence of temperature gradient and concentration gradient in the solution that fills the cavity. A fundamental investigation of the combined heat transfer and mass transfer process effect by that class of flows is demanded by contemporary engineering questions such as the migration of contaminants through buildings, passive solar system components, shallow bodies of water, etc., and the role of convection during the growth of a crystal.

The effect of heat and mass transfer process in a tiled rectangular tall cavity which is filled with fluid, because of its importance in many practical problems. The physical configuration is shown in Figure 1 where one of the vertical wall is heated and the other wall is cooled subjected to uniform heat and mass fluxes for wider range of inclination angle $\emptyset$. Variety of engineering applications usually involve inclined enclosures and hence we have to esteem the effects of both the tangential component and normal component of the buoyancy force related to the differentially heated walls with uniform heat flux and mass flux. At a very large inclination angles, the reaction of the component of normal buoyancy to the surface which is heated become very important in modifying the structure of the flow, the heat transfer and mass transfer.

The significance of this convection in inclined cavities is carried out in the review paper by Ostrach (1972), Catton (1978) and by Raithby and Hollands (1985). The flows addressed in the present study are identified for the first time as an important research area by Ostrach in his 1982 Keynote Paper in Munich Until about 1970 there have been few articles reported to understand the effect of tiled boundaries on thermal convection or to the effect of inclusion of parameters such as the angle of inclination or the enclosure aspect ratio. During that time, the magnificent work was conducted by Hart (1971), who did both experimental and analytical approach to bring the remarkable features of the effect of inclination enclosure between the two restricting case of Benard convection (heated from below) and convection in a perpendicular slot.

The combined heat transfer and mass transfer enclosure flow examined in the study and by Kamotani et al (1985) is related to the established and very active area of "double-diffusive" convection research. The analysis of this activity is the one which was published by Viskanta et al (1985), who insist that "the two requirements for the occurrence of double-diffusive convection are that the fluid contains two or more components with different molecular diffusivities and that these components make opposing contributions to the vertical density gradients.

The main focus of double-diffusive convection, the study deals with the phenomenon of natural convection in a vertical slot, where the combined buoyancy effect is due to the horizontal density gradient caused by heat and mass transfer from the side. Furthermore, in our study the buoyancy effects of mass transfer (concentration gradient) and heat transfer (temperature gradient) do not necessarily oppose one another. Recent developments pointed to the need of a more comprehensive treatment of the subject. Ayyaswamy and Catton (1973) analytically considered the fluid flow in a differentially heated inclined rectangular cavity, and developed a correlation for the average Nusselt number in terms of the average Rayleigh number and the angle of inclination. Later, Catton et al (1974) applied the Galerkin method to analyse the natural convection flow of a large Prandtl number fluid at various inclination angle and for the Rayleigh numbers up to $2*10^5$.

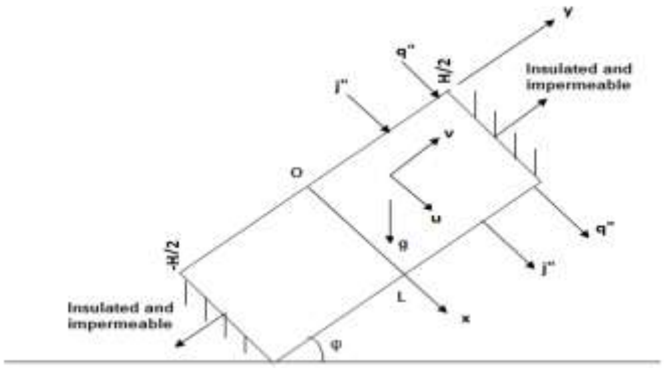

Fig. 1 Schematic illustration of an Inclined Rectangular cavity filled with fluid and subjected to heat and mass transfer from the side

In a series of papers Ozoe et al (1974, 1975 and 1983) carried pit experimental and numerical studies in inclined enclosures with different thermal boundary conditions and aspect ratios. Their studies provided valuable information concerning flow patterns, velocities and temperature distributions. The overall nature of heat transfer agrees very well with that of flow patterns. Some of the recent contributions to the basic aspects of analysis of natural convection in inclined enclosures were the introduction of variable properties in the numerical methods and the establishment of the limits of validity of the Boussinesq approximation. Zhong et al (1985) and Yang et al (1986) have applied numerical method to study the effects of variable thermal properties, thermal conductivity, viscosity and heat capacity. In their work flow patterns and heat transfer were analysed for a complete set of inclination angles.

Conductive heat transfers were found to dominate the heat transfer for inclination angles ranging from 0° (heated from above) to 45°. For larger angles, convection was the prevailing heat transfer mode, due to the apparent increase of the gravitational effect along the differentially heated walls. Transition from unicell to three-dimensional oblique rolls have been seen at critical angles between 150° and 180°, and are accompanied by a local minimum in the heat transfer rate. Moreover, their correlation for the mean Nusselt number based on fully variable properties compared favourably with the results of Ayyaswamy and Catton (1973) and Arnold et al (1976).

Although papers in this fields are still appearing (for example Chen et al (1985), Reddy (1982), Symons and Peck (1984)) it would seem that much work has to be done to understand the effects of inclined boundaries and their impact on the heat transfer distribution. The work reviewed above reveals that a substantial amount of theoretical and experimental work has been conducted to improve our understanding of the fundamental aspects of heat transfer in enclosures.

In the present work, heat and mass transfer in an inclined tall rectangular enclosure where both side walls are rigid and are subjected to uniform heat and mass flux and the top and bottom boundaries of the enclosure are thermally well insulated and impermeable. The buoyancy effect of mass transfer and heat transfer with the inclined angle do not necessarily oppose one another. In other words the value of buoyancy ratio is not restricted to a narrow range around -1. The object of this study is to document the flow, heat and mass transfer characteristics in an inclined rectangular enclosure where both the walls are subjected to uniform heat and mass transfer.

In this work, heat and mass transfer in an inclined tall rectangular enclosure are studied analytically, in domain of Prandtl numbers Pr, Schmidt numbers Sc, and buoyancy ratios n along with the inclination angle $\emptyset$. In line with an overall engineering objective of this study, the simultaneous heat and mass transfer effect is modelled as one characterized by uniform fluxes (q'', j'').

This study is to find analytical solution, using Oseen linearization method, boundary layer approximation. These analytical solutions obtained are useful not only to find the nature of heat transfer and mass transfer across this tilted enclosure but also useful to describe the details of the motion and temperature distribution. This is useful to provide effective insulation in variety reactors (nuclear, thermal and chemical).

For varying Le, closed form solution is also obtained by employing similarity argument valid for heat and mass transfer driven flow.

Nomenclature

a = core temperature gradient
b = core concentration gradient
c(x) = concentration boundary layer profile
ΔC = average side to side concentration difference
C = concentration of constituent
C_0 = core concentration
c_p = specific heat - constant pressure
D = mass diffusivity of constituent through the fluid mixture
D_1 = constant
g = gravitational acceleration
H = enclosure height
j " = mass flux from the side
k = thermal conductivity
l = thermal boundary layer thickness
L = enclosure thickness
Le = Lewis number = $\frac{\alpha}{D}$
n = buoyancy ratio = $\beta_c b\alpha/(\beta a D)$
Nu = overall Nusselt number
P = total pressure
Pr = Prandtl number = $\frac{\nu}{\alpha}$
$\vec{q}$ = velocity vector
q" = heat flux from the side
Ra = Rayleigh number = $g\beta q''H^4/(\alpha\nu k)$
Re_x = Reynolds number
Sh = overall Sherwood number
t(x) = temperature boundary layer profile
T = temperature
T_0 = core temperature
ΔT = average side to side temperature difference
u, v = horizontal and vertical velocity components
x, y = horizontal and vertical coordinates
α = thermal diffusivity
β = thermal expansion coefficient
β_c = coefficient of concentration expansion
γ = $\{g\beta a(1+n)sin\emptyset/(\nu\alpha)\}^{1/4}$ = parameter
ν = $\frac{\mu_f}{\rho_0}$ = kinematic viscosity
μ_f = viscosity of the fluid
ρ_0 = reference density
ψ = stream function
ξ = vorticity function
$\emptyset$ = inclination angle

II. MATHEMATICAL FORMULATION

The physical configuration, considered in this study, consist of the fluid occupying a tilted tall rectangular slot of thickness L and height H such that H≫L (Fig.1). The top and bottom walls of the two-dimensional cavity are impermeable and insulating; while the vertical walls are impermeable and covered by uniform distributions of heat flux q'' and mass flux j″.

$$q^{''} = -k\left(\frac{\partial T}{\partial x}\right)_{x=0,\ L} \quad , \quad \text{constant} \tag{1}$$

$$j^{''} = -D\left(\frac{\partial C}{\partial x}\right)_{x=0,\ L} \quad , \quad \text{constant} \tag{2}$$

The mathematical model is expressed in terms of the dimensionless variables such as vorticity vector, vector potential functions, temperature and concentration. The following dimensionless form of the equations:

$$x^* = \frac{x}{l}\ , \quad y^* = \frac{y}{l}\ , \quad u^* = \frac{ul}{\alpha}, \quad v^* = \frac{vl}{\alpha}, \quad T^* = \frac{T}{\Delta T}\ , \quad C^* = \frac{C}{\Delta C}\ , \quad \xi^* = \frac{l^2\xi}{\alpha} \tag{3}$$

The two analyses reported in this section are of the boundary layer type. The boundary layer-approximated equations that govern the steady-state conservation of mass, momentum, energy, and constituent in each vertical boundary layer region are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{4}$$

$$0 = \beta g\left(\sin\emptyset\ \frac{\partial T}{\partial x} - \cos\emptyset\ \frac{\partial T}{\partial y}\right) + \beta_c\ g\left(\sin\emptyset\ \frac{\partial C}{\partial x} - \cos\emptyset\ \frac{\partial C}{\partial y}\right) + \nu\ \frac{\partial^3 v}{\partial x^3} \tag{5}$$

$$u\ \frac{\partial T}{\partial x} + v\ \frac{\partial T}{\partial y} = \alpha\frac{\partial^2 T}{\partial x^2} \tag{6}$$

$$u\ \frac{\partial C}{\partial x} + v\ \frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial x^2} \tag{7}$$

These equations have been further approximated by invoking the Boussinesq-incompressible fluid model, where β and β_c represent the thermal and concentration expansion coefficients (these and other symbols are defined in the Nomenclature). The inertia terms that usually appear on the left-hand side of equation (5) have been neglected based on the assumption that the fluid has a Prandtl number greater than one.

Oseen-Linearized Solution

It is possible to construct a matched boundary layer analytical solution along the lines of Oseen linearization for the case of a long, shallow, horizontal, fluid layer with the two vertical walls held at constant heat flux q'' and mass flux j″. For this situation it is assumed that A ≫ 1 with Ra constant.

It was shown by asymptotic expansions the flow inside the cavity can be disintegrate into three parts

1. a motionless and stratified core region
2. a constant (altitude-independent) boundary layer thickness
3. temperature of the side wall that linearly increase with height at the same rate for the core temperature

The results in the three regions are combined by the coordinating requirements in the areas of overlap. Substantially the basic flow which consists of buoyancy-driven parallel flow that is moderated by the viscous effects over the length H. The flow that turns down 180° in the ending regions. In the present investigation, this procedure will be followed in order to estimate the study of both the effects of the tiled angle, and the occurrence of constant heat fluxes and mass fluxes inflict on the two opposite walls.

In the case of the layer of thin fluid, the flow within the main region of this cavity may be predicted to be parallel. As the outcome, the temperature field and concentration field should be respectively of the following transformation

$$T(x, y) = T_0 + ay + t(x) \tag{8}$$

$$C(x, y) = C_0 + by + c(x) \tag{9}$$

where T_0, the constant, the reference temperature and C_0, the constant, the reference concentration and that are measured in the cavity of geometric center, and where *a* and *b* are the constant which are vertical gradients of temperature and vertical gradient of concentration. The functions $t(x)$, the temperature profile shapes and $c(x)$ account for the concentration profile shapes in the boundary layer region. Outside the region of boundary layer that lines the left wall, the vertical velocity *v* as well as functions t and c satisfy the condition

$$\lim_{x\to\infty}(v\ , t\ , c) = 0 \tag{10}$$

Subjecting the governing equations (5) to (7) to the transformation (8) & (9) yields, in order,

$$0 = v''' + \frac{\beta\, g}{\nu}(t'\sin\emptyset - a\cos\emptyset) + \frac{\beta_c\, g}{\nu}(c'\sin\emptyset - b\cos\emptyset) \tag{11}$$

$$av = \alpha\, t'' \quad (12)$$

$$bv = D\, c'' \quad (13)$$

Eliminating t and c between equation (11) – (13) we obtain

$$v'''' + \gamma^4 v = 0 \quad (14)$$

with the notation
$$\gamma = \left(\frac{g\beta a\,(1+n)}{\nu\alpha} \sin\emptyset\right)^{\frac{1}{4}} \quad (15)$$

where n is the buoyancy ratio for the system with stipulated heat flux and mass flux, $n = \beta_c\, b\alpha/(\beta a D)$. The solution that satisfies equation (14), the no-slip boundary condition at x = 0, and equation (10) is

$$v = D_1 \exp\left(-2^{-\left(\frac{1}{2}\right)} \gamma x\right) \sin\left(2^{-\left(\frac{1}{2}\right)} \gamma x\right) \quad (16)$$

The corresponding expressions for t(x) and c(x) are obtained immediately by integrating equations (12), (13) subject to conditions (10). The resulting expressions for $t(x)$ and $c(x)$ have an unknown constant D_1 as a factor: Two expressions for D_1 are obtained by subjecting $t(x)$ and $c(x)$) to the heat transfer and mass transfer boundary conditions (1), (2)

$$D_1 = 2^{\frac{1}{2}} \left(\frac{\gamma\,\alpha\, q''}{k\; a}\right) = 2^{\frac{1}{2}} \left(\frac{\gamma\, j''}{b}\right) \quad (17)$$

In other words $\frac{a}{b} = \frac{q''\,\alpha}{j''\,k}$. In centrosymmetric flow view, temperature and concentration fields, the results of this entire analysis may be summarized as

$$T = \pm\, 2^{\frac{1}{2}} \left(\frac{q''}{k\,\gamma}\right) \exp\left(-\, 2^{-\frac{1}{2}} \gamma x\right) \cos\left(2^{-\frac{1}{2}} \gamma x\right) + T_0 + ay \quad (18)$$

$$C = \pm\, 2^{\frac{1}{2}} \left(\frac{j''}{D\,\gamma}\right) \exp\left(-\, 2^{-\frac{1}{2}} \gamma x\right) \cos\left(2^{-\frac{1}{2}} \gamma x\right) + C_0 + by \quad (19)$$

$$v = \pm\, 2^{\frac{1}{2}} \left(\frac{\gamma\,\alpha\, q''}{k\; a}\right) \exp\left(-2^{-\frac{1}{2}} \gamma x\right) \sin\left(2^{-\frac{1}{2}} \gamma x\right) \quad (20)$$

$$v = \pm\, 2^{\frac{1}{2}} \left(\frac{\gamma\, j''}{b}\right) \exp\left(-2^{-\frac{1}{2}} \gamma x\right) \sin\left(2^{-\frac{1}{2}} \gamma x\right) \quad (21)$$

where the (-) and (+) signs differentiate between the right-side and the left-side boundary layer solutions (in the solution for the right side the horizontal coordinate *x* is measured from the right wall into the fluid).

Regarding the unknown core gradients *a* and *b*, it was shown in (8), (9) that at any *y*, the vertical enthalpy flow must be well balanced downward through the core by thermal diffusion

$$\int_0^L \rho\, c_p\, v\, T\, dx = \int_0^L k \left(\frac{\partial\, T}{\partial\, y}\right) dx \quad (22)$$

Condition (22), which is conceptually the same as the aggregate (heat and fluid flow) end condition proposed as improvement on the original Oseen-linearized solution to this problem yields

$$a = 2^{-\frac{1}{4}} \left(\frac{q''}{k}\right) (\gamma L)^{-\frac{1}{2}} \quad (23)$$

The corresponding integral condition of zero net mass transfer in the vertical direction

$$\int_0^L v\, C\, dx = \int_0^L D \left(\frac{\partial\, C}{\partial\, y}\right) dx \quad (24)$$

yields
$$b = 2^{-\frac{1}{4}} \left(\frac{j''}{D}\right) (\gamma L)^{-\frac{1}{2}} \quad (25)$$

The solution is complete now; however, an important limitation of this solution is by eliminating *a* and *b* between equations (17), (23), and (25). We obtain $\alpha = D$, in other words the solution of Oseen-linearized is valid for fluids with a Lewis number (Le = 1) and with an arbitrary buoyancy ratio *n*.

The engineering conclusion of the above analysis is one compact formula for the overall Nusselt number (Nu) and the overall Sherwood number (Sh)

$$Nu = \frac{q''}{k\left(\frac{\Delta T}{L}\right)} = 2^{-\left(\frac{3}{2}\right)} \gamma\, L \quad (26)$$

$$Sh = \frac{j''}{D\left(\frac{\Delta C}{L}\right)} = 2^{-\left(\frac{3}{2}\right)} \gamma\, L \quad (27)$$

where ΔT is the side to side temperature difference and ΔC is the side to side concentration difference (note that ΔT and ΔC are y in-dependent). Recalling the definition of γ, equations (26) and (27) can be rewritten as

$$Nu = Sh = 0.34 \left(\frac{L}{H}\right)^{\frac{8}{9}} (Ra)^{\frac{2}{9}} (1+n)^{\frac{2}{9}} (sin\emptyset)^{\frac{2}{9}} \tag{28}$$

where the Rayleigh number Ra = $\frac{g\,\beta\,q^{''}\,H^4}{\alpha\;\nu\;k}$ is based on imposed heat flux.

The value of γ is determined from the equation

$$\gamma^{18} = \frac{F}{2} \tag{29}$$

where $F = Ra^4\, Re_x^{-9} \left(\frac{L}{H}\right)^{16} (1+n)^4 (sin\emptyset)^4$ and $Re_x^{-\frac{1}{2}} = l/L$.

The T – temperature distribution, C – concentration distribution, v – velocity, Nu – overall Nusselt number and Sh – overall Sherwood number are calculated for distinct values of Ra – Rayleigh number , n – buoyancy ratio, $\emptyset$ - tiled angle.

III. SIMILARITY SOLUTION

The analysis of the previous section was concerned with finding analytical solution when Le =1 with different values of Ra, n and $\emptyset$. In this section we obtain the effect of Lewis number on quantities such as Sh and Nu for distinct values of Le and $\emptyset$. The buoyancy ratio (n) extremes, is so called $|n| << 1$ (heat transfer driven flow) and $|n| >> 1$ (mass driven flows), and the flow and temperature fields in this extreme are obtained by setting $n = 0$ in the preceding solution.

In the limitation of large Le, the layer region of buoyancy concentration in which (7) is solved in much slighter than the velocity and Hartmann region of boundary layer. Accordingly, in the place of v in (7), we can use $v(x)$, then the velocity distribution approaches

$$v = \left(\frac{\partial v}{\partial x}\right)_{x=0} x \tag{30}$$

where $v(x)$ is given by equation (20). Therefore the limit Le→ ∞, the concentration field and the mass transfer rate begins with substituting equation (30) and u = 0 in the constituent conservation equation (7)

$$\left(2^{\frac{1}{4}}\, \gamma^{\frac{5}{2}}\, \alpha\, L^{\frac{1}{2}}\right) x \frac{\partial c}{\partial y} = D \frac{\partial^2 c}{\partial x^2} \tag{31}$$

This equation is solved subject to the form of uniform mass flux at x = 0, and the uniform concentration $C = C_0$ outside the boundary layer of concentration. The similarity formulation of the problem is

$$f'' + \frac{\eta^2}{3} f' - \frac{\eta}{3} f = 0 \tag{32}$$

subject to the condition $\qquad f'(0) = -1, \quad f(\infty) = 0 \qquad (33)$

where $\eta = \hat{x}\left(\frac{\hat{y}}{B}\right)^{-\frac{1}{3}}, \quad \hat{x} = \left(\frac{H}{x}\right)^{-1}, \quad \hat{y} = \left(\frac{H}{y+\frac{H}{2}}\right)^{-1}, \quad B = 2^{\frac{1}{4}}\, \gamma^{\frac{5}{2}}\, \alpha\, L^{\frac{1}{2}}\, Le\, H^2, \quad f = \frac{(c-c_0)}{j^{''}\left(\frac{H}{D}\right)}\left(\frac{\hat{y}}{B}\right)^{-\frac{1}{3}} \qquad (34)$

Trevisan and Bejan (1987) have solved this problem numerically using the fourth-order Runge-Kutta method combined with the standard shooting method. The novelty of this section is to find the analytical solution of the present problem. These analytical solutions are important to understand the effect of parameters and the solutions find have vide application in many practical situation.

The solution of equation (32) satisfying (33), is

$$f(\eta) = 1.5368 \left(e^{-\frac{\eta^3}{9}} + \eta \int_{\infty}^{\eta} \left(\frac{\eta}{3}\, e^{-\frac{\eta^3}{9}}\right) d\eta\right) \tag{35}$$

The solution is listed in Table 1. With the known value of f, it can be easily find the overall Nusselt number Nu and Sherwood number Sh by using the definition

$$Nu = \frac{q^{''}}{k\left(\frac{\Delta T}{L}\right)} = 0.445\, (Ra\, |n|)^{\frac{5}{27}} \left(\frac{L}{H}\right)^{\frac{29}{27}} Le^{-\frac{1}{3}} (sin\emptyset)^{\frac{5}{27}} \tag{36}$$

$$Sh = \frac{j^{''}}{D\left(\frac{\Delta C}{L}\right)} = 0.445\, (Ra)^{\frac{5}{27}} \left(\frac{L}{H}\right)^{\frac{29}{27}} Le^{+\frac{1}{3}} (sin\emptyset)^{\frac{5}{27}} \tag{37}$$

Here, the value of γ is obtained from (29). For the inclination angle $\emptyset = 90^{\circ}$, equation (36) and (37) reduces to

$$Nu = 0.445 \; (\, Ra \, |n| \,)^{\frac{5}{27}} \left(\frac{L}{H} \right)^{\frac{29}{27}} \; Le^{-\frac{1}{3}} \tag{38}$$

$$Sh = 0.445 \; (\, Ra \,)^{\frac{5}{27}} \left(\frac{L}{H} \right)^{\frac{29}{27}} \; Le^{+\frac{1}{3}} \tag{39}$$

which is exactly the same as given by Trevisan and Bejan (1987).

Table 1: Similarity $c(x)$ for $|\, n \,| << 1$ where Le > > 1 (Similarity $t(x)$ for $|\, n \,| >> 1$ where Le < < 1)

η	*f*	*f'*
0	1.536	- 1.000
.5	1.046	- 0.936
1	0.619	- 0.755
1.5	0.304	- 0.501
2	0.116	- 0.257
2.5	0.033	- 0.095
3	0.006	- 0.023
3.5	0.001	- 0.004
4	0.000	- 0.000

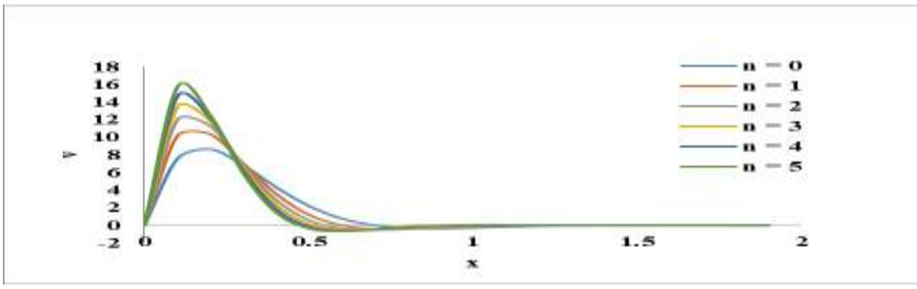

Fig. 2 Velocity profiles for Ø = 30 and for different values of ' n '

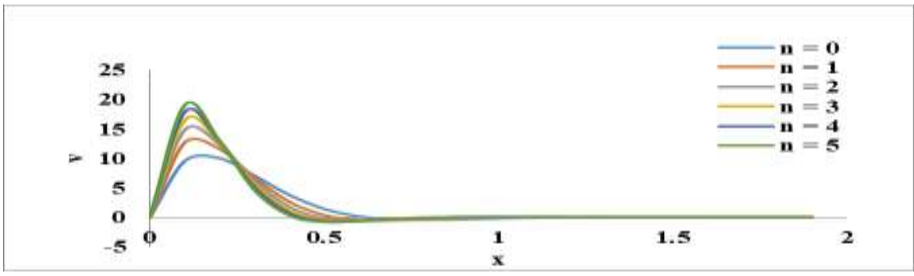

Fig. 3 Velocity profiles for Ø = 120 and for different values of ' n '

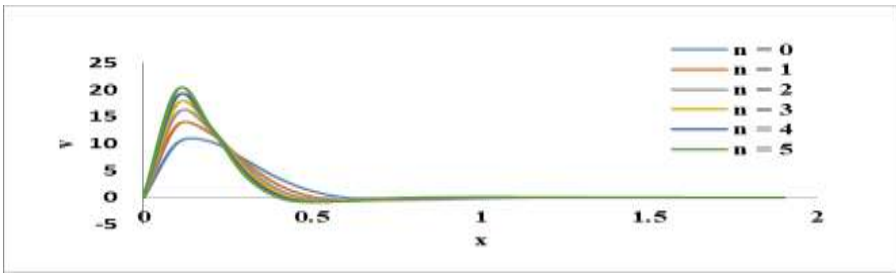

Fig. 4 Velocity profiles for Ø = 90 and for different values of ' n '

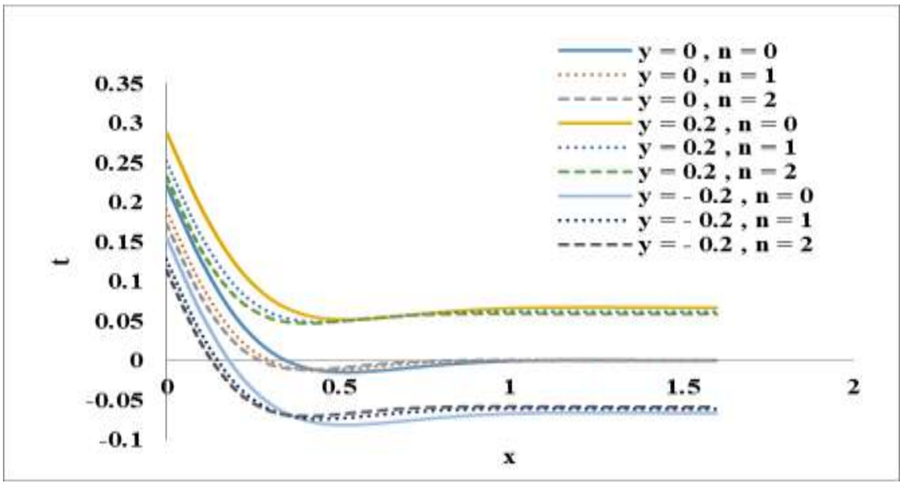

Fig. 5 The Horizontal variation of Temperature 't' at the level y =0, ±0.2 and at ∅ = 30

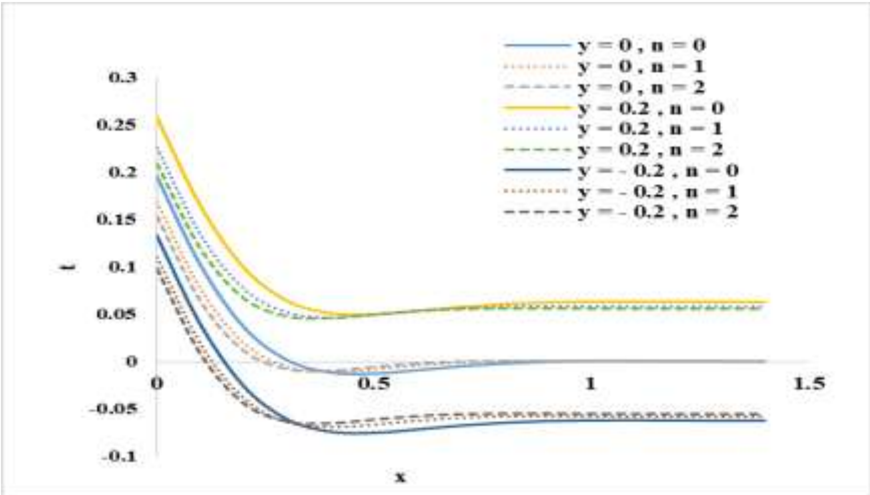

Fig. 6 The Horizontal variation of Temperature 't' at the level y =0, ±0.2 and at ∅ = 120

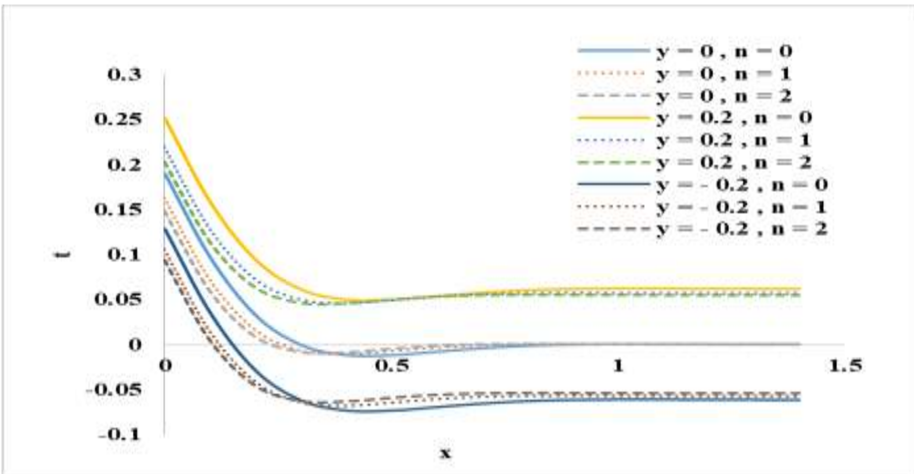

Fig. 7 The Horizontal variation of Temperature 't' at the level y =0, ±0.2 and at ∅ = 90

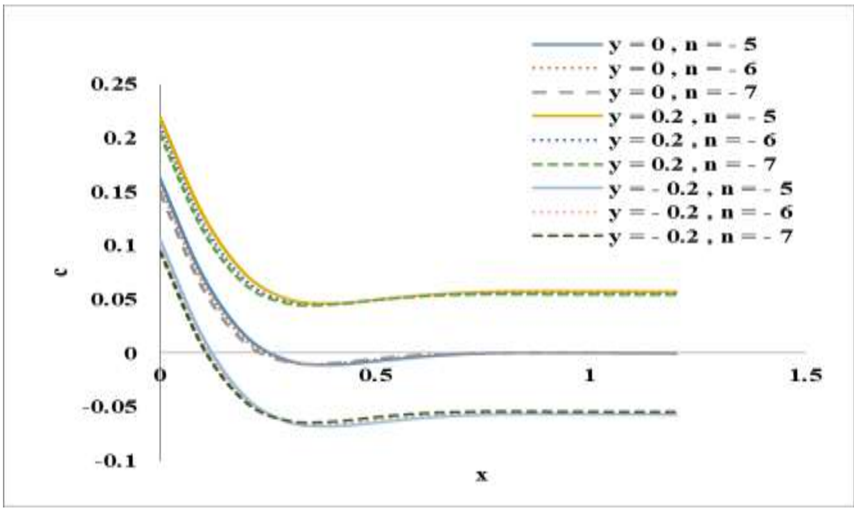

Fig. 8 The Horizontal variation of Concentration 'c' at the level y =0, ±0.2 and at ∅ = 30

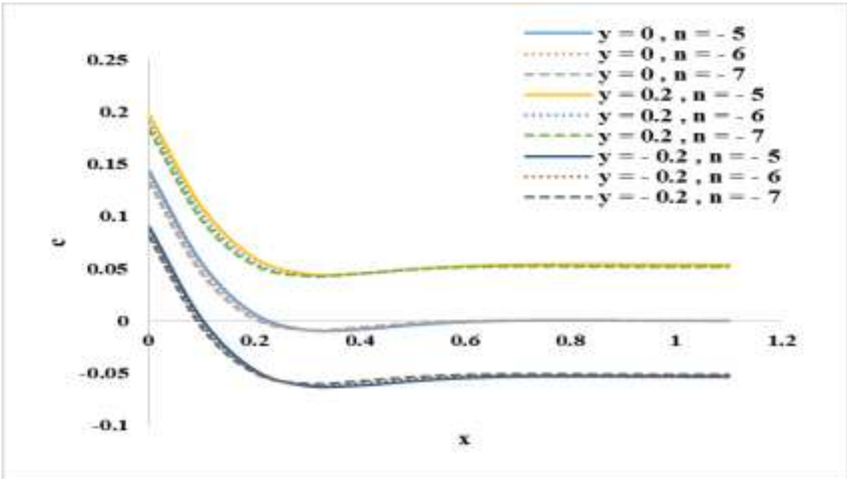

Fig. 9 The Horizontal variation of Concentration 'c' at the level y =0, ±0.2 and at ∅ = 120

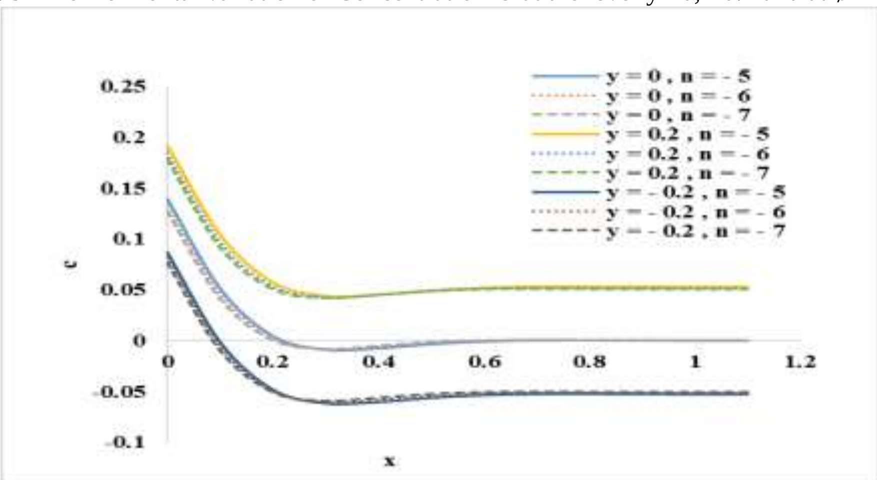

Fig. 10 The Horizontal variation of Concentration 'c' at the level y =0, ±0.2 and at ∅ =90

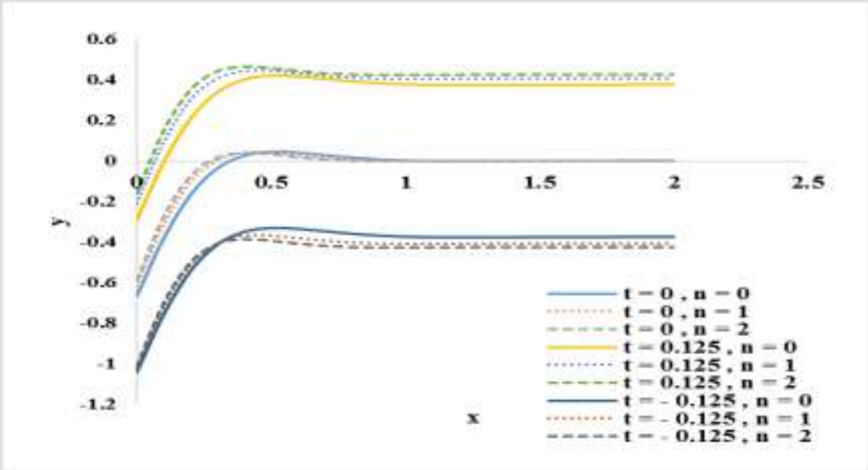

Fig. 11 Isotherms at ∅ = 30

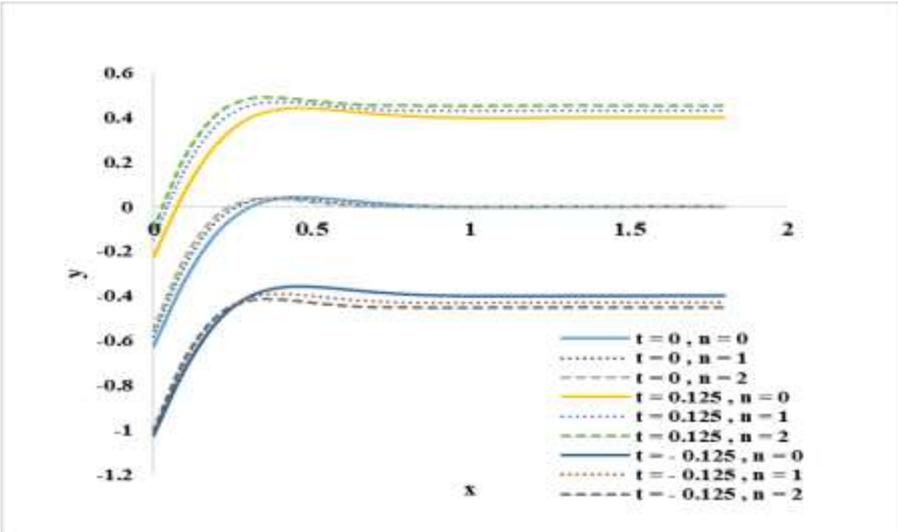

Fig. 12 Isotherms at ∅ = 120

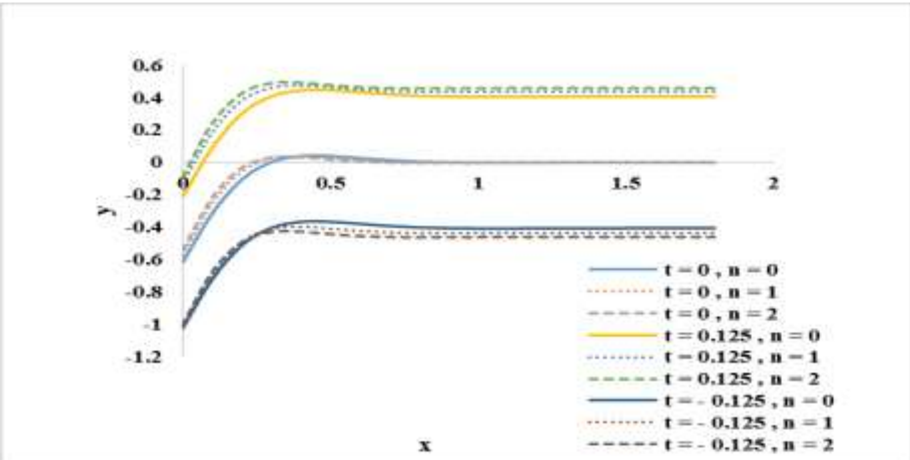

Fig. 13 Isotherms at ∅ = 90

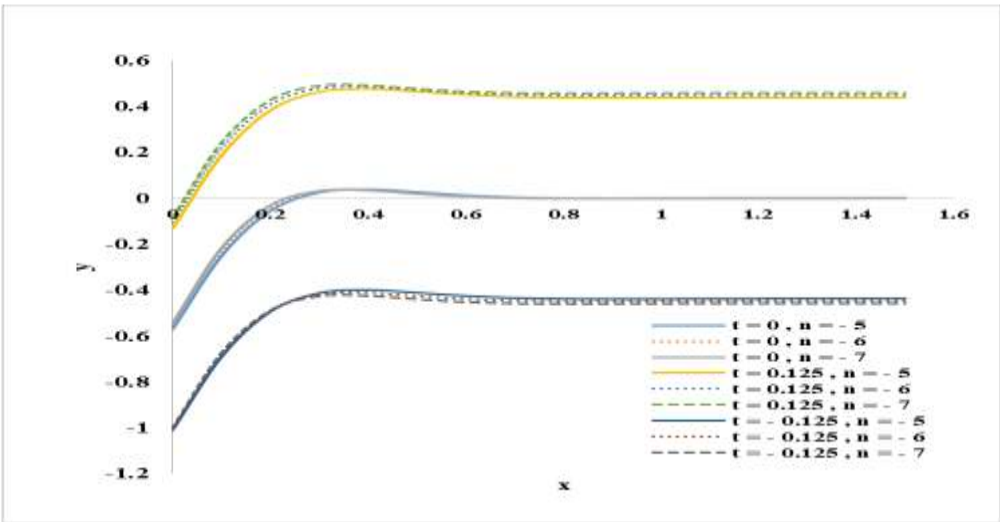

Fig. 14 Isohalines at Ø = 30

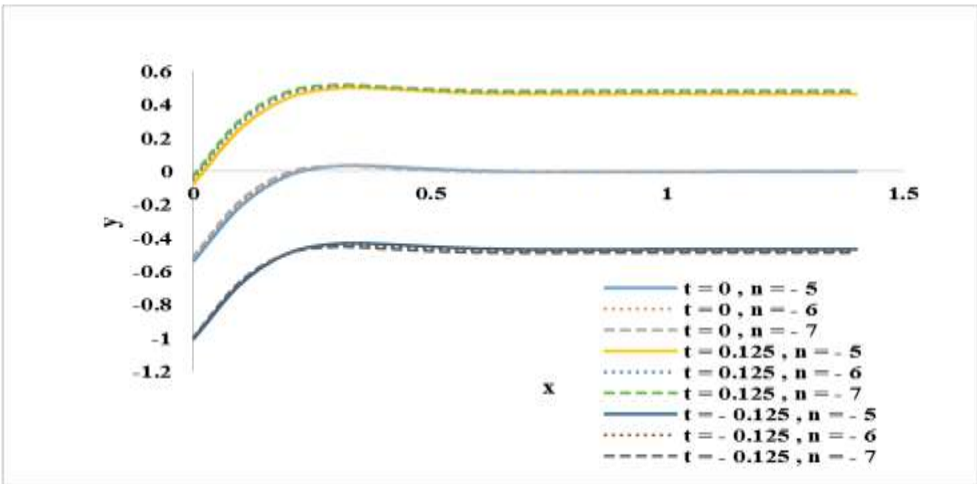

Fig. 15 Isohalines at Ø = 120

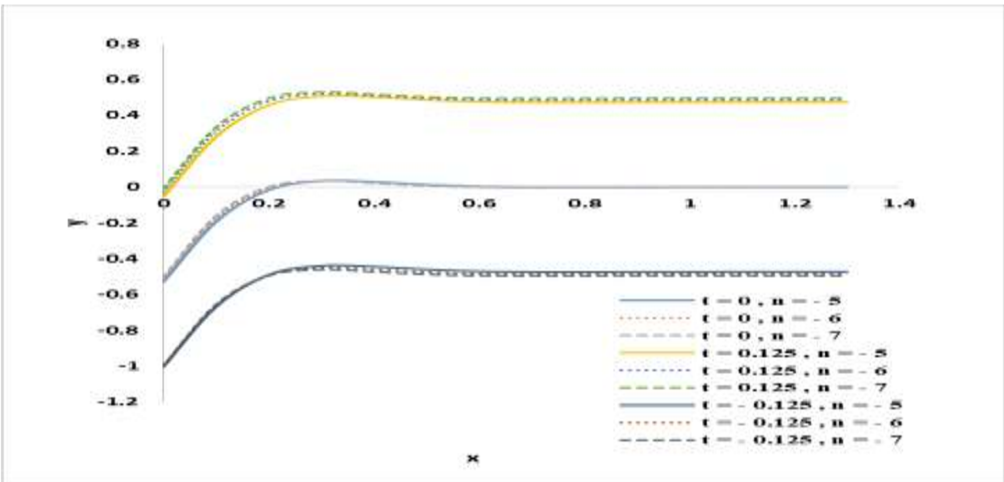

Fig. 16 Isohalines at Ø = 90

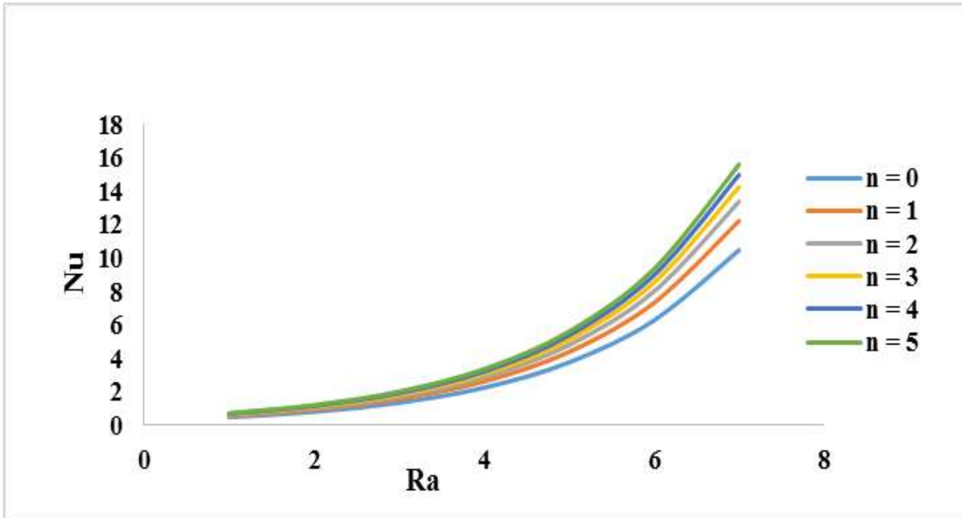

Fig. 17 Nu Vs Ra for different values of 'n' when Ø = 30
(In x-axis 2=10^2, 4=10^4, 6=10^6 …….)

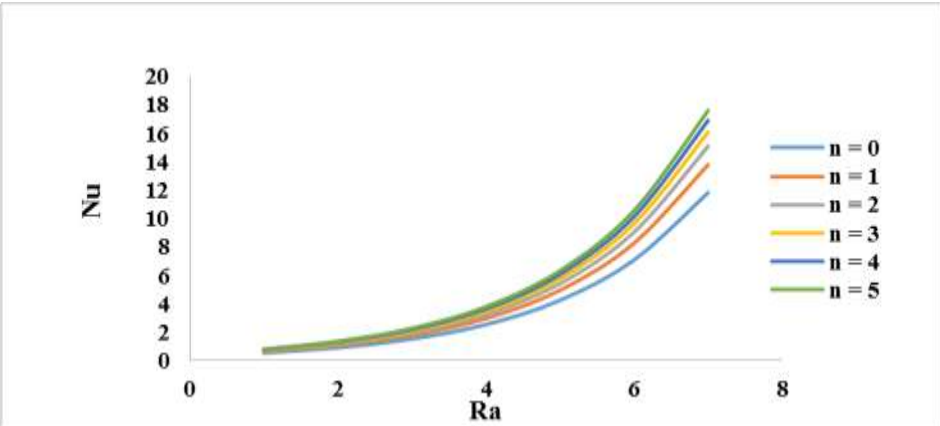

Fig. 18 Nu Vs Ra for different values of 'n' when Ø = 120
(In x-axis 2=10^2, 4=10^4, 6=10^6 …….)

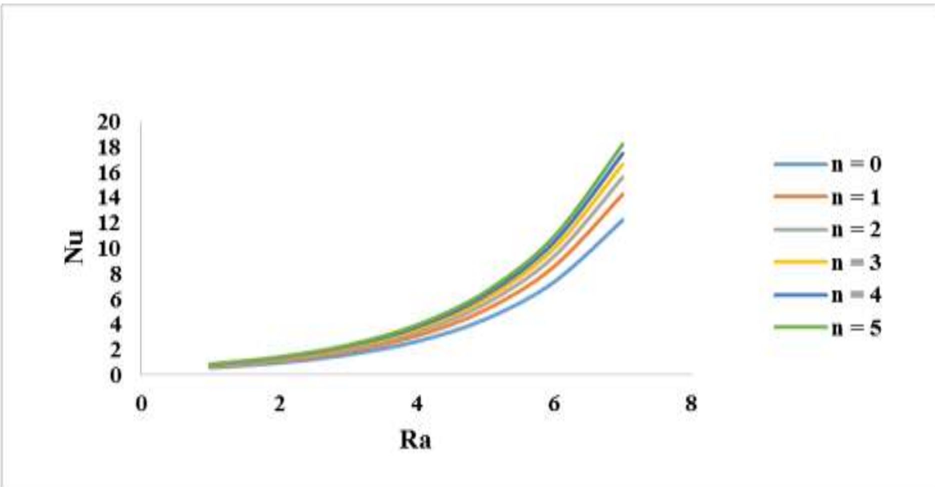

Fig. 19 Nu Vs Ra for different values of 'n' when Ø = 90
(In x-axis 2=10^2, 4=10^4, 6=10^6 …….)

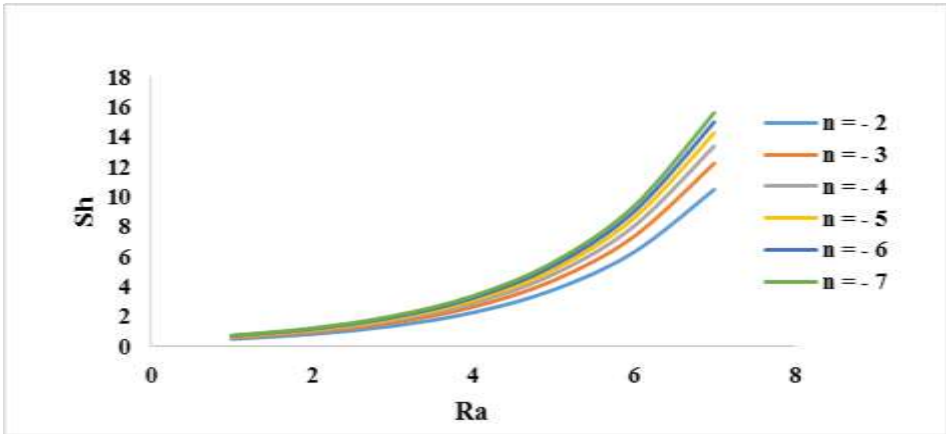

Fig. 20 Sh Vs Ra for different values of 'n' when ∅ = 30
(In x-axis $2=10^2$, $4=10^4$, $6=10^6$ …….)

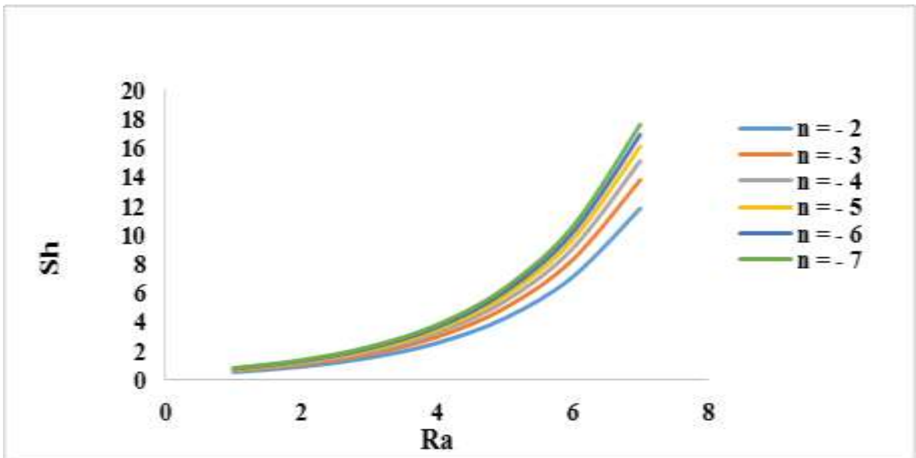

Fig. 21 Sh Vs Ra for different values of 'n' when ∅ = 120
(In x-axis $2=10^2$, $4=10^4$, $6=10^6$ …….)

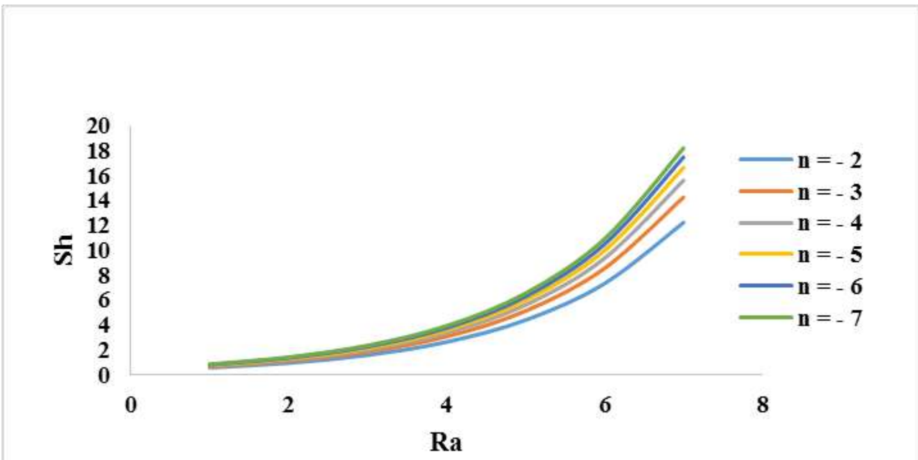

Figure 22 Sh Vs Ra for different values of 'n' when ∅ = 90
(In x-axis $2=10^2$, $4=10^4$, $6=10^6$ …….)

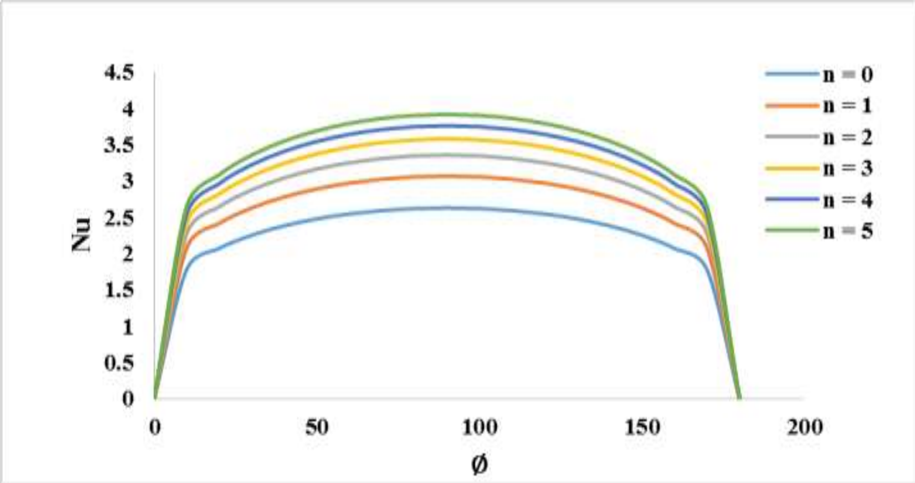

Fig. 23 Nu Vs Ø for different values of 'n'

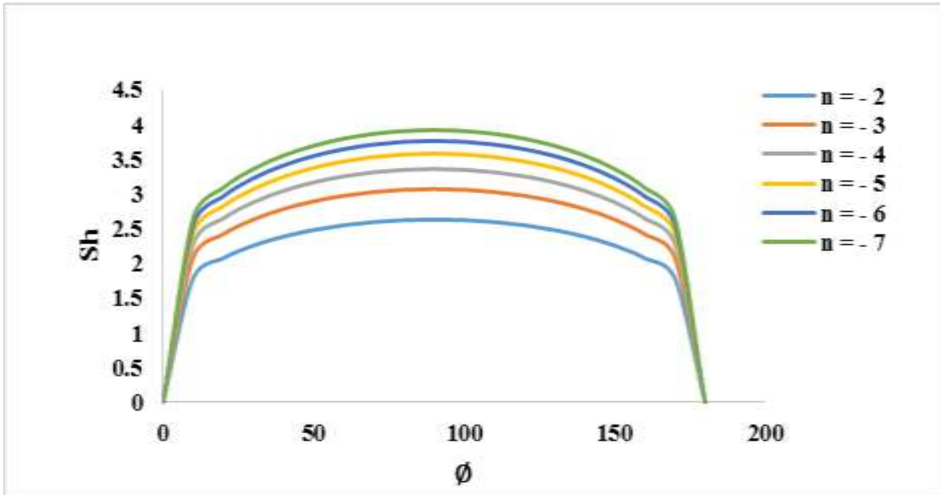

Fig. 24 Sh Vs Ø for different values of 'n

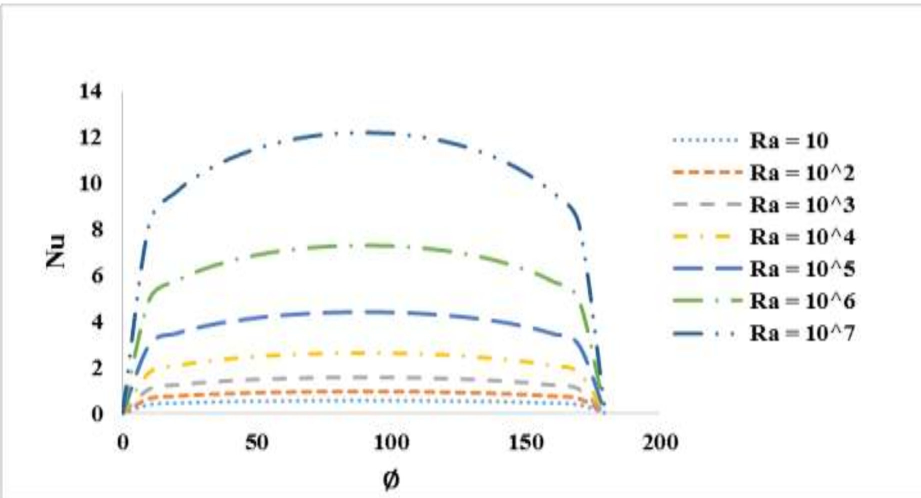

Fig. 25 Nu Vs Ø for different values of 'Ra

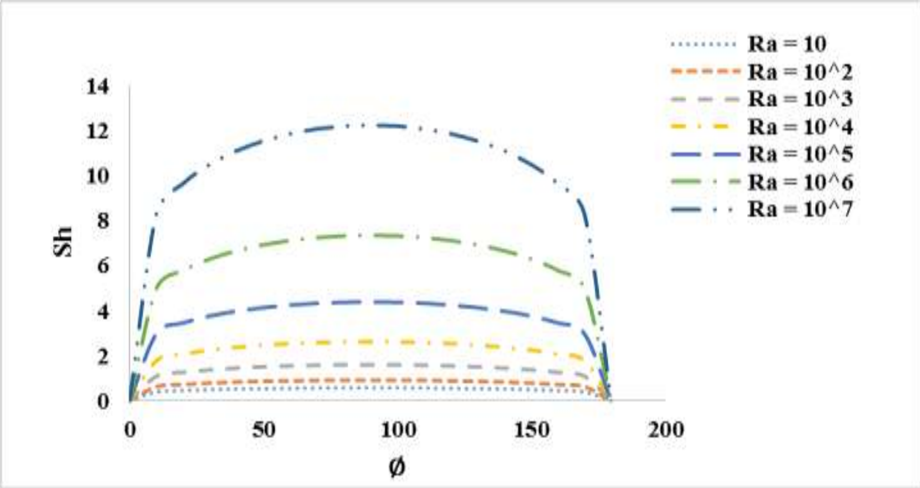

Fig. 26 Sh Vs Ø for different values of 'Ra'

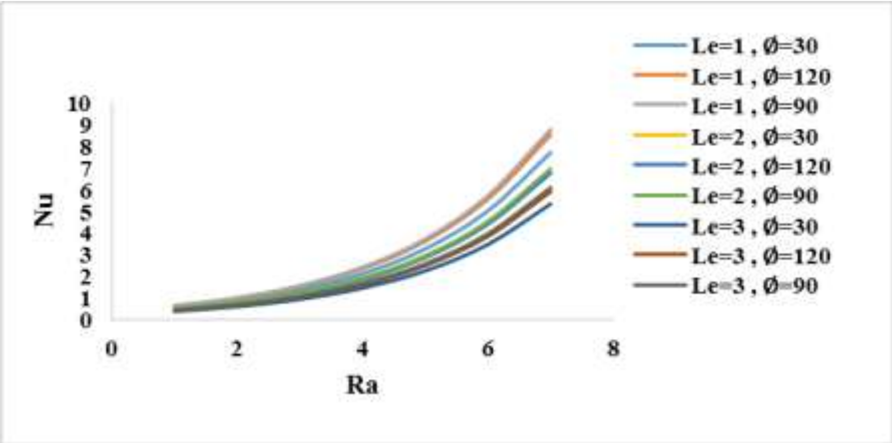

Fig. 27 Nu Vs Ra for different values of Ø and Le
(In x-axis 2=10^2, 4=10^4, 6=10^6 …….)

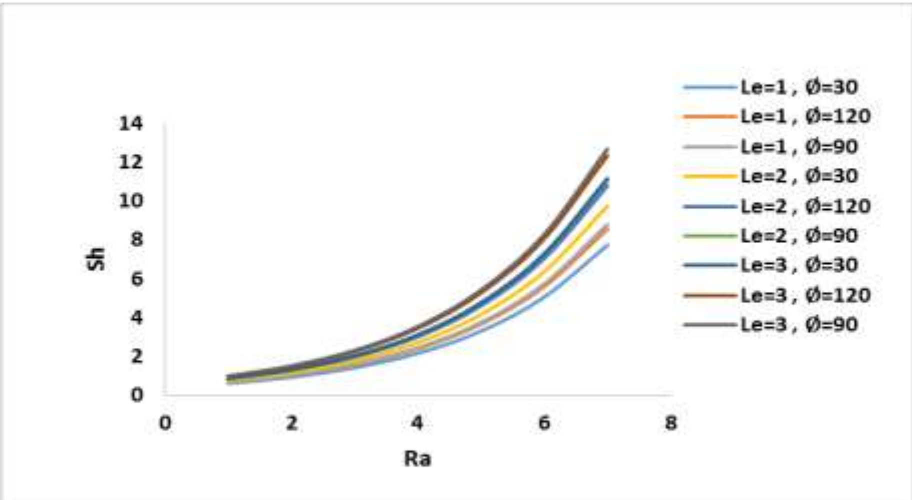

Fig. 28 Sh Vs Ra for different values of Ø and Le
(In x-axis 2=10^2, 4=10^4, 6=10^6 …….)

IV. CONCLUSIONS

A systematic study is presented on natural convection of a tiled rectangular cavity, perpendicular to gravity. The walls of two side are retained at constant heat flux and mass flux condition and the parallel top and bottom walls are thermally insulated. The parameter of non-dimension are the tilt angle $\emptyset$, the Rayleigh number Ra and the aspect ratio H/L. This study H/L$\gg$1 and estimations are execute for the tilt angle $\emptyset$ differ from $0^{\circ} - 180^{\circ}$, Rayleigh number Ra ranging from 10 to 10^7. Outcomes are presented graphically to demonstrate the effects of angle of inclination on the flow pattern and the temperature characteristics. The heat transfer rate and mass transfer rate are got by estimate the mean Nusselt number and Sherwood number respectively. The variations of the overall Nusselt number Nu and overall Sherwood number Sh with the angle of inclinations are also presented.

Figure 2 to 4 are plots of dimensionless velocity verse the stretched horizontal coordinate x for distinct values of buoyancy ratio n and the inclination angle $\emptyset$. It is clear that the velocity reduces with raising values of buoyancy ratio (n = 0 to 5) and for different inclination angle ($\emptyset = 30^{\circ}, 90^{\circ}, 120^{\circ}$).

Figure 5 to 7 are plots of non-dimensional temperature profiles versus stretched horizontal coordinates x at various position (y = 0, ± 0.2) for various values of the inclination angle $\emptyset$ and buoyancy ratio n. It depicts the exponentially decreasing nature of the temperature. The field of thermal in the internal core shown a linear perpendicular stratification. This is characteristic of Oseen linearized based solution.

Figure 8 to 10 are plots of non-dimensional concentration profiles versus stretched horizontal coordinates x at various position (y = 0, ± 0.2) for different values of the inclination angle $\emptyset$ and negative buoyancy ratio n. It depicts the exponentially decreasing nature of the concentration. The field of concentration in the internal core shown a linear perpendicular stratification. This is characteristic of Oseen linearized based solution.

Figure 11 to 13 shows isotherms for $\emptyset = 30^{\circ}, 90^{\circ}, 120^{\circ}$ respectively for different values of n. The isotherms are parallel to x-axis in the major part of configuration expect in very fine thermal layer of the boundary near the vertical rigid plates. In this case, the thermal field resembles that of conductive distribution. In this situation the viscous layer of the boundary is covered by the thermal layer of the boundary. It conclude that, for all angles of inclination, the boundary layer that exists close to the perpendicular walls which is very favourable to control heat transfer over the enclosure by suppressing convection.

Figure 14 to 16 shows isohalines for $\emptyset = 30^{\circ}, 90^{\circ}, 120^{\circ}$ respectively for different values of n. The isohalines are parallel to x-axis in the major part of configuration expect in very fine concentration layer of the boundary near the vertical rigid plates. In this case, the concentration field resembles that of conductive distribution. In this situation the viscous layer of the boundary is covered by the concentration layer of the boundary. We conclude that, for all angles of inclination, the boundary layer that exists close to the perpendicular walls which is very favourable to control mass transfer across the enclosure by suppressing convection.

The complete rate of heat transfer over the cavity is got by estimating the Nusselt number Nu along the perpendicular walls. Figure 17 to 19, 23 and 25 which gives the difference of mean in the Nusselt number Nu for different values of buoyancy ratio n, the inclination angle $\emptyset$ and Rayleigh Number Ra. Where the enclosure is heated from the tip, there is a change in heat transfer which will fall in the range $\emptyset < \frac{\pi}{2}$. As the angle of inclination $\emptyset$ is raised above $\frac{\pi}{2}$, it yields a situation where in the enclosure is heated from the base. The Nusselt number Nu sustains to raise with raising value of $\emptyset$ which passes through a top and then begin to fall down. The result of heating the enclosure from the tip $0 < \emptyset < \frac{\pi}{2}$, the Nusselt number Nu is observe to be huge when compare with that of the heating from base $\frac{\pi}{2} < \emptyset < \pi$. It is also observed that the result of inclination angle on Nusselt number Nu verses Rayleigh number Ra, the Nu increases with an increases in Ra and buoyancy ratio n. The peak of the Nu that takes place at a lesser inclination angle when the Rayleigh number are raised. As n increases, the figure shows that the thermal effects are dominant.

The complete rate of mass transfer over the cavity is got by estimating the Sherwood number Sh along the perpendicular walls. Figure 20 to 22, 24 and 26 which gives the difference of mean in the Sherwood number Sh for different values of negative buoyancy ratio n, the inclination angle $\emptyset$ and Rayleigh number Ra. Where the enclosure is heated from the tip, there is a change in mass transfer which will fall in the range $\emptyset < \frac{\pi}{2}$. As the angle of inclination $\emptyset$ is raised above $\frac{\pi}{2}$, it yields a situation where in the enclosure is heated from the base. The Sherwood number Sh sustain to raise with raising value of $\emptyset$ which passes through a top and then begin to fall down. The result of heating the enclosure from the tip $0 < \emptyset < \frac{\pi}{2}$, the Sherwood number Sh is observe to be huge when compare with that of the heating from base $\frac{\pi}{2} < \emptyset < \pi$. It is also observed that the result of inclination angle on Sherwood number Sh verses Rayleigh number Ra, the Sh increases with an increases in Ra and negative buoyancy ratio n. The peak of the Sh that takes place at a lesser inclination angle when the Rayleigh number are raised. As the negative n increases, the figure shows that the thermal effects are dominant.

Figure 27 is a plot of an average Nusselt number verses Rayleigh number Ra for various values of inclination angle and buoyancy ratio n = 0. As Lewis number Le, increases, the heat transfer rates decreases. This indicates the temperature effect is dominant. Figure 28 is a plot of an average Sherwood number verses Ra for different values of inclination angle and buoyancy ratio n = 0. As Lewis number Le, increases. The mass transfer rate decreases. This indicates the concentration effect is dominant.

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