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Effects of chemical reaction, radiation and thermo-diffusion on convective heat and mass transfer flow of a viscous dissipated fluid in a vertical channel with constant heat flux

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ABSTRACT

We made attempt in this paper to study thermo-diffusion effect on non-Darcy convective heat and Mass transfer flow of a viscous fluid through a porous medium in a vertical channel with Radiation and heat generating sources. The governing equations flow, heat and mass transfer are solved by using regular perturbation method with δ, the porosity parameter as a perturbation parameter. The velocity, temperature, concentration, shear stress and rate of Heat and Mass transfer are evaluated numerically for different variations of parameter.

Keywords: Non-Darcy flow, Heat and Mass Transfer, Constant heat flux, Heat sources

INTRODUCTION

The phenomenon of heat and mass transfer has been the object of extensive research due to its applications in Science and Technology. Such phenomena are observed in buoyancy induced motions in the atmosphere, in bodies of water, quasisolid bodies such as earth and so on.

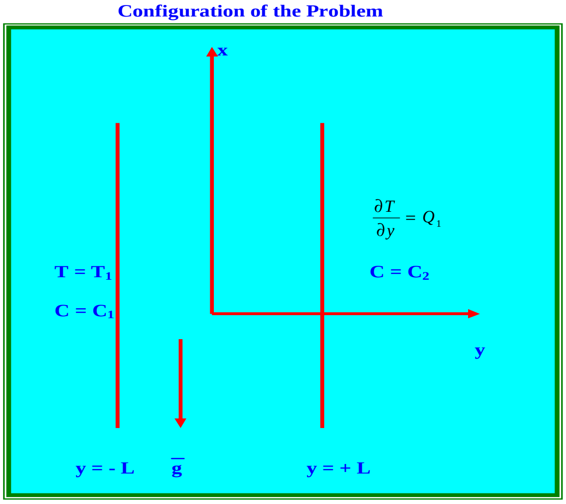
Non – Darcy effects on natural convection in porous media have received a great deal of attention in recent years because of the experiments conducted with several combinations of solids and fluids covering wide ranges of governing parameters which indicate that the experimental data for systems other than glass water at low Rayleigh numbers, do not agree with theoretical predictions based on the Darcy flow model. This divergence in the heat transfer results has been reviewed in detail in Cheng [5] and Prasad et al. [16] among others. Extensive effects are thus being made to include the inertia and viscous diffusion terms in the flow equations and to examine their effects in order to develop a reasonable accurate mathematical model for convective transport in porous media. The work of Vafai and Tien [21] was one of the early attempts to account for the boundary and inertia effects in the momentum equation for a porous medium. They found that the momentum boundary layer thickness is of order of $\sqrt{\frac{k}{\varepsilon}}$. Vafai and Thiyagaraja [22] presented analytical solutions for the velocity and temperature fields for the interface region using the Brinkman Forchheimer –extended Darcy equation. Detailed accounts of the recent efforts on non-Darcy convection have been recently reported in Tien and Hong [19], cheng [5], Prasad et al [16], and Kladias and Prasad [9]. Here, we will restrict our discussion to the vertical cavity only. Poulikakos and Bejan [13] investigated the inertia effects through the inclusion of Forchheimer's velocity squared term, and presented the boundary layer analysis for tall cavities. They also obtained numerical results for a few cases in order to verify the accuracy of their boundary layer analysis for tall cavities. They also obtained numerical results for a few cases in order to verify the accuracy of their boundary layer solutions. Later, Prasad and Tuntomo [14] reported an extensive numerical work for a wide range of parameters, and demonstrated that effects of Prandtl number remain almost unaltered while the dependence on the modified Grashof number, Gr, changes significantly with an increase in the Forchheimer number. This result in reversal of flow regimes from boundary layer to asymptotic to conduction as the contribution of the inertia term increases in comparison with that of the boundary term. They also reported a criterion for the Darcy flow limit.

The Brinkman – Extended – Darcy modal was considered in Tong and Subramanian [20], and Lauriat and Prasad [23] to examine the boundary effects on free convection in a vertical cavity. While Tong and Subramanian performed a Weber – type boundary layer analysis, Lauriat and Prasad solved the problem numerically for A=1 and 5. It was shown that for a fixed modified Rayleigh number, Ra, the Nusselt number; decrease with an increase in the Darcy number; the reduction being larger at higher values of Ra. A scale analysis as well as the computational data also showed that the transport term $(v.\nabla)v$, is of low order of magnitude compared to the diffusion plus buoyancy terms. A numerical study based on the Forchheimer-Brinkman-Extended Darcy equation of motion has also been reported recently by Beckerman et al [4]. They demonstrated that the inclusion of both the inertia and boundary effects is important for convection in a rectangular packed – sphere cavity.

Also in all the above studies the thermal diffusion effect (known as Soret effect) has been neglected. This assumption is true when the concentration level is very low. Therefore, so ever, exceptions the thermal diffusion effects for instance, has been utilized for isotropic separation and in mixtures between gases with very light molecular weight (H_2.He) and the medium molecular weight (N_2, air) the diffusion – thermo effects was found to be of a magnitude just it can not be neglected. In view of the importance of this diffusion – thermo effect, recently Jha and singh [7] studied the free convection and mass transfer flow in an infinite vertical plate moving impulsively in its own plane taking into account the Soret effect. Kafousias [8] studied the MHD free convection and mass transfer flow taking into account Soret effect. The analytical studies of Jha and singh [7] and Kafousias [8] were based on Laplace transform technique. Abdul Sattar and Alam [1] have considered an unsteady convection and mass transfer flow of viscous incompressible and electrically conducting fluid past a moving infinite vertical porous plate taking into the thermal diffusion effects. Similarity equations of the momentum energy and concentration equations are derived by introducing a time dependent length scale. Malsetty et al [12] have studied the effect of both the soret coefficient and Dufour coefficient on the double diffusive convective with compensating horizontal thermal and solutal gradients.

The effects of radiation on MHD flow and heat transfer problem have become more important industrially. Many processes in engineering areas occur at high temperature, and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, Gas turbines and various propulsion devices, for aircraft, missiles, satellites and space vehicles are examples of such engineering areas.

Configuration of the Problem



Recently Bharathi [3] has studied thermo-diffusion effect on unsteady convective Heat and Mass transfer flow of a viscous fluid through a porous medium in vertical channel. Radiative flow plays a vital role in many industrial and environmental process e.g. heating and cooling chambers , fossil fuel combustion energy process, evaporation form larger open water reservoirs, ,astrophysical flows, solar power technology and space vehicle re-entry. Taneja et al [18] studied the effects of magnetic field on free convective flow through porous medium with radiation and variable permeability in the slip flow regime. Kumar et al [10] studied the effect of MHD free convection flow of viscous fluid past a porous vertical plate through non homogeneous porous medium with radiations and temperature gradient dependent heat source in slip flow regime. The effect of free convection flow with thermal radiation and mass transfer past a moving vertical porous plate was studied by Makinde [11]. Ayani et al [2] studied the effect of radiation on the laminar natural convection induced by a line source. Raphil[17] have discussed the effect of radiation and free convection flow through porous medium. MHD oscillating flow on free convection radiation through porous medium with constant suction velocity was investigated by El.Hakiem[6]

Keeping the above application in view we made attempt in this paper to study thermo-diffusion effect on non-Darcy convective heat and Mass transfer flow of a viscous fluid through a porous medium in a vertical channel with Radiation and heat generating sources. The governing equations flow, heat and mass transfer are solved by using regular perturbation method with δ, the porosity parameter as a perturbation parameter. The velocity, temperature, concentration, shear stress and rate of Heat and Mass transfer are evaluated numerically for different variations of parameter

FORMULATION OF THE PROBLEM

We consider a fully developed laminar convective heat and mass transfer flow of a viscous, fluid through a porous medium confined in a vertical channel bounded by flat walls. We choose a Cartesian co-ordinate system O(x,y,z) with x- axis in the vertical direction and y-axis normal to the walls. The walls are taken at $y=\pm L$. The walls are maintained at constant concentration .The wall y=-L is maintained at constant temperature and the wall y=+L is maintained at a constant heat flux. The temperature gradient in the flow field is sufficient to cause natural convection in the flow field .A constant axial pressure gradient is also imposed so that this resultant flow is a mixed convection flow. The porous medium is assumed to be isotropic and homogeneous with constant porosity and effective thermal diffusivity. The thermo physical properties of porous matrix are also assumed to be constant and Boussinesq approximation is invoked by confining the density variation to the buoyancy term. In the absence of any extraneous force flow is unidirectional along the x-axis which is assumed to be infinite.

The Brinkman-Forchheimer-extended Darcy equation which account for boundary inertia effects in the momentum equation is used to obtain the velocity field.

Since the flow is unidirectional, the continuity of equation reduces to

$\frac{\partial u}{\partial x} = 0$ where u is the axial velocity implies u = u(y)

The momentum, energy and diffusion equations in the scalar form reduces to

$$-\frac{\partial p}{\partial x} + (\frac{\mu}{\delta})\frac{\partial^2 u}{\partial y^2} - (\frac{\mu}{k})u - \frac{\rho\delta F}{\sqrt{k}}u^2 - \rho g = 0 \tag{1}$$

$$\rho_0 C_p u\frac{\partial T}{\partial x} = \lambda\frac{\partial^2 T}{\partial y^2} + Q - \frac{\partial(q_R)}{\partial y} + \mu(\frac{du}{dy})^2 \tag{2}$$

$$u\frac{\partial C}{\partial x} = D_1\frac{\partial^2 C}{\partial y^2} - k_1 C + k_{11}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

The boundary conditions are

$$\left.\begin{aligned} &u = 0 \quad , \quad T = T_1 \quad C = C_1 \qquad on \quad y = -L \\ &u = 0 \quad , \quad \frac{\partial T}{\partial y} = q_1 \; , \; C = C_2 \qquad on \quad y = +L \end{aligned}\right. \tag{4}$$

The axial temperature and concentration gradients $\frac{\partial T}{\partial x}$ & $\frac{\partial C}{\partial x}$ are assumed to be constant say, A &B respectively.

We define the following non-dimensional variables as

$$\left.\begin{aligned} &u' = \frac{u}{(\nu/L)}, \; (x',y') = (x,y)/L \; , \quad p' = \frac{p\delta}{(\rho\nu^2/L^2)} \\ &\theta = \frac{T - T_e}{T_1 - T_e} \quad , \quad C' = \frac{C - C_1}{C_2 - C_1} \end{aligned}\right| \tag{5}$$

Introducing these non-dimensional variables the governing equations in the dimensionless form reduce to (on dropping the dashes)

$$\frac{d^2u}{dy^2} = \pi + \delta(D^{-1})u - \delta G(\theta + NC) - \delta^2 \Delta u^2 \tag{6}$$

$$\frac{d^2\theta}{dy^2} = -\alpha_1 + (P_1 N_T)u + P_1 E_c (\frac{du}{dy})^2 \tag{7}$$

$$\frac{d^2C}{dy^2} - \gamma C = (Sc\, N_C)u + \frac{ScSo}{N}\frac{d^2\theta}{dy^2} \tag{8}$$

where

$\Delta = FD^{-1/2}$ (Inertia or Fochhemeir parameter) $G = \frac{\beta g(T_1 - T_2)L^3}{\nu^2}$ (Grashof Number)

$D^{-1} = \frac{L^2}{k}$ (Darcy parameter) $Sc = \frac{\nu}{D_1}$ (Schmidt Number)

$S_o = \frac{k_{11}\beta^{\bullet}}{\nu\beta}$ (Soret parameter) $N = \frac{\beta^{\bullet}(C_1 - C_2)}{\beta(T_1 - T_2)}$ (Buoyancy ratio)

$P = \frac{\mu C_p}{\lambda}$ (Prandtl Number) $\alpha = \frac{QL^2}{(T_1 - T_e)\lambda}$ (Heat source parameter)

$\gamma = \frac{k_1 L^2}{D_1}$ (Chemical reaction parameter) $N_T = \frac{AL}{(T_1 - T_2)}$ (Non-dimensional temperature gradient),

$N_c = \frac{BL}{(C_1 - C_2)}$ (non-dimensional concentration gradient)

The corresponding boundary conditions are

$$u = 0 \;,\; \theta = 1 \;,\; C = 1 \quad on \;\; y = -1$$

$$u = 0 \;,\; \frac{\partial\theta}{\partial y} = 1, \; C = 0 \quad on \;\; y = +1 \tag{9}$$

SOLUTION OF THE PROBLEM

The governing equations of flow, heat and mass transfer are coupled non-linear differential equations. Assuming the porosity δ to be small we write

$$u = u_0 + \delta u_1 + \delta^2 u_2 + \ldots.., \; \theta = \theta_0 + \delta\theta_1 + \delta^2\theta_2 + \ldots., C = C_0 + \delta\, C_1 + \delta^2\, C_2 + \ldots \tag{10}$$

Substituting the above expansions in the equations (8)-(10) and equating like powers of δ ,we obtain equations to the zeroth order as

$$\frac{d^2u_0}{dy^2} = \pi \tag{11}$$

$$\frac{d^2\theta_0}{dy^2} = -\alpha_1 + (P_1 N_T)u_0 + P_1 E_c (\frac{du_0}{dy})^2 \tag{12}$$

$$\frac{d^2C_0}{dy^2} - \gamma C_0 = (ScN_C)u_0 \tag{13}$$

The equations to the first order are

$$\frac{d^2u_1}{dy^2}-(D^{-1})u_1=-G(\theta_0+NC_0) \tag{14}$$

$$\frac{d^2\theta_1}{dy^2}=(PN_T)u_1+2P_1E_c(\frac{du_o}{dy})(\frac{du_1}{dy}) \tag{15}$$

$$\frac{d^2C_1}{dy^2}-\gamma C_1=(ScN_C)u_1 \tag{16}$$

The equations to the second order are

$$\frac{d^2u_2}{dy^2}-(D^{-1})u_2=-G(\theta_1+NC_1)-\Delta u_0^2 \tag{17}$$

$$\frac{d^2\theta_2}{dy^2}=(P_1N_T)u_2+P_1E_c((\frac{du_1}{dy})^2+2(\frac{du_o}{dy})(\frac{du_2}{dy}) \tag{18}$$

$$\frac{d^2C_2}{dy^2}-\gamma C_2=(ScN_C)u_2 \tag{19}$$

The corresponding conditions are

$$u_0(1)=u_0(-1)=0\ ,\ (\frac{d\theta_o}{dy})(+1)=0,\ \ \theta_0(-1)=1, C_0(+1)=0,\ \ C_0(-1)=1 \tag{20}$$

$$u_1(1)=u_1(-1)=0\ ,\ (\frac{d\theta_1}{dy})(+1)=0,\ \ \theta_1(-1)=0, C_1(+1)=0,\ \ C_1(-1)=0 \tag{21}$$

$$u_2(1)=u_2(-1)=0\ ,\ (\frac{d\theta_2}{dy})(+1)=0,\ \ \theta_2(-1)=0, C_2(+1)=0,\ \ C_2(-1)=0 \tag{22}$$

Solving the equations (11)-(19) subject to the boundary conditions (21) –(22) we get

$$u_0(y)=\frac{\pi}{2}(y^2-1)$$

$$\theta_0=0.5a_2y(y+1)+\frac{a_2}{8}y(y^3+1)+\frac{a_3}{30}y(y^5+1)-a_6(y+1)(y+2)$$

$$C_0=0.5a_8(y^2-1)+\frac{a_9}{12}(y^4-1)+\frac{a_{10}}{30}(y^6-1)+0.5(y+1)$$

$$u_1=a_{19}(1-\frac{Ch(\beta_1y)}{Ch(\beta_1)})+a_{20}(y-\frac{Sh(\beta_1y)}{Sh(\beta_1)})+a_{21}(y^2-\frac{Ch(\beta_1y)}{Ch(\beta_1)})+$$

$$+a_{22}(y^4-\frac{Ch(\beta_1y)}{Ch(\beta_1)})+a_{23}(y^6-\frac{Ch(\beta_1y)}{Ch(\beta_1)})$$

$$\theta_1=a_{34}(y^2-2y-3)+a_{35}(y^3-3y-2)+a_{36}(y^4-4y-5)+$$

$$+a_{37}(y^6-6y-7)+a_{38}(y^8-8y-9)+a_{39}(Ch(\beta_1y)-$$

$$-\beta_1ySh(\beta_1)-Ch(\beta_1)-\beta_1Sh(\beta_1))a_{40}(Sh(\beta_1y)-\beta_1yCh(\beta_1)-$$

$$-\beta_1Ch(\beta_1)+Sh(\beta_1))a_{41}(ySh(\beta_1y)-\beta_1Ch(\beta_1)-\beta_1yCh(\beta_1)$$

$$-Sh(\beta_1)+a_{42}(yCh(\beta_1y)-yCh(\beta_1)-\beta_1(y+1)Sh(\beta_1)$$

$$C_1 = a_{54}(y^2-1)+a_{55}(y^3-y)+a_{56}(y^4-1)+a_{57}(y^6-1)+a_{58}(y^8-1)$$
$$+a_{59}(Ch(\beta_1 y0 - Ch(\beta_1))+a_{60}(Sh(\beta_1 y)-ySh(\beta_1))-a_{60}(ySh(\beta_1 y)-$$
$$-Sh(\beta_1)-a_{62}y(Ch(\beta_1 y)-Ch(\beta_1))$$

$$u_2 = b_2(y-1)+_3(y^2-1)+b_4(y^3-y)+b_5(y^4-1)+b_6(y^6-1)+b_7(y^8-1)$$
$$+b_9 y(Ch(\beta_1 y)-Ch(\beta_1))+(b_8+yb_{10})(ySh(\beta_1 y)-Sh(\beta_1))+b_{17}(y^2 Ch(\beta_1 y)$$
$$-Ch(\beta_1))$$

$$C_2 = a_{77}(Ch(M_1 y)-Ch(M_1)\frac{Ch(\beta_1 y)}{Ch(\beta_1)})+a_{78}(Sh(M_1 y)-Sh(M_{12})\frac{Sh(\beta_1 y)}{Sh(\beta_1)})+$$
$$+a_{79}(yCh(\beta_1 y)-Ch(\beta_1)\frac{Sh(\beta_2 y)}{Sh(\beta_2)})+a_{80}(y^2-1)Ch(\beta_1 y)+$$
$$+a_{79}(y^4-1)+a_{81}(y^2-1)+a_{80}(ySh(\beta_1 y)-$$
$$-\frac{Ch(\beta_1 y)}{Ch(\beta_1)}Sh(\beta_1))+a_{81}(Ch(\beta_2 y)-\frac{Ch(\beta_1 y)}{Ch(\beta_1)}Ch(\beta_2))+$$
$$+a_{82}(Sh(\beta_2 y)-\frac{Sh(\beta_1 y)}{Sh(\beta_1)}Sh(\beta_2))-a_{83}(yCh(M_1 y)-Ch(M_1)\frac{Sh(\beta_1 y)}{Sh(\beta_1)})-$$
$$-a_{84}(ySh(M_1 y)-Sh(M_1)\frac{Ch(\beta_1 y)}{Ch(\beta_1)})-a_{85}(yCh(\beta_2 y)-Ch(\beta_2)\frac{Sh(\beta_1 y)}{Sh(\beta_1)})-$$
$$-a_{86}(ySh(\beta_2 y)-Sh(\beta_2)\frac{Ch(\beta_1 y)}{Ch(\beta_1)})-a_{87}(y^2-1)Ch(\beta_1 y)-a_{88}(y^2-1)Sh(\beta_1 y)-$$
$$-a_{89}(y^4-\frac{Ch(\beta_1 y)}{Ch(\beta_1)})+a_{90}(y^2-\frac{Ch(\beta_1 y)}{Ch(\beta_1)})+a_{91}(1-\frac{Ch(\beta_1 y)}{Ch(\beta_1)})$$

$$\theta_2 = b_{18}(Ch(\beta_1 y)-Ch(\beta_1)\frac{Ch(\beta_2 y)}{Ch(\beta_2)})+b_{18}(Sh(\beta_1 y)-Sh(\beta_1)\frac{Sh(\beta_2 y)}{Sh(\beta_2)})+$$
$$+b_{20}(ySh(\beta_2 y)-Sh(\beta_2)\frac{Ch(\beta_2 y)}{Ch(\beta_2)})+b_{21}(yCh(\beta_2 y)-Ch(\beta_2)\frac{Sh(\beta_2 y)}{Sh(\beta_2)})$$
$$+b_{22}(Ch(M_1 y)-Ch(M_1)\frac{Ch(\beta_2 y)}{Ch(\beta_2)})+b_{23}(Sh(M_1 y)-Sh(M_1)\frac{Sh(\beta_2 y)}{Sh(\beta_2)})+$$

$$+b_{24}(yCh(M_1y)-Ch(M_1)\frac{Sh(\beta_2 y)}{Sh(\beta_2)})+b_{25}(ySh(M_1y)-Sh(M_1)\frac{Ch(\beta_2 y)}{Ch(\beta_2)})+$$

$$+b_{26}(yCh(\beta_1 y)-\frac{Sh(\beta_2 y)}{Sh(\beta_2)}Ch(\beta_1))+b_{27}(ySh(\beta_1 y)-\frac{Ch(\beta_2 y)}{Ch(\beta_2)}Sh(\beta_1))+$$

$$+b_{28}(y^2Ch(\beta_1 y)-\frac{Ch(\beta_2 y)}{Ch(\beta_2)}Ch(\beta_1))+b_{29}(y^2Sh(\beta_1 y)-\frac{Sh(\beta_2 y)}{Sh(\beta_2)}Ch(\beta_1)+$$

$$+b_{30}(y^2-1)Sh(\beta_2 y)+b_{31}(y^2-1)Ch(\beta_2 y)+b_{32}(y^4-\frac{Ch(\beta_2 y)}{Ch(\beta_2)})+$$

$$+b_{33}(y^2-\frac{Ch(\beta_2 y)}{Ch(\beta_2)})+b_{34}(1-\frac{Ch(\beta_2 y)}{Ch(\beta_2)})$$

Where $a_1.a_2,a_3,$……………$a_{91,}b_{1,...}$ ...... b_{34} are constants.

NUSSELT NUMBER AND SHERWOOD NUMBER

The rate of heat transfer (Nusselt Number) is given by

$$Nu_{y=\pm i}=(\frac{d\theta}{dy})_{y=\pm 1}$$ and corresponding expressions are

$$Nu_{y=+1}=e_5+\delta e_7+O(\delta^2) \qquad Nu_{y=-1}=e_6+\delta e_8+O(\delta^2)$$

The rate of mass transfer (Sherwood Number) is given by

$$Sh_{y=\pm 1}=(\frac{dC}{dy})_{y=\pm 1}$$ and corresponding expressions are

$$Sh_{y=+1}=e_9+\delta e_{11}+O(\delta^2) \qquad Sh_{y=-1}=e_{10}+\delta e_{12}+O(\delta^2)$$

where $b_1,b_2,$………………$,b_{49},e_1,$……..e_{12} are constants

RESULTS AND DISCUSSION

In this analysis we investigate the effect of thermo-diffusion on the convective heat and mass transfer flow in a vertical channel on whose walls a constant heat flux is maintained and also a uniform concentration is prescribed on the walls. Figs.1-5 represents the axial velocity (u) with different values of N, N_1, Sc, So, and Ec.

The variation of u with buoyancy ratio N shows that when the molecular buoyancy force dominates over the thermal buoyancy force |u| depreciates when the buoyancy forces act in the same direction and for the forces acting in opposite directions |u| depreciates in the fluid region (fig.1). From fig.2 we find that higher radiative heat flux ($N_1 \leq 1.5$), |u| enhances in the fluid region and for further higher $N_1 \geq 10$, |u| depreciates in the entire fluid region except in a narrow region adjacent to y =+1.The variation of u with Schmidt number (Sh) shows that lesser the molecular diffusivity larger |u| in the entire flow region except in the vanity of y=+1 and for further lowering of the diffusivity smaller |u| in the flow region (fig.3). Fig.4 represents u with soret parameter S_0. It is found that |u| experiences an enhancement with increase in $|S_0|$. The variation of u with Eckert number Ec shows that higher the dissipative heat larger |u| in the flow region (Fig.5).

The non-dimensional temperature (θ) is shown in figs.6-10 for different parametric values. When the molecular buoyancy force dominates over the thermal buoyancy force the actual temperature depreciates when the forces act in the same direction and for the forces acting in opposite directions it enhances in the flow region (fig.6). Also higher the radiative heats flux smaller the actual temperature in the entire region (fig.7). With respect to Sc we find that lesser the molecular diffusivity smaller the actual temperature and further lowering of the diffusivity larger the temperature and for still lowering of the diffusivity smaller the actual temperature in the flow region. Also the actual temperature depreciates with increase in $S_0>0$ and enhances with $|S_0|(<0)$ (fig.9). The variation of θ with Ec shows that higher the dissipative heat smaller the actual temperature and for further higher dissipative heat larger the actual temperature except in the vicinity of y =+1 where it depreciates (fig.10).

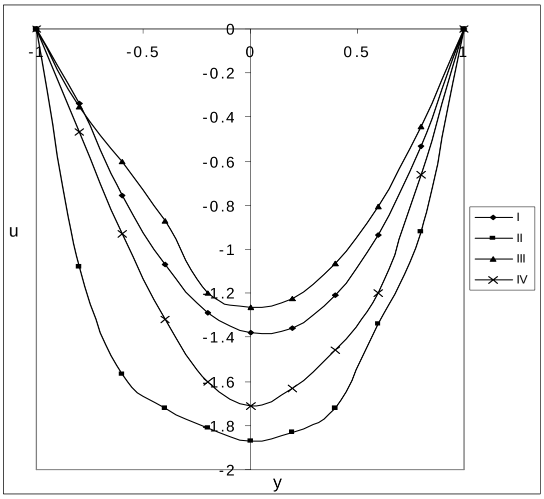


Fig.1 u with N

	I	II	III	IV
N	1	2	-0.5	-0.8

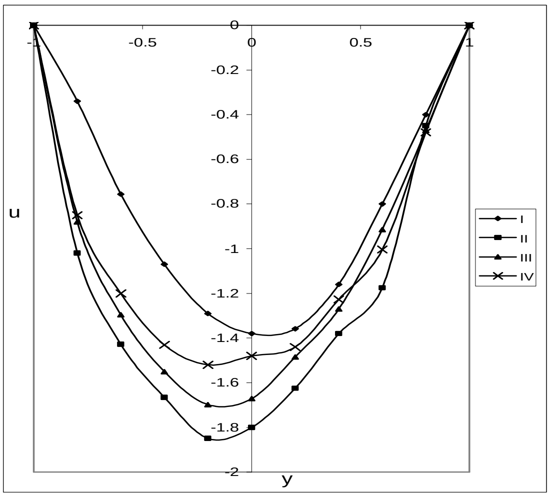


Fig.2 u with N_1

	I	II	III	IV
N_1	1.5	5	10	100

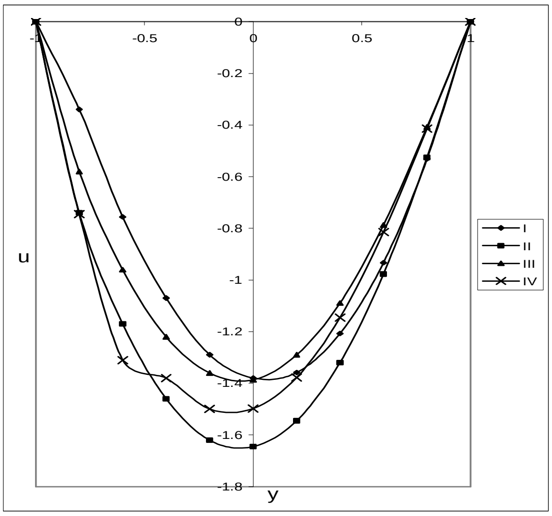


Fig.3 u with Sc

	I	II	III	IV
Sc	1.3	2.01	0.24	0.6

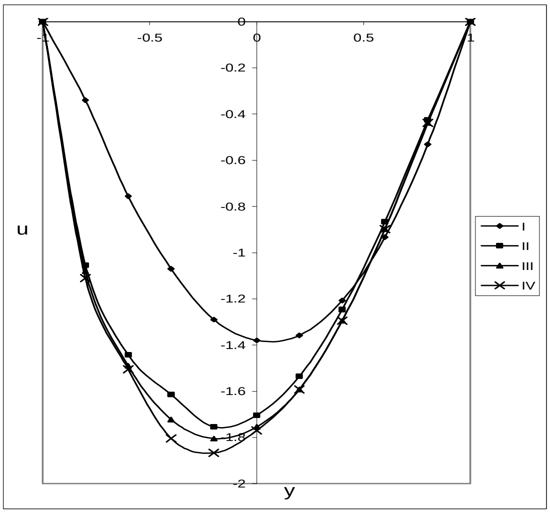


Fig.4 u with S_0

	I	II	III	IV
S_0	0.5	1.0	-0.5	-1.0

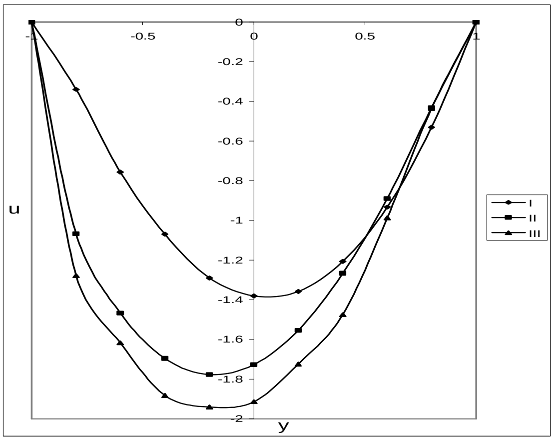
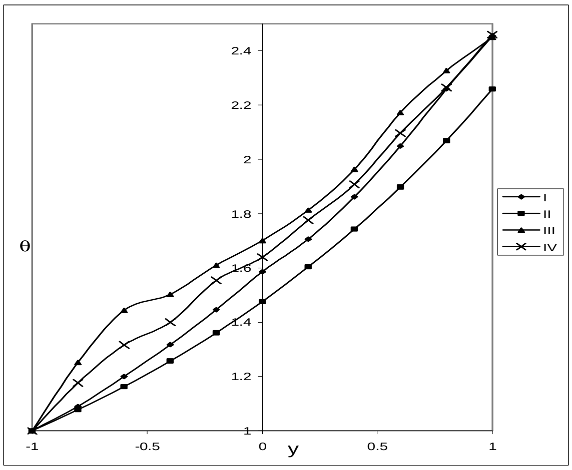


Fig.5 u with Ec

	I	II	III
Ec	0.01	0.03	0.05



Fig,6 θ with N

	I	II	III	IV
N	1	2	-0.5	-0.8

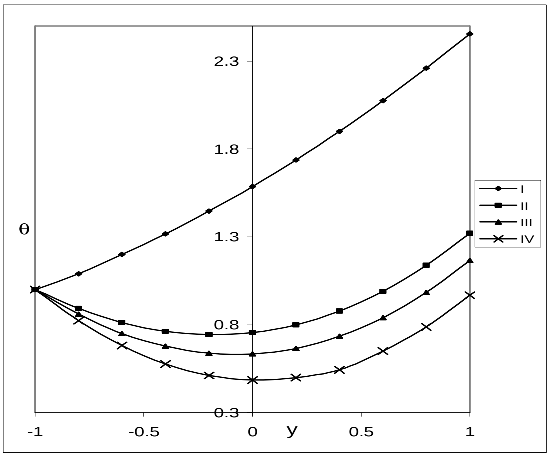


Fig.7 θ with N_1
N=1 ,α = 2

	I	II	III	IV
N_1	1.5	5	10	100

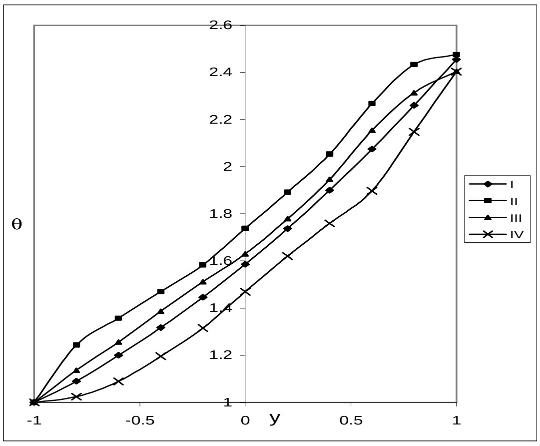


Fig.8 θ with Sc

	I	II	III	IV
Sc	1.3	2.01	0.24	0.6

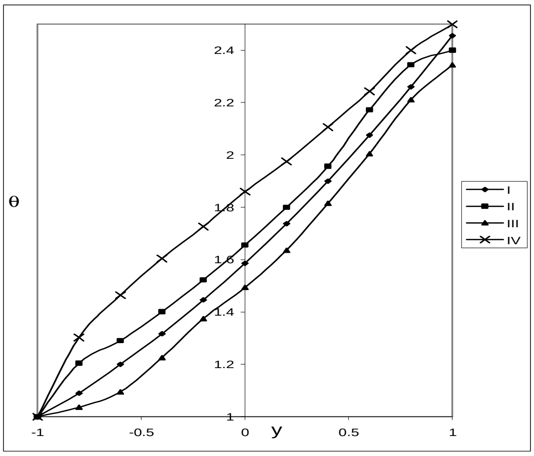


Fig.9 θ with S_0

	I	II	III	IV
S_0	0.5	1.0	-0.5	-1.0

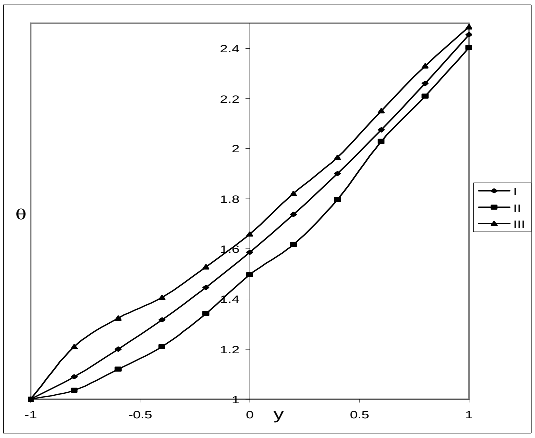


Fig.10 θ with Ec
Sc=1.3,S_0=0.5,N=1

	I	II	III
Ec	0.01	0.03	0.05

The non-dimensional concentration (C) is exhibited in figs11-15 for different parametric values. With respect to buoyancy ratio N we find that the actual concentration enhances in the left half and reduces in the right half with increase in N>0 and for N<0 we notice an enhancement in C (fig.11). Also higher the radiative heat flux larger the actual concentration (fig.12). Lesser the molecular diffusivity larger the concentration (fig.13). The actual concentration enhances with increase in S_0>0 and reduces with $|S_0|(<0)$ in the entire flow region (fig.14). The variation of C with Ec shows that higher the dissipative heat lesser the concentration. Thus the inclusion of the dissipation results in a depreciation in the concentration (fig.15).

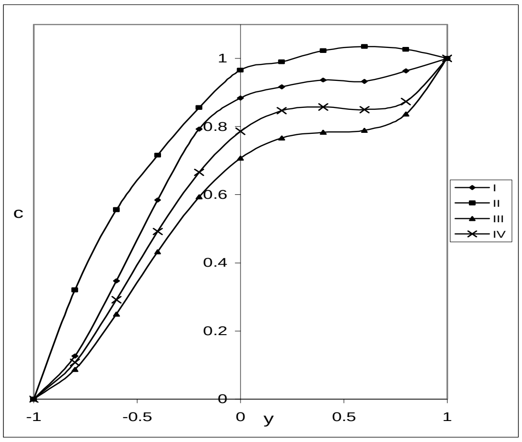


Fig.11 C with N
$N_1=1.5, \alpha=2, Sc=1.3$

	I	II	III	IV
N	1	2	-0.5	-0.8

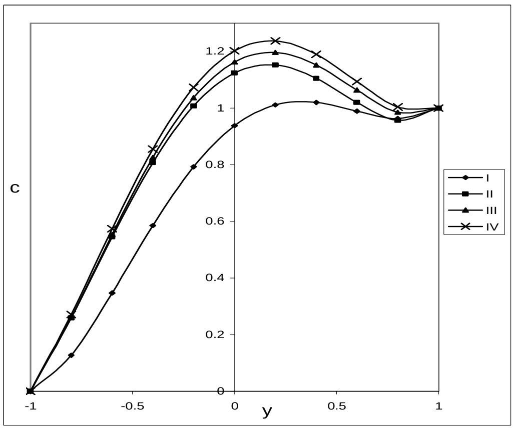


Fig.12 C with N_1
$N=1, Sc=1.3, \alpha=2$

	I	II	III	IV
N_1	1.5	5	10	100

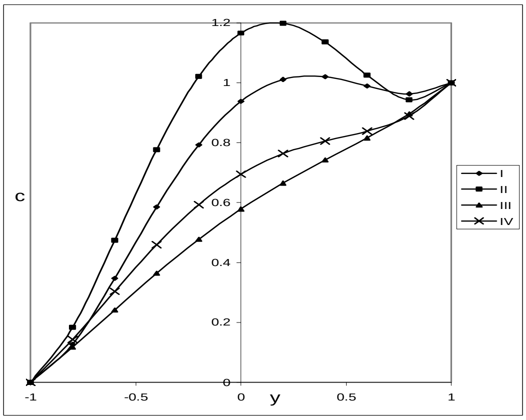


Fig.13 C with Sc
$S_0=0.5, N=1, N_1=1.5$

	I	II	III	IV
Sc	1.3	2.01	0.24	0.6

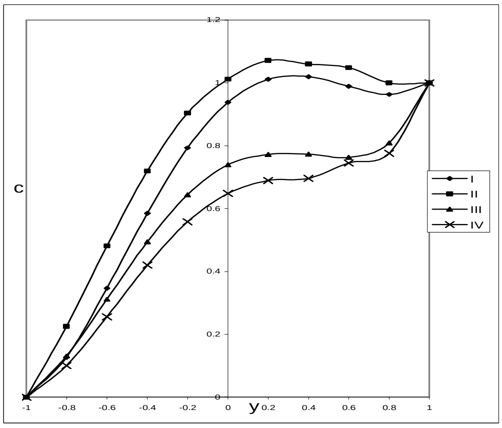


Fig.14 C with S_0
$Sc=1.3, \alpha=2, N=1$

	I	II	III	IV
S_0	0.5	1.0	-0.5	-1.0

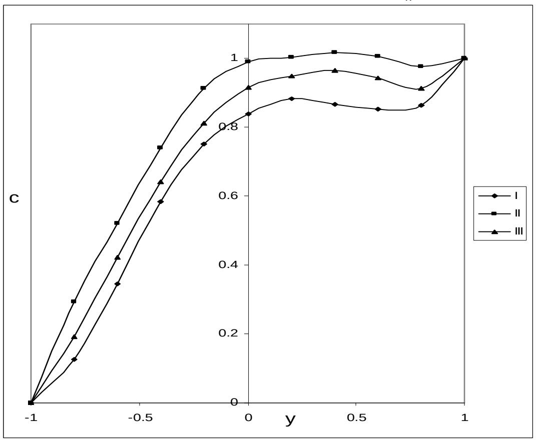


Fig.15 C with Ec

	I	II	III
Ec	0.01	0.03	0.05

The rate of heat transfer (Nusselt number) is depicted in tables 1-4 for different values D^{-1},N,N_1 and Ec. It is found that the rate of heat transfer enhances at y =+1 and reduces at y =-1 with increase in G>0 while a reversed effect is observed in |Nu| with G<0. The variation of Nu with D^{-1} shows that lesser the permeability of the porous medium lesser |Nu| at y =+1 and larger at y =+1 in the heating case and in the cooling case larger |Nu| at y =+1 and lesser at y =-1. The variation of Nu with Ec shows that higher the dissipative heat larger |Nu| at both the walls (tables 1 & 3). The variation of Nu with buoyancy ratio N shows that when the molecular buoyancy force dominates over the thermal buoyancy force it enhances at y=1 when the forces act in the same direction and for the forces acting in the opposite directions. At y =-1, it reduces with N>0 and enhances with N<0 in the heating case in the cooling case a reversed effect is noticed in the behavior of |Nu|. With respect to radiation parameter N_1 shows that higher the radiative heat flux smaller |Nu| at y =+1 and at y =-1 it enhances in the heating case and in the cooling case, it reduces with $N_1 \leq 5$ and enhances with higher $N_1 \geq 10$ (tables 2&4).

Table 1: Nusselt Number (Nu) at y=1

G/Nu	I	II	III	IV	V	VI
10^3	1.7555	1.7432	1.7552	1.3466	1.4042	1.4625
$3x10^3$	1.7618	1.7588	1.7583	1.3674	1.4408	1.5166
-10^3	1.7510	1.7520	1.7522	1.3276	1.3704	1.4124
$-3x10^3$	1.7456	1.7490	1.7777	1.3076	1.3351	1.3603
D^{-1}	$5x10^2$	10^3	$2x10^3$	$5x10^2$	$5x10^2$	$5x10^2$
Ec	0.01	0.01	0.01	0.03	0.05	0.07

Table.2: Nusselt Number (Nu) at y=1

G/Nu	I	II	III	IV	V	VI	VII
10^3	1.7555	1.7606	1.7544	1.7542	1.5234	1.2876	1.2967
$3x10^3$	1.7618	1.7609	1.7558	1.7552	1.5301	1.2964	1.3087
-10^3	1.7510	1.7513	1.7532	1.7536	1.5192	1.2839	1.2001
$-3x10^3$	1.7456	1.7465	1.7516	1.7526	1.5738	1.2777	1.1938
N	1	2	-0.5	-0.8			
N_1	0.5	0.5	0.5	0.5	1.5	5	10

Table.3: Nusselt Number (Nu) at y=-1

G/Nu	I	II	III	IV	V	VI
10^3	1.1745	1.2021	1.2977	-0.2356	-0.3689	-0.4101
$3x10^3$	0.8833	1.0179	1.0702	-0.7550	-0.8725	-1.0134
-10^3	1.3771	1.3422	1.3247	0.2684	0.5094	0.7581
$-3x10^3$	1.6389	1..4595	1.3842	0.7801	1.2003	1.6438
D^{-1}	$5x10^2$	10^3	$2x10^3$	$5x10^2$	$5x10^2$	$5x10^2$
Ec	0.01	0.01	0.01	0.03	0.05	0.07

Table.4: Nusselt Number (Nu) at y=-1

G/Nu	I	II	III	IV	V	VI	VII
10^3	1.1745	1.1131	1.2141	1.2208	0.4195	-0.5066	-0.5783
$3x10^3$	0.8833	0.9501	1.1198	1.1402	0.1543	-0.6609	-0.9341
-10^3	1.3771	1.30648	1.3082	1.3015	0.7029	0.0332	-0.2082
$-3x10^3$	1.6389	1.5722	1.3640	1.3421	0.9772	0.3833	-0.1566
N	1	2	-0.5	-0.8	1	1	1
N_1	0.5	0.5	0.5	0.5	1.5	5	10

The rate of mass transfer (Sherwood number) at y =±1 is exhibited in tables 5-10. It is found that the rate of mass transfer enhances with increase in |G| at both the walls. The variation of Sh with D^{-1} shows that lesser permeability of the porous medium smaller |Sh| ($D^{-1} \leq 10^3$) and for further lowering of the permeability ($D^{-1} \geq 3x10^3$) smaller |Sh| at y =+1 while at y =-1, smaller the rate of mass transfer. With respect to Eckert number Ec we find that higher the dissipative heat lesser |Sh| and for further higher dissipative heat larger |Sh| at y=+1 and at y =-1, smaller |Sh| for all G (tables 5 & 8). When the molecular buoyancy force dominates over the thermal buoyancy force the rate of mass transfer at y =±1 enhances in the heating case when buoyancy forces act in the same direction and for the forces acting in opposite directions it reduces at both the walls for all G. Also higher the radiative heat flux smaller the rate of mass transfer at y =±1 (tables 6&9).

Table.5: Sherwood Number (Sh)at y=1

G/Nu	I	II	III	IV	V	VI
10^3	0.4609	1.1627	1.0901	0.5395	0.5784	0.6163
$3x10^3$	2.7188	1.7618	2.5924	1.5782	1.6398	1.6986
-10^3	-0.4543	-0.8334	0.7786	-0.4645	-0.4886	-0.5117
$-3x10^3$	-1.9096	-3.1782	0.5288	-1.4558	-1.4628	-1.4669
D^{-1}	$5x10^2$	10^3	$2x10^3$	$5x10^2$	$5x10^2$	$5x10^2$
Ec	0.01	0.01	0.01	0.03	0.05	0.07

Table.6: Sherwood Number (Sh) at y=1

G/Nu	I	II	III	IV	V	VI	VII
10^3	0.4609	2.8691	1.2601	1.0371	0.9684	0.6676	0.4721
$3x10^3$	2.7188	3.6834	1.7557	1.7086	2.1071	1.5139	1.3086
-10^3	-0.4543	-0.6685	0.3839	0.3655	-0.4525	-0.4595	-0.4642
$-3x10^3$	-1.9096	-2.8445	-0.4922	-0.3061	-1.7322	-1.4462	-1.3506
N	1	2	-0.5	-0.8			
N_1	0.5	0.5	0.5	0.5	1.5	5	10

Table.7: Sherwood Number (Sh) at y=1

G/Nu	I	II	III	IV	V	VI	VII
10^3	0.5676	0.7865	0.9684	1.2344	0.75678	1.4567	2.0123
$3x10^3$	0.6814	0.9635	2.7188	2.0751	0.8361	2.7996	3.3934
-10^3	0.3247	0.3586	-0.4543	-0.9859	-0.8551	0.3573	0.4625
$-3x10^3$	0.1464	-0.3938	-1.9086	-2.5165	-1.7006	-0.8603	-0.9609
Sc	0.24	0.6	1.3	2.01	1.3	1.3	1.3
So	0.5	0.5	0.5	0.5	1.0	-0.5	-1.0

Table.8: Sherwood Number (Sh) at y=-1

G/Nu	I	II	III	IV	V	VI
10^3	0.7491	0.2618	0.9718	1.0004	0.9915	0.9828
$3x10^3$	0.9038	1.0569	1.5933	1.1876	1.2146	1.2422
-10^3	0.8801	0.5291	0.3509	0.8558	0.8105	0.7648
$-3x10^3$	1.3182	-0.1713	-0.2736	0.6899	0.6084	0.5262
D^{-1}	$5x10^2$	10^3	$2x10^3$	$5x10^2$	$5x10^2$	$5x10^2$
Ec	0.01	0.01	0.01	0.03	0.05	0.07

The variation of Sh with Schmidt number Sc shows that lesser the molecular diffusivity larger |Sh| and for further lowering of the diffusivity smaller |Sh| at y =±1. Also |Sh| reduces at y=+1 and enhances at y=-1 with increase in S_0>0 while an increase in $|S_0|$ enhances |Sh| at both the walls for all G (tables 7&10).

Table.9: Sherwood Number (Sh) at y=-1

G/Nu	I	II	III	IV	V	VI	VII
10^3	0.7491	1.8782	0.1343	1.0371	0.9684	0.6675	0.4721
$3x10^3$	0.9038	1.2388	0.0478	1.7086	2.1071	1.5139	1.3086
-10^3	0.8801	0.3611	0.2215	0.3655	-0.4524	-04595	-0.4640
$-3x10^3$	1.3182	-0.0711	-0.4922	-0.3061	-1.7322	-1.4463	-1.3345
N	1	2	-0.5	-0.8			
N_1	0.5	0.5	0.5	0.5	1.5	5	10

Table.10: Sherwood Number (Sh) at y=-1

G/Nu	I	II	III	IV	V	VI	VII
10^3	0.5999	0.7466	0.7491	-0.3125	1.5337	0.0519	-0.4248
$3x10^3$	0.6778	-0.6307	0.9038	-0.6914	1.7366	0.0881	-0.5426
-10^3	0.5721	0.6352	0.8801	0.0454	1.3308	0.0158	0.0342
$-3x10^3$	0.9978	1.1045	1.3182	0.0675	1.5678	0.0456	0.0567
Sc	0.24	0.6	1.3	2.01	1.3	1.3	1.3
So	0.5	0.5	0.5	0.5	1.0	-0.5	-1.0

CONCLUSION

In this analysis we investigate effect of radiation and thermo-diffusion on free and forced convective heat and mass transfer flow of a viscous fluid in vertical channel with the right wall maintained at constant heat flux. The important conclusions of this analysis are:

1. Higher radiative heat flux (N_1≤1.5), |u| enhances in the fluid region and for further higher N_1≥10, |u| depreciates in the entire fluid region except in a narrow region adjacent to y =+1. u with soret parameter S_0. It is found that |u| experiences an enhancement with increase in $|S_0|$. The variation of u with Eckert number Ec shows that higher the dissipative heat larger |u| in the flow region.
2. Higher the radiative heat flux smaller the actual temperature in the entire region. Also the actual temperature depreciates with increase in S_0>0 and enhances with $|S_0|$(<0). Higher the dissipative heat smaller the actual temperature and for further higher dissipative heat larger the actual temperature except in the vicinity of y =+1 where it depreciates.

3. Higher the radiative heat flux larger the actual concentration. The actual concentration enhances with increase in $S_0>0$ and reduces with $|S_0|(<0)$ in the entire flow region. Higher the dissipative heat lesser the concentration. Thus the inclusion of the dissipation results in a depreciation in the concentration.
4. Higher the dissipative heat larger |Nu| at both the walls. Higher the radiative heat flux smaller |Nu| at y =+1 and at y =-1 it enhances in the heating case and in the cooling case, it reduces with $N_1\leq 5$ and enhances with higher $N_1\geq 10$.
5. Higher the radiative heat flux smaller the rate of mass transfer at y =±1. |Sh| reduces at y=+1 and enhances at y=-1 with increase in $S_0>0$ while an increase in $|S_0|$ enhances |Sh| at both the walls for all G.

REFERENCES

[1] Md.Abdul Sattar, Md.Alam; Thermal diffusion as well as transportation effect on MHD free convection and Mass Transfer flow past an accelerated vertical porous plate, Ind.J. of Pure and App. Maths., **1995**, 24, 679.
[2] M.B.Ayani, J.H.Fsfahani; The effect of radiation on the natural convection induced by a line heat source, Int. J. Num. Method Heat fluid flow., **2006**, 16, 28.
[3] K.Bharathi ;Convective heat and mass transfer through a porous medium in channels / pipes with radiation and soret effects, PhD thesis, S.K. University (S.K. University, Anantapur, A.P, India, **2007**).
[4] C.Beckermann, R.Visakanta, S.Ramadhyani; A numerical study of non-Darcian natural convection in a vertical enclosure filled with a porous medium, Num.Heat.Trans., **1986**, 10, 557.
[5] P.Cheng; Heat transfer in Geothermal systems, Adv.Heat Trans., **1978**, 14, 1.
[6] M.A.El.Hakiem; MHD oscillatory flow on free convection radiation though a porous medium with constant suction velocity, J.Mason.Mater., **2000**, 220, 271.
[7] B. K. Jha, A. K.Singh , Astrophys. Space Sci.,**1990**, **173**, 251.
[8] N.G. Kafousia, Astrophys. Space Sci., **1990**, **173**, 251.
[9] N.Kalidas, V.Prasad; Benard convection in porous media Effects of Darcy and Pransdtl Numbers, Int. Syms. Convection in porous media, non-Darcy effects, Conference of Nat. Heat Transfer., **1988**, 1, 593.
[10] A.Kumar,N.P Singh,A.K Singh, H.Kumar; MHD free convection flow of a viscous fluid past a porous vertical plate through non-homogeneous porous medium with radiation and temperature gradient dependent heat source in slip glow regime, Ultra Sci.Phys.Sci., **2006** , 18, 39.
[11] O.D.Makinde; Free convection flow with thermal radiation and mass transfer pass a moving vertical porous plate, Int.Commun.Heat and Mass Trans.,**2005** , 32, 1411.
[12] M.S.Malasetty, S.N .Gaikwad; Effect of cross diffusion on double diffusive convection in the presence of horizontal gradient, Int.J. Eng.Science., **2002**, 40, 773.
[13] D.Poulikakos, A.Bejan; The Departure from Darcy flow in Nat. Convection in a vertical porous layer, physics fluids., **1985**, 28, 3477.
[14] V.Prasad, A.Tuntomo; Inertia Effects on Natural Convection in a vertical porous cavity, Num. Heat Trans., **1987**, 11, 295.
[15] V.Prasad; Natual convectin inporous media.,PhD thesis(S.K. University, Anantapur, A.P, India, **1983**).
[16] V Prasad, F.A,Kulacki, M.keyhani; Natural convection in a porous medium, J.Fluid Mech., **1985**, 150, 89.
[17] A.Raphil; Radiation and free convection flow through a porous medium, Int.Commun.Heat and Mass Trans., **1998**, 25, 289.
[18] Taneja, Rajeev, N.C.Jain ; Effect of magnetic field on free convection mass transfer flow through porous medium with radiation and variable permeability in slip flow regime., Janabha, **2002**, 31/32, 69.
[19] D.Tien, C.V, J.T.Hong; Natural convection in porous media under non-Darcian and non-uniform permeability conditions, Hemisphere, Washington.C (**1985**).
[20] T.L.Tong , E.Subramanian ; A boundary layer analysis for natural correction in porous enclosures use of the Brinkman-extended Darcy model., Int.J.Heat Mass Trans. **1985**, 28, 563.
[21] K.Vafai, C.L Tien; Boundary and Inertia effects on flow and Heat Transfer in Porous Media, Int. J. Heat Mass Trans., **1981**, 24, 195.
[22] K.Vafai, R.Thyagaraju; Analysis of flow and heat Transfer at the interface region of a porous medium, Int. J. Heat Mass Trans., **1987**, 30, 1391.
[23] G.Laurait ,V.Prasad; Natural convection in a vertical porous cavity a numerical study of Brinkman extended Darcy formulation, J.Heat Trans., **1987**, 295.
[24] S.S.Saxena ,G.K.Dubey, *Advances in Applied Science Research*, **2011**, 2(4), 259.
[25] K.J.Reddy, K.Sunitha, M.J.Reddy, *Advances in Applied science and Research*, **2012**, 3(3), 1231.