Finite Element Analysis of Non-Darcy Double –Diffusive Convection Flow of a Viscous Chemically Reacting Fluid in a Vertical Channel with Soret and Dufour effect

M.Nagasasikala [1] and Prof.A.Leelarathnam [2]

[1]Lecturer in Mathematics,K.S.N,Government Degree College for Women,Anantapur,A.P
[2]Department of Applied Mathematics,S.P.Mahila University,Tirupathi,A.P

ABSTRACT

We made an attempt to investigate the combined influence of Soret and Dufour effects on convective heat and mass transfer flow of viscous chemically reacting fluid in a vertical channel The governing equations flow, heat and mass transfer are solved by using Galerkin finite element analysis with three nodded line segments. The velocity, temperature, concentration, rate of heat and mass transfer are analysed for different variations of So, Du, N, k.

Key Words : Soret effect, Dufour effect, Chemical reaction, Non-Darcy flow, Heat and
Mass transfer

INTRODUCTION

Natural convection heat and mass transfer driven by combined thermal and solutal buoyancy forces in fluid-saturated porous media may be met in geophysical, geothermal and industrial applications, such as the dispersion of chemical contaminants through water-saturated soil, the migration of moisture through air contained in fibrous insulations, and grain storage installations.

Raptis et al(1981) constructed similarity solutions for boundary layer near a vertical surface in a porous medium with constant temperature and concentration. Bejan and Khair(1985)used Darcy's law to study the features of natural convection boundary layer flow driven by temperature and concentration gradients. Forchheimer(1991) proposed a quadratic term in Darcian velocity to describe the inertia effects in porouis media. Plumb and Huenefeld(1981) studied the problem on non-Darcian free convection over a vertical isothermal flat plate. Bejan and Poulikakos(1984) pointed out that non-Darcy model should be used for high velocity flows in porous media with low permeability. Kumari et al(1985)studied the non-Darcy free convection from a vertical flat plate in a saturated porous media with mass transfer. Rastogi et al(1995)studied the double diffusion near a vertical surface in porous media saturate4d with a non-newtonian fluid. Murthy and Singh(99) studied the effect of lateral mass flux on the heat and mass transfer by natural convection in a non-Darcy porous medium. Cheng(1977) considered the problem of free and forced convection past inclined surface or wedge. He obtained numerical solutions for isothermal plate inclined at an angle of 45^0 to the vertical, neglecting the component of the buoyancy force normal to the inclined plate. A combined experimental and numerical study was illustrated of dendritic solidification of ammonium chloride–water solution inside a vertical enclosure inducing a variety of double-diffusive phenomena in liquid by Beckerman and Visakanta(1988).Nithurasu et al(1997) used a general model of Darcy and non-Darcy porous medium to study the double –diffusive free convection. Double-diffusive mixed convection in non-Darcy porous medium with moving boundary is investigated numerically by Khanafer

and Vafai(2002) obtaining strong dependence of the heat transfer rate and flow mechanisms inside the porous cavities on Richardson number. A detailed review of convective heat and mass transfer in Darcian and nonm-Darcian porous medium can be found in the book by Nield and Bejan(2013). Vafai and Thiyagaraja (1987) 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 (1985), Cheng (1978), Prasad et al (1987), and Kladias and Prasad (1988). Here, we will restrict our discussion to the vertical cavity only. Poulikakos and Bejan (1985) 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 (1987) reported an extensive numerical work for a wide range of parameters, and demonstrated that effects of Prandtal 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 (1985), and Lauriat and Prasad (1977) to examine the boundary effects on free convection in a vertical cavity. While Tong and Subramanian performed a Weber – type boundary layer analysis, Nagaleelakumari(2012) has studied the convective heat and mass transfer on non-Darcy flow of a viscous fluid through a porous medium in a vertical channel in the presence of heat generating sources.

In all of the above mentioned studies the thermal-diffusion and the diffusion-thermo are negligible. However, the thermal-diffusion and the diffusion-thermo effects with suction or injection are an interesting macroscopically physical phenomenon in fluid mechanics. The effects of the thermal-diffusion and the diffusion-thermo on the transport of heat and mass has been developed from the kinetic theory of gases by Chapman and Cowling (1952) and Hirshfelder et al. (1991) explained the phenomena and derived the necessary formulae to calculate the thermal-diffusion coefficient and thermal-diffusion factor for monatomic gases or for polyatomic gas mixtures. Sparrow et al. (1954) studied experimentally the effect of diffusion thermo in stagnation-point flow of air with injection of gases of various molecular weights into the boundary layer. Kafoussias and Williams (1995) studied the effects of thermal-diffusion and diffusion thermo on steady mixed free-forced convective and mass transfer over a vertical flat plate, when the viscosity of the fluid is-varies with temperature. Alam et al (2005) studied the effects of Dufour and Soret numbers on unsteady free convection and mass-transfer flow past an impulsively started infinite vertical porous flat plate, of a viscous incompressible and electrically conducting fluid, in the presence of an uniform transverse magnetic field. Alam et. al. (2007) studied diffusion thermo and thermal-diffusion effects on unsteady free convection and mass transfer flow past an accelerated vertical porous flat plate embedded in a porous medium with time dependent temperature and concentration. Alam et al. (2006) studied the effects of Dufour and Soret numbers on unsteady MHD free convection and mass transfer flow past an infinite vertical porous plate embedded in a porous medium. Alam et al. (2006) studied the effects of Dufour and Soret numbers on steady combined free-forced convective and mass transfer flow past a semi-infinite vertical flat plate in the presence of an uniform transverse magnetic field. Malsetty et

al (2002) have studied the effect of both the Soret coefficient and Dufour coefficient on the double diffusive convective with compensating horizontal thermal and solutal gradients.

Keeping the above application in view we made an attempt in this chapter to study the combined influence of thermo-diffusion, diffusion-thermo and chemical reaction effects on non-Darcy convective heat and Mass transfer flow of a viscous fluid in a vertical channel. The governing equations flow, heat and mass transfer are solved by using Galerkin finite element analysis with three nodded line segments. The velocity, temperature, concentration, rate of Heat and Mass transfer are evaluated numerically for different variations of parameters.

FORMULATION OF THE PROBLEM

We consider a fully developed laminar convective heat and mass transfer flow of a viscous, electrically conducting 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=±L. The walls are maintained at constant temperature and concentration ..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.

Configuration of the Problem
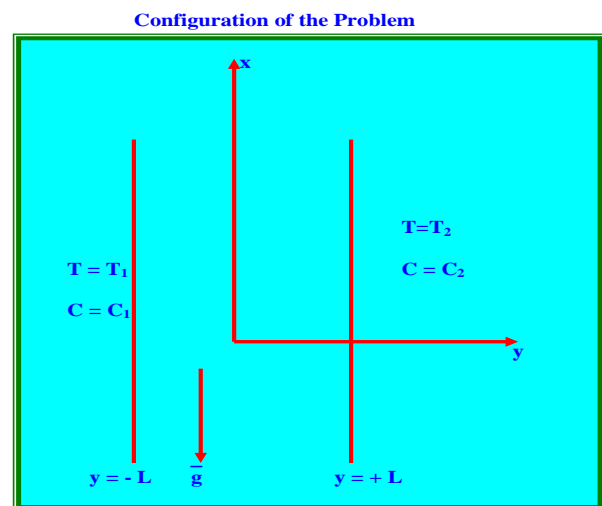
The Brinkman-Forchheimer-extended Darcy equation which account for boundary inertia effects in the momentum equation is used to obtain the velocity field. Based on the above assumptions the governing equations are

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

$$\rho_0 C_p u \frac{\partial T}{\partial x} = k_f \frac{\partial^2 T}{\partial y^2} + k_{12} \frac{\partial^2 C}{\partial y^2} \tag{2}$$

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

The boundary conditions are

$$u = 0 \quad , \quad T = T_1 \quad C = C_1 \qquad on \quad y = -L$$
$$u = 0 \quad , \quad T = T_2 \quad C = C_2 \qquad on \quad y = +L \tag{4}$$

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

where $\bar{q} =(u,0,0)$ is the velocity, T, C are the temperature and Concentration, p is the pressure ,ρ is the density of the fluid ,Cp is the specific heat at constant pressure, μ is the coefficient of viscosity, k is the permeability of the porous medium, δ is the porosity of the medium,β is the coefficient of thermal expansion ,k_f is the coefficient of thermal conductivity ,F is a function that depends on the Reynolds number and the microstructure of porous medium, $\beta^{\bullet}$ is the volumetric coefficient of expansion with mass fraction concentration, k is the chemical reaction coefficient and D_1 is the chemical molecular diffusivity,q_R is the radiative heat flux,$k_{11}$is the cross diffusivity and Q is the strength of the heat generating source. Here ,the thermophysical properties of the solid and fluid have been assumed to be constant except for the density variation in the body force term(Boussinesq approximation) and the solid particles and the fluid are considered to be in the thermal equilibrium) .
Introducing the on-dimensional variables as

$$u' = \frac{u}{(v/L)}, \ (x',y') = (x,y)/L , \ p' = \frac{p\delta}{(\rho v^2/L^2)}$$

$$\theta = \frac{T-T_2}{T_1-T_2} \ , \ C' = \frac{C-C_2}{C_1-C_2} \tag{5}$$

the governing equations in the dimensionless form reduce to (on dropping the dashes)

$$\frac{d^2u}{dy^2} = \pi + \delta(M_1^2)u - \delta G(\theta + NC) - \delta^2 \Delta u^2 \tag{6}$$

$$\frac{d^2\theta}{dy^2} = (PN_T)u - Du\frac{d^2C}{dy^2} \tag{7}$$

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

Where

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

$D^{-1} = \dfrac{L^2}{k}$ (Darcy parameter), $Sc = \dfrac{v}{D_1}$ (Schmidt number),

$N = \dfrac{\beta^{\bullet}(C_1-C_2)}{\beta(T_1-T_2)}$ (Buoyancy ratio), $P = \dfrac{\mu C_p}{k_f}$ (Prandtl Number)

$\gamma = \dfrac{k_1 L^2}{D_1}$ (Chemical reaction parameter), $S_0 = \dfrac{k_{11}\Delta T}{v\Delta T}$ (Soret parameter)

$N_T = \dfrac{AL}{(T_1-T_2)}$ (non-dimensional temperature gradient)

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

$Du = \dfrac{k_{12}\Delta C}{k_f \Delta t}$ (Dufour parameter), $M_1^2 = D^{-1}$

The corresponding boundary conditions are

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

(9)

FINITE ELEMENT ANALYSIS

To solve these differential equations with the corresponding boundary conditions, we assume if u^i, θ^i, c^i are the approximations of u, θ and C we define the errors (residual) E_u^i, E_θ^i, E_c^i as

$$E_u^i = \frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - M_1^2 u^i + \delta^2 A(u^i)^2 - \delta G(\theta^i + NC^i)$$

(10)

$$E_c^i = \frac{d}{dy}\left(\frac{dC^i}{dy}\right) - (\gamma Sc)C^i + \frac{ScSo}{N}\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - ScN_c u^i$$

(11)

$$E_\theta^i = \frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - PN_T u^i + DuN_2 \frac{d}{dy}(\frac{dC^i}{dy})$$

(12)

where

$$u^i = \sum_{k=1}^{3} u_k \psi_k$$
$$C^i = \sum_{k=1}^{3} C_k \psi_k$$
$$\theta^i = \sum_{k=1}^{3} \theta_k \psi_k$$

(13)

These errors are orthogonal to the weight function over the domain of e^i under Galerkin finite element technique we choose the approximation functions as the weight function. Multiply both sides of the equations (10 - 12) by the weight function i.e. each of the approximation function ψ_j^i and integrate over the typical three nodded linear element (η_e, η_{e+1}) we obtain

$$\int_{\eta_e}^{\eta_{e+1}} E_u^i \psi_j^i dy = 0 \qquad (i = 1,2,3,4,)$$

(14)

$$\int_{\eta_e}^{\eta_{e+1}} E_c^i \psi_j^i dy = 0 \qquad (i = 1,2,3,4,)$$

(15)

$$\int_{\eta_e}^{\eta_{e+1}} E_\theta^i \psi_j^i dy = 0 \qquad (i = 1,2,3,4,)$$

(16)

where

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{d\eta}\left(\frac{du^i}{d\eta}\right) - M_1^2 u^i + \delta^2 A(u^i)^2 - \delta G(\theta^i + NC^i) \ \psi_j^i dy = 0$$

(17)

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{dy}\left(\frac{dC^i}{dy}\right) - \gamma C^i + \frac{ScSo}{N}\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - ScN_c u^i)\psi_j^i dy = 0$$

(18)

$$\int_{\eta_e}^{\eta_{e+1}} (\frac{d}{dy}\left(\frac{d\theta^i}{dy}\right) - P_1 N_T u^i + Du\frac{d}{dy}(\frac{dC^i}{dy}))\psi_j^i dy = 0$$

(19)

Following the Galerkin weighted residual method and integration by parts method to the equations (17) – (19) we obtain

$$\int_{\eta_e}^{\eta_{e\pm1}} \frac{d\Psi_j^i}{dy}\frac{d\psi^i}{dy}dy - \delta M_1^2 \int_{\eta_e}^{\eta_{e\pm1}} u^i \Psi_j^i dy + \delta^2 A \int_{\eta_e}^{\eta_{e\pm1}} (u^i)^2 \Psi_j^i dy - $$

$$- \delta G \int_{\eta_e}^{\eta_{e\pm1}} (\theta^i + NC^i)\Psi_j^i dy = Q_{1,j} + Q_{2,j} \qquad (20)$$

where – $Q_{1,j} = \Psi_j(\eta_e)\dfrac{du^i}{d\eta}(\eta_e)$

$Q_{1,j} = \Psi_j(\eta_e)\dfrac{du^i}{d\eta}(\eta_e)$

$$\int_{\eta_e}^{\eta_{e\pm1}} \frac{d\Psi_j^i}{dy}\left(\frac{dC^i}{dy}\right)dy - (\gamma\,Sc)\int_{\eta_e}^{\eta_{e\pm1}} C^i \psi_j^i dy - ScN_c \int_{\eta_e}^{\eta_{e\pm1}} u^i \psi_j^i dy = R_{1,j} + R_{2,j} \qquad (21)$$

where – $R_{1,j} = \Psi_j(\eta_e)\dfrac{dC^i}{dy}(\eta_e)$

$R_{2,j} = \Psi_j(\eta_{e+1})(\dfrac{dC^i}{dy}(\eta_{e+1})$

$$\int_{\eta_e}^{\eta_{e\pm1}} \frac{d\Psi_j^i}{dy}\frac{d\theta^i}{dy}dy - PN_T \int_{\eta_e}^{\eta_{e\pm1}} u^i \psi_j^i dy = S_{1,j} + S_{2,j} \qquad (22)$$

where – $S_{1,j} = \Psi_j(\eta_e)\dfrac{d\theta^i}{dy}(\eta_e)$

$S_{2,j} = \Psi_j(\eta_{e+1})\dfrac{d\theta^i}{dy}(\eta_{e+1})$

Making use of equations (13) we can write above equations as

$$\sum_{k=1}^{3} u_k \int_{\eta_e}^{\eta_{e\pm1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy - \sum_{k=1}^{3}\delta M_1^2 u_k \int_{\eta_e}^{\eta_{e\pm1}} \psi_j^i \psi_k dy - \delta G(\sum_{k=1}^{3}\theta_k \int_{\eta_e}^{\eta_{e\pm1}} \psi_j^i \psi_k dy + NC_k \sum_{k=1}^{3} \psi_j^i \psi_k dy +$$

$$+ \delta^2 A \sum_{k=1}^{3} u_k^2 \int_{\eta_e}^{\eta_{e\pm1}} \left(\frac{d\psi_k}{d\eta}\right)^2 \psi_j^i dy = Q_{1,j} + Q_{2,j}$$

$$(23)$$

$$\sum_{k=1}^{3} C_k \int_{\eta_e}^{\eta_{e\pm1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy - (\gamma\,Sc)\sum_{k=1}^{3} C_k \int_{\eta_e}^{\eta_{e\pm1}} \psi_j^i \psi_k d\eta - ScN_c \sum_{k=1}^{3} C_k \int_{\eta_e}^{\eta_{e\pm1}} \psi_j^i \psi_k dy$$

$$= R_{1,j} + R_{2.j} \qquad (24)$$

$$\sum_{k=1}^{3}\theta_k \int_{\eta_e}^{\eta_{e\pm1}} \frac{d\psi_j^i}{dy}\frac{d\psi_k}{dy}dy - PN_T \sum_{k=1}^{3} u_k \int_{\eta_e}^{\eta_{e\pm1}} \psi_k \psi_j^i dy = S_{1,j} + S_{2.j} \qquad (25)$$

choosing different Ψ_j^i's corresponding to each element η_e in the equation (23) yields a local stiffness matrix of order 3×3 in the form

$$(f_{i,j}^k)(u_i^k) - \delta G(g_{i,j}^k)(\theta_i^k + NC_i^k) + \delta D^{-1}(m_{i,j}^k)(u_i^k) + \delta^2 A(n_{i,j}^k)(u_{i,j}^k) = (Q_{i,j}^k) + (Q_{2,j}^k)$$

(26)

Likewise the equation (24) & (25) gives rise to stiffness matrices

$$(e_{i,J}^k)(C_i^k) + \frac{ScSo}{N}(t_{iJ}^k)(\theta_i^k) - PN_C(m_{i,j}^k)(u_i^k) = R_{1J}^k + R_{2J}^k$$

(27)

$$(l_{iJ}^k)(\theta_i^k) - P_r N_T(t_{iJ}^k)(\theta_i^k) = S_{1,J}^k + S_{2,J}^k$$

(28)

where
$(f_{i,J}^k), (g_{i,J}^k), (m_{i,J}^k), (n_{i,J}^k), (e_{i,J}^k), (t_{iJ}^k)$ are 3×3 matrices and $(Q_{2,J}^k), (Q_{1,J}^k), (R_{2,J}^k), (R_{1J}^k), (S_{2J}^k)$ and (S_{1J}^k)
are 3×1 column matrices and such stiffness matrices (26) – (28) in terms of local nodes in each element are assembled using inter element continuity and equilibrium conditions to obtain the coupled global matrices in terms of the global nodal values of k, θ & C. In case we choose n-quadratic elements then the global matrices are of order 2n+1. The ultimate coupled global matrices are solved to determine the unknown global nodal values of the velocity, temperature and concentration in fluid region. In solving these global matrices an iteration procedure has been adopted to include the boundary and effects in the porous region.

STIFFNESS MATRICES
The global matrix for θ is
$\quad$ A$_3$ X$_3$ = B$_3$ $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (29)
The global matrix for N is
$\quad$ A$_4$ X$_4$ = B$_4$ $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (30)
The global matrix u is
$\quad$ A$_5$ X$_5$ = B$_5$ $\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad$ (31)

$\qquad$ In fact, the non-linear term arises in the modified Brinkman linear momentum equation (17) of the porous medium. The iteration procedure in taking the global matrices as follows. We split the square term into a product term and keeping one of them say u_i's under integration, the other is expanded in terms of local nodal values as in (13), resulting in the corresponding coefficient matrix $(n_{i\;j}^k{}'s)$ in (26), whose coefficients involve the unknown u_i's . To evaluated (27) to begin with choose the initial global nodal values of u_i's as zeros in the zeroth approximation. We evaluate u_i's , θ_i's and C_i's in the usual procedure mentioned earlier. Later choosing these values of u_i's as first order approximation calculate θ_i's, C_i's. In the second iteration, we substitute for u_i's the first order approximation of and u_i's and the first approximation of θ_i's and C_i's obtain second order approximation. This procedure is repeated till the consecutive values of u_i's , θ_i's and C_i's differ by a preassigned percentage. For computational purpose we choose five elements in flow region.

NUSSELT NUMBER AND SHERWOOD NUMBER

The rate of heat transfer (Nusselt Number) is given by $\qquad Nu_{y=\pm i} = (\frac{d\theta}{dy})_{y=\pm 1}$

The rate of mass transfer (Sherwood Number) is given by $\quad Sh_{y=\pm 1} = (\frac{dC}{dy})_{y=\pm 1}$

DISCUSSION OF RESULTS

$\qquad$ In this analysis we discuss the combined influence of Soret and Dufour effect on convective heat and mass transfer flow of a viscous incompressible fluid through a porous medium in a vertical channel bounded by flat walls. The non- linear coupled equations

governing the flow, heat and mass transfer have been solved by employing a Galerkin finite element analysis with Quadratic approximation polynomial.

The axial velocity (u) is exhibited in fig1-5 for different values of,Sc, So, N, Du and γ .The variation of u with Sc is exhibited in Fig-1. It is found that lesser the molecular diffusivity, larger |u| and for further lowering of molecular diffusivity smaller|u| in the flow region. Effect of thermo- diffusion on u is shown in fig-2. It can be seen from the profiles that |u| depreciates with increase in So. Fig-3 represents u with buoyancy ratio N. When the molecular buoyancy force dominates over the thermal buoyancy force |u| depreciates irrespective of the directions of the buoyancy forces. Fig-4 represent u with Dufour parameter Du. We observe from this fig. that higher the Dufour parameter, larger |u| in the entire flow region. Fig-5 represents u with chemical reaction parameterγ. It is observed that |u| enhances with increase in γ ≤ 1.5 and depreciates with higher γ≥ 2.5 while in the generating chemical reaction case |u| enhances in the flow region.
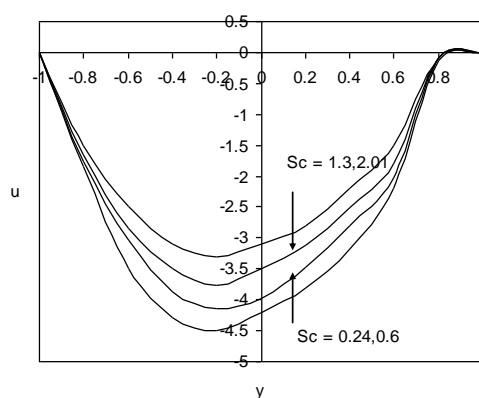

Fig. 1 : Variation of u with Sc
$G=10^3$, $D^{-1}=10^2$, $S_0=0.5$, $Du=0.03$,
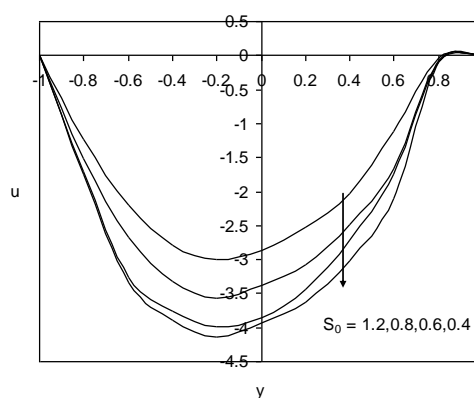$\gamma=0.5$, $N = 1$

Fig. 2 : Variation of u with S_0
$G=10^3$, $D^{-1}=10^2$, $Sc=1.3$, $Du=0.03$,
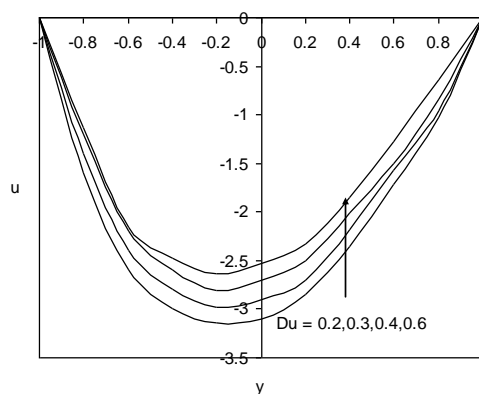$\gamma=0.5$, $N = 1$

Fig. 3 : Variation of u with Du
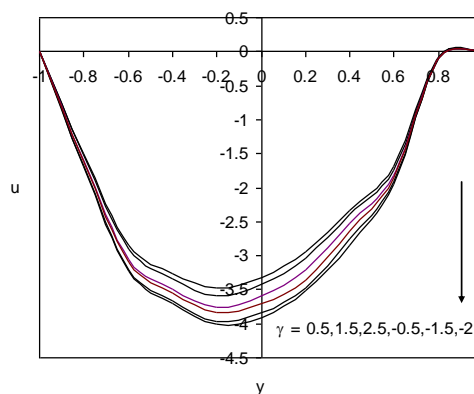$G=10^3$, $D^{-1}=10^2$, $Sc=1.3$, $S_0=0.5$,
$\gamma=0.5$, $N = 1$

Fig. 4 : Variation of u with γ
$G=10^3$, $D^{-1}=10^2$, $Sc=1.3$, $S_0=0.5$, $Du=0.03$,
$N = 1$

The non-dimensional temperature distribution (Ө) is exhibited in fig6-10 for different parametric values. We follow the convention that the non - dimension temperature positive or negative according as the actual temperature is greater/ lesser than T_2, the temperature on the right wall y =+L. Fig-6 represents Ө with Sc. It is observed that lesser the molecular diffusivity, smaller the actual temperature in the entire flow region except in a narrow region

adjacent to y = +L and for further lowering of the molecular diffusivity, larger the actual temperature in the left half and smaller in the right half. Fig-7 represents Ɵ with Soret parameter So. It reveals that actual temperature enhances with increase in So. Fig-8 represents the variation of Ɵ with buoyancy ratio N. It shows that when the molecular buoyancy force dominates over the thermal buoyancy force the actual temperature depreciates when the buoyancy forces act in the same direction and enhances for the buoyancy forces acting in opposite direction. From fig-9 we observe that the actual temperature enhances with increase in Dufour parameter Du. The variation of Ɵ with chemical reaction parameter γ shows that the actual temperature enhances with increase in $\gamma \leq$ 1.5 and depreciates with in $\gamma \geq 2.5$ while it enhances in the generating chemical reaction parameter K(fig.10).
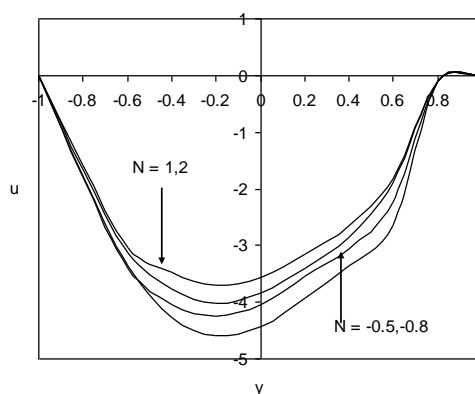

Fig. 5 : Variation of u with N
$G=10^3$, $D^{-1}=10^2$, $Sc=1.3$, $S_0=0.5$, $Du=0.03$,
$\gamma=0.5$
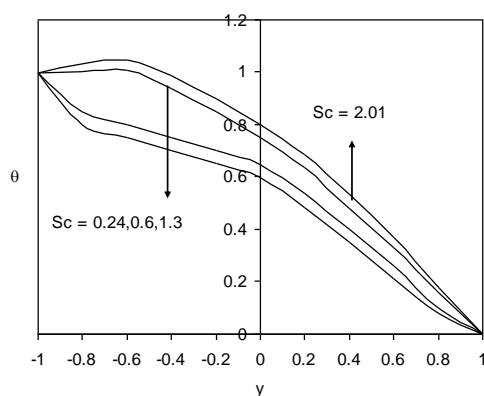

Fig. 6 : Variation of θ with Sc
$G=10^3$, $D^{-1}=10^2$, $S_0=0.5$, $Du=0.03$,
$\gamma=0.5$, $N = 1$

Fig. 7 : Variation of θ with S_0
$G=10^3$, $D^{-1}=10^2$, $Sc=1.3$, $Du=0.03$,
$\gamma=0.5$, $N = 1$

Fig. 8 : Variation of θ with Du
G=10^3, D^{-1}=10^2, Sc=1.3, S$_0$=0.5,
γ=0.5, N = 1

Fig. 9 : Variation of θ with γ
G=10^3, D^{-1}=10^2, Sc=1.3, S$_0$=0.5, Du=0.03,
N = 1

Fig. 10 : Variation of θ with N
G=10^3, D^{-1}=10^2, Sc=1.3, S$_0$=0.5, Du=0.03,
γ=0.5

Fig. 11 : Variation of C with Sc
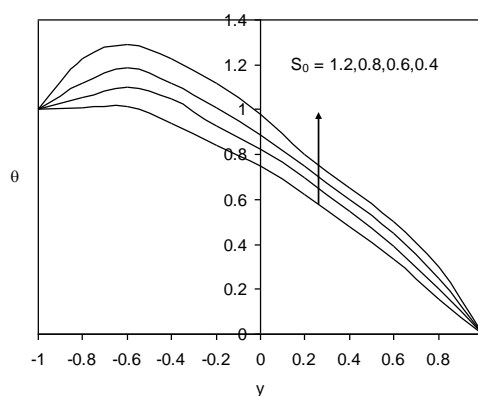G=10^3, D^{-1}=10^2, S$_0$=0.5, Du=0.03,
γ=0.5, N = 1

Fig. 12 : Variation of C with S$_0$
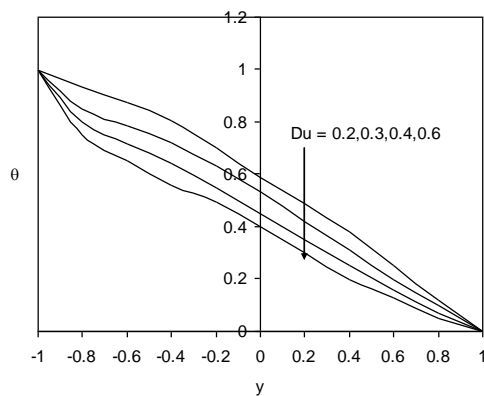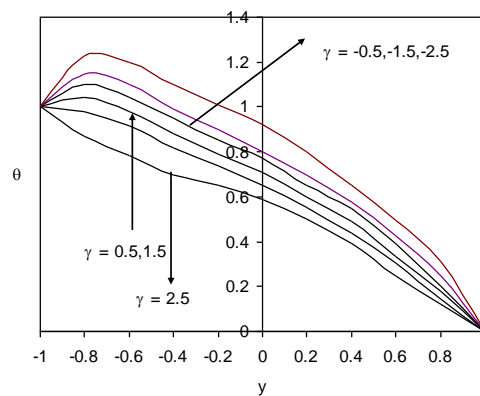G=10^3, D^{-1}=10^2, Sc=1.3, Du=0.03,
γ=0.5, N = 1

Fig. 13 : Variation of C with Du
$G=10^3$, $D^{-1}=10^2$, Sc=1.3, S_0=0.5,
γ=0.5, N = 1

Fig. 14 : Variation of C with γ
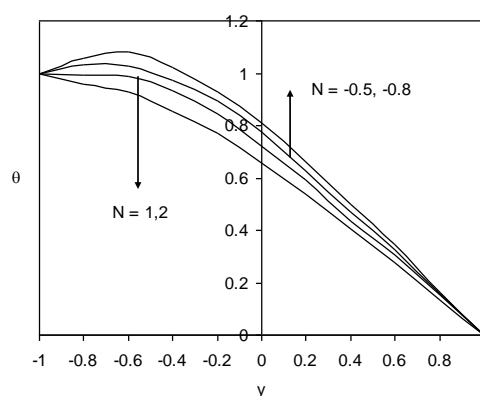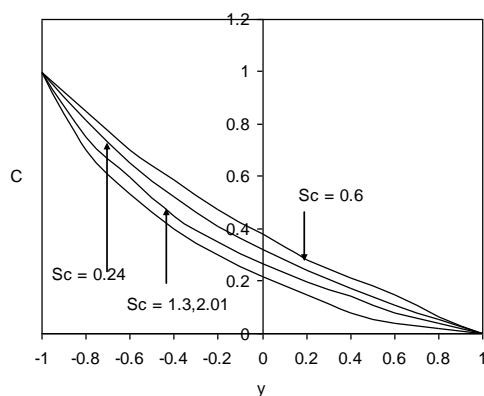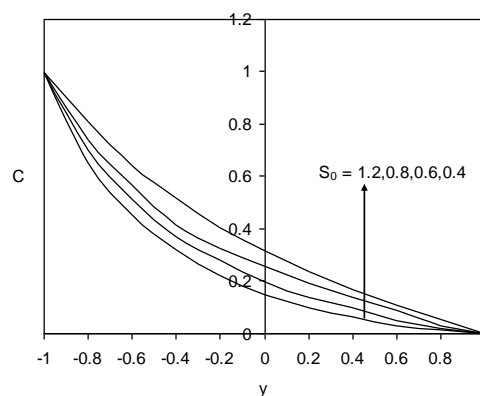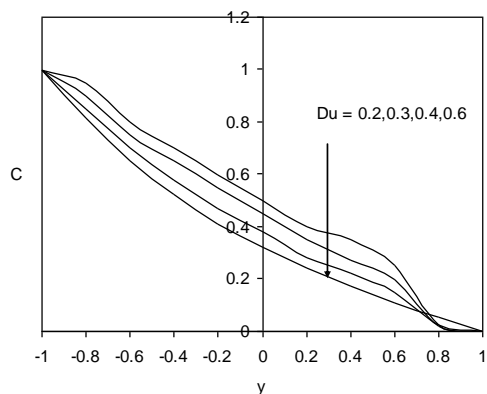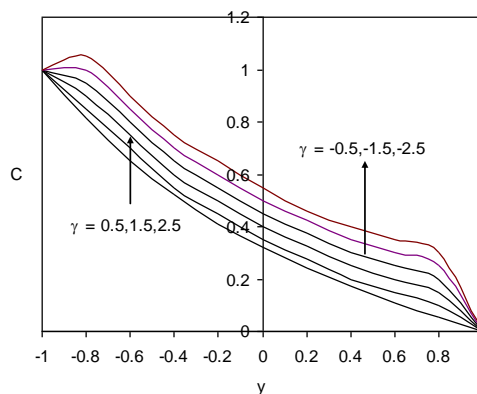$G=10^3$, $D^{-1}=10^2$, Sc=1.3, S_0=0.5, Du=0.03,
N = 1

The concentration distribution C is exhibited in fig11-15 for different parametric values. It is found that the non dimensional concentration is positive for all variations. This indicates that the actual concentration is greater than C_2, the concentration on the wall y = +L. From fig-11 it is observed that the variation of C with Sc shows that lesser the molecular diffusivity, larger the actual concentration and for further lowering of diffusivity (Sc $\geq$1.3), smaller the actual concentration. From fig-12 we find that the actual concentration depreciates with So. With respect to buoyancy ratio N we find that the actual concentration depreciates with increase in N > and enhances with |N| (<0) (fig-13). The variation of C with Du shows that the actual concentration depreciates with increase Du $\leq$ 0.07 and enhances with Du $\geq$ 0.09(fig-14). The variation of C with chemical reaction parameter γ shows that the actual concentration enhances in the degenerating chemical reaction case and depreciates in the generating chemical reaction case (fig-15).
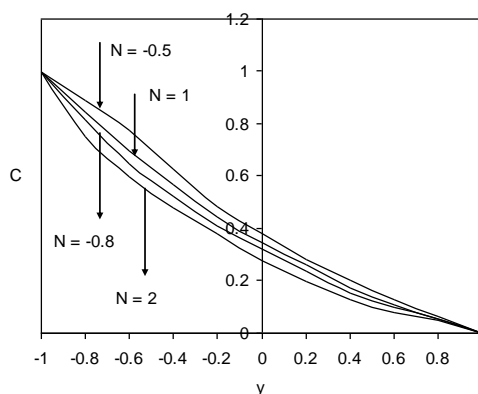
Fig. 15 : Variation of C with N
$G=10^3$, $D^{-1}=10^2$, Sc=1.3, S_0=0.5, Du=0.03,
γ=0.5

The Rate of heat transfer (Nusselt number) at y = ±1 is shown in tables 1-4 for different parametric values. It is found that the rate of heat transfer depreciates with increase in |G| and enhances with D^{-1}. An increase in Sc $\leq$ 0.6, depreciates |Nu| at y =±1. While for higher Sc $\geq$ 2.01 |Nu| depreciates at y = +1 and enhances at y = -1 for |G| = 10^2 and for higher |G| = 3×10^2 a reversal effect is noticed in the behavior of |Nu|. An increase in Soret parameter So depreciates |Nu| at y =+1 and enhances at y = -1while for an increase in |So| enhances |Nu| for |G| = 10^2 and depreciates for |G| = 3×10^2 on both the walls. (tables5&7). The variation of Nu with Dufour Parameter Du indicates that |Nu| at y = +1 enhances with $D^{-1}<10^2$ and depreciates for $D^{-1}>3 \times 10^2$ At y = -1 |Nu|, enhances with increase in Du$\leq$ 0.07 and higher Du$\geq$

0.09, |Nu| enhances for $|G| = 10^2$ and depreciates for $|G| = 3 \times 10^2$. With respect to chemical reaction parameter γ it is observed that |Nu| depreciates for G>0 and enhances for G<0 in the degenerating chemical reaction case and in the generating chemical reaction case |Nu| enhances for $|G| = 10^2$ at y = ±1 and for higher $|G| = 3 \times 10^2$ |Nu| depreciates at y = +1 and enhances at y = -1. The variation of Nu with buoyancy ratio N shows that |Nu| enhances with increase in N>0 and depreciates with |N| at both the walls(tables 2&4)

Table 1
Nusselt Number(Nu) at y=1

G	I	II	III	IV	V	VI	VII	VIII	IX
10	84.4228	14.5446	14.4538	14.9214	14.9184	14.9687	15.5563	14.9264	15.57
30	-21.9935	15.5926	14.9493	-26.051	-24.5954	-19.5567	-24.5938	-16.2063	-12.9535
-10	93.3733	14.1088	14.1676	13.9684	13.966	14.0113	14.6004	13.9642	14.6051
-30	84.4228	13.8369	13.9802	-42.6777	-38.2614	-23.4224	-39.289	-15.8744	-9.69538
D^{-1}	10^2	2×10^2	3×10^2	10^2	10^2	10^2	10^2	10^2	10^2
Sc	1.3	1.3	1.3	0.24	0.6	2.01	1.3	1.3	1.3
So	0.5	0.5	0.5	0.5	0.5	0.5	1	-0.5	-1

Table 2 : Nu at y=1

G	1	II	111	IV	V	VI	VII	VIII	IX	X	XI	XII
10	14.3169	14.3429	14.3686	14.3941	14.9109	14.8995	14.9103	14.9154	14.9163	14.919	14.9081	15.4787
30	22.1465	21.0024	19.2332	17.4489	-25.1871	-25.8503	-32.0832	-28.5113	-27.8329	-30.7924	-21.2926	-21.6913
-10	13.6868	13.6987	13.7104	13.7222	13.956	13.9434	13.959	13.9615	13.9624	13.9614	13.9666	14.5365
-30	11.4654	9.52424	7.58567	5.65905	-40.3254	-42.4356	-64.1161	-51.5353	-49.1985	-53.6582	-43.8291	-44.89
Du	0.03	0.05	0.07	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
γ	0.5	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5	0.5
N	1	1	1	1	1	1	1	1	1	2	-0.8	-0.5

Table 3
Nu at y=-1

G	I	II	III	IV	V	VI	VII	VIII	IX
10	506.52	23.1511	42.2263	27.3136	27.0949	27.2341	28.6167	27.1472	28.6928
30	-443.695	22.9195	47.5973	-494.995	-476.43	-413.393	-26.834	-164.664	15.1764
-10	644.32	18.6731	19.2861	17.2184	17.198	17.5941	18.6848	17.1925	18.6947
-30	606.56	15.8923	17.4318	-716.837	-663.075	-479.235	116.3224	15.581	12.265
AD	10^2	2×10^2	3×10^2	10^2	10^2	10^2	10^2	10^2	10^2
Sc	1.3	1.3	1.3	0.24	0.6	2.01	1.3	1.3	1.3
So	0.5	0.5	0.5	0.5	0.5	0.5	1	-0.5	-1

Table 4
Nu at y=-1

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
10	21.208	21.4652	21.7229	21.9654	27.0421	27.0245	27.0312	27.0572	27.0597	27.087	26.9529	28.3487
30	60.8637	89.8717	89.9254	65.9704	83.925	9.998	14.24	14.718	14.6375	14.6799	0.131	-44.667
-10	14.6972	14.8033	14.9082	15.0136	17.1514	17.1496	17.1322	17.1418	17.1418	17.1409	17.1577	18.4531
-30	-11.941	-37.415	12.9311	11.2231	-68.606	-71.516	-73.75	-82.867	-83.867	-49.709	28.134	34.8969
Du	0.03	0.05	0.07	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
γ	0.5	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5	0.5
N	1	1	1	1	1	1	1	1	1	2	-0.8	-0.5

The rate of mass transfer at y = ±1 is exhibited in tables5-8 for different values. It is found that the rate of mass transfer depreciates at y = +1 and enhances at y = -1 with increase in G>0, while for G<0, |Sh| enhances at y = +1 and depreciates at y = -1. The variation of Sh with D^{-1} shows that an increase in $D^{-1} < 2 \times 10^2$ depreciates |Sh| at y = +1 and enhances at y = -1 and for higher $D^{-1} \geq 3 \times 10^2$ it enhances at y = +1 and depreciates at y = -1. The variation of Sh with Sc shows that lesser the molecular diffusivity, larger |Sh| at y =±1. With Soret parameter So it can be seen that |Sh| depreciates at y = +1 and enhances at y = -1 with increase in So. (tables5&7). The variation of Sh with Du shows that higher the diffusion- thermo effects, larger |Sh| at y =±1. The rate of mass transfer enhances at y = +1 and reduces at y = -1 in the degenerating chemical reaction case, while in the generating chemical reaction case |Sh|

reduces at y = +1 and enhances at y = -1. The variation of Sh with buoyancy ratio N shows that when the molecular buoyancy force dominates over the thermal buoyancy force the rate of mass transfer enhances at both the walls. When the buoyancy forces act in the same direction and for the forces acting in opposite direction |Sh| depreciates at y = +1 and enhances at y = -1(tables6&8).

Table 5
Sherwood Number (Sh) at y=1

G	I	II	III	IV	V	VI	VII	VIII	IX
10	14.5796	13.0859	13.0881	13.0842	13.0868	13.1243	12.2578	13.0496	13.8713
30	13.9342	13.0612	13.0763	13.2624	13.5095	14.2512	12.6777	14.568	15.6268
-10	14.3302	13.0963	13.098	13.0884	13.0924	13.1295	12.2681	13.0977	13.9318
-30	14.5796	13.1029	13.1225	13.3355	13.6644	14.4553	12.8477	14.5899	15.4628
D^{-1}	10^2	2×10^2	3×10^2	10^2	10^2	10^2	10^2	10^2	10^2
Sc	1.3	1.3	1.3	0.24	0.6	2.01	1.3	1.3	1.3
So	0.5	0.5	0.5	0.5	0.5	0.5	1	-0.5	-1

Table 6
Sh at y=1

G	I	II	II	III	IV	V	VI	VII	VIII	IX	X	XI
10	13.0767	13.0767	13.0787	13.0767	13.1033	13.1413	13.1247	13.106	13.1014	13.1036	13.1135	13.8541
30	12.858	12.9661	12.9845	13.0066	13.4133	13.5301	12.0385	12.7708	12.9034	12.8335	12.7405	13.4057
-10	13.0919	13.0923	13.096	13.093	13.1109	13.1461	13.1022	13.0984	13.0969	13.0979	13.1035	13.8422
-30	13.1449	13.1913	13.2377	13.2838	13.534	13.6085	12.3559	12.1996	12.0076	13.2218	12.5099	12.7624
Du	0.03	0.05	0.07	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
γ	0.5	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5	0.5
N	1	1	1	1	1	1	1	1	1	2	-0.8	-0.5

Table 7
Sh at y=-1

G	I	II	III	IV	V	VI	VII	VIII	IX
10	13.2269	14.4885	14.4876	13.0842	14.4927	14.4988	14.6091	14.511	14.3809
30	13.9427	14.5022	14.4941	13.2624	14.2189	14.7094	14.342	13.5369	13.2517
-10	13.4298	14.4843	14.4839	13.0884	14.4875	14.6818	14.604	14.4872	14.3527
-30	13.2269	14.4999	14.4814	13.3355	14.1118	14.7442	14.2228	13.4621	13.2902
D^{-1}	10^2	2×10^2	3×10^2	10^2	10^2	10^2	10^2	10^2	10^2
Sc	1.3	1.3	1.3	0.24	0.6	2.01	1.3	1.3	1.3
So	0.5	0.5	0.5	0.5	0.5	0.5	1	-0.5	-1

Table.8
Sh at y=-1

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
10	14.4961	14.496	14.4929	14.4918	14.4398	14.266	14.4865	14.5035	14.5107	14.5076	14.4995	14.4116
30	14.6467	14.5803	14.577	14.5483	14.2414	14.1459	15.1806	15.7181	15.6375	14.6799	14.7455	14.7026
-10	14.4885	14.4883	14.4784	14.4678	14.4358	14.2629	14.4976	14.5072	14.5129	14.5104	145045	14.4175
-30	14.4571	14.4263	14.3955	14.3649	14.1589	14.0905	15.6139	15.8302	15.9008	14.7661	14.8906	14.7929
Du	0.03	0.05	0.07	0.09	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
γ	0.5	0.5	0.5	0.5	1.5	2.5	-0.5	-1.5	-2.5	0.5	0.5	0.5
N	1	1	1	1	1	1	1	1	1	2	-0.8	-0.5

REFERENCE

Alam MS Rahman MM. Ferdows M. Kaino K. Mureithi E. Postelnicu A. Diffusion-thermo and thermal-Diffusion effects on free convective heat and mass transfer. *Int J Appl Eng Res*:2:81-96, (2007.

Alam MS. Rahman MM. Abdul Maleque M. Ferdows M. Dufour and soret effects on steady MHD combined free-forced convective and mass transfer flow past a semi-infinite vertical plate. Thammasat *Int J Sci Tech*:11:1-12(2006).

Alam MS. Rahman MM. Abdul Maleque M. Local Similarity solutions for unsteady MHD free convention and mass transfer flow past an impulsively started vertical porous plate with Dufour and Soret effects. Thammasat *Int J Sci Tech*:10:-18(2005)

Alam MS. Rahman MM. Samad MA. Dufour and soret effects on unsteady MHD free convection and mass transfer flow past a vertical porous plate in a porous medium. *Non-linear Anal Modell Contr*:11:217-26(2006).

Beckermann, C and Viskanta, R : Double diffusive convection during dendritic solidification of a binary mixture., *Physico Chem.Hydrodyn*,V.10,pp.195-213(1988)

Beckermann, C.. Visakanta, R and Ramadhyani, S : A numerical study of non-Darcian natural convection in a vertical enclosure filled with a porous medium., *Numerical Heat transfer* 10, pp.557-570, (1986).

Bejan,A and Khair,K.R:Heat and Mass transfer by natural convection in porous medium.,*Int.J.Heat Mass transfer*,V.28,pp.909-918(1985).

Bejan,A and Poulikakos,D:The non-Darcy regime for vertical boundary layer natural convection in porous medium,*Int-J.Heat Mas Transfer*.,V.27,pp.77-722(1984)

Chapman S. Cowling TG. The mathematical theory of non-uniform gases. Cambridge. UK: Cambridge University Press : (1952).

Cheng,P:Combined free and forces convection flow about inclined surface in porous medium.,*Int'J.Heat and Mass transf*.V.20,pp.807-814(1977)

Forchheimer,P:Wasserbewegung durch Boden,*ForschHft,Ver Dt.Ing*.45,pp.1782-1788(1991)

Harshfelder JO,. Curtis CF. Bird RB Molecular theory of gases and liquids New York: Wiley: (1954).

Kafoussias NG. Williams EW. Thermal-diffusion and diffusion-thermo effects on mixed free-force convective and mass transfer boundary layer flow with temperature dependent viscosity. *Int J Eng Sci*:33:1369-84, (1995)

Kalidas.N. and Prasad, V: Benard convection in porous media Effects of Darcy and Pransdtl Numbers, Int. Syms. Convection in porous media, non-Darcy effects, proc.25th *Nat. Heat Transfer Conf.*V.1,pp.593-604 (1988)

Khanafer,K and Vafai,K:Double –diffusive free convection in a Lid-driven enclosure filled with a fluid –saturated porous medium.,*Numer.Heat Transf.*V.42,pp.465-   486(2002)

Kumari,M,Pop,I and Nath,G:Non-Darcy natural; convection from a heated vertical plate in saturated in a saturated porpous medium with mass transfer.,*Int.Commun.Heat Mass Transfer,*V.12,pp.337-346(1985)

Laurait,G and Prasad.,V : natural convection in a vertical porous cavity a numerical study of Brinkman extended Darcy formulation., *J.Heat Transfer*.pp.295-320(1987).

Leelakumari,S.N:Effect of chemical reaction and thermo-diffusion on non-Darcy convective heat and mass transfer through a poropus medium in a vertical channel.,*Int.J.Emerging trends in Engineering and Development*.,V.5,pp.124-134(2012)

Malasetty.M.S,Gaikwad.S.N: Effect of cross diffusion on double diffusive convection in the presence of horizontal gradient,*Int.Journal Eng.Science*, Vol.40,PP773-787(2002)

Murthy,P.V.S.N and Singh,P:Heat and Mass transfer by natural convection in a non-Darcy porous medium.,*Acta Mech.*,V.138,pp.243-254(1999)

Murthy,P.V.S.N and Sutradhar,A and Ramreddy,Ch:Double-Diffusive free convection flow past an inclined plate embedded in a non-Darcy porous medium saturated with a nanofluid., *Transp Porous Med*.,V.98,pp.553-564(2013)

Nield,D.A and Bejan,A:Convection porous media,*4th edn,Springer,New York*(2013)

Nitharasu,P,Seetharamu,K.N and Sundararajan,T:Non-Darcy double-diffusive natural convection in axisymmetric fluid saturated porous medium cavities.,*Heat Mass transf.*, V.32, pp.427-433(1997)

P.Cheng : Heat transfer in geothermal systems., *Adv.Heat transfer* 14,1-105(1978)

Plumb,O.A and Huenefeld,J.C:Non-Darcy natural convection from heated surface in saturated porous medium .,*Int.J.Heat Mass transfer*,V.24,pp.765-768(1981)

Poulikakos D., and Bejan, A.: The Departure from Darcy flow in Nat. Convection in a vertical porous layer, *physics fluids* V.28,pp.3477-3484 (1985)

Prasad, V.and Tuntomo, A. : Inertia Effects on Natural Convection in a vertical porous cavity, *numerical Heat Transfer*,V.11,pp.295-320 (1987)

Prasad.V, Kulacki,F.A and Keyhani,M;" Natural convection in a porous medium" *J.Fluid Mech.*150p.89-119(`1985)

Raptis,A Tzivanidis,G and Kafousias,N:Free convection and mass transfer flow through a porous medium bounded by an infinite vertical limiting surface with constant suction.,*Letter Haeat Mass transfer*,V.8,pp.417-424(1981).

Rastogi,S.K and Poulikakis,D:Double-diffusive from a vertical surface in a porous region saturated with a non-Newtonian fluid.,*Int.J.Heat Mass tyraqnsfer.*,V.38,pp.935-946(1995)

Sparrow EM. Minkowycz WJ. Eckert ERG. Diffusion-thermo effects in stagnation—point flow of air with injection of gases of various molecular weight into the boundary layer. *AIAAJ*:2:652-9(1964).

Tien,D C.V. and Hong, J.T.: Natural convection in porous media under non-Darcian and non-uniform permeability conditions*, hemisphere, Washington*.C. (1985)

Tong,T.L and Subramanian,E : A boundary layer analysis for natural correction in porous enclosures: use of the Brinkman-extended Darcy model,., *Int.J.Heat Mass Transfer.* 28,pp.563-571 (1985).

Vafai, K., Thiagaraju, R.: Analysis of flow and heat Transfer at the interface region of a porous medium, *Int. J. Heat Mass Trans*.,V.30pp.1391-1405 (1987)

Vafai, K., Tien, C.L: Boundary and Inertia effects on flow and Heat Transfer in Porous Media, *Int. J. Heat Mass Transfer*, V.24.,pp.195-203 (1981)