

Combined Influence of Thermal Radiation, Radiation Absorption, Soret, Dufour Effects on Non-Darcy Mixed Convective Heat and Mass Transfer Flow with Dissipation in a Vertical Channel

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ABSTRACT: An attempt has been made to investigate the effect of dissipation and radiation absorption on convective heat and mass transfer in a vertical channel with Soret and Dufour effects using Galerkin finite element technique. The governing equations of flow heat and mass transfer have been solved to obtain Velocity, Temperature and Concentration. The effects of dissipation and thermal radiation on the flow characteristics have been investigated.

KEYWORDS: Dissipation, Radiation absorption, Soret and Dufour effect.

I. INTRODUCTION

The vertical channel is a frequently encountered configuration in thermal engineering equipment, for example, collectors of solar energy, cooling devices of electronic and Micro-electronic equipments etc. The combined forced and free convective flow in a vertical channel with viscous dissipation and isothermal –isoflux boundary conditions have been studied by Barletta [2]. Barletta et al [3] have presented a dual mixed convection flow in a vertical channel. Barletta et al [4] have described a buoyancy MHD flow in a vertical channel.

When heat and mass transfer occur simultaneously in a moving fluid, the relation between the fluxes and the driving potentials are of more intricate nature. Mass fluxes can be created by temperature gradients and this is the Soret effect or thermo-diffusion effect. Adrian Postelnicu [1] has studied thermo-diffusion and diffusion thermo effects on combined heat and mass transfer through a porous medium under different conditions. Sreevani et. al. [11] has studied the unsteady free convective heat and mass transfer flow through porous medium dissipative effect in rotating channel. Dulal pal et al [6] have studied the effect of Soret, Dufour, chemical reaction and thermal radiation on MHD, non-darcy, unsteady mixed convective heat and mass transfer over stretching sheet. Ching-Yang-Cheng [5] have investigated Soret and Dufour effects on free convective boundary layer over inclined wavy surface in a porous medium. Dulal pal et al [7] have investigated the effects on MHD non-darcian mixed convective heat and mass transfer over a stretching sheet with non-uniform heat source/sink. Sulochana.C, Tayappa.H et al [12] Finite element analysis of thermo-diffusion and diffusion- thermo effects on combined heat and mass transfer flow of viscous, electrically conducting fluid through a porous medium in vertical channel.

The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. We are particularly interested in cases in which diffusion and chemical reaction occur at

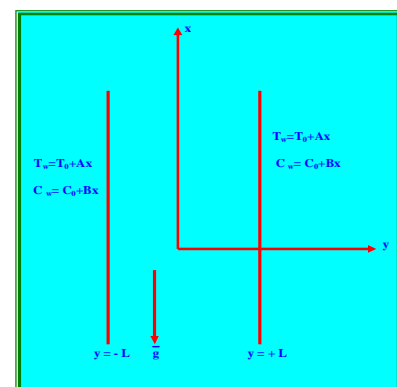


Fig.1: Configuration of the problem

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roughly the same speed. When diffusion is much faster than chemical reaction, then only chemical factors influence the chemical reaction rate; when diffusion is not much faster than reaction, the diffusion and kinetics interact to produce very different effects. Ibrahim et al [9] have discussed the combined influence of chemical reaction, radiation absorption on unsteady convective flow past a semi-infinite plate. Sreerangavani et al [10] have investigated the influence of radiation absorption on convective heat and mass transfer in a vertical channel.

In this paper, we investigate the effect of dissipation and radiation absorption on convective heat and mass transfer in a vertical channel with Soret and Dufour effects using Galerkin finite element technique.

II. 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 $y = \pm L$. The walls are maintained at constant temperature and concentration.

The momentum, energy and diffusion equations under Boussinesq appear are

$$-\frac{\partial p}{\partial x} + \left(\frac{\mu}{\delta}\right) \frac{\partial^2 u}{\partial y^2} - \left(\frac{\mu}{k}\right)u - \left(\frac{\sigma \mu_e^2 H_o^2}{\rho_e}\right)u - \frac{\rho \delta F}{\sqrt{k}} u^2 - \rho g = 0 \quad (1)$$

$$\rho_0 C_p u \frac{\partial T}{\partial x} = k_f \frac{\partial^2 T}{\partial y^2} + Q_H (T - T_0) + \mu \left(\frac{\partial u}{\partial y}\right)^2 + \frac{Dm K_T}{C_s C_p} \frac{\partial^2 C}{\partial y^2} + Q_1 (C - C_0) \quad (2)$$

$$u \frac{\partial C}{\partial x} = D_1 \frac{\partial^2 C}{\partial y^2} - k_1 C + \frac{D_m K_T}{T_m} \frac{\partial^2 \theta}{\partial y^2} \quad (3)$$

The relevant boundary conditions are

$$u = 0, \quad T = T_w, \quad C = C_w \quad \text{at} \quad y = \pm L \quad (4)$$

where u , T , C are the velocity, temperature and Concentration, p is the pressure, ρ is the density of the fluid, 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, β^* is the volumetric coefficient of expansion with mass fraction concentration, k_1 is the chemical reaction coefficient and D_1 is the chemical molecular diffusivity, q_R is the radiative heat flux. Dm is the coefficient of mass diffusivity, Q_H is the strength of the heat source, K_T thermo-diffusion ratio, T_m is the mean fluid temperature. Here, the thermo physical 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 fluids are considered to be in the thermal equilibrium. Following Tao [13] and Das et al [8], we assume that the temperature and concentration of the both walls is $T_w = T_0 + Ax$, $C_w = C_0 + Bx$ where A and B are the vertical temperature and concentration gradients which are positive for buoyancy –aided flow and negative for buoyancy –opposed flow, respectively, T_0 and C_0 are the upstream reference wall temperature and concentration respectively. The velocity depend only on the radial coordinate and all the other physical variables except temperature, concentration and pressure are functions of y and x , x being the vertical co-ordinate.

The temperature and concentration inside the fluid can be written as

$$T = T^*(y) + Ax, \quad C = C^*(y) + Bx$$

We define the following non-dimensional variables as

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$$u' = \frac{u}{(v/L)}, (x', y') = (x, y)/L, \quad p' = \frac{p\delta}{(\rho v^2/L^2)} \tag{10}$$

$$\theta(y) = \frac{T^* - T_0}{P_1 AL}, \quad C = \frac{C^* - C_0}{P_1 BL}, \quad P_1 = \frac{dp}{dx}$$

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

$$\frac{d^2 u}{dy^2} = 1 + \delta(D^{-1})u - \delta G(\theta + NC) - \delta^2 \Delta u^2 \tag{11}$$

$$\frac{d^2 \theta}{dy^2} = (P_r)u + Ec \Pr \left(\frac{du}{dy}\right)^2 + Q\theta - Du \Pr \frac{d^2 C}{dy^2} + Q_1 C \tag{12}$$

$$\frac{d^2 C}{dy^2} - \gamma C = (Sc)u - ScSr \frac{d^2 \theta}{dy^2} \tag{13}$$

Where $\Delta = FD^{-1/2}$ is the Inertia or Forchheimer parameter, $G = \frac{\beta g AL^3}{v^2}$ is the Grashof number, $D^{-1} = \frac{L^2}{k}$ is

the Inverse Darcy parameter, $Sc = \frac{v}{D_1}$ is the Schmidt number, $N = \frac{\beta^* B}{\beta A}$ is the Buoyancy ratio, $P_r = \frac{\mu C_p}{k_f}$ is the

Prandtl number, $\gamma = \frac{k_1 L^2}{D_1}$ is the Chemical reaction parameter, $Q_1 = \frac{Q_1 BL^2}{C_p A}$ is the Radiation absorption parameter,

$Ec = \frac{v^2}{P_1 AL^3 C_p}$ is the Eckert number, $Sr = \frac{D_m K_T A}{k_f T_m B}$ is the Soret Parameter, $Du = \frac{D_m K_T B}{C_s C_p A}$ is the Dufour

Parameter, $Q = \frac{Q_H L^2}{C_p k_f}$ is the Heat source parameter

The corresponding boundary conditions are

$$u = 0, \quad \theta = 0, \quad C = 0 \quad \text{on } y = \pm 1 \tag{14}$$

The non-linear, coupled equations have been solved by using Galerkin finite element technique with quadrate approximation functions

III. SHEAR STRESS, NUSSLETT NUMBER AND SHERWOOD NUMBER

The shear stress on the boundaries $y = \pm 1$ is given by $\tau_{y=\pm 1} = \mu \left(\frac{du}{dy}\right)_{y=\pm 1}$

In the non-dimensional form is $\tau_{y=\pm 1} = \left(\frac{du}{dy}\right)_{y=\pm 1}$

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

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

IV. DISCUSSION OF THE NUMERICAL RESULTS

In order to get physical insight into the problem we have carried out numerical calculations for non-dimensional velocity, temperature and species concentration, skin-friction, Nusselt number and Sherwood number by assigning some specific values to the parameters N , Ec , Sr , Du and Q_1 entering into the problem. The conclusions of this analysis are

Effects of parameters on velocity profiles:

The variation of u with variations in different parameters is negative. This shows that axial velocity is in the vertically downward direction (figs. 2a – 5a).

Fig.2a exhibits the variation of u with buoyancy ratio (N). It is found that when the molecular buoyancy force dominates over the thermal buoyancy force the axial velocity decreases when the buoyancy forces are in the same direction and for the forces acting in opposite directions it reduces in the flow region. Fig.4a shows the variation of u with Eckert number Ec . It is found that higher the dissipative effects smaller the axial velocity in the flow region. The variation of u with Soret parameter Sr /Dufour parameter Du is exhibited in fig.3a.It can be seen from the profiles that increasing Soret parameter Sr (or decreasing Dufour parameter Du larger the axial velocity in the flow region.Fig.5a shows the variation of u with radiation absorption parameter Q_1 . It can be seen from the profiles that higher the radiation absorption smaller the magnitude of the velocity.

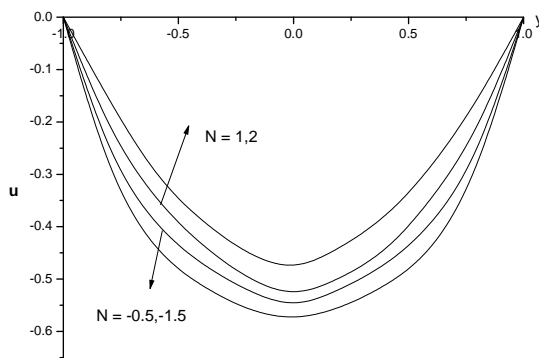


Fig. 2a: Variation of u with N
 $Sr= 2, Du= 0.3, Q_1= 0.5, Ec= 0.01$

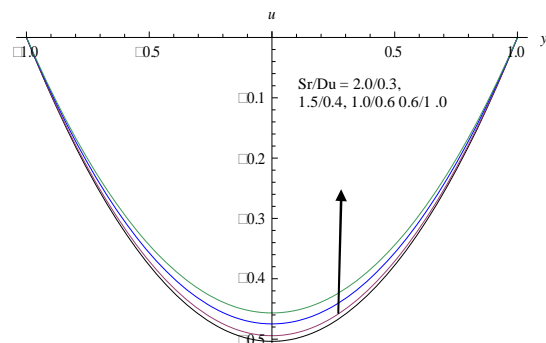


Fig. 3a: Variation of u with Sr/Du
 $N= 1, Q_1= 0.5, Ec= 0.01$

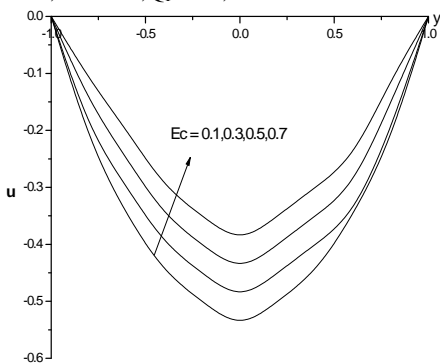


Fig. 4a: Variation of u with Ec
 $N= 1, Sr= 2, Du= 0.3, Q_1= 0.5$

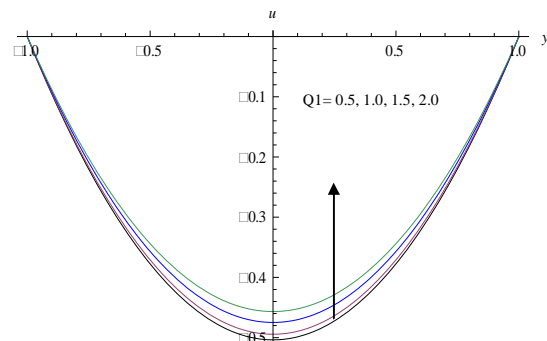


Fig. 5a: Variation of u with Q_1
 $N= 1, Sr= 2, Du= 0.3, Ec= 0.01$

Effects of parameters on temperature profiles:

The non-dimensional temperature (θ) is shown in (figs. 2b – 5b) for different parametric variations. We follow the convention that the non-dimensional temperature (θ) is positive/negative according as the actual temperature

(T^*) is greater/lesser than the reference temperature T_0 . Fig.2b shows the variation of θ with buoyancy ratio (N). It is observed from the profiles that when the molecular buoyancy force dominates over the thermal buoyancy force the actual temperature reduces when the buoyancy forces are in the same direction and for the forces acting in opposite directions it enhances in the flow region. Fig.4b represents θ with Ec. It is found that higher the dissipation smaller the actual temperature. The variation of θ with Soret parameter (Sr) and Dufour parameter Du is exhibited in fig.3b. It can be seen from the profiles that increasing Sr (or decreasing Du) larger the actual temperature in the flow region. The effect of θ with Q_1 shows that higher the radiation absorption lesser the actual temperature (fig.5b).

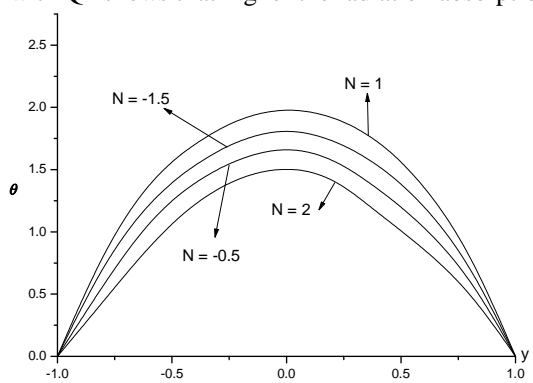


Fig. 2b: Variation of θ with N
Sr= 2, Du= 0.3, $Q_1= 0.5$, Ec= 0.01

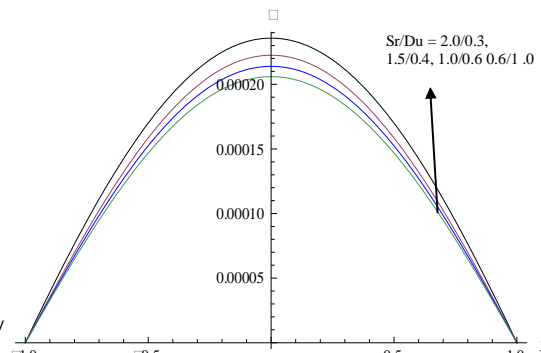


Fig. 3b: Variation of θ with Sr/Du
N= 1, $Q_1= 0.5$, Ec= 0.01

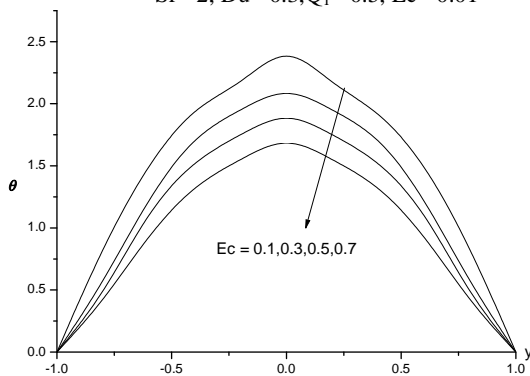


Fig. 4b: Variation of θ with Ec
N= 1 Sr= 2, Du = 0.3, $Q_1= 0.5$

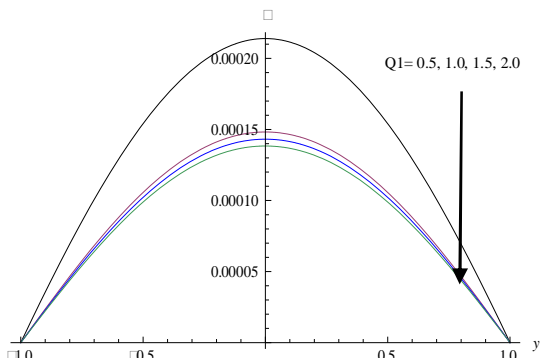


Fig. 5b: Variation of θ with Q_1
N= 1, Sr= 2, Du= 0.3, Ec= 0.01

Effects of parameters on concentration profiles:

The non-dimensional concentration (C) is shown in (figs. 2c – 5c) for different parametric variations. We follow the convention that the non-dimensional concentration (C) is positive/negative according as the actual concentration (C^*) is greater/lesser than the reference concentration (C_0).

Fig.2c shows the variation of C with buoyancy ratio N. We find that when the molecular buoyancy force dominates over the thermal buoyancy force the actual concentration decreases when the buoyancy forces are in the same direction and for the forces acting in opposite directions it enhances in the flow region. Fig.4c represents C with Ec. It can be seen from the profiles that higher the dissipation larger the actual concentration in the flow region. Fig.5c shows the variation of C with Sr and Du. We find from the profiles that increasing Soret parameter Sr (or decreasing Du) larger the actual concentration in the flow region. The variation of C with radiation absorption parameter Q_1 is exhibited in fig.5c. It can be seen from the profiles that the actual concentration reduces with increase in Q_1 .

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Effects of parameters on Nusselt number and Sherwood number:

The rate of heat transfer (Nusselt number) reduces on the walls with increasing in the buoyancy ratio ($N > 0$) when the buoyancy forces are in the same direction and forces acting in opposite directions it enhances on the walls. The Nusselt number reduces with increasing $Ec \leq 0.05$ and smaller the Nusselt number for still higher $Ec \geq 0.07$ on the walls. Increasing Soret parameter Sr (or decreasing Du) increases the Nusselt number on both the walls. Also lesser the thermal diffusivity larger the rate heat transfer at the walls. With respect to Q_1 we find that higher the radiation absorption smaller the rate of heat transfer on the walls.

The rate of mass transfer (Sherwood number) reduces with increase in $N > 0$ and enhances with $N < 0$ on both the walls. With respect to Soret parameter Sr , and Dufour parameter Du we find that increasing Sr (or decreasing Du) enhances the rate of mass transfer on the both the walls. The variation of Sh with Ec shows that the rate of mass transfer decreases with $Ec \leq 0.03$ and for higher $Ec \geq 0.05$, we notice an enhancement in Sh on the walls. With respect to Q_1 we find that higher the radiation absorption smaller the rate of mass transfer on the walls.

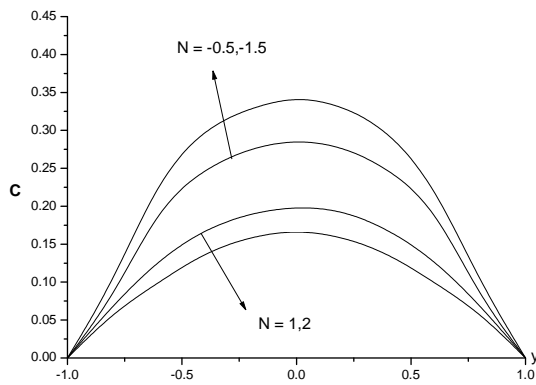


Fig. 2c: Variation of C with N
 $Sr = 2, Du = 0.3, Q_1 = 0.5, Ec = 0.01$

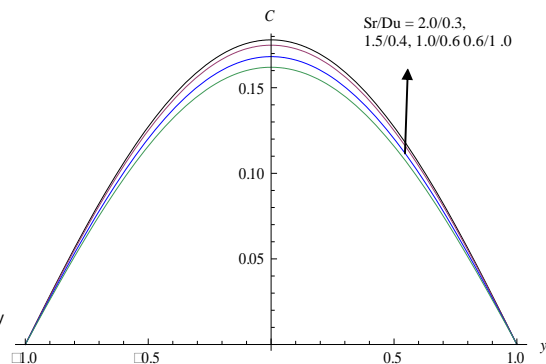


Fig. 3c: Variation of C with Sr/Du
 $N = 1, Q_1 = 0.5, Ec = 0.01$

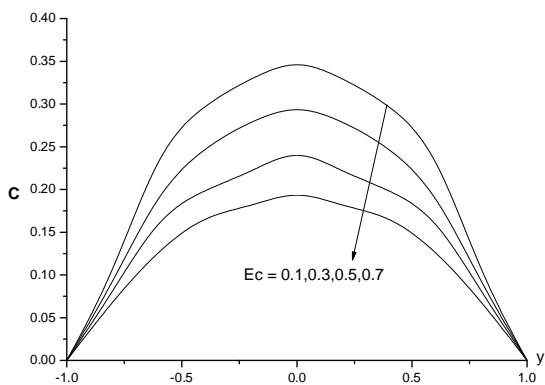


Fig. 4c: Variation of C with Ec
 $N = 1, Sr = 2, Du = 0.3, Q_1 = 0.5$

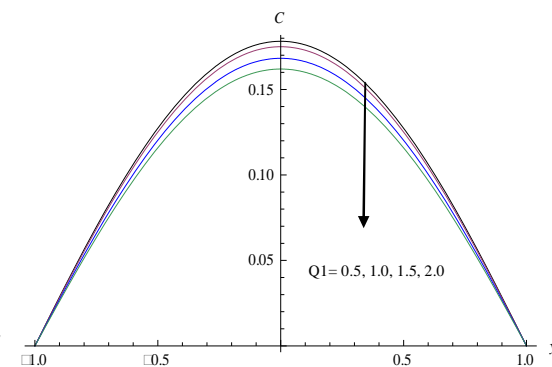


Fig. 5c: Variation of C with Q_1
 $N = 1, Sr = 2, Du = 0.3, Ec = 0.01$

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Table – 1 : The rate of heat and mass transfer at $\eta = \pm 1$

Parameter		Nu(+1)	Nu(-)	Sh(+1)	Sh(-1)
N	1	-0.486113	0.486113	-0.287269	0.287269
	2	-0.361889	0.361889	-0.238739	0.238739
	-0.5	-0.368937	0.368937	-0.291399	0.291399
	-1.5	-0.371571	0.371571	-0.293451	0.293451
Ec	0.1	-0.486113	0.486113	-0.287269	0.287269
	0.3	-0.368121	0.368121	-0.240114	0.240114
	0.5	-0.375767	0.375768	-0.28737	0.28737
	0.7	-0.399736	0.399737	-0.28756	0.287346
Sr/du	2.0/0.3	-0.237273	-0.237273	-0.000237273	-0.000237273
	1.5/0.4	-0.193658	-0.193658	-0.0002194365	-0.0002143658
	1.0/0.6	-0.165633	-0.165633	-0.000205633	-0.000205633
	0.6/1.0	-0.141743	-0.147434	-0.000187434	-0.0001817434
Q1	0.5	-0.486113	0.486113	-0.287269	0.287269
	1.0	-0.366011	0.366011	-0.240115	0.240115
	1.5	-0.356858	0.3568576	-0.237377	0.237377
	2.5	-0.3270973	0.3270973	-0.217374	0.217374

V. CONCLUSIONS

The non-linear coupled equations governing the flow have solved by employing Galerkin finite element technique. The effect of Soret effect, dissipation, radiation on all the flow characteristics have displayed graphically. The conclusions of this analysis are:

- 1) An increase in Grashof number reduces the velocity, temperature, concentration and Skin friction on the walls. The Nusselt number reduces and the Sherwood number enhances with $G \leq 20$ and for higher $G \geq 30$, a reversed effect is noticed on Nu and Sh.
- 4) Lesser the molecular diffusivity smaller the velocity, temperature, skin friction and larger the concentration and Sherwood number. An increase in $Sc \leq 1.3$ reduces Nu and enhances Nu with higher $Sc \geq 2.01$.
- 5) The velocity, temperature, concentration, Skin friction, Nusselt number and Sherwood number reduce with increase in the buoyancy ratio $N > 0$ and for $N < 0$, except temperature all flow variables enhance in the flow region.
- 6) An increase in the strength of the heat generating source enhances the velocity, skin friction, reduces the Nusselt number and for $Q < 0$, the velocity, skin friction reduce and the Nusselt number enhance on the walls. The temperature, concentration, and Sherwood number reduce with increase in the strength of the heat generating/absorbing source.
- 7) Higher the radiative heat flux lesser the velocity, temperature, concentration, skin friction, Nusselt number and larger the Sherwood number on the walls.
- 8) The velocity, temperature and concentration, Nusselt number and Sherwood number reduce, skin friction enhances in the degenerating chemical reaction case. In the generating chemical reaction case, the velocity, temperature enhances, the concentration reduces with increase in $|\gamma| \leq 1.5$ and for higher $|\gamma| \geq 2.5$, we notice a reversed effect on them. The skin friction, Nusselt number and Sherwood number enhance on the both walls.
- 10) Increasing Sr (or decreasing Du) enhances the velocity, temperature and Sherwood number, while the concentration, skin friction, Nusselt number reduce on the walls.
- 11) Increase in Forchheimer number Δ reduces the velocity, concentration, skin friction, Nusselt number while the temperature and Sherwood number increases.
- 12) The velocity, concentration reduce, the temperature and Nusselt number enhances with increase in Pr. An increase in $Pr \leq 1.71$, enhances the Skin friction and reduces the Sherwood number while for higher $Pr \geq 3.71$, we notice reduction in Skin friction and enhancement in Sh.

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