Effect of Thermo- Diffusion and Dissipation on Double Diffusive Heat and Mass Transfer Flow Of A Kuvshinski Fluid

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Abstract: *In this paperthe combined influence of chemical reaction, thermo diffusion and dissipation on convective heat and mass transfer flow of a Kuvshinski fluid past a vertical plate embedded in a porous medium is discussed. The equations governing the flow, heat and mass transfer have been solved by a regular perturbation technique. The effect of chemical reaction parameter (K), thermo-diffusion parameter (S_r), Eckert number (E_c), heat source parameter (α) and time (t) on the velocity, temperature and concentration distributions are discussed. It is observed that the temperature and concentration reduces with increase in the strength of the heat source parameter where as the velocity depreciates with increase in heat source parameter. In the presence of E_c, it is observe that higher the dissipative heat smaller the velocity, temperature, and concentration in the flow field and we notice an enhancement in the case of time (t).*
Keywords: *Kuvshinski fluid, MHD, Thermo-Diffusion, Chemical Reaction*

I. Introduction

The convection problem in a porous medium has important applications in geothermal reservoirs and geothermal extractions. The process of heat and mass transfer is encountered in aeronautics, fluid fuel nuclear reactor, chemical process industries and many engineering applications in which the fluid is the working medium. The unsteady fluid flow past a moving plate in the presence of free convection and radiation were studies by Monsure [8], Raptis and Perdikis [12], Ganesan and Loganathan [3], Mbeledogu et al. [9], Makinde [7], and Abdus –Satter and Hamid Kalim [1],Cookeyet al.[2],Hassanien.et al.[5],Kim [6] ,Raptis, etal. [13,14,15]. All these studies have been confined to unsteady flow in a non-porous medium.

The study of heat generation or absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reactions. Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore received a considerable amount of attention in recent years. For example in the power industry among the methods of generation electric power is one in which electrical energy is extracted directly form a moving conducting fluids. Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemical reaction within or at the boundary. There are two types of reactions; a homogeneous reaction is one that occurs uniformly throughout a give phase. The species generation in a homogeneous reaction is analogous to internal source of heat generation. In constraint a heterogeneous reaction takes place in a restricted region or within the boundary of a phase. It can therefore be treated as a boundary condition similar to the constant heat flux condition in heat transfer the study of heat and mass transfer withchemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Muthucumaraswamy and Ganesan [11] studied first-order chemical reaction on flow past on impulsively started vertical plate with uniform heat and mass flux. Recently, Mohamed [10] has discussed double-diffusive convection-radiation interaction on unsteady MHD flow over a vertical moving porous plate with heat generation and Soret effects. Recently Kuvshinski fluid is attracting the attention of many researchers [16-18]. Ravikumar et al. [19] addressedMHD three dimensional Couette flow past a porous plate with heat transfer. Numerical study of Magneto-Convective and radiation absorption fluid flow past an exponentially accelerated vertical porous plate with variable temperature and concentration in the presence of Soret and Dufour effects was reported by Umamaheswar et al. [20]. MHD transient free convection and chemically reactive flow past a porous vertical plate with radiation and temperature gradient dependent heat source in slip flow regime was considered by Rao et al.[21]. Important applications of double diffusive flows are highlighted by few authors [22-27]. Influence of thermal diffusion on convective flows was also addressed by several authors [28-30].

In spite of all these studies the effect of Kuvshinski fluid on unsteady MHD double diffusive free convection for a heat generating fluids with thermal radiation and chemicals reaction has received more

attention. Hence in this paper combined influence of chemical reaction, thermo diffusion and dissipation on convective heat and mass transfer flow of a Kuvshinski fluid past a vertical plate embedded in a porous medium is investigated.

II. Formulation Of The Problem

We consider a rectangular Cartesian system $O(x,y)$ with x-axis along the plate and y-axis normal to it. Initially it is assumed that the plate and the fluid are at the same temperature T_∞ and the concentration level C_∞ everywhere in the fluid. The radiating heat flux in the x-direction is considered negligible in comparison to that in the y-direction. The fluid assumed to be gray emitting and absorbing radiation but non-scattering medium. All the fluid properties are considered constant except in the influence of the density variation with temperature in the body-force term. Under the above assumptions the equations governing the flow, heat and mass transfer are

Continuity equation is

$$\frac{\partial v}{\partial y} = 0 \tag{1}$$

Momentum equation is

$$(1+\lambda \frac{\partial}{\partial t})\frac{\partial u}{\partial t} + v\frac{\partial u}{\partial y} = \beta g(T-T_\infty) + \beta^\bullet g(C-C_\infty) + v\frac{\partial^2 u}{\partial y^2} - \frac{v}{k}(1+\lambda \frac{\partial}{\partial t})u - \frac{\sigma \mu_e^2 H_o^2}{\rho}u \tag{2}$$

Energy equation

$$(1+\lambda \frac{\partial}{\partial t})\frac{\partial T}{\partial t} + v\frac{\partial T}{\partial y} = \frac{k_0}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{v}{C_p}(\frac{\partial u}{\partial y})^2 + Q(T-T_\infty) \tag{3}$$

Diffusion equation

$$(1+\lambda \frac{\partial}{\partial t})\frac{\partial C}{\partial t} + v\frac{\partial C}{\partial y} = D_1\frac{\partial^2 C}{\partial y^2} - k_r'(C-C_\infty) + k_{11}\frac{\partial^2 T}{\partial y^2} \tag{4}$$

The initial and boundary conditions are

$$u = 0, T = T_w, C = C_w \quad at \quad y = 0$$

$$u \to 0, T \to T_\infty, C \to C_\infty \quad as \quad y \to \infty \tag{5}$$

Where u and v are the parallel and perpendicular components of velocity to the plate, t is the time, ρ is the density, υ is the kinematic viscosity, Cp is the specific heat at constant pressure, g is the acceleration due to gravity, β is the volumetric coefficient of thermal expansion, $\beta^\bullet$ is the volumetric coefficient of concentration expansion. T, C are the temperature and Species concentration in the fluid region. T_w, C_w are wall temperature and Concentration, $T_\infty \& C_\infty$ are the free stream temperature and concentration in fluid far away from the plate, k_o is the thermal conduction, D_1 is the mass diffusivity, q_r is the radiation heat flux, k is the permeability of the porous medium, k_r' is the chemical reaction coefficient, Q is the strength of the heat source, k_{11} is the cross diffusivity. The third term on the right hand side of equation (2.3) represents radiative heat flux term.

The equation of continuity (1) gives

$$v = -v_0 \tag{6}$$

Where v_o is the constant suction velocity normal to the plate.

In view of (6) the equations (2), (3) and (4) now reduce to

$$(1+\lambda \frac{\partial}{\partial t})\frac{\partial u}{\partial t} - v_0\frac{\partial u}{\partial y} = \beta g(T-T_\infty) + \beta^\bullet g(C-C_\infty) + v\frac{\partial^2 u}{\partial y^2} - \frac{v}{k}(1+\lambda \frac{\partial}{\partial t})u - \frac{\sigma \mu_e^2 H_o^2}{\rho}u \tag{7}$$

$$(1+\lambda \frac{\partial}{\partial t})\frac{\partial T}{\partial t} - v_0\frac{\partial T}{\partial y} = \frac{k_0}{\rho C_p}\frac{\partial^2 T}{\partial y^2} + \frac{v}{C_p}(\frac{\partial u}{\partial y})^2 + Q(T-T_\infty) \tag{8}$$

$$(1 + \lambda \frac{\partial}{\partial t}) \frac{\partial C}{\partial t} - v_0 \frac{\partial C}{\partial y} = D_1 \frac{\partial^2 C}{\partial y^2} - k_r'(C - C_\infty) + k_{11} \frac{\partial^2 T}{\partial y^2} \qquad (9)$$

On introducing the following non-dimensional variables

$$u' = \frac{u}{v_0}, y' = \frac{y v_0}{v}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_w - C_\infty}, t' = \frac{v_o^2 t}{v}, \qquad (10)$$

The governing equations reduce to

$$\alpha_1 \frac{\partial u}{\partial t} + \alpha_2 \frac{\partial^2 u}{\partial t^2} = G(\theta + N\phi) + \frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} - (M^2 + D^{-1})u \qquad (11)$$

$$\Pr \frac{\partial \theta}{\partial t} + \Pr \alpha_2 \frac{\partial^2 \theta}{\partial y^2} + \frac{\partial^2 \theta}{\partial y^2} + \Pr \frac{\partial \theta}{\partial y} + \Pr Ec (\frac{\partial u}{\partial y})^2 - \alpha \Pr \theta \qquad (12)$$

$$Sc \frac{\partial \phi}{\partial t} + Sc \alpha_2 \frac{\partial^2 \phi}{\partial t^2} = \frac{\partial^2 \phi}{\partial y^2} + Sc \frac{\partial \phi}{\partial y} - (k_r Sc)\phi + \frac{Sc So}{N} \frac{\partial^2 \theta}{\partial y^2} \qquad (13)$$

Where

$$M^2 = \frac{\sigma \mu_e^2 H_o^2 v}{\rho v_o^2} \text{ (Magnetic parameter)}, \; D^{-1} = \frac{v^2}{k v_o^2} \quad \text{(Darcy parameter)}$$

$$G = \frac{\beta g (T_w - T_\infty) v}{v_o^3} \text{(Grashof number)}, \; \Pr = \frac{\rho v C_p}{k_o} \text{(Prandtl Number)}$$

$$N_1 = \frac{\beta_R k_0}{4 \sigma^\bullet T_\infty^3}, \text{(Radiation parameter)}, N = \frac{\beta^\bullet (C_w - C_\infty)}{\beta (T_w - T_\infty)} \text{(Buoyancy ratio)}$$

$$kr = \frac{k_r' v}{v_o^2} \text{(Chemical reaction parameter)} \; \alpha = \frac{Q v}{v_o^2} \text{ (Heat source parameter)}$$

$$Sr = \frac{k_{11}(T_w - T_\infty)}{(C_w - C_\infty)} \quad \text{(Soret parameter)}, \; \alpha_1 = 1 + \frac{v \lambda}{k}, \alpha_2 = \frac{\lambda v_o^2}{v}$$

The corresponding boundary conditions are

$$u = 0, \theta = 1, \phi = 1 \quad at \; y = 0$$

$$u \to 0, \theta \to 0, \phi \to 0 \; as \; y \to \infty \qquad (14)$$

III. Method Of Solution

To solve the coupled non-linear equations (11) - (13) subject to the boundary conditions (14), we may represent the velocity (u), temperature (θ), concentration (φ) of the fluid in powers of Eckert number (Ec) assuming it to be very small. Hence we can write

$$u = u_0 + Ec u_1 e^{-nt}$$

$$\theta = \theta_0 + Ec \theta_1 e^{-nt} \qquad (15)$$

$$\phi = \phi_0 + Ec \phi_1 e^{-nt}$$

Substituting (15) into the equations (11) - (13) and equating harmonic, non-harmonic terms and neglecting Ec^2 and higher order terms, we get

$$\frac{d^2 u_0}{dy^2} + \frac{du_0}{dy} - (M^2 + D^{-1})u_0 = -G(\theta_0 + N\phi_0) \qquad (16)$$

$$\frac{d^2 u_1}{dy^2} + \frac{du_1}{dy} - (M^2 + D^{-1} - n\alpha_1 + n^2 \alpha_2)u_1 = -G(\theta_1 + N\phi_1) \qquad (17)$$

$$\frac{d^2\theta_0}{dy^2} + \Pr\frac{d\theta_0}{dy} - \alpha\Pr u_0 = 0 \tag{18}$$

$$\frac{d^2\theta_1}{dy^2} + \Pr\frac{d\theta_1}{dy} + (n\Pr - n^2\Pr\alpha_2 - \alpha\Pr)\theta_1 = -\Pr(\frac{du_0}{dy})^2 \tag{19}$$

$$\frac{d^2\phi_0}{dy^2} + Sc\frac{d\phi_0}{dy} - (Sck_r)\phi_0 = -ScSr\frac{d^2\theta_0}{dy^2} \tag{20}$$

$$\frac{d^2\phi_1}{dy^2} + Sc\frac{d\phi_1}{dy} + (nSc - n^2Sc\alpha_2 - KrSc)\phi_1 = -ScSr\frac{d^2\theta_1}{dy^2} \tag{21}$$

The corresponding boundary conditions now become

$$u_0 = 0, u_1 = 0, \theta_0 = 1, \theta_1 = 0, \phi_0 = 1, \phi_1 = 0 \quad at \quad y = 0$$

$$u_0 \to 0, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, \phi_0 \to 0, \phi_1 \to 0 \quad as \quad y \to \infty \tag{22}$$

Solving the equations (16) - (21) under the boundary conditions (22) we get

$$\theta_o = \exp(-m_1 y)$$

$$\phi_0 = \exp(-m_2 y) + a_2(\exp(-m_1 y - \exp(-m_2 y))$$

$$u_0 = a_3(\exp(-m_1 y) - \exp(-m_3 y)) + a_4(\exp(-m_2 y) - \exp(-m_3 y))$$

$$\theta_1 = a_{16}\exp(-m_4 y) + f_2(y)$$

$$f_2(y) = a_6\exp(-2m_1 y) + (a_7 + a_{10} + a_{13})\exp(-2m_3 y) - (a_8 + a_{14})\exp(-(m_1 + m_3)y) +$$

$$+ a_9\exp(-2m_2 y) - a_{11}\exp(-(m_2 + m_3)y + a_{12}\exp(-(m_1 + m_2)y)$$

$$\phi_1 = a_{26}\exp(-m_5 y) + f_3(y)$$

$$f_3(y) = a_{16}\exp(-m_4 y) + a_{17}\exp(-2m_1 y) + (a_{18} + a_{21})\exp(-2m_3 y) +$$

$$+ (a_{19} + a_{24})\exp(-(m_1 + m_3)y) + a_{20}\exp(-2m_2 y) + (a_{22} + a_{25})\exp(-(m_2 + m_3)y)$$

$$+ a_{23}\exp(-(m_1 + m_2)y)$$

$$u_1 = a_{35}\exp(-m_6 y) + f_4(y)$$

$$f_4(y) = a_{27}\exp(-m_4 y) + a_{28}\exp(-2m_1 y) + a_{29}\exp(-2m_3 y) +$$

$$+ (a_{30} + a_{34})\exp(-(m_1 + m_3)y) + a_{31}\exp(-2m_2 y) +$$

$$+ a_{32}\exp(-(m_2 + m_3)y) + a_{33}\exp(-(m_1 + m_2)y)$$

IV. Skin Friction, Nusselt Number And Sherwood Number

The skin friction (τ) at the wall y=0 is given by

$$\tau = (\frac{\partial u}{\partial y})_{y=0} = a_{36} + Eca_{37}e^{-nt}$$

The rate of heat transfer (Nusselt Number) at the wall y=0 is given by

$$Nu = (\frac{\partial\theta}{\partial y})_{y=0} = -m_4 + Eca_{38}e^{-nt}$$

The rate of mass transfer (Sherwood Number) at the wall y=0 is given by

$$Sh = (\frac{\partial\phi}{\partial y})_{y=0} = a_{39} + Eca_{40}e^{-nt}$$

Particular case: In the absence of thermo-diffusion and heat sources the result are in good agreement with the

Giresh Kumar etal. [4].

V. Results And Discussion

In this analysis we investigate the effect of chemical reaction and thermo-diffusion on MHD Convective heat and mass transfer flow of a Kuvshinski fluid past a vertical plate embedded in a saturated porous medium.
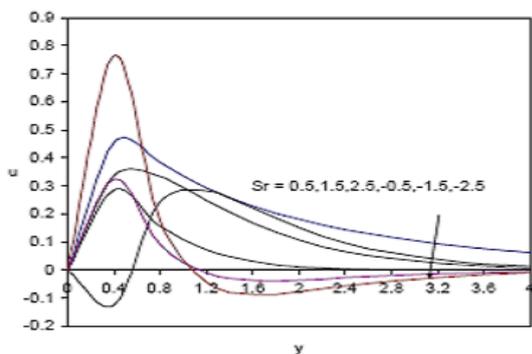

Fig. 1 : Variation of u with S_r
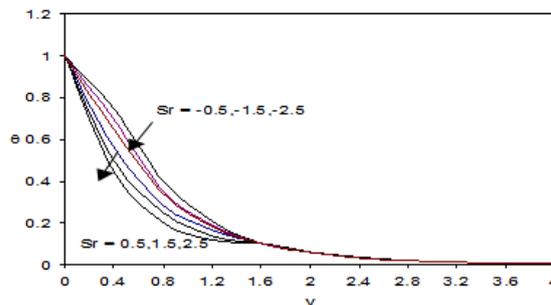G=10^3, M = 2, D^{-1}= 2,N=1, Sc=1.3, K=0.5,

Fig. 2 : Variation of θ with S_r
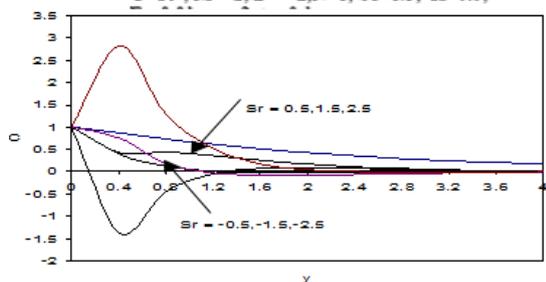G=10^2, M = 2, D^{-1}= 2,N=1, S_c=1.3, K=0.5,
E_c=0.01, α = 2, t = 0.1

Fig. 3 : Variation of C with S_r
G=10^2, M = 2, D^{-1}= 2,N=1, Sc=1.3, K=0.5,
E_c=0.01, α = 2, t = 0.1
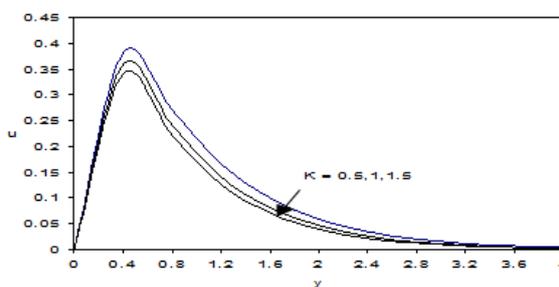
Fig.4: Variation of u with K
G=10^2, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
E_c=0.01, α = 2, t = 0.1
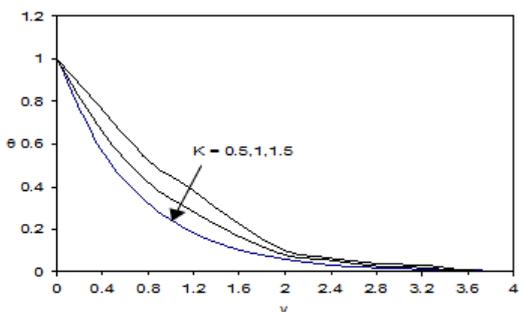
Fig. 5 : Variation of θ with K
G=10^2, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
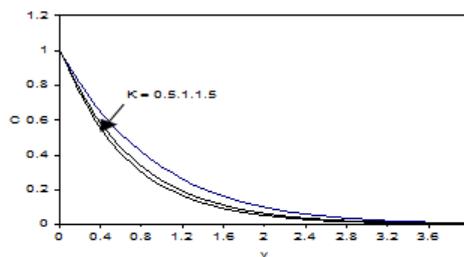E_c=0.01, α = 2, t = 0.1

Fig. 6 : Variation of C with K
G=10^2, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
E_c=0.01, α = 2, t = 0.1
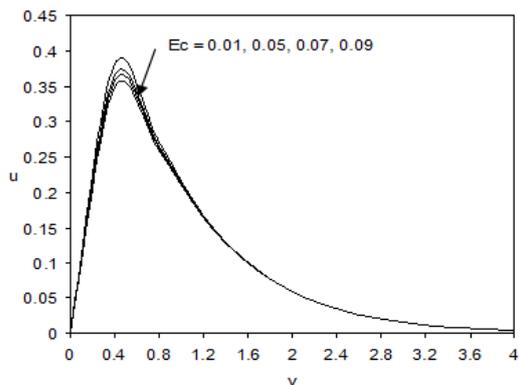
Fig. 7 : Variation of u with Ec
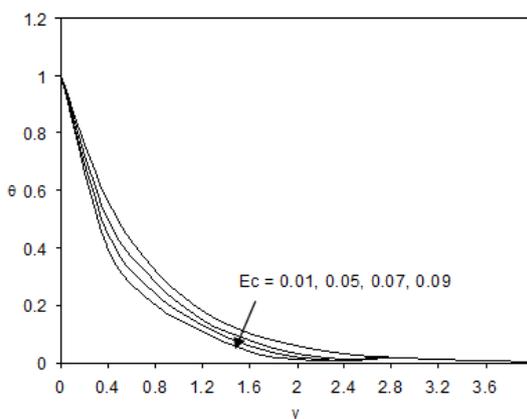G=10^3, M = 2, D^{-1}= 2,N=1, Sc=1.3, S_r=0.5
K=0.5,α = 2, t = 0.1

Fig. 8 : Variation of θ with Ec
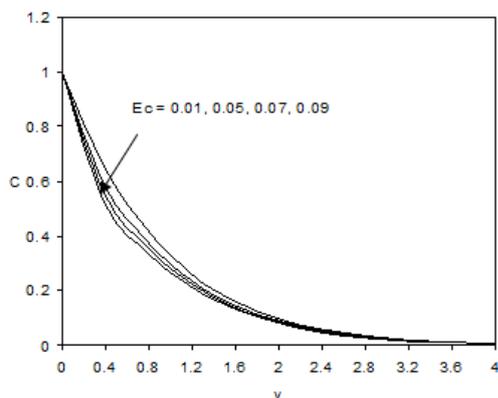G=10^3, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
K=0.5,α = 2, t = 0.1

Fig. 9: Variation of C with Ec
$G=10^3$, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
K=0.5,α = 2, t = 0.1
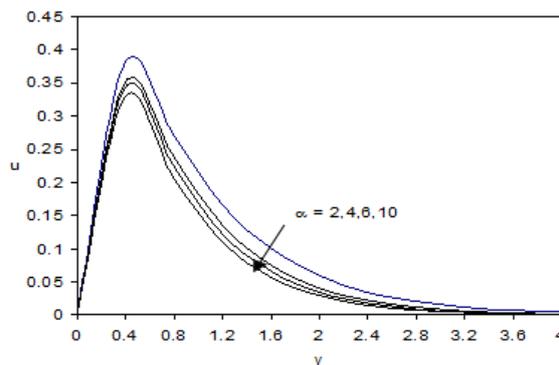
Fig. 10: Variation of u with α
$G=10^3$, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
K=0.5, E_c=0.01, t = 0.1
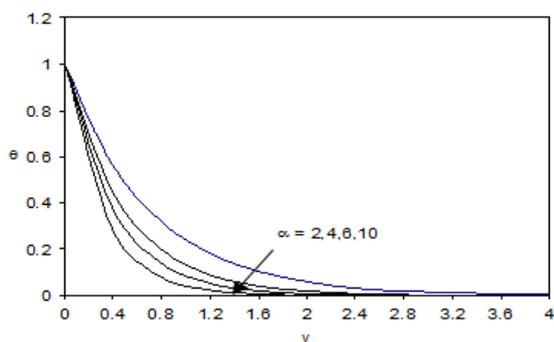
Fig. 11 : Variation of θ with α
$G=10^3$, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
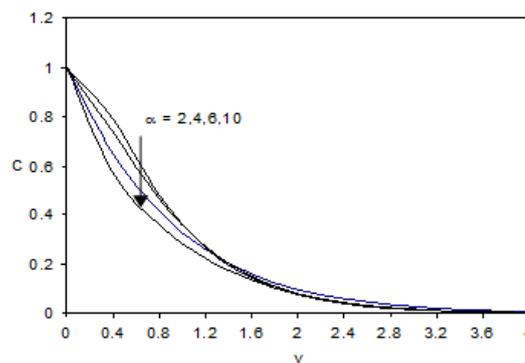K=0.5, E_c=0.01, t = 0.1

Fig. 12 : Variation of C with α
$G=10^3$, M = 2, D^{-1}= 2,N=1, S_c=1.3, S_r=0.5
K=0.5, E_c=0.01, t = 0.1

The effect of thermo – diffusion on u is shows in fig.1. It is found that higher the value of |Sr| larger |u| in the boundary layer (fig.1). An increase in the Soret parameter leads to a depreciation in the temperature (fig.2).From fig.3 we find that the concentration depreciates with Sr ≤ 1.5 and enhances with higher Sr ≥ 2.5, while it enhances with |Sr| in the entire flow region.From fig.4 we find that the velocity experiences depreciation in the degenerating chemical reaction case.

Fig.5 shows the variation of θ with chemical reaction parameter K. It can be seen from the profiles that the actual temperature enhances in the degenerating chemical reaction case. An increase in K leads to a depreciation in C (fig. 6).

The effect of a dissipation on u is exhibited in fig.7 .The Eckert number Ec expresses the relationship between the kinetic energy in the flow and the enthalpy. It embodies the conversion of kinetic energy into internal energy by work done against the viscous fluid stresses. The positive Eckert number implies cooling of the plate i.e loss of heat from the plate to the fluid. Hence, greater viscous dissipation heat causes a depreciation in the velocity.Higher the viscous dissipation heat smaller the actual temperature in the boundary layer (fig.8). An increase in Ec leads to a depreciation in C (fig. 9).Fig.10 represents u with heat source parameter α. It is found that higher the strength of the heat source smaller the velocity in the boundary layer.

An increase in α (>0) results in a depreciation in θ .Thus the presence of the heat sources in the flow region reduces the temperature in the flow region (fig.11).

From fig.12 we find that the actual concentration reduces with α≤4 and enhances with higher α≥6 .

Table - 1
Shear stress (τ) at y = 0

G	I	II	III	IV	V	VI
10^3	3.60205	3.74875	4.11637	3.01351	2.64589	2.27826
3×10^3	10.79402	11.23412	12.337	9.02839	7.92553	6.82266
-10^3	-3.58992	-3.73662	-4.10424	-3.00138	-2.63376	-2.26613
-3×10^3	-10.78189	-11.222	-12.3249	-9.01626	-7.91339	-6.81053
Sr	0.5	1.5	2.5	-0.5	-1.5	-2.5

Table - 2
Shear stress (τ) at y = 0

G	I	II	III	IV	V	VI	VII
10^3	3.38113	3.28536	3.21638	3.39326	3.41752	3.3084	3.26145
3×10^3	10.1313	9.84395	9.63702	10.14339	10.1677	9.91306	9.77221
-10^3	-3.369	-3.27323	-3.2043	-3.35687	-3.33261	-3.29626	-3.2493
-3×10^3	-10.1191	-9.62489	-9.6249	-10.107	-10.0827	-9.90092	-9.7601
K_r	0.5	1	1.5	0.5	0.5	0.5	0.5
E_c	0.01	0.01	0.01	0.03	0.07	0.01	0.01
α	2	2	2	2	2	4	6

The skin friction(τ) at y=0 is depicted in tables 1-2 for different values of $S_r, K_r, E_c, α$. The magnitude of τ enhances with increase in $S_r > 0$ and reduces with $|S_r|$ (<0) (table 1).

An increase in K or α reduces $|τ|$. Also $|τ|$ enhances with increase in Eckert number E_c. (table 2).

Table - 3
Sherwood Number (Sh) at y = 0

G	I	II	III	IV	V	VI
10^3	0.05231	-25.1257	-66.9701	-5.26524	25.6062	70.5738
3×10^3	-0.35859	-36.0984	-89.1292	10.91665	113.387	437.496
-10^3	0.36335	-13.6595	-48.7106	3.1449	16.6926	54.8669
-3×10^3	0.57455	-67.0056	-96.1482	4.55561	86.6457	390.375
S_r	0.5	1.5	2.5	-0.5	-1.5	-2.5

Table - 4
Sherwood Number (Sh) at y = 0

G	I	II	III	IV	V	VI	VII
10^3	-6.34634	-3.22176	-2.1806	-6.8387	-7.82343	6.03599	4.63377
3×10^3	-12.9887	-6.52919	-2.8098	-17.42	-26.2826	-11.1216	2.96094
-10^3	-1.6734	-2.03916	2.68332	-2.16577	-3.1505	2.70971	3.48244
-3×10^3	1.03007	5.78186	6.18186	-3.40122	-12.2638	-21.1004	-4.49303
K_r	0.5	1	1.5	0.5	0.5	0.5	0.5
E_c	0.01	0.01	0.01	0.03	0.07	0.01	0.01
α	2	2	2	2	2	4	6

The rate of mass transfer (Sherwood number) at the plate y=0 is shown in tables 3 & 4 for different parametric values. From table 3 we find that the rate of mass transfer enhances with increase in Soret parameter | S_r | for all G. An increase in K or α reduces |Sh| for G >0 and for G <0, |Sh| experiences an enhancement at y=0 (table 4).

VI. Conclusions

➢ Higher the value of |Sr| larger |u| in the boundary layer.
➢ An increase in the Soret parameter leads to a depreciation in the temperature. the concentration depreciates with Sr ≤ 1.5 and enhances with higher Sr ≥ 2.5, while it enhances with |Sr| in the entire flow region.
➢ The kinetic energy in the flow and the enthalpy. It embodies the conversion of kinetic energy into internal energy by work done against the viscous fluid stresses.
➢ Higher the viscous dissipation heat smaller the actual temperature in the boundary layer.
➢ An increase in Ec leads to a depreciation in C.
➢ The magnitude of τ enhances with increase in Sr>0 and reduces with |Sr| (<0).
➢ |τ| enhances with increase in Eckert number Ec.

The rate of mass transfer enhances with increase in Soret parameter | Sr | for all G.

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