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# INFLUENCE OF THERMAL DIFFUSION ON MHD FREE CONVECTIVE FLOW PAST A SEMI-INFINITE INCLINED MOVING PLATE IN A POROUS MEDIUM WITH RAMPED TEMPERATURE

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***Abstract*:**

*The present paper aims to investigate the effect of thermal diffusion in a free convective, radiative, viscous, chemically reacting, incompressible, and unsteady MHD flow past an exponentially accelerated moving inclined plate submerged in a porous medium. The fluid is taken as optically thick and non-gray. A uniform magnetic field is applied in the transverse direction of the plate. The ramped temperature effect is also considered. The radiative heat flux that appears in the energy equation is described by the Rosseland approximation method. A closed form of the Laplace transformation technique is adopted to obtain analytical solutions to the non-dimensional governing equations. A detailed discussion on the effects of various governing parameters on the velocity field, temperature field, concentration field, Nusselt number, Sherwood number, and skin friction are analyzed using suitable graphs and tables. The investigation shows that the Soret effect hikes both concentration and velocity of the fluid. The chemical reaction effect upsurges the process of mass transfer from the plate to the fluid.*

***Keywords*:** Chemical reaction, Rosseland approximation, thermal diffusion, inclined plate, porosity

## NOMENCLATURE

| | |
|---|---|
| $a$ | surface acceleration parameter |
| $a^*$ | absorption coefficient ($m^2mol^{-1}$) |
| $\vec{B}$ | magnetic flux density |
| $B_0$ | strength of the applied magnetic field (Weber. $m^{-2}$) |
| $C$ | molar species concentration (mol.$m^{-3}$) |
| $C_p$ | specific heat at constant pressure (J.$Kg^{-1}K^{-1}$) |
| $C_\infty$ | concentration far away from the plate (mol.$m^{-3}$) |
| $C_w$ | concentration at the plate (mol.$m^{-3}$) |
| $D_M$ | mass diffusivity ($m^2s^{-1}$) |
| $D_T$ | molar thermal diffusivity (J.$K^{-1}mol^{-1}$) |
| $\vec{g}$ | gravitation acceleration vector |
| $g$ | gravitational acceleration ($ms^{-2}$) |
| $Gr$ | thermal Grashof number |
| $Gm$ | solutal Grashof number |
| $K^*$ | porosity parameter |
| $\vec{J}$ | current density vector (A.$m^{-2}$) |
| $\overline{K}$ | chemical reaction rate (mol.$m^{-2}s^{-1}$) |
| $K$ | chemical reaction parameter |
| $M$ | magnetic parameter |
| $N$ | radiation parameter |
| $\overline{t}$ | time (s) |
| $t_0$ | critical time for rampedness (s) |
| $t_1$ | non-dimensional critical time for rampedness |
| $T_w$ | temperature at the plate (K) |
| $T_\infty$ | undisturbed temperature (K) |
| $u'$ | x-component of fluid velocity (m.$s^{-1}$) |
| $U_0$ | plate velocity (m.$s^{-1}$) |
| $\vec{q_r}$ | radiation heat flux vector |
| $q_r$ | radiation heat flux (W.$m^{-2}$) |
| $Sc$ | Schmidt number |
| $Sr$ | Soret number |

*Greek Symbols*

| | |
|---|---|
| $\gamma$ | angle of inclination to the vertical |
| $\mu$ | coefficient of viscosity (Kg.$m^{-1}s^{-1}$) |
| $\sigma$ | electrical conductivity (S.$m^{-1}$) |
| $\sigma^*$ | Stefan-Boltzmann constant (W.$m^{-2}K^{-4}$) |
| $\rho$ | fluid density (Kg.$m^{-3}$) |
| $\rho_\infty$ | fluid density far away from the plate (Kg.$m^{-3}$) |
| $\kappa$ | thermal conductivity (W.$m^{-1}K^{-1}$) |
| $\kappa^*$ | mean absorption constant ($m^{-1}$) |

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| | | | |
|---|---|---|---|
| $p$ | pressure ($N.m^{-2}$) | $\beta$ | volumetric coefficient of thermal expansion ($K^{-1}$) |
| Pr | Prandtl number | $\overline{\beta}$ | volumetric coefficient of solutal expansion ($K^{-1}mol^{-1}$) |
| $\vec{q}$ | fluid velocity vector | $\nu$ | kinematic viscosity ($m^2s^{-1}$) |

## 1. Introduction

Magnetohydrodynamics (MHD) is a branch of physics that is concerned with the interaction of the magnetic field with electrically conducting fluid. Some common examples of this kind of fluids are plasmas, liquid metals (e.g. mercury), electrolytes, etc. The basic principle behind MHD is that magnetic fields can induce a current in moving conducting fluids which in turn polarizes the fluid and as a result changes the magnetic field. Renowned Swiss scientist Hannes Alfven (1942) initiated the concept of MHD for which he received the prestigious Nobel prize in physics in 1970. But, MHD is at present form due to valuable contributions from researchers like Cowling (1957), Shercliff (1965), Ferraro and Plumpton (1966), Roberts (1967), Crammer and Pai (1973), etc. There are numerous applications of MHD in present-day technologies. Many geophysical and astrophysical phenomena can be elaborated by the MHD principle. Engineering applications of MHD include Dynamo, motor, fusion reactors, dispersion of metals, metallurgy, MHD pumps, etc. Farrokhi et al. (2019) studied biomedical applications of MHD.

Density variation in fluid mixture arises owing to changes in fluid temperature and species concentration. This variation generates buoyancy force which acts on the fluid. The flow produced by these forces is termed free convection or natural convection. Ullah et al. (2021) studied two-dimensional unsteady MHD free convection flow over a vertical plate. Abdullah (2018) considered free convection MHD flow past an accelerated vertical plate with periodic temperature. Kumar and Singh (2013) studied unsteady MHD free convective flow over an infinite vertical moving plate.

The process of heat transfer through electromagnetic waves is defined as radiation. Radiative convective flow occurs in many environmental and industrial processes. This is the reason behind many model researches by researchers on free convection with thermal radiation under various physical and geometrical circumstances. Mbeldogu (2007) explored unsteady free convection on a compressible fluid past a moving vertical plate with radiative heat transfer. Orhan and Ahmet (2008) considered the effect of radiation on MHD mixed convection flow about a permeable vertical plate. Prasad et al. (2006) studied transient radiative free convection flow past an impulsively started vertical plate. Takhar et al. (1996) explored radiation effects on MHD free convection flow of a radiating gas. Ghaly (2002) studied radiation effects in certain MHD convection flows. Sheikholeslami et al. (2016) explored free convection and thermal radiation effects on $Al_2O_3$-$H_2O$ nanofluid. Ali et al. (2013) considered radiation effects on MHD free convection flow along the vertical flat plate with Joule heating and heat generation.

A medium containing holes or voids so that fluid can pass through it is termed a porous medium. Sponge, wood, cork, etc. are some well-known examples of porous materials. The concept of the porous medium is widely used in many disciplines of applied science and chemistry such as filtration, solid mechanics, geomechanics, soil mechanics, bio remediating construction engineering, material science, fuel cells, etc. Sharma and Gupta (2018) studied the effect of radiation on MHD boundary layer flow along a stretching cylinder in a porous medium. Raju and Varma (2011) considered unsteady MHD Couette flow through a porous medium with periodic wall temperature. Pattnaik and Biswal (2015) obtained an analytical solution of an MHD free convection flow through a porous medium with time-dependent temperature and concentration. Sinha et al. (2017) explored MHD free convection flow through a porous medium past a vertical plate with ramped wall temperature. Basha and Nagarthna (2019) observed the process of heat and mass transfer on a free convective MHD flow through a porous medium past an infinite vertical plate.

The chemical reaction effect has great practical importance in many heat and mass transfer processes. Suresh et al (2019) studied the combined effects of chemical reaction and radiation on MHD flow along a moving vertical porous plate with heat source and suction. Rudraswamy and Gireesha (2014) explored the influences of both chemical reactions and thermal radiation in an MHD boundary layer flow. Mohamed and Abo- Daheb (2009) studied the effects of chemical reaction and heat generation in an MHD micropolar flow over a vertically moving porous plate in a porous medium while Babu et al. (2013) extended this work by considering viscous dissipation. Malathy et al (2017) considered both chemical reaction and radiation effects on an Oldroyd- B fluid in a porous medium. Lavanya (2020) examined the effects of chemical reaction, heat generation, and radiation on MHD convective flow over a porous plate through a porous medium. Sumathi et al (2017) numerically investigated the effects of thermal radiation and chemical reaction on three-dimensional MHD flow in a porous medium.

When both thermal and solutal convection occurs simultaneously in a fluid mixture, then the relation between driving potential and flux becomes more complicated. The mass flux is generated by both temperature gradient and concentration gradient. The effect of mass flux under temperature gradient is termed the Soret effect or thermal diffusion effect. This effect appears due to the flow of fluid molecules from the hotter region to the cooler region. This effect was first observed by Ludwing in 1859. But, the first experimental work was done by Swiss chemist Charles Soret in 1879. This effect has many applications in different chemical and physical processes, isotope separation, etc. Ahmed and Sarma (2021) studied the thermal diffusion effect in an MHD free convective flow past an impulsively started semi-infinite vertical plate considering parabolic ramped conditions. Ahmed (2012) considered the combined effects of Soret and radiation in a free convective transient MHD flow past an infinite vertical plate. Sivaiah et al. (2012) considered the combined effects of thermal diffusion and radiation on unsteady MHD free convective flow past an infinite heated vertical plate in a porous medium. Narahari et al (2021) explored the effects of Soret, heat generation, and radiation in a free convective MHD flow past an infinite plate with oscillating temperature in a porous medium.

Significance of ramped temperature in flow of an unsteady viscoelastic fluid was considered by Khan (2022). Sarma and Ahmed (2022) investigated diffusion thermo effect on an unsteady MHD flow in porous medium with ramped temperature. Reddy and Goud (2023) analyzed the impact of thermal radiation in a nanofluid flow across infinite vertical flat plate considering ramped temperature and heat consumption.

The objective of the present investigation is to analyze the problem of a free convective MHD flow past an exponentially accelerated inclined plate. Thermal radiation, chemical reaction, ramped wall temperature and thermal diffusion effects are also considered. The flow medium is taken to be porous. Reviewing the existing literature, we have not found any work considering all these effects simultaneously. The equations governing the flow are first normalized into non – dimensional equations and they are solved analytically using a closed form of the Laplace transformation technique. The effects of different flow parameters on the velocity field, temperature field, concentration field, Nusselt number, Sherwood number, and skin friction are analyzed and results are discussed with the assistance of graphs and tables. This type of investigation has tremendous application in many industrial and chemical engineering processes such as heat exchangers, designing energy systems different types of fluids etc.

## 2. Theoretical Background

### 2.1 Mathematical model of the problem

Governing equations of the convective flow of an incompressible, electrically conducting, viscous, and radiating fluid in a porous medium in presence of a magnetic field having constant mass diffusivity and thermal diffusivity past an inclined plate considering the thermal diffusion effect is

Continuity equation:

$$\vec{\nabla} \cdot \vec{q} = 0 \tag{1}$$

Magnetic field continuity equation:

$$\vec{\nabla} \cdot \vec{B} = 0 \tag{2}$$

Ohm's Law:

$$\vec{J} = \sigma\left(\vec{E} + \vec{q} \times \vec{B}\right) \tag{3}$$

Momentum equation:

$$\rho\left[\frac{\partial \vec{q}}{\partial \bar{t}} + \left(\vec{q} \cdot \vec{\nabla}\right)\vec{q}\right] = -\vec{\nabla}p + \vec{J} \times \vec{B} + \rho\vec{g} + \mu\nabla^2\vec{q} - \frac{\mu\vec{q}}{K*} \tag{4}$$

Energy equation:

$$\rho C_p\left[\frac{\partial T}{\partial \bar{t}} + \left(\vec{q} \cdot \vec{\nabla}\right)T\right] = \kappa\nabla^2 T - \vec{\nabla} \cdot \vec{q}_r \tag{5}$$

Species continuity equation:

$$\frac{\partial C}{\partial \bar{t}} + \left(\vec{q} \cdot \vec{\nabla}\right)C = D_M\nabla^2 C + D_T\nabla^2 T + \bar{K}\left(C_\infty - C\right) \tag{6}$$

Equation of state as per Boussinesq approximation:

$$\rho_\infty = \rho\left[1 + \beta\left(T - T_\infty\right) + \bar{\beta}\left(C - C_\infty\right)\right] \tag{7}$$

The radiation heat flux as per Rosseland approximation for optically thick and non- gray fluid is given by

$$\vec{q}_r = -\frac{4\sigma^*}{3\kappa^*}\vec{\nabla}T^4$$

Now,

$$T^4 = \left(T - T_\infty + T_\infty\right)^4 = 4TT_\infty^3 - 3T_\infty^4, as\left|T - T_\infty\right| \ll 1$$

So,

$$\vec{\nabla} \cdot \vec{q}_r = -\frac{16\sigma^* T_\infty^3}{3\kappa^*}\nabla^2 T$$

Therefore, Energy equation (5) reduces to

$$\rho C_p\left[\frac{\partial T}{\partial \bar{t}} + \left(\vec{q} \cdot \vec{\nabla}\right)T\right] = \kappa\nabla^2 T + \frac{16\sigma^* T_\infty^3}{3\kappa^*}\nabla^2 T \tag{8}$$

We, now consider a transient MHD free convective flow of a viscous incompressible electrically conducting fluid through a porous medium past an infinite inclined plate in presence of a uniform magnetic field applied normally to the plate, directed into the fluid region. Initially, the plate and the surrounding fluid were at rest with uniform temperature $T_\infty$ and concentration $C_\infty$ at all points in the fluid. At time $\bar{t} > 0$, the plate is exponentially accelerated with velocity $U_o e^{a't'}$. The plate temperature is instantly raised to $T_\infty + \left(T_w - T_\infty\right)\frac{\bar{t}}{t_0}$, for $0 < \bar{t} \le t_0$, and thereafter $T_w$ when $\bar{t} > t_0$. The concentration is raised to $C_w$ and maintained thereafter.

To idealize the mathematical model of the problem, we impose the following constraints-

a) All the fluid properties are constant except for the variation in density in the buoyancy force term.
b) Dissipation of energy due to friction and Joule heating is negligible.
c) As the magnetic Reynolds number of the flow is very small, the induced magnetic field in comparison to the applied magnetic field is negligible.
d) Flow is one- dimensional and is parallel to the plate.
e) The plate is electrically non-conducting.
f) No external electric field is applied for which the polarization voltage is insignificant.
g) The chemical reaction is of first order with constant rate is considered to occur between the fluid and the diffusing species.

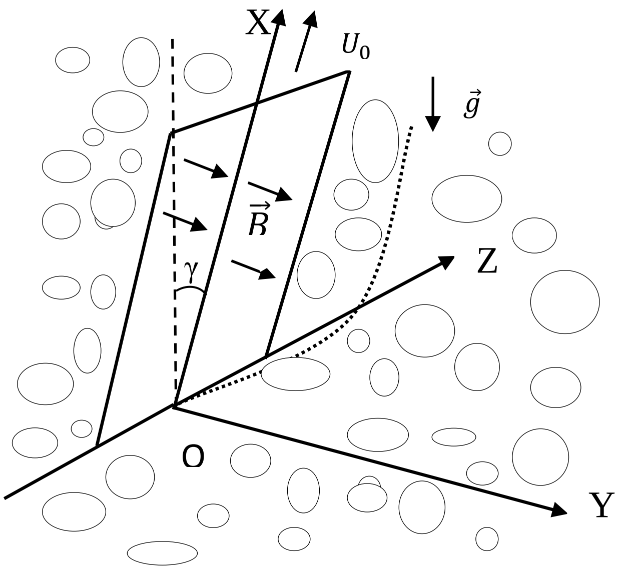


Fig. 1: Flow Geometry

We now consider a tri- rectangular Cartesian co-ordinate system $(\bar{x}, \bar{y}, \bar{z}, \bar{t})$ with X- axis vertically upwards along the plate, Y- axis normal to the plate directed into the fluid region, and Z- axis along the width of the plate. Let $\vec{q} = (u', 0, 0)$ be the fluid velocity and $\vec{B} = (0, B_0, 0)$ be the magnetic induction vector at the point $(\bar{x}, \bar{y}, \bar{z}, \bar{t})$ in the fluid. Let the plate is inclined to vertical direction by an angle γ.

Equation (1) yields,

$$\frac{\partial u'}{\partial \bar{x}} = 0 \quad i.e., u' = u'(\bar{y}, \bar{t}) \tag{9}$$

Equation (2) is trivially satisfied by $\vec{B} = (0, B_0, 0)$

Equation (4) reduces to

$$\rho\left[\frac{\partial u'}{\partial \bar{t}}\hat{i} + 0\right] = -\hat{i}\frac{\partial p}{\partial \bar{x}} - \hat{j}\frac{\partial p}{\partial \bar{y}} - \rho g \cos\gamma \hat{i} - \sigma B_0^2 u' \hat{i} + \mu \frac{\partial^2 u'}{\partial \bar{y}^2}\hat{i} - \frac{\mu u'}{K^*}\hat{i} \tag{10}$$

Equation (10) gives

$$\rho \frac{\partial u'}{\partial \bar{t}} = -\frac{\partial p}{\partial \bar{x}} - \rho g.\cos\gamma - \sigma B_0^2 u' + \mu \frac{\partial^2 u'}{\partial \bar{y}^2} - \frac{\mu u'}{K^*} \tag{11}$$

And

$$0 = -\frac{\partial p}{\partial \bar{y}} \tag{12}$$

Equation (12) shows that pressure near the plate and pressure far away from the plate are same along the normal to the plate.

For fluid region far away from the plate, equation (11) takes the form

$$0 = -\frac{\partial p}{\partial \bar{x}} - \rho_\infty g \cos\gamma \tag{13}$$

Eliminating $\frac{\partial p}{\partial \bar{x}}$ from (11) and (13), we get,

$$\rho \frac{\partial u'}{\partial \bar{t}} = (\rho_\infty - \rho) g \cos\gamma - \sigma B_0^2 u' + \mu \frac{\partial^2 u'}{\partial \bar{y}^2} - \frac{\mu u'}{K^*} \tag{14}$$

Now, (7) gives,

$$\rho_\infty - \rho = \rho\left[\beta\left(T - T_\infty\right) + \bar{\beta}\left(C - C_\infty\right)\right] \tag{15}$$

Putting value of (15) in (14),

$$\rho\frac{\partial u'}{\partial \bar{t}} = \rho\left[\beta\left(T - T_\infty\right) + \bar{\beta}\left(C - C_\infty\right)\right]g\cos\gamma - \sigma B_0^2 u' + \mu\frac{\partial^2 u'}{\partial \bar{y}^2} - \frac{\mu u'}{K*}$$

$$i.e., \frac{\partial u'}{\partial \bar{t}} = g\beta\left(T - T_\infty\right)\cos\gamma + g\bar{\beta}\left(C - C_\infty\right)\cos\gamma - \frac{\sigma B_o^2 u'}{\rho} + \nu\frac{\partial^2 u'}{\partial \bar{y}^2} - \nu\frac{u'}{K*} \tag{16}$$

Equation (8) yields,

$$\rho C_p\frac{\partial T}{\partial \bar{t}} = \kappa\frac{\partial^2 T}{\partial \bar{y}^2} + \frac{16\sigma^* T_\infty^3}{3\kappa^*}\frac{\partial^2 T}{\partial \bar{y}^2} \tag{17}$$

Equation (6) becomes,

$$\frac{\partial C}{\partial \bar{t}} = D_M\frac{\partial^2 C}{\partial \bar{y}^2} + D_T\frac{\partial^2 T}{\partial \bar{y}^2} + \bar{K}\left(C_\infty - C\right) \tag{18}$$

The relevant initial and boundary conditions are:

$$\left.\begin{array}{l} u' = 0, T = T_\infty, C = C_\infty : \forall \bar{y} \geq 0; \bar{t} \leq 0 \\ u' = U_0 e^{a'\bar{t}}, C = C_W : \bar{y} = 0, \bar{t} > 0 \\ T = T_\infty + \left(T_w - T_\infty\right)\dfrac{\bar{t}}{t_0} : \bar{y} = 0; 0 < \bar{t} \leq t_0 \\ T = T_w : \bar{y} = 0; \bar{t} > t_0 \\ u' \to 0, T \to T_\infty, C \to C_\infty : \bar{y} \to \infty; \bar{t} > 0 \end{array}\right\} \tag{19}$$

For the sake of normalization of the mathematical model of the problem, we introduce the following non-dimensional quantities-

$$Sr = \frac{D_T\left(T_w - T_\infty\right)}{\left(C_w - C_\infty\right)\nu}, N = \frac{\kappa\kappa^*}{4\sigma^* T_\infty^3}, u = \frac{u'}{U_0}, y = \frac{U_0}{\nu}\bar{y}, t = \frac{U_0^2}{\nu}\bar{t}, Gr = \frac{\nu g\beta\left(T_w - T_\infty\right)}{U_0^3}, a = a'\frac{\nu}{U_0^2},$$

$$Gm = \frac{\nu g\bar{\beta}\left(C_w - C_\infty\right)}{U_0^3}, \theta = \frac{T - T_\infty}{T_w - T_\infty}, \phi = \frac{C - C_\infty}{C_w - C_\infty}, \Pr = \frac{\mu C_p}{\kappa}, M = \frac{\sigma B_0^2 \nu}{\rho U_0^2}, Sc = \frac{\nu}{D_M}, \Lambda = 1 + \frac{4}{3N},$$

$$K = \frac{\nu\bar{K}}{U_0^2}, t_1 = \frac{U_0^2}{\nu}t_0, M_1 = M + \frac{1}{K*}$$

The non- dimensional governing equations are

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\theta\cos\gamma + Gm\phi\cos\gamma - M_1 u \tag{20}$$

$$\frac{\partial \theta}{\partial t} = \frac{\Lambda}{\Pr}\frac{\partial^2 \theta}{\partial y^2} \tag{21}$$

$$\frac{\partial \phi}{\partial t} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} + Sr\frac{\partial^2 \theta}{\partial y^2} - K\phi \tag{22}$$

Subject to the initial and boundary conditions

$$\left.\begin{array}{l} u = 0, \theta = 0, \phi = 0 : \forall y \geq 0; t \leq 0 \\ u = e^{at}, \phi = 1 : y = 0, t > 0 \\ \theta = \dfrac{t}{t_1} : y = 0; 0 < t \leq t_1 \\ \theta = 1 : y = 0; t > t_1 \\ u \to 0, \theta \to 0, \phi \to 0 : y \to \infty; t > 0 \end{array}\right\} \tag{23}$$

## 2.2 Method of solution

On taking Laplace transform of the equations (22), (21) and (20) respectively, we get the following equations:

$$s\bar{\phi} = \frac{1}{Sc}\frac{d^2\bar{\phi}}{dy^2} + Sr\frac{d^2\bar{\theta}}{dy^2} - K\bar{\phi} \tag{24}$$

$$s\bar{\theta} = \frac{\Lambda}{\Pr}\frac{d^2\bar{\theta}}{dy^2} \tag{25}$$

$$s\bar{u} = \frac{d^2\bar{u}}{dy^2} + Gr\cos\gamma\bar{\theta} + Gm\cos\gamma\bar{\phi} - M_1\bar{u} \tag{26}$$

Subject to the initial and boundary conditions:

$$\left.\begin{array}{l} y = 0 : \bar{\theta} = \dfrac{2}{s^2 t_1}\left(1 - e^{-st_1}\right), \bar{\phi} = \dfrac{1}{s}, \bar{u} = \dfrac{1}{s-a} \\ y \to \infty : \bar{\theta} \to 0, \bar{\phi} \to 0, \bar{u} \to 0 \end{array}\right\} \tag{27}$$

Solving equations from (24) to (26) subject to the conditions (27) and taking inverse Laplace transform of the solutions, the expression for temperature field $\theta$, concentration field $\phi$, and velocity field $u$ are as follows:

$$\theta = \frac{1}{t_1}\Delta\lambda_1 \tag{28}$$

$$\phi = \begin{cases} \phi_{1,1} + \phi_{1,2} - \phi_{1,3} : \Lambda Sc \neq \Pr \\ \phi_{2,1} + \phi_{2,2} - \phi_{2,3} : \Lambda Sc = \Pr \end{cases} \tag{29}$$

$$u = \begin{cases} u_{1,1} - u_{1,2} - u_{1,3} - u_{1,4} + u_{1,5} : \Pr \neq \Lambda, Sc \neq 1, \Pr \neq \Lambda Sc \\ u_{2,1} - u_{2,2} - u_{2,3} - u_{2,4} + u_{2,5} : \Pr = \Lambda, Sc \neq 1 \\ u_{3,1} - u_{3,2} - u_{3,3} - u_{3,4} + u_{3,5} : \Pr \neq \Lambda, Sc = 1 \\ u_{4,1} - u_{4,2} - u_{4,3} - u_{4,4} + u_{4,5} : \Pr = \Lambda, Sc = 1 \\ u_{5,1} - u_{5,2} - u_{5,3} - u_{5,4} + u_{5,5} : \Pr \neq \Lambda, Sc \neq 1, \Pr = \Lambda Sc \end{cases} \tag{30}$$

Where

$$a_1 = \frac{\Pr}{\Lambda}, \lambda_1 = \lambda\left(a_1, y, t\right) a_2 = \frac{SrSca_1}{t_1\left(a_1 - Sc\right)}, a_3 = \frac{ScK}{a_1 - Sc}, \phi_{1,1} = \psi_1, \psi_1 = \psi\left(Sc, K, y, t\right), A_1 = \frac{1}{a_3},$$

$$A_2 = -A_1, \phi_{1,2} = a_2\left(A_1\Delta\psi_2 + A_2\Delta\psi_1\right), \psi_2 = \Psi\left(Sc, K, a_3, y, t\right), \phi_{1,3} = a_2\left(A_1\Delta\psi_3 + A_2\Delta E_1\right),$$

$$\psi_3 = \Psi\left(a_1, 0, a_3, y, t\right), E_1 = erfc\left(\frac{y\sqrt{a_1}}{2\sqrt{t}}\right), \phi_{2,1} = \phi_{1,1}, a_4 = -\frac{SrSc}{K}, \phi_{2,2} = a_4\Delta\psi_1, \phi_{2,3} = a_4\Delta E_1,$$

$$a_5 = \frac{M_1}{a_1 - 1}, a_6 = \frac{Gr\cos\gamma}{t_1\left(a_1 - 1\right)}, u_{1,1} = u_{1,1,1} + u_{1,1,2} + u_{1,1,3} + u_{1,1,4} - u_{1,1,5}, u_{1,1,1} = h_2, h_2 = e^{at}h_1,$$

$$h_1 = h\left(M_1 + a, y, t\right), A_3 = \frac{1}{a_5{}^2}, A_4 = -A_3, A_5 = -\frac{1}{a_5}, u_{1,1,2} = a_6\left(A_3\Delta h_5 + A_4\Delta h_3 + A_5\Delta r_1\right),$$

$$h_3 = h\left(M_1, y, t\right), h_4 = h\left(M_1 + a_5, y, t\right), h_5 = e^{a_5 t}h_4, r_1 = r\left(M_1, y, t\right), a_7 = \frac{ScK - M_1}{Sc - 1}, a_8 = \frac{Gm\cos\gamma}{Sc - 1},$$

$$A_6 = -\frac{1}{a_7}, A_7 = -A_6, u_{1,1,3} = a_8\left(A_6 h_7 + A_7 h_3\right), h_7 = e^{-a_7 t}h_6, h_6 = h\left(M_1 - a_7, y, t\right), a_9 = \frac{Gm\cos\gamma a_2}{Sc - 1},$$

$$A_8 = \frac{1}{\left(a_3 + a_7\right)a_7}, A_9 = \frac{1}{\left(a_3 + a_7\right)a_3}, A_{10} = -\frac{1}{a_3 a_7}, u_{1,1,4} = a_{11}\left(A_9\Delta h_9 + A_{10}\Delta h_7 + A_{11}\Delta h_3 + A_{12}\Delta r_1\right),$$

$$h_9 = e^{a_3 t} h_8, h_8 = h\left(M + a_3, y, t\right), a_{10} = \frac{Gm\cos\gamma a_2}{a_1 - 1}, A_{11} = \frac{1}{\left(a_5 - a_3\right)a_5}, A_{12} = \frac{1}{\left(a_3 - a_5\right)a_3}, A_{13} = \frac{1}{a_3 a_5},$$
$$u_{1,1,5} = a_{10}\left(A_{11}\Delta h_{11} + A_{12}\Delta h_9 + A_{13}\Delta h_3\right), h_{11} = e^{a_8 t} h_{10}, h_{10} = h\left(M_1 + a_5, y, t\right),$$
$$u_{1,2} = a_6\left(A_3\Delta\psi_4 + A_4\Delta E_1 + A_5\Delta\lambda_1\right), \psi_4 = \Psi\left(a_1, 0, a_5, y, t\right), u_{1,3} = a_8\left(A_6\psi_5 + A_7\psi_1\right),$$
$$\psi_5 = \Psi\left(Sc, K, -a_7, y, t\right), u_{1,4} = a_9\left(A_8\Delta\psi_5 + A_9\Delta\psi_2 + A_{10}\Delta\psi_1\right),$$
$$u_{1,5} = a_{10}\left(A_{11}\Delta\psi_6 + A_{12}\Delta\psi_3 + A_{13}\Delta E_1\right), \psi_6 = \Psi\left(a_1, 0, a_8, y, t\right), u_{2,1} = u_{2,1,1} + u_{2,1,2} + u_{2,1,3} + u_{2,1,4} - u_{2,1,5},$$
$$u_{2,1,1} = u_{1,1,1}, a_{11} = -\frac{Gr\cos\gamma}{M_1 t_1}, u_{2,1,2} = a_{11}\Delta r_1, u_{2,1,3} = u_{1,1,3}, u_{2,1,4} = u_{1,1,4}, u_{2,1,5} = a_{12}\left(A_1\Delta h_9 + A_2\Delta h_3\right),$$
$$a_{12} = -\frac{Gm\cos\gamma a_2}{M_1}, u_{2,2} = a_{11}\Delta\lambda_1, u_{2,3} = u_{1,3}, u_{2,4} = u_{1,4}, u_{2,5} = a_{12}\left(A_1\Delta\psi_3 + A_2\Delta E_1\right),$$
$$u_{3,1} = u_{3,1,1} + u_{3,1,2} + u_{3,1,3} + u_{3,1,4} - u_{3,1,5}, u_{3,1,1} = u_{1,1,1}, u_{3,1,2} = u_{1,1,2}, u_{3,1,3} = a_{12} h_3, a_{13} = \frac{Gm\cos\gamma}{K - 1},$$
$$u_{3,1,4} = a_{14}\left(A_1\Delta h_9 + A_2\Delta h_3\right), a_{14} = \frac{Gm\cos\gamma a_2}{K - 1}, u_{3,1,5} = u_{1,1,5}, u_{3,2} = u_{1,2}, u_{3,3} = a_{13}\psi_1,$$
$$u_{3,4} = a_{14}\left(A_1\Delta\psi_2 + A_2\Delta\psi_1\right), u_{3,5} = u_{1,5}, u_{4,1} = u_{4,1,1} + u_{4,1,2} + u_{4,1,3} + u_{4,1,4} - u_{4,1,5}, u_{4,1,1} = u_{1,1,1},$$
$$u_{4,1,2} = u_{2,1,2}, u_{4,1,3} = u_{3,1,3}, u_{4,1,4} = a_{15}\Delta h_3, a_{15} = \frac{Gm\cos\gamma Sr}{t_1 K\left(K - 1\right)}, u_{4,1,5} = a_{16}\Delta h_3, a_{16} = \frac{Gm\cos\gamma Sr}{t_1 K M_1},$$
$$u_{4,2} = u_{2,2}, u_{4,3} = u_{3,3}, u_{4,4} = a_{15}\Delta\psi_1, u_{4,5} = a_{16}\Delta E_1, u_{5,1} = u_{5,1,1} + u_{5,1,2} + u_{5,1,3} + u_{5,1,4} - u_{5,1,5}, u_{5,1,1} = u_{1,1,1},$$
$$u_{5,1,2} = u_{1,1,2}, u_{5,1,3} = u_{1,1,3}, u_{5,1,4} = a_{17}\left(A_6\Delta h_7 + A_7\Delta h_3\right), a_{17} = -\frac{Gm\cos\gamma Sr a_1}{t_1 K},$$
$$u_{5,1,5} = a_{17}\left(A_{14}\Delta h_{11} + A_{15}\Delta h_3\right), A_{14} = \frac{1}{a_8}, A_{15} = -A_{14}, u_{5,2} = u_{1,2}, u_{5,3} = u_{1,3},$$
$$u_{5,4} = a_{17}\left(A_6\Delta\psi_5 + A_7\Delta\psi_1\right), u_{5,5} = a_{17}\left(A_{14}\Delta\psi_6 + A_{15}\Delta E_1\right)$$

## 2.3 Nusselt number

By Fourier's law of conduction, the heat flux $q^*$ at the plate $\bar{y} = 0$ is given by

$$q^* = -\kappa_0^* \left.\frac{\partial T}{\partial \bar{y}}\right]_{\bar{y}=0} \tag{31}$$

Here, $\kappa_0^* = \kappa + \frac{16\sigma^* T_\infty^3}{3\kappa^*}$ is modified thermal conductivity.
Equation (31) yields

$$Nu = -\left.\frac{\partial\theta}{\partial y}\right]_{y=0} \tag{32}$$

Here, $Nu = \frac{q^*\nu}{\kappa_0^* U_0\left(T_w - T_\infty\right)}$ is termed as Nusselt number which is associated with the rate of heat transfer at the plate.
Equation (32) gives,

$$Nu = -\frac{1}{t_1}\Delta\nu_1 \tag{33}$$

Where

$$v_1 = v\left(a_1, t\right)$$

## 2.4 Sherwood number

By Fick's law of diffusion, the mass flux $M_w$ at the plate $\bar{y} = 0$ is given by

$$M_w = -D_M \left.\frac{\partial C}{\partial \bar{y}}\right]_{\bar{y}=0} \tag{34}$$

Equation (34) gives

$$Sh = -\left.\frac{\partial \phi}{\partial y}\right]_{y=0} \tag{35}$$

In (35), $Sh = \dfrac{M_w \nu}{D_M U_0 \left(C_w - C_\infty\right)}$ is labeled as the Sherwood number which determines the rate of mass transfer at the plate.

Equation (35) yields

$$Sh = -\begin{cases} Sh_{1,1} + Sh_{1,2} - Sh_{1,3} : \Pr \neq \Lambda Sc \\ Sh_{2,1} + Sh_{2,2} - Sh_{2,3} : \Pr = \Lambda Sc \end{cases} \tag{36}$$

Here,

$$Sh_{1,1} = \Omega_1, \Omega_1 = \Omega\left(Sc, K, t\right), Sh_{1,2} = a_2\left(A_1 \Delta Z_1 + A_2 \Delta \Omega_1\right), Z_1 = Z\left(Sc, K, a_3, t\right),$$

$$Sh_{1,3} = a_2\left(A_1 \Delta Z_2 + A_2 \Delta \alpha_1\right), Z_2 = Z\left(a_1, 0, a_3, t\right), \alpha_1 = \alpha\left(\frac{\sqrt{a_1}}{2\sqrt{t}}\right), Sh_{2,1} = Sh_{1,1}, Sh_{2,2} = a_4 \Delta \Omega_1, Sh_{2,3} = a_4 \Delta \alpha_1$$

$$Sh_{2,2} = a_4 \Delta \Omega_1, Sh_{2,3} = a_4 \Delta \alpha_1$$

## 2.5 Skin friction

By Newton's law of viscosity, the viscous drag at the plate $\bar{y} = 0$ is given by

$$\bar{\tau} = -\mu \left.\frac{\partial u}{\partial \bar{y}}\right]_{\bar{y}=0} \tag{37}$$

Equation (37) gives

$$\tau = -\left.\frac{\partial u}{\partial y}\right]_{y=0} \tag{38}$$

In (38), $\tau = \dfrac{\bar{\tau}\nu}{\mu U_0^{\,2}}$ is entitled as the skin friction or coefficient of friction which gives the rate of momentum transfer at the plate.

Equation (38) yields,

$$\tau = -\begin{cases} \tau_{1,1} - \tau_{1,2} - \tau_{1,3} - \tau_{1,4} + \tau_{1,5} : \Pr \neq \Lambda, Sc \neq 1, \Pr \neq \Lambda Sc \\ \tau_{2,1} - \tau_{2,2} - \tau_{2,3} - \tau_{2,4} + \tau_{2,5} : \Pr = \Lambda, Sc \neq 1 \\ \tau_{3,1} - \tau_{3,2} - \tau_{3,3} - \tau_{3,4} + \tau_{3,5} : \Pr \neq \Lambda, Sc = 1 \\ \tau_{4,1} - \tau_{4,2} - \tau_{4,3} - \tau_{4,4} + \tau_{4,5} : \Pr = \Lambda, Sc = 1 \\ \tau_{5,1} - \tau_{5,2} - \tau_{5,3} - \tau_{5,4} + \tau_{5,5} : \Pr \neq \Lambda, Sc \neq 1, \Pr = \Lambda Sc \end{cases} \tag{39}$$

Where

$$\tau_{1,1}=\tau_{1,1,1}+\tau_{1,1,2}+\tau_{1,1,3}+\tau_{1,1,4}-\tau_{1,1,5},\tau_{1,1,1}=N_2,N_2=e^{at}N_1,N_1=N\left(M_1+a,t\right),$$
$$\tau_{1,1,2}=a_6\left(A_3\Delta N_5+A_4\Delta N_3+A_5\Delta O_1\right)N_3=N\left(M_1,t\right),N_4=N\left(M_1+a_5,t\right),N_5=e^{a_5t}N_4,$$
$$O_1=O\left(M_1,t\right),\tau_{1,1,3}=a_8\left(A_6N_7+A_7N_3\right),N_7=e^{-a_9t}N_6,N_6=N\left(M_1-a_7,t\right),$$
$$\tau_{1,1,4}=a_9\left(A_8\Delta N_7+A_9\Delta N_9+A_{10}\Delta N_3\right),N_8=N\left(M_1+a_3,t\right),N_9=e^{a_3t}N_8,$$
$$\tau_{1,1,5}=a_{10}\left(A_{11}\Delta N_{11}+A_{12}\Delta N_9+A_{13}\Delta N_3\right),N_{11}=e^{a_8t}N_{10},N_{10}=N\left(M_1+a_5\right),$$
$$\tau_{1,2}=a_6\left(A_3\Delta Z_3+A_4\Delta\alpha_1+A_5\Delta\nu_1\right),Z_3=Z\left(a_1,0,a_5,t\right),\tau_{1,3}=a_8\left(A_6Z_4+A_7\Omega_1\right),Z_4=Z\left(Sc,K,-a_7,t\right),$$
$$\tau_{2,1}=\tau_{2,1,1}+\tau_{2,1,2}+\tau_{2,1,3}+\tau_{2,1,4}-\tau_{2,1,5},\tau_{2,1,1}=\tau_{1,1,1},\tau_{2,1,2}=a_{11}\Delta O_1,\tau_{2,1,3}=\tau_{1,1,3},\tau_{2,1,4}=\tau_{1,1,4},$$
$$\tau_{1,4}=a_9\left(A_8\Delta Z_4+A_9\Delta Z_1+A_{10}\Omega_1\right),\tau_{1,5}=a_{10}\left(A_{11}\Delta Z_5+A_9\Delta Z_2+A_3\Delta\alpha_1\right),Z_5=Z\left(a_1,0,a_8,t\right),$$
$$\tau_{2,1,5}=a_{12}\left(A_1\Delta N_9+A_2\Delta N_3\right),\tau_{2,2}=a_{11}\Delta\nu_1,\tau_{2,3}=\tau_{1,3},\tau_{2,4}=\tau_{1,4},\tau_{2,5}=a_{12}\left(A_1\Delta Z_2+A_2\Delta\alpha_1\right),$$
$$\tau_{3,1}=\tau_{3,1,1}+\tau_{3,1,2}+\tau_{3,1,3}+\tau_{3,1,4}-\tau_{3,1,5},\tau_{3,1,1}=\tau_{1,1,1},\tau_{3,1,2}=\tau_{1,1,2},\tau_{3,1,3}=a_{14}N_3,$$
$$\tau_{3,1,4}=a_{14}\left(A_1\Delta N_9+A_2\Delta N_3\right),\tau_{3,1,5}=\tau_{1,1,5},\tau_{3,2}=\tau_{1,2},\tau_{3,3}=a_{13}\Omega_1,\tau_{3,4}=a_{14}\left(A_1\Delta Z_1+A_2\Delta\Omega_1\right),$$
$$\tau_{3,5}=\tau_{1,5},\tau_{4,1}=\tau_{4,1,1}+\tau_{4,1,2}+\tau_{4,1,3}+\tau_{4,1,4}-\tau_{4,1,5},\tau_{4,1,1}=\tau_{1,1,1},\tau_{4,1,2}=\tau_{1,1,2},\tau_{4,1,3}=\tau_{3,1,3},\tau_{4,1,4}=a_{15}\Delta N_3,$$
$$\tau_{4,1,5}=a_{16}\Delta N_3,\tau_{4,2}=\tau_{2,2},\tau_{4,3}=\tau_{3,3},\tau_{4,4}=a_{15}\Delta\Omega_1,\tau_{4,5}=a_{16}\Delta\alpha_1,$$
$$\tau_{5,1}=\tau_{5,1,1}+\tau_{5,1,2}+\tau_{5,1,3}+\tau_{5,1,4}-\tau_{5,1,5},\tau_{5,1,1}=\tau_{1,1,1},\tau_{5,1,2}=\tau_{1,1,2},\tau_{5,1,3}=\tau_{1,1,3},$$
$$\tau_{5,1,4}=a_{17}\left(A_6\Delta N_7+A_7\Delta N_3\right),\tau_{5,1,5}=a_{17}\left(A_{14}\Delta N_{11}+A_{15}\Delta N_3\right),\tau_{5,2}=\tau_{1,2},\tau_{5,3}=\tau_{1,3},$$
$$\tau_{5,4}=a_{17}\left(A_6\Delta Z_4+A_7\Delta\Omega_1\right),\tau_{5,5}=a_{17}\left(A_{14}\Delta Z_5+A_{15}\Delta\alpha_1\right)$$

## 3. Results and Discussion

The effects of various flow parameters on flow and transport characteristics are analyzed by assigning some specific values.

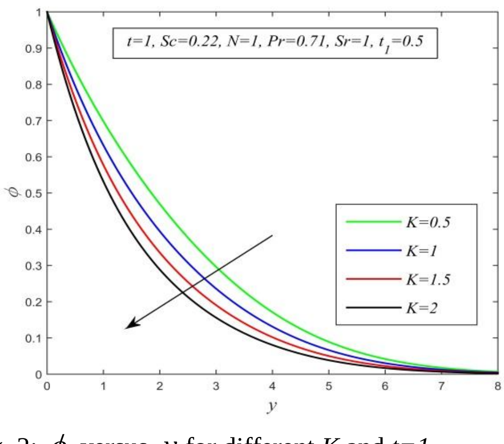


Fig. 2: $\phi$ versus $y$ for different *K* and *t=1, Sc=0.22, N=1, Pr=0.71, Sr=1,* $t_1$*=0.5*

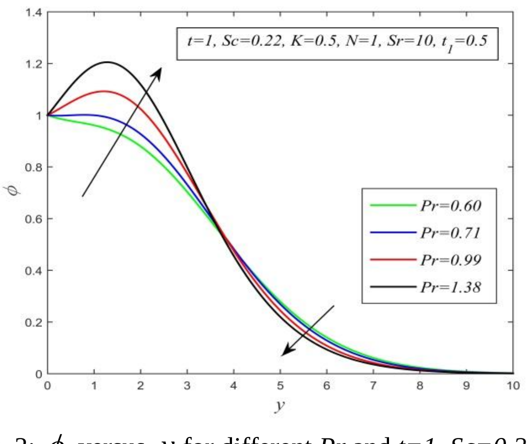


Fig. 3: $\phi$ versus $y$ for different *Pr* and *t=1, Sc=0.22, K=0.5, N=1, Sr=10,* $t_1$*=0.5*

Figures 2 to 5 display the variation of concentration field versus normal co- ordinate y. Fig2 reveals that the concentration field keeps on decreasing with an increment in the chemical reaction parameter. Increasing chemical reaction absorbs the chemical substances present in the fluid quickly and as a result reduces concentration boundary layer thickness. Consequently, fluid concentration diminishes. Fig3 admits that concentration hikes in a thin layer adjacent to the plate but its behavior reverses outside the layer with ascending values of Prandtl number. This implies that higher thermal diffusivity decreases the fluid concentration in a slim layer adjoining the plate but its nature takes a reverse turn outside the layer. There is a comprehensive fall in fluid concentration with increasing Schmidt number as displayed in Fig4. Thus, greater mass diffusivity hikes fluid concentration. Fig5 suggests that ascending Soret number raises the concentration field. As the Soret number is the ratio of temperature gradient to concentration gradient, so rapid change in temperature hikes the concentration field speedily.

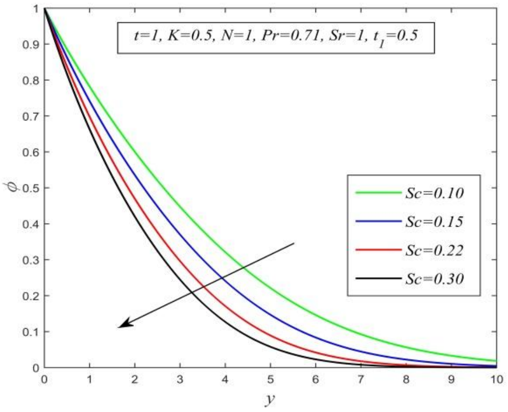


Fig. 4: $\phi$ versus $y$ for different *Sc* and *t=1, K=0.5, N=1, Pr=0.71, Sr=1,* $t_1$*=0.5*

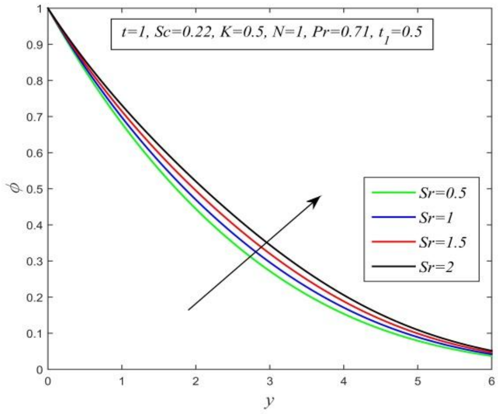


Fig. 5: $\phi$ versus $y$ for different *Sr* and *t=1, Sc=0.22, K=0.5, N=1, Pr=0.71,* $t_1$*=0.5*

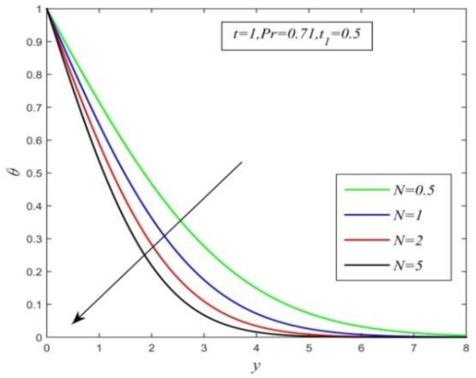


Fig. 6: $\theta$ versus $y$ for different *N* and *t=1, Pr =0.71,* $t_1$ *=0.5*

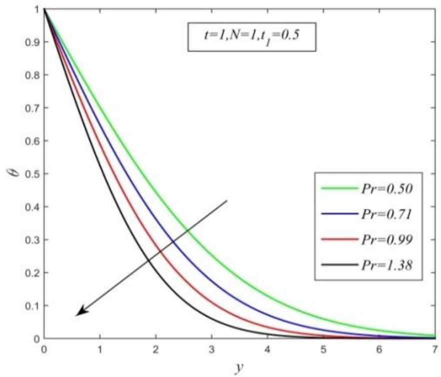


Fig. 7: $\theta$ versus $y$ for different *Pr* and *t=1, N=1,* $t_1$ *=0.5*

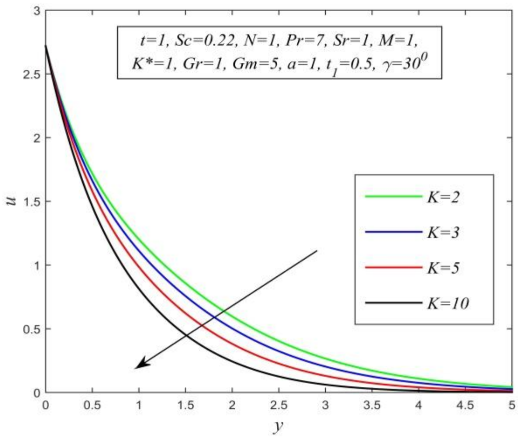


Fig. 8: *u* versus *y* for different *K* and *t=1, Sc=0.22, N=1, Pr =7, Sr=1, M=1, K*=1, Gr=1, Gm=5, a=1* , $t_1$ *=0.5, γ=30°*

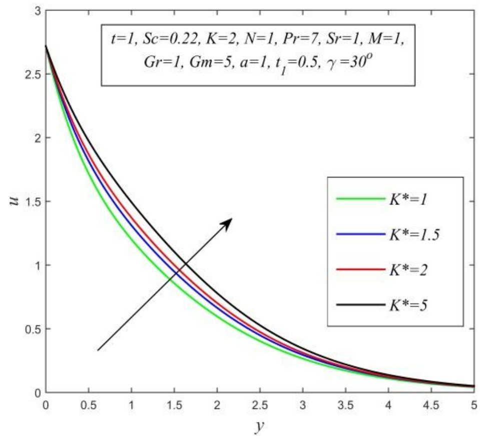


Fig. 9: *u* versus *y* for different *K** and *t=1, Sc=0.22, K=2, N=1, Pr =7, Sr=1, M=1, Gr=1, Gm=5, a=1,* $t_1$ *=0.5, γ=30°*

Figs. 6 and 7 depict the variation of temperature field versus normal co- ordinate y. Fig. 6 suggest that the temperature field falls with increasing radiation parameter. It establishes the fact that radiation tends to decline fluid temperature. The temperature field declines with an uplift in the Prandtl number as displayed in Fig. 7. Thus, higher thermal diffusivity hikes fluid temperature.

Figs. 8 to 15 show the variation of. velocity field versus normal co- ordinate y. Fig. 8 displays that increasing chemical reaction parameter decline fluid velocity. The collision between fluid molecules increases as the chemical reaction parameter hikes. As a result, Kinetic energy is lost and velocity decelerates. There is a comprehensive rise in velocity field with increasing porosity parameter as shown in Fig. 9. Ascending values of the porosity parameter indicate that there is more free space in the medium for the fluid to flow and accordingly, fluid velocity accelerates. Fig. 10 admits that an increment in the Prandtl number diminishes fluid velocity. Consequently, higher thermal diffusivity hikes fluid velocity. Growing Soret number escalates velocity field as noticed in Fig. 11. This implies that a high-temperature gradient compared to concentration gradient results in a hike in the velocity field. Increasing thermal Grashof number lowers velocity as noticed in Fig. 12. Thus high thermal diffusivity leads to a dip in the velocity field. Fig. 13 displays that ascending values of solutal Grashof number upsurges velocity field. This asserts to us that rising solutal diffusivity upsurges fluid velocity. Fig. 14 demonstrate that growing magnetic parameter slow down fluid velocity. This is because the application of a transverse magnetic field generates a resistive force known as Lorentz force, which declines fluid velocity. Fig. 15 displays that an increment in the angle of inclination diminishes velocity at all points of the fluid.

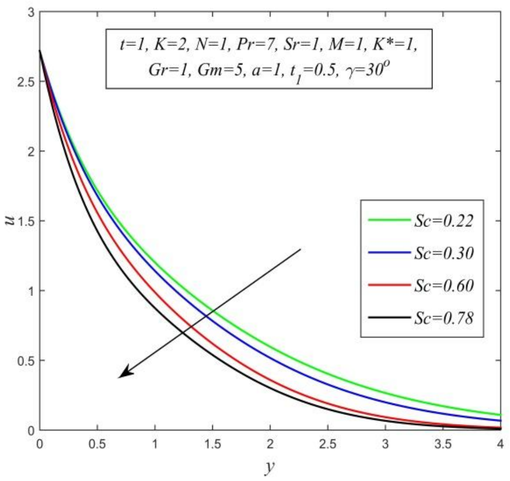


Fig. 10: *u* versus *y* for different *Sc* and *t=1, K=2, N=1, Pr =7, Sr=1, M=1, K*=1, Gr=1, Gm=5, a=1,* $t_1$ *=0.5, γ=30º*

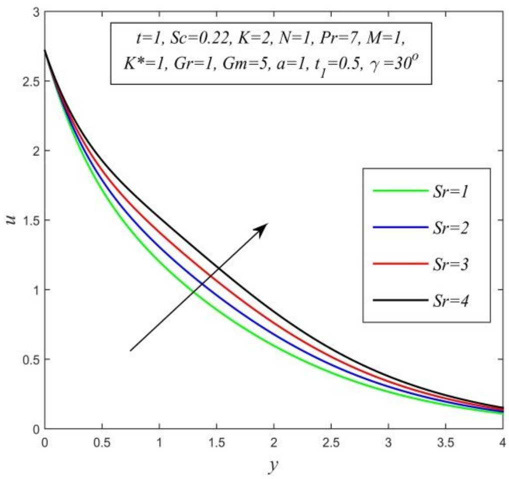


Fig. 11: *u* versus *y* for different *Sr* and *t=1, Sc=0.22, K=2, N=1, Pr =7, M=1, K*=1, Gr=1, Gm=5, a=1,* $t_1$ *=0.5, γ=30º*

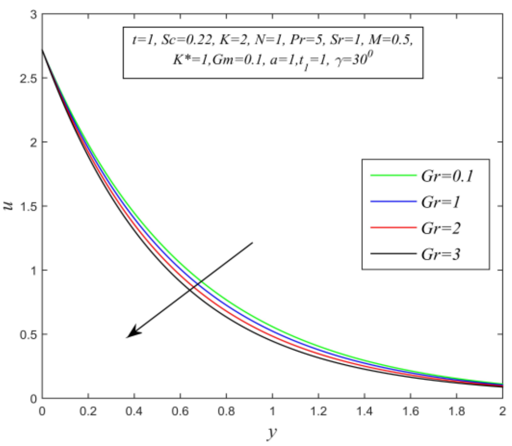


Fig. 12: *u* versus *y* for different *Gr* and *t=1, Sc=0.22, K=2, N=1, Pr =5, Sr=1, M=0.5, K*=1, Gm=0.1, a=1,* $t_1$ *=0.5, γ=30º*

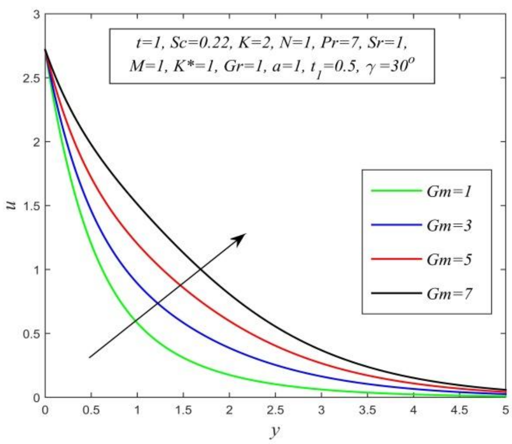


Fig. 13: *u* versus *y* for different *Gm* and *t=1, Sc=0.22, K=2, N=1, Pr =7, Sr=1, M=1, K*=1, Gr=1, a=1 ,* $t_1$ *=0.5, γ=30º*

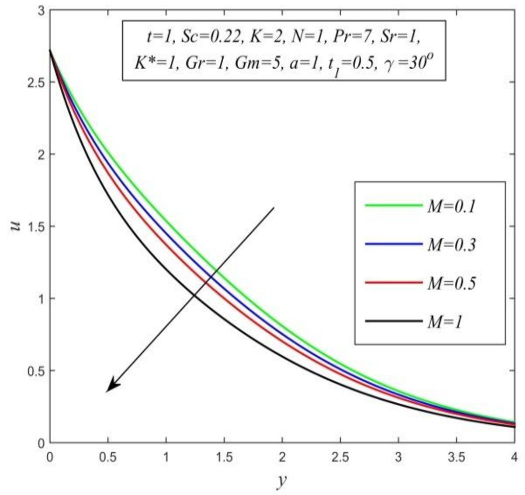


Fig. 14: *u* versus *y* for different *M* and *t=1, Sc=0.22, K=2, N=1, Pr =7, Sr=1, K*=1, Gr=1, Gm=5, a=1,* $t_1$ *=0.5, γ=30º*

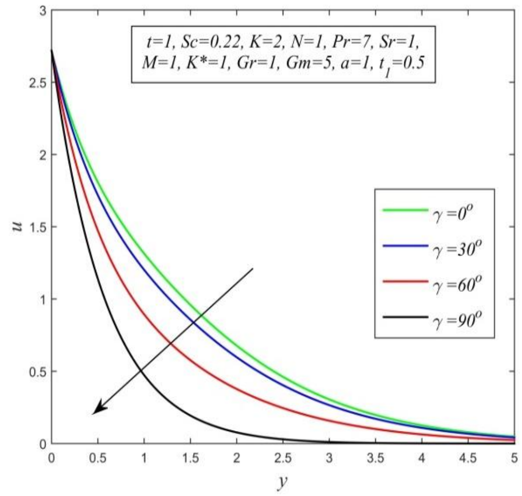


Fig. 15: *u* versus *y* for different *γ* and *t=1, Sc=0.22, K=2, N=1, Pr =7, Sr=1, M=1, K*=1, Gr=1,Gm=5, a=1,* $t_1$ *=0.5*

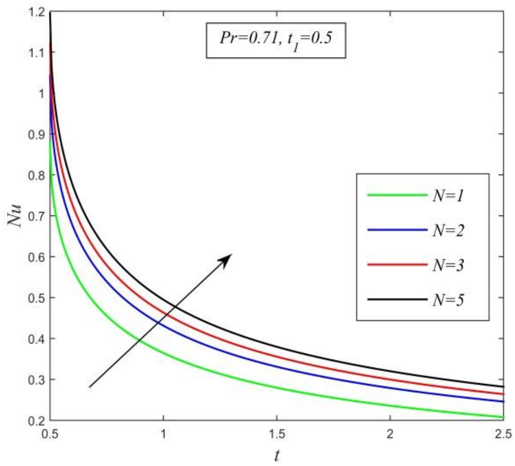


Fig. 16: *Nu* versus *t* for different *N* and *Pr=0.71,* $t_1=0.5$

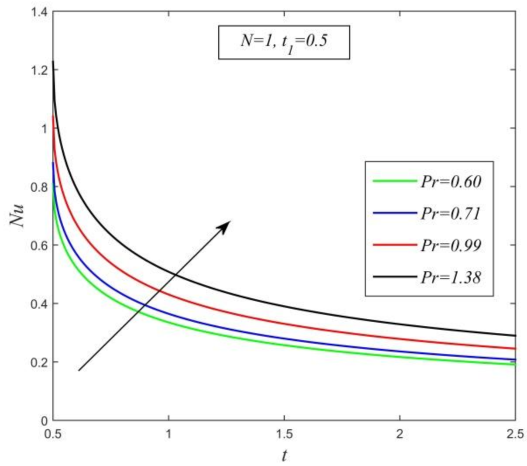


Fig. 17: *Nu* versus *t* for different *Pr* and *N=1,* $t_1=0.5$

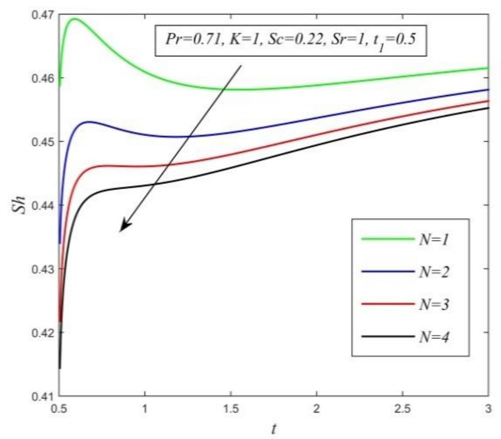


Fig. 18: *Sh* versus *t* for different *N* and *Pr=0.71, K=1, Sc=0.22, Sr=1,* $t_1$ *=0.5*

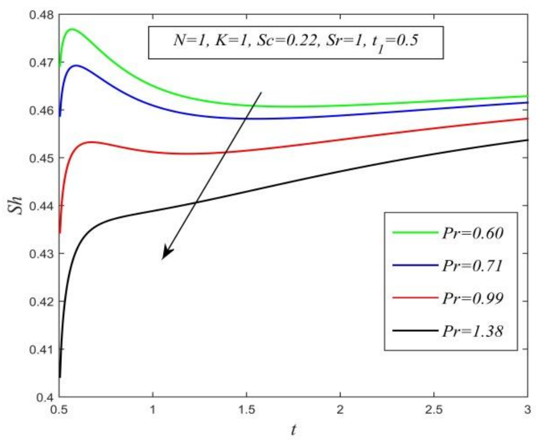


Fig. 19: *Sh* versus *t* for different *Pr* and *N=1, K=1, Sc=0.22, Sr=1,* $t_1$ *=0.5*

Figures 16 and 17 demonstrate the variation of Nusselt number versus time *t*. Nusselt number hikes with increment in radiation parameter as noticed in Fig16. Thus, radiation accelerates the process of heat transfer from the plate to the fluid. From Fig17, it is observed that increasing the Prandtl number lifts the Nusselt number. This result establishes the fact that higher thermal diffusivity speed up the rate of heat transfer

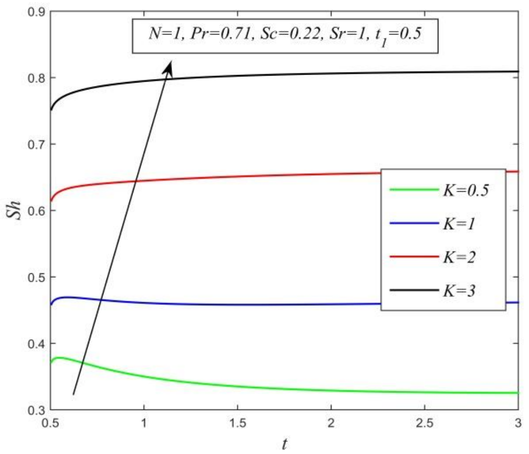


Fig. 20: *Sh* versus *t* for different *K* and *N=1, Pr=0.71, Sc=0.22, Sr=1,* $t_1$ *=0.5*

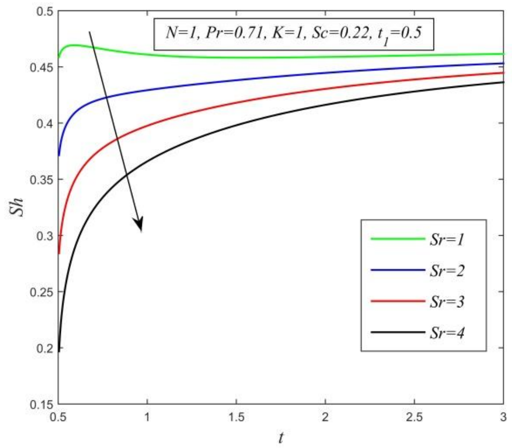


Fig. 21: *Sh* versus *t* for different *Sr* and *N=1, Pr=0.71, K=1, Sc=0.22,* $t_1$ *=0.5*

Figures 18 to 21 exhibit the variation of Sherwood number versus time t. Sherwood number decreases with ascending radiation parameter as noticed in Fig18. This implies that radiation slows down the rate of mass transfer from the plate to the fluid. Fig 19 reveals that the Sherwood number declines with an increment in the Prandtl number. Thus, higher thermal diffusivity speeds up the rate of mass transfer time progresses. Increasing chemical reaction parameter lifts Sherwood number as displayed in Fig20. It is noticed from Fig21 that increasing Soret number declines the Sherwood number. This result agrees with the fact that a high concentration gradient compared to a temperature gradient accelerates the process of mass transfer from the plate to the fluid.

Table 1: Computational values of skin friction for various *t*, *N*, *Sr*, and *M* when *Pr=7, Sc=0.22, K=2, a=1, K*=1*, Gr=1, Gm=5, γ=30°, $t_1$ =0.5

| *t* | *N* | *Sr* | *M* | $\tau$ |
|---|---|---|---|---|
| 1 | 1 | 1 | 1 | 4.0964 |
| 1.5 | | | | 4.5736 |
| 2 | | | | 5.8117 |
| 1 | 1 | 1 | 1 | 4.0964 |
| | 1.5 | | | 4.8201 |
| | 2 | | | 5.4763 |
| | 3 | | | 6.5574 |
| 1 | 1 | 1 | 1 | 4.0964 |
| | | 1.5 | | 4.5147 |
| | | 2 | | 4.9385 |
| | | 3 | | 5.7806 |
| 1 | 5 | | 0.1 | 6.3056 |
| | | | 0.5 | 4.6683 |
| | | | 1 | 4.0964 |

Numerical values of Skin friction τ against different time *t*, radiation parameter *N*, Soret number *Sr* and magnetic parameter *M* are demonstrated in Table 1. It is noticed that skin friction upsurges as time progresses. Skin friction hikes as radiation parameter increases. Thus, radiation accelerates the process of momentum transfer. Increasing Soret number hikes skin friction. This is because a high-temperature gradient exerts more drag force. An opposite behavior is noticed for increasing magnetic parameter. This asserts that Lorentz force arising from the application of transverse magnetic field reduces the frictional resistance of the plate.

Table 2: Computational values of skin friction for various *Gr, Gm, K** and $\gamma$ when t=1, *Pr=7, Sc=0.22, K=2, N=1, Sr=1, M=1, a=1,* $t_1$=0.5

| *Gr* | *Gm* | *K** | $\gamma$ | $\tau$ |
|---|---|---|---|---|
| 1 | 5 | 1 | 30º | 4.0964 |
| 3 | | | | 5.1495 |
| 5 | | | | 6.2027 |
| 1 | 1 | 1 | 30º | 5.0143 |
| | 3 | | | 4.5554 |
| | 5 | | | 4.0964 |
| 1 | 5 | 1 | 30º | 4.0964 |
| | | 2 | | 4.6683 |
| | | 5 | | 5.6991 |
| 1 | 5 | 1 | 30º | 4.0964 |
| | | | 45º | 4.2103 |
| | | | 60º | 4.3588 |
| | | | 90º | 4.7172 |

Numerical values of skin friction $\tau$ against different thermal Grashof number *Gr*, solutal Grashof number *Gm*, porosity parameter K*, and angle of inclination γ of the plate are analyzed in Table2. It is observed that increasing thermal Grashof number hikes skin friction, but ascending solutal Grashof number lowers skin friction. Thus, thermal buoyancy force accelerates the process of momentum transfer, whereas, solutal buoyancy force shows its reverse character. Increasing porosity parameter hikes the viscous drag of the plate. The increasing angle of inclination of the plate hikes skin friction. The more the plate is inclined from the vertical, the more it experiences frictional resistance.

## 3.1 Comparison of Results

To check the accuracy of our result, we have compared one of our results with Pattnaik et al. (2015) who considered MHD flow past an exponentially accelerated inclined plate submerged in a porous medium with variable temperature. In absence of Soret and radiation effects and for vanishing Prandtl number (i.e., *Sr=0, N=0* and *Pr=0*), expression of Sherwood number of the present investigation is

$$Sh = -\Omega_1$$

Table 3: Comparison of computational values of Sherwood number for various *Sc*, *t* and *K* obtained by Pattnaik et.al (2015) and present authors

| *Sc* | *t* | *K* | *Sh* obtained by Pattnaik et. al (2015) (isothermal condition) | *Sh* obtained by present authors (isothermal condition) and considering *Sr*=0, *N*=0 and *Pr*=0 |
|---|---|---|---|---|
| 0.6 | 0.4 | 0.2 | 0.5674 | 0.5674 |
| 3 | 0.4 | 0.2 | 1.2688 | 1.2688 |
| 0.6 | 0.4 | 2.0 | 0.6896 | 0.6896 |
| 0.6 | 0.8 | 0.2 | 0.8228 | 0.8228 |

Table 3 display the variation of Sherwood number for different *Sc*, *t* and *K* obtained by Pattnaik et. al (2015) and present authors respectively. From this table, an excellent agreement of results between present authors and Pattnaik et al. (2016) is observed.

## 4. Conclusion

The prominent outcomes of our investigation are:

i) The chemical reaction effect lowers the concentration field.
ii) Soret effect upsurges both concentration and velocity fields.
iii) Radiation tends to decline temperature field.
iv) Both Lorentz force and increasing angle of inclination slow down fluid velocity.
v) Ascending Prandtl number uplifts Nusselt number, but diminishes Sherwood number.
vi) Skin friction gets enhanced with increment in Soret number, porosity parameter, and angle of inclination.

The governing equations of the present problem are solved using Laplace transform technique. The problem is idealized by imposing some realistic constraints (e.g., viscous dissipation, Joule heating, effect of suction, induced magnetic field are neglected for mathematical simplicity). The same problem may be re- investigated by removing or reducing number of constraints. In this context, some numerical and computational techniques like Runge-Kutta method, shooting method, Crank- Nicolson method etc. may be suggested.

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