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THREE DIMENSIONAL MHD FLOW WITH HEAT AND MASS TRANSFER THROUGH A POROUS MEDIUM WITH PERIODIC PERMEABILITY AND CHEMICAL REACTION

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ABSTRACT

A three - dimensional MHD flow with heat and mass transfer of a viscous, incompressible, conducting fluid, through a semi-infinite porous medium, in the presence of viscous dissipative heat and chemical reaction, is considered. The porous medium is bounded by an infinite porous flat surface, kept at a uniform temperature. The cross flow (suction) velocity at the surface is assumed to be constant. A uniform magnetic field is applied normal to the bounding surface. The expressions for the velocity, temperature and concentration are obtained using the perturbation method, subject to the relevant boundary conditions. Velocity of the fluid is increasing with velocity ratio parameter, Hartman number and Reynolds number whereas decreases with permeability parameter. Increase in Prandtl number and Reynolds number led to increase in temperature of the fluid. Fluid concentration decreased with increase in Chemical parameter and Schmidt number. The numerical results are shown graphically for different values of the parameters entering into the problem.

Keywords: *MHD, periodic permeability, chemical effect, Heat and mass transfer.*

1. NOMENCLATURE

$\bar{T}$: temperature of the fluid
$\bar{T}_w$: temperature of the fluid at the surface
$\bar{T}_\infty$: temperature of the free stream
$\bar{C}$: molar species concentration of the fluid
$\bar{C}_w$: molar species concentration of the fluid at the surface
$\bar{C}_\infty$: molar species concentration of the free stream
C_p : specific heat of the fluid at constant pressure
D : chemical molecular diffusivity
k_T : thermal conductivity of the fluid
Ec : Eckert number
K : chemical reaction parameter
K_1 : chemical reaction rate constant
$\bar{k}$: permeability of the porous medium
k : permeability parameter
l : wave length of the permeability distribution
$\bar{p}$: fluid pressure
Re : Reynolds's number
Pr : Prandtl number
Sc : Schmidt number
M : Hartmann number
B_o : uniform magnetic field
$\bar{u}, \bar{v}, \bar{w}$: velocity components in the $\bar{x}, \bar{y}, \bar{z}$ directions
u, v, w : velocity components in the x, y, z directions
U : free stream velocity
V : suction velocity at the surface
$\bar{x}, \bar{y}, \bar{z}$: Cartesian co-ordinates
x, y, z : dimensionless Cartesian co-ordinates

Greek Symbols

υ : kinematic viscosity of the fluid
θ : dimensionless temperature
θ_o, θ_1 : dimensionless temperatures of rest and far away plates
ϕ : dimensionless concentration
ϕ_o, ϕ_1 : dimensionless concentrations at rest and far away plates
ρ : fluid density
σ : electrical conductivity of the fluid
α : velocity ratio parameter

2. INTRODUCTION

In recent years, the possible use of MHD is to affect a flow stream of an electrically conducting fluid for the purpose of thermal protection, braking, propulsion and control. Model studies on the effects of magnetic field on flows through porous medium have been made by several investigators. Heat and mass transfer on flow past a vertical plate have been studied by several authors; viz. Soundalgekar and Ganesan [11] and Lin and Wu [5] in numerous ways to include various physical aspects. In the above mentioned studies the chemical effect is ignored. Chemical reaction can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. In many chemical engineering processes, there does occur the chemical reaction between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications, e.g., polymer production, manufacturing of ceramics or glassware and food processing. Das et al. [3] studied mass transfer effects on moving isothermal vertical plate in the presence of chemical reaction. Muthucumaraswamy et al. [7] studied the effect of chemical reaction on unsteady MHD flow through an impulsively started semi-infinite vertical plate. The effect of chemical reaction on an unsteady hydro magnetic free convection and mass transfer flow past an infinite inclined porous plate is studied numerically by Alam et al. [1]. Muthucumaraswamy and Ganesan [6] derived numerical solution of the natural convection flow of an incompressible viscous fluid past an impulsively started semi-infinite isothermal vertical plate with chemical reaction of first order. Ananda Reddy et al. [2] studied effects of thermo diffusion and chemical reaction with simultaneous thermal and mass diffusion in MHD mixed convection flow with ohmic heating.

Singh and Sharma [8], Gupta and Johari [4], Singh and Sharma [9] and Singh et al. [10] have studied the problems of three dimensional flows by considering various flow parameters that entering into the problems. But, no attention has been paid to the problem of three dimensional hydro magnetic flows with heat and mass transfer in presence of chemical reaction. Hence, the objective of this paper is to study the three dimensional MHD flow with heat and mass transfer through a porous medium with periodic permeability and chemical reaction.

3. BASIC EQUATIONS

A three dimensional steady flow with heat and mass transfer of a viscous, incompressible conduction fluid through a semi-infinite porous medium, bounded by an infinite porous surface is considered. The surface lying, horizontally on the x-z plane is subjected to a constant suction. The x-axis is taken along the infinite surface being the direction of flow and the y-axis is taken normal to the surface directed into the fluid flowing laminarily with free stream velocity. A uniform magnetic field (Bo) is applied normal to the fluid flow i.e., in the direction of y-axis. Let $\overline{u}, \overline{v}$ and $\overline{w}$ be the velocity components in $\overline{x}, \overline{y}$ and $\overline{z}$ directions respectively. The flow is considered under the following assumptions:

i. The viscous dissipation is considered.
ii. The induced electrical field is neglected
iii. The permeability of the porous medium is periodic.
iv. The permeability of the porous surface is assumed to be of the form

$$\overline{k}(\overline{z}) = \frac{\overline{k}}{1+\varepsilon \cos \pi \overline{z}/l}$$

The problem becomes three dimensional due to such a permeability variation.

Under the above assumptions, the flow in the semi-infinite porous medium is governed by the following equations.

Continuity Equation:

$$\frac{\partial \overline{v}}{\partial \overline{y}} + \frac{\partial \overline{w}}{\partial \overline{z}} = 0 \tag{1}$$

Momentum equations:

$$\overline{v}\frac{\partial \overline{u}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{u}}{\partial \overline{z}} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{x}} + \upsilon\left(\frac{\partial^2 \overline{u}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{u}}{\partial \overline{z}^2}\right) - \left(\frac{\upsilon}{\overline{k}(\overline{z})} + \frac{\sigma B_0^{\,2}}{\rho}\right)\overline{u} \tag{2}$$

$$\overline{v}\frac{\partial \overline{v}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{v}}{\partial \overline{z}} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{y}} + \upsilon\left(\frac{\partial^2 \overline{v}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{v}}{\partial \overline{z}^2}\right) - \frac{\upsilon}{\overline{k}(\overline{z})}\overline{v} \tag{3}$$

$$\overline{v}\frac{\partial \overline{w}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{w}}{\partial \overline{z}} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial \overline{z}} + \upsilon\left(\frac{\partial^2 \overline{w}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{w}}{\partial \overline{z}^2}\right) - \left(\frac{\upsilon}{\overline{k}(\overline{z})} + \frac{\sigma B_0^{\,2}}{\rho}\right)\overline{w} \tag{4}$$

Energy equation:

$$\overline{v}\frac{\partial \overline{T}}{\partial \overline{y}} + \overline{w}\frac{\partial \overline{T}}{\partial \overline{z}} = \frac{k_T}{\rho C_p}\left(\frac{\partial^2 \overline{T}}{\partial \overline{y}^2} + \frac{\partial^2 \overline{T}}{\partial \overline{z}^2}\right) + \frac{\mu}{\rho C_p}\overline{\Phi} \tag{5}$$

Where

$$\overline{\Phi} = 2\left[\left(\frac{\partial \overline{v}}{\partial \overline{y}}\right)^2 + \left(\frac{\partial \overline{w}}{\partial \overline{z}}\right)^2\right] + \left[\left(\frac{\partial \overline{u}}{\partial \overline{y}}\right)^2 + \left(\frac{\partial \overline{w}}{\partial \overline{y}} + \frac{\partial \overline{v}}{\partial \overline{z}}\right)^2 + \left(\frac{\partial \overline{u}}{\partial \overline{z}}\right)^2\right]$$

MassTransfer equation:

$$\bar{v}\frac{\partial\bar{C}}{\partial\bar{y}}+\bar{w}\frac{\partial\bar{C}}{\partial\bar{z}}=D(\frac{\partial^2\bar{C}}{\partial\bar{y}^2}+\frac{\partial^2\bar{C}}{\partial\bar{z}^2})-K_l(\bar{C}-C_\infty) \quad (6)$$

For free stream, the momentum equation become

$$\frac{1}{\rho}\frac{d\bar{p}}{dx}+(\frac{\upsilon}{\bar{k}(\bar{z})}+\frac{\sigma B_0{}^2}{\rho})U=0$$

The corresponding boundary conditions are:

$$\begin{aligned}&\bar{y}=0:\ \bar{u}=0;\bar{v}=-V;\bar{w}=0;\bar{T}=\bar{T}_w;\bar{C}=\bar{C}_w\\&\bar{y}\to\infty:\ \bar{u}=U;\bar{v}=0;\bar{w}=0;\bar{p}=p_\infty;\\&\qquad\bar{T}=\bar{T}_\infty;\bar{C}=\bar{C}_\infty\end{aligned} \quad (7)$$

The following dimensionless quantities

$$\begin{aligned}&y=\frac{\bar{y}}{l};z=\frac{\bar{z}}{l};\ u=\frac{\bar{u}}{U};\ v=\frac{\bar{v}}{U};\ w=\frac{\bar{w}}{U};\\&p=\frac{\bar{p}}{\rho U^2};Re=\frac{Ul}{\upsilon};\ \Pr=\frac{\mu C_p}{k_T};\ Sc=\frac{\upsilon}{D};\\&\theta=\frac{(\bar{T}-\bar{T}_\infty)}{(\bar{T}_w-\bar{T}_\infty)};\ \upsilon=\frac{\mu}{\rho};\ \phi=\frac{(\bar{C}-\bar{C}_\infty)}{(\bar{C}_w-\bar{C}_\infty)};\\&M=\frac{\sigma B_0{}^2l^2}{\rho V};\ K=\frac{K_l\upsilon}{v_0{}^2};Ec=\frac{U^2}{C_p(\bar{T}_w-\bar{T}_\infty)}\end{aligned} \quad (8)$$

are introduced into the equations (1) – (6). Then the governing equations become

$$\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0 \quad (9)$$

$$v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=\frac{1}{\mathrm{Re}}\left(\frac{\partial^2u}{\partial y^2}+\frac{\partial^2u}{\partial z^2}\right)-\left(\frac{\mathrm{Re}}{k(z)}+\frac{M}{\mathrm{Re}}\right)(u-1) \quad (10)$$

$$v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}=-\frac{\partial p}{\partial y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2v}{\partial y^2}+\frac{\partial^2v}{\partial z^2}\right)-\frac{\mathrm{Re}}{k(z)}v \quad (11)$$

$$\begin{aligned}v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}=-\frac{\partial p}{\partial z}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2w}{\partial y^2}+\frac{\partial^2w}{\partial z^2}\right)\\-\left(\frac{\mathrm{Re}}{k(z)}+\frac{M}{\mathrm{Re}}\right)w\end{aligned} \quad (12)$$

$$v\frac{\partial\theta}{\partial y}+w\frac{\partial\theta}{\partial z}=\frac{1}{\Pr\mathrm{Re}}\left(\frac{\partial^2\theta}{\partial y^2}+\frac{\partial^2\theta}{\partial z^2}\right)+\frac{Ec}{\mathrm{Re}}\Phi \quad (13)$$

where

$$\begin{aligned}\Phi=2\left[\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\\\left[\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)^2+\left(\frac{\partial u}{\partial z}\right)^2\right]\end{aligned}$$

$$v\frac{\partial\phi}{\partial y}+w\frac{\partial\phi}{\partial z}=\frac{1}{Sc\mathrm{Re}}\left(\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2}\right)-\mathrm{Re}K\phi \quad (14)$$

The relevant boundary conditions obtained from (7) using the dimensionless quantities (8) are as under:

$$\begin{aligned}&y=0:\ u=0;\ v=-\alpha;\ w=0;\ \theta=1;\ \phi=1\\&y\to\infty:\ u=1;\ p=p_\infty;\ w=0;\ \theta=0;\ \phi=0\end{aligned} \quad (15)$$

4. METHOD OF SOLUTION

We note that the amplitude ε of the injection velocity is very small and hence, using Perturbation technique, the solution to this flow problem may be assumed to be of the form:

$$f(y,z)=f_0(y)+\varepsilon f_1(y,z)+...... \quad (16)$$

Where f denotes u, v, w, p, θ and ϕ. When ε = 0, the problem reduces to a two -dimensional flow and is governed by the following equations obtained from (9) to (14) using (16).

$$\frac{dv_0}{dy}=0 \quad (17)$$

$$\frac{d^2u_0}{dy^2}+\alpha\mathrm{Re}\frac{du_0}{dy}-\left(M+\frac{\mathrm{Re}^2}{k}\right)u_0=-\left(M+\frac{\mathrm{Re}^2}{k}\right) \quad (18)$$

$$\frac{d^2\theta_0}{dy^2}+\alpha\Pr\mathrm{Re}\frac{d\theta_0}{dy}=-Ec\Pr\left(\frac{du_0}{dy}\right)^2 \quad (19)$$

$$\frac{d^2\phi_0}{dy^2}+\alpha Sc\mathrm{Re}\frac{d\phi_0}{dy}-Sc\mathrm{Re}^2K\phi_0=0 \quad (20)$$

Using (16) in (15), the corresponding boundary conditions are

$$\left.\begin{aligned}&y=0;\ u_0=0;\ \theta_0=1;\ \phi_0=1\\&y\to\infty;u_0=1;\theta_0=0;\phi_0=0\end{aligned}\right\} \quad (21)$$

The solutions for the equations (17) - (20) w.r.t the corresponding boundary conditions (21) are

$$u_0=1-e^{-t_1y}; \quad (22)$$

$$\theta_0=c_1e^{-t_1y}+(1-c_0)e^{-\alpha\Pr\mathrm{Re}\,y}; \quad (23)$$

$$\phi_0=e^{-t_2y}; \quad (24)$$

with $w_0(y)=0;\quad v_0(y)=-\alpha;\quad p_0(y)=p_\infty;$

When $\varepsilon\neq 0$, substituting the expressions (16) into the equations (9) to (14) respectively and equating the coefficients of like powers of ε on both sides and neglecting those of $\varepsilon^2,\varepsilon^3$ etc., the following equations are equations are obtained.

$$\frac{\partial v_1}{\partial y}+\frac{\partial w_1}{\partial y}=0 \quad (25)$$

$$\begin{aligned}v_1\frac{\partial u_0}{\partial y}-\alpha\frac{\partial u_1}{\partial y}=\frac{1}{\mathrm{Re}}(\frac{\partial^2u_1}{\partial y^2}+\frac{\partial^2u_1}{\partial z^2})\\-\frac{\mathrm{Re}}{k}(u_1+(u_0+1)\cos\pi z)-\frac{M}{\mathrm{Re}}u_1\end{aligned} \quad (26)$$

$$-\alpha\frac{\partial v_1}{\partial y}=-\frac{\partial p_1}{\partial y}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 v_1}{\partial y^2}+\frac{\partial^2 v_1}{\partial z^2}\right)-\frac{\mathrm{Re}}{k}(v_1-\alpha\cos\pi z) \qquad (27)$$

$$-\alpha\frac{\partial w_1}{\partial y}=-\frac{\partial p_1}{\partial z}+\frac{1}{\mathrm{Re}}\left(\frac{\partial^2 w_1}{\partial y^2}+\frac{\partial^2 w_1}{\partial z^2}\right)-\left(\frac{\mathrm{Re}}{k}+\frac{M}{\mathrm{Re}}\right)w_1 \qquad (28)$$

$$v_1\frac{\partial\theta_0}{\partial y}-\alpha\frac{\partial\theta_1}{\partial y}=\frac{1}{\Pr\mathrm{Re}}\left(\frac{\partial^2\theta_1}{\partial y^2}+\frac{\partial^2\theta_1}{\partial z^2}\right)+\frac{2Ec}{\mathrm{Re}}\frac{du_0}{dy}\frac{\partial u_1}{\partial y} \qquad (29)$$

$$v_1\frac{\partial\phi_0}{\partial y}-\alpha\frac{\partial\phi_1}{\partial y}=\frac{1}{Sc\,\mathrm{Re}}\left(\frac{\partial^2\phi_1}{\partial y^2}+\frac{\partial^2\phi_1}{\partial z^2}\right)-\mathrm{Re}K\phi_1 \qquad (30)$$

The corresponding boundary conditions are

$$\left.\begin{array}{l} y=0: u_1=0, v_1=0, w_1=0, \theta_1=0,\ \phi_1=0 \\ y\to\infty: u_1=0,\ v_1=0,\ p_1=0,\ w_1=0, \\ \qquad \theta_1=0,\ \phi_1=0 \end{array}\right\} \qquad (31)$$

4.1 Solution for the Secondary flow:

The equations governing the secondary flow are given by (25), (27) and (28). The solutions for $v_1(y,z)$, $w_1(y,z)$ and $p_1(y,z)$ are assumed to be of the following form.

$$\left.\begin{array}{l} v_1(y,z)=v_{11}(y)\cos\pi z \\ w_1(y,z)=-\dfrac{1}{\pi}v'_{11}(y)\sin\pi z \\ p_1(y,z)=p_{11}(y)\cos\pi z \end{array}\right\} \qquad (32)$$

The expressions for $v_1(y,z)$ and $w_1(y,z)$ have been chosen so that the continuity equation (25) is satisfied. Here $v'_{11}(y)$ denotes the differentiation of $v_{11}(y)$ with respect to y.

Using the above substitutions (32) in (31), the following boundary conditions are obtained.

$$\left.\begin{array}{l} y=0:\ v_{11}=0,\ v'_{11}=0 \\ y\to\infty:\ v_{11}=0,\ v'_{11}=0 \end{array}\right\} \qquad (33)$$

Putting the above substitutions (32) for v_1, w_1 and p_1 in equations (25), (27) and (28), the equation for velocity components v_1, w_1 and pressure p_1 in terms of $v_{11}(y)$ is

$$v''''_{11}(y)+\alpha\mathrm{Re}\,v'''_{11}(y)-\left(M+2\pi^2+\frac{\mathrm{Re}^2}{k}\right)v''_{11}(y)$$
$$-\alpha\mathrm{Re}\,\pi^2 v'_{11}(y)+\pi^2\left(\pi^2+\frac{\mathrm{Re}^2}{k}\right)v_{11}(y)=\frac{\alpha\mathrm{Re}\,\pi^2}{k}$$

Here $v''''_{11}(y), v'''_{11}(y), v''_{11}(y), v'_{11}(y)$ are the derivatives of $v_{11}(y)$ with respect to y. Solving the above equation subject to the boundary conditions (33) and substituting in equation (32), the solutions for v_1 and w_1 are obtained as follows:

$$v_1=(c_2e^{-t_3y}+c_3e^{-t_4y}+c_4)\cos\pi z\ ;$$

$$w_1=\frac{c_5}{\pi}(e^{-t_3y}-e^{-t_4y})\sin\pi z$$

4.2 Solutions of the main flow, temperature and species concentration fields:

The equations governing the main flow, the temperature and the species concentration fields are given by (26), (29) and (30) respectively. The solutions to these equations may be assumed as:

$$u_1(y,z)=u_{11}(y)\cos\pi z$$
$$\theta_1(y,z)=\theta_{11}(y)\cos\pi z$$
$$\phi_1(y,z)=\phi_{11}(y)\cos\pi z$$

The following boundary conditions are obtained using the above substitutions in (31),

$$\left.\begin{array}{l} y=0: u_{11}=0,\ \theta_{11}=0,\ \phi_{11}=0 \\ y\to\infty: u_{11}=0, \theta_{11}=0, \phi_{11}=0 \end{array}\right\} \qquad (34)$$

Putting the above substitutions for u_1, θ_1 and ϕ_1 in equations (26), (29) and (30), the following equations for velocity, temperature and concentration of main flow are obtained.

$$u''_{11}(y)+\alpha\mathrm{Re}\,u'_{11}(y)-\left(M+\pi^2+\frac{\mathrm{Re}^2}{k}\right)u_{11}(y)=A_1e^{-t_5y}+A_2e^{-t_6y}+A_3e^{-t_1y}$$

Here $u''_{11}(y), u'_{11}(y)$ are the derivatives of $u_{11}(y)$ with respect to y.

$$\theta''_{11}(y)+\alpha\Pr\mathrm{Re}\,\theta'_{11}(y)-\pi^2\theta_{11}(y)= A_4e^{-\alpha\Pr\mathrm{Re}\,y}+A_5e^{-t_1y}+A_6e^{-2t_1y}+A_7e^{-t_5y}+A_8e^{-t_6y}+A_9e^{-t_8y}+A_{10}e^{-t_9y}+A_{11}e^{-t_{10}y}+A_{12}e^{-t_{11}y}+A_{13}e^{-t_{12}y}$$

Here $\theta''_{11}(y), \theta'_{11}(y)$ are the derivatives of $\theta_{11}(y)$ with respect to y.

$$\phi''_{11}(y)+\alpha Sc\,\mathrm{Re}\,\phi'_{11}(y)-(\mathrm{Re}^2KSc+\pi^2)\phi_{11}(y)=A_{14}e^{-t_2y}+A_{15}e^{-t_{14}y}+A_{16}e^{-t_{15}y}$$

Here $\phi''_{11}(y), \phi'_{11}(y)$ are the derivatives of $\phi_{11}(y)$ with respect to y.

Solving these equations subject to the boundary conditions (34), the following solutions are obtained:

$$u_1=(c_6e^{-t_1y}+c_7e^{-t_5y}+c_8e^{-t_6y}+c_9e^{-t_7y})\cos\pi z$$

$$\theta_1=(c_{10}e^{-\alpha\Pr\mathrm{Re}\,y}+c_{11}e^{-t_1y}+c_{12}e^{-2t_1y}+c_{13}e^{-t_5y}+c_{14}e^{-t_6y}+c_{15}e^{-t_8y}+c_{16}e^{-t_9y}+c_{17}e^{-t_{10}y}+c_{18}e^{-t_{11}y}+c_{19}e^{-t_{12}y}+c_{20}e^{-t_{13}y})\cos\pi z$$

$$\phi_1 = (c_{21}e^{-t_2 y} + c_{22}e^{-t_{14} y} + c_{23}e^{-t_{15} y} + c_{24}e^{-t_{16} y})\cos\pi z$$

Here t_1, t_2,…….t_{16}, c_1,c_2,c_3,……….c_{23}, c_{24} are the constants obtained, but not mentioned because of brevity.

Substituting the values of $u_0, v_0, w_0, \theta_0, \phi_0, u_1, v_1, w_1, \theta_1$ *and* ϕ_1 in equation (16), we get the solutions of equations governing the flow.

5. DISCUSSION

In the present paper, a three dimensional MHD flow with heat and mass transfer through a porous medium with periodic permeability and chemical reaction is studied. The Prandtl number for air at 298^0 K and 1 atm is given by Pr = 0.71 while ε = 0.01 and z = 0.3. It is observed that the velocity of the fluid 'u' increases as the velocity ratio parameter α and magnetic parameter M increases as shown in Figure 1. From Figure 2, an increase in Reynolds number Re lead to an increase in u. But an increase in permeability parameter k decreased u. The effects of Pr and Re on temperature of the fluid θ are shown in Figure 3. An increase in Pr and Re resulted in decrease of θ. This is due to the fact that there would be a decrease of thermal boundary layer thickness with the increase of Prandtl number. Finally, the effects of K and Sc on concentration of the fluid □ are also studied. □ is decreasing with increments in K and Sc as shown in Figure 4.

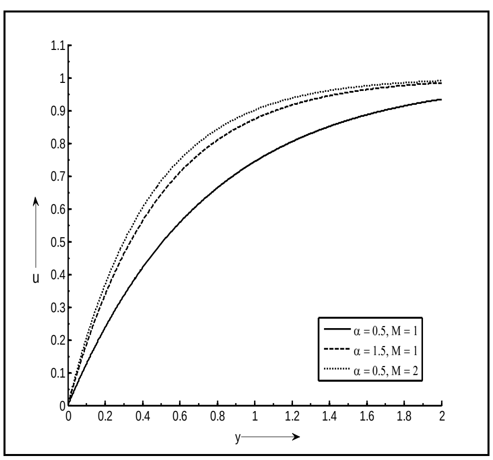

Figure 1. Velocity variations for α and M

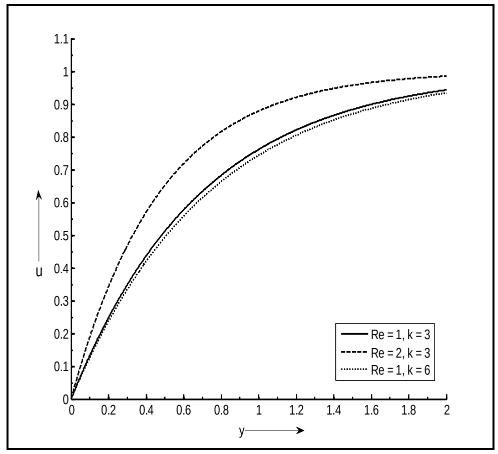

Figure 2. Velocity variations for Re and k

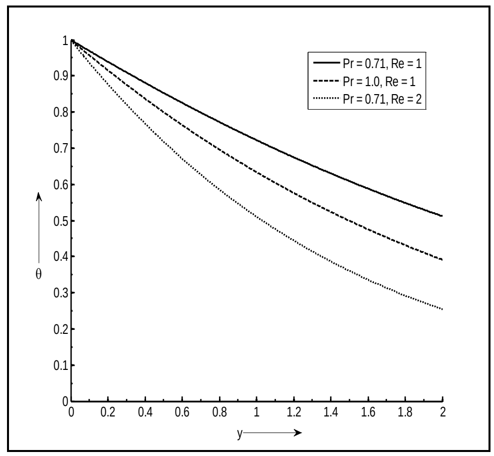

Figure 3. Temperature variations for Pr and Re

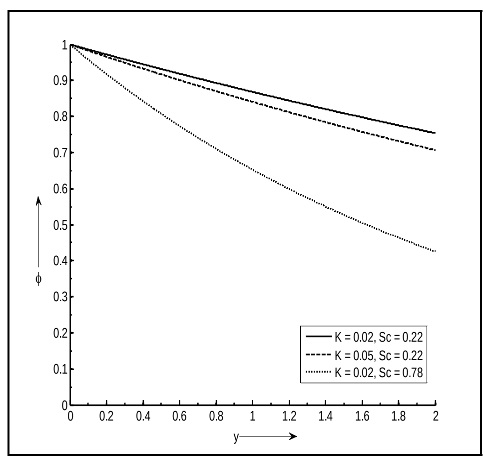

Figure 4. Concentration variations for K and Sc

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