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Radiation effect on an unsteady MHD free convective flow past a vertical porous plate in the presence of soret

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ABSTRACT

Aim of the paper is to investigate the radiation effect on an unsteady megnetohydrodynamic free convective flow past a vertical porous plate in the presence of soret is analyzed. The problem is governed by the system of coupled non-linear partial differential equations whose exact solutions are difficult to obtain, if possible. So, Galerkin finite element method has been adopted for its solution . The flow phenomenon has been characterized with the help of flow parameters such as velocity, temperature and concentration profiles for different parameters such as Grashof number, modified Grashof number, Schmidt number, Prandtl number, Soret number, Magnetic field, Heat source and Radiation parameter. The velocity, temperature and concentration are shown graphically. The coefficient of skin-friction, Nusselt number and Sherwood number are shown in tables.

Keywords: Radiation effect, MHD, free convective, Porous plate, FEM.

INTRODUCTION

Convective heat transfer in a porous media is a topic of rapidly growing interest due to its application to geophysics, geothermal reservoirs, thermal insulation engineering, exploration of petroleum and gas fields, water movements in geothermal reservoirs, etc. The study of convective heat transfer mechanisms through porous media in relation to the applications to the above areas has been made by Nield and Bejan [19] . Kafousias et al [7] have studied unsteady free convective flow past vertical plates with suction. Hossain and Begum [5] have discussed unsteady free convective mass transfer flow past vertical porous plates. MHD convective flow of a micro-polar fluid past a continuously moving vertical porous plate in the presence of heat generation/absorption was studied by Rahman and Sattar [12]. Recently, the study of free convective mass transfer flow has become the object of extensive research as the effects of heat transfer along with mass transfer effects are dominant features in many engineering applications such as rocket nozzles, cooling of nuclear reactors, high sinks in turbine blades, high speed aircrafts and their atmospheric reentry, chemical devices and process equipments. Unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat flux in rotating system studied by Sharma [15]. But in all these papers thermal diffusion effects have been neglected, whereas in a convective fluid when the flow of mass is caused by a temperature difference, thermal diffusion effects cannot be neglected. In view of the importance of this diffusion-thermo effect, Jha and Singh [6] presented an analytical study for free convection and mass transfer flow past an infinite vertical plate moving impulsively in its own plane taking Soret effects into account. In all the above studies, the effect of the viscous dissipative heat was ignored in free-convection flow. However, Gebhart and Mollendorf [3] have shown that when the temperature difference is small or in high Prandtl number fluids or when the gravitational field is of high intensity, viscous dissipative heat should be taken into account in free convection flow past a semi-infinite vertical plate. The unsteady free convection flow of a viscous incompressible fluid past an infinite vertical plate with constant heat flux is considered on taking into account viscous dissipative heat, under the influence of a transverse magnetic field studied by Srihari. K et al [16] . Ramana Kumari and Bhaskar Reddy [13] have studied a two-dimensional unsteady MHD free convective flow of a viscous incompressible electrically conducting fluid past an infinite vertical porous plate with variable suction. Suneetha [17] examined the problem of radiation and mass transfer effects on MHD free convection flow past an impulsively started isothermal vertical plate with dissipation. The effect of temperature dependent viscosity and thermal conductivity on unsteady MHD convective heat transfer past a semi-infinite vertical porous plate has studied Seddek and Salama [14]. In recent years, progress has been considerably made in the study of heat and mass transfer in magneto hydrodynamic flows due to its application in many devices, like the MHD power generator and Hall accelerator. The influence of magnetic field on the flow of an electrically conducting viscous fluid with mass transfer and radiation absorption is also useful in planetary atmosphere research. Kinyanjui et al. [8] presented simultaneous heat and mass transfer in unsteady free convection flow with radiation absorption past an impulsively started infinite vertical porous plate subjected to a strong magnetic field. Yih [18] numerically analyzed the effect of transpiration velocity on the heat and mass transfer characteristics of mixed convection about a permeable vertical plate embedded in a saturated porous medium under the coupled effects of thermal and mass diffusion. Elbashbeshy [2] studied the effect of surface mass flux on mixed convection along a vertical plate embedded in porous medium. Chin et al.[1] obtained numerical results for the steady mixed convection boundary layer flow over a vertical impermeable surface embedded in a porous medium when the viscosity of the fluid varies inversely as a linear function of the temperature. Pal and Talukdar [11] analyzed the combined effect of mixed convection with thermal radiation and chemical reaction on MHD flow of viscous and electrically conducting fluid past a vertical permeable surface embedded in a porous medium is analyzed. Mukhopadhyay [9] performed an analysis to investigate the effects of thermal radiation on unsteady mixed convection flow and heat transfer over a porous stretching surface in porous medium. Hayat et al. [4] analyzed a mathematical model in order to study the heat and mass transfer characteristics in mixed convection boundary layer flow about a linearly stretching vertical surface in a porous medium filled with a visco-elastic fluid, by taking into account the diffusion thermo (Dufour) and thermal-diffusion (Soret) effects.Satya sagar sexena and Dubey [19] M.H.D free convection heat and mass transfer flow of viscoelastic fluid embedded in a porous medium of variable permeability with radiation effect and heat source in slip flow region. Rathore and Asha [20-21] discussed recently the effects of heat transfer MHD unsteady free convection flow past an infinite/semi infinite vertical plate was analysed. Sudhir Babu et al. [22] discussed radiation and chemical reaction effects on an unsteady MHD convection flow past a vertical moving porous plate embedded in a porous medium with viscous dissipation.

The object of the present paper is to study the radiation effect on an unsteady megnetohydrodynamic free convective flow past a vertical porous plate in the presence of soret.The problem is governed by the system of coupled non-linear partial differential equations whose exact solutions are difficult to obtain, if possible. So, Galerkin finite element method has been adopted for its solution, which is more economical from computational point of view.

NOMENCLATURE

B_o	External magnetic field
C'	Species concentration
C'_w	Spice concentration near the plate
C'_∞	Spice concentration of the fluid
C	Dimensionless concentration
C_p	Specific heat at constant pressure
g	Acceleration due to gravity
G_Γ	Thermal Grashof number
G_C	Modified Grashof number
R	Radiation Parameter
K_T	Thermal conductivity of the fluid

M	Magnetic field parameter
D	Chemical molecular dieeusivity
P_Γ	Prandtl number
S_C	Schmidt number
S_O	Soret number
Q	Heat source parameter
T'_w	Temperature of the plate
T'_∞	Temperature of the fluid far away from the plate
t'	Time
t	Dimensionless time
u'	Velocity of the fluid in the x -Direction
u_o	Velocity of the plate
u	Dimensionless velocity
y'	Coordinate axis normal to the plate
y	Dimensionless coordinate axis normal to the plate

Greek symbols

β	Volumetric coefficient of thermal expansion
β^*	Volumetric coefficient of expansion With Concentration
μ	Coefficient of viscosity
q'	Radiative heat flux
ν	Kinematic viscosity
ρ	Density of the fluid
σ_s	Stefan-Boltzmann constant
σ	Electric conductivity
τ'	Skin-friction
τ	Dimensionless skin-friction
η	Similarity parameter

FORMATION OF THE PROBLEM

Unsteady flow of an incompressible, electrically conducting viscous fluid past an infinite vertical porous plate under the influence of a uniform transverse magnetic field is considered. Here the origin of the co-ordinate system is taken to be at any point of the plate. Let the components of the velocity along with x' and y' axes should be u', v' and which are chosen in the upward direction along the plate and normal to the plate respectively. The polarization effects are assumed to be negligible and hence the electric field is also negligible Hence the governing equations of the problem are

$$\frac{\partial\rho'}{\partial t'}+\frac{\partial(\rho' u')}{\partial x'}+\frac{\partial(\rho' u')}{\partial y'}=0 \tag{1}$$

$$\rho'\left(\frac{\partial u'}{\partial t'}+u'\frac{\partial u'}{\partial x'}+v'\frac{\partial u'}{\partial y'}\right)=-\frac{\partial p'}{\partial x'}+g\beta(T'-T'_\infty)+\rho' g\beta^*(C'-C'_\infty)+$$

$$\frac{\partial}{\partial x'}\left(2\mu\frac{\partial u'}{\partial x'}\right)+\frac{\partial}{\partial y'}\left\{\mu\left(\frac{\partial u'}{\partial y'}+\frac{\partial v'}{\partial x'}\right)\right\}-\frac{\mu}{k'}u'-\sigma B_O^2 u' \tag{2}$$

$$\rho' Cp'\left(\frac{\partial T'}{\partial t'}+u'\frac{\partial T'}{\partial x'}+v'\frac{\partial T'}{\partial y'}\right)=K_{T}\left(\left(\frac{\partial^{2}T'}{\partial x'^{2}}+\frac{\partial^{2}T'}{\partial y'^{2}}\right)-\frac{1}{K_{\Gamma}}\left(\frac{\partial q'}{\partial x'}+\frac{\partial q'}{\partial y'}\right)\right)+Q_0'\left(\frac{\partial^{2}T'}{\partial x'^{2}}+\frac{\partial^{2}T'}{\partial y'^{2}}\right) \quad (3)$$

$$\rho'\left(\frac{\partial C'}{\partial t'}+u'\frac{\partial C'}{\partial x'}+v'\frac{\partial C'}{\partial y'}\right)=\rho' D\left(\frac{\partial^{2}C'}{\partial x'^{2}}+\frac{\partial^{2}C'}{\partial y'^{2}}\right)+\rho' D_1\left(\frac{\partial^{2}T'}{\partial x'^{2}}+\frac{\partial^{2}T'}{\partial y'^{2}}\right) \quad (4)$$

Here, the status of an equation of state is that of equation ρ' is constant. This means that the density variations produced by the pressure, temperature and concentration variations are sufficiently small to be unimportant. Variations of all fluid properties other than the variations of density except in so far as they give rise to a body force are ignored completely (Boussinesq approximation). All the physical variables are functions of y' and t' only as the plate are infinite. It is also assumed that the variation of expansion coefficient is negligibly small and the pressure and influence of the pressure on the density are negligible. In a convective fluid the flow of mass is caused by a temperature difference, the thermal diffusion (Soret effect) cannot be neglected. Within the framework of above assumptions the governing equations reduce to

$$\frac{\partial v'}{\partial y'}=0 \quad (5)$$

$$\frac{\partial u'}{\partial t'}+v'\frac{\partial u'}{\partial y'}=g\beta(T'-T'_{\infty})+g\beta^{*}(C'-C'_{\infty})+\upsilon\frac{\partial^{2}u'}{\partial y'^{2}}-\frac{\upsilon}{K'}u'-\frac{\sigma B_{O}^{2}}{\rho'}u' \quad (6)$$

$$\frac{\partial T'}{\partial t'}+v'\frac{\partial T'}{\partial y'}=\frac{K_{T}}{\rho' Cp'}\left[\frac{\partial^{2}T'}{\partial y'^{2}}-\frac{1}{K_{\Gamma}}\frac{\partial q'}{\partial y'}\right]+\frac{Q_0}{\rho c_p}(T'-T'_{\infty}) \quad (7)$$

$$\frac{\partial C'}{\partial t'}+v'\frac{\partial C'}{\partial y'}=D\frac{\partial^{2}C'}{\partial y'^{2}}+D_1\frac{\partial^{2}T'}{\partial y'^{2}} \quad (8)$$

and the corresponding boundary conditions are

$$t>0, u'=0, \qquad T'=T'_{W}=1+\varepsilon e^{i\omega' t'}, \qquad C'=C'_{W} \quad at \quad y'=0$$
$$u'\to 0, \qquad T'\to T'_{\infty}, \qquad C'\to C'_{\infty}, \quad as \quad y'\to\infty \quad (9)$$

From the continuity equation, it can be seen that v' is either a constant or a function of time. So, assuming suction velocity to be oscillatory about a non-zero constant mean, one can write

$$v'=-v_{O}(1+\varepsilon Ae^{i\omega' t'}) \quad (10)$$

Where v_{O} is the mean suction velocity and ε, A are small such that $\varepsilon A<<1$ the negative sign indicates the suction velocity is directed towards the plate.

In order to write the governing equations and the boundary conditions in dimensional following non-dimensional quantities are introduced.

$$y=\frac{v_0 y'}{v}, \qquad y=\frac{v_0 y'}{v}, \qquad t=\frac{t' v_o^2}{4v}, \qquad T=\frac{T'-T''_{\infty}}{T'_{w}-T'_{\infty}}, \qquad C=\frac{C'-C'_{\infty}}{C'_{w}-C'_{\infty}},$$

$$G_\Gamma = \frac{g\beta\nu(T'_w - T'_\infty)}{v_o^3}, \quad G_C = \frac{\upsilon g\beta^*(C'_w - C'_\infty)}{v_o^3}, \quad Sc = \frac{\upsilon}{D}, \quad v = \frac{v'}{v_o},$$

$$w = \frac{4vw'}{v^2{}_o}, \quad M = \frac{\sigma B_o^2 v}{\rho v_o}, \quad K = \frac{K'v}{v^2{}_o}, \quad So = \frac{D_1(T_w - T_\infty)}{\upsilon(C'_w - C'_\infty)}, \quad P_\Gamma = \frac{\mu C_p}{K_T}$$

$$Q = \frac{Q_0 v}{\rho c_p V_0^2}, \quad R = \frac{16\sigma_s T'^3_\infty}{3K_\Gamma k}, \tag{11}$$

Hence, using the above non-dimensional quantities, the equations (6) - (9) in the non-dimensional form can be written as

$$\frac{1}{4}\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y} = G_\Gamma T + G_C C + \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u \tag{12}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial T}{\partial y} = \left(\frac{1+R}{\Pr}\right)\frac{\partial^2 T}{\partial y^2} + QT \tag{13}$$

$$\frac{1}{4}\frac{\partial C}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial C}{\partial y} = \frac{1}{S_C}\frac{\partial^2 C}{\partial y^2} + ScSo\frac{\partial^2 T}{\partial y^2} \tag{14}$$

and the corresponding boundary conditions are

$$\begin{aligned} &t > 0 : u = 0,\ T = T_w = 1 + \varepsilon e^{i\omega t},\ C = 1 && at && y = 0 \\ &u \to 0,\ T \to 0\ , C \to 0 && as && y' \to \infty \end{aligned} \tag{15}$$

Method of solution

The Galerkin expansion for the differential equation (12) becomes

$$\int_{y_J}^{y_K} N^{(e)^T}\left(\frac{\partial^2 u^{(e)}}{\partial y^2} + B\frac{\partial u^{(e)}}{\partial y} - \frac{1}{4}\frac{\partial u^{(e)}}{\partial t} - Nu^{(e)} + R_1\right)dy = 0 \tag{16}$$

Where

$$R_1 = G_\Gamma T + G_C C \qquad B = 1 + \varepsilon A e^{i\omega t}$$

$$N = M + \frac{1}{K} \qquad D = \frac{1+R}{\Pr}$$

Let the linear piecewise approximation solution

$$u^{(e)} = N_j(y)u_j(t) + N_k(y)u_k(t) = N_j u_j + N_k u_k$$

Where

$$N_j = \frac{y_k - y}{y_k - y_j} \qquad N_k = \frac{y - y_j}{y_k - y_j} \qquad N^{(e)^T} = \left[N_j \quad N_k\right]^T = \begin{bmatrix} N_j \\ N_k \end{bmatrix}$$

The Galerkin expansion for the differential equation (16) becomes

$$N^{(e)^T}\frac{\partial u^{(e)}}{\partial y}\Bigg\}_{y_j}^{y_K} - \int_{y_j}^{y_K}\left\{\frac{\partial N^{(e)^T}}{\partial y}\frac{\partial u^{(e)}}{\partial y} - N^{(e)^T}\left(B\frac{\partial u^{(e)}}{\partial y} + \frac{1}{4}\frac{\partial u^{(e)}}{\partial t} + Nu^{(e)} - R_1\right)\right\}dy = 0 \tag{17}$$

Neglecting the first term in equation (17) we gets

$$\int_{y_j}^{y_K}\left\{\frac{\partial N^{(e)^T}}{\partial y}\frac{\partial u^{(e)}}{\partial y} - N^{(e)^T}\left(B\frac{\partial u^{(e)}}{\partial y} - \frac{1}{4}\frac{\partial u^{(e)}}{\partial t} - Nu^{(e)} + R_1\right)\right\}dy = 0$$

$$\frac{1}{l^{(e)}}\begin{bmatrix}1 & -1\\ -1 & 1\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix} - \frac{B}{2}\begin{bmatrix}-1 & 1\\ -1 & 1\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix} + \frac{l_{(e)}}{24}\begin{bmatrix}2 & 1\\ 1 & 2\end{bmatrix}\begin{bmatrix}u_j^{\bullet}\\ u_k^{\bullet}\end{bmatrix} + \frac{Nl^{(e)}}{6}\begin{bmatrix}2 & 1\\ 1 & 2\end{bmatrix}\begin{bmatrix}u_j\\ u_k\end{bmatrix} = R_1\frac{l_{(e)}}{2}\begin{bmatrix}1\\ 1\end{bmatrix}$$

Where $l^{(e)} = y_k - y_j = h$ and dot denotes the differentiation with respect to t .

We write the element equations for the elements $y_{i-1} \le y \le y_i$ and $y_j \le y \le y_k$ assemble three element equations, we obtain

$$\frac{1}{l^{(e)^2}}\begin{bmatrix}1 & -1 & 0\\ -1 & 2 & -1\\ 0 & -1 & 1\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix} - \frac{B}{2l^{(e)}}\begin{bmatrix}-1 & 1 & 0\\ -1 & 0 & 1\\ 0 & -1 & 1\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix} + \frac{1}{24}\begin{bmatrix}2 & 1 & 0\\ 1 & 4 & 1\\ 0 & 1 & 2\end{bmatrix}\begin{bmatrix}u_{i-1}^{\bullet}\\ u_i^{\bullet}\\ u_{i+1}^{\bullet}\end{bmatrix} + \frac{N}{6}\begin{bmatrix}2 & 1 & 0\\ 1 & 4 & 1\\ 0 & 1 & 2\end{bmatrix}\begin{bmatrix}u_{i-1}\\ u_i\\ u_{i+1}\end{bmatrix} = \frac{R_1}{2}\begin{bmatrix}1\\ 2\\ 1\end{bmatrix} \tag{18}$$

Now put row corresponding to the node *i* to zero, from equation (18) the difference schemes is

$$\frac{1}{l^{(e)^2}}\left[-u_{i-1} + 2u_i - u_{i+1}\right] - \frac{B}{2l^{(e)}[\,]}\left[-u_{i-1} + u_{i+1}\right] + \frac{1}{24}\left[u_{i-1}^{\bullet} + 4u_i^{\bullet} + u_{i+1}^{\bullet}\right] + \frac{N}{6}\left[u_{I-1} + 4u_i + u_{i+1}\right] = R_1$$

Applying Crank-Nicholson method to the above equation then we gets

$$A_1 u_{i-1}^{j+1} + A_2 u_i^{j+1} + A_3 u_{i+1}^{j+1} = A_4 u_{i-1}^{j} + A_5 u_i^{j} + A_6 u_{i+1}^{j} + R^* \tag{19}$$

Where

$A_1 = 1 - 12r + 6Brh + 2Nk$ $\quad A_2 = 4 + 24r + 8Nk$ $\quad A_3 = 1 - 12r - 6Brh + 2Nk$

$A_4 = 1 + 12r - 6Brh - 2Nk$ $\quad A_5 = 4 - 24r - 8Nk$ $\quad A_6 = 1 + 12r + 6Brh - 2Nk$

$R^* = 24(G_\Gamma)kT_i^{\,j} + 24(Gc)kC_i^{\,j}$

Applying similar procedure to equation (11) and (12) then we gets

$$B_1 T_{i-1}^{j+1} + B_2 T_i^{j+1} + B_3 T_{i+1}^{j+1} = B_4 T_{i-1}^{j} + B_5 T_i^{j} + B_6 T_{i+1}^{j} \tag{20}$$

$$C_1C_{i-1}^{j+1} + C_2C_i^{j+1} + C_3C_{i+1}^{j+1} = C_4C_{i-1}^{j} + C_5C_i^{j} + C_6C_{i+1}^{j} \tag{21}$$

Where

$B_1 = 1 - 12Ar + 6Brh - 2Qk$ $B_2 = 4 + 24Ar - 8Qk$
$B_3 = 1 - 12Ar - 6Brh - 2Qk$ $B_4 = 1 + 12Ar - 6Brh + 2Qk$ $B_5 = 4 - 24Ar + 8Qk$
$B_6 = 1 + 12Ar + 6Brh + 2Qk$

$C_1 = S_C - 12r + 6BS_C rh$ $C_2 = 4S_C + 24r$
$C_3 = S_C - 12r - 6BS_C rh$ $C_4 = S_C + 12r - 6BS_C rh$
$C_5 = 4S_C - 24r$ $C_6 = S_C + 12r + 6BS_C rh$

$$R^{***} = 24kS_c^2 S_o(T[i-1] - 2T[i] + T[i+1])$$

Here $r = \frac{k}{h^2}$ and h, k are the mesh sizes along y-direction and time t-direction respectively. Index i refers to the space and j refers to the time. In Equations (19)-(21), taking i = 1(1)n and using initial and boundary conditions (12), the following system of equations are obtained:
$A_i X_i = B_i$ $i = 1(1)3$

Where A_i's are matrices of order n and X_i, B_i's column matrices having $n-$ components. The solutions of above system of equations are obtained by using Thomas algorithm for velocity, temperature and concentration. Also, numerical solutions for these equations are obtained by C-program. In order to prove the convergence and stability of finite element method, the same C-program was run with slightly changed values of h and k and no significant change was observed in the values of u, T and C. Hence, the finite element method is stable and convergent.

Skin friction
The skin-friction, Nusselt number and Sherwood number are important physical parameters for this type of boundary layer flow. The skin friction, rate of heat and mass transfer are

Skin friction coefficient (C_f) is given by $C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0}$ (22)

Nusselt number (Nu) at the plate is $Nu = \left(\frac{\partial T}{\partial y}\right)_{y=0}$ (23)

Sherwood number (Sh) at the plate is $Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0}$ (24)

RESULTS AND DISCUSSION

As a result of the numerical calculations, the dimensionless velocity, temperature and concentration distributions for the flow under consideration are obtained and their behaviour have been discussed for variations in the governing parameters viz., the thermal Grashof number G_Γ, modified Grashof number G_C, magnetic field parameter M, permeability parameter K, Prandtl number P_Γ, heat absorption parameter Q, Radiation Parameter R, Schmidt number S_C and Soret number S_O . Here we fixed $\varepsilon = 0.002$, $\omega = 1, t = 0.1$.

The influence of the Schmidt number S_C on the velocity and concentration profiles are plotted in Figs 1(a) and 1(b) respectively. The Schmidt number embodies the ratio of the momentum to the mass diffusivity. The Schmidt number therefore quantifies the relative effectiveness of momentum and mass transport by diffusion in the hydrodynamic (velocity) and concentration (species) boundary layers. As the Schmidt number increases the concentration decreases. This causes the concentration buoyancy effects to decrease yielding a reduction in the fluid velocity. The reductions in the velocity and concentration profiles are accompanied by simultaneous reductions in the velocity and concentration boundary layers. These behaviors are clear from Figs 1(a) and 1(b).

Figs 2(a) and 2(b) illustrate the velocity and temperature profiles for different values of heat source parameter Q , the numerical results show that the effect of increasing values of heat source parameter result in a increasing velocity and temperature.

Figs 3(a) and 3(b) illustrates the behavior velocity and Temperature for different values of Radiation parameter R . It is observed that an increase in R contributes to increase in both the values of velocity and Temperature.

Figs 4(a) and 4(b) illustrate the velocity and temperature profiles for different values of the Prandtl number P_Γ . The Prandtl number defines the ratio of momentum diffusivity to thermal diffusivity. The numerical results show that the effect of increasing values of Prandtl number results in a decreasing velocity (Fig 4 (a)). From Fig 4 (b), it is observed that an increase in the Prandtl number results a decrease of the thermal boundary layer thickness and in general lower average temperature within the boundary layer. The reason is that smaller values of P_Γ are equivalent to increasing the thermal conductivities, and therefore heat is able to diffuse away from the heated plate more rapidly than for higher values of P_Γ . Hence in the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer is reduced.

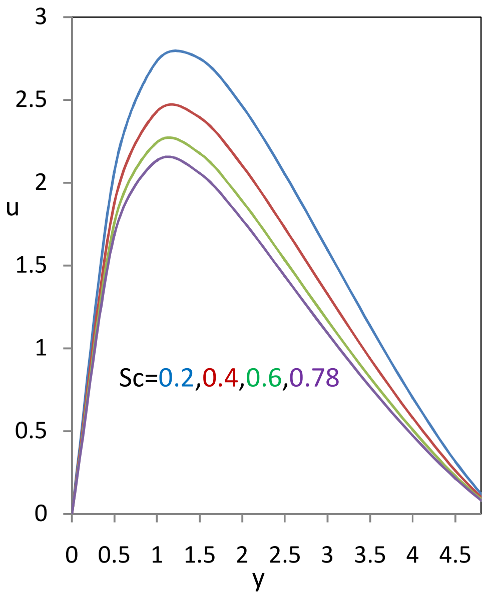
Figs 5(a) and 5(b) depict the velocity and concentration profiles for different values of the Soret number S_O . The Soret number S_O defines the effect of the temperature gradients inducing significant mass diffusion effects. It is noticed that an increase in the Soret number S_O results in an increase in the velocity and concentration within the boundary layer.

The influence of the modified Grashof number G_C on the velocity is presented in Fig 6. The modified Grashof number signifies the relative effect of the thermal buoyancy force to the viscous hydrodynamic force in the boundary layer. As expected, it is observed that there is a rise in the velocity due to the enhancement of thermal buoyancy force. Here, the positive values of G_C correspond to cooling of the plate. Also, as G_C increases, the peak values of the velocity increases rapidly near the porous plate and then decays smoothly to the free stream velocity.
Fig 7 presents typical velocity profiles in the boundary layer for various values of the Grashof number G_Γ , while all other parameters are kept at some fixed values. The Grashof number G_Γ defines the ratio of the species buoyancy force to the viscous hydrodynamic force. As expected, the fluid velocity increases and the peak value is more distinctive due to increase in the species buoyancy force. The velocity distribution attains a distinctive maximum value in the vicinity of the plate and then decreases properly to approach the free stream value.

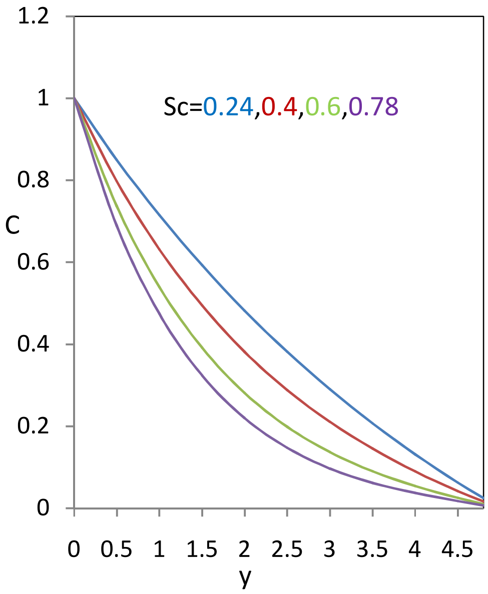
The effect of the permeability parameter K on the velocity field is shown in Fig 8. An increase the resistance of the porous medium which will tend to increase the velocity. This behavior is evident from Fig 8.

For various values of the magnetic parameter M , the velocity profiles are plotted in Fig 9. It can be seen that as M increases, the velocity decreases. This result qualitatively agrees with the expectations, since the magnetic field exerts a retarding force on the flow.

Tables (1), (2) and (3) show the numerical values of the skin friction coefficient, Nusselt number and Shear wood number. The effects of where $Gr, Gm, M, K, \Pr, R, Q, Sc$ and S_0 on the skin-friction C_f, Nusselt number Nu, Sherwood number Sh are shown in Tables 1 to 3. From Table 1, it is observed that as Gr or Gm or K increases, the skin-friction coefficient increases, where as the skin-friction coefficient decreases as M increases. From Table 2, it is noticed that as the skin-friction coefficient and the Nusselt number decreases as $\Pr$ increases. R, Q increases the skin-friction coefficient and the Nusselt number also increases. From Table 3, it is found that as Sc increases, the skin-friction coefficient decreases while the Sherwood number decreases. S_0 increases, the skin-friction coefficient increases while the Sherwood number increases



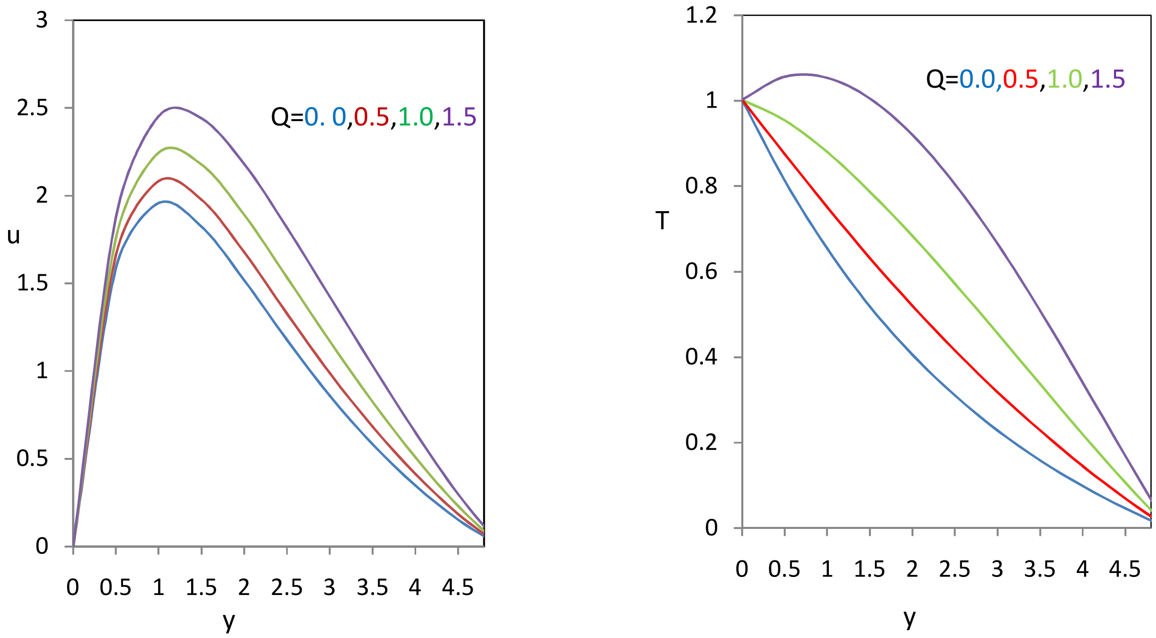
(a)



(b)

Fig.1.Effects of S_C on a) velocity and b)Concentration profile.

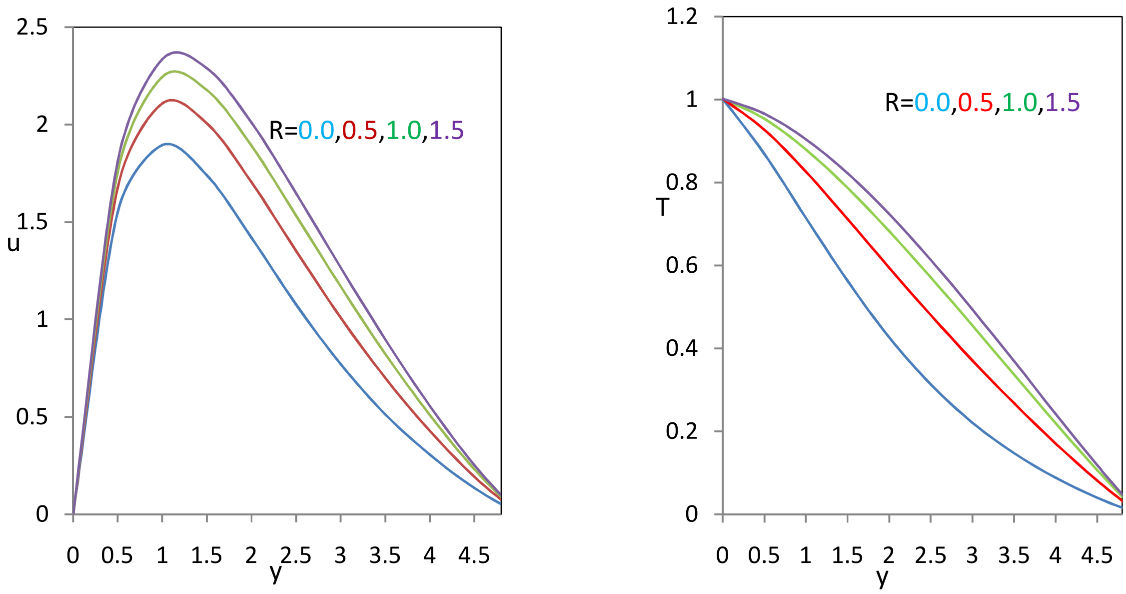
$(Q = 1, \varepsilon = 0.002, P_\Gamma = 0.71, M = 1, G_C = 5, G_\Gamma = 5, S_O = 1, K = 5, \omega = 1, t = 0.1, R = 1)$



(a) (b)

Fig.2.Effets on Q on a) velocity and Temperature profile

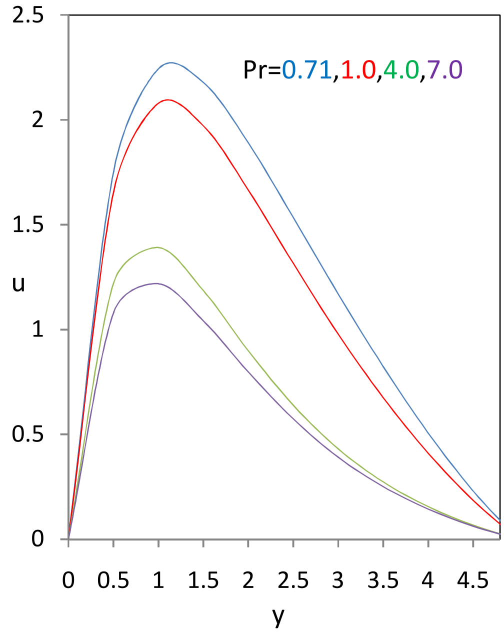
$$\left(S_C = 0.6, \varepsilon = 0.002, P_\Gamma = 0.71, M = 1, G_\Gamma = 5, G_C = 5, S_O = 1, K = 5, \omega = 1, t = 0.1, R = 1\right)$$



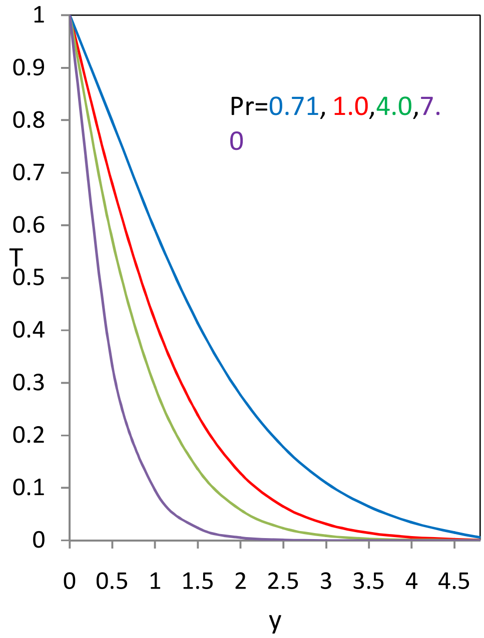
(a) (b)

Fig.3.Effects of R on a) Velocity and b)Temperature profile.

$$\left(S_C = 0.6, \varepsilon = 0.002, P_\Gamma = 0.71, M = 1, G_\Gamma = 5, G_C = 5, S_O = 1, K = 5, \omega = 1, t = 0.1, Q = 1\right)$$



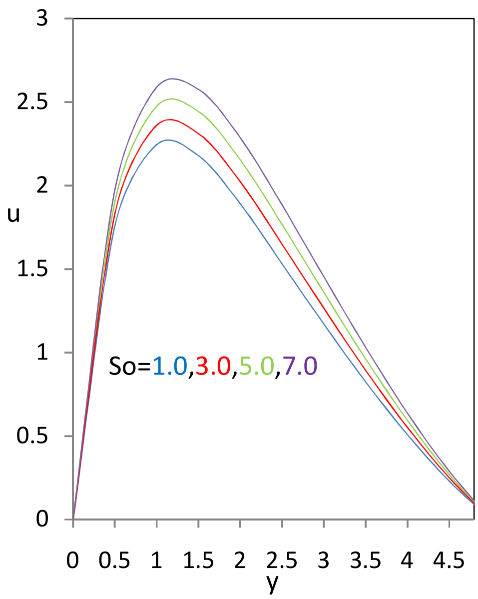
(a)



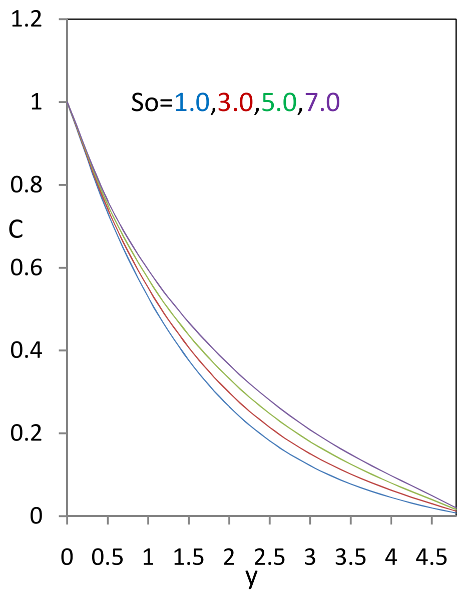
(b)

Fig.4.Effects of P_Γ on a)Velocity and b)Temperature profile.

$$\left(S_C = 0.6, \varepsilon = 0.002, R = 1, M = 1, G_\Gamma = 5, G_C = 5, S_O = 1, K = 5, \omega = 1, t = 0.1, Q = 1\right)$$



(a)



(b)

Fig.5.Effects of S_o on a) Velocity and b)Concentration profile.

$$\left(S_C = 0.6, \varepsilon = 0.002, R = 1, M = 1, G_\Gamma = 5, G_C = 5, P_\Gamma = 0.71, K = 5, \omega = 1, t = 0.1, Q = 1\right)$$

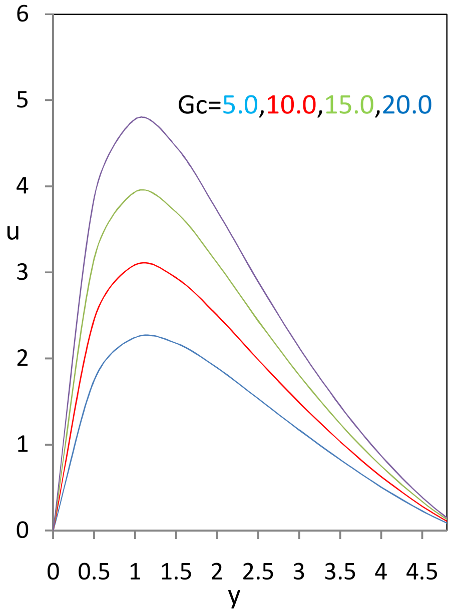


Fig.6.Effects of G_C on Velocity.

$$\begin{pmatrix} S_C = 0.6, \varepsilon = 0.002, R = 1, M = 1, G_\Gamma = 5, \\ S_O = 5, P_\Gamma = 0.71, K = 5, \omega = 1, t = 0.1, Q = 1 \end{pmatrix}$$

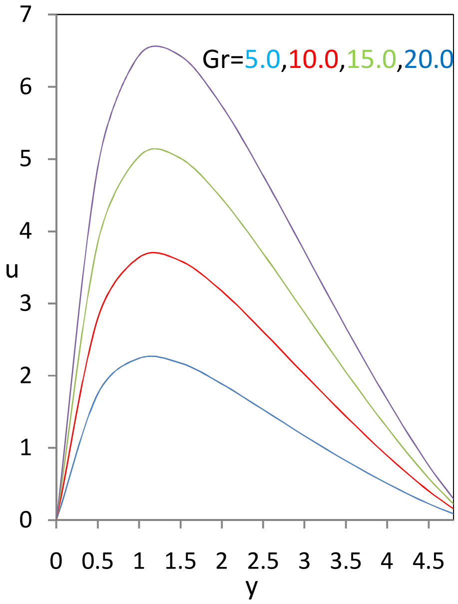


Fig.7.Effects of G_Γ on Velocity.

$$\begin{pmatrix} S_C = 0.6, \varepsilon = 0.002, R = 1, M = 1, G_C = 5, \\ S_O = 5, P_\Gamma = 0.71, K = 5, \omega = 1, t = 0.1, Q = 1 \end{pmatrix}$$

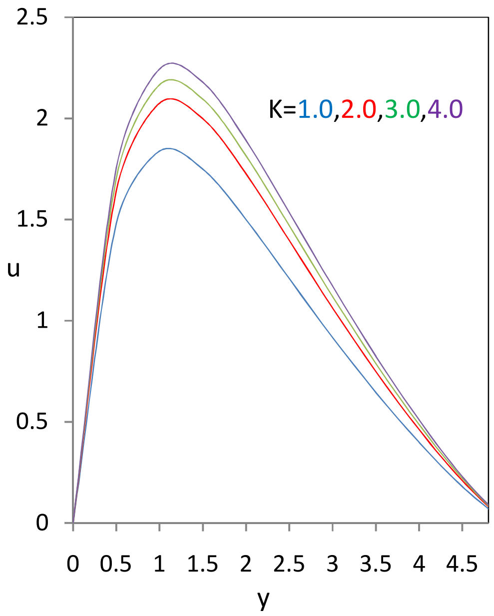


Fig.8.Effects of K on Velocity.

$$\begin{pmatrix} S_C = 0.6, \varepsilon = 0.002, R = 1, M = 1, G_\Gamma = 5, \\ S_O = 5, P_\Gamma = 0.71, G_C = 5, \omega = 1, t = 0.1, Q = 1 \end{pmatrix}$$

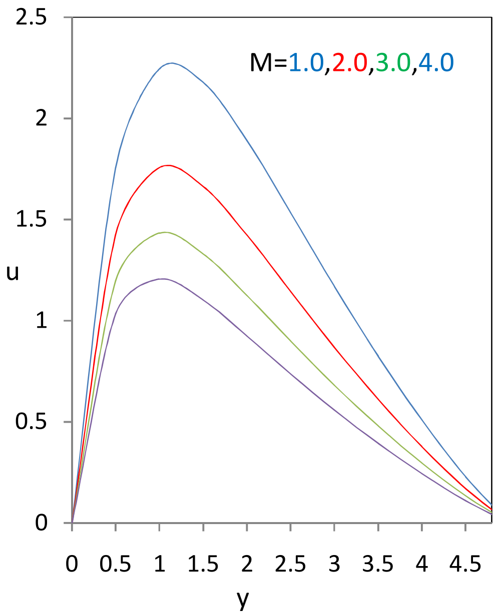


Fig.9.Effets of M on Velocity.

$$\begin{pmatrix} S_C = 0.6, \varepsilon = 0.002, R = 1, K = 5, G_\Gamma = 5, \\ S_O = 5, P_\Gamma = 0.71, G_C = 5, \omega = 1, t = 0.1, Q = 1 \end{pmatrix}$$

Table 1: Effect of G_r, Gc, M and K on C_f

(R=0.5, Pr =0.71, Q=1.0, Sc =0.6, S_0 =1.0)

Gr	Gm	M	K	C_f
2.0	2.0	1.0	0.5	1.0132
4.0	2.0	1.0	0.5	1.9568
2.0	4.0	1.0	0.5	2.2752
2.0	2.0	2.0	0.5	0.6254
2.0	2.0	1.0	1.0	1.5456

Table 2: Effect of R, Pr and Q on C_f and Nu

(G_r =2.0, Gc=2.0, M =0.3, K =0.5, Sc =0. 6, S_0 =1.0)

R	Pr	Q	C_f	Nu
0.5	0.71	1.0	1.4456	1.1489
1.0	0.71	1.0	1.5429	0.9458
0.5	7.0	1.0	0.6724	0.5435
0.5	0.71	1.0	1.4354	1.0512
0.5	0.71	2.0	1.5428	1.4465

Table 3: Effect of Sc and S_0 on C_f and Sh

(G_r = 2.0, Gc= 2.0, M = 0.3, K =0.5, R = 0.5, Pr = 0.71, S_0 = 1.0, Q=1.0)

Sc	S_0	C_f	Sh
0.22	1.0	1.4479	0.5654
0.60	1.0	1.1364	0.4429
0.22	3.0	1.4758	0.7458

CONCLUSION

In this article a mathematical model has been presented for the radiation effect on an unsteady megnetohydrodynamic free convective flow past a vertical porous plate in the presence of soret. The non-dimensional governing equations are solved with the help of finite element method. The results illustrate the flow characteristics for the velocity, temperature, concentration, skin-friction, Nusselt number, and Sherwood number. The conclusions of the study are as follows:

- The velocity increases with the increase Grashof number and modified Grashof number.
- The velocity decreases with an increase in the magnetic parameter.
- The velocity increases with an increase in the permeability of the porous medium parameter.
- Increasing the Prandtl number substantially decreases the translational velocity and the temperature function.
- Increasing the heat source parameter increase both velocity and temperature.
- The velocity as well as temperature increases with an increase in the Radiation parameter.
- The velocity as well as concentration decreases with an increase in the Schmidt number.
- An increase in the Soret number leads to increase in the velocity and temperature.

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