Finite element solution of thermal radiation effect on unsteady MHD flow past a vertical porous plate with variable suction

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Abstract

The paper examined the thermal radiation effect on unsteady megnetohydrodynamic flow past a vertical porous plate with variable suction is analyzed. The non dimensional governing equations are formed with the help of suitable dimensionless governing parameter. The resultant coupled non dimensional governing equations are solved by a finite element method. The velocity, temperature and concentration distributions are derived, discussed numerically and their profiles for various values of physical parameters are shown through graphs. The coefficient of skin-friction, Nusselt number and Sherwood number at the plate are derived, discussed numerically and their numerical values for various values of physical parameters are presented through Tables. It is observed that, when the radiation parameter increases the velocity and temperature increase in the boundary layer. Also, it is found that as increase in the magnetic field leads to decrease in the velocity field and rise in the thermal boundary thickness.

Keywords: Thermal Radiation, MHD, Porous plate, Variable suction, FEM.

1. INTRODUCTION

Radiation and on the optical properties of the emitter, with its internal energy being converted to is the process of heat propagation by means of electromagnetic waves, depending only on the temperature radiation energy. The process involving the convection of internal energy of the solution in to radiation energy is known as radiation heat transfer. In contrast to the mechanism of conduction and convection, where energy transfer through a material medium is involved, heat also be transferred through regions where a perfect vacuum exists. The mechanism in this case is electromagnetic radiation. The electromagnetic radiation which is propagated as a result of temperature differences, this is called thermal radiation.

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.

The object of the present paper is to study the thermal radiation effect on unsteady magnetohydrodynamic flow past a vertical porous plate with variable suction. 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.

2. FORMULATION OF THE PROBLEM

An unsteady two-dimensional laminar free convective boundary layer flow of a viscous, incompressible, electrically conducting and the chemical reaction effects on an unsteady magnetohydrodynamics free convection fluid flow past a semi-infinite vertical plate embedded in a porous medium with heat absorption is considered. The x' - axis is taken along the vertical plate and the y' - axis normal to the plate. It is assumed that there is no applied voltage, which implies the absence of an electric field. The transverse applied magnetic field and magnetic Reynolds number are assumed to be very small so that the induced magnetic field and the Hall Effect are negligible. The concentration of the diffusing species in the binary mixture is assumed to be very small in comparison with the other chemical species which are present, and hence the Soret and Dufour are negligible. Further due to the semi-infinite plane surface assumption, the flow variables are functions of normal distance y' and t' only. Now, under the usual Boussinesq's approximation, the governing boundary layer equations of the problem are:

Continuity equation:

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

Momentum equation:

$$\frac{\partial u'}{\partial t'} + v'\frac{\partial u'}{\partial y'} = \nu\frac{\partial^2 u'}{\partial y'^2} + g\beta(T' - T'_\infty) + g\beta^*(C' - C'_\infty) - \frac{\sigma B_0^2}{\rho}u' - \frac{\nu}{K'}u' \tag{2}$$

Energy equation:

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{1}{k}\frac{\partial q'}{\partial y'} + \frac{\nu}{c_p}\left(\frac{\partial u'}{\partial y'}\right)^2 - \frac{Q_0}{\rho c_p}(T' - T'_\infty) \tag{3}$$

Diffusion equation:

$$\frac{\partial C'}{\partial t'} + v'\frac{\partial C'}{\partial y'} = D\frac{\partial^2 C'}{\partial y'^2} - K_r'^2 C' \tag{4}$$

Where u', v' are the velocity components in x', y' directions respectively. t' - the time, ρ -the fluid density, ν - the kinematic viscosity, c_p - the specific heat at constant pressure, g -the acceleration due to gravity, β and β^* - the thermal and concentration expansion coefficient respectively, B_0 - the magnetic induction , α - the fluid thermal diffusivity, K' - the permeability of the porous medium, T' - the dimensional temperature, C' - the dimensional concentration, k - the thermal conductivity, μ - coefficient of viscosity, D - the mass diffusivity.

The boundary conditions for the velocity, temperature and concentration fields are:

$$\begin{aligned} &u' = u'_p,\ T' = T'_\infty + \varepsilon(T'_w - T'_\infty)\, e^{n't'},\ C' = C'_\infty + \varepsilon(C'_w - C'_\infty)\, e^{n't'} && at\ \ y' = 0 \\ &u' \to 0,\ T' \to T'_\infty,\ C' \to C'_\infty && as\ \ y' \to \infty \end{aligned} \tag{5}$$

T_∞' and

Where u'_p is the plate velocity, T_w' and C_w' are the wall dimensional temperature and concentration respectively, C_∞' are the free stream dimensional temperature and concentration respectively, n' - the constant. By using Rossel and approximation, the radiative heat flux q' is given by

$$q' = -\frac{4\sigma_s}{3k_e}\frac{\partial T'^4}{\partial y'} \tag{6}$$

Where σ_s -the Stefan-Boltzmann constant and k_e - the mean absorption coefficient. It should be noted that by using Rossel and approximation, the present analysis is limited to optically thick fluids. If temperature differences within the flow are sufficient, small, then equation (6) can be linearised by expanding T'^4 in the Taylor series about T_∞' , which after neglecting higher order terms take the form

$$T'^4 \cong 4T_\infty^{3}T' - 3T_\infty'^4 \tag{7}$$

In view of equations (6) and (7), equation (3) reduces to

$$\frac{\partial T'}{\partial t'} + v'\frac{\partial T'}{\partial y'} = \frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2} + \frac{16\sigma_s T'^3_\infty}{3\rho c_p k_e}\frac{\partial^2 T'}{\partial y'^2} + \frac{\mu}{\rho c_p}\left(\frac{\partial u'}{\partial y'}\right)^2 \tag{8}$$

From the continuity equation (1), it is clear that suction velocity normal to the plate is either a constant or function of time. Hence, it is assumed in the form

$$v' = -V_0\left(1 + \varepsilon A e^{n't'}\right) \tag{9}$$

Where A is a real positive constant, ε and εA are small values less than unity and V_0 is scale of suction velocity at the plate surface.

In order to write the governing equations and the boundary condition in dimension less form, the following non- dimensional quantities are introduced.

$$u = \frac{u'}{V_0},\ v = \frac{v'}{V_0},\ y = \frac{V_0 y'}{\nu},\ t = \frac{V_0^2 t'}{4\nu},\ U_p = \frac{u'_p}{V_0},\ n = \frac{\nu n'}{V_0^2},\ T = \frac{T' - T'_\infty}{T'_w - T'_\infty},$$
$$Sc = \frac{\nu}{D},\ C = \frac{C' - C'_\infty}{C'_w - C'_\infty},\ M = \frac{\sigma B_0^2 \nu}{\rho V_0^2},\ K = \frac{K' V_0^2}{\nu^2},\ \Pr = \frac{\nu \rho c_p}{k\alpha} = \frac{\nu}{\alpha}, \tag{10}$$
$$G_r = \frac{g\beta\nu\left(T'_w - T'_\infty\right)}{V_0^3},\ Gc = \frac{g\beta^*\nu\left(C'_w - C'_\infty\right)}{V_0^3},\ R = \frac{16\sigma^* T'^3_\infty}{3k_e k}$$

In view of equations (6) - (9), equations (2) - (4) reduced to the following dimensionless form.

$$\frac{1}{4}\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial u}{\partial y} = G_r T + G_C C + \frac{\partial^2 u}{\partial y^2} - \left(M + \frac{1}{K}\right)u \tag{11}$$

$$\frac{1}{4}\frac{\partial T}{\partial t} - \left(1 + \varepsilon A e^{i\omega t}\right)\frac{\partial T}{\partial y} = \frac{1 + R}{\Pr}\frac{\partial^2 T}{\partial y^2} \tag{12}$$

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

and the corresponding boundary conditions are

$$\begin{aligned} &t > 0 : u = 0,\ T = 1 + \varepsilon e^{i\omega t},\ C = 1 \quad at \quad y = 0 \\ &u \to 0,\ T \to 0,\ C \to 0 \quad as \quad y' \to \infty \end{aligned} \tag{14}$$

3. METHOD OF SOLUTION

The Galerkin expansion for the differential equation (12) becomes

$$\int_{y_J}^{y_K} {}_{N}^{(e)T}\left[\frac{\partial^2 u^{(e)}}{\partial y^2} + B\frac{\partial u^{(e)}}{\partial y} - \frac{1}{4}\frac{\partial u^{(e)}}{\partial t} - Nu^{(e)} + R_1\right] dy = 0 \tag{15}$$

Where

$$R_1 = G_r T + G_C C, \quad B = 1 + \varepsilon A e^{i\omega t}$$

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

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

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

The Galerkin expansion for the differential equation (16) becomes

$$N^{(e)T}\frac{\partial u^{(e)}}{\partial y}\Big|_{y_j}^{y_K} - \int_{y_j}^{y_K}\left[\frac{\partial N^{(e)T}}{\partial y}\frac{\partial u^{(e)}}{\partial y} - NB\,N^{(e)T}\frac{\partial u^{(e)}}{\partial y} + \frac{1}{4}\frac{\partial u^{(e)}}{\partial t} + Nu^{(e)} - R_1\right]dy = 0 \tag{16}$$

Neglecting the first term in equation (17) we gets

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

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

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

$$\frac{1}{l^{(e)2}}\begin{bmatrix} 1 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} - \frac{B}{2l^{(e)}}\begin{bmatrix} -1 & 1 & 0 \\ -1 & 0 & 1 \\ 0 & -1 & 1 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} + \frac{1}{24}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} \dot{u}_{i-1} \\ \dot{u}_i \\ \dot{u}_{i+1} \end{bmatrix} + \frac{N}{6}\begin{bmatrix} 2 & 1 & 0 \\ 1 & 4 & 1 \\ 0 & 1 & 2 \end{bmatrix}\begin{bmatrix} u_{i-1} \\ u_i \\ u_{i+1} \end{bmatrix} = \frac{R_1}{2}\begin{bmatrix} 1 \\ 2 \\ 1 \end{bmatrix} \tag{17}$$

Now put row corresponding to the node i to zero, from equation (17) the difference schemes is

$$\frac{1}{l_{(e)}^{2}}\left[-u_{i-1}+2u_i-u_{i+1}\right]-\frac{B}{2l_{(e)}}\left[-u_{i-1}+u_{i+1}\right]+\frac{1}{24}\left[\dot{u}_{i-1}+4\dot{u}_i+\dot{u}_{i+1}\right]+\frac{N}{6}\left[u_{I-1}+4u_i+u_{i+1}\right]=R_1$$

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

$$A_1u_{i-1}^{j+1}+A_2u_i^{j+1}+A_3u_{i+1}^{j+1}=A_4u_{i-1}^{j}+A_5u_i^{j}+A_6u_{i+1}^{j}+R^{*} \tag{18}$$

Where

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

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

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

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

$$B_1T_{i-1}^{j+1}+B_2T_i^{j+1}+B_3T_{i+1}^{j+1}=B_4T_{i-1}^{j}+B_5T_i^{j}+B_6T_{i+1}^{j} \tag{19}$$

$$C_1C_{i-1}^{j+1}+C_2C_i^{j+1}+C_3C_{i+1}^{j+1}=C_4C_{i-1}^{j}+C_5C_i^{j}+C_6C_{i+1}^{j} \tag{20}$$

Where

$B_1=1-12\,Ar+6Brh$ $\quad B_2=4+24\,Ar$

$B_3=1-12Ar-6Brh,$ $\quad B_4=1+12Ar-6Brh$

$B_5=4-24Ar,$ $\quad B_6=1+12Ar+6Brh$

$C_1=S_C-12r+6BS_C\,rh$ $\quad C_2=4S_C+24r$

$C_3=S_C-12r-6BS_C\,rh,$ $\quad C_4=S_C+12r-6BS_C\,rh$

$C_5=4\,S_C-24\,r,$ $\quad C_6=S_C+12\,r+6\,BS_C\,rh$

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 (18)-(20), taking $i = 1(1)n$ and using initial and boundary conditions (14), the following system of equations are obtained:

$$A_i X_i = B_i \qquad i = 1(1)3$$

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.

4. 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 $C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0}$ (21)

Nusselt number (Nu) at the plate is $Nu = \left(\frac{\partial T}{\partial y}\right)_{y=0}$ (22)

Sherwood number (Sh) at the plate is $Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0}$ (23)

5. 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_r, modified Grashof number G_C, magnetic field parameter M, permeability parameter K, Prandtl number P_r, Thermal Radiation Parameter R and Schmidt number S_C. In the present study we adopted the following default parameter values of finite element computations:

$G_r = 5.0$, $Gc = 5.0$, $M = 1.0$, $K = 5.0$, $\Pr = 0.71$, $R = 1.0$, $Sc = 0.6$, $A = 0.01$, $\varepsilon = 0.002$, $\omega = 1.0$, $t = 1.0$. All graphs therefore correspond to these values unless specifically indicated on the appropriate graph.

Fig 1 presents typical velocity profiles in the boundary layer for various values of the Grashof number G_r, while all other parameters are kept at some fixed values. The Grashof number G_r 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 influence of the modified Grashof number G_C on the velocity is presented in Fig 2. 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.

For various values of the magnetic parameter M, the velocity profiles are plotted in Fig 3. 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. The effect of the permeability parameter K on the velocity field is shown in Fig 4. An increase the resistance of the porous medium which will tend to increase the velocity. This behavior is evident from Fig 4.

Figs 5(a) and 5(b) illustrate the velocity and temperature profiles for different values of the Prandtl number P_r. 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 5(a)). From Fig 5 (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 Pr 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 Pr . Hence in the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer is reduced.

For different values of the radiation parameter R , the velocity and the temperature profiles are shown in Figs 6(a) and 6(b). It is noticed that an increase in the radiation parameter results a decrease in the velocity and temperature within the boundary layer, as well as decreased the thickness of the velocity and temperature boundary layers.

The influence of the Schmidt number S_C on the velocity and concentration profiles are plotted in Figs 7(a) and 7(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 7(a) and 7(b).

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 and Sc 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 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.

6. CONCLUSION

In this article a mathematical model has been presented for the thermal radiation effect on unsteady magnetohydrodynamic flow past a vertical porous plate with variable suction. The non-dimensional governing equations are solved with the help of finite element method. 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.
- 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.

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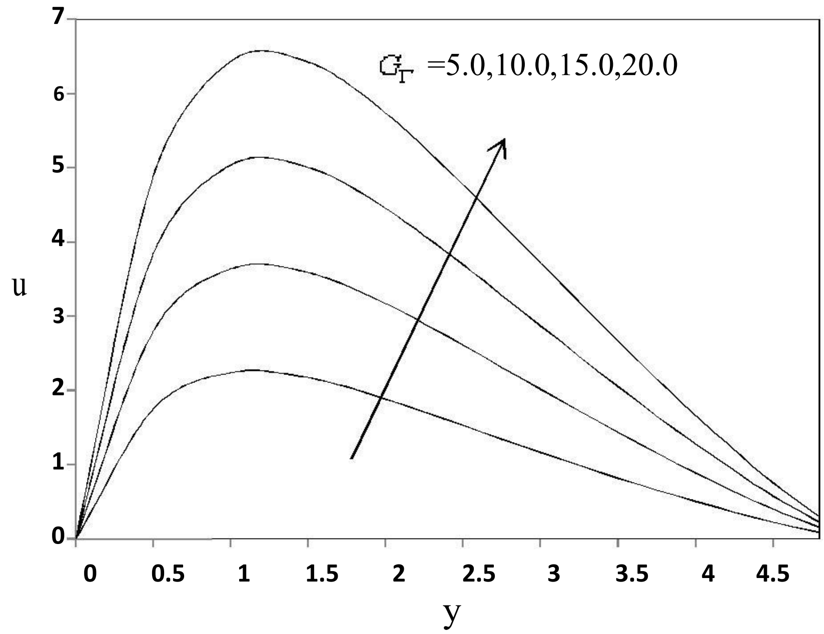

Fig.1. Velocity profile for different values of G_Γ

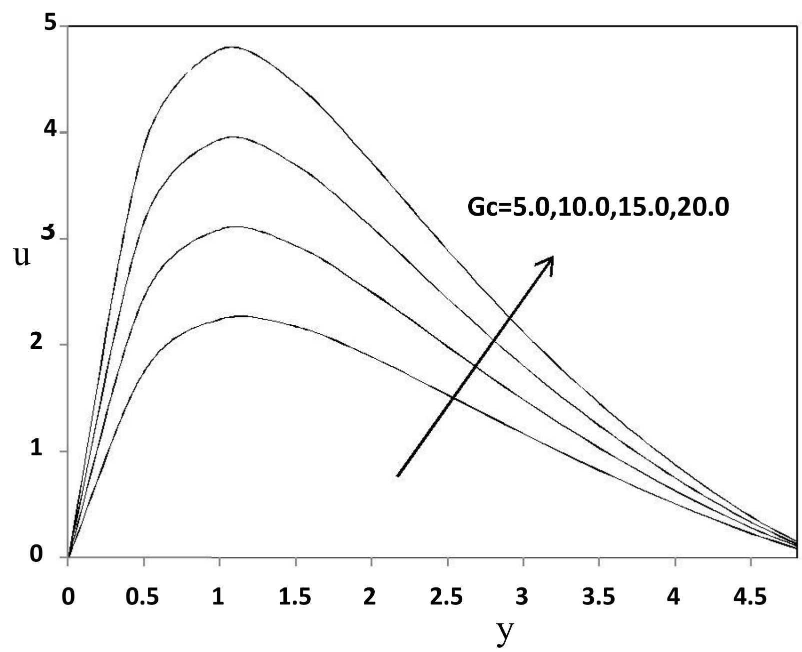

Fig.2. Velocity profile for different values of Gc

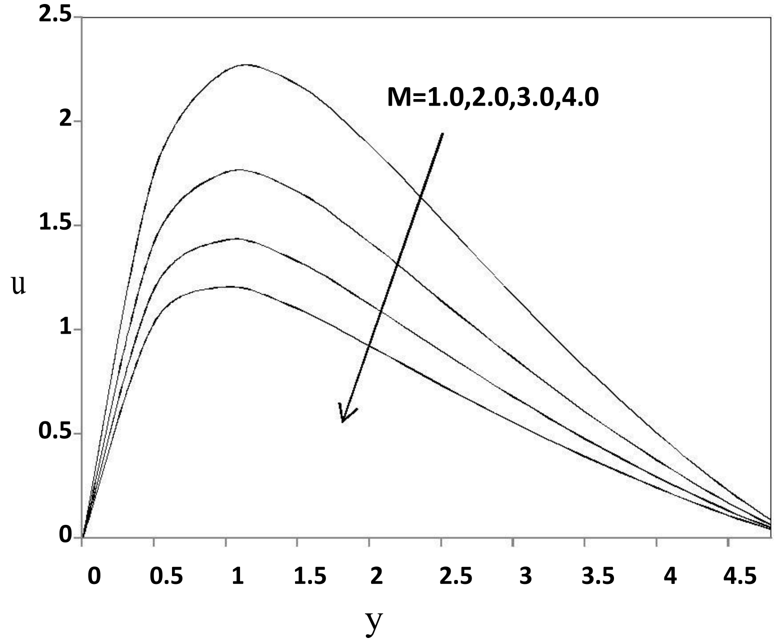

Fig.3. Velocity profile for different values of M

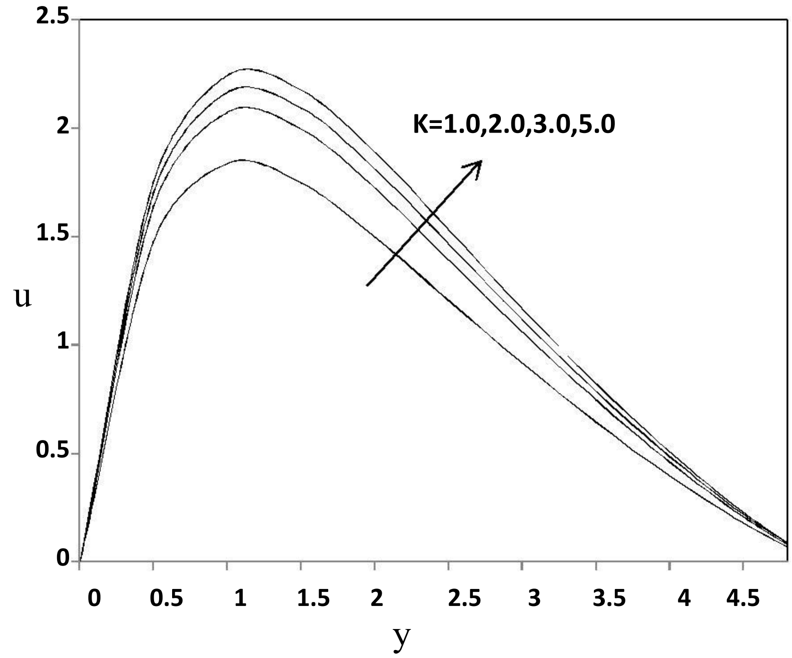

Fig.4. Velocity profile for different values of K

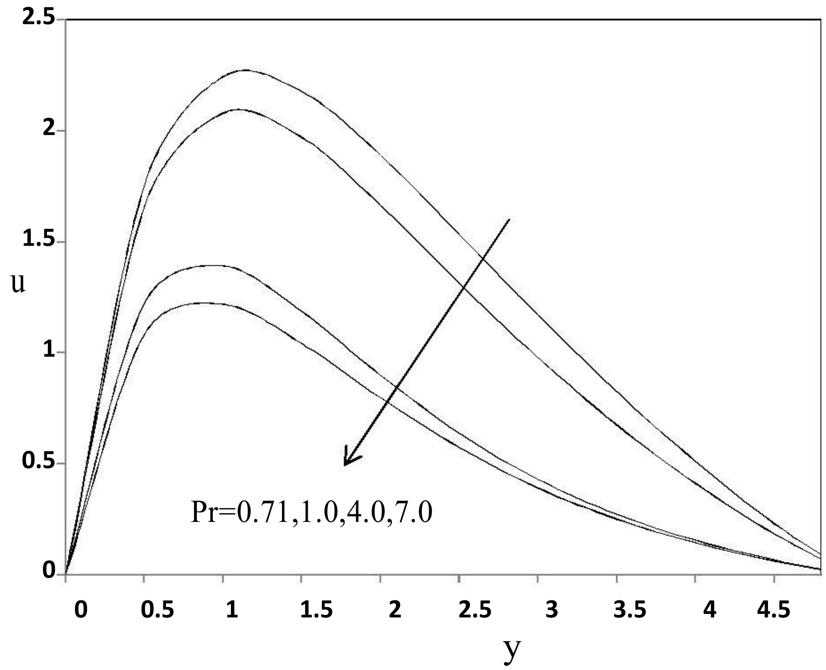

Fig. 5 (a). Velocity profile for different values of Pr

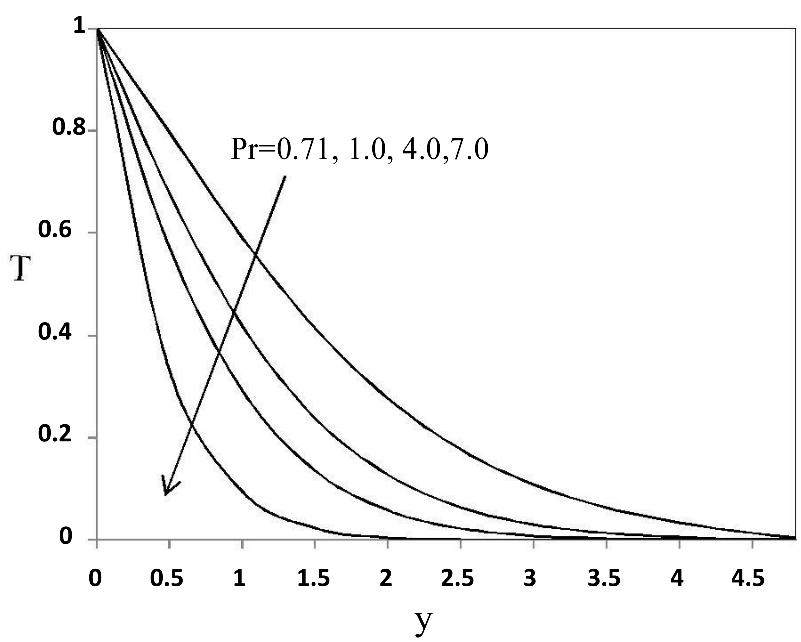

Fig. 5 (b). Temperature profile for different values of Pr

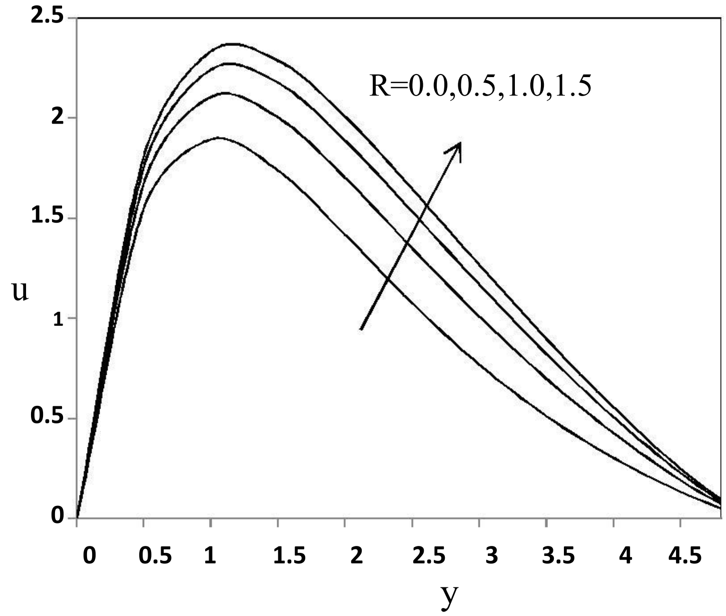

Fig. 6 (a). Velocity profile for different values of R

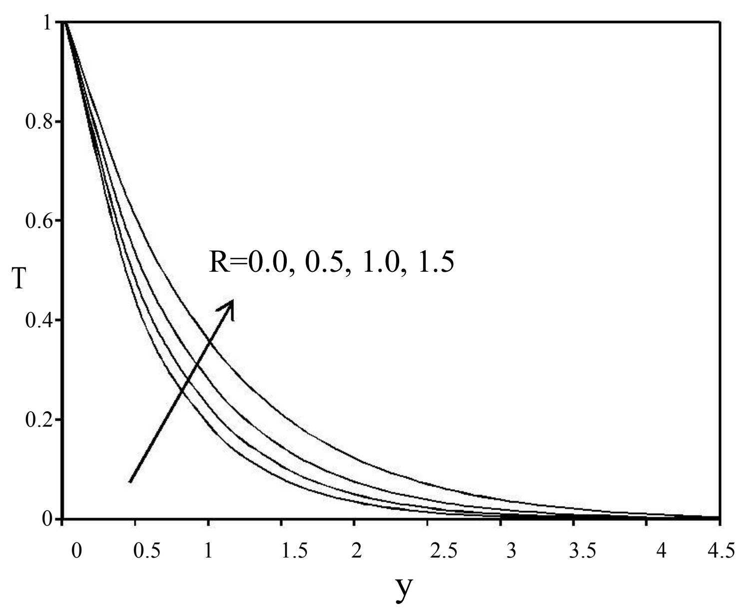

Fig. 6 (b). Temperature profile for different values of R

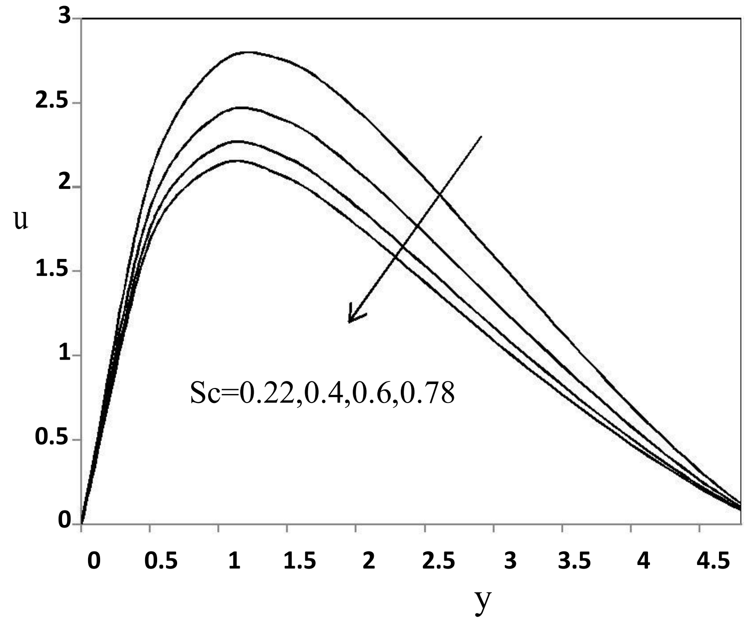

Fig. 7 (a). Velocity profile for different values of *Sc*

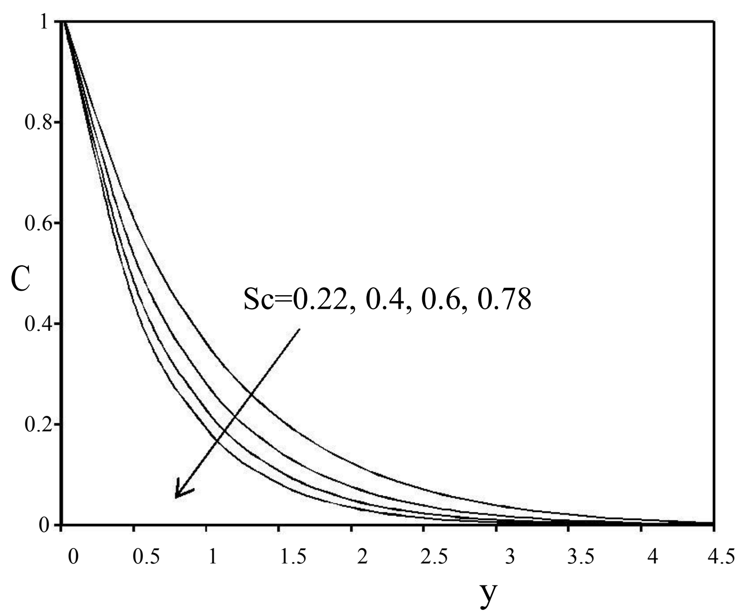

Fig. 7 (b). Concentration profile for different values of *Sc*

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

(R =1.0, Pr =0.71, Sc =0.6)

Gr	Gm	M	K	C_f
5.0	5.0	1.0	5.0	1.4562
10.0	5.0	1.0	5.0	1.8526
5.0	10.0	1.0	5.0	2.1261
5.0	5.0	2.0	5.0	0.6143
5.0	5.0	1.0	10.0	1.4265

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

(G_Γ =5.0, Gc=5.0, M =1.0, K =5.0, Sc =0.6)

R	Pr	C_f	Nu
1.0	0.71	1.4456	1.1419
2.0	0.71	1.5429	1.3654
1.0	7.0	1.2315	1.0946

Table 3: Effect of Sc on C_f and Sh

(G_Γ = 5.0, Gc= 5.0, M = 1.0, K =5.0, R = 1.0, Pr = 0.71)

Sc	C_f	Sh
0.22	1.4479	0.5654
0.60	1.1364	0.4429