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RADIATION AND CHEMICAL REACTION EFFECTS ON MHD MIXED CONVECTIVE FLOW OF A VERTICAL SURFACE WITH OHMIC HEATING AND VISCOUS DISSIPATION

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ABSTRACT

We consider the radiation and chemical reaction effects on MHD mixed convective heat and mass transfer flow past a vertical surface under the influence of Ohmic and viscous dissipation. The governing system of partial differential equations is transformed to dimensionless equations using dimensionless variables. The dimensionless equations are then solved analytically using perturbation technique. The various parameters entering into the problem on the dimensionless velocity, temperature and concentration fields within the boundary layer are discussed and the skin-friction coefficient, the Nusselt number and Sherwood number are presented numerically in tabular form also explained qualitatively.

Keywords: *Mixed convective flow; MHD; Ohmic heating; viscous dissipation; Radiation; Chemical reaction.*

1. INTRODUCTION

The study of boundary layer flow heat and mass transfer over an inclined plate has generated much interest from astrophysical, renewable energy systems and also hypersonic aerodynamics researchers for a number of decades. In recent years, MHD flow problems have come in view of its significant applications in industrial manufacturing processes such as plasma studies, petroleum industries, Magneto hydrodynamics, power generator cooling of clear reactors and boundary layer control in aerodynamics. Many authors have studied the effects of magnetic fields on mixed, natural and force convection, heat and mass transfer problems. Heat transfer considerations arise due to chemical reactions and often due to the very nature of the process. MHD free convection fluid-flows frequently occur in natural world. Fluid passing through porous medium is of great interest nowadays and many researchers are attracted towards the applications in the fields of science and technology, namely in the area of agriculture engineering to know about ground water resources, in technology to study the moment of natural gas, oil, and water through the oil reservoirs. The effects of mixed convection unsteady stagnation point flow of a viscous fluid, with a variable free stream velocity. The mass transfer effects on unsteady flow past an accelerated vertical porous plate have been noticed by Das *et al.* [1]. Sattar [2] has investigated the free convection and mass transfer flow, past an infinite vertical porous plate with time dependent temperature and concentration. Chen *et al.* [3] examined heat and mass transfer in MHD flow by natural convection from a permeable, inclined surface with variable wall temperature and concentration**.** Masood *et al.* [4] used HAM to formulate the MHD mixed convection Falkner–Skan flow with convective boundary conditions. The MHD conjugative heat transfer problem from vertical surfaces embedded in saturated porous media was discussed by Duwairi and Al-Kablawi [5]. Nasir Uddin *et al.* [6] discovered the effect of conjugate heat and mass transfer on magneto hydrodynamic mixed convective flow past inclined plate in a porous medium. The skin friction in the MHD mixed convection stagnation point with mass transfer was studied by Abdelkhalek [7].The number of investigations of natural convection flow with thermal radiation has increased greatly during the past few decades due to its importance in many practical situations. When natural convection flows occur at high temperature, radiation effects on the fluid flow become significant. Radiation effects on the natural convection flow are important in the context of furnace design, electric power generation, thermo-nuclear fusion, glass production, casting and levitation,

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plasma physics, cosmic flights, propulsion systems, solar power technology, spacecraft re-entry, aerothermodynamics, etc., It is worth noting that unlike convection/conduction, the governing equations taking into account the effects of radiation become quite complicated. Hence, many difficulties arise while solving such equations. However, some reasonable approximations are proposed to solve the governing equations with radiative heat transfer.

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] investigated 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. Suneetha [9] noticed the problem of radiation and mass transfer effects on MHD free convection flow past an impulsively started isothermal vertical plate with dissipation. Aydin and Kaya [10] proposed the MHD mixed convective heat transfer about a semi-infinite inclined plate in the presence of magneto and thermal radiation effects. Israel Cookey *et al.* [11] noticed the influence of viscous dissipation and radiation on unsteady MHD free convection flow past an infinite heated vertical plate in a porous medium with time dependent suction. Ogulu [12] examined the influence of radiation absorption on unsteady free convection and mass transfer flow of a polar fluid in the presence of uniform magnetic field. Rajesh [13] has investigated radiation effects on MHD free convection flow near a vertical plate with ramped wall temperature. Sivaiah *et al.* [14] noticed that the heat and mass transfer effects on MHD free convective flow past a vertical porous plate. Radiation effects on mixed convection along anisothermal vertical plate were investigated by Hossain and Takhar [15]. Raptis and Perdiki [16] discovered the effects of thermal radiation and free convection flow past a moving vertical plate.

In many chemical engineering processes, chemical reaction occurs between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications viz., polymer production, manufacturing of ceramics or glassware and food processing. The effect of chemical reaction on unsteady MHD flow through an impulsively started semi-infinite vertical plate was examined by Muthucumaraswamy *et al.* [17]. Sudhir Babu *et al.* [18] studied 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. Dulal Pal *et al.* [19] analyzed Perturbation Analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip, flow past a vertical permeable plate with thermal radiation and chemical reaction. The effect of radiation and chemical reaction on transient MHD free convective flow over a vertical plate through porous media was formulated by Sandeep *et al.* [20]. Recently, Kumar *et al.* [21] investigated effects of chemical reaction and radiation on MHD free convection flow past an exponentially accelerated vertical plate. Anjali Devi and Kandasamy [22] have discovered the effects of chemical reaction, heat and mass transfer on MHD flow past a semi-infinite plate. Ibrahim *et al.* [23] have examined the effects of the chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Effects of chemical reaction and radiation absorption on MHD flow of dusty viscoelastic fluid are analyzed by Prakash *et al.* [24]. The chemical and radiation absorption effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate with time dependent suction was proposed by Ramana Reddy *et al.* [25]. Sudheer Babu *et al.* [26] investigated the effects of thermal radiation and chemical reaction on MHD convective flow of a polar fluid past a moving vertical plate with viscous dissipation. Saritha and Satya Narayana [27] investigated thermal diffusion and chemical reaction effects on unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate. For the problem of coupled heat and mass transfer in MHD free convection, the effect of Ohmic heating has not been considered in the above investigations. However, it is more realistic to include this effect to explore the impact of the magnetic field on the thermal transport in the boundary layer. With this awareness, the effect of Ohmic heating on the MHD free convection heat transfer has been examined on a Newtonian fluid by Hossain [28]. Chaudhary *et al.* [29] have discovered the radiation effect with simultaneous thermal and mass diffusion in MHD mixed convection flow from a vertical surface with Ohmic heating. The effect of Ohmic heating on the MHD free convection heat transfer has been studied on a Newtonian fluid by Hossain [30]. The problem of combined heat and mass transfer of an electrically conducting fluid in MHD natural convection, adjacent to a vertical surface with Ohmic heating was analyzed by Chen [31]. The effect of Ohmic heating and viscous dissipation on MHD mixed convection heat and mass transfer about a vertical plate are analyzed by Aydin and Kaya [32]. Babu and Reddy [33] have discovered the mass transfer effects on MHD mixed convective flow from a vertical surface with ohmic heating and viscous dissipation. Sibanda and Makinde [34] proposed the effects of magnetic fields on heat transfer on a rotating disk in a porous medium with Ohmic heating and viscous dissipation.

For the problem of coupled heat and mass transfer in MHD free convection, the effect of both viscous dissipation and Ohmic heating are not studied in the above investigations. However, it is more realistic to include these two effects to explore the impact of the magnetic field on the thermal transport in the boundary layer. With this awareness, the effect of Ohmic heating on the MHD free convection heat transfer has been studied for a Newtonian fluid by Hossain [35].

2. FORMATION OF THE PROBLEM

We consider the mixed convection flow of an incompressible, electrically conducting viscous fluid such that x^* - axis which is taken along the plate in upward direction and y^* - axis is normal to it. A transverse constant magnetic field is applied in the direction y^* -axis. Since the motion is two dimensional and length of the plate is large therefore all the physical variables are independent of x^*. Let u^* and v^* be the components of velocity in x^* and y^* directions respectively, taken along and perpendicular to the plate. The governing equations of continuity, momentum and energy for a flow of an electrically conducting radiation is given by

$$\frac{\partial v^*}{\partial y^*} = 0 \Rightarrow v^* = -v_0 \,(\text{constant}) \tag{1}$$

$$\frac{\partial p^*}{\partial y^*} = 0 \Rightarrow P^* \text{ is independent of } y^* \tag{2}$$

$$\rho v^* \frac{\partial u^*}{\partial y^*} = \mu \frac{\partial^2 u^*}{\partial y^{*2}} + \rho g \beta \left(T^* - T_\infty^*\right) + \rho g \beta^* \left(C^* - C_\infty^*\right) - \sigma B_0^2 u^* - \frac{\vartheta u^*}{K^*} \tag{3}$$

$$\rho C_p v^* \frac{\partial T^*}{\partial y^*} = k \frac{\partial^2 T^*}{\partial y^{*2}} + \mu \left(\frac{\partial u^*}{\partial y^*}\right)^2 - \frac{\partial q_r^*}{\partial y^*} + \sigma B_0^2 u^{2*} \tag{4}$$

$$v^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - R^* \left(C^* - C_\infty^*\right) \tag{5}$$

Here, g is the due to gravity, T^* the temperature of the fluid near the plate, T_∞^* the free stream temperature, c^* -the concentration, β -the coefficient of thermal expansion, k the thermal conductivity, P^* the pressure, C_p the specific heat of constant pressure, B_0 the magnetic field coefficient, μ the viscosity of the fluid, q_r^* the radiative heat flux, ρ the density, σ the magnetic Permeability of the fluid, v_0 -the constant suction velocity, v the kinematic viscosity and D molecular diffusivity.

The radiative heat flux is given by

$$\frac{\partial q_r}{\partial y^*} = 4\left(T^* - T_\infty^*\right) I' \tag{6}$$

where $\int_0^\infty K_{\lambda w} \left(\frac{de_{b\lambda}}{dT^*}\right)_w d\lambda,\ K\lambda w$ is the absorption coefficient at wall and $e_{b\lambda}$ is Planck's function.

The boundary conditions are

$$u^* = 0,\ T^* = T_w,\ C^* = C_w \ y^* = 0$$
$$u^* \to 0,\ T^* \to T_\infty,\ C^* \to C_\infty \ y^* \to \infty \tag{7}$$

Introducing the following non–dimensional quantities are

$$u = \frac{u^*}{v_0},\ y = \frac{v_0 y^*}{\vartheta},\ \theta = \frac{T^* - T_\infty^*}{T_w - T_\infty},\ C = \frac{C^* - C_\infty^*}{C_w - C_\infty},\ \Pr = \frac{\mu c_p}{k},\ Sc = \frac{\vartheta}{D},$$
$$Gr = \frac{g\beta\vartheta(T_w - T_\infty)}{v_0^3},\ Gm = \frac{g\beta^*\vartheta(C_w - C_\infty)}{v_0^3},\ M = \frac{\sigma B_0^2 \vartheta}{\rho v_0^2},\ K = \frac{v_0^2 K^* \rho}{\vartheta^2},$$
$$E = \frac{v_0^2}{C_p\left(T_w - T_\alpha\right)},\ F = \frac{4I'\vartheta}{\rho c_p v_0^2},\ Kr = \frac{\vartheta R^*}{v_0^2} \tag{8}$$

The non-dimensional form of the governing Eqs. (3) - (5) reduce to

$$u'' + u' - \left(M + \frac{1}{K} \right) u = -\left[GrT + GmC \right] \tag{9}$$

$$T'' + \Pr T' - F \Pr T + \Pr E(u')^2 + \Pr EMu^2 = 0 \tag{10}$$

$$C'' + ScC' - ScKrC = 0 \tag{11}$$

where *Gr* is the Grashof number, *Gm* – the modified Grashof number, *Pr* - the Prandtl number, *F*- the radiation parameter, *Sc*- the Schmidt number, *E*-the Eckert number, *M*-the magnetic parameter, *Kr*-the chemical reaction.

The corresponding boundary conditions in dimension less form are reduced to

$$\begin{aligned} &u = 0, T = 1, C = 1 \quad \text{at} \quad y = 0 \\ &u \to 0, T \to 0,\ C \to 0, \quad \text{as} \ y \to \infty \end{aligned} \tag{12}$$

The physical variable *u, T* and *C* can expand in the power of Eckert number €. This can be possible physically as E for the flow of an incompressible fluid is always less than unity. It can be interpreted physically due to the Ohmic dissipation which is improved on the main flow.

3. SOLUTION OF THE PROBLEM

To reduce the above system of partial differential equations to the system of ordinary differential equations in a dimension less from, we may represent the translational velocity, temperature and concentration as

$$\begin{aligned} u(y) &= u_0(y) + Eu_1(y) + O(E^2) \\ T(y) &= T_0(y) + ET_1(y) + O(E^2) \\ C(y) &= C_0(y) + EC_1(y) + O(E^2) \end{aligned} \tag{13}$$

Using equation (13) in equation (9) - (11) and equating the Coefficient of like power of E, we have

$$u_0'' + u_0' - n_1 u_0 = -GrT_0 - GmC_0 \tag{14}$$

$$T_0'' + \Pr T_0' - F \Pr T_0 = 0 \tag{15}$$

$$C_0'' + ScC_0{}' - ScKrC_0 = 0 \tag{16}$$

$$u_1'' + u_1' - n_1 u_1 = -GrT_1 - GmC_1 \tag{17}$$

$$T_1'' + \Pr T_1' - E \Pr T_1 + \Pr\left(u_0'\right)^2 + \Pr Mu_0{}^2 = 0 \tag{18}$$

$$C_1'' + ScC_1{}' - ScKrC_1 = 0 \tag{19}$$

The corresponding boundary conditions are

$$\begin{aligned} &u_0 = 0, u_1 = 0, T_0 = 1, T_1 = 0, C_0 = 1, C_1 = 0 \quad \text{at} \quad y = 0 \\ &u_0 \to 0, u_1 \to 0, T_0 \to 0, T_1 \to 0, C_0 \to 0, C_1 \to 0 \quad \text{as} \ y \to \infty \end{aligned} \tag{20}$$

Solving equations (15)-(19) with the help of (20), we get

$$u_0(y) = A_3 e^{-m_4 y} - A_1 e^{-m_3 y} - A_2 e^{-m_1 y} \tag{21}$$

$$u_1(y) = A_{18} e^{-m_6 y} - A_{11} e^{-m_5 y} + A_{12} e^{-2m_4 y} + A_{13} e^{-2m_3 y} + A_{14} e^{-2m_1 y} - A_{15} e^{-(m_4+m_3)y} + A_{16} e^{-(m_1+m_3)y} - A_{17} e^{-(m_1+m_4)y} \tag{22}$$

$$T_0 = e^{-m_3 y} \tag{23}$$

$$T_1 = A_{10} e^{-m_5 y} - A_4 e^{-2m_4 y} - A_5 e^{-2m_3 y} - A_6 e^{-2m_1 y} + A_7 e^{-(m_3+m_4)y} - A_8 e^{-(m_1+m_3)y} + A_9 e^{-(m_1+m_4)y} \tag{24}$$

$$C_0 = e^{-m_1 y} \tag{25}$$

$$C_1 = 0 \tag{26}$$

Substituting equations (21)-(26) in Equation (13), we obtain the velocity, Temperature and concentration distribution in the boundary layer as follows:

$$u\left(y,t\right)=\left[A_3e^{-m_4y}-A_1e^{-m_3y}-A_2e^{-m_1y}\right]+E\begin{bmatrix}A_{18}e^{-m_6y}-A_{11}e^{-m_5y}+A_{12}e^{-2m_4y}+A_{13}e^{-2m_3y}\\+A_{14}e^{-2m_1y}-A_{15}e^{-(m_4+m_3)y}+A_{16}e^{-(m_1+m_3)y}-A_{17}e^{-(m_1+m_4)y}\end{bmatrix} \tag{27}$$

$$T\left(y,t\right)=\left(e^{-m_3y}\right)+E\begin{bmatrix}A_{10}e^{-m_5y}-A_4e^{-2m_4y}-A_5e^{-2m_3y}-A_6e^{-2m_1y}\\+A_7e^{-(m_3+m_4)y}-A_8e^{-(m_1+m_3)y}+A_9e^{-(m_1+m_4)y}\end{bmatrix} \tag{28}$$

$$C\left(y,t\right)=e^{-m_1y} \tag{29}$$

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

Skin Friction:
The non-dimensional skin friction at the plate is given by:

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}$$

$$\tau=\left(-m_4A_3+A_1m_3+m_1A_2\right)+E\begin{pmatrix}-m_6A_{18}+A_{11}m_5-2m_4A_{12}-2m_3A_{13}-2A_{14}m_1\\+(m_3+m_4)A_{15}-(m_1+m_3)A_{16}+(m_4+m_1)A_{17}\end{pmatrix} \tag{30}$$

Nusselt Number:
The non- dimensional form of the rate of heat transfer in terms of Nusselt number at the plate is given by:

$$Nu=-\left(\frac{\partial T}{\partial y}\right)_{y=0}$$

$$Nu=m_3-E\begin{pmatrix}-m_5A_{10}+2A_4m_4+2m_3A_5+2m_1A_6\\-\left(m_3+m_4\right)A_7+\left(m_1+m_3\right)A_8-\left(m_4+m_1\right)A_9\end{pmatrix} \tag{31}$$

Sherwood Number:
The non- dimensional form of the rate of heat transfer in terms of Sherwood number at the plate is given by:

$$Sh=-\left(\frac{\partial C}{\partial y}\right)_{y=0}$$

$$Sh=m_1 \tag{32}$$

RESULTS AND DISCUSSION

The system of ordinary differential equations (14) - (19) with boundary conditions (20) is solved analytically by employing the perturbation technique. The solutions are obtained for the velocity fields from (21) - (22), temperature fields from (23) - (24), and concentration fields are given by (25) - (26). To assess the physical depth of the problem the effects of various parameters like Grashof number *Gr*, modified Grashof number *Gm*, magnetic parameter *M*, porosity parameter *K*, Prandtl number *Pr*, Eckert number *E*, Schmidt number *Sc*, Chemical reaction *Kr*, Radiation parameter *F*,on velocity distribution, temperature distribution and concentration distribution are studied in figures 1-8, while keeping the other parameters as constants. The variation in Skin friction, the rate of mass transfer in the form of Sherwood number studied through the following default parameter values are adopted Gr=5.0, *Gm*=2.0, *M*=2.0, *K*=1.0, *Pr*=0.71, *E*=0.001, *Sc* = 0.22, *K*r=1.0, *F*=3.0.

Figure. 1 depicts the velocity profile *u* against *y* for different values of Grashof number *Gr* and modified Grashof number *Gm*. From this, we observe that as Grashof number *Gr* increases, velocity field *u* increases, modified Grashof number *Gm* increases and velocity field *u* increases.

The effects of the magnetic parameter *M* and porosity parameter *K* on the dimensionless velocity is shown in the Figure 2. It is obvious that an increase in magnetic parameter *M* results in a decrease in the velocity. For different values of porosity parameter *K,* it can be seen that the velocity profile increase with the increase of permeability parameter *K.*

Figure 3&6 show the dimensionless velocity and temperature profiles for different values of Prandtl number *Pr*. It can be seen that both velocity and the temperature profiles decrease with the increase of Prandtl number *Pr.*

In figure 4, it exhibits the velocity profiles for various value of chemical reaction parameter *Kr*, Schmidt number *Sc.* From this figure, it is observed that velocity decreases with increases in chemical reaction *Kr*, and the velocity increases with a decrease in Schmidt number *Sc*. Figure 8 illustrates the effects of chemical reaction *Kr*, Schmidt number *Sc* on the concentration profile. It is seen from these figures that there is a steady decrease in the concentration with the increase in chemical reaction *Kr*, and there is a decrease in the velocity with the increase in Schmidt number *Sc*.

Effects of Eckert number *E* and Radiation parameter *F* on velocity and temperature profiles are studied from figure 5&7. From these figures, it is observed that velocity and temperature profiles decrease as Radiation parameter *F* increases and it can be seen that both velocity and the temperature profiles increase with the increase of Eckert number *E*.

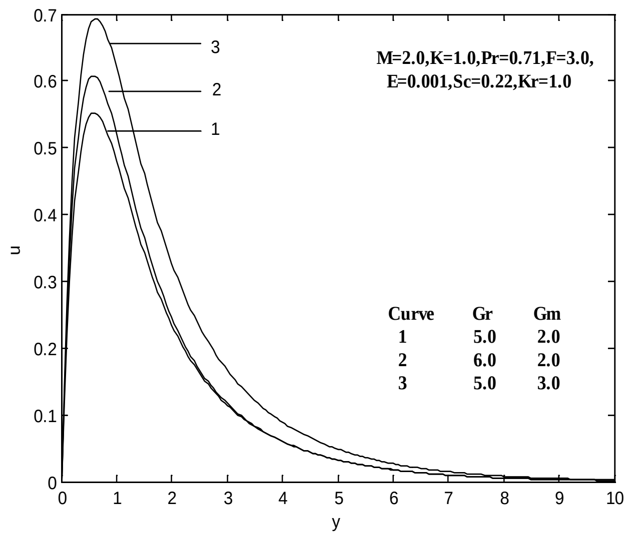

Figure-1: Velocity profiles for different values of *Gr* and *Gm.*

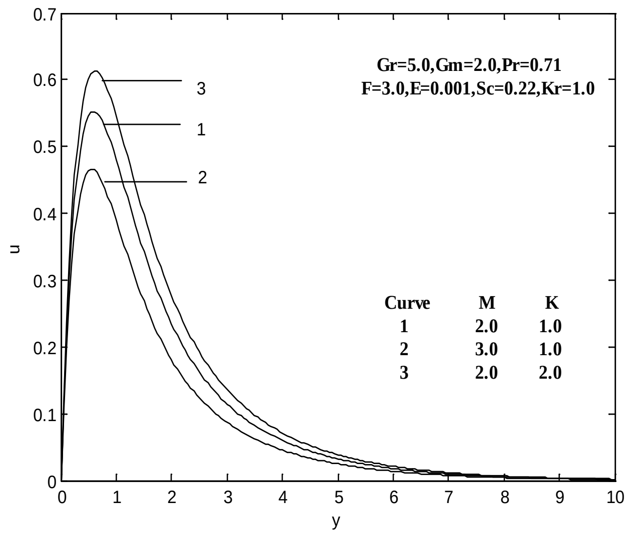

Figure-2: Velocity profiles for different values of *K* and *M*

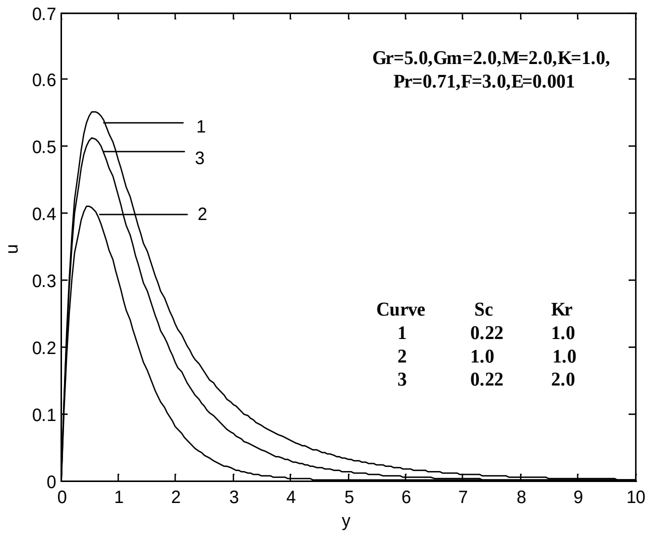

Figure-3: Velocity profiles for different values of *Sc*and *Kr*

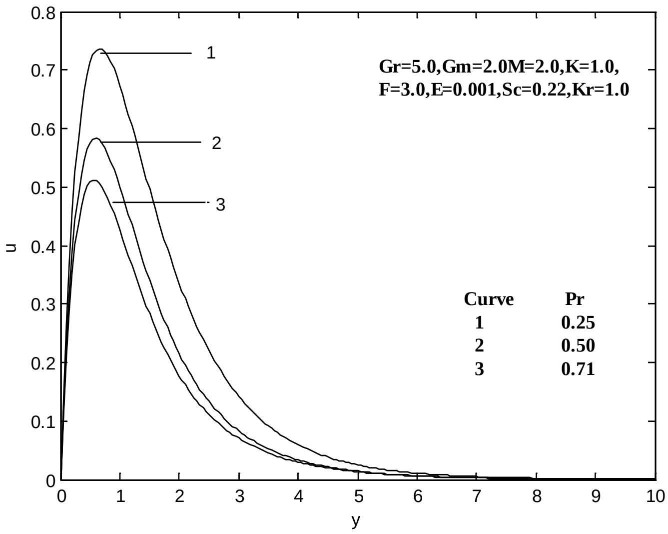

Figure-4: Velocity profile for different values of *Pr*

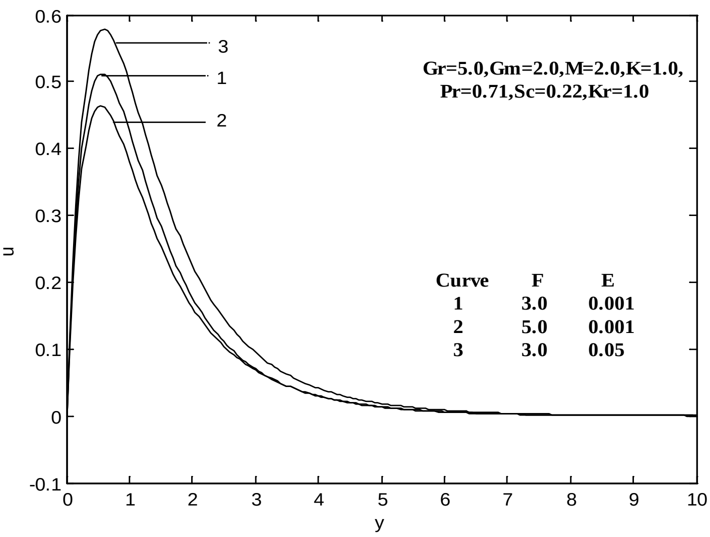

Figure-5: Velocity profiles for different values of *F* and *E*

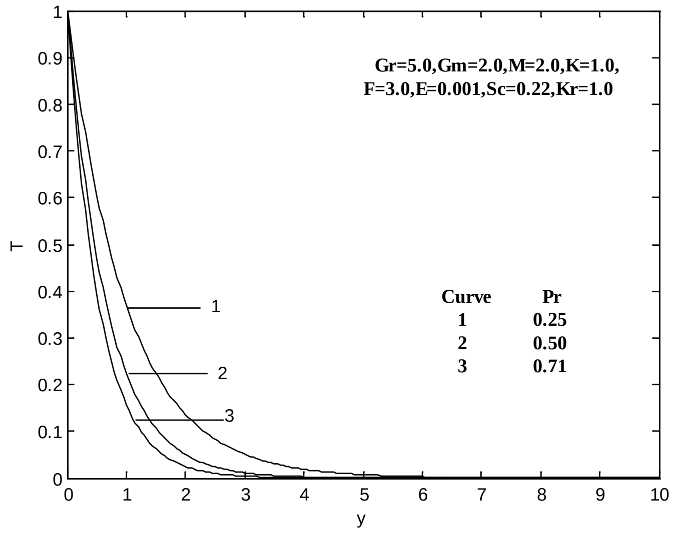

Figure-6: Temperature profile for different values of *Pr*

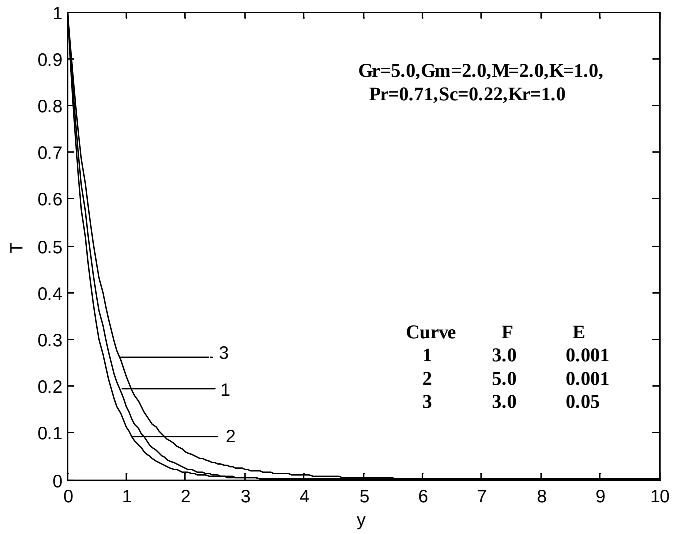

Figure-7: Temperature profiles for different values of *F* and *E*

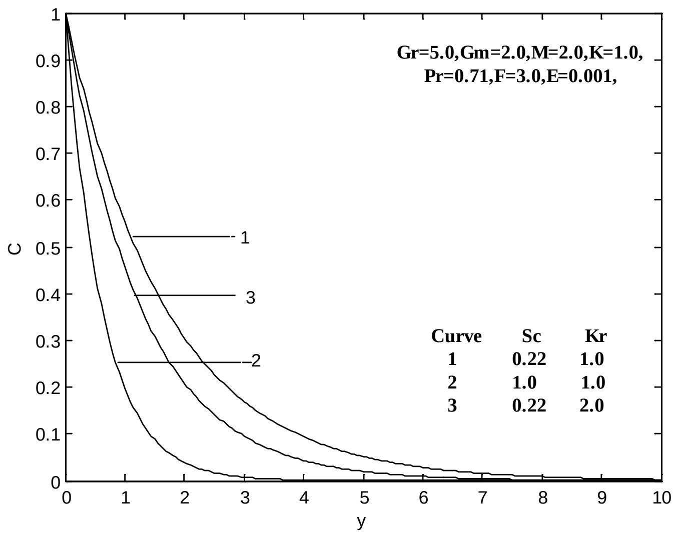

Figure-8: Concentration profiles for different values of *Sc*and *Kr*

Table-1: Numerical values of the Skin-friction (*Cf*), Nusselt number (*Nu*) and Sherwood number (*Sh*) for *Gr*, *Gc*, *M*, *K*.

Gr	*Gc*	*M*	*K*	*Cf*	*Nu*	*Sh*
5.0	2.0	2.0	1.0	2.6422	1.8493	0.5918
1.0	2.0	2.0	1.0	1.3724	1.8548	0.5918
3.0	2.0	2.0	1.0	2.0067	1.8521	0.5918
5.0	**1.0**	2.0	1.0	2.1122	1.8532	0.5918
5.0	**1.5**	2.0	1.0	2.3772	1.8513	0.5918
5.0	2.0	**1.0**	1.0	3.0238	1.8299	0.5918
5.0	2.0	**1.5**	1.0	2.8080	1.8450	0.5918
5.0	2.0	2.0	**0.3**	2.1597	1.8548	0.5918
5.0	2.0	2.0	**0.5**	2.3932	1.8531	0.5918

Table-2: Numerical values of the Skin-friction (*Cf*), Nusselt number (*Nu*) and Sherwood number (*Sh*) for *Pr*, *F*, *E*.

Pr	*F*	*E*	*Cf*	*Nu*	*Sh*
0.71	3.0	0.001	2.6422	1.8493	0.5918
0.25	3.0	0.001	3.2304	0.9961	0.5918
0.50	3.0	0.001	2.8430	1.4950	0.5918
0.71	**1.0**	0.001	3.0033	1.2639	0.5918
0.71	**2.0**	0.001	2.7827	1.5924	0.5918
0.71	3.0	**0.01**	2.6790	1.7800	0.5918
0.71	3.0	**0.05**	2.8363	1.4765	0.5918

Table-3: Numerical values of the Skin-friction (*Cf*), Nusselt number (*Nu*) and Sherwood number (*Sh*) for *Sc*, *Kr*.

Sc	*Kr*	*Cf*	*Nu*	*Sh*
0.22	1.0	2.6422	1.8493	0.5918
0.6	1.0	2.4084	1.8488	1.1307
0.5	1.0	2.4549	1.8491	1
0.22	**0.3**	2.7688	1.8489	0.3895
0.22	**0.5**	2.7217	1.8491	0.4594

Tables (1), (2) and (3) show the numerical values of the skin friction (*Cf*), Nusselt number (*Nu*) and Shear wood number (*Sh*). The effects of where Grashof number *Gr*, modified Grashof number *Gm*, magnetic parameter *M*, porosity parameter *K*, Prandtl number *Pr*, Radiation parameter *F*, Eckert number *E* Schmidt number *Sc* and Chemical reaction *Kr* on the skin-friction(*Cf*), Nusselt number(*Nu*), Sherwood number (*Sh*)are shown in Tables 1 to 3.

From Table 1, it is noticed that as the skin-friction increases as Grashof number *Gr*, modified Grashof number *Gc*, porosity parameter *K* increases. Magnetic parameter *M* increases the skin-friction decreases. The Nusselt number decreases as Grashof number *Gr*, modified Grashof number *Gc*, porosity parameter *K* increases. Magnetic parameter *M* increases the Nusselt number also increases.

From the table 2 presents, it is observed that the Prandtl number *Pr*, Radiation parameter *F* increases skin-friction decreases, Nusselt number increases .Eckert number *E* increases and the skin-friction increase, Nusselt number decreases.

From the table 3 presents it is observed that the Schmidt number *Sc* increases the skin-friction and the Sherwood number also increases. Chemical reaction *Kr* increases the skin-friction and Nusselt number decreases but Sherwood number increases.

CONCLUSION

In this paper, we discussed the radiation and chemical reaction effects on MHD flow of a vertical surface in presence of ohmic heating and viscous dissipation has been studied. The governing equations are solved for the velocity field, temperature and concentration by using perturbation technique in terms of dimensionless parameters. In the analysis of the flow the following conclusions are made:

- The velocity increases with an increase in Grashof number *Gr* and modified Grashof number *Gc*.
- The velocity decreases with an increase in the magnetic parameter *M*.
- The velocity increases with an increase in the porosity parameter *K*.
- Increase the Prandtl number *Pr,* decreases the velocity and the temperature field.
- Increase the Radiation parameter *F,* decreases the velocity and the temperature field.
- An increase in the Eckert number *E* leads to increase in the velocity and the temperature field.
- The velocity as well as concentration decreases with an increase in the Schmidt number *Sc*and Chemical reaction *Kr*.

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APPENDIX

$$m_1 = \frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}, m_2 = \frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2}, m_3 = \frac{\Pr + \sqrt{\Pr^2 + 4F\Pr}}{2}\ m_4 = \frac{1 + \sqrt{1 + 4n_1}}{2},$$

$$m_5 = \frac{\Pr + \sqrt{\Pr^2 + 4E\Pr}}{2}, m_6 = \frac{1 + \sqrt{1 + 4n_1}}{2}, A_1 = \frac{Gr}{m_3^2 - m_3 - n_1}, A_2 = \frac{Gm}{m_1^2 - m_1 - n_1}, A_3 = A_1 + A_2$$

$$A_4 = \frac{A_3^2\left(m_4^2 + \Pr M\right)}{4m_4^2 - 2\Pr m_4 - E\Pr},\ n_1 = M + \frac{1}{K},\ A_5 = \frac{A_1^2\left(m_3^2 + \Pr M\right)}{4m_3^2 - 2\Pr m_3 - E\Pr},\ A_6 = \frac{A_2^2\left(m_1^2 + \Pr M\right)}{4m_1^2 - 2\Pr m_4 - E\Pr},$$

$$A_7 = \frac{2A_3A_1\left(m_4m_3 + \Pr M\right)}{\left(m_4+m_3\right)^2 - \Pr\left(m_4+m_3\right) - E\Pr},\ A_8 = \frac{2A_2A_1\left(m_1m_3 + \Pr M\right)}{\left(m_1+m_3\right)^2 - \Pr\left(m_1+m_3\right) - E\Pr},$$

$$A_9 = \frac{2A_3A_2\left(m_4m_1 + \Pr M\right)}{\left(m_4+m_1\right)^2 - \Pr\left(m_4+m_1\right) - E\Pr},\ A_{10} = A_4 + A_5 + A_6 - A_7 + A_8 - A_9,\ A_{11} = \frac{A_{10}Gr}{m_5^{\,2} - m_5 - n_1},$$

$$A_{12} = \frac{A_4Gr}{4m_4^{\,2} - 2m_4 - n_1},\ A_{13} = \frac{A_5Gr}{4m_3^{\,2} - 2m_3 - n_1},\ A_{14} = \frac{A_6Gr}{4m_1^{\,2} - 2m_1 - n_1},$$

$$A_{15} = \frac{A_7Gr}{\left(m_3+m_4\right)^2 - \left(m_3+m_4\right) - n_1},\ A_{16} = \frac{A_8Gr}{\left(m_3+m_1\right)^2 - \left(m_3+m_1\right) - n_1},$$

$$A_{17} = \frac{A_9Gr}{\left(m_1+m_4\right)^2 - \left(m_1+m_4\right) - n_1},\ A_{18} = A_{11} - A_{12} - A_{13} - A_{14} + A_{15} - A_{16} + A_{17},$$

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