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COMBINED CONSTANT HEAT AND MASS FLUX EFFECT ON MHD FREE CONVECTIVE FLOW THROUGH A POROUS MEDIUM BOUNDED BY A VERTICAL SURFACE IN PRESENCE OF CHEMICAL REACTION AND RADIATION

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Abstract

This paper presents the effects of radiation on a free convection flow bounded by a vertical surface embedded in porous medium with constant suction velocity under the influence of uniform magnetic field in the presence of a homogenous chemical reaction and viscous dissipation in detail considering in two cases viz. Case–I: Uniform plate Temperature and Uniform Concentration and Case–II: Constant heat flux and mass flux. The non-dimensional governing equations are solved analytically and the expressions for velocity, temperature, concentration fields are obtained. With the aid of the above, the expressions for skin friction, rate of heat and mass transfer are derived. The effects of various physical parameters on the above quantities have been discussed and analysed though graphs and tables. It is observed that in both the cases, the velocity decreases with increasing values of magnetic parameter M or radiation parameter F or chemical reaction parameter K_c or Prandtl number P_r.

Keywords: MHD, Free convection, Radiation, Chemical reaction and constant heat and mass flux.

1. INTRODUCTION

In nature, there exist flows which are caused not only by the differences in temperature but also by differences in concentration. These mass transfer differences do affect the rate of heat transfer. In industries, many transport process exist in which heat and mass transfer takes place simultaneously as a result of combined buoyancy effect of thermal diffusion and diffusion thermo chemical species. The phenomenon of heat and mass transfer frequently exists in chemically processed industries such as food processing and polymer production. Free convection flows are of great interest in a number of industrial applications such as fiber and granular insulation, geothermal systems etc. convection in porous media has applications in geothermal energy recovery, oil extraction, thermal energy storage and flow through filtering devices. Magnetohydrodynamics is now attracting the attention of the many authors due to its applications in geophysics; it is applied to study the stellar and solar structures, interstellar matter, radio propagation through the ionosphere etc. In engineering in MHD pumps, MHD bearings etc. at high temperatures attained in some engineering devices, gas, for example, can be ionized and so becomes an electrical conductor. The ionized gas or plasma can be made to interact with the magnetic and alter heat transfer and friction characteristic. Since some fluids can also emit and absorb thermal radiation, it is of interest to study the effect of magnetic field on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and absorbing thermal radiation. This is of interest because heat transfer by thermal radiation is becoming of greater importance when we are concerned with space applications and higher operating temperatures. The effects of transversely magnetic field, on the flow of an electrically conducting fluid past an immpulsively started infinite isothermal vertical plate studied by Soundalgekar *et al*. [1]. Again, Soundalgekar and Takhar [2] studied the effect of radiation on the natural convection flow of a gas past a semi-infinite plate using the Cogly-Vincentine-Gilles equilibrium model. For the same gas Takhar *et al*. [3] investigated the effect of radiation on the MHD free convection flow past a semi-infinite vertical plate. Later, Hossain *et al*. [4] studied the effect of radiation on free convection from a porous vertical plate. Muthucumarswamy and Kumar [5] examined the thermal radiation effects on moving infinite vertical plate in presence of variable temperature and mass diffusion. An analytical solution for unsteady free convection in porous media has been studied by Magyari *et al*. [6]. Chamkha *et al*. [7] investigated the effects of Hydro magnetic combined heat and mass transfer by natural convection from a permeable surface embedded in a fluid saturated porous medium. Mazumdar and Deka [8] studied MHD flow past an impulsively started infinite vertical plate in presence of thermal radiation.

The growing need for chemical reactions in chemical and hydrometallurgical industries require the study of heat and mass transfer with chemical reaction. The presence of a foreign mass in a fluid such as water or air causes some kind of chemical reaction. This may be present either by itself or as mixtures with air or water. In many chemical engineering processes, a chemical reaction occurs between a foreign mass and the fluid in which the plate is moving. These processes take place in numerous industrial applications, for example, polymer production, manufacturing of ceramics or glassware and food processing. Generally a chemical reaction processes can be codified as either a homogenous or heterogeneous. This depends on whether it occurs on an interface or a single phase volume reaction. A reaction is said to be of first order if its rate is directly proportional to the concentration itself [Cussler 9]. The effect of chemical reaction on heat and mass transfer in a laminar boundary layer flow has been studied under different conditions by several authors [10-19]. The effect of a chemical reaction on a moving isothermal vertical surface with suction has been studied by Muthucumarswamy [20]. Recently, Manivannan *et al*. [21] investigated radiation and chemical reaction effects on isothermal vertical oscillating plate with variable mass diffusion. Influence of chemical reaction and radiation on unsteady MHD free convection flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in the presence of heat source was investigated by Sharma *et al*. [22]. Vasu *et al.* [23] studied radiation and mass transfer effects on transient free convection flow of a dissipative fluid past semi-infinite vertical plate with uniform heat and mass constant flux. Saravana *et al*. [24] examined mass transfer effects on MHD viscous flow past an impulsively started infinite vertical plate with constant mass flux. O.D.Makinde [25] studied on MHD boundary-layer flow and mass transfer past a vertical plate in a porous medium with constant heat flux. Recently, Mahapatra *et al* [26] investigated the effects of chemical reaction on a free convection flow through a porous medium bounded by a vertical infinite surface.

In this paper, we have made an attempt to study the radiation effects on MHD free convection flow through porous medium bounded by a vertical surface in presence of homogeneous chemical reaction. The solutions are obtained for velocity, temperature and concentration profiles using a perturbation technique.

2. NOMENCLATURE

u^*, v^* : Velocity components in x and y directions
u : Non- dimensional velocity
v_0 : Suction velocity
C : Non-dimensional fluid concentration
C^* : Concentration
C_∞ : Fluid concentration far away from the wall
T : Non-dimensional fluid temperature
T^* : Temperature in the fluid
T_∞ : Fluid temperature for away from the wall
c_p : Specific heat at a constant pressure
D : Mass diffusivity
E : Eckert number
G_m : Mass Grashof number
G_r : Thermal Grashof number
g : Acceleration due to gravity
k : Permeability coefficient of a porous medium
K_c : Non- dimensional rate of chemical reaction
K_c^* : Rate of chemical reaction
k^* : Permeability parameter of porous mediu
Nu :Nusselt number
P_r : Prandtl number
S_c : Schmidt number
F : Radiation parameter
$K_{\lambda w}$: Absorption coefficient
$e_{b\lambda}$: Planck function
M : Magnetic parameter
Sh : Non- dimensional Sherwood number
q_r :Radiative heat flux
q_w^* : Mass flux per unit area
q : Heat flux per unit area at theplate

Greek symbols

κ : Thermal conductivity
Y : Kinematic viscosity
θ : Dimensionless temperature
σ : Electrical conductivity
μ : Dynamic viscosity
β_T :Coefficient of volume expansion
β_c : Coefficient of volume expansion with concentration
ρ : Fluid density
τ : Non-dimensional skin friction

3. FORMULATION OF THE PROBLEM

In this problem we consider a viscous incompressible, radiating and electrically conducting fluid through a porous medium occupying a semi-infinite region of the space bounded by a vertical infinite surface discussed in two cases viz. Case (I): uniform temperature and concentration. Case (II): Constant heat and mass flux. In both cases, the x^* - axis is taken along the plate in vertical upward direction and the y^* - axis normal to it. A uniform magnetic field of strength B_0 is assumed to be applied in a direction perpendicular to the surface against to the gravitational field. Apart from this we made the following assumptions

- The fluid properties are assumed to be constant except the influence of the body force term.
- A chemically reactive species is emitted from the vertical surface into a hydrodynamic flow field. It diffuses into the fluid, where it under goes a homogenous chemical reaction that is assumed to take place entirely in the stream.
- As the plate is infinite in extent, all the physical variables are functions of y alone.
- The magnetic Reynolds number is assumed to be very small so the induced magnetic field is neglected.
- A uniform, isotropic porous medium is considered and it is in thermal equilibrium with the plate.

Then by usual Boussinesq's approximation the fully developed flow under the above assumptions is governed by the following set of equations

Continuity equation:

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

Momentum equation:

$$v^*\frac{\partial u^*}{\partial y^*} = \vartheta\frac{\partial^2 u^*}{\partial y^{*2}} + g\beta_T(T^* - T_\infty^*) + g\beta_C(C^* - C_\infty^*) - \frac{\sigma B_0^2}{\rho}u^* - \frac{\vartheta}{k^*}u^* \tag{2}$$

Energy equation:

$$v^*\frac{\partial T^*}{\partial y^*} = \frac{\kappa}{\rho C_P}\frac{\partial^2 T^*}{\partial y^{*2}} + \frac{\vartheta}{C_P}\left(\frac{\partial u^*}{\partial y^*}\right)^2 - \frac{1}{\rho C_P}\frac{\partial q_r}{\partial y^*} \tag{3}$$

Concentration equation:

$$v^*\frac{\partial C^*}{\partial y^*} = D\frac{\partial^2 C^*}{\partial y^{*2}} - k_c(C^* - C_\infty^*) \tag{4}$$

It is assumed that the level of species concentration is very low; hence the heat generated due to chemical reaction is neglected. The relevant boundary conditions are given as follows.

Case I: Uniform Temperature and Concentration

$$u^* = 0, \quad T^* = T_W, \quad C^* = C_W \quad \text{at } y = 0$$

$$u^* \to 0, \quad T^* \to T_\infty, \quad C^* \to C_\infty \text{ as } y \to \infty \tag{5}$$

Case II:Constant heat and mass flux

$$u^* = 0, \quad \frac{\partial T^*}{\partial y^*} = -\frac{q}{k}, \quad \frac{\partial C^*}{\partial y^*} = -\frac{q_w}{D} \quad \text{at } y = 0$$

$$u^* \to 0, \quad T^* \to T_\infty, \quad C^* \to C_\infty \text{ as } y \to \infty \tag{6}$$

Equation (1) gives that $v^* = constant = -v_0$ (7)

In the optically thick limit, the fluid does not absorb its own emitted radiation but it absorbs radiation emitted by the bounadries. Cookey et al. [26] showed that in the optically thick limit for a non gray gas near equilibrium as given below.

$$\frac{\partial q_r}{\partial y^*} = 4(T^* - T_w^*)\int_0^\infty K\lambda_w w\left(\frac{de_{b\lambda}}{dT^*}\right)/d\lambda = 4I_1(T^* - T_w^*) \tag{8}$$

On introducing the following non - dimensional quantities:

$$y=\frac{v_0 y^*}{v},\ u=\frac{u^*}{v_0},\ \theta=\frac{T^*-T_\infty^*}{T_W^{\ *}-T_\infty^*}, G_r=\frac{\vartheta g\beta_T(T_W^*-T_\infty^*)}{v_0^3},\ C=\frac{C^*-C_\infty^*}{C_W^{\ *}-C_\infty^*},\ \mathrm{P_r}=\frac{\mu c_p}{k},$$
$$S_c=\frac{\vartheta}{D},\ F=\frac{4I_1\vartheta}{kv_0^2},\ K_C=\frac{\vartheta K_C^{\ *}}{v_0^2}\ G_m=\frac{\vartheta g\beta_c(C_W^*-C_0^*)}{v_0^3},\ E=\frac{v_0^2}{C_P(T_0^*-T_w^*)},$$
$$M=\frac{\sigma B_0^2\vartheta}{\rho v_0^2},\ k=\frac{v_0^2 k^*}{\vartheta^2} \tag{9}$$

The governing equations in the dimensionless form are obtained from equations (2) to (4) as listed below

$$u''+u'=-G_r\theta-G_mC+M_1u \quad \text{where } M_1=M+\frac{1}{k} \tag{10}$$
$$\theta''+P_r\theta'=-P_rEu'^2+F\theta \tag{11}$$
$$C''+S_cC'=K_cS_cC \tag{12}$$

The corresponding boundary conditions are given by

Case I:

$$u=0, \theta=1, C=1 \qquad \text{at } y=0$$
$$u\to 0,\ \theta\to 0,\ C\to 0 \qquad \text{as } y\to\infty \tag{13}$$

Case II:

$$u=0, \frac{\partial\theta}{\partial y}=-1, \frac{\partial C}{\partial y}=-1 \qquad \text{at } y=0$$
$$u\to 0,\ \theta\to 0,\ C\to 0 \qquad \text{as } y\to\infty \tag{14}$$

4. SOLUTION OF THE PROBLEM

In order to solve the coupled nonlinear system of partial differential equations (11) to (13) with the boundary conditions (13) and (14), the following simple perturbation is used. The governing equations (10) to (12) are expanded in powers of Eckert number $E(<<1)$.

$$u=u_0+Eu_1+O(E^2),\ \theta=\theta_0+E\theta_1+O(E^2),\ C=C_0+EC_1+O(E^2) \tag{15}$$

Substituting equations (15) into equations (10) to (12) and equating the coefficients of the terms with the same powers of E, and neglecting the terms of higher order, the following equations are obtained.

Zeroth order terms:

$$u_0''+u_0'=-G_r\theta_0-G_mC_0+M_1u_0 \tag{16}$$
$$\theta_0''+P_r\theta_0'-F\theta_0=0 \tag{17}$$
$$C_0''+S_CC_0'=S_CK_CC_0 \tag{18}$$

First order terms:

$$u_1''+u_1'=-G_r\theta_1-G_mC_1+M_1u_1 \tag{19}$$

$$\theta_1'' + P_r\theta_1' - F\theta_1 = -\mathrm{P_r}\, u_0'^2 \tag{20}$$
$$C_1'' + S_C C_1' = S_C k_C C_1 \tag{21}$$

The relevant boundary conditions are given below

Case I:

$$u_0 = 0,\ \ u_1 = 0,\ \theta_0 = 1,\ \ \theta_1 = 0,\ C_0 = 1,\ \ C_1 = 0 \quad \text{at } y = 0$$
$$u_0 \to 0,\ \ u_1 \to 0, \theta_0 \to 0,\ \ \theta_1 \to 0, C_0 \to 0,\ \ C_1 \to 0 \text{ as } y \to \infty \tag{22}$$

Case II:

$$u_0 = 0,\ \ u_1 = 0, \frac{\partial\theta_0}{\partial y} = -1,\ \ \frac{\partial\theta_1}{\partial y} = 0, \frac{\partial C_0}{\partial y} = -1,\ \ \frac{\partial C_1}{\partial y} = 0$$
$$\text{at } y = 0\ u_0 \to 0,\ \ u_1 \to 0, \theta_0 \to 0,\ \ \theta_1 \to 0, C_0 \to 0,\ \ C_1 \to 0 \text{ as } y \to \infty$$
(23)

Solving equations (16) to (21) under the boundary conditions (22) and (23), the following solutions are obtained.

Case I:

$$C_0 = e^{-k_1 y} \tag{24}$$
$$C_1 = 0 \tag{25}$$
$$\theta_0 = e^{-k_2 y} \tag{26}$$
$$u_0 = (-k_3 - k_4)e^{-l_1 y} + k_3 e^{-k_2 y} + k_4 e^{-k_1 y} \tag{27}$$
$$\begin{aligned} u_1 &= k_{18}e^{-2k_2 y} + k_{19}e^{-2k_1 y} + k_{20}e^{-2l_1 y} + k_{21}e^{-l_2 y} + k_{22}e^{-l_3 y} \\ &+ k_{23}e^{-l_4 y} + k_{24}e^{-l_6 y} + k_{25}e^{-k_1 y} - k_{26}e^{-l_7 y} \end{aligned} \tag{28}$$
$$\begin{aligned} \theta_1 &= k_{11}e^{-2k_2 y} + k_{12}e^{-2k_1 y} + k_{13}e^{-2l_1 y} + \\ & k_{14}e^{-l_2 y} + k_{15}e^{-l_3 y} + k_{16}e^{-l_4 y} - k_{17}e^{-l_6 y} \end{aligned} \tag{29}$$
$$\theta = e^{-k_2 y} + E\begin{pmatrix} k_{11}e^{-2k_2 y} + k_{12}e^{-2k_1 y} + \\ k_{13}e^{-2l_1 y} + k_{14}e^{-l_2 y} + k_{15}e^{-l_3 y} + k_{16}e^{-l_4 y} - k_{17} \end{pmatrix} \tag{30}$$
$$C = e^{-k_1 y} \tag{31}$$
$$\begin{aligned} u &= (-k_3 - k_4)e^{-l_1 y} + k_3 e^{-k_2 y} + k_4 e^{-k_1 y} + \\ & E\begin{pmatrix} k_{18}e^{-2k_2 y} + k_{19}e^{-2k_1 y} + k_{20}e^{-2l_1 y} + k_{21}e^{-l_2 y} + k_{22}e^{-l_3 y} \\ + k_{23}e^{-l_4 y} + k_{24}e^{-l_6 y} + k_{25}e^{-k_1 y} - k_{26}e^{-l_7 y} \end{pmatrix} \end{aligned} \tag{32}$$

Case II:

$$C_0 = s_1 e^{-k_1 y} \tag{33}$$
$$\theta_0 = s_2 e^{-k_2 y} \tag{34}$$
$$u_0 = (-k_3 - k_4)e^{-l_1 y} + k_3 e^{-k_2 y} + k_4 e^{-k_1 y} \tag{35}$$

$$u_1 = k_{18}e^{-2k_2 y} + k_{19}e^{-2k_1 y} + k_{20}e^{-2l_1 y} + k_{21}e^{-l_2 y} + k_{22}e^{-l_3 y} + k_{23}e^{-l_4 y} + s_{12}e^{-l_6 y} + k_{25}e^{-k_1 y} - s_{13}e^{-l_7 y} \quad (36)$$

$$\theta_1 = k_{11}e^{-2k_2 y} + k_{12}e^{-2k_1 y} + k_{13}e^{-2l_1 y} + k_{14}e^{-l_2 y} + k_{15}e^{-l_3 y} + k_{16}e^{-l_4 y} + s_{11}e^{-l_6 y} \quad (37)$$

$$C_1 = 0 \quad (38)$$

$$\theta = s_2 e^{-k_2 y} + E\begin{pmatrix} k_{11}e^{-2k_2 y} + k_{12}e^{-2k_1 y} + k_{13}e^{-2l_1 y} + \\ k_{14}e^{-l_2 y} + k_{15}e^{-l_3 y} + k_{16}e^{-l_4 y} + s_{11}e^{-l_6 y} \end{pmatrix} \quad (39)$$

$$C = s_1 e^{-k_1 y} \quad (40)$$

$$u = (-k_3 - k_4)e^{-l_1 y} + k_3 e^{-k_2 y} + k_4 e^{-k_1 y} + E\begin{pmatrix} k_{18}e^{-2k_2 y} + k_{19}e^{-2k_1 y} + k_{20}e^{-2l_1 y} + k_{21}e^{-l_2 y} + k_{22}e^{-l_3 y} \\ + k_{23}e^{-l_4 y} + s_{12}e^{-l_6 y} + k_{25}e^{-k_1 y} - s_{13}e^{-l_7 y} \end{pmatrix} \quad (41)$$

5. NUSSELT NUMBER

From temperature field, the rate of heat transfer in terms of Nusselt number is given in non-dimensional form as follows:

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} \quad (42)$$

For Case (I): From equations (30) and (42), it is derived as:

$$Nu = k_2 + E(2k_2 k_{11} + 2k_1 k_{12} + 2l_1 k_{13} + l_2 k_{14} + l_3 k_{15} + l_4 k_{16} - l_6 k_{17}) \quad (43)$$

For Case (II): it is given by from equations (39) and (42) as:

$$Nu = 1 \quad (44)$$

6. SHERWOOD NUMBER

From concentration field, the rate of mass transfer in terms of Sherwood number is given in non-dimensional form as follows:

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} \quad (45)$$

For Case (I): From equations (31) and (45), it is derived as:

$$Sh = k_1 \quad (46)$$

For Case (II): From equations (39) and (45) it is given as:

$$Sh = 1 \quad (47)$$

7. SKIN-FRICTION:

From velocity field, rate of change of velocity at the plate in terms of Skin-friction is given in non-dimensional form as follows:

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0} \quad (48)$$

For Case (I): From equations (32) and (48), it is derived as

$$\tau = (k_3 + k_4)l_1 - k_3k_2 - k_4k_1 + E(-2k_2k_{18} - 2k_1k_{19} - 2l_1k_{20} - l_2k_{21} - l_3k_{22} - l_4k_{23} - l_6k_{24} - k_1k_{25}e^{-k_1y} + l_7k_{26} \quad (49)$$

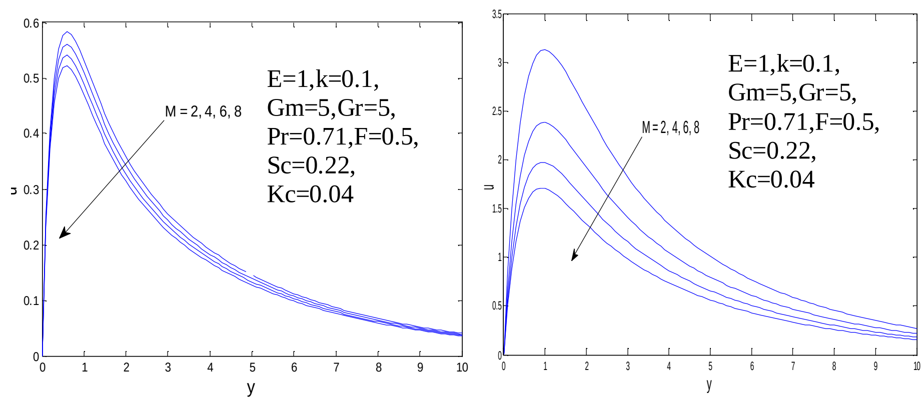
Case (II): From equations (41) and (48) it is given as follows:

$$\tau = (k_3 + k_4)l_1 - k_3k_2 - k_4k_1 + E(-2k_2k_{18} - 2k_1k_{19} - 2l_1k_{20} - l_2k_{21} - l_3k_{22} - l_4k_{23} - l_6s_{12} - k_1k_{25}e^{-k_1y} + l_7s_{13}) \quad (50)$$

8. RESULTS AND DISCUSSION

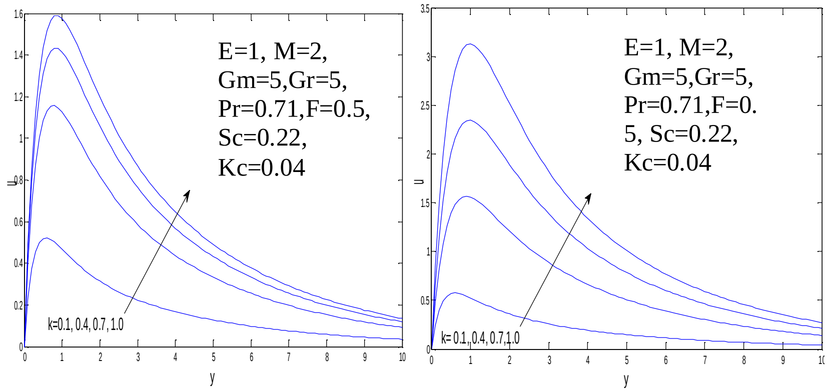
In order to point out the effects of various parameters on flow characteristic, the following discussion is set out for figures 1-7 for the cases of uniform temperature and concentration and for constant heat and mass flux simultaneously. The values of Prandtl number are chosen P_r =7 (water) and P_r = 0.71 (air). The values of Schmidt number are chosen to represent the presence of species by hydrogen (0.22), water vapour (0.60), ammonia (0.78), Ethyl benzene (2.01) and Carbon dioxide (0.96).

Figure 1 depicts the velocity profiles for various values of magnetic parameter M From this figure it is seen that with the increase in M the velocity decreases. Physically it meets the logic that the magnetic field extorts a retarding force on free convection flow which retards the flow. It is also noticed that near the plate in the vicinity of the boundary layer velocity is considerably high and there after gradually decrease uniformly.



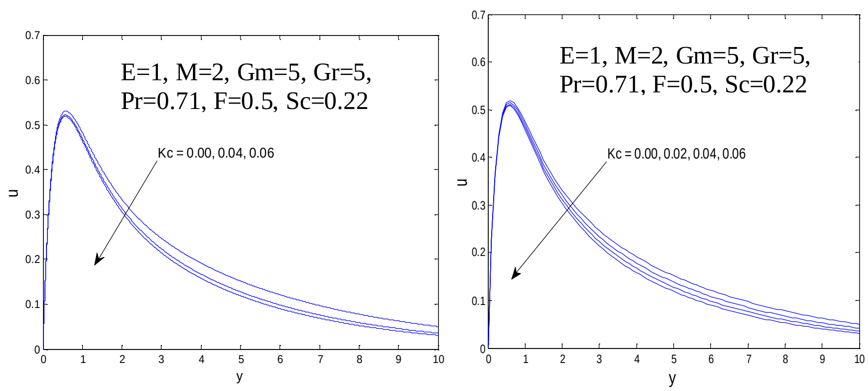
(a) case-1 (b) case-2

Figure1: Effect of Magnetic parameter M on velocity



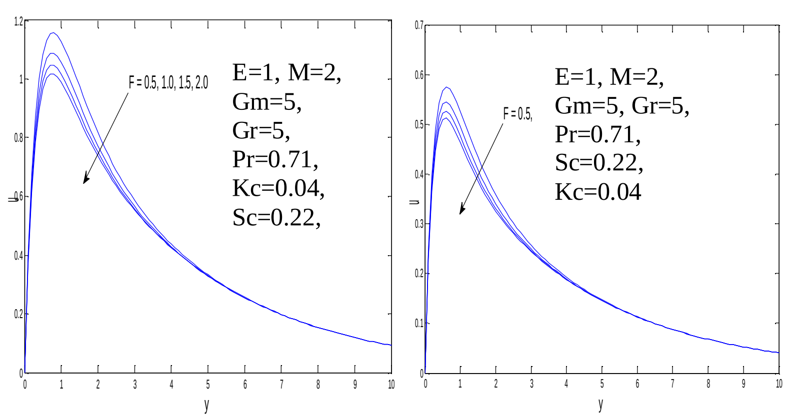
(a) case-1 (b) case-2

Figure2: Effect of permeability parameter k on velocity



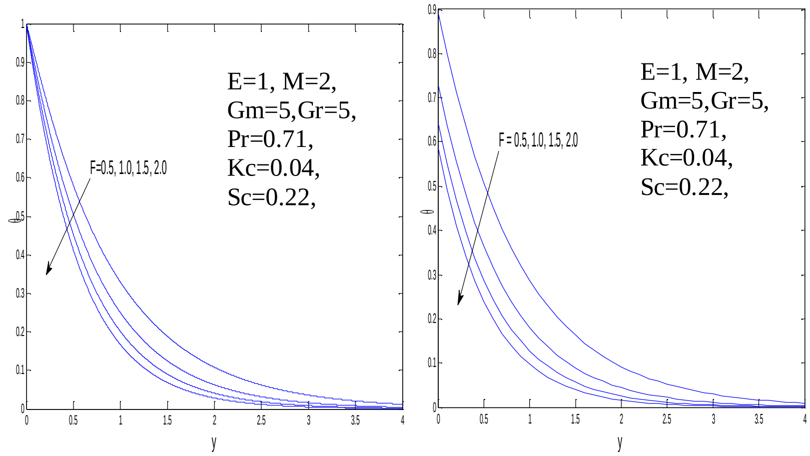
(a) case-1 (b) case-2

Figure.3: Effect of chemical reaction parameter K_c on velocity



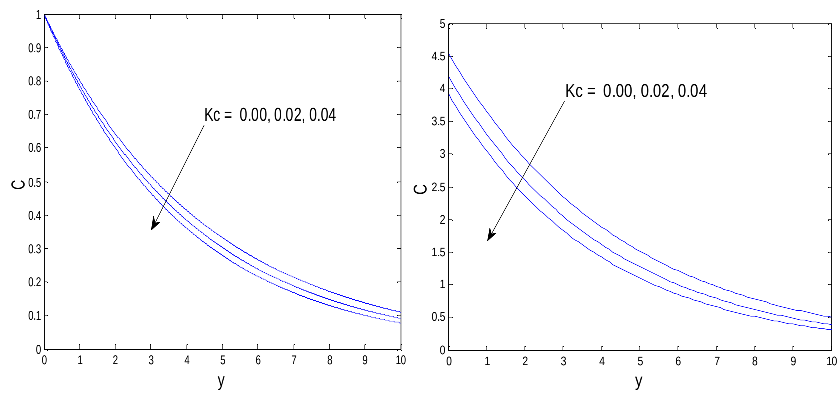
(a) case-1 (b) case-2

Figure4: Effect of radiation parameter F on velocity



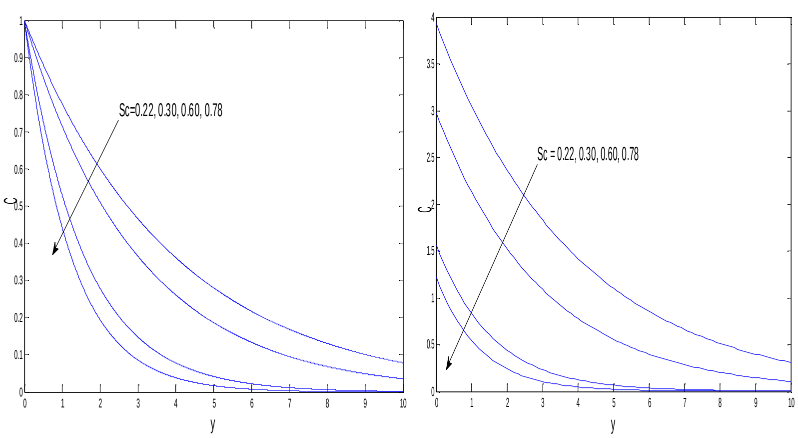
(a) case-1 (b) case-2

Figure5: Effect of radiation parameter F on temperature field



(a) case-1 (b) case-2

Figure 6: Effect of chemical reaction parameter K_c on concentration field



(a) case-1 (b) case-2

Figure7: Effect of Schmidt number Sc on concentration field

Table 1: Variations in Sherwood number

Sc	K_c	Sherwood number
0.22	0.04	0.2546
0.60	0.04	0.6376
0.78	0.04	0.8181
0.22	0.00	0.2200
0.22	0.02	0.2385

Table 2: Variations in rate of mass transfer

M	F	K_c	k	Nusselt number
1	0.5	0.04	0.1	1.0998
2	0.5	0.04	0.1	1.1044
3	0.5	0.04	0.1	1.1082
2	1.0	0.04	0.1	1.3790
2	2.0	0.04	0.1	1.7812
2	0.5	0.02	0.1	1.1041
2	0.5	0.00	0.1	1.1038
2	0.5	0.04	0.7	0.9813

Table 3: Variations in skin friction

M	F	K_c	k	Skin-friction (case-1)	Skin-friction (case-2)
1	0.5	0.04	1	6.9002	6.8127
2	0.5	0.04	1	5.6603	5.3150
3	0.5	0.04	1	4.9247	4.6208
2	1.0	0.04	1	5.4341	5.0258
2	2.0	0.04	1	5.1802	4.1860
2	3.0	0.04	1	5.0258	5.2798
2	0.5	0.02	1	5.7130	5.2984
2	0.5	0.00	1	5.7430	5.2798
2	0.5	0.04	0.7	5.3056	4.9702
2	0.5	0.04	0.1	5.1056	2.8311

9. CONCLUSIONS

In this paper, we have studied analytically, the radiation and chemical reaction effects on MHD free convection flow through porous medium bounded by a vertical surface in presence of viscous dissipation. The solutions are obtained for velocity, temperature and concentration using a perturbation technique. The effects of various physical parameters on the flow quantities are studied with the help of graphs and tables. The following are the list of conclusions.

1. In Case (I) and as well as in case (II), the velocity decreases with increase values of magnetic parameter M or radiation parameter F or chemical reaction parameter K_c or Prandtl number P_r where as it shows the reverse trend in the cases of Grashof number G_r or Modified Grashof number G_m or Eckert number E or porosity parameter k .
2. Temperature increases as the permeability parameter k increases while it decreases as radiation parameter F increases in both Cases of the study.

3. Concentration decreases with increasing chemical reaction parameter K_c or Schmidt number Sc in both Cases of the study.

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