Original Article

Bulletin of Pure and Applied Sciences.
Vol. 37E (Math & Stat.), No.1, 2018.P.184-199
Print version ISSN 0970 6577
Online version ISSN 2320 3226
DOI: 10.5958/2320-3226.2018.00019.X

Radiation Absorption Effect on MHD Dissipative Fluid Past A Vertical Porous Plate Embedded in Porous Media

M. Obulesu[1,*], R. Siva Prasad[2]

Author Affiliation:
[1]Research Scholar, Department of Mathematics, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India-515 003.
E-mail: mopuriobulesu1982@gmail.com
[2] Department of Mathematics, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India-515003.
E-mail: rsprasad_racharla@yahoo.co.in

***Corresponding Author:**
M. Obulesu, Research Scholar, Department of Mathematics, Sri Krishnadevaraya University, Anantapur, Andhra Pradesh, India-515 003.

E-mail: mopuriobulesu1982@gmail.com

Received on 20.03.2018, **Accepted on 27.04.2018**

Abstract

In this manuscript, an attempt is made to study the radiation absorption effect on MHD dissipative fluid past a vertical porous plate embedded in porous media; under the influence of a uniform magnetic field applied normal to the surface is studied. The governing equations are solved analytically using a regular perturbation technique. The expression for velocity, temperature and concentration fields are obtained with the aid of these, the expressions for the coefficient of skin friction, the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number are derived. Finally the effect of variation of physical parameters on the flow quantities is studied with the help of graphs and tables. It is observed that the velocity and concentration increase during a generative reaction and decrease in a destructive reaction. The same is observed to be true for the behaviour of the fluid temperature. The presence of magnetic field and radiation diminishes the velocity and also the temperature.

Keywords: Radiation absorption; MHD; Viscous dissipation; Porous media; Heat source/ sink; Chemical reaction and Thermal radiation.

1. INTRODUCTION

Induced magnetic forces modify the free stream flow and this in turn, affects the external pressure gradient or the free stream velocity that is imposed on the boundary layer. From the technological point of view, MHD free-convection flows have great significance for the applications in the fields of stellar and planetary magnetospheres, aeronautics, chemical engineering and electronics. Hydromagnetic flows and heat transfer have become more important in recent years because of their varied applications in agricultural engineering and petroleum industries. Recently, considerable attention has also been focused on new applications of MHD and heat transfer such as metallurgical processing, melt refining involved magnetic field applications to control excessive heat transfer rate. Other applications of MHD heat transfer include MHD generators, plasma propulsion in astronautics, nuclear reactor thermal dynamics and ionized-geothermal energy systems.

MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates was studied by Ravikumar et al. [1]. MHD free convective flow through a porous medium past a vertical plate with ramped Wall temperature was studied by Sinha et al. [2]. Radiation and chemical reaction effects on MHD flow fluid over an infinite vertical oscillating porous plate was studied by Kumar et al. [3]. The effect of chemical reaction on an unsteady MHD free convection flow past an infinite vertical porous plate with variable suction was discussed by Sarada et al. [4]. Unsteady MHD free convection oscillatory couette flow through a porous medium with periodic wall temperature was discussed by Raju et al. [5]. Free convection flow involving coupled heat and mass transfer occurs frequently in nature and in industrial processes. A few representative fields of interest in which combined heat and mass transfer plays an important role are designing chemical processing equipment, formation and dispersion of fog, distribution of temperature and moisture over agricultural fields and groves of fruit trees, crop damage due to freezing, and environmental pollution. Convection flow direction by temperature and concentration differences has been the objective of extensive research because such process exists in nature and has engineering applications. The process occurring in nature induces the photosynthetic mechanism, calm-day vaporization of mist and fog, while the engineering include chemical vapour deposition on surfaces and cooling of electronic equipment. Sudhakar Reddy [6] studied the chemical reaction and radiation effects on MHD free convection flow through a porous medium bounded by a vertical surface with constant heat and mass flux. The effect of chemical reaction on MHD free convection flow of dissipative fluid past an exponentially accelerated vertical plate was discussed by Kishore et al. [7]. Mandal et al. [8] have discussed the effects of radiation and chemical reaction on MHD free convection flow past a vertical plate in the porous medium. Heat and mass transfer in MHD free convection flow over an inclined plate with hall current were studied by Mohammad Shah Alam et al. [9]. Hemalatha et al. [10] analyzed the effect of thermal radiation and chemical reaction on MHD free convection flow past a flat plate with heat source and convective surface boundary condition. The Study of heat generation or absorption effects in moving fluids is important in view of several physical problems such as fluids under-going exothermic or endothermic chemical reactions. The volumetric heat generation has been assumed to be constant or a function of space variable. For example, a hypothetical core-disruptive accident in a Liquid Metal Fast Breeder Reactor (LMFBR) could result in the setting of fragmented fuel debris on horizontal surfaces below the core. The porous debris could be saturated sodium coolant and heat generation will result from the radioactive decay of the fuel particulate. Chamkha [11] studied MHD flow of uniformly stretched vertical permeable surface in the presence of heat generation / absorption and chemical reaction. Mishra et al. [12] discussed mass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source. Shanker et al. [13] studied Radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation or absorption Saxena et al [14] observed chemical reaction and heat generation on moving isothermal vertical surface through porous medium with uniform mass flux and transposition. Ramaiah et al. [15] considered the chemical reaction and radiation absorption effects on MHD convective heat and mass transfer flow of a visco-elastic fluid past an oscillating porous plate with heat generation / absorption. The radiative heat and mass transfer has wide applications in geophysics, geothermal, engineering and solar physics. It plays an important role in manufacturing industries for the design of nuclear power plants, gas turbines, steel rolling and various propulsion devices for space vehicles, missiles, combustion and furnace design, energy utilization, aircrafts, satellites, remote sensing, astronomy and space exploration, etc. Satyanarayana et al. [16] considered the effects of Hall current and radiation absorption on MHD micropolar fluid in a rotating system. Raju et al. [17] studied the unsteady MHD free convection oscillating couette flow through a porous medium with periodic wall temperature in the presence of chemical reaction and thermal radiation. Durga Prasad et al. [18] studied heat and mass transfer analysis for the MHD flow of nanofluid with radiation absorption. Venkateswarlu et al. [19] considered the radiation absorption and viscous-dissipation on MHD flow of casson fluid over a vertical plate filled with porous layers. Raju et al. [20] investigated radiation absorption effect on MHD, free convection, chemically reacting visco-elastic fluid past an oscillatory vertical porous plate in slip flow regime. Recently researchers [26-31] showed interest in this area.

Keeping in mind the above aspects, in this paper, we study the radiation absorption effect on MHD dissipative fluid past a vertical porous plate embedded in porous media, under the influence of uniform magnetic field applied normal to the surface. The effect of variation of physical parameters on the flow quantities is also studied with the help of graphs and tables.

2. MATHEMATICAL FORMULATION

We consider a viscous, incompressible, electrically conducting and radiating fluid through a porous medium occupying a semi-infinite region of the space bounded by a vertical infinite surface. The *x** axis is taken along the surface in an upward direction and the *y** axis is normal to it. A uniform magnetic field B_0 is assumed to be applied in a direction perpendicular to the surface. The properties of a fluid are assumed to be constant except for the density in the body force term. In addition a chemically reactive species is assumed to be emitted from the vertical surface into a hydrodynamic flow field. It diffuses into the fluid, where it under goes a homogenous chemical reaction. The reaction is assumed to take place entirely in the stream. Then the fully developed flow under the above assumptions through a highly porous medium is governed by the following set of equations:

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

$$V^*\frac{\partial u^*}{\partial y^*}=\nu\frac{\partial^2 u^*}{\partial y^{*2}}+g\beta_T(T^*-T_\infty^*)+gB_C(C^*-C_\infty^*)-\frac{\sigma B_0^2}{\rho}u^*-\frac{\nu u^*}{K_p} \tag{2}$$

$$V^*\frac{\partial T^*}{\partial y^*}=\frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial\ y^{*2}}+\frac{\nu}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial y^*}-\frac{Q_1}{\rho C_p}(T^*-T_\infty^*)+\frac{R_1}{\rho C_p}(C^*-C_\infty^*) \tag{3}$$

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

The relevant boundary conditions are given as follows

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

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

Eq.(1) gives that V^* = Constant = - V_0 (6)

In the optically thick limit, the fluid does not absorb its own emitted radiation in which there is no self-absorption, but it does absorb radiation emitted by the boundaries. Cogley et al. [21] showed that in the optically thick limit for a non-gray gas near equilibrium as given below.

$$\frac{\partial q_r}{\partial y^*}=4(T^*-T_\infty^*)\int_0^\infty K_{\lambda w}\frac{de_{b\lambda}}{dT^*}d\lambda=4I_1(T^*-T_\infty^*) \tag{7}$$

On introducing the following non-dimensional quantities,

$$u=\frac{u^*}{v_0},y=\frac{v_0y^*}{\nu},\theta=\frac{T^*-T_\infty^*}{T_w-T_\infty^*},C=\frac{C^*-C_\infty^*}{C_w-T_\infty^*},\Pr=\frac{\mu C_p}{k},Sc=\frac{\nu}{D},M=\frac{\sigma B_0^2\nu}{\rho v_0^2},$$

$$Gr=\frac{\nu g\beta_T(T_w-T_\infty^*)}{v_0^3},Gm=\frac{\beta_C(C_w-C_\infty^*)}{v_0^3},\ E=\frac{v_0^2}{C_P(T_w-T_\infty^*)},\ k=\frac{v_0^2K_P}{\nu^2}$$

$$k_0=\frac{\nu K_C}{v_0^2},F=\frac{4I_1\nu^2}{Kv_0^2},Q=\frac{Q\nu^2Q_1}{Kv_0^2},R=\frac{R_1\nu^2(C_w-C_\infty)}{Kv_0^2(T_w-T_\infty)}. \tag{8}$$

where M is the magnetic parameter, E is the Eckert Number, k is the Permeability parameter, k_0 is the chemical reaction parameter, F is the radiation parameter, Q is the heat source parameter and R is the radiation absorption parameter. The non-dimensional form of the governing equations (2) – (4) reduce to

$$u'' + u' = -Gr\theta - Gm\,C + M_1 u \tag{9}$$

$$\theta'' + Pr\theta' = Pr\,E\,u'^2 + F\theta + Q\theta - RC \tag{10}$$

$$C'' + ScC' = K_0 Sc\,C \tag{11}$$

where $M_1 = M + 1/k$.

The corresponding boundary conditions are given by

$$u = 0,\quad \theta = 1,\quad C = 1 \quad \text{at} \quad y = 0$$
$$u \to 0,\quad \theta \to 0,\quad C \to 0 \quad \text{at} \quad y \to \infty \tag{12}$$

3. SOLUTION OF THE PROBLEM

In order to solve the coupled nonlinear system of Eqs. (9)–(11) with the boundary conditions (12), the following simple perturbation is used. The governing equations (9)–(11) are expanded in powers of Eckert number E (<<1).

$$u = u_0 + Eu_1 + O(E^2)$$
$$\theta = \theta_0 + E\theta_1 + O(E^2) \tag{13}$$
$$C = C_0 + EC_1 + O(E^2)$$

Substituting equations (13) into equation (9)–(11) and equating the coefficients at the terms with the same powers of E, and neglecting the terms of higher order, the following equations are obtained.

Zero order terms:

$$u_0'' + u_0' = -Gr\theta_0 - Gm\,C_0 + M_1 u_0 \tag{14}$$

$$\theta_0'' + \Pr\theta_0' - (F+Q)\theta_0 = -RC_0 \tag{15}$$

$$C_0'' + ScC_0' = K_0\,ScC_0 \tag{16}$$

First order terms :

$$u_0'' + u_0' = -Gr\theta_1 - Gm\,C_1 + M_1 u_1 \tag{17}$$

$$\theta_1'' + \Pr\theta_1' - (F+Q)\theta_1 = -Pr\,u_0'^2 - RC_1 \tag{18}$$

$$C_1'' + ScC_1' = K_0\,ScC_1 \tag{19}$$

T

he corresponding boundary conditions are

$$u_0 = 0,\ u_1 = 0,\quad \theta_0 = 1,\ \theta_1 = 0,\quad C_0 = 1,\ C_1 = 0 \quad \text{at } y = 0$$
$$u_0 \to 0,\ u_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\quad C_0 \to 0,\ C_1 \to 0 \quad \text{as } y \to \infty \tag{20}$$

Solving equations (14) – (19) under the boundary conditions (20), the following solutions are obtained

$$C_0 = \exp(-m_1 y), \tag{21}$$

$$\theta_0 = (1 - l_1)\exp(-m_2 y) + l_1 \exp(-m_1 y) \tag{22}$$

$$u_0 = (-l_2 - l_3)\exp(-m_3 y) + l_2 \exp(-m_2 y) + l_3 \exp(-m_1 y) \tag{23}$$

$$\begin{aligned}\theta_1 = {} & l_4 \exp(-2m_3 y) + l_5 \exp(-2m_2 y) + l_6 \exp(-2m_1 y) + l_7 \exp(-m_4 y) + \\ & l_8 \exp(-m_5 y) + l_9 \exp(-m_6 y) + l_{10} \exp(-m_2 y)\end{aligned} \tag{24}$$

$$\begin{aligned}u_1 = {} & l_{11} \exp(-2m_3 y) + l_{12} \exp(-2m_2 y) + l_{13} \exp(-2m_1 y) + l_{14} \exp(-m_4 y) + \\ & l_{15} \exp(-m_5 y) + l_{16} \exp(-m_6 y) + l_{17} \exp(-m_2 y) + l_{18} \exp(-m_3 y)\end{aligned} \tag{25}$$

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

Substituting equations (21) – (26) in equation (13) we obtain the velocity temperature and concentration field as

$$\begin{aligned} u &= (-l_2 - l_3)\exp(-m_3 y) + l_2 \exp(-m_2 y) + l_3 \exp(-m_1 y) \\ &\quad + E\big[l_{11}\exp(-2m_3 y) + l_{12}\exp(-2m_2 y) + l_{13}\exp(-2m_1 y) + l_{14}\exp(-m_4 y) \\ &\qquad + l_{15}\exp(-m_5 y) + l_{16}\exp(-m_6 y) + l_{17}\exp(-m_2 y) + l_{18}\exp(-m_3 y)\big] \end{aligned} \tag{27}$$

$$\begin{aligned} \theta &= (1 - l_1)\exp(-m_2 y) + l_1 \exp(-m_1 y) \\ &\quad + E\big[l_4\exp(-2m_3 y) + l_5\exp(-2m_2 y) + l_6\exp(-2m_1 y) + l_7\exp(-m_4 y) \\ &\qquad + l_8\exp(-m_5 y) + l_9\exp(-m_6 y) + l_{10}\exp(-m_2 y)\big] \end{aligned} \tag{28}$$

$$C = \exp(-m_1 y) \tag{29}$$

Skin Friction :

The non-dimensional skin friction at the surface is given by

$$\begin{aligned} C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} &= \left[m_3(l_2 + l_3) - m_2 l_2 - m_1 l_3\right] \\ &\quad + E\left[-m_3 l_{18} - 2m_3 l_{11} - 2m_2 l_{12} - 2m_1 l_{13} - m_4 l_{14} - m_5 l_{15} - m_6 l_{16} - m_2 l_{17}\right] \end{aligned} \tag{30}$$

Nusselt Number :

The rate of heat transfer in terms of the Nusselt number is given by

$$Nu = -\left(\frac{\partial \theta}{\partial y}\right)_{y=0} = \left[m_2(1 - l_1) + m_1 l_1\right] + E\left[2m_3 l_4 + 2m_2 l_5 + 2m_1 l_6 + m_4 l_7 + m_5 l_8 + m_6 l_9 + m_2 l_{10}\right] \tag{31}$$

Sherwood Number :

The rate of mass transfer on the wall in terms of Sherwood number is given by

$$Sh = -\left(\frac{\partial C}{\partial y}\right)_{y=0} = m_1 \tag{32}$$

4. RESULTS AND DISCUSSION

In order to reveal the effects of various parameters on the dimensionless velocity fields, temperature field, concentration field, skin friction, Nusselt number and Sherwood number and the effect of the various physical parameters such as the thermal Grashof number (Gr), the modified Grashof number (Gm), magnetic parameter (M), Permeability parameter(k), Prandtl number (Pr), Heat Sink(Q), Radiation Parameter (F), Radiation absorption parameter (R) and Chemical reaction parameter(k_0) on velocity, temperature and concentration we draw a number of figures marked as figs. 1-11 and study these by choosing arbitrary values. The influence of these parameters on skin friction, Nusselt number and Sherwood number is also shown in Tables 1 – 3.

Figs. 1 – 6 demonstrate the variations of the fluid velocity under the effects of different parameters. In Fig.1, we represent the velocity profile for different values of chemical reaction parameter (K_0). From this figure it is noticed that, velocity decreases with increases in K_0. In Fig. 2, velocity profiles are displayed with the variation in magnetic parameter (M). From this figure it is noticed the velocity gets reduced by the increase of magnetic parameter (M). Fig.3, depicts the variations in velocity profiles for different values of permeability parameter (k).from where it is noticed that, velocity increases as k increases. Fig.4 depicts the variations in velocity profiles for different values of Radiation absorption parameter (R) which shows that velocity increases as R increases. In Fig.5 the effect of modified Grashof number (Gm) on velocity is presented. As Gm increases, velocity also increases. A similar effect is noticed from fig.6, in the presence of thermal Grashof number (Gr) which also increases the fluid velocity. This is due to the buoyancy which is acting on the fluid particles due to gravitational force that enhances the fluid velocity.

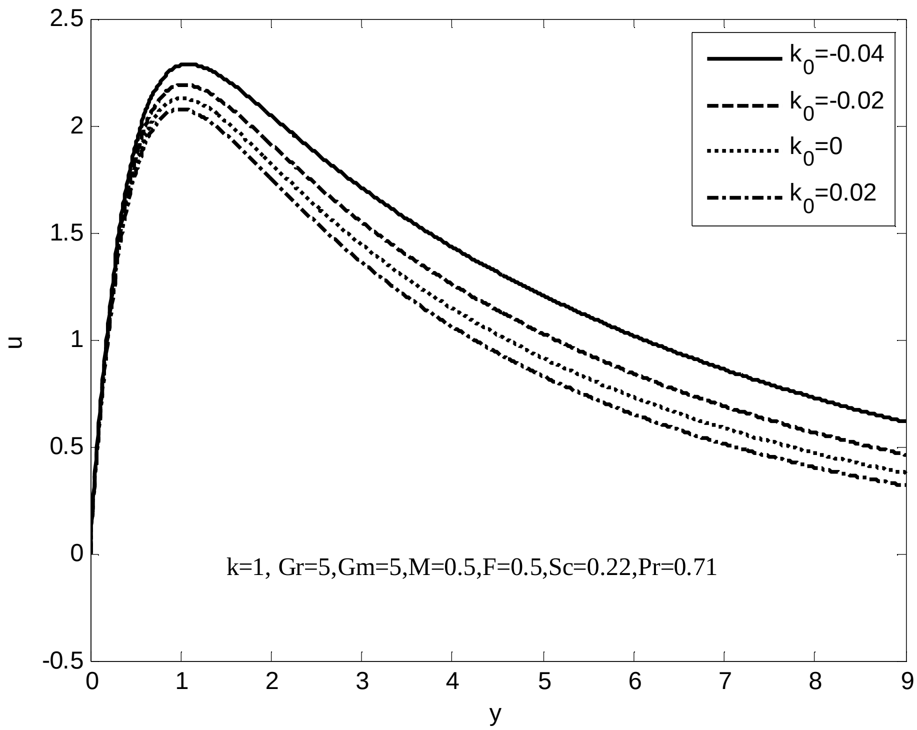

Fig. 1: Velocity profiles for different values of k_0

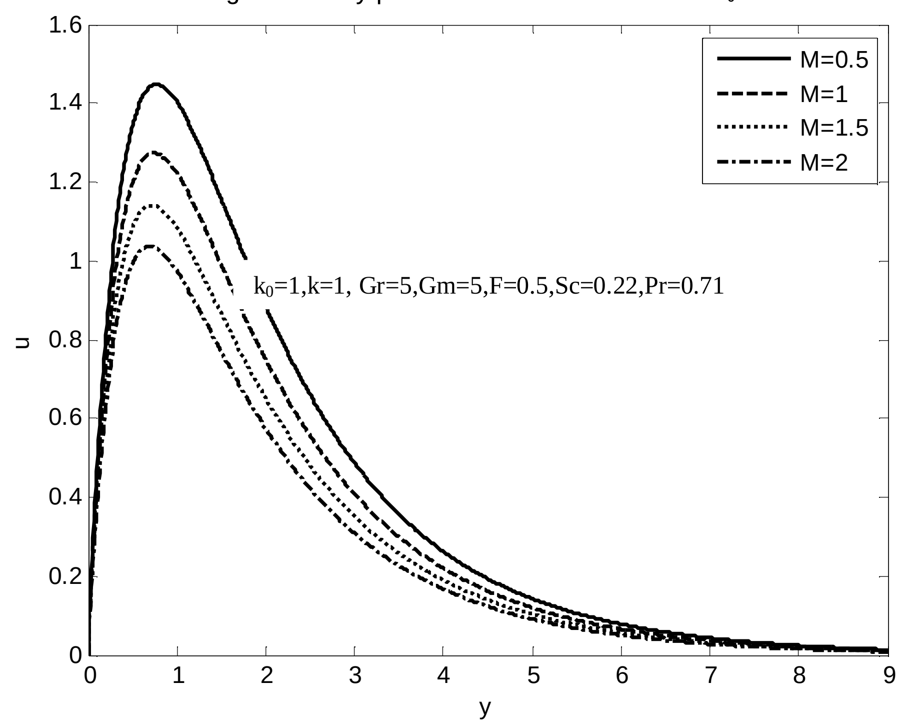

Fig. 2: Velocity profiles for different values of M

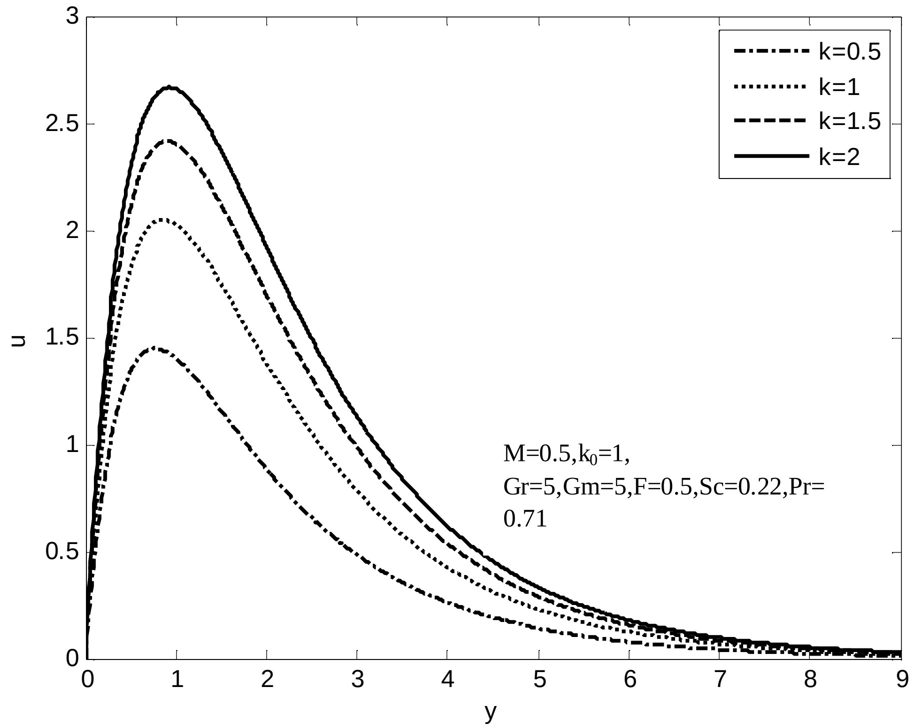

Fig. 3: Velocity profiles for different values of k

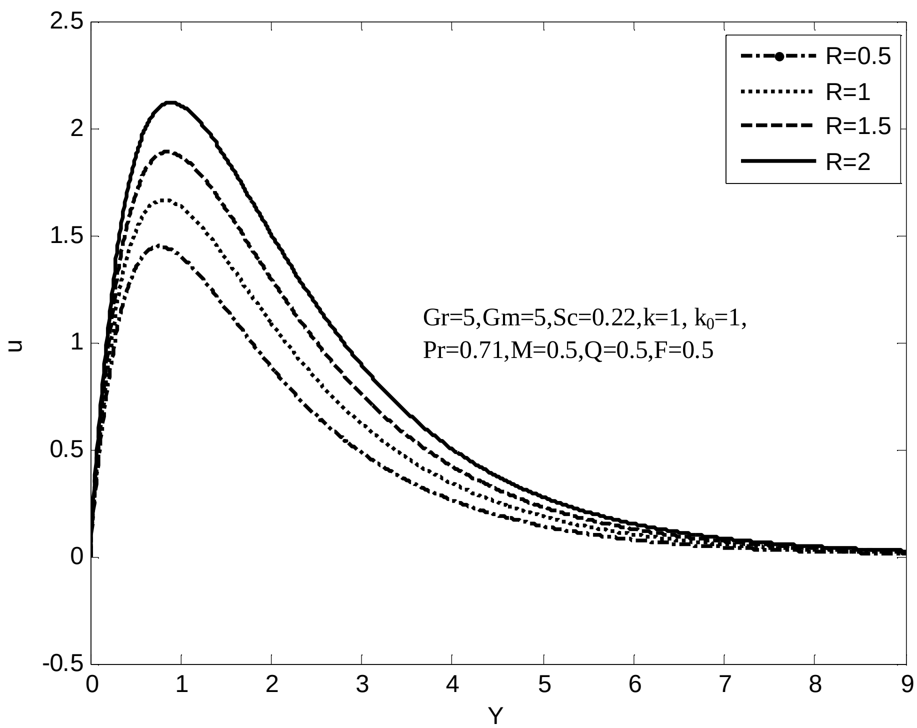

Fig. 4: Velocity profiles for different values of R

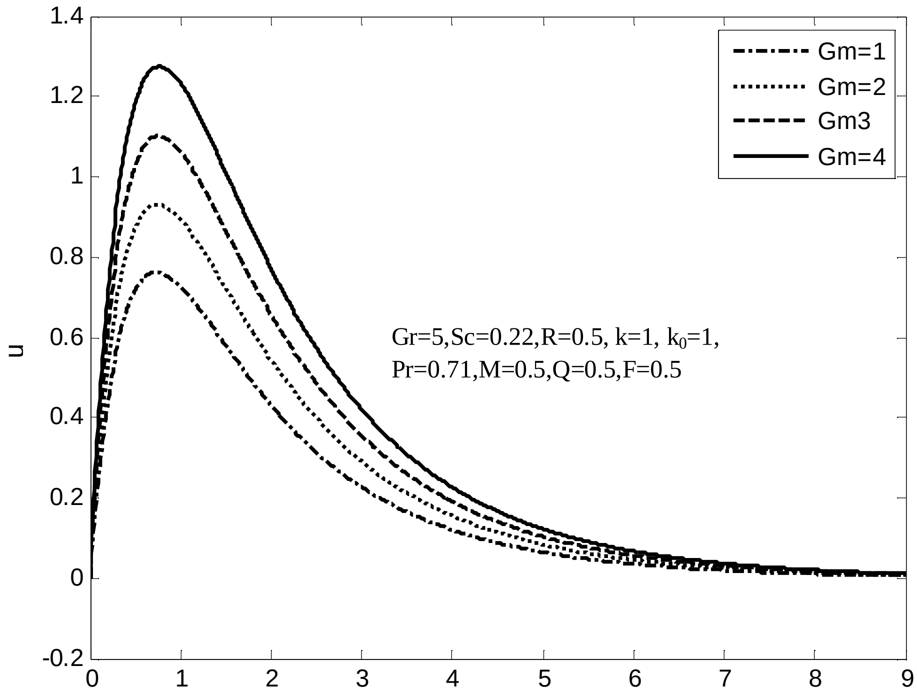

Fig. 5: Velocity profiles for different values of Gm

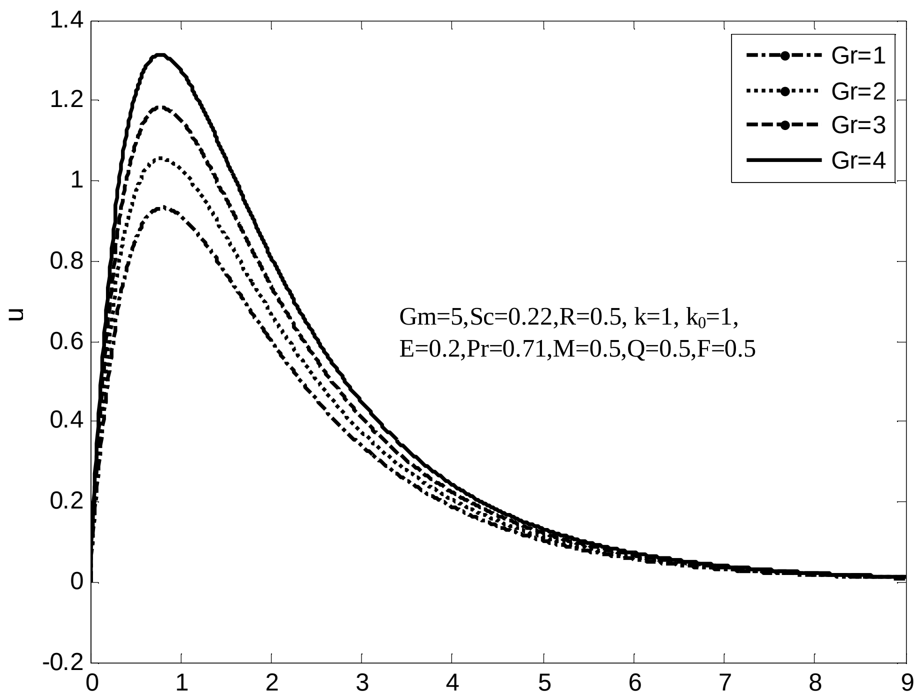

Fig. 6: Velocity profiles for different values of Gr

Figures 7 – 10, display the variations of the fluid temperature under the effects of different parameters. From Fig.7, it is clear that temperature decreases with the increase in radiation parameter (F).

In Fig.8 the effect of magnetic parameter (M) in the case of water and air is observed on the temperature, it is known that temperature decreases with the increase in M, but in the case of water the magnitude of the decrease of temperature is very low.

In Fig.9 the effect of radiation absorption parameter (R) is shown on temperature profile. From this figure it is observed that temperature increases with an increase in R.

Fig.10 depicts the variations in temperature profile for different values of heat source parameter (Q). From this figure it is noticed that, temperature decreases when Q increases.

Fig.11 exhibits the concentration profiles for different values of Chemical reaction parameter (k_0), from which it is noticed that concentration decreases with an increase in Chemical reaction parameter (k_0). This is because the chemical reaction mass diffuses from higher concentration levels to lower concentration levels.

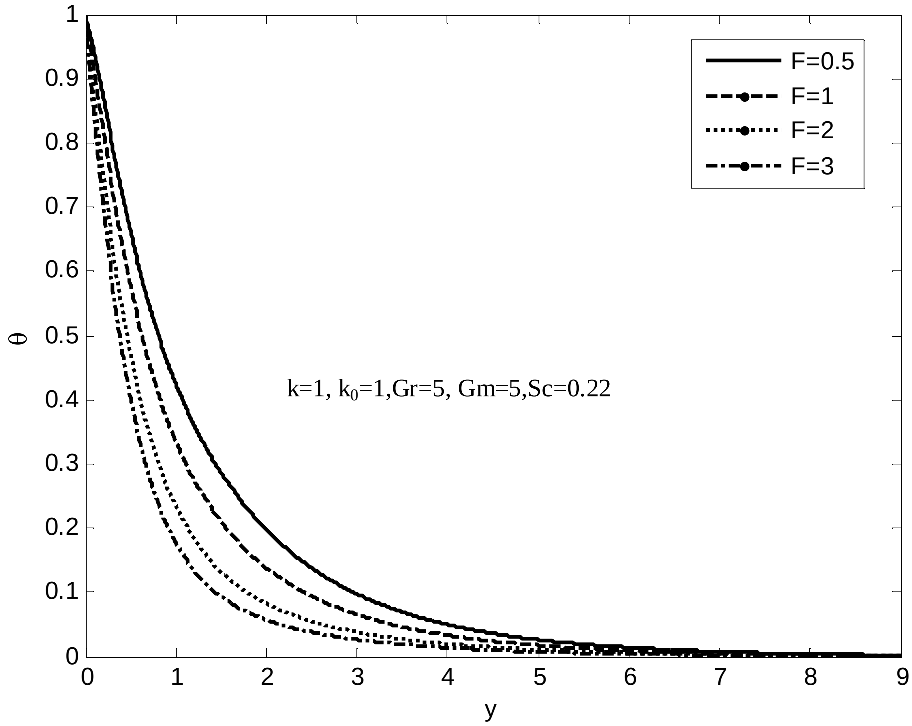

Fig. 7: Temperature profiles for different values of F

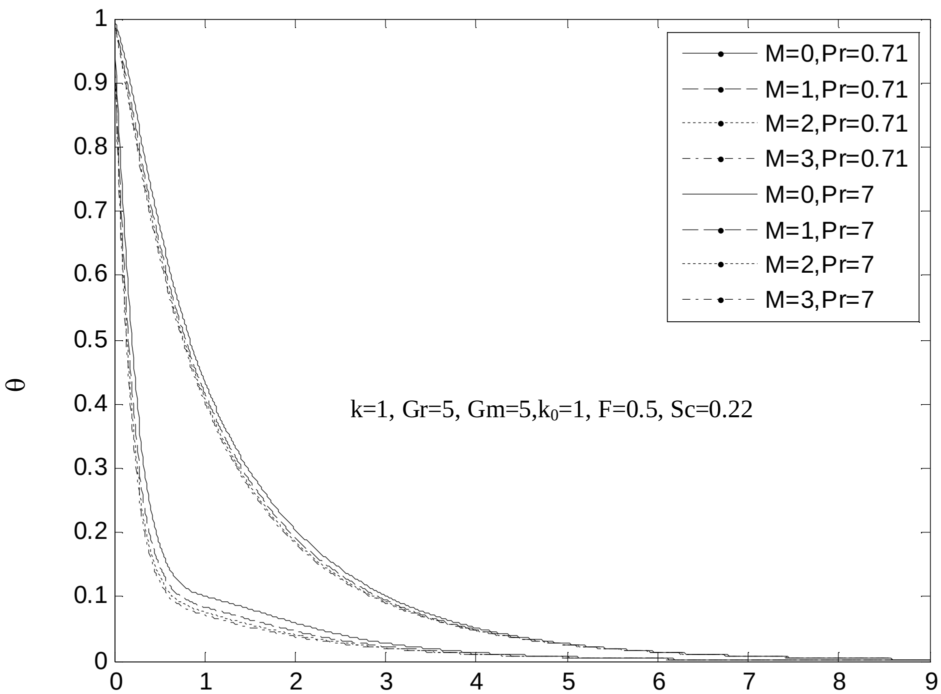

Fig. 8: Temperature profiles for different values of M

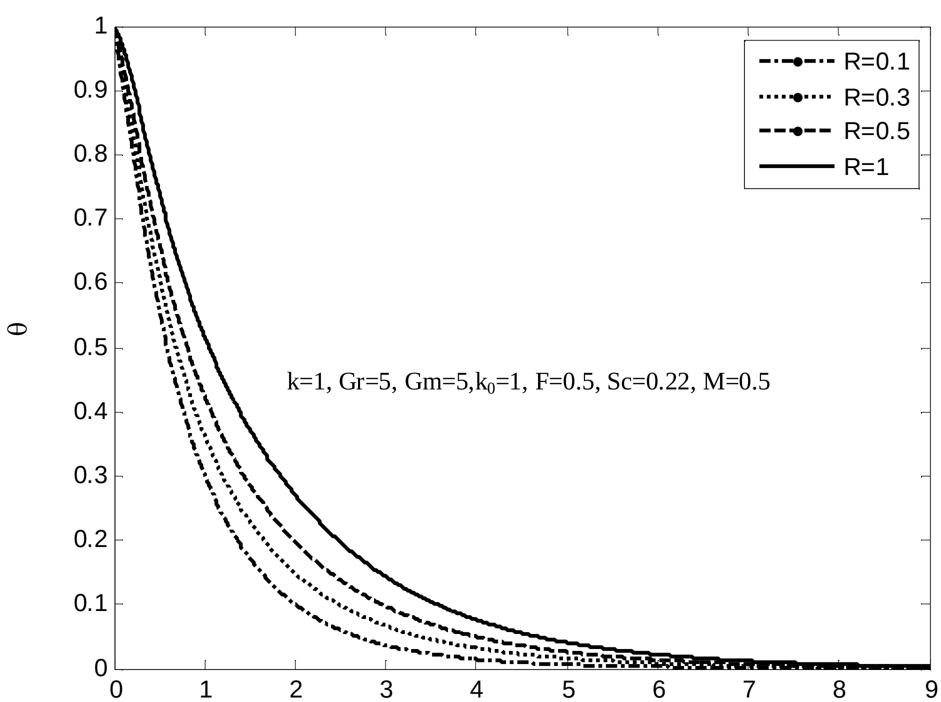

Fig. 9: Temperature profiles for different values of R

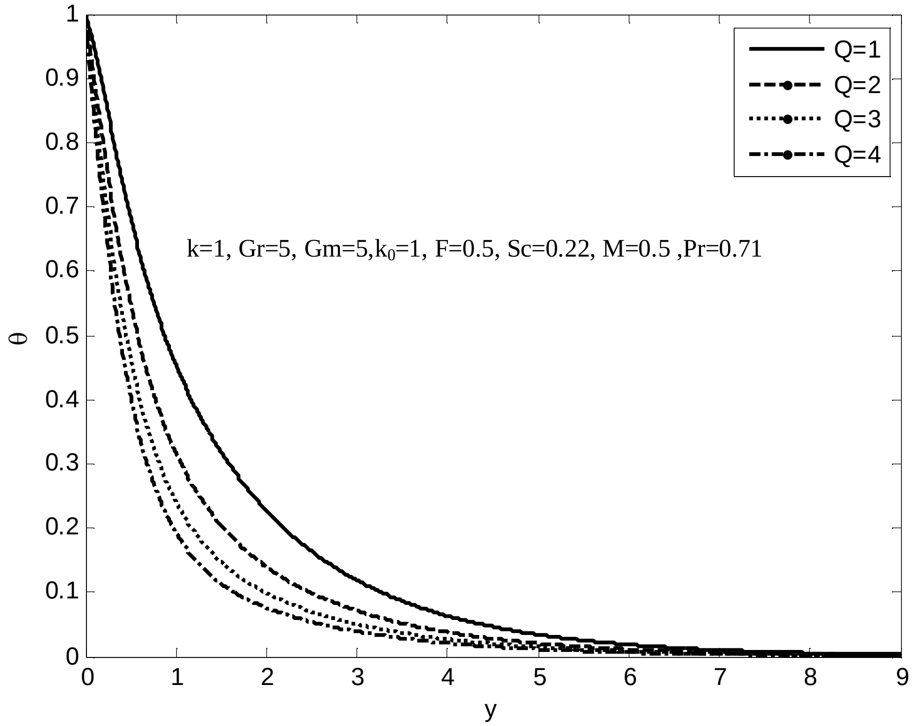

Fig. 10: Temperature profiles for different values of Q

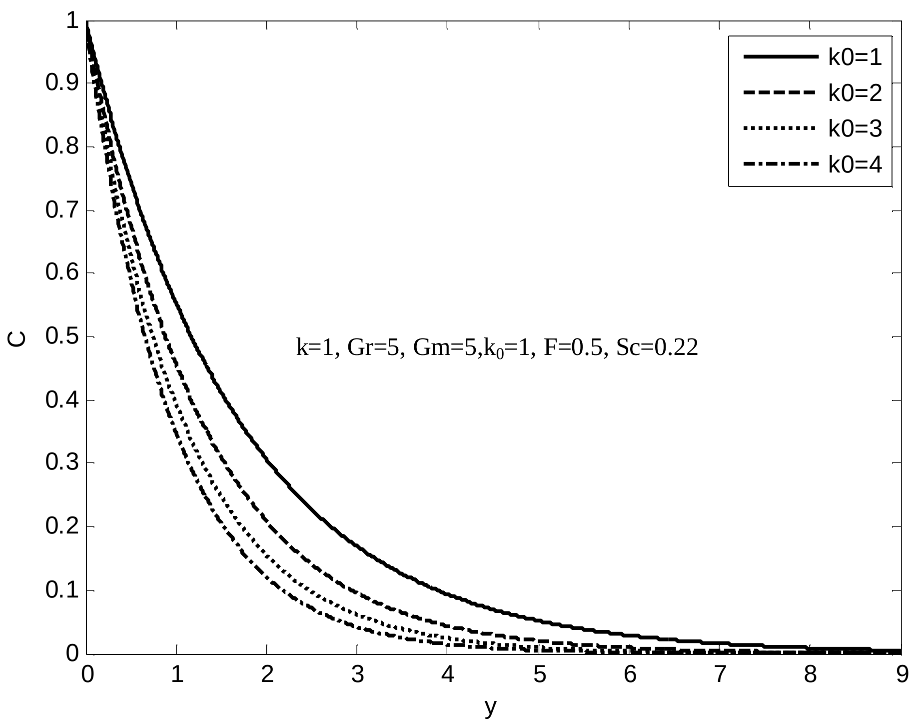

Fig. 11: Concentration profiles for different values of k_0

Table – 1, shows numerical values of skin-friction for various of Grashof number (Gr), modified Grashof number (Gm), Magnetic parameter (M), Permeability parameter (K). From table 1, we observe that the skin-friction increases with an increase in Grashof number (Gr), modified Grashof number (Gm), Permeability parameter (k) where as it decreases under the influence of magnetic parameter.

Table – 1 :
Variations in Skin Friction

Gr	Gm	k	M	C_f
5	5	1	0.5	5.6154
7	5	1	0.5	6.4357
9	5	1	0.5	7.0258
11	5	1	0.5	7.2831
5	7	1	0.5	2.9851
5	9	1	0.5	4.7468
5	11	1	0.5	5.6154
5	13	1	0.5	6.0514
5	5	0.1	0.5	2.9851
5	5	0.3	0.5	4.7468
5	5	0.5	0.5	5.6154
5	5	0.7	0.5	6.0514
5	5	1	0.1	5.9269
5	5	1	0.3	5.7715
5	5	1	0.5	5.6154
5	5	1	0.7	5.4639

Table – 2 :
Variations in Nusselt Number

Pr	F	Q	R	Nu
0.3	0.5	0.5	1	1.7696
0.7	0.5	0.5	1	1.7888
1	0.5	0.5	1	1.8143
7.1	1	0.5	1	4.7979
0.71	2	0.5	1	0.5426
0.71	3	0.5	1	1.0794
0.71	4	0.5	1	1.4707
0.71	0.5	1	1	1.7888
0.71	0.5	2	1	1.9299
0.71	0.5	3	1	2.1863
0.71	0.5	4	1	2.6267
0.71	0.5	0.5	1	1.7888
0.71	0.5	0.5	2	1.3485
0.71	0.5	0.5	3	0.9049
0.71	0.5	0.5	4	0.4578

Table – 3 : Variations in Sherwood Number

Sc	k_0	Sh
0.22	1	0.5918
0.6	1	1.1307
0.8	1	1.3798
0.9	1	1.5
0.22	1	1
0.22	2	1.2808
0.22	3	1.5
0.22	4	1.6861

Table – 2 demonstrates the numerical values of Nusselt number (Nu) for different values of Prandtl number (Pr), Radiation parameter (F), Heat source parameter (Q), Radiation absorption parameter (R). From table 2, we notice that the Nusselt number increases with an increase in Prandtl number, Radiation parameter and Heat source parameter where as it decrease under the influence of Radiation absorption parameter. Table – 3 shows numerical values of Sherwood number (Sh) for the distinction values of Schmidt number (Sc), Chemical reaction parameter (k_0). It can be noticed from Table - 3 that the Sherwood number enhances with rising values of Schmidt number, and the Chemical reaction parameter.

5. CONCLUSIONS

In this problem, we have studied Radiation absorption effect on MHD dissipative fluid past a vertical porous plate embedded in porous media. In the analysis of the flow the following conclusions are made:

1. Velocity increases with an increase in Grashof number and as well as modified Grashof number, Radiation absorption parameter and permeability of the porous medium while, it decreases in the existence of magnetic parameter and chemical reaction parameter.
2. Temperature increases in the presence of radiation absorption parameter while it decreases in the presence of magnetic parameter, heat sink and radiation parameter.
3. Concentration decreases with an increase in chemical reaction parameter.
4. As significant increase in seen in skin friction for Grashof number, modified Grashof number and permeability parameter while a decrease is seen in the presence of magnetic parameter.
5. The rate of heat transfer increases with Prandtl number, heat sink and radiation parameter while it shows adverse effect in the case of radiation absorption parameter.
6. The rate of mass transfer increases with Schmidt number and Chemical reaction parameter.

Nomenclature

C	nondimensional fluid concentration
C^*	concentration
C_α	fluid concentration far away from the wall
C_p	specific heat at a constant pressure
D	mass diffusivity
E	Eckert number
$e_{b\lambda}$	Planck function
F	radiation parameter
Gm	mass Grashof number
Gr	thermal Grashof number
g	acceleration due to gravity
k	nondimensional permeability coefficient of a porous medium
k_0	nondimensional rate of chemical reaction
k_c	rate of chemical reaction
k_p	permeability of porous medium
$K_{\lambda w}$	absorption coefficient
M	magnetic parameter
Nu	Nusselt number
Pr	Prandtl number
q_r	radiative flux
Sc	Schmidt number
T_∞	fluid temperature far away from the wall
T^*	temperature
u^*, v^*	velocity components
u	nondimensional velocity
v_0	suction velocity

Greek symbols

K	thermal conductivity
ν	kinematic viscosity
σ	electrical conductivity
μ	dynamic viscosity
β_T	coefficient of volume expansion
β_e	coefficient of volume expansion with concentration
ρ	fluid density
τ	non-dimensional skin friction
θ	nondimensional temperature

Subscripts and super scripts

W	wall
∞	for away from the wall
Prime	denotes differentiation with respect to y

APPENDIX

$$M_1 = M + \frac{1}{K} \qquad m_1 = \frac{Sc + \sqrt{Sc^2 + 4K_0 Sc}}{2} \qquad m_2 = \frac{\Pr + \sqrt{\Pr^2 + 4(F+Q)}}{2}$$

$$m_3 = \frac{1 + \sqrt{1 + 4M_1}}{2} \qquad m_4 = m_2 + m_3, \qquad m_5 = m_1 + m_2, \quad m_6 = m_1 + m_3 \qquad l_1 = \frac{-R}{m_1^2 - \Pr m_1 - (F+Q)}$$

$$l_2 = \frac{-Gr(1 - l_1)}{m_2^2 - m_2 - M_1} \qquad l_3 = \frac{-Gr\ l_1 - Gm}{m_1^2 - m_1 - M_1} \qquad K_1 = m_3(l_2 + l_3)$$

$$K_2 = -m_2 l_2, \qquad K_3 = -m_1 l_3 \qquad l_4 = \frac{-\Pr K_1^2}{4m_3^2 - 2\Pr m_3 - (F+Q)} \qquad l_5 = \frac{-\Pr K_2^2}{4m_2^2 - 2\Pr m_2 - (F+Q)}$$

$$l_6 = \frac{-\Pr K_3^2}{4m_1^2 - 2\Pr m_1 - (F+Q)} \qquad l_7 = \frac{-\Pr(2K_1 K_2)}{m_4^2 - \Pr m_4 - (F+Q)} \qquad l_8 = \frac{-\Pr(2K_2 K_3)}{m_5^2 - \Pr m_5 - (F+Q)}$$

$$l_9 = \frac{-\Pr(2K_1 K_3)}{m_6^2 - \Pr m_6 - (F+Q)} \qquad l_{10} = -(l_4 + l_5 + l_6 + l_7 + l_8 + l_9) \qquad l_{11} = \frac{-Gr\, l_4}{4m_3^2 - 2m_3 - M_1}$$

$$l_{12} = \frac{-Gr\, l_5}{4m_2^2 - 2m_2 - M_1} \qquad l_{13} = \frac{-Gr\, l_6}{4m_1^2 - 2m_3 - M_1} \qquad l_{14} = \frac{-Gr\, l_7}{m_4^2 - m_4 - M_1}$$

$$l_{15} = \frac{-Gr\, l_8}{m_5^2 - m_5 - M_1} \qquad l_{16} = \frac{-Gr\, l_9}{m_6^2 - m_6 - M_1} \qquad l_{17} = \frac{-Gr\, l_{10}}{m_2^2 - m_2 - M_1}$$

$$l_{18} = -(l_{11} + l_{12} + l_{13} + l_{14} + l_{15} + l_{16} + l_{17})$$

6. REFERENCES

[1]. Ravikumar V, Raju M.C., Raju G.S.S., Chamkha A.J. : MHD double diffusive and chemically reactive flow through porous medium bounded by two vertical plates. *Int. J. Energy Technology*, 2013, Vol.5 (4), pp.1-8.

[2]. Sinha A., Ahmed N., Agarwalla S. : MHD Free convective flow through a porous medium past a vertical plate with ramped wall temperature. *Applied Mathematical Sciences*, Vol.11, 2017, No.10, pp.963-974.

[3]. Kumar G.C. and Reddy G.V.R. : Radiation and chemical reaction effects on MHD flow fluid over an infinite vertical oscillating porous plate. *Int. J. Mathematics*, 2014, Vol.5 (6), pp.247-258.

[4]. Sarada K., Shanker B. : The effect of chemical reaction on an unsteady MHD free convection flow past an infinite vertical porous plate with variable suction, *IJMER,* 2013, Vol.3(2), pp.725-735.

[5]. Raju M.C., Varma S.V.K. : Unsteady MHD free convection oscillatory couette flow through a porous medium with periodic wall temperature. *J. Future Engg. Technology*, 2011, Vol.6 (4), pp.7-12.

[6]. Sudhakar Reddy T., Raju M.C., Varma S.V.K. : Chemical reaction and radiation effects on MHD free convection flow through a porous medium bounded by a vertical surface with constant heat and mass flux, *JCARME*, 2013, Vol.3(1), pp.53-62.

[7]. Kishore P.M., Vijaya Kumar, Varma S., Masthan Rao S., Bala K.S. : The effect of chemical reaction on MHD free convection flow of dissipative fluid past an exponentially accelerated vertical plate. *Int. J. Computational Engineering Research*, 2014, Vol 4(1).

[8]. Mondal S., Parvin S., Ahmmed S.F.: Effects of radiation and chemical reaction on MHD free convection flow past a vertical plate in the porous medium. *AJER*, 2014, Vol.3 (12), pp.15-22.

[9]. Mohammad Shah Alam, Mohammad Ali, Delwar Hossain Md. : Heat and mass transfer in MHD free convection flow over an inclined plate with hall current, *Int. J. Engineering and Science*, 2013, Vol.2(7), pp.81-88.

[10]. Hemalatha E., Bhasker Reddy N.: Effect of thermal radiation and chemical reaction on MHD free convection flow past a flat plate with heat source and convective surface boundary condition. *Int. J. Engg. Research and Applications*, 2015, Vol. 5(9), pp.107-116.

[11]. Chamkha A.J. : MHD flow of uniformly stretched vertical permeable surface in the presence of heat generation / absorption and chemical reaction, *Int. Commun.. Heat Mass transfer*, 2003, Vol.30 (3), pp.413-422.

[12]. Mishra S.R., Dash G.C., Acharya M. : Mass and heat transfer effect on MHD flow of a visco-elastic fluid through porous medium with oscillatory suction and heat source, *Int. J. Heat Mass transfer*, 2013, Vol.57, pp.157-165.

[13]. Shamker B. Prabhakar Reddy B., Anand Rao J. : Radiation and mass transfer effects on unsteady MHD free convective fluid flow embedded in a porous medium with heat generation / absorption. *Indian Journal of Pure and Applied Physics*, 2010, Vol.48, pp.157-165.

[14]. Saxen S.S. and Singh V.K. : Chemical reaction and heat generation on moving isothermal vertical surface through porous medium with uniform mass flux and transposition, *International Journal of Archive,* 2013, Vol. 4(4), pp.342-349.

[15]. Ramaiah P., Vijaya Kumar, Varma S., Ramakrishna Prasad K. and Balamurugan K.S.: Chemical reaction and radiation absorption effects on MHD convective heat and mass transfer flow of a visco-elastic fluid past an oscillating porous plate with heat generation / absorption. *Int. J. Chem. Sci.*, 2016, Vol. 14(2). Pp.570-584.

[16]. Satyanarayana P.V., Venkateswarlu B., Venaktaramana S.: Effects of Hall current and radiation absorption on MHD micro-polar fluid in a rotating system, Ain *Shams Engg. J.*, 2013, Vol.4 (4). Pp.843-854.

[17]. Raju M.C., Varma S.V.K., Reddy T.S.: Unsteady MHD free convection oscillating couette flow through a porous medium with periodic wall temperature in presence of chemical reaction and thermal radiation. *International Journal of Science and Advances in Technology,* 2011, Vol. 1(10), pp.51-58.

[18]. Durga Prasad P., Kiran Kumar R.V.M.S.S., Varma S.V.K.: Heat and mass transfer for the MHD of nanofluid with radiation absorption. *Aim Shams Engg. J.*, 2016.

[19]. Venkateswarlu S., Varma S.V.K., Kiran Kumar R.V.M.S.S., Raju C.S.K., Durga Prasad P.: Radiation absorption and viscous-dissipation on MHD flow of casson fluid over a vertical plate filled with porous layers, 2017, Vol. 11. Pp.43-56.

[20]. Raju M.C., Vidyasagar B., Varma S.V.K., Venakataramana S.: Radiation absorption effect on MHD, free convection, chemically reacting visco-ealsticf luid past an oscillatory vertical porous plate in slip flow regime, *Int. J. Engg. and Compt. Sci.,* 2014, Vol. 3(9), pp.8212-8221.

[21]. Cogley A.C., Vincenti W.G., Gill Se: Differential approximation for radiative transfer in a non-gray gas near equilibrium, *AIAAJ,* 1968, Vol.6, pp.551-553.

[22]. Mahapatra N., Dash G.C., Panda S., Acharya M.: Effects of chemical reaction on free convection flow through a porous medium bounded by a vertical surface, *Int. Eng. Phys. Thermo Phys.*, 2010, Vol.83(1).

[23]. Makinda O.D.: Free convection flow with thermal radiation and mass transfer past a moving vertical porous plate. *International Communications in Heat and Mass Transfer*, 2005, Vol. 32(10), pp.1411-1419.

[24]. Prakash, J., Sivsraj R., Rusikumar, B.: Influence of chemical reaction on unsteady MHD mixed convective flow over a moving vertical porous plate, *Int. J. Fluid Mech.*, 2011, Vol.3, pp.1-14.

[25]. Hitesh Kumar : Heat and mass transfer over an isothermal inclined plate at constant concentration gradient and with heat source, *World Applied Science Journal*, 2013, Vol.24(3), pp.364-369.

[26]. Reddy, P.C., Raju M.C., Raju G.S.S., Reddy C.M.: Diffusion thermo and thermal diffusion effects on MHD free convection flow of Rivlin- Ericksen fluid past a semi-infinite vertical plate, *Bulletin of Pure and Applied Sciences,* Vol.36E (Math &Stat.), No.2, 2017. pp.266-284 DOI: 10.5958/2320-3226.2017.00029.7

[27]. Reddy, P.R.K., Raju M.C.: 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, *Bulletin of Pure and Applied Sciences,* Vol.36E (Math & Stat.), No.2, 2017. pp.152-164. DOI: 10.5958/2320-3226.2017.00017.0

[28]. Krishniah, G., Varma S.V.K., Raju M.C. and Venkateswarlu : Study of free and forced convection flow in an inclined channel, *Bulletin of Pure and Applied Sciences*, Vol.24E (No.2), 2005, pp.491-509.

[29]. Raju, M.C., Varma S.V.K., Chamkha A.J.: Unsteady free convection flow past a periodically accelerated vertical plate with Newtonian heating, *International Journal of Numerical Methods for Heat and Fluid Flow*, Vol. 26, No. 7, 2016, pp. 2119-2138. DOI 10.1108/HFF-05-2014-0123.

[30]. Umamaheswar, M., Raju M.C., Varma S.V.K. and Kumar J.G.: Numerical investigation of MHD free convection flow of a non-Newtonian fluid past an impulsively started vertical plate in the presence of thermal diffusion and radiation absorption, *Alexandria Engg. J.* (2016), 55 (3), 2005-2014. http://dx.doi.org/10.1016/j.aej.2016.07.014

[31]. Umamaheswar, M., Varma S.V.K., Raju M.C., Chamkha A.J.: Unsteady MHD free convective double diffusive visco-elastic fluid flow past an inclined permeable plate in the presence of viscous dissipation and heat absorption, *Special topics and Reviews in Porous media: An International Journal*., Vol.6 (4). 2016, pp. 333-342.
DOI: 10.1615/SpecialTopicsRevPorousMedia.v6.i4.20