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UNSTEADY MHD FREE CONVECTION BOUNDARY LAYER FLOW OF RADIATION ABSORBING KUVSHINSKI FLUID THROUGH POROUS MEDIUM

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ABSTRACT

An analytical study is carried out for an unsteady MHD two dimensional free convection flow of a viscous, incompressible, radiating, chemically reacting and radiation absorbing Kuvshinski fluid through a porous medium past a semi-infinite vertical plate. The dimensionless equations governing the flow are solved by simple perturbation technique. The expressions for velocity, temperature and concentration are derived. The influence of various material parameters on flow quantities are studied and discussed with the help of graphs. The expressions for Skin friction, Nusselt number and Sherwood number are also derived and discussed numerically. Temperature increases with an increase in radiation parameter and radiation absorption parameter where as it decreases with an increase in Prandtl number. Concentration is observed to be decreased when chemical reaction parameter and Schmidt number increase.

Keywords: MHD, Heat and mass transfer, Radiation, Chemical reaction, Radiation absorption, Porous medium, Viscous dissipation, Kuvshinski fluid.

Contribution/ Originality

This study contributes in the existing literature of Newtonian fluids. Most of the practical problems involve non-Newtonian fluids type. This study uses new estimation methodology of analyzing the heat transfer characteristics of non-Newtonian fluid. This study originates new formula of solving nonlinear governing equations using perturbation method. This study is one of very few studies which have investigated on the heat and mass transfer characteristics of a well-known non-Newtonian fluid Kuvshinski fluid in the presence of uniform magnetic field. The paper's primary contribution is finding that effects of various physical parameters on the flow quantities. This study documents a well-known non Newtonian fluid namely Kuvshinski fluid in the presence of thermal radiation, radiation absorption and chemical reaction of first order.

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1. INTRODUCTION

Convective flow with simulation heat and mass transfer under the influence of magnetic field and chemical reaction arise in many transfer process both natural and artificial in many braches of sciences and engineering applications this phenomenon plays an important role in the chemical industry, power and cooling industry for drying, chemical vapor deposition on surfaces, cooling of nuclear reactors and petroleum industry. Natural convection flow occurs frequently in nature, as well as due to concentration differences or the combination of these two, for example in atmosphere flows, there exists differences in water concentration and hence the flow is influenced by such concentration difference. Abo Eldahab and Gendy [1] studied a problem of convective heat transfer past a continuously moving plate embedded in a non-Darcian porous medium in the presence of a magnetic field. Abo Eldahab and Gendy [2] also studied radiation effects on convective heat transfer in an electrically conducting fluid past a stretching surface with variable viscosity and uniform free-stream. Beg, et al. [3] studied the magneto hydrodynamic convection flow from a sphere to a non-Darcian porous medium with heat generation or absorption. Chamkha [4] considered unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Cortell [5] investigated, the suction, viscous dissipation and thermal radiation effects on the flow and heat transfer of a power-law fluid past an infinite porous plate. Shateyi, et al. [6] considered the magneto hydrodynamic flow past a vertical plate with radiative heat transfer.

Soudalgekar [7] analyzed the viscous dissipation effects on unsteady free convective flow past an infinite vertical porous plate with constant suction. Changes in fluid density gradients may be caused by non-reversible chemical reaction in the system as well as by the differences in molecular weight between values of the reactants and the products. In most cases of a chemical reaction, the reaction rate depends on the concentration of the species itself. A reaction is said to be first order, if rate of reactions is directly proportional to the concentration itself, for example, the formation smog is a first order homogeneous reaction. Consider the emission of nitrogen dioxide from the automobiles and other smoke –stacks, this Nitrogen dioxide reacts chemically in the atmosphere with unburned hydrocarbons (aided by sunlight) and produce peroxyacety initrate. Anjalidevi and Kandaswamy [8] investigated the effects of chemical reaction, heat and mass transfer on laminar flow along a semi-infinite horizontal plate. Das, et al. [9] studied the effects of mass transfer on flow past an impulsively started Infinite vertical plate with constant heat flux and chemical reaction. Ibrahim, et al. [10] considered the effects of chemical reaction and radiation absorption on unsteady MHD free convection flow past a semi-infinite vertical permeable moving plate with heat source and suction. Kandaswamy, et al. [11], [12] discussed the effects of chemical reaction, heat and mass transfer in boundary layer flow over a porous wedge with heat radiation in presence of suction or injection. Mahdy [13] considered the effect of chemical reaction and heat generation or absorption on double-diffusive convection from a vertical truncated cone in a porous media with variable viscosity. Muthucumarswamy and Ganesan [14] analyzed the diffusion and first order chemical reaction on impulsively started infinite vertical plate with variable temperature. Muthucumarswamy [15] studied the chemical reaction effects on vertical oscillating plate variable temperature. Patil and Kulkarni [16] considered the effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. Raju, et al. [17], [18] studied heat and mass transfer flow problems in the presence of chemical reaction and radiation. Heat absorption effect on MHD convective Rivlin-Ericksen fluid flow past a semi-infinite vertical porous plate was investigated by Ravikumar, et al. [19]. Reddy, et al. [20], [21] studied radiation and chemical reaction effects on unsteady MHD free convection flow past a moving vertical plate.

In all the above studies the fluid considered is Newtonian. Most of the practical problems involve non-Newtonian fluids type. Saleh, et al. [22] considered the heat and mass transfer in MHD visco-elastic fluid flow through a porous medium over a stretching with chemical reaction. Seddeek, et al. [23], [24] studied the effect of chemical reaction and variable viscosity on hydro magnetic mixed convection heat and mass transfer for Hiemenz flow through porous media with radiation in different flow geometries. Umamaheswar, et al. [25] studied an unsteady MHD free convective visco-elastic fluid flow bounded by an infinite inclined porous plate in the presence of heat source. In all the above studies the fluid considered was Newtonian and in few cases a non-Newtonian fluid. Motivated by the above studies, in this paper we have considered a well-known non Newtonian fluid namely Kuvshinski fluid in the presence of thermal radiation, radiation absorption and chemical reaction of first order. MHD free convection flow of a visco-elastic (Kuvshiniski type) dusty gas through a semi-infinite plate moving with velocity decreasing exponentially with time and radiative heat transfer was investigated by Prakash, et al. [26]. Effect 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 was investigated by Ibrahim, et al. [10]. Motivated by the above studies in this paper we have studied an unsteady MHD two dimensional free convection flow of a viscous, incompressible, radiating, chemically reacting and radiation absorbing Kuvshinski fluid through a porous medium past a semi-infinite vertical plate.

2. FORMULATION OF THE PROBLEM

We have considered an unsteady MHD two dimensional free convection flow of a viscous, incompressible, radiating, chemically reacting and radiation absorbing Kuvshinski fluid through a porous medium past a semi-infinite vertical plate. Let x^* axis is taken along the vertical plate in the upward direction in the direction of the flow and y^* axis is taken perpendicular to it. It is assumed that, initially, the plate and the fluid are at the same temperature T_∞^* and concentration C_∞^* in the entire region of the fluid. The effects of Soret and Dufour are neglected, as the level of foreign mass is assumed to be very low. The radiative heat flux in x^* direction is considered to be negligible in comparison to that of y^* axis. The fluid considered here is gray, emitting and absorbing radiation but non scattering medium. The presence of viscous dissipation cannot be neglected and also the presence of chemical reaction of first order and the influence of radiation absorption are considered. All the fluid properties are considered to be constant except the influence of the density variation caused by the temperature changes, in the body force term. It is also assumed that the induced magnetic field is neglected in comparison with applied magnetic field, as the magnetic Reynolds number is very small. Now, under the above assumptions, the flow field is governed by the following set of equations.

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

$$\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{\partial u^*}{\partial t*}+v^*\frac{\partial u^*}{\partial y^*}=g\beta\left(T^*-T^*_\infty\right)+g\beta^*\left(C^*-C^*_\infty\right)+\vartheta\frac{\partial^2u^*}{\partial y^{*2}}-\left(\frac{\sigma B_0^2}{\rho}+\frac{\vartheta}{K^*}\right)\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)u^* \tag{2}$$

$$\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{\partial T^*}{\partial t^*}+v^*\frac{\partial T^*}{\partial y^*}=\frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}}+\frac{\vartheta}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2-\frac{1}{\rho C_p}\frac{\partial q_r^{\ *}}{\partial y^*}+\frac{R_1}{\rho C_p}\left(C^*-C^*_\infty\right) \tag{3}$$

$$\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{\partial C^*}{\partial t^*}+v^*\frac{\partial C^*}{\partial y^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-K_1\left(C^*-C^*_\infty\right) \tag{4}$$

The boundary conditions at the wall and in the free stream are

$$u^*=v_0\left(1+\varepsilon e^{-t^*n^*}\right),\quad T^*=T^*_\infty,\ C^*=C^*_\infty \text{ at } y^*=0$$
$$u^*\to 0,\quad T^*\to 0,\quad C^*\to 0 \qquad \text{as } y^*\to\infty \tag{5}$$

The equation (1) gives $v^*=-V_0$ (6)

Where V_0 is the constant suction Velocity. The radiative heat flux $q^*{}_r$ using the Rosseland diffusion model for radiation heat transfer is expressed as

$$q^*=\frac{-4\sigma^*}{3K^*}\frac{\partial T^{*4}}{\partial y^*} \tag{7}$$

Where σ^* and K^* are respectively the Stream-Boltzmann constant and the main absorption coefficient. We assume that the temperature difference with in the flow are sufficiently small and T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding in Taylor series about T^*_∞ and neglecting higher order terms, thus

$$T^{*4}\cong 4T_\infty^{*3}-3T_\infty^{*4} \tag{8}$$

In view of equations (8) and (9) the equation (3) reduced to the following form

$$\left(1+\lambda^*\frac{\partial}{\partial t^*}\right)\frac{\partial T^*}{\partial t^*}+v^*\frac{\partial T^*}{\partial y^*}=\frac{K}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}}+\frac{16\sigma^*T_\infty^{*3}}{3\rho C_pK^*}\frac{\partial^2 T^*}{\partial y^{*^2}}+\frac{\vartheta}{C_p}\left(\frac{\partial u^*}{\partial y^*}\right)^2+\frac{R_1}{\rho C_p}\left(C^*-C^*_\infty\right) \tag{9}$$

Introducing the following dimensionless variable and parameters,

$$u=\frac{u^*}{V_0},y=\frac{y^*V_0}{\vartheta},t=\frac{t^*V_0^2}{\vartheta},n=\frac{n^*\vartheta}{V_0^2},\theta=\frac{T^*-T_\infty^*}{T_w^*-T_\infty^*},\varphi=\frac{C^*-C_\infty^*}{C_w^*-C_\infty^*},R=\frac{4\sigma^*T_\infty^{*3}}{K^*K},$$

$$Gr=\frac{g\beta\vartheta\left(T_w^*-T_\infty^*\right)}{V_0^3},Gm=\frac{g\beta^*\vartheta\left(C_w^*-C_\infty^*\right)}{V_o^3},\Pr=\frac{\mu C_p}{k},Sc=\frac{\vartheta}{D},K=\frac{K^*V_0^2}{\vartheta^2},$$

$$M=\frac{\sigma\beta_0^2\vartheta}{\rho V_0^2},\lambda=\frac{V_0^2\lambda^*}{\vartheta},E=\frac{V_0^2}{C_p(T_w^*-T_w^*)},R_a=\frac{R_1\vartheta(C_w^*-C_\infty^*)}{kV_0^2\left(T_w^*-T_\infty^*\right)},Kr=\frac{K_1\vartheta}{V_0^2} \tag{10}$$

into set of equations (2)-(5), we obtain

$$\alpha_1\frac{\partial u}{\partial t}+\lambda\frac{\partial^2 u}{\partial t^2}=\frac{\partial^2 u}{\partial y^2}+\frac{\partial u}{\partial y}-M_1u+Gr\theta+Gm\phi \tag{11}$$

$$\Pr\frac{\partial\theta}{\partial t}+\Pr\lambda\frac{\partial^2\theta}{\partial t^2}=N_1\frac{\partial^2\theta}{\partial y^2}+\Pr\frac{\partial\theta}{\partial y}+\Pr E\left(\frac{\partial u}{\partial y}\right)^2+R_a\phi \tag{12}$$

$$Sc\frac{\partial\phi}{\partial t}+Sc\lambda\frac{\partial^2\phi}{\partial t^2}=\frac{\partial^2\phi}{\partial y^2}+Sc\frac{\partial\phi}{\partial y}-KrSc\phi \tag{13}$$

Where $M_1=M+\frac{1}{K},N_1=1+\frac{4R}{3},\alpha_1=1+\lambda M_1$

The corresponding boundary conditions in non-dimensional form are

$$u=1+\varepsilon e^{-nt},\ \ \theta=1,\ \ \varphi=1\ \ at\ \ y=0,u\to 0,\ \ \ \theta\to 0,\ \ \ \varphi\to 0\ \ \ as y\to\infty \tag{14}$$

3. SOLUTION OF THE PROBLEM

The governing equations (11)-(13), of the flow, momentum, temperature and concentration respectively are coupled non-linear differential equations. Assuming ε to be very small, the perturbation parameter, we write.

$$u=u_0(y)+\varepsilon u_1(y)e^{-nt}+o(\varepsilon^2)................$$
$$\theta=\theta_0(y)+\varepsilon\theta_1(y)e^{-nt}+o(\varepsilon^2)................ \tag{15}$$
$$\varphi=\varphi_0(y)+\varepsilon\varphi_1(y)e^{-nt}+o(\varepsilon^2)...............$$

By substituting the above equation (15) into set of equations (11)-(13), and equating the harmonic terms and neglecting the higher order terms of $O(\varepsilon^2)$,we obtain the following pairs of equations for $\left(u_{0,}\theta_0,\phi_0\right)and(u_1,\theta_1,\phi_1)$

$$u_0^{11} + u_0^1 - M_1 u_0 = -Gr\theta_0 - Gm\phi_0 \quad (16)$$

$$u_1^{11} + u_1^1 - M_2 u_1 = -Gr\theta_1 - Gm\phi_1 \quad (17)$$

$$N_1\theta_0^{11} + \Pr\theta_0^1 = \Pr Eu_0^{12} - R_a\phi_1 \quad (18)$$

$$N_1\theta_1^{11} + \Pr\theta_1^1 + N_1\theta_1 = 2\Pr Eu_0^1 u_1^1 - R_a\phi_1 \quad (19)$$

$$\phi_0^{11} + Sc\phi_0^1 + ScKr\phi_0 = 0 \quad (20)$$

$$\phi_1^{11} + Sc\phi_1^1 + L_1\phi_1 = 0 \quad (21)$$

Where the primes denote differentiation with respect to y and $M_2 = M_1 - \alpha_1 n + \lambda n^2$,

$N_2 = n\Pr - n^2\Pr\lambda, L_1 = nSc - n^2 Sc\lambda - KrSc$

The corresponding boundary conditions are

$$\begin{aligned} &u_0 = 1,\ u_1 = 1,\ \theta_0 = 0,\ \theta_1 = 1,\ \varphi_0 = 0,\ \varphi_1 = 0,\ at\ \ y = 0 \\ &u_0 \to 0,\ u_1 \to 0,\ \theta_0 \to 0,\ \theta_1 \to 0,\ \varphi_0 \to 0,\ \varphi_1 \to 0\ \ as\ \ y \to \infty \end{aligned} \quad (22)$$

Solving the equations (20) and (21) subject the corresponding boundary conditions, we obtain.

$$\phi_0 = e^{-a_1 y} \quad (23)$$

The set of equations (16)-(19) are still coupled non-linear ordinary differential equations, whose exact solutions are not possible. To solve these equations, assuming the Eckert number E to be small, we write.

$$\begin{aligned} &u_0 = u_{01} + Eu_{02} + o\left(\varepsilon^2\right), u_1 = u_{11} + Eu_{12} + o\left(\varepsilon^2\right), \\ &\theta_0 = \theta_{01} + E\theta_{02} + o\left(\varepsilon^2\right), \theta_1 = \theta_{11} + E\theta_{12} + o\left(\varepsilon^2\right) \end{aligned} \quad (24)$$

Substituting the equations (24) in to equations (16)-(19), equating the coefficients of like powers of E and neglecting the higher order $O(E^2)$ terms of ,we obtain

$$u_{01}^{11} + u_{01}^1 - M_1 u_{01} = -Gr\theta_{01} - Gm\phi_0 \quad (25)$$

$$u_{11}^{11} + u_{11}^1 - M_2 u_{11} = -Gr\theta_{11} - Gm\phi_0 \quad (26)$$

$$N_1\theta_{01}^{11} + \Pr\theta_{01}^1 = -R_a\phi_0 \quad (27)$$

$$N_1\theta_{11}^{11} + \Pr\theta_{11}^1 + N_2\theta_{11} = -R_a\phi_1 \quad (28)$$

$$u_{02}^{11} + u_{02}^{1} - M_1 u_{02} = \_Gr\theta_{02} \quad (29)$$

$$u_{12}^{11} + u_{12}^{1} - M_2 u_{12} = -Gr\theta_{12} \quad (30)$$

$$N_1\theta_{02}^{11} + \Pr\theta_{02}^{1} = -\Pr u_{02}^{12} \quad (31)$$

$$N_1\theta_{12}^{11} + \Pr\theta_{12}^{1} + N_2\theta_{12} = -2\Pr u_{01}^{1} u_{11}^{1} \quad (32)$$

The corresponding boundary conditions are

$$\begin{aligned} &u_{01} = 1,\ u_{02} = 0,\ u_{11} = 1,\ u_{12} = 0 \\ &\theta_{01} = 1\ \ \theta_{02} = 0,\ \theta_{11} = 0,\ \theta_{12} = 0 \quad at \quad y = 0 \\ &u_{01} \to 0,\ u_{02} \to 0,\ u_{11} \to 0,\ u_{12} \to 0 \\ &\theta_{01} \to 0,\ \theta_{02} \to 0,\ \theta_{11} \to 0,\ \theta_{12} \to 0 \ \ as\ \ y \to \infty \end{aligned} \quad (33)$$

The analytical solutions of equations (26)-(33) under the boundary conditions (34) are given by

$$\theta_{01} = l_1 e^{-a_1 y} + l_2 e^{-b_1 y} \quad (34)$$

$$u_{01} = l_3 e^{-a_1 y} + l_4 e^{-b_1 y} + l_5 e^{-a_2 y} \quad (35)$$

$$\theta_{02} = l_6 e^{-b_1 y} + l_7 e^{-m_1 y} + l_8 e^{-m_2 y} + l_9 e^{-m_3 y} + l_{10} e^{-m_4 y} + l_{11} e^{-m_5 y} + l_{12} e^{-m_6 y} \quad (36)$$

$$u_{02} = l_{13} e^{-a_2 y} + l_{14} e^{-b_1 y} + l_{15} e^{-m_1 y} + l_{16} e^{-m_2 y} + l_{17} e^{-m_3 y} + l_{18} e^{-m_4 y} + l_{19} e^{-m_5 y} + l_{20} e^{-m_6 y} \quad (37)$$

$$u_{11} = e^{-b_2 y} \quad (38)$$

$$\theta_{12} = l_{21} e^{-a_3 y} + l_{22} e^{-m_7 y} + l_{23} e^{-m_8 y} + l_{24} e^{-m_9 y} \quad (39)$$

$$u_{12} = l_{25} e^{-b_2 y} + l_{26} e^{-a_3 y} + l_{27} e^{-m_7 y} + l_{28} e^{-m_8 y} + l_{29} e^{-m_9 y} \quad (40)$$

In view of the solutions (34)-(41), (23)-(24) and equations (15) and (25),the velocity, temperature and concentration distributions in the boundary layer become

$$\begin{aligned} u(y,t) = &\left[\left(l_3 e^{-a_1 y} + l_4 e^{-b_1 y} + l_5 e^{-a_2 y}\right) + E\begin{pmatrix} I_{13} e^{-a_2 y} + I_{14} e^{-b_1 y} + I_{15} e^{-m_1 y} + I_{16} e^{-m_2 y} \\ + I_{17} e^{-m_3 y} + I_{18} e^{-m_4 y} + I_{19} e^{-m_5 y} + I_{20} e^{-m_6 y} \end{pmatrix}\right] \\ &+ \varepsilon[e^{-b_2 y} + E\left(I_{25} e^{-b_2 y} + I_{26}\right) e^{-a_3 y} + I_{27} e^{-my_7} + I_{28} e^{-m_8 y} + I_{29} e^{-m_9}) e^{-nt})] \end{aligned} \quad (41)$$

$$\theta(y,t)=\begin{bmatrix}(I_1e^{-ay_1}+I_2e^{-b_1y})+E(I_6e^{-b_1y}+I_7e^{-m_2y}+I_8e^{-m_2y}+I_9e^{-m_3y}\\+I_{10}e^{-m_4y}+I_{11}e^{-m_5y}+I_{12}e^{-m_6y}\end{bmatrix}+ \tag{42}$$
$$\varepsilon\left[E\left(I_{21}e^{-a_3y}+I_{22}e^{-m_7y}+I_{23}e^{-m_8y}+I_{24}e^{-m_9y}\right)\right]e^{-nt}$$

$$\phi=e^{-a_1y} \tag{43}$$

3.1. Skin Friction

$$\tau=\left(\frac{\partial u}{\partial y}\right)_{y=0}=-\left[I_3a_1+I_4b_1+I_5a_2\right]-E\begin{bmatrix}I_{13}a_{12}+I_{14}b_1+I_{15}m_1+I_{16}m_2+I_{17}m_3+I_{18}m_4\\+I_{19}m_5+I_{20}m_6\end{bmatrix}- \tag{44}$$
$$\varepsilon\left[-b_2-E\left(I_{25}b_2+I_{26}a_3-I_{27}m_7-I_{28}m_8-I_{29}m_9\right)e^{-nt}\right]$$

3.2. Nusselt Number

$$\left(\frac{\partial\theta}{\partial y}\right)_{y=0}=-\left[(I_1a_1+I_2b_1)-E\left(I_6b_1+I_7m_1+I_8m_2+I_9m_3+I_{10}m_4+I_{11}m_5+I_{12}m_6\right)\right] \tag{45}$$
$$-\varepsilon\left[E\left(I_{21}a_3+I_{22}m_7+I_{23}\,m_8+I_{24}m_9\right)e^{-nt}\right]$$

3.3. Sherwood Number

$$\left(\frac{\partial\phi}{\partial y}\right)_{y=0}=-a_1 \tag{46}$$

4. RESULTS AND DISCUSSION

In order to look into the physical insight of the problem, the expressions obtained in previous section are studied with help of graphs from figures 1-12. The effects of various physical parameters viz., the Schmidt number (Sc), the thermal Grashof number (Gr), the mass Grashof number (Gm), magnetic parameter (M), radiation parameter (R), radiation absorption parameter (Ra) and chemical reaction parameter (Kr) are studied numerically by choosing arbitrary values. Fig.1depicts the variations in velocity profiles for different values of Schmidt number. From this figure it is noticed that, velocity decreases as Sc increases. Physically it is true as the concentration increase the density of the fluid increases which results a decrease in fluid particles. In fig.2, effect of thermal Grashof number on velocity is presented. As Gr increases, velocity also increases. This is due to the buoyancy which is acting on the fluid particles due to gravitational force that enhances the fluid velocity. A similar effect is noticed from Fig.3, in the presence of solute Grashof number, which also increases fluid velocity. In figure 4, velocity profiles are displayed with the variation in magnetic parameter. From this figure it is noticed that velocity gets reduced by the increase of magnetic parameter. Because the magnetic force which is applied perpendicular to the plate, retards the flow, which is known as Lorentz force.

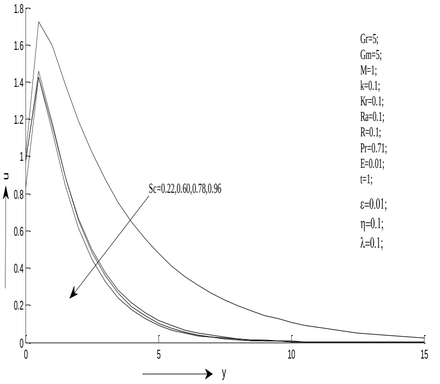

Fig-1. Effect of Schmidt number on Velocity

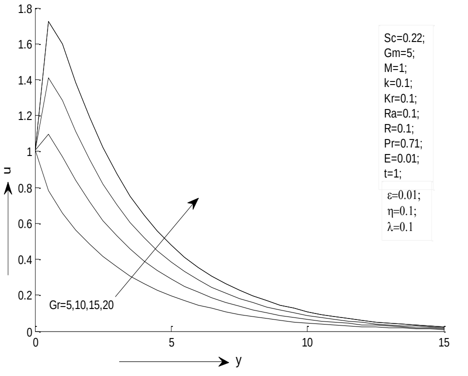

Fig-2. Effect of Grashof number on Velocity

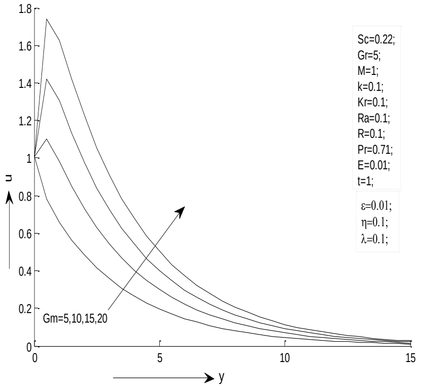

Fig-3. Effect of modified Grashof number on Velocity

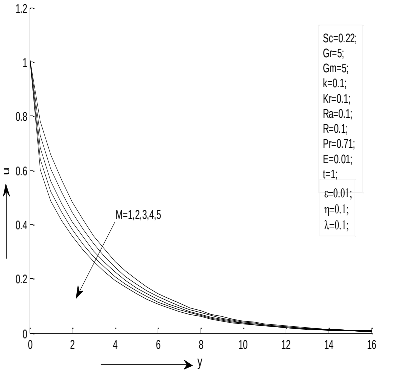

Fig-4. Effect of magnetic parameter on Velocity

Hence the presence of this retarding force reduces the fluid velocity. Effect of chemical reaction on velocity is presented in figure 5, from which it is noticed that velocity decreases with an increase in chemical reaction parameter because of the presence of viscous dissipation. But it is quite interesting to notice that a reverse phenomenon near the plate. As usual the magnitude of velocity is high near the plate and it gradually decreases and reaches to free stream velocity.

Figure 6, depicts the radiation parameter effect on velocity, as radiation increases, velocity also increases. This is because of the fluid considered here which is gray, emitting and absorbing radiation but non-scattering medium. Whereas reverse phenomenon is noticed in the case of radiation absorption parameter, from figure 7. Figure 8 exhibits the velocity profiles for various values of Prandtl number. From this figure it is observed that velocity decreases with an increase in Prandtl number.This is physically true because, the Prandtl number is a dimensionless number which is the ratio of momentum diffusivity (kinematic viscosity) to thermal diffusivity. In many of the heat transfer problems, the Prandtl number controls the relative thickness of the momentum and thermal boundary layers. When Pr is small, it means that the heat diffuses very quickly compared to the velocity (momentum). This means that for liquid metals the thickness of the thermal boundary layer is much bigger than the velocity boundary layer.

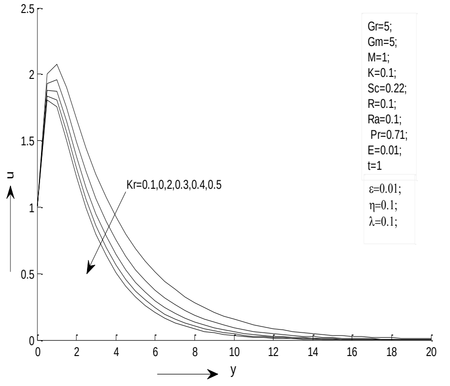

Fig-5. Effect of chemical reaction parameter on Velocity

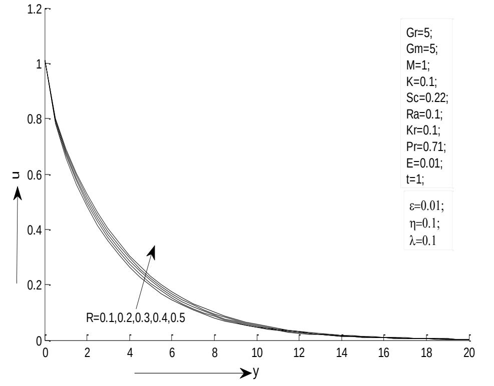

Fig-6. Effect of radiation parameter on Velocity

This is absolutely coincide with the result that is shown in figure 9 where the thermal boundary layer shrinks for higher values of Prandtl number. Effect of radiation parameter and radiation absorption parameter on temperature are studied from figures 10 and 11. From these figures it is noticed that temperature increases as radiation parameter and radiation absorption parameter increases. This is because the thermal radiation is associated with high temperature, thereby increasing the temperature distribution of the fluid flow. Effect of chemical reaction parameter on temperature and concentration are presented in figures 12 and 13 respectively. From these figures it is noticed that both thermal boundary layer and concentration boundary layer shrink when the values of chemical reaction parameter increases. Influence of Schmidt number on concentration is shown in figure 14, from this figure it is noticed that concentration decreases with an increase in Schmidt number. Because, Schmidt number is a dimensionless number defined as the ratio of momentum diffusivity and mass diffusivity, and is used to characterize fluid flows in which there are simultaneous momentum and mass diffusion convection processes. Therefore concentration boundary layer decreases with an increase in Schmidt number.

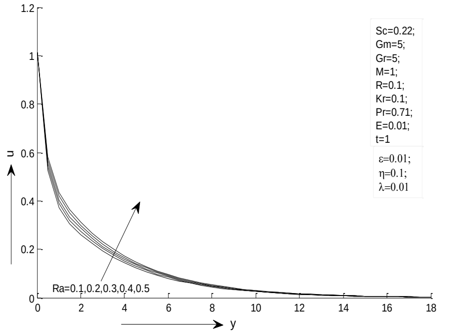

Fig-7. Effect of radiation absorption parameter on Velocity

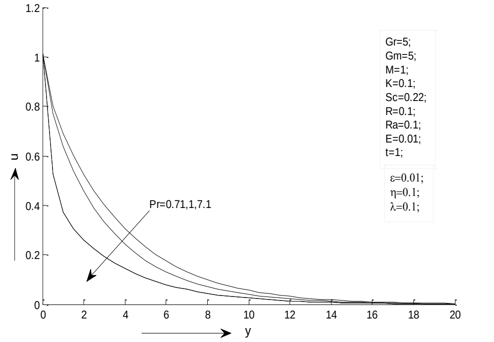

Fig-8. Effect of Prandtl number on Velocity

The effect of various material parameters on Skin friction, Nusselt number and Sherwood number are presented in table 1. From this table it is noticed that both Skin friction and as well as Nusselt number increase with an increase in Prandtl number. A similar effect is seen in the case of permeability parameter of the porous medium. Both Skin friction and Nusselt number decrease with an increase in radiation parameter, where as they increase in the presence of the radiation absorption parameter. Similar results are reported by Kesavaiah, et al. [27], Sudheer Babu and Satya Narayana [28] and Venkateswarlu and Satya Narayana [29]. When an increase in Grashof number Skin friction and Nusselt number also increase. But they have shown opposite phenomenon in the case of modified Grashof number. When magnetic parameter increases Skin friction decreases but Nusselt number increases. When Schmidt number increases, Skin friction, Nusselt number and Sherwood number also decrease. Whereas the presence of chemical reaction parameter increases the Skin friction and Nusselt number and it decreases the Sherwood number.

5. CONCLUSION

In this paper a theoretical study is carried out for an unsteady MHD two dimensional free convection flow of a viscous, incompressible, radiating, chemically reacting and radiation absorbing Kuvshinski fluid through a porous medium past a semi-infinite vertical plate. The dimensionless equations governing the flow are solved by simple perturbation technique. The fundamental parameters found to have an influence on the problem under consideration are magnetic field parameter, radiation parameter, permeability of the porous medium, radiation absorption parameter, Grashof number, modified Grashof number, Schmidt number, chemical reaction parameter and Prandtl number. The main conclusions are as follows.

(i) Velocity increases when Grashof number Gr, modified Grashof number Gm, radiation parameter R, increase where as it decreases when an increase in magnetic parameter M, Schmidt number Sc, chemical reaction parameter Kr, radiation absorption parameter Ra, Prandtl number Pr .

(ii) Temperature increases with an increase in radiation parameter R and radiation absorption parameter Ra where as it decreases with an increase in Prandtl number.

(iii) Concentration is observed to be decreased when chemical reaction parameter Kr and Schmidt number Sc increase.

(iv) Skin friction increases with an increase in Prandtl number Pr, permeability parameter K, radiation absorption parameter Ra, Grashof number Gr, chemical reaction parameter Kr where as it has reverse effect in the case of magnetic parameter M, radiation parameter R, modified Grashof number Gm , Schmidt number Sc.

(v) Nusselt number increases with an increase in Pr, Ra, Gr, Kr, Gm, M where as it has reverse effect in the case of R, Sc. Sherwood number gets decreased when Sc and Kr both are increased.

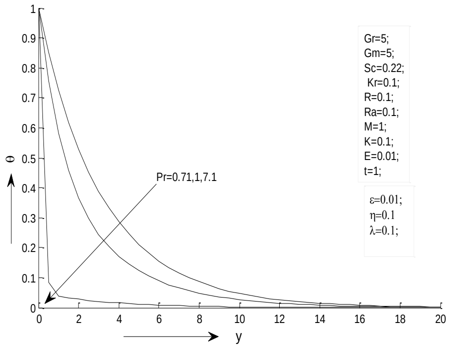

Fig-9. Effect of Prandtl number on Temperature

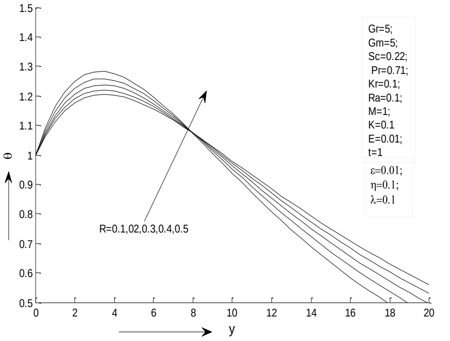

Fig-10. Effect of Rradiation parameter on Temperature

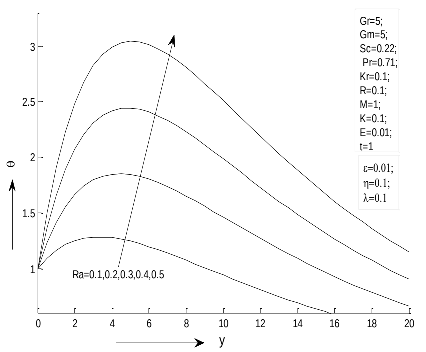

Fig-11. Effect of radiation absorption parameter on Temperature

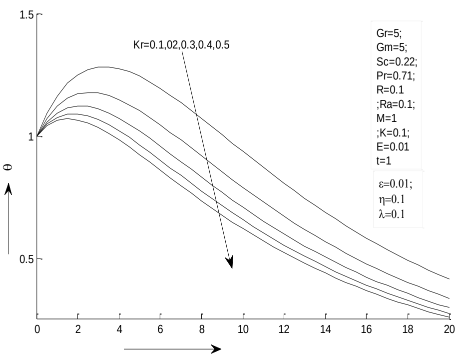

Fig-12. Effect of chemical reaction parameter on Temperature

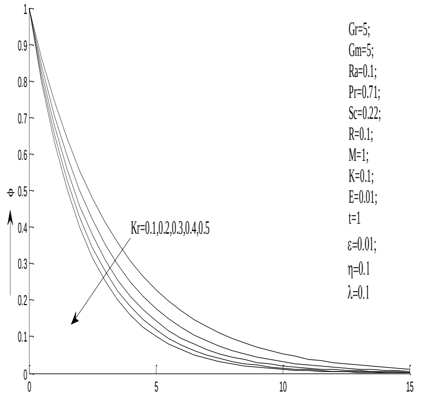

Fig-13. Effect of chemical reaction parameter on concentration

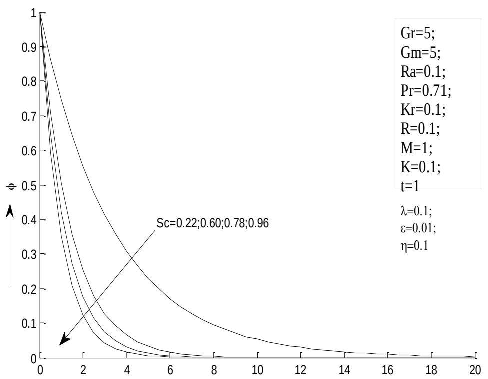

Fig-14. Effect of Schmidt number on concentration

Table-1. Effect of various physical parameters on Skin friction, Nusselt number and Sherwood number

Pr	K	R	Ra	Gr	Gm	M	Sc	Kr	τ	Nu	Sh
0.71	0.1	0.1	0.1	5	5	1	0.22	0.1	-404.4865	-833.2364	-0.2947
1	0.1	0.1	0.1	5	5	1	0.22	0.1	-330.1611	-583.1306	-0.2947
7.1	0.1	0.1	0.1	5	5	1	0.22	0.1	237.2012	-32.0932	-0.2947
0.71	0.2	0.1	0.1	5	5	1	0.22	0.1	-295.2018	-400.5198	-0.2947
0.71	0.3	0.1	0.1	5	5	1	0.22	0.1	-258.2399	-284.7547	-0.2947
0.71	0.4	0.1	0.1	5	5	1	0.22	0.1	-239.5018	-231.7190	-0.2947
0.71	0.1	0.2	0.1	5	5	1	0.22	0.1	-408.9999	-828.7282	-0.2947
0.71	0.1	0.3	0.1	5	5	1	0.22	0.1	-412.4082	-835.1465	-0.2947
0.71	0.1	0.4	0.1	5	5	1	0.22	0.1	-413.3485	-850.9968	-0.2947
0.71	0.1	0.1	0.2	5	5	1	0.22	0.1	-401.9730	-826.3209	-0.2947
0.71	0.1	0.1	0.3	5	5	1	0.22	0.1	-399.4634	-819.4343	-0.2947
0.71	0.1	0.1	0.4	5	5	1	0.22	0.1	-396.958	-812.5765	-0.2947
0.71	0.1	0.1	0.1	10	5	1	0.22	0.1	-858.5686	-48.297682	-0.2947
0.71	0.1	0.1	0.1	5	10	1	0.22	0.1	-479.1602	-898.7450	-0.2947
0.71	0.1	0.1	0.1	5	15	1	0.22	0.1	-468.2879	-966.5552	-0.2947
0.71	0.1	0.1	0.1	5	5	2	0.22	0.1	-426.3409	-936.2306	-0.2947
0.71	0.1	0.1	0.1	5	5	3	0.22	0.1	-448.2408	-28.220179	-0.2947
0.71	0.1	0.1	0.1	5	5	4	0.22	0.1	-470.1964	-23.238163	-0.2947
0.71	0.1	0.1	0.1	5	5	1	0.60	0.1	172.3885	-269.4857	-0.6873
0.71	0.1	0.1	0.1	5	5	1	0.78	0.1	162.6170	-261.6384	-0.8697
0.71	0.1	0.1	0.1	5	5	1	0.96	0.1	160.8191	-271.7923	-1.0513
0.71	0.1	0.1	0.1	5	5	1	0.22	0.2	-312.4792	-581.0448	-0.3469
0.71	0.1	0.1	0.1	5	5	1	0.22	0.3	-267.6948	-469.1161	-0.3895
0.71	0.1	0.1	0.1	5	5	1	0.22	0.4	-241.1264	-406.8787	-0.4264

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