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Chemical Reaction and Soret Effects on Unsteady MHD Free Convective Flow past a Vertical Porous Plate Embedded In a Porous Medium ina Slip Flow Regime

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Abstract:*Unsteady MHD free convection laminar heat and mass transfer flow past a semi-infinite vertical porous plate embedded with porous medium in a slip flow regime in presence of chemical reaction and thermo diffusion is analytically investigated. A magnetic field of uniform strength is applied in the direction normal to the plate. Slip flow condition for the velocity are taken into account in the boundary conditions. The governing equations are solved using perturbation technique. The analytical solutions of the velocity profile, temperature profile, concentration profile, skin-friction coefficient, Nusselt number and Sherwood number are reported in the present study. All numerical calculations are done with respect to air at 20^0C (Pr = 0.71). The effects of various parameters such as Pr, Gr, Gm, Sc, So, Kr M, K, R and Q are discussed through graphs and tables.*

Key Words:*MHD, free convection, chemical reaction, thermo-diffusion, skin-friction.*

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I INTRODUCTION

Flow through porous medium past infinite vertical plate is common in nature and has many applications in engineering and science. The study of heat and mass transfer with chemical reaction is of great importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. A chemical reaction is said to be first – order if the rate of reaction is directly proportional to the concentration itself. In many chemical processes a reaction occurs between a foreign mass and a fluid in which a plate is moving. These processes are found in many industrial applications such as food processing, manufacturing of chemicals and polymer production. Recently, many researchers have given attention to the effects of transversely applied magnetic field and thermal perturbation on the flow of electrically conducting viscous fluids. Various properties associated with the interplay of magnetic fields and thermal perturbation in porous medium past vertical plate find useful applications in astrophysics, geophysical fluid dynamics and engineering.

Chamkha (2004) [5] studied the unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption. Natural convection boundary layerflow along a heated vertical plate in a Stratified environment was studied by Henkes et al. (1989) [4]. The effects of chemical reaction, thermophoresis and variable viscosity on a study of hydro magnetic flow with heat and mass transfer over a flat plate in the presence of heat generation/absorption was examined by Seddeek [3]. Takhar et al. (1996) [2] investigated the radiation effects on MHD free convection flow of a radiating gas past a semi-infinite vertical plate. The unsteady hydro magnetic free convection flow with radiative transfer in a rotating fluid was discussed by Bestman and Adjepong (1998) [1]. Muthucumaraswamy and Ganesan (2002) [6] studied the diffusion and first-order chemical reaction on impulsively started infinite vertical plate with variable temperature. Badruddin et al. (2005) [7] analyzed the free convection and radiation characteristics for a vertical plate embedded in a porous medium. Abd-ElAziz(2006) [8] investigated the thermal radiation effects on a magneto hydrodynamic mixed convection flow of a micro polar fluid past a continuously moving semi-infinite plate for high temperature differences. The influence of chemical reaction on transient MHD free convection over a moving vertical plate was discussed by Al-Odat and Al-Azab(2007) [9]. The heat and mass transfer of unsteady MHD natural convection flow of a rotating fluid past a vertical porous plate in the presence of radiative heat transfer was analyzed by Mbeledogu and Ogulu (2007) [10]. The mathematical analysis of time-varying 2-dimensional natural convective flow of an incompressible, electrically conducting fluid along an infinite vertical porous plate embedded in a porous medium was studied the boundary layer flow over a semi-infinite plate with an aligned magnetic field in the presence of a pressure gradient and obtained the solutions for large and small magnetic prandtl number, using the method of matched asymptotic expansion.

The main aim of proposed paper is to study the Unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with heat absorption, radiation, chemical reaction, soret effect and thermal diffusivity. In obtaining the solution, the terms regarding radiation effect, temperature gradient dependent heat source are taken into account of energy equation and chemical reaction parameter, soret effect and thermal diffusion effect are taken into account of concentration equation. Most of the earlier works are assumed that the semi-infinite plate is at rest. But in the present project the plate is embedded in a uniform porous medium and moves with a constant velocity in the direction of flow and in the presence of a transverse magnetic field. The Permeability of the porous medium and the suction velocity are considered to be as exponentially decreasing function of time.

II MATHEMATICAL ANALYSIS

We consider a two-dimensional unsteady flow of a laminar, incompressible, electrical conducting and heat absorbing fluid past a semi-infinite vertical porous plate embedded in a uniform porous medium. The governing equations for this study are based on the conservation of mass, linear momentum, energy and species concentration. Taking in to consideration the assumptions made above, these equations in Cartesian frame of reference are given by equation of

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

$$\frac{\partial \bar{u}}{\partial \bar{t}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial \bar{x}} + g\beta(T - \bar{T}_\infty) + g\beta^*(\bar{C} - \bar{C}_\infty) + v\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} - \frac{\sigma B_0^2}{\rho}\bar{u} - \frac{v}{K^*}\bar{u}$$

(2)Energy Equation $\frac{\partial \bar{T}}{\partial \bar{t}} + \bar{v}\frac{\partial \bar{T}}{\partial \bar{y}} = \frac{k}{\rho C_p}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - \frac{1}{\rho C_p}\frac{\partial q_r^*}{\partial \bar{y}} - \frac{Q_0(\bar{T} - \bar{T}_\infty)}{\rho C_p}$

(3)Species equations $\frac{\partial \bar{C}}{\partial \bar{t}} + \bar{v}\frac{\partial \bar{C}}{\partial \bar{y}} = D_M\frac{\partial^2 \bar{C}}{\partial \bar{y}^2} D_T\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} - K(\bar{C} - \bar{C}_\infty)$

(4)Where x,y and t* are the dimensional distances along and perpendicular to the plate and dimensional time, respectively. u *and v*are the components of the dimensional velocities along x and y respectively. P is the density of the medium, *g* is the acceleration due to gravity, v is the kinematic viscosity, σ is the fluid electrical conductivity, $B_0$is the magnetic induction, K* is the permeability of the porous medium, $\beta_T$is the coefficient of thermal expansion, β_C is the coefficient of mass expansion, T is the dimensional temperature of the fluid near the plate, T_∞ is the dimensional free stream temperature, c is the dimensional concentration of the fluid near the plate, c_∞ is the dimensional free stream concentration, *k* is the thermal conductivity of the fluid, q_r*is the radioactive heat flux, the term Q_0 (T - T_∞) is assumed to be amount of heat generated or absorbed per unit volume, Q_0 is constant, which may take on either positive or negative values. When plate temperature T exceeds the free stream temperature T_∞ , the source term Q_0> 0 and heat sink when Q_0< 0, μ is the fluid viscosity, c_p is the specific heat at constant pressure, D_M is the coefficient of chemical molecular diffusivity and D_T is the coefficient of thermal diffusivity,and K is chemical reaction parameter .

Under the assumption, the appropriate boundary conditions for velocity involving slip flow, temperature and concentration fields are given by

$$\bar{u} = \bar{u}_{slip} = \bar{h}\frac{\partial \bar{u}}{\partial \bar{y}},\ \bar{T} = \bar{T}_W + \varepsilon(\bar{T} - \bar{T}_\infty)e^{n^* t^*},\ \bar{C} = \bar{C}_W + \varepsilon(\bar{C}_W - \bar{C}_\infty)\,\mathrm{e}^{n^* t^*} \quad \text{at} \quad \bar{y} = 0 \tag{6}$$

$$\bar{u} \to \bar{U}_\infty = U_0(1 + \varepsilon e^{n^* t^*}), \qquad \bar{T} \to \bar{T}_\infty, \qquad \bar{C} \to \bar{C}_\infty \quad \text{as} \quad \bar{y} \to \infty$$

(7)Where T_w and C_w are the dimensional temperature and species concentration at the wall respectively and **h** is the characteristic dimension of the flow fluid. The suction velocity normal to the plate is a function of time only, it can be taken in the exponential form as $\bar{v} = -V_0(1 + \varepsilon A e^{n^* t^*})$ (8), Where*A* is a real positive constant**, ε** and**εA** are small quantities less than unity and **V_0**is a scale of suction velocity which is a non-zero positive constant. In the free stream, from equation (2) we get

$$-\frac{1}{\rho}\frac{\partial \bar{P}}{\partial \bar{x}} = \frac{d\bar{U}_\infty}{d\bar{t}} + \frac{\sigma B_0^2}{\rho}\bar{U}_\infty + \frac{v}{K^*}\bar{U}_\infty \tag{9}$$

Now we introduce the dimensionless variables as follows $u=\frac{\bar{u}}{U_0}$ $,v=\frac{\bar{v}}{V_0}$ $,y=\frac{\bar{y}V_0}{v}$ $,U_\infty=\frac{\bar{U}_\infty}{U_0}$ $,t=\frac{\bar{t}V_0^2}{v}$ $,\theta=\frac{\bar{T}-\bar{T}_\infty}{\bar{T}_w-\bar{T}_\infty}$ $,\phi=\frac{\bar{C}-\bar{C}_\infty}{\bar{C}_w-\bar{C}_\infty}$, $n=\frac{n^*v}{V_0^2}$ $,K=\frac{K^*V_0^2}{v^2}$ $,\Pr=\frac{\mu C_p}{k}$ $,M=\frac{\sigma B_0^2 v}{\rho V_0^2}$,

$Gr=\frac{v\beta g(\bar{T}_w-\bar{T}_\infty)}{U_0V_0^2}$, $Gm=\frac{v\beta^* g(\bar{C}_w-\bar{C}_\infty)}{U_0V_0^2}$ $,Q=\frac{Q_0 v}{\rho C_p V_0^2}$, $R=\frac{4vI^*}{\rho C_p V_0^2}$ $,h=\frac{V_0\bar{h}}{v}$,

$$So=\frac{D_T}{v}\left(\frac{\bar{T}_w-\bar{T}_\infty}{\bar{C}_w-\bar{C}_\infty}\right),\ Sc=\frac{v}{D_M},\qquad K=\frac{k^*V_0^2}{v^2} \tag{10}$$

where *Pr* is the Prandtl number, *M* is the magnetic field parameter, *Gr* is the Grashof number for heat transfer, *Gm* is the Grashof number for mass transfer, *Q* is the heat sink parameter, α is the permeability parameter, θ is the non dimensional temperature, C is the non dimensional concentration, *R* is the radiation parameter, *h* is the rarefaction parameter, *So* is the Soret number and *Sc* is the Schmidt number.In view of equations (8) to (10) the governing equations (2), (3) and (4) reduce the following non-dimensional form:

$$\frac{\partial u}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}+G_r\theta+G_m\phi+N(U_\infty-u) \tag{11}$$

$$\frac{\partial\theta}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial\theta}{dy}=\frac{1}{\Pr}\frac{\partial^2\theta}{\partial y^2}-R\theta-Q\theta \tag{12}$$

$$\frac{\partial\phi}{\partial t}-(1+\varepsilon Ae^{nt})\frac{\partial\phi}{dy}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}+So\frac{\partial^2\theta}{\partial y^2}-Kr\phi \tag{13}$$

Where N=M+1/K, The boundary conditions (6) and (7) in the dimensionless form can be written as

$$u=u_{slip}=h\frac{\partial u}{\partial y},\qquad \theta=1+\varepsilon e^{nt},\quad \phi=1+\varepsilon e^{nt}\quad \text{at } y=0 \tag{14}$$

$$u=U_\infty=1+\varepsilon e^{nt},\qquad \theta\to 0,\qquad \phi\to 0\quad \text{as } y\to\infty \tag{15}$$

III SOLUTION OF THE PROBLEM

Equations (11) to (13) are coupled non-linear partial differential equations and these can be solved in closed form However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. These can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the plate as

$$u=u_0(y)+\varepsilon e^{nt}u_1(y)+O(\varepsilon^2) \tag{16}$$

$$\theta=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)+O(\varepsilon^2) \tag{17}$$

$$\phi=\phi_0(y)+\varepsilon e^{nt}\phi_1(y)+O(\varepsilon^2) \tag{18}$$

Substituting (16) to (18) in equations (11) to (13) and equating the harmonic and non harmonic terms and neglecting the coefficient of $O(\varepsilon^2)$ we get the following pairs of equations for(u_0,θ_0,h_0) and (u_1,θ_1,h_1).

$$u_0''+u_0'-Nu_0=-N-G_r\theta_0-G_m\phi_0 \tag{19}$$

$$u_1''+u_1'-(N+n)u_1=-Au_0'-G_r\theta_1-G_m\phi_1-(N+n) \tag{20}$$

$$\theta_0''+\Pr\theta_0'-\Pr(R+Q)\theta_0=0 \tag{21}$$

$$\theta_1''+\Pr\theta_1'-\Pr(R+Q+n)\theta_1=-\Pr A\theta_0',\qquad \phi_0''+Sc\phi_0'-KrSc\phi_0=-ScSo\theta_0'' \quad (22)\ \&(23)$$

$$\phi_1''+Sc\phi_1'-Sc(\mathrm{Kr}+n)\phi_1=-ASc\phi_0'-SoSc\theta_1'' \tag{24}$$

where the primes denote the differentiation with respect to *y*. The corresponding boundary conditions can be written as

$u_0 = hu_0'$, $u_1 = hu_1'$, $\theta_0 = 1,\ \theta_1 = 1,\ \phi_0 = 1,\ \phi_1 = 1$ at y=0 (25)

$u_0 = 1,$ $u_1 = 1$, $\theta_0 \to 0$, $\theta_1 \to 0$, $\phi_0 \to 0$, $\phi_1 \to 0$ at $y \to \infty$ (26)

The solutions of equations (19) to (24) which satisfy the boundary conditions (25) and (26) are given by

$$u_0 = 1 + A_{10}e^{-m_1 y} + (A_7 + A_9)e^{-m_4 y} + A_8 e^{-m_8 y} \quad (27)$$

$$u_1 = 1 + A_{22}e^{-m_{12} y} + A_{11}e^{-m_1 y} + A_{12}e^{-m_4 y} + A_{13}e^{-m_8 y} + A_{14}e^{-m_6 y} + A_{15}e^{-m_4 y} + A_{16}e^{-m_{10} y} + A_{17}e^{-m_8 y} + A_{18}e^{-m_4 y} + A_{19}e^{-m_6 y} \quad (28)$$

$$\theta_0 = e^{-m_4 y} \quad (29)$$

$$\theta_1 = (1 - A_1)e^{-m_6 y} + A_1 e^{-m_4 y} \quad (30)$$

$$\phi_0 = (1 - A_2)e^{-m_8 y} + A_2 e^{-m_4 y} \quad (31)$$

$$\phi_1 = [1 - (A_3 + A_4 + A_5 + A_6)]e^{-m_{10} y} + A_3 e^{-m_8 y} + (A_4 + A_6)e^{-m_4 y} + A_5 e^{-m_6 y} \quad (32)$$

It is now important to calculate the physical quantities of primary interest, which are the local wall shear stress, the local surface heat and mass flux. Given the velocity field in the boundary layer, we can now calculate the local wall shear stress (i.e., skin-friction) is given by

$$\tau_w^* = \mu\left(\frac{\partial u^*}{\partial y^*}\right) \ at\ y^* = 0 \quad (36)$$

And in dimension less form we obtain $C_f = \frac{\tau_w^*}{\rho U_0 V_0} = \frac{\partial u}{\partial y}$ at y = 0 (37)

$$= -m_1 A_{10} - m_4 (A_7 + A_9) - m_8 A_8 + \varepsilon e^{nt}(-m_{12}A_{22} - m_1 A_{11} - m_4 A_{12} - m_8 A_{13} - m_6 A_{14} - m_4 A_{15} - m_{10}A_{16} - m_8 A_{17} - m_4 A_{18} - m_6 A_{19})$$

Knowing the temperature field, it is interesting to study the non-dimensional form of the rate of heat transfer in terms of Nusselt number at the plate is given by: $N_u = -\left(\frac{\partial \theta}{\partial y}\right) \ at\ y = 0 \ = -(-m_4 + \varepsilon e^{nt}(-m_6 (1 - A1 - m4\, A1)$

Knowing the concentration field, it is interesting to study the non-dimensional form of the rate of mass transfer in terms of Sherwood number at the plate is given by: $S_h = -\left(\frac{\partial \phi}{\partial y}\right) \ at\ y = 0$, $= -[-m_8(1 - A_2) - m_4 A_2 + \varepsilon e^{nt}[-m_{10}(1 - (A_3 + A_4 + A_5 + A_6))] - m_8 A_3 - m_4(A_4 + A_6) - m_6 A_5]$

IV RESULTS AND DISCUSSIONS

To evaluate the physical intensity of the problem, we have carried out numerical calculations for non-dimensional velocity field, temperature field, concentration field, co-efficient of skin-friction C_f at the plate, the rate of heat transfer in terms of Nusselt number N_u and the rate of mass transfer in terms of Sherwood number S_h by assigning specific values to the different values to the parameters involved in the problem, viz., Magnetic field parameter *M,* chemical reaction perameter Kr and Soret number *So*. In the present study, the following default parametric values are adopted. *Gr = 6.0, Gm = 4.0, M = 3.0, K = 1.0, n = 0.1, A = 1.0, t = 1.0, Pr = 0.71, R = 1.0, Q = 1.0, Sc = 0.6, So = 1.0, h = 0.3 and* ε*= 0.2.* All graphs therefore correspond to these unless specifically indicated on the appropriate graph. The numerical results are demonstrated through different graphs and table and their results are interpreted physically. Figure 1 plots the velocity profiles against the span-wise coordinate y for different magnetic field parameter *M*. this illustrates that velocity decreases as the existence of magnetic field becomes stronger. This conclusion agrees with the fact that magnetic field exerts retarding force on the free-convection flow.In figure 2 the effects of Soret number So on velocity is shown. From this figure it is notified that velocity increases as So increases. In figure.3 the velocity decrease as chemical reaction parameter Kr increase.In figures.4, it is clearly shown that the concentration profile decrease as the chemical reaction parameter Kr increase.And finally from the figure.5, the concentration distribution increases as the Soret effect So increases.

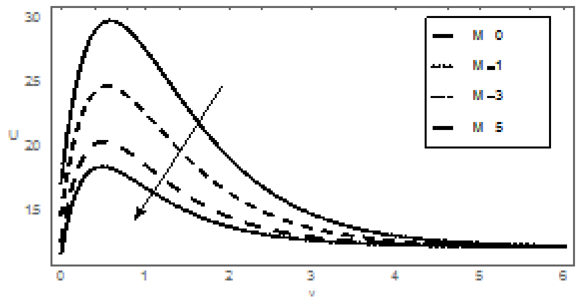

Fig.1 Velocity u versus y under the effect of M.

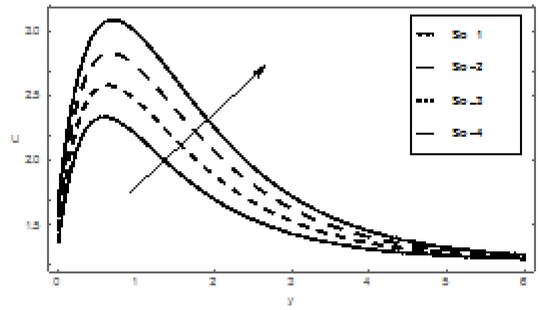

Fig.2.Velocity u versus y under the effect ofSo

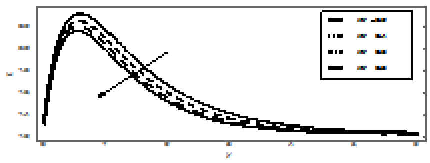

Fig.3.Velocity u versus y under the effectofKr

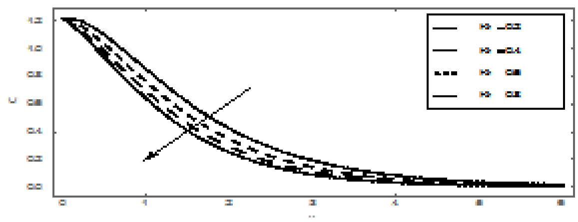

Fig.4 concentration C versus y under the effectofKr

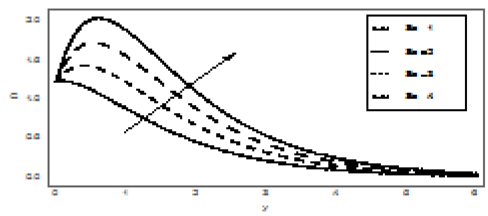

Fig.5 concentration C versus y under the effectof So

V CONCLUSIONS

The plate velocity was maintained at a constant value and the flow was subjected to a transverse magnetic field. The governing equations for unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat absorption, radiation parameter and soret effect were formulated. The resulting partial deferential equations were transformed into a set of ordinary deferential equations using two-term series and solved in closed-form. Numerical evaluations of the closed-form results were performed and some graphical results were obtained to illustrate the details of the flow and heat and mass transfer characteristics and their dependence on some of the physical parameters. It was found that the velocity profiles decreased due to increases the chemical reaction parameter.It was found that the Concentration distribution increases as the Soret effect So increases, and it was observed that the velocity decreases as Magnetic parameter M increases.

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