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ANALYTICAL STUDY OF DARCIAN DRAG FORCED AND HEAT ABSORPTION ON A PERIODIC HEAT AND MASS TRANSPORT ALONG A VERTICAL SURFACE IN PRESENCE OF MAGNETIC FIELD

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ABSTRACT: Analytical solution for unsteady Magnetohydrodynamic (MHD) flow for a semi-infinite vertical permeable moving plate embedded in a Darcian Porous medium subject to time-dependent wall suction in presence of first order Homogeneous Chemical Reaction is presented. A uniform transverse magnetic field to the wall with thermal and concentration buoyancy effects is considered. In this investigation, the fluid is considered to be of two-dimensional, laminar, viscous, incompressible, electrically-conducting, and heat absorbing fluid. The plate is assumed to move with a constant velocity in the direction of fluid flow while the free stream velocity is assumed to follow the exponentially increasing small perturbation law. The dimensionless governing equations for this investigation are solved analytically using two-term Harmonic and Non-Harmonic functions. Analytical solutions of these equations are obtained by perturbation method. Numerical evaluation of the analytical results is performed and some graphical results for the velocity, temperature and concentration profiles within the boundary layer are presented and discussed. It is found that both the velocity and temperature profile decreases as heat absorption increases. Both velocity and concentration boundary layers decreases as chemical reaction increases.
Keywords: MHD, Permeable moving plate, Darcian, Suction, Thermal buoyancy, Laminar, Viscous, Incompressible, Electrically-Conducting, Heat absorbing, Perturbation Method

1. INTRODUCTION

Heat and mass transport with chemical reaction occurs almost in many branches of science and engineering. There are two types of chemical reactions, homogeneous and heterogeneous. In a mixed system, a reaction is said to be homogeneous if it takes place uniformly in the entire given phase and heterogeneous if it takes place in a restricted region or within the boundary of the phase. In most chemical reactions, the reaction rate depends on the concentration of the species itself. A reaction is said to be first order if the rate of reaction is directly proportional to concentration. In many chemical engineering processes, chemical reaction occurs between a foreign mass of the fluid. This type of chemical reaction may change the temperature and the heat content of the fluid and may affect the free convection process.

In many chemical engineering processes, the chemical reaction do occur between a mass and fluid in which plate is moving. These processes take place in numerous industrial applications such as polymer production, manufacturing of ceramics or glassware and food processing. In the light of the fact that, the combination of heat and mass transfer problems with chemical reaction are of importance in many processes, and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries. For example, in the power industry, among the methods of generating electricity is one in which electrical energy is extracted directly from moving conducting fluid.Navingkumar and Sandeep

Gupta (2008) investigated the effect of variable permeability on unsteady two-dimensional free convective flow through a porous bounded by a vertical porous surface. P. R. Sharma, Navin and Pooja (2011) have studied the influence of chemicalreaction on unsteady MHD free convective flow and mass transfer through viscous incompressible fluid past a heated vertical plate immersed in porous medium in the presence of heat source. R. Muthucumaraswamy and Ganesan (2001) studied the effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate.

Simultaneous heat and mass transfer from different geometries embedded in porous media has many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulation, enhanced oil recovery, packed-bed catalytic reactors, cooling of nuclear reactors and underground energy transport. Cheng and Minkowycz (1977) have presented similarity solutions for free thermal convection from a vertical plate in a fluid-saturated porous medium. The Problem of combined thermal convection from a semi-infinite vertical plate in the presence or absence of a porous medium has been studied by many authors. Nakayama and Koyama (1987) have studied pure, combined and forced convection in Darcian and non-Darcian porous medium. Lai and Kulacki(1991) have investigated coupled heat and mass transfer by mixed convection from an isothermal vertical plate in a porous medium. Hsieh et al. (1993) has presented non-similar solutions for combined convection in porous medium. Chamkha(1997) has investigated hydrodynamic natural convection from an isothermal inclined surface adjacent to a thermally stratified porous medium.

Magnetohydrodynamic(MHD) transient convective flow with heat and mass transfer has been a subject of interest of many researchers because of its varied applications in science and technology, which involves the interaction of several phenomena. The phenomena of free convection arise in the fluid when temperature changes cause density variation leading to buoyancy forces acting on the fluid elements. In natural process and industrial applications many transport processes exist where transfer of heat and mass takes place simultaneously as a result of combined buoyancy effects of thermal diffusion and diffusion of chemical species. The process of heat and mass transfer is encountered in fluid fuel nuclearreactor, chemical process industries and many engineering applications in which fluid is considered to be working medium. Chamkha (2004) analyzed the unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate with heat absorption.Chen and Strobal(1980) analyzed the nature of convective flows resulting from buoyancy induced pressure gradient in a laminar boundary layer of a stretched sheet with constant velocity and temperature. Soundalgekar(1972) analyzed the viscous dissipation effects on unsteady free convective flows past and infinite vertical porous plate with constant suction. It was assumed that the plate temperature oscillates in such a way that its amplitude is small. An effect of heat and mass transfer on MHD free convection along a moving permeable vertical surface has been studied by AbdulKhalek(2009). Also Ahmed and Liu (2010) analyzed the effects of mixed convection and mass transfer of three-dimensional oscillatory flow of a viscous incompressible fluid past an infinite vertical porous plate in presence of transverse sinusoidal suction velocity oscillating with time and a constant free stream velocity. Ahmed (2010) investigated the effect of periodic heat transfer on unsteady MHD mixed convection flow past a vertical porous flat plate with constant suction and heat sink when the free stream velocity oscillates in about a non-zero constant mean. Chamkha(2000)considered the problem of steady, hydromagnetic boundary layer flow over an accelerating semi-infinite porous surface in the presence of thermal radiation, buoyancy and heat generation or absorption effects.

In fact, flows of fluids through porous media have possible applications in many branches of science and technology. In fact, flows of fluids through porous media have attracted the attention of a number of scholars because of their possible applications in many branches of sciences and technology. Classically theDarcian model is used to simulate the bulk effects of porous materials on flow dynamics and is valid for Reynolds numbers based on the pore radius, up to approximately 10. Chamkha(2000) studied transient-free convection Magnetohydrodynamic boundary layer flow in a fluid-saturated porous medium channel. B' eget. al.(2005) presented perturbation solutions for the transient oscillatory hydromagnetic convection in a Darcian porous media with a heat source present. Ahmed and Kalita(2013) presented the Magnetohydrodynamictransient convective radiative heat transfer one-dimensional flow in an isotropic, homogeneous porous regime adjacent to a hot vertical plate.

The present paper is to investigate the effects of magnetic body force and Chemical reaction of first order for the unsteady mixed convection boundary layer flow along a vertical permeable surface which is immersed in a Darcianporous regime in presents of mass blowing or suction and absorption. It is assumed that the surface is moving uniformly with constant velocity and the free stream velocity varying with time. The flow model is solved analytically.

2. PROBLEM FORMULATION

Consider unsteady two-dimensional flow of a laminar, incompressible, viscous, electrically conducting and heat-absorbing fluid past a semi-infinite vertical permeable moving plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of thermal and concentration buoyancy effects. It is assumed that there is no applied voltage which implies the absence of an electrical field. The transversely applied magnetic field and magnetic Reynolds number are assumed to be very small so thatthe induced magnetic field and the Hall effects are negligible. A consequence of the small magnetic Reynolds number is the uncoupling of the Navier-Stokes equations from Maxwell's equations. The governing equations for this investigation are based on the balances of mass, linear momentum, energy and concentration species. Taking into consideration the assumption made above, these equations can be written in Cartesian frame of reference, as follows:

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

$$\frac{\partial u^*}{\partial t^*}+v^*\frac{\partial u^*}{\partial y^*}=\left\{\begin{matrix}-\frac{1}{\rho}\frac{\partial p^*}{\partial x^*}+\nu\frac{\partial^2 u^*}{\partial y^{*2}}+g\beta_T(T-T_\infty)\\ +g\beta_c(C-C_\infty)-\left(\frac{\nu}{K^*}+\frac{\sigma}{\rho}B_0^2\right)u^*\end{matrix}\right\} \tag{2}$$

$$\frac{\partial T}{\partial t^*}+v^*\frac{\partial T}{\partial y^*}=\alpha\frac{\partial^2 T}{\partial {y^*}^2}-\frac{Q_0}{\rho C_p}(T-T_\infty) \tag{3}$$

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

The magnetic and viscous dissipations are neglected in this study. The third and fourth terms on the RHS of the momentum equation (2) denote the thermal and concentration buoyancy effects respectively. Also the last term of the energy equation (3) respectively the heat absorption effects. It is assumed that the permeable plate moves with a constant velocity in the direction of fluid flow, and the free stream velocity follows the exponentially increasing small perturbation law. In addition, it is assumed that the temperature and the concentration at the wall as well as the suction velocity are exponentially varying with time.

Under these assumptions, the appropriate boundary conditions for the velocity, temperature and concentration fields are

$$\left\{\begin{matrix}u^*=u_p^*,\ \ T=T_w+\varepsilon(T_w-T_\infty)e^{n^*t^*},\ \ C=C_W^*+\varepsilon(C_W^*-C_\infty^*)e^{n^*t^*}\ \text{at}\ y^*=0\\ u^*\to U_\infty^*=U_0\left(1+\varepsilon e^{n^*t^*}\right),\ \ T\to T_\infty,\ \ C\to C_\infty\qquad \text{as}\ \ y^*\to\infty\end{matrix}\right\} \tag{5}$$

It is clear from Eq. (1) that the suction velocity at the plate surface is a function of time only. Assuming that it takes the following exponential form:

$$v^*=-V_0\left(1+\ \varepsilon Ae^{n^*t^*}\right) \tag{6}$$

Outside the boundary layer, Eq. (2) gives,

$$-\frac{1}{\rho}\frac{dp^*}{dx^*}=\frac{dU_\infty^*}{dt^*}+\frac{\nu}{\kappa^*}U_\infty^*+\frac{\sigma}{\rho}B_0^2U_\infty^* \tag{7}$$

It is convenient to employ the following dimensionless variables:

$$\left\{\begin{matrix}u=\frac{u^*}{U_0},\ \ v=\frac{v^*}{V_0},\ \ y=\frac{V_0y^*}{\nu},\ \ U_\infty=\frac{U_\infty^*}{U_0},\ \ U_p=\frac{u_p^*}{U_0}\\ t=\frac{t^*V_0^2}{\nu},\ \ \theta=\frac{T-T_\infty}{T_w-T_\infty},\ \ C=\frac{C^*-C_\infty^*}{C_W^*-C_\infty^*},\ \ n=\frac{n^*\nu}{V_0^2}\\ K=\frac{K^*V_0^*}{\nu^2},\ \ Pr=\frac{\nu\rho C_p}{k}=\frac{\nu}{\alpha},\ \ Sc=\frac{\nu}{D},\ \ M=\frac{\sigma B_0^2\nu}{\rho V_0^2},\ \ C_r=\frac{\nu C_r^*}{V_0^2}\\ Gr=\frac{\nu\beta_T g(T_w-T_\infty)}{U_0V_0^2},\ \ Gm=\frac{\nu\beta_C g(C_W^*-C_\infty^*)}{U_0V_0^2},\ \ \phi=\frac{\nu Q_0}{\rho C_pV_0^2}\end{matrix}\right\} \tag{8}$$

In view of Eqs. (6) – (8), Eqs. (2) – (4) reduces to the following dimensionless form:

$$\frac{\partial u}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial u}{\partial y}=\frac{dU_\infty}{dt}+\frac{\partial^2 u}{\partial y^2}+Gr\theta+GmC+N(U_\infty-u) \tag{9}$$

$$\frac{\partial \theta}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial \theta}{\partial y}=\frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2}-\phi\theta \tag{10}$$

$$\frac{\partial C}{\partial t}-(1+\varepsilon A e^{nt})\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}-C_rC \tag{11}$$

where $N=(M+\frac{1}{K})$

Thus the dimensionless form of the boundary conditions (5) become

$$\begin{Bmatrix} u=U_p, & \theta=1+\varepsilon e^{nt}, & C=1+\varepsilon e^{nt} & \text{at } y=0 \\ u\to U_\infty, & \theta\to 0, & C\to 0 & \text{as } y\to\infty \end{Bmatrix} \tag{12}$$

3.PROBLEM SOLUTION

Equations(9) – (11) represent a set of partial differential equations that cannot be solved in closed form. However it can be reduced to a set of ordinary differential equations in dimensionless form that can be solved analytically. This can be done by representing the velocity, temperature and concentration as

$$u(y,t)=u_0(y)+\varepsilon e^{nt}u_1(y)+0(\varepsilon^2)+\cdots\cdots \tag{13}$$

$$\theta(y,t)=\theta_0(y)+\varepsilon e^{nt}\theta_1(y)+0(\varepsilon^2)+\cdots\cdots \tag{14}$$

$$C(y,t)=C_0(y)+\varepsilon e^{nt}C_1(y)+0(\varepsilon^2)+\cdots\cdots \tag{15}$$

Substitutingeqs. (13) – (15) into Eqs. (9) – (11), equating the harmonic and non-harmonic terms and neglecting the higher-order terms of $0(\varepsilon^2)$

$$u_0''+u_0'-Nu_0=-N-Gr\theta_0-GmC_0 \tag{16}$$

$$u_1''+u_1'-(N+n)u_1=-(N+n)-Au_0'-Gr\theta_1-GmC_1 \tag{17}$$

$$\theta_0''+Pr\theta_0'-Pr\phi\theta_0=0 \tag{18}$$

$$\theta_1''+Pr\theta_1'-Pr(\phi+n)\,\theta_1=-APr\theta_0' \tag{19}$$

$$C_0''+ScC_0'-Sc\,C_rC_0=0 \tag{20}$$

$$C_1''+ScC_1'-nScC_1=-AScC_0' \tag{21}$$

The corresponding boundary conditions can be written as

$$\begin{Bmatrix} u_0=U_p, & u_1=0, & \theta_0=1, & \theta_1=1, & C_0=1, & C_1=1 & \text{at } y=0 \\ u_0=1, & u_1=1, & \theta_0\to 0, & \theta_1\to 0, & C_0\to 0, & C_1\to 0 & \text{as } y\to\infty \end{Bmatrix} \tag{22}$$

The solutions of eqs. (16) – (21) subjects to boundary conditions (22) can be shown as

$$u_0(y)=1+C_3e^{-\xi_1 y}+B_2e^{-m_1 y}+B_3e^{-\lambda_1 y}, \tag{23}$$

$$u_1(y)=\begin{Bmatrix}1+C_4e^{-\xi_2 y}+B_4e^{-\xi_1 y}+B_5e^{-m_1 y}+B_6e^{-\lambda_1 y}\\ +B_5e^{-m_1 y}+B_6e^{-\lambda_1 y}+B_7e^{-m_2 y}+B_8e^{-\lambda_2 y}\end{Bmatrix}, \tag{24}$$

$$\theta_0(y)=e^{-m_1 y}, \tag{25}$$

$$\theta_1(y)=e^{-m_2 y}+B_1(e^{-m_1 y}-e^{-m_2 y}), \tag{26}$$

$$C_0(y)=e^{-\lambda_1 y}, \tag{27}$$

$$C_1(y)=e^{-\lambda_2 y}+B\left(e^{-\lambda_1 y}-e^{-\lambda_2 y}\right) \tag{28}$$

All the constants appeared in the above equations have been given in Appendix.

In view of the above solutions, the velocity, temperature and concentration distribution in the boundary layer becomes,

$$u(y,t)=\begin{Bmatrix} 1+C_3e^{-\xi_1 y}+B_2e^{-m_1 y}+B_3e^{-\lambda_1 y} \\ +\varepsilon e^{nt}\begin{pmatrix}1+C_4e^{-\xi_2 y}+B_4e^{-\xi_1 y}+B_5e^{-m_1 y}+B_6e^{-\lambda_1 y}\\ +B_7e^{-m_2 y}+B_8e^{-\lambda_2 y}\end{pmatrix}\end{Bmatrix} \tag{29}$$

$$\theta(y,t)=e^{-m_1 y}+\varepsilon e^{nt}[e^{-m_2 y}+B_1(e^{-m_1 y}-e^{-m_2 y})] \tag{30}$$

$$C(y,t)=e^{-\lambda_1 y}+\varepsilon e^{nt}\left[e^{-\lambda_2 y}+B\left(e^{-\lambda_1 y}-e^{-\lambda_2 y}\right)\right] \tag{31}$$

3.1. Rate of Skin-friction

The Skin-friction at the plate y=0 is given by

$$\tau=\left.\frac{\partial u}{\partial y}\right|_{y=0}=\left.\frac{\partial u_0}{\partial y}\right|_{y=0}+\varepsilon e^{nt}\left.\frac{\partial u_1}{\partial y}\right|_{y=0}$$

$$=1-\xi_1C_3-m_1B_2-\lambda_1B_3+\varepsilon e^{nt}(1-\xi_2C_4-\xi_1B_4-m_1B_5-\lambda_1B_6-m_2B_7-\lambda_2B_8)$$

3.2. Rate of heat transfer

The rate of heat transfer in terms of Nusselt number (Nu) is given by

$$Nu = \frac{\partial\theta}{\partial y}\bigg|_{y=0} = \frac{\partial\theta_0}{\partial y}\bigg|_{y=0} + \varepsilon e^{nt}\frac{\partial\theta_1}{\partial y}\bigg|_{y=0} = -m_1 + \varepsilon e^{nt}[-m_2 + B_1(m_2 - m_1)]$$

3.3. Rate of mass transfer

The rate of mass transfer in terms of Sherwood number (Sh) is given by

$$Sh = \frac{\partial C}{\partial y}\bigg|_{y=0} = \frac{\partial C_0}{\partial y}\bigg|_{y=0} + \varepsilon e^{nt}\frac{\partial C_1}{\partial y}\bigg|_{y=0} = -\lambda_1 + \varepsilon e^{nt}[-\lambda_2 + B(\lambda_2 - \lambda_1)]$$

4.VALIDITY

1. When $M = 0$ and without chemical reaction(C_r), the present paper reduces to the work which is done by Chamkha (2004).
2. When $M = 0$, $\phi = 0$, and without chemical reaction(C_r),the present paper reduces to the work which is done by Kim(2000).

The present flow model is validated in comparison with the previous authors Chamkha (2000) and Kim (2000). From both the Tables 1& 2, it has been seen that the buoyancy forces due to heat transfer escalated the velocity distribution in the boundary layer regime.

Table 1: Comparison of present results with those of Chamkha (2000) with different values of Gr when $n = 0.1,\ Pr = 0.7,\ Sc = 0.6,\ Gc = 1,\ Up = 0.5,\ A = 0.5,\ t = 1,\ \mathcal{E} = 0.2$ for velocity profiles

	Present work Gr			Chamkha (2004) Gr		
y	0	1	2	0	1	2
0	0.5	0.5	0.5	0.5	0.5	0.5
2	1.25171	1.25558	1.31894	1.26008	1.25182	1.32035
4	1.23069	1.23677	1.32286	1.23106	1.23793	1.32101
6	1.22352	1.22396	1.22497	1.22324	1.22410	1.22485
8	1.22155	1.22164	1.22191	1.22149	1.22169	1.22198
10	1.22113	1.22115	1.22116	1.22112	1.22116	1.22119

Table 2: Comparison of present results with those of Kim (2000) with different values of Gr when $n = 0.1, Pr = 0.71, Sc = 0.6,\ Gc = 1,\ Up = 0.5,\ A = 0.005,\ t = 0.2,\ \mathcal{E} = 0.001$ for velocity profiles

	Present work Gr			Kim (2000) Gr		
y	0	1	2	0	1	2
0	0.5	0.5	0.5	0.5	0.5	0.5
2	0.98957	1.19727	1.29558	0.98962	1.19726	1.29570
4	1.00958	1.20631	1.30304	1.00953	1.20597	1.30315
6	1.00415	1.00567	1.00819	1.00387	1.00589	1.00845
8	1.00185	1.00188	1.00189	1.00174	1.00194	1.00197
10	1.00122	1.00131	1. 00145	1.00211	1.00201	1.00209

5. RESULTS AND DISCUSSION

The effects of flow parameters such as the Magnetic parameter (M), Heat absorption coefficient (ϕ), Porosity parameter (k), Chemical reaction (Cr), Prandtl number (Pr), Schmidt number (Sc) on velocity field, temperature, concentration, Skin-friction (τ), Nusselt number (Nu) and Sherwood number (Sh) have been studied analytically and presented in Figs. 1 to 10.

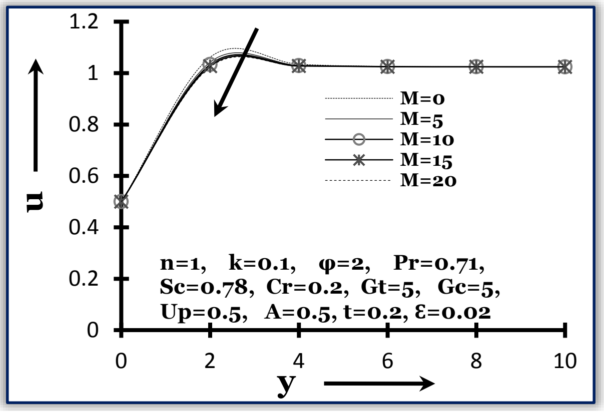

Figure 1: Velocity distribution for Magnetic field

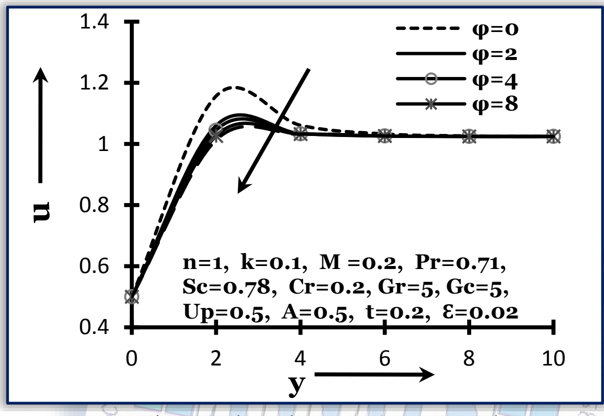

Figure 2: Velocity distribution for Heat absorption

The typical velocity profiles in the boundary layer represents in Figure 1 for various values of Magnetic body force (M). It is obvious that an increase in M reduces the velocity. The application of a transverse magnetic field to an electrically conducting field gives rise to a resistive type of force called Lorentz force. This force has the tendency to slow down the fluid. This trend is evident in this figure.

Figures 2 and 3 illustrate the influence of the heat absorption coefficient ϕ on the velocity and temperature profiles respectively. Physically speaking, the presents of heat absorption effects has the tendency to reduce the fluid temperature. This causes the thermal buoyancy effects to decrease resulting in a net reduction in the fluid velocity. These behaviors are clearly obvious from Figures 2 and 3 in which both the velocity and temperature distribution decrease as ϕ

increases. It is also observed that both the velocity and the thermal boundary layers decrease as the heat absorption coefficient effects increase.

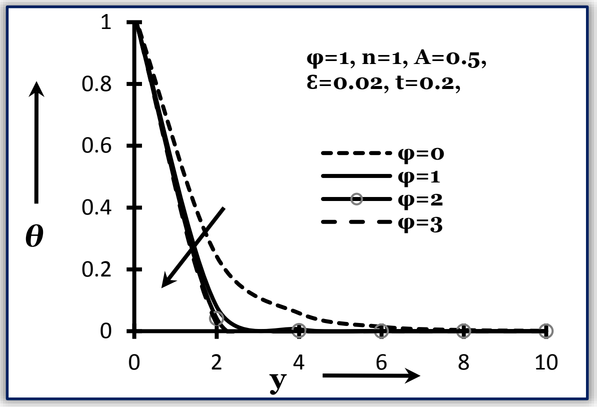

Figure 3: Temperature distribution for heat absorption

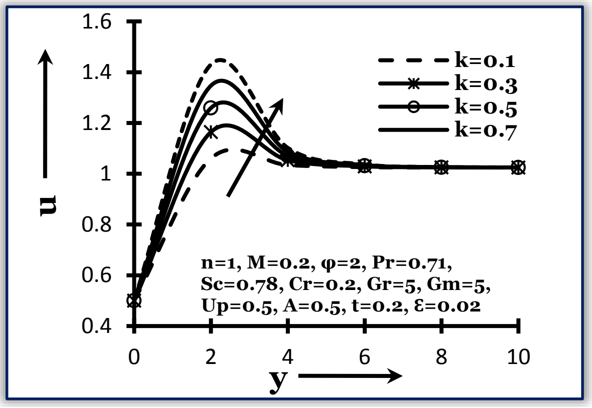

Figure 4: Velocity distribution for porosity parameter

The opposite trend is observed in Figure 4 for the case when the value of the porosity (k = 0.1, 0.3, 0.5, 0.7 and 0.9) is increased. As depicted in this figure, the effects of increasing the values of porous permeability is to increase the value of the velocity component in the boundary layer due to the fact that drag is reduced by increasing the values of the porous permeability on the fluid flow which results in increased velocity. The trend shows that the velocity is accelerated with increasing porosity parameter.

Figs. 5 and 6 illustrate the influence of Chemical reaction Cr on the velocity and concentration distribution respectively. It is clear that increasing the Chemical reaction parameter tends to decrease the velocity as well as species concentration of the fluid. This means that in the case of suction, the Chemical reaction decelerates the fluid motion. In turn, this causes the concentration buoyancy effects to decrease as chemical reaction increases. Consequently less flow is induced along the plate resulting in decrease in the fluid velocity in the boundary layer.

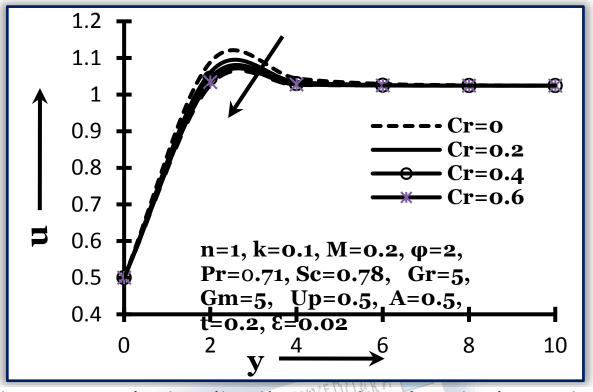

Figure 5: Velocity distribution for chemical reaction

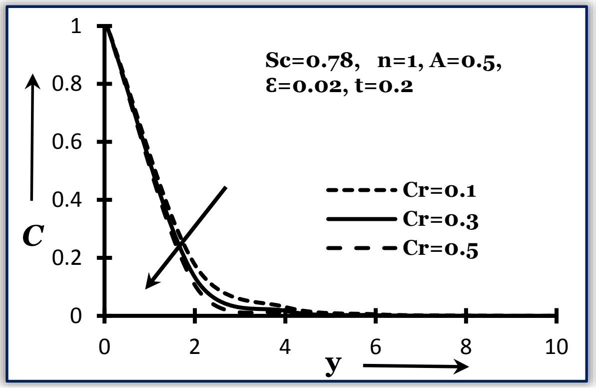

Figure 6: Concentration distribution for chemical reaction

Figure 7 displays the effects of the Schmidt number Sc on the concentration profiles. It is noticed that effect of increasing values of Sc is to decrease concentration profile. This is consistent with the fact that, increase in Sc means decrease of molecular diffusivity D those results in decrease of concentration boundary layer. Hence concentration of species is higher for smaller values of Sc and lower for lager values of Sc.

In Figure 8 the Skin-friction distribution for the effect of Chemical reaction (Cr) and Magnetic body force (M) is presented. The maximum values of shear stress (is observed at the plate y=0 for the effects of M and Cr. Moreover, when M increases the shear stresses becomes small in magnitude. While a substantial depression of shear stress has been observed when the Chemical reaction increases from 0 through 0.3, 0.6 to 0.9.

Figure 9 depicts the behavior of Rate of heat transfer (Nu) at the plate y=0 for the effects heat absorption and Prandtl number (Pr). An increase in heat absorption leads to increase the rate of heat transfer throughout the thermal boundary layer. The minimum values of Nu occurred near the plate y=0 for different values of Nu and Pr. Due to the negative values of Nu, the heat of the fluid is diffused to the vertical wall y=0. Moreover, increasing values of Pr enhanced the rate of heat transfer.

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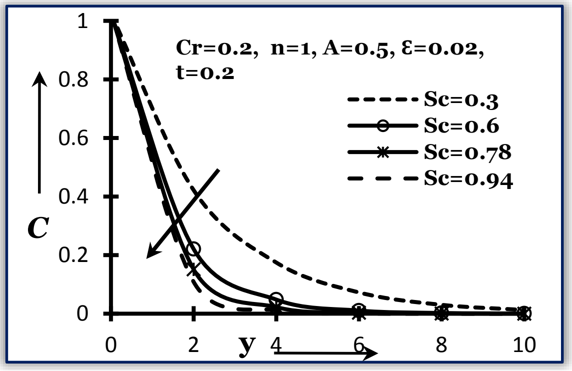

Figure 7: Concentration distribution for Schmidt number

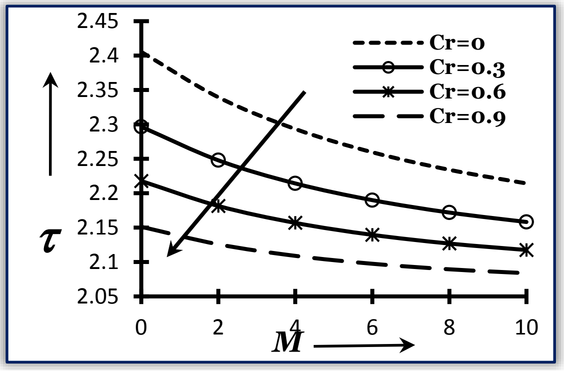

Figure 8: Skin Friction for Chemical Reaction

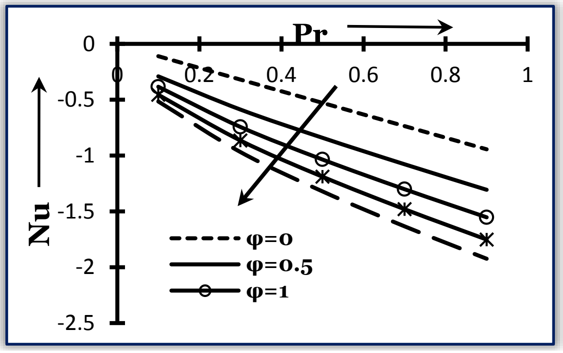

Figure 9: Nusselt Number for Heat Absorption Parameter

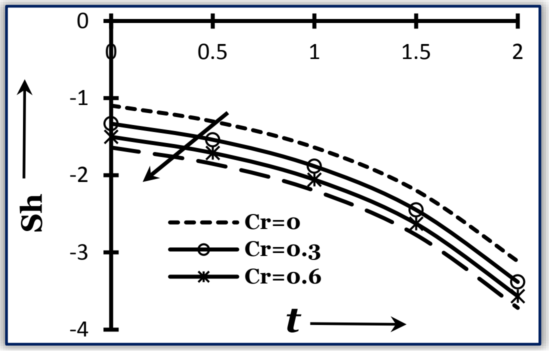

Figure 10: Sherwood Number for Chemical reaction

The variation of rate of mass transfer(Sh) for different values of Chemical reaction (Cr) and time (t) has analyses Figure 10. It is marked that increasing Cr and t enhanced the Sherwood number. Also it is seen that due to negativity of Sh the mass is diffused to the vertical wall y = 0. Moreover, minimum values of Sh occurred near y = 0 when time is small and maximum values of Sh is observed for large values of time.

6.CONCLUSIONS

The Governing equations for unsteady MHD convective heat and mass transfer past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat absorption and first order chemical reaction was formulated. The plate velocity was maintained at a constant value and the flow was subjected to a transverse magnetic field. The resulting partial differential equations were transformed into a set of ordinary differential 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 some of the physical parameters. The above analysis brings out the following results.

- It is observed that existence of Magnetic body force, Heat absorption coefficient and Chemical reaction decreases the velocity.
- It is observed that the existence of Porosity parameter increases the velocity.
- The Heat absorption co-efficient have the influence of decreasing the Temperature and Nusselt number.
- The Concentration boundary layer decreases with the increasing values of Chemical reaction and Schmidt number.
- The Chemical reaction has the influence of decreasing the Skin-friction and Sherwood number.

Appendix:

$$\xi_1 = \frac{1+\sqrt{1+4n}}{2},\quad \xi_2 = \frac{1+\sqrt{1+4(N+n)}}{2},\quad m_1 = \frac{Pr+\sqrt{Pr^2+4Pr\phi}}{2}, m_2 = \frac{Pr+\sqrt{Pr^2+4Pr(\phi+n)}}{2} \lambda_1 = \frac{Sc+\sqrt{Sc^2+4ScCr}}{2},\quad \lambda_2 = \frac{Sc+\sqrt{Sc^2+4nSc}}{2}), C_3 = U_p - 1 - B_2 - B_3, B_2 = \frac{G_r}{-m_1^2+m_1+N},\quad B_3 = \frac{G_c}{-\lambda_1^2+\lambda_1+N},\quad B = \frac{ASc\lambda_1}{\lambda_1^2-Sc\lambda_1-nSc}, B_1 = \frac{APrm_1}{m_1^2-Prm_1-Pr(\phi+n)},\quad C_4 = -(1+B_4+B_5+B_6+B_7+B_8),$$

$$B_4 = \frac{A\xi_1C_3}{\xi_1^2-\xi_1-(N+n)},\quad B_5 = \frac{AB_2m_1-G_rB_1}{m_1^2-m_1-(N+n)},\quad B_6 = \frac{AB_2\lambda_1-G_CB}{\lambda_1^2-\lambda_1-(N+n)}, B_7 = \frac{G_r(1-B_1)}{-m_2^2+m_2+(N+n)},\quad B_8 = \frac{G_C(1-B)}{-\lambda_2^2+\lambda_2+(N+n)}.$$

Nomenclature:

A Suction velocity parameter
B_0 Magnetic induction
C^* Concentration
C_p Specific heat at constant pressure
C_r Chemical reaction
C Dimensionless Concentration
D Mass diffusion coefficient
Gr SolutalGrashof number
Gm Thermal Grashof number
g Acceleration due to gravity
K Permeability of porous medium
M Magnetic field parameter
N Dimensionless exponential index
Nu Nusselt number
Pr Prandtl number
Q_o Heat absorption coefficient
Sc Schmidt number
Sh Sherwood number
T Temperature
t dimensionless time
U_o Scale of free stream velocity
u, v Components of velocities along and perpendicular to the plate
V_o Scale of Suction velocity
x, y Distances along and perpendicular to the plate respectively

Greek Symbols

α Fluid thermal diffusivity
β_c Coefficient of volumetric concentration expansion
β_T Coefficient of volumetric thermal expansion
ε Scalar constant (<<1)
κ Thermal conductivity
ϕ Dimensionless heat absorption coefficient
σ Fluid electrical conductivity
ρ Fluid density
ν Fluid kinematic viscosity
τ Friction coefficient
θ Dimensionless temperature

Superscripts

′ Differentiation with respect to y*
Dimensionless properties

Subscripts

p Plate
w Wall condition
∞ Free stream condition

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