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Effects Of Chemical Reaction And Joule Heating On Mhd Heat And Mass Transfer Free On Convective Radiative Flow In A Moving Inclined Porous Surface With Hall Current And Alinged Magnetic Temperature Dependent Heat Source

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ABSTRACT
The effects of mixed convection with thermal radiation, chemical reaction, Hall current and aligned magnetic on MHD flow of viscous, incompressible and electrically conducting fluid on a moving inclined heated porous plate is analyzed. The nonlinear coupled partial differential equations are solved analytically by employing perturbation technique. The influence of different pertinent parameters such as Grashof number (Gr), modified Grashof number (Gc), magnetic field parameter (M), heat source parameter (ϕ), chemical reaction parameter (γ), Schmidt number (Sc), Hall Current Parameter (m), Aligned angle (ξ) and angle of inclination (α) on velocity, temperature and concentration distribution have been studied and analyzed with the help of graphs. An analysis of the coupled heat and mass transfer phenomena is provided in detail. We have an excellent agreement with the existed results [27]. Results indicate that an increase in aligned magnetic field angle reduces the velocity boundary layer and friction factor. The skin friction, Nusselt number and Sherwood number are also obtained and are shown in tabular form.

***Keywords*:** Viscous and Ohmic Dissipation, Chemical reaction, Inclined plate, radiation, Alinged Magnetic, Hall Current.

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I. INTRODUCTION

The convective heat and mass transfer flows in an inclined porous plate find a number of applications in many branches of science and technology like chemical industry, cooling of nuclear reactors. MHD power generators, geothermal energy extractions processes, petroleum engineering etc. Convective heat and mass transfer flows in the presence of various physical properties for the cases of horizontal and vertical flat plates have been attracting the attention of many researchers now a days[1]–[17]. However, the boundary layer flows adjacent to inclined plates or wedges have received less attention. For the problem of coupled heat and mass transfer in MHD free convection, the effect of both viscous dissipation and Ohmic heating are not studied in the above investigations. However, it is more realistic to include these two effects to explore the impact of the magnetic field on the thermal transport in the boundary layer. With this awareness, the effect of Ohmic heating on the MHD free convection heat transfer has been examined for a Newtonian fluid by Hossain [18]. Hossain and Gorla [19] studied Joule heating effect on magnetohydrodynamic mixed convection boundary layer flow. To investigate the mixed convection flow of an electrically conducting and viscous incompressible fluid past an isothermal vertical surface with Joule heating in the presence of a uniform transverse magnetic field fixed relative to the surface. It was assumed that the electrical conductivity of the fluid varies linearly with the transverse velocity component. Beg et al. [20] solved magnetohydrodynamic Hartmann–Couette flow and heat transfer in a Darcian channel with Hall current, ionslip, viscous and Joule heating effects. In their study Reddy et al. Chen [21] studied the problem of combined heat and mass transfer of an electrically conducting fluid in MHD natural convection, adjacent to a vertical surface with Ohmic heating. Reddy et al. [22] considered thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating. Sibanda and Makinde [23] proceeded on steady MHD flow and heat transfer past a rotating disk in a porous medium with Ohmic heating and viscous dissipation. Mixed convection of Non-Newtonian fluids from a vertical plate embedded in a porous medium is studied by Wang et al., [24]. Viscous and Joule heating effects on non-Darcy MHD natural convection flow over a permeable sphere in porous media with internal heat generation was considered by Yia [25]. Choudhury and Das [26] examined on Mixed Convective visco elastic MHD flow with Ohmic heating. Motivated by the above studies, in this manuscript an attempt is made to investigate the effects of radiation absorption, temperature dependant heat source, viscous dissipation and Joule heating effects on a radiative and reactive, mixed convection MHD flow of a viscous, incompressible, electrically conducting and Newtonian fluid on a moving inclined heated porous plate. This is an extension to the work of Raju MC et al. [27], which has the novelty in studying Aligned magnetic and Hall Current in the momentum equation.

The convective heat and mass transfer flows in porous medium find a number of applications in many branches of science and technology like chemical industry, cooling of nuclear reactors. MHD power generators, geothermal energy extractions processes, petroleum engineering etc. [28, 29]. Convective boundary layer flow problems in the cases of horizontal and vertical flat plates have been investigated quite extensively. The boundary layer flows adjacent to inclined plates or wedges have received less attention. The study of Sparrow et al. [30] is related to the convection flow about an inclined surface in which the combined forced and free boundary layer problem has been discussed using the similarity method. Chaudhury [28] have analyzed the effect of radiation on heat transfer in MHD mixed convection flow with simultaneous thermal and mass diffusion from an infinite vertical plate with viscous dissipation and Ohmic heating. Dulal [29] studied the combined effect of mixed convection with thermal radiation and chemical reaction on MHD flow of viscous and electrically conducting fluid past a vertical permeable surface embedded in a porous medium. Singh [31] studied Heat and Mass Transfer in MHD Boundary Layer Flow past an Inclined Plate with Viscous Dissipation in Porous Medium. Mansour [32] studied the boundary layer analysis has been presented for the free convection flow past an inclined surface in a Newtonian fluid-saturated porous medium. Chen [33] investigated the heat and mass transfer characteristics of MHD natural convection flow over a permeable, inclined surface with variable wall temperature and concentration, taking into consideration the effects of Ohmic heating and viscous dissipation. Hossain [34] have studied the convection flow from an isothermal plate inclined at a small angle to the horizontal. Dulal pal [35] investigated the unsteady mixed convection with thermal radiation and first order chemical reaction on magnetohydrodynamic. Noor [36] studied the problem involving the conjugate phenomenon of heat and mass transfer analytically. Bhuvaneswari [37] analyzed on the magnetohydrodynamic (MHD) free convection flow with simultaneous effects of heat and mass transfer. Ziyauddin [38] developed closed form exact solutions for the unsteady MHD free convection flow of a viscous fluid over an inclined plate with variable heat and mass transfer in a porous medium. Alam [39] studied the combined effect of viscous dissipation and Joule heating on steady MHD free convective heat and mass transfer flow of a viscous incompressible fluid past a semi-infinite inclined radiate isothermal permeable moving surface in the presence of thermophoresis. Ganesan et al. [40] studied the problem of unsteady natural convection flow of a viscous incompressible electrically conducting fluid past an inclined plate with variable heat and mass flux's. Orthan Aydm et al. [41] studied MHD mixed convective heat transfer flow about an inclined plate.

Magnetic fields are commonly used to pump, stir and stabilize liquid metals. In casting operations, the motion of submerged liquid metal jets that feed the casting moulds is suppressed by the application of an intense, static magnetic field. One of the particular importance of this work is the flow through porous media in the presence of a magnetic field. This type of flow may find some industrial applications in the design of filtration systems, in addition to the study of lubrication mechanism is enhanced through the introduction of porous lining into the mechanism and the imposition of a magnetic field in a transverse direction to the flow. Other applications to this type of flow include the occurrence of this type of flow in nature. Typically, the magnetic field is available everywhere on earth, hence, the study of any natural flow phenomena mandates taking into account the magnetic effects in the flow equations. The main type of single-phase flow models have been developed and reviewed by [46]. A vast amounts of research has been carried out on the motion of electrically conducting fluids moving in a magnetic field. Mathematical complexity of the phenomenon induced many researches to adopt a rather useful alternative technique of investigating special classes of flows such as aligned or parallel flows, crossed or orthogonal flows, (for more details see for example [42-45]). They studied finitely conducting orthogonal MHD plane flows. In which they discussed that the velocity and magnetic field vectors are mutually orthogonal everywhere in the flow region.

In this study, we consider Hall Current and aligned fluid flow through porous media in the presence of a magnetic field. The importance of thermal radiation on unsteady forced convection with an align magnetic field pay an attention now a days. The study of heat and mass transfer due to chemical reaction is also very important because of its occurrence in most of the branches of science and technology. The processes involving mass transfer effects are important in chemical processing equipments which are designed to draw high value products from cheaper raw materials with the involvement of chemical reaction. In many industrial processes, the species undergo some kind of chemical reaction with the ambient fluid which may affect the flow behavior and the production quality of final products. Magnetic-field aligned electric fields play an important role in fluid dynamics. They allow decoupling of plasma elements by violation of the frozen field condition, breakdown of equipotential mapping, efficient acceleration of charged particles and rapid release of magnetic energy. A number of mechanisms that can support magnetic field aligned electric fields have been identified. They include wave turbulence, solitary structures, magnetic mirrors, electric double layers and dynamic trapping. Some of them have been observationally confirmed to be important in the auroral process, but their relative roles are still not well known. Before the era of in situ measurements in space it was common wisdom that magnetic-field aligned electric fields cannot not exist, because the unimpeded motion of electrons and ions along magnetic field lines would "short circuit" them. The existence of magnetic-field aligned electric fields in collision less space plasma is a matter of great importance. (For brevity the term "parallel" will also be used for "magnetic-field aligned".)**.** For a non vanishing magnetic-field aligned electric field to exist other than as a brief transient, the momentum that this field continually imparts to the charged particles must be balanced. Depending on how this momentum balance is achieved, a number of different types of magnetic-field aligned electric fields are possible, each with its own characteristics.(1)Forces from ac electric fields.(2) Forces from the dc magnetic field(3) Inertial forces.

The objective of this article is the effects of mixed convection with thermal radiation, chemical reaction, Hall current and aligned magnetic on MHD flow of viscous, incompressible and electrically conducting fluid on a moving inclined heated porous plate is analyzed. The nonlinear coupled partial differential equations are solved analytically by employing perturbation technique.

II. MATHEMATICAL FORMULATION

Consider a free convective laminar boundary layer flow of a viscous incompressible electrically conducting, chemically reactive, radiative and heat absorbing fluid past a semi-infinite moving permeable plate inclined at an angle α a in vertical direction embedded in a uniform porous medium, which is subject to thermal and concentration buoyancy effects along with Joule's dissipation. The temperature of the wall is maintained T_w and concentration C_w which is higher than the ambient temperature T_∞ and concentration C_∞ respectively. Also it is assumed that there exists a homogeneous chemical reaction of first order with rate constant between the diffusing species and the fluid. With these physical considerations, the equations governing the fluid in Cartesian frame of reference are given below.

$$\frac{\partial v}{\partial y} = 0 \quad \Rightarrow \quad v^* = -V_0 \tag{2.1}$$

Momentum Equation

$$\rho v^* \frac{\partial u^*}{\partial y^*} = \mu \frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\mu}{k^*} u^* - \left(\frac{m}{1+m^2} - M_1^2 \sin^2 \xi \right) \sigma B_0^2 u^* + \rho g \cos\alpha \; \beta_T (T^* - T_\infty) + \rho g \cos\alpha \; \beta_C (C^* - C_\infty) \tag{2.2}$$

Energy Equation

$$\rho C_p v^* \frac{\partial T^*}{\partial y^*} = \alpha_1 \frac{\partial^2 T^*}{\partial y^{*2}} + \mu \left(\frac{\partial u^*}{\partial y^*} \right)^2 - \frac{\partial q_r^*}{\partial y^*} + \sigma B_0^2 u^{*2} - Q_0 (T^* - T_\infty) \tag{2.3}$$

Concentration Equation

$$v^* \frac{\partial C^*}{\partial y^*} = D \frac{\partial^2 C^*}{\partial y^{*2}} - R(C^* - C_\infty) \tag{2.4}$$

The radiative heat flux

$$\frac{\partial q_r^*}{\partial y^*} = 4(T^* - T_\infty) I' \tag{2.5}$$

Where

$I' = \int_0^\infty K_{\lambda w} \frac{\partial e_{b\lambda}}{\partial T^*} d\lambda$, $K_{\lambda w}$ is the absorption coefficient at the wall and $e_{b\lambda}$ is Plank's function.

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

$$u^* = 0, \quad T^* = T_\infty, \quad C^* = C_\infty \qquad at \quad y = 0 \tag{2.6}$$

$$u^* \to 0, \quad T^* \to T_\infty, \quad C^* \to C_\infty \qquad as \quad y \to \infty \tag{2.7}$$

Introducing the following non-dimensional quantities

$$u = \frac{u^*}{v_0}, \upsilon = \frac{\mu}{\rho}, R_1 = \frac{\upsilon(C_w - C_\infty)R_A}{v_0^2 \rho C_p (T_w - T_\infty)}, y = \frac{v_0 y^*}{\upsilon}, u_p = \frac{u_p^*}{v_0}, M^2 = \frac{B_0^2 \upsilon^2 \sigma}{v_0^2 \mu}, K = \frac{K^* v_0^2}{\upsilon^2},$$

$$\theta = \frac{T^* - T_\infty}{T_w - T_\infty}, C = \frac{C^* - C_\infty}{C_w - C_\infty}, Sc = \frac{\upsilon}{d}, \gamma = \frac{R\upsilon}{v_0^2}, \Pr = \frac{\mu Cp}{\alpha_1}, H = \frac{Q_0}{\rho C_p v_0^3}, F = \frac{4\upsilon I'}{\rho C_p v_0^2},$$

$$Ec = \frac{v_0^2}{C_p (T_w - T_\infty)}, Gr = \frac{\rho g \beta_T \upsilon^2 (T_w - T_\infty)}{v_0^3 \mu}, Gc = \frac{\rho g \beta_C \upsilon^2 (C_w - C_\infty)}{v_0^3 \mu}, M_1^2 = \frac{M_d v_0^2 \rho}{B_0^2 \upsilon^2 \sigma} \tag{2.8}$$

Where the parameters are Grashof number Gr, modified Grashof number Gm, angle of inclination α, radiation parameter F, Schmidt number Sc, chemical reaction parameter γ , Hartmaan number M, temperature dependent heat source parameter H, porosity parameter K, Prandtl number Pr, Schmidt number Sc, Hall Current Parameter m and Aligned angle ξ.

The basic field equations (2.2) – (2.4), can be expressed in non-dimensional form as

$$\frac{\partial^2 u}{\partial y^2} + \frac{\partial u}{\partial y} - D_4 u = -D_1\theta - D_2 C - D_3 u \tag{2.9}$$

$$\frac{\partial^2 \theta}{\partial y^2} + \Pr \frac{\partial \theta}{\partial y} + \Pr Ec \left(\frac{\partial u}{\partial y}\right)^2 + \Pr EcM^2 u^2 - \Pr(F + \phi) = 0 \tag{2.10}$$

$$\frac{\partial^2 C}{\partial y^2} + Sc \frac{\partial C}{\partial y} - Sc\, \gamma\, C = 0 \tag{2.11}$$

Where $D_1 = Gr \cos\alpha$; $D_2 = Gm \cos\alpha$; $D_3 = M_d \sin^2 \xi$; $D_4 = \frac{1}{K} + M_a$; $M_a = \frac{mM^2}{1 + m^2}$.

The corresponding boundary conditions in non-dimensional form are:

$$u = 0, \theta = 1, C = 1 \qquad at \quad y = 0 \tag{2.12}$$

$$u \to 0, \quad \theta \to 0, \quad C \to 0 \qquad as \quad y \to \infty \tag{2.13}$$

III. METHOD OF SOLUTION

The set of partial differential equations (2.9) – (2.11) cannot be solved in closed form. However, they can be solved analytically after reducing them into into a set of ordinary differential equations by taking the expressions for velocity u(y), temperature θ(y) and concentration C(y) in dimensionless form as follows:

$$u(y) = u_0(y) + Ec\, u_1(y) + O(E_c^2) \tag{3.1}$$

$$\theta(y) = \theta_0(y) + Ec\theta_1(y) + O(E_c^2) \tag{3.2}$$

$$C(y) = C_0(y) + C_1(y) + O(E_c^2) \tag{3.3}$$

Substituting (3.1) – (3.3) in (2.9) – (2.11) and equating the coefficients of zero[th] order of Eckert number (constants), and equating the coefficients of the first order of Eckert number, and neglecting the higher order of $O(E_c^2)$ and simplifying to get the following set of equations

$$u_0'' + u_0' + D_5 u_0 = -D_1\theta_0 - D_2 C_0 \tag{3.4}$$

$$\theta_0'' + \Pr\theta_0' - \Pr(F+\phi)\theta_0 = 0 \tag{3.5}$$

$$C_0'' + ScC_0' - Sc\,\gamma\, C_0 = 0 \tag{3.6}$$

$$u_1'' + u_1' + D_5 u_1 = -D_1\theta_1 - C_1 D_2 \tag{3.7}$$

$$\theta_1'' + pr(1-H)\theta_1' - \Pr(F+\phi)\theta_1 = -\Pr u_0'^2 - \Pr M^2 u_0^2 \tag{3.8}$$

$$C_1'' + ScC_1' - Sc\,\gamma\, C_1 = 0 \tag{3.9}$$

Where prime denotes ordinary differentiation with respect to ‘y’ and $p = M^2 + \frac{1}{K}$

The corresponding boundary conditions are:

$$u_0 = 0, u_1 = 0, \theta_0 = 1, \theta_1 = 0, C_0 = 1, C_1 = 0 \quad at \quad y = 0 \tag{3.10}$$

$$u_0 \to 0, u_1 \to 0, \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \quad as \quad y \to \infty \tag{3.11}$$

Using boundary conditions (3.10) and (3.11), the solutions of (3.4) – (3.9), we obtain the following expressions for velocity, temperature and concentration.

$$u_0 = A_5 e^{-A_2 y} - A_3 e^{-A_1 y} - A_4 e^{-m_1 y} \tag{3.12}$$

$$\theta_0 = e^{-A_1 y} \tag{3.13}$$

$$C_0 = e^{-m_1 y} \tag{3.14}$$

$$\begin{aligned} u_1 = {} & A_{26} e^{-A_{16} y} - A_{17} e^{-A_1 y} - A_{18} e^{-A_2 y} + A_{19} e^{-m_1 y} + A_{20} e^{-2A_2 y} \\ & + A_{21} e^{-2A_1 y} + A_{22} e^{-2m_1 y} - A_{23} e^{-B_1 y} + A_{24} e^{-B_2 y} - A_{25} e^{-B_3 y} \end{aligned} \tag{3.15}$$

$$\begin{aligned} \theta_1 = {} & A_{15} e^{-A_1 y} + A_6 e^{-A_2 y} - A_7 e^{-A_1 y} - A_8 e^{-m_1 y} + A_9 e^{-2A_2 y} \\ & - A_{10} e^{-2A_1 y} - A_{11} e^{-2m_1 y} + A_{12} e^{-B_1 y} - A_{13} e^{-B_2 y} + A_{14} e^{-B_3 y} \end{aligned} \tag{3.16}$$

$$C_1 = 0 \tag{3.17}$$

Substituting the above solutions (3.12) – (3.17) in (3.1) – (3.3), we get the final form of Velocity, Temperature, Concentration distributions in the boundary layer as follows

$$\begin{aligned} u(y) = {} & [A_5 e^{-A_2 y} - A_3 e^{-A_1 y} - A_4 e^{-m_1 y}] + Ec \\ & [A_{26} e^{-A_{16} y} - A_{17} e^{-A_1 y} - A_{18} e^{-A_2 y} + A_{19} e^{-m_1 y} + A_{20} e^{-2A_2 y} \\ & + A_{21} e^{-2A_1 y} + A_{22} e^{-2m_1 y} - A_{23} e^{-B_1 y} + A_{24} e^{-B_2 y} - A_{25} e^{-B_3 y}] \end{aligned} \tag{3.18}$$

$$\theta(y) = [e^{-A_1 y}] + Ec\begin{bmatrix} A_{15}e^{-A_1 y} + A_6 e^{-A_2 y} - A_7 e^{-A_1 y} - A_8 e^{-m_1 y} + A_9 e^{-2A_2 y} \\ -A_{10}e^{-2A_1 y} - A_{11}e^{-2m_1 y} + A_{12}e^{-B_1 y} - A_{13}e^{-B_2 y} + A_{14}e^{-B_3 y} \end{bmatrix} \tag{3.19}$$

$$C(y) = e^{-m_1 y} \tag{3.20}$$

The physical quantities of interest are the wall shear stress τ_w is given by

$$\tau_w = \mu \left.\frac{\partial u^*}{\partial y^*}\right|_{y^*=0} = \rho v_0^2 u'(0)$$

The local skin friction factor C_{fx} is given by

$$C_{fx} = \frac{\tau_w}{\rho v_0^2} = u'(0) = [-A_2A_5 + A_1A_3 + m_1A_4] + Ec[-A_{16}A_{26} + A_1A_{17} \tag{3.21}$$

$$+ A_2A_{18} - m_1A_{19} - 2A_2A_{20} - 2A_1A_{21} - 2m_1A_{22} + B_1A_{23} - B_2A_{24} + B_3A_{25}]$$

The local surface heat flux is given by:

$$q_w = -\kappa \left.\frac{\partial T^*}{\partial y^*}\right|_{y^*=0}$$

Where κ is the effective thermal conductivity. The local Nusselt number

$Nu_x = \dfrac{q_w}{(T_w - T_\infty)}$ can be written as

$$\frac{Nu_x}{\mathrm{Re}_x} = -\left.\frac{\partial \theta}{\partial y}\right|_{y=0} = -\theta'(0) = [A_1] + Ec[A_1A_{15} + A_2A_6 - A_1A_7 - m_1A_8 \tag{3.22}$$

$$- 2A_2A_9 - 2A_1A_{10} - 2m_1A_{11} + B_1A_{12} - B_2A_{13} + B_3A_{14}]$$

The local surface mass flux is given by

$$\frac{Sh_x}{\mathrm{Re}_x} = -\left.\frac{\partial C}{\partial y}\right|_{y=0} = -m_1 \tag{3.23}$$

Where $\mathrm{Re}_x = \dfrac{v_0 x}{\upsilon}$ is the local Reynolds Number.

IV. RESULTS AND DISCUSSIONS

The present study considers the effects of radiation absorption R_1 and chemical reaction γ , on transient free convection flow of heat and mass transfer in MHD free convective joule heating and radiative flow in a moving inclined porous plate with temperature dependent heat source. Solutions for velocity, temperature and concentration field are obtained by using perturbation technique with γ = 0.1, Ec = 0.01, Sc = 0.60, Pr = 0.7, M = 2.0, K = 0.5, Gc = 2.0, Gr = 4.0, α = π/6, F =1.0, ϕ = 0.1, ξ = π/6, m = 0.1, Md = 0.5 and therefore all the graphs corresponds to these unless specifically indicated on the appropriate graph. The effects of various parameters like Grashof number Gr, modified Grashof number Gc, angle of inclination α, radiation parameter F, Schmidt number Sc, chemical reaction parameter γ , Hartmaan number M, heat source parameter ϕ, porosity parameter K, Prandtl number Pr, Schmidt number Sc, Hall Current Parameter m and Aligned angle ξ on velocity, temperature and concentration have been studied analytically and effects are executed with the help of Figures. Also the behavior of skin-friction, rate of heat transfer and rate of mass transfer with respect to various parameters have been studied and results were presented in Tables.

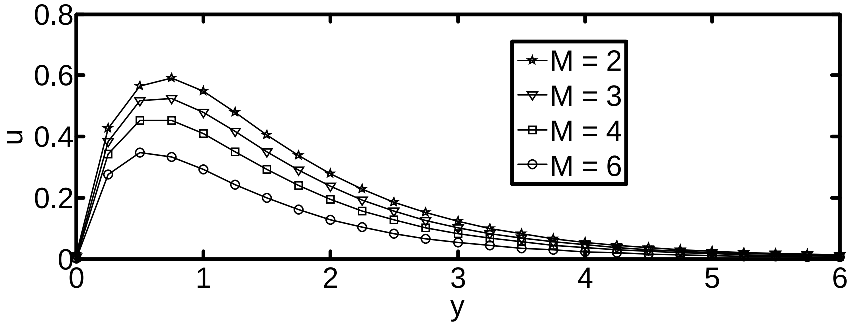

Figure 1: Velocity profiles for different values of Hartmaan number M

Figure 1 exhibits the effect of Hartmaan number (M). It is noticed that as the values of M increase velocity profiles gradually decrease. The effect of magnetic field is more prominent at the point of peak value i.e. the peak value drastically decreases with increases in the value of magnetic field, because the presence of magnetic field in an electrically conducting fluid introduce a force called the Lorentz force, which acts against the flow if the magnetic field is applied in the normal direction, as in the present problem. This type of resisting force slows down the fluid velocity as shown in this figure.Figure 2 shows that velocity profile for different values of porosity parameter (K). As K increases velocity also increases.

Figure 3 shows that the effects of angle of inclination (α) on velocity profile. We observed that the velocity decreases for increasing the angle of inclination α. Figure 4 depicts that the effects of Grashof number (Gr) on velocity profile.From this figure it is noticed that the velocity increases as Grashof number increases. Fig.5 represents typical velocity profiles in the boundary layer for various values of the modified Grashof number, while all other parameters are kept at some fixed values. The velocity distribution attains a distinctive maximum value in the vicinity of the plate surface and then decrease properly to approach the free stream value. As expected, the fluid velocity increases and the peak value more distinctive due to increase in the concentration buoyancy effects represented by modified Grashof number. This is evident in the increase in the value of velocity as modified Grashof number increases. Figure 6 shows the velocity profiles for different values of the radiation parameter (F), clearly as radiation parameter increases the peak values of the velocity tends to decreases. For different values of the Schmidt number (Sc) the velocity profiles are plotted in Figure 7. It is obvious that an increase in the Schmidt number results in decrease in the velocity within the boundary layer. Figure 8 illustrates the velocity profiles for different values of Prandtlnumber. It is observed that the velocity decrease as an increasing the Prandtl number. The influence of Aligned Angle ξ on the velocity profile are shown in Figure 9. It is observed that an increase in the Aligned Angle ξ causes to increase the fluid velocity. Velocity profiles for different values of hall current parameter (m) is shown in Figure 10. As m increases velocity distrribution decreases. Velocity profiles for different values of heat source parameter ϕ is shown in Figure 11. As ϕ increases velocity distrribution decreases. Figure 12 exhibits the effect of radiation parameter (F). It is seen that F increases temperature decreases. Figure 13 illustrates the temperature profiles for different values of Prandtlnumber. It is observed that the temperature decrease as an increasing the Prandtl number. The reason is that smaller values of Prandtl number are equivalent to increase in the thermal conductivity of the fluid and therefore heat is able to diffuse away from the heated surface more rapidly for higher values of Prandtl number. Hence in the case of smaller Prandtl number the thermal boundary layer is thicker and the rate of heat transfer is reduced. Effects of ϕ on temperature is presented in Figure 14. From this figure It is observed that the temperature decrease as an increasing the heat source parameter ϕ. Figure 15 illustrates the behavior concentration for different values of chemical reaction parameter γ. It is observed that an increase in leads to a decrease in the values of concentration. Figure 16 displays the effect of Schmidt number **Sc** on the concentration profiles respectively. As the Schmidt number increases the concentration decreases.

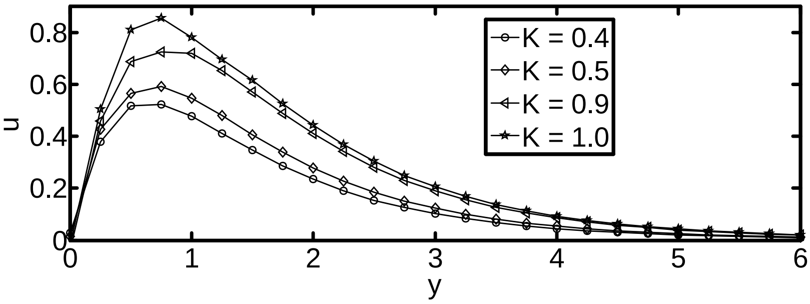

Figure 2: Velocity profiles for different values of porosity parameter K

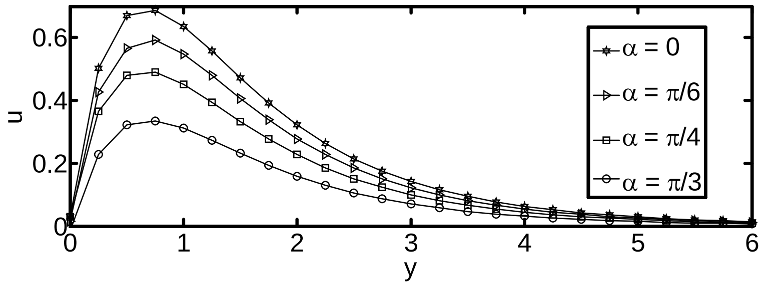

Figure 3: Velocity profiles for different values of angle of inclination α.

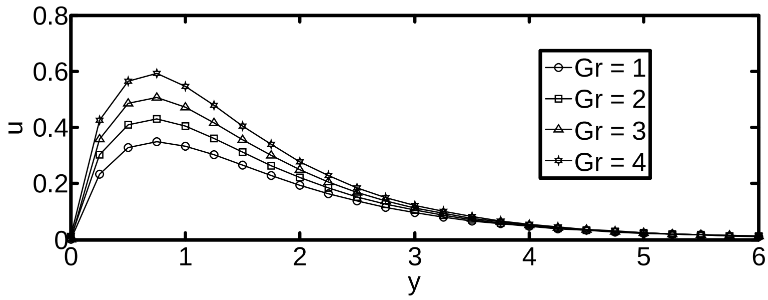

Figure 4: Velocity profiles for different values of Grashof number Gr.

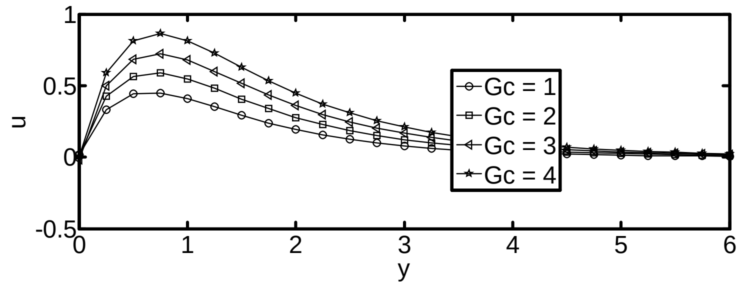

Figure 5: Velocity profiles for different values of modified Grashof number Gc.

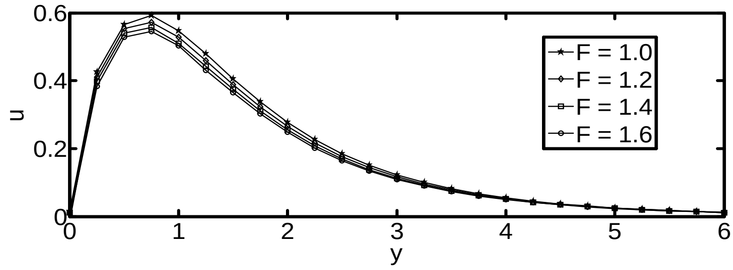

Figure 6: Velocity profiles for different values of radiation parameter F.

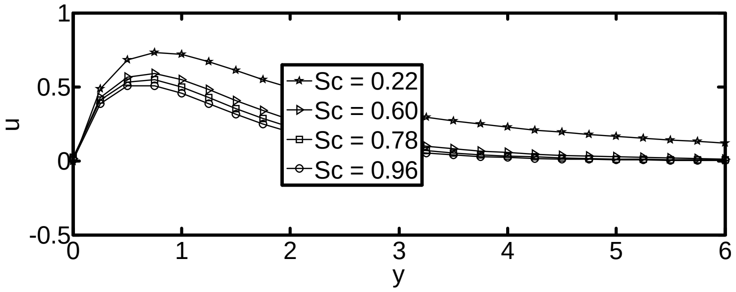

Figure 7: Velocity profiles for different values of Schmidt number Sc.

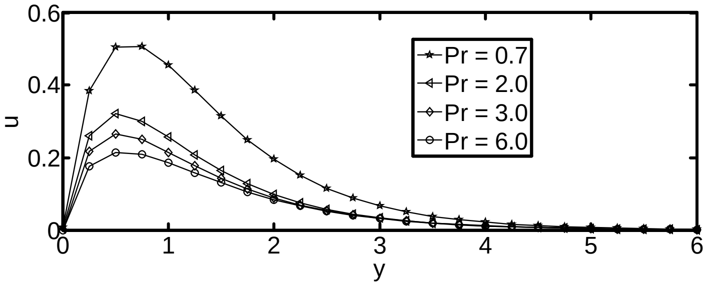

Figure 8: Velocity profiles for different values of Prandtl number Pr.

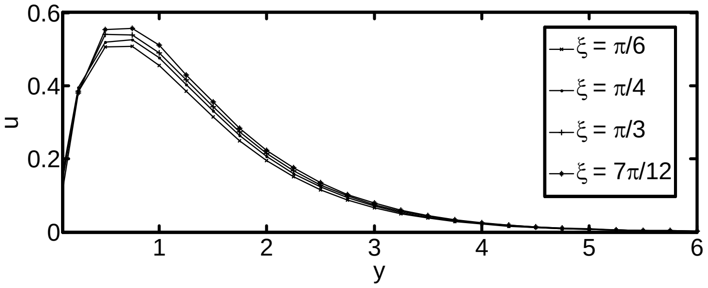

Figure 9: Velocity profiles for different values of Aligned Angle ξ .

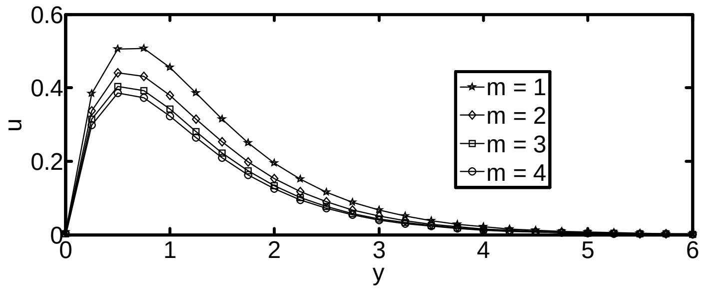

Figure 10: Velocity profiles for different values of hall current parameter m.

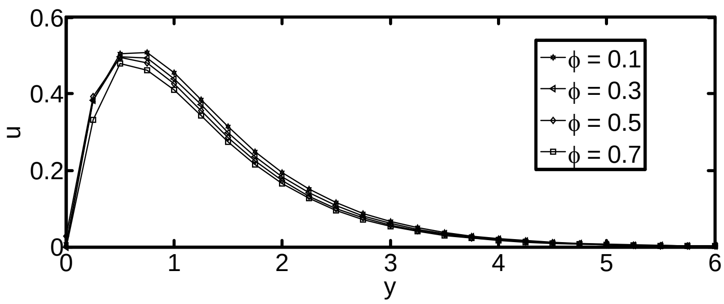

Figure 11: Velocity profiles for different values of heat source parameter ϕ.

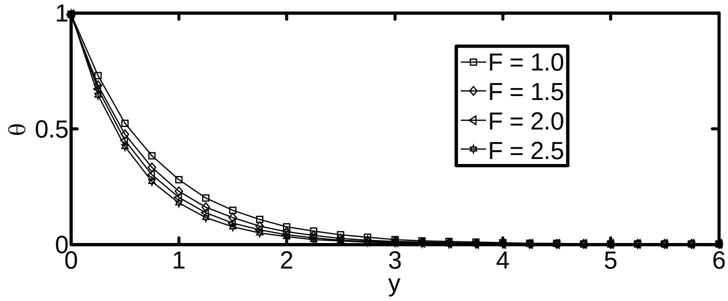

Figure 12: Temperature profiles for different values of radiation parameter F.

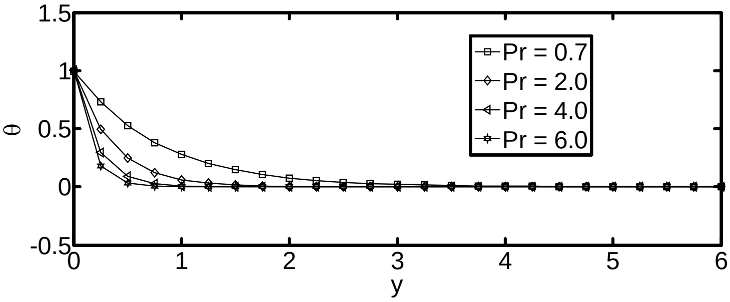

Figure 13: Temperature profiles for different values of Prandtl number Pr.

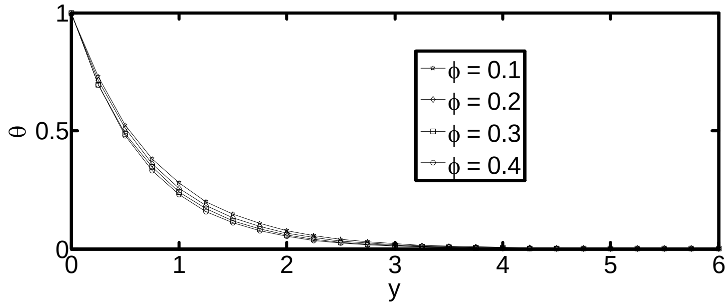

Figure 14: Temperature profiles for different values of heat source parameter ϕ.

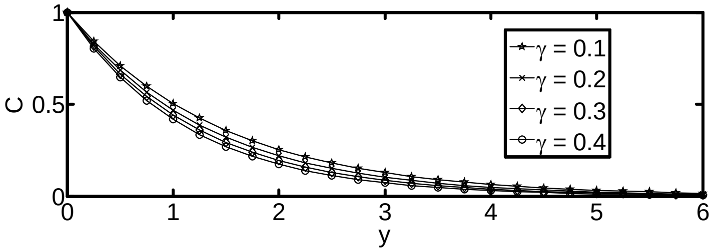

Figure 15: Concentration profiles for different values of Chemical reaction parameter γ .

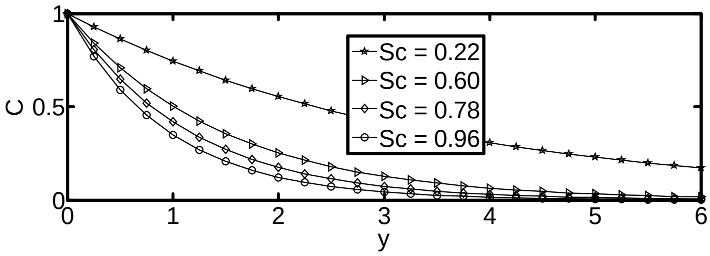

Figure 16: Concentration profiles for different values of Schmidt number Sc.

From Table 1, we conclude that Increasing of K, Gr, Gc skin-friction increasing. Also Increasing of M, α, F, Sc, m, ξ skin-friction decreasing. From Table 2, we have Increasing of Pr, F and ϕ Nusselt number is increasing. From Table 3, we say that Increasing of Sc, γ Sherwood number is decreasing.

M	K	α	Gr	Gc	F	Sc	ξ	m	τ
2.0	0.5	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.4092
3.0	0.5	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.2785
4.0	0.5	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.1097
2.0	**0.5**	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.4092
2.0	**0.7**	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.5490
2.0	**0.9**	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.9473
2.0	**1.0**	π/6	4.0	2.0	1.0	0.60	π/6	0.1	2.9786
2.0	0.5	**0**	4.0	2.0	1.0	0.60	π/6	0.1	2.7375
2.0	0.5	**□/4**	4.0	2.0	1.0	0.60	π/6	0.1	1.9028
2.0	0.5	**□/3**	4.0	2.0	1.0	0.60	π/6	0.1	1.4550
2.0	0.5	π/6	**1.0**	2.0	1.0	0.60	π/6	0.1	1.3446
2.0	0.5	π/6	**2.0**	2.0	1.0	0.60	π/6	0.1	1.6911
2.0	0.5	π/6	**3.0**	2.0	1.0	0.60	π/6	0.1	2.0633
2.0	0.5	π/6	4.0	**3.0**	1.0	0.60	π/6	0.1	2.9934
2.0	0.5	π/6	4.0	**4.0**	1.0	0.60	π/6	0.1	3.4640
2.0	0.5	π/6	4.0	**5.0**	1.0	0.60	π/6	0.1	3.9410
2.0	0.5	π/6	4.0	2.0	**1.5**	0.60	π/6	0.1	2.4465
2.0	0.5	π/6	4.0	2.0	**2.0**	0.60	π/6	0.1	2.2410
2.0	0.5	π/6	4.0	2.0	**2.5**	0.60	π/6	0.1	2.2188
2.0	0.5	π/6	4.0	2.0	1.0	**0.22**	π/6	0.1	2.7363
2.0	0.5	π/6	4.0	2.0	1.0	**0.78**	π/6	0.1	2.3267
2.0	0.5	π/6	4.0	2.0	1.0	**0.96**	π/6	0.1	2.3007
2.0	0.5	π/6	4.0	2.0	1.0	0.60	**□/3**	0.1	2.6239
2.0	0.5	π/6	4.0	2.0	1.0	0.60	**□/4**	0.1	2.5463
2.0	0.5	π/6	4.0	2.0	1.0	0.60	**□/6**	0.1	2.4121
2.0	0.5	π/6	4.0	2.0	1.0	0.60	**□/12**	0.1	2.3803
2.0	0.5	π/6	4.0	2.0	1.0	0.60	π/6	**0.3**	2.2070
2.0	0.5	π/6	4.0	2.0	1.0	0.60	π/6	**0.5**	2.0955
2.0	0.5	π/6	4.0	2.0	1.0	0.60	π/6	**0.7**	2.0268

Table 1: The effects of Skin-friction coefficient.

Pr	ϕ	F	Nu
0.7	0.1	**0.0**	0.8527
0.7	0.1	**1.0**	1.3985
0.7	0.1	**2.0**	1.7799
0.7	0.1	**3.0**	2.5214
0.72	0.1	1.0	1.4094
1.72	0.1	1.0	2.5937
2.72	0.1	1.0	3.5799
3.72	0.1	1.0	4.5892
0.7	**0.0**	1.0	1.3337
0.7	**0.1**	1.0	1.3985
0.71	**0.2**	1.0	1.4028
0.71	**0.3**	1.0	1.4623

Table 2: The effects of Nusselt number.

γ	Sc	Sh
0.1	**0.22**	-0.2947
0.1	**0.60**	-0.6873
0.1	**0.78**	-0.8697
0.1	**0.96**	-1.0513
0.2	0.60	-0.7583
0.3	0.60	-0.8186
0.4	0.60	-0.8745

Table 3: The effect of Sherwood number at the plate.

REFERENCES

[1]. A. J. Chamkha, M. C. Raju, T. S. Reddy, and S. V. K. Varma, "unsteady MHD free convection flow past an exponentially accelerated vertical plate with mass transfer, chemical reaction and thermal radiation," Int. J.Microscale Nanoscale Therm. …, vol. 5, no. 1, pp. 1949–4955.

[2]. K. V. S. Raju, M. C. Raju, S. Venkataramana, and G. S. S. Raju, "Unsteady MHD thermal diffusive, radiative and free convective flow past a vertical porous plate through non- homogeneous porous medium," Int. J. Adv. Res.Technol., vol. 2, no. 7, 2013.

[3]. N. A. Reddy, S. Varma, and M. C. Raju, "Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in mhd mixed convection flow with ohmic heating," J. Nav. Archit. Mar. Eng., vol. 6, no. 2, Jul.2010.

[4]. D. A. S. Rees and I. Pop, "Vertical free convection in a porous medium with variable permeability effects," 2010.

[5]. M. C. Raju, N. A. Reddy, and S. V. K. Varma, "Analytical study of MHD free convective, dissipative boundary layer flow past a porous vertical surface in the presence of thermal radiation, chemical reaction and constant suction," 2014.

[6]. K. D. Singh and R. Kumar, "Fluctuating Heat and Mass Transfer on Unsteady MHD Free Convection Flow of Radiating and Reacting Fluid past a Vertical Porous Plate in Slip- Flow Regime," vol. 4, no. 4, pp. 101–106, 2011.

[7]. P. Chandrakala and P. N. Bhaskar, "Effects of Heat Transfer on Flow Past an Exponentially Accelerated Vertical Plate with Uniform Heat Flux," Int. J. Dyn. Fluids, vol. 7, no. 1, pp. 9–16, 2011.

[8]. A. Sahin, "Influence of chemical reaction on transient mhd free convective flow over a vertical plate in slip-flow regime," Engineering, vol. 15, no. 1, pp. 25–34, 2010.

[9]. M. Narahari, "Natural Convection in Unsteady Couette Flow Between Two Vertical Parallel Plates in the Presence of Constant Heat Flux and Radiation," Appl. Sci., pp. 73–78.

[10]. M.C.Raju, "Radiation and mass transfer effects on a free convection flow through a porous medium," i Manag. J.Futur. Eng. Technol., vol. 7, no. 2, pp. 7–12, 2012.

[11]. D. B. Ingham, I. Pop, and P. Cheng, "Combined free and forced convection in a porous medium between two vertical walls with viscous dissipation," Transp Porous Media, vol. 5, no. 4, pp. 381–398, 1990.

[12]. J. C. Umavathi, A. J. Chamkha, and A. Mateen, "Unsteady Oscillatory Flow and Heat Transfer in a Horizontal Composite Porous Medium Channel," vol. 14, no. 3, pp. 397–415, 2009.

[13]. A.Vidya Sagar, M. C. Raju, S. V. K. Varma, and S. Venkataramana, "Unsteady MHD free convection boundary layer flow of radiation absorbing kuvshinski fluid through porous medium," Rev. Adv. Phys. Theor. Appl., vol. 1, no. 3, pp. 48–62, 2014.

[14]. A. J. Chamkha, S. E. Ahmed, and A. S. Aloraier, "Melting and radiation effects on mixed convection from a vertical surface embedded in a non-Newtonian fluid saturated non-Darcy porous medium for aiding and opposing eternal flows," Int. J., vol. 5, no. July, pp. 1212–1224, 2010.

[15]. F. Flows, "Introduction , Importance and Development of Fluid Mechanics," Development, pp. 1–14.

[16]. N. C. Mahanti and P. Gaur, "Effects of Varying Viscosity and Thermal Conductivity on Steady Free Convective Flow and Heat Transfer Along an Isothermal Vertical Plate in the Presence of Heat Sink," vol. 2, no. 1, pp. 23–28, 2009.

[17]. M. A. Abd El-Naby, E. M. E. Elbarbary, and N. Y. Abdelazem, "Finite difference solution of radiation effects on MHD unsteady free-convection flow over vertical plate with variable surface temperature," J. Appl. Math., vol. 2003, no. 2, pp. 65–86, 2003.

[18]. M.A.Hossain, "Viscous and Joule heating effects on MHD-free convection flow with variable plate Temperature". International Journal of Heat and Mass Transfer, 35(12), 1992, 3485–3487.

[19]. M.A. Hossain, R.S. Gorla, "Joule heating effect on magnetohydrodynamic mixed convection boundary layer flow with variable electrical conductivity", International Journal of Numerical Methods for Heat & Fluid Flow, Vol. 23(2), 275 – 288, 2013.

[20]. O.A. Bég, J. Zueco &H.S. Takhar, "Unsteady magnetohydrodynamic Hartmann–Couette flow and heat transfer in a Darcian channel with Hall current, ionslip, viscous and Joule heating effects: Network numerical solutions", Communications in nonlinear science and numerical simulation, 14(4), 1082-1097, 2009.

[21]. C.H. Chen, "Combined heat and mass transfer in MHD free convection from a

vertical surface with Ohmic heating and viscous dissipation", International journal of engineering science, 42(7), 699-713, 2004.

[22]. N.A. Reddy, S.V.K. Varma, M. C. Raju, "Thermo diffusion and chemical effects with simultaneous thermal and mass diffusion in MHD mixed convection flow with Ohmic heating", Journal of Naval Architecture and Marine Engineering, 6, 84-93, 2009.

[23]. P. Sibanda, O.D. Makinde, "On steady MHD flow and heat transfer past a rotating disk in a porous medium with Ohmic heating and viscous dissipation", International Journal of Numerical Methods for Heat & Fluid Flow, 20 (3), 269 – 285, 2010.

[24]. A. Wang, C. Tu &X. Zhang, "Mixed convection of non-newtonian fluids from a vertical plate embedded in a porous medium", Acta Mechanica Sinica, 6 (3), 214-220, 1990.

[25]. K. A. Yih, "Viscous and Joule heating effects on non-Darcy MHD natural convection flow over a permeable sphere in porous media with internal heat generation", International communications in heat and mass transfer, 27(4), 591-600, 2000.

[26]. R. Choudhury& S.K. Das, "Mixed Convective visco elastic MHD flow with Ohmic heating", International Journal of computer applications, 68 (10), 7-13, 2013.

[27]. Raju M.C, C.Veeresh, S.V.K.Varma, Rushikumar B and Vijayakumar AG, "Heat And Mass Transfer In MHD Free Convection Flow on a Moving Inclined Porous Plate", J Appl Computat Math ,4(5),1-7, 2015.

[28]. 28.Chaudhary RC, Sharma BK, Jha AK (2006) Radiation effect with simultaneous thermal and mass diffusion in MHD mixed convective flow. Rom j Phys 51: 715-727.

[29]. Dulal P, Talukdar BP (2010) Buoyancy and Chemical Reaction Effects on MHD Mixed Convection Heat and Mass Transfer in a Porous Medium with Thermal Radiation and Ohmic Heating. Commun Nonlinear Sci Numer Simulat 15: 2878-2893.

[30]. Sparrow EM, Eichhorn R, Grigg JL (1959) Combined and Free Convection in a Boundary Layer. Physics of Fluids 2: 319-320.

[31]. Singh PK (2012) Heat and Mass Transfer in MHD Boundary Layer Flow past an Inclined Plate with Viscous Dissipation in Porous Medium. International Journal of Scientific Engineering Research 3(6): 2229-5518.

[32]. Mansour MA, El-Anssary NF, Aly AM (2010) Chemical reaction and magnetohydrodynamic effects on free convection flow past an inclined surface in a porous medium. Journal of porous Media 13: 87-96.

[33]. Chen CH (2004) Heat and mass transfer in MHD flow by natural convection from a permeable inclined surface with variable wall temperature and concentration. Acta Mech 172: 219-235.

[34]. Hossain MA, Pop I, Ahmed M (1996) MHD free convection flow from an isothermal plate inclined at a small angle to the horizontal. J Theo Appl Fluid Mech 1: 194-207.

[35]. Pal D, Talukdar B (2010) Pertubation Analysis of Unsteady Magneto hydrodynamic onvective Heat and Mass Transfer in a Boundary layer Slip Flow Past a Vertical Permeable Plate with Thermal Radiation and Chemical Reaction. Commun Nonlinear Sci Numer Simulat 15: 1813-1830.

[36]. Noor NFM, Abbasbandy S, Hashim I (2012) Heat and mass transfer of thermophoretic MHD flow over an inclined radiate isothermal permeable surface in the presence of heat source/sink. Int J Heat Mass Transf 55: 2122–2128.

[37]. Bhuvaneswari M, Sivasankaran S, Kim YJ (2010) Exact Analysis of Radiation Convective Flow Heat and Mass Transfer Over an Inclined Plate in a Porous Medium. World Appl Sci J 10(7): 774-778.

[38]. Ziyauddin, Kumar M (2010) Radiation Effect on Unsteady MHD Heat and Mass Transfer Flow on a Moving Inclined Porous Heated Plate in the Presence of Chemical Reaction. Int J Math Modell Simul Appl 3: 155–163.

[39]. Alam MS, Rahman MM, Sattar MA (2009) On the Effectiveness of Viscous Dissipation and Joule Heating on Steady Magneto hydrodynamic Heat and Mass Transfer Flow Over an Inclined Radiate Isothermal Permeable Surface in the Presence of Thermophoresis. Commun Nonlinear Sci Numer Simul 14: 2132-2143.

[40]. Ganesan Palani G (2004) Finite Difference Analysis of Unsteady Natural Convection MHD Flow past an Inclined Plate with Variable Surface Heat and Mass Flux. Int J Heat Mass Transfer 47: 4449-4457.

[41]. Aydm O, Kaya A (2009) MHD Mixed Convective Heat Transfer Flow about an Inclined Plate. International Journal of Heat and Mass Transfer 46(1): 129-136.

[42]. O. Chandna and M. Garg, On steady plane MHD flows with orthogonal magnetic and

velocity fields, Int. J. Engng. Sci. ,17, pp. 251-257, 1979.

[43]. O. Chandna, R. Barron and K. Chew, Hodograph transformations and solutions in variably inclined MHD plane flows, J. Engg. Math. , 16, pp. 223-243, 1982.

[44]. O. Chandna, R. Barron and K. Chew, Finitely conducting orthogonal MHD plane flows, Can. J. phys. , 67, pp. 56- 62, 1989.

[45]. O. Chandna and P. Nguyen, Hodograph transformation method and solutions in aligned MHD plane flows, Int. J. Engng. Sci. , 28(10), pp. 973-987, 1992.

[46]. M. Hamdan, Single-phase flow through channels, A review: Flow models and entry conditions, J. Appl. Math. Comput. 62, pp. 203-222, 1994.

APPENDIX

$$m_1 = \frac{Sc + \sqrt{Sc^2 + 4Sc\gamma}}{2};$$

$$A_1 = \frac{\Pr + \sqrt{\Pr^2 + 4\Pr(F+\phi)}}{2};$$

$$A_2 = \frac{1+\sqrt{1-4D_5}}{2};$$

$$B_1 = A_1 + A_2;$$

$$B_2 = A_1 + m_1;$$

$$B_3 = A_2 + m_1;$$

$$A_{16} = \frac{1+\sqrt{1-4D_5}}{2};$$

$$D_3 - D_4 = D_5;$$

$$A_3 = \frac{D}{A_1^2 - D_1 + D_5};$$

$$A_4 = \frac{D_2}{m_1^2 - m_1 + D_5};$$

$$A_5 = A_3 + A_4;$$

$$A_6 = \frac{\Pr A_2 A_5}{A_2^2 - \Pr A_2 - \Pr(F+\phi)};$$

$$A_7 = \frac{\Pr A_1 A_3}{A_1^2 - \Pr A_1 - \Pr(F+\phi)};$$

$$A_8 = \frac{\Pr m_1 A_4}{m_1^2 - \Pr m_1 - \Pr(F+\phi)};$$

$$A_9 = \frac{\Pr M^2 A_5^2}{4A_2^2 - 2\Pr A_2 - \Pr(F+\phi)};$$

$$A_{10} = \frac{\Pr M^2 A_3^2}{4A_1^2 - 2\Pr A_1 - \Pr(F+\phi)};$$

$$A_{11} = \frac{\Pr M^2 A_4^2}{4m_1^2 - 2\Pr m_1 - \Pr(F+\phi)};$$

$$A_{12} = \frac{2\Pr M^2 A_3 A_5}{B_1^2 - \Pr B_1 - \Pr(F+\phi)};$$

$$A_{13} = \frac{2\Pr M^2 A_3 A_4}{B_2^2 - \Pr B_2 - \Pr(F+\phi)};$$

$$A_{14} = \frac{2\Pr M^2 A_4 A_5}{B_3^2 - \Pr B_3 - \Pr(F+\phi)};$$

$$A_{15} = -A_6 - A_{12} - A_{14} + A_7 + A_8 + A_9 + A_{10} + A_{11} + A_{13};$$

$$A_{17} = \frac{D_1(A_{15} - A_7)}{A_1^2 - A_1 + D_5};$$

$$A_{18} = \frac{D_1 A_6}{A_2^2 - A_2 + D_5};$$

$$A_{19} = \frac{D_1 A_8}{m_1^2 - m_1 + D_5};$$

$$A_{20} = \frac{D_1 A_9}{4A_2^2 - 2A_2 + D_5};$$

$$A_{21} = \frac{D_1 A_{10}}{4A_1^2 - 2A_1 + D_5};$$

$$A_{22} = \frac{D_1 A_{11}}{4m_1^2 - 2m_1 + D_5};$$

$$A_{23} = \frac{D_1 A_{12}}{B_1^2 - B_1 + D_5};$$

$$A_{24} = \frac{D_1 A_{13}}{B_2^2 - B_2 + D_5}; \qquad A_{25} = \frac{D_1 A_{14}}{B_3^2 - B_3 + D_5};$$

$$A_{26} = -A_{19} - A_{20} - A_{21} - A_{22} - A_{24} + A_{17} + A_{18} + A_{23} + A_{25};$$

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