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A STUDY ON CHEMICAL REACTION AND SORET EFFECT ON A STEADY MHD FLOW OVER A VERTICAL POROUS PLATE WITH OHMIC HEATING, VISCOUS DISSIPATION AND RADIATION

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Abstract:

The present article deals with the analysis of steady MHD flow of an incompressible and electrically conducting viscous fluid through a vertical porous plate with ohmic heating, viscous dissipation and radiation in presence of chemical reaction and Soret effect. The governing non-linear partial differential equations are transformed into a set of coupled ordinary differential equations which are then solved analytically by using the regular perturbation techniques. The effect of various parameters like Schmidt number (Sc), Prandtl number (Pr), Grashof number (Gr), Modified Grashof number (Gm), Magnetic parameter (M), Radiation parameter (F), Porosity parameter (K), Chemical reaction parameter (R) and Soret number (Sr) on velocity, temperature and concentration profiles and also on skin friction, Nusselt number and Sherwood number are discussed with the help of numerical values and the relevant graphs.

Key Words: MHD, Heat and Mass Transfer, Porous Medium, Ohmic Heating, Viscous Dissipation, Radiation, Chemical Reaction & Soret effect.

Introduction:

Magneto hydrodynamic equations are ordinary electromagnetic and hydrodynamic equations modified to take into account the interplay between the motion of the fluid and the electromagnetic field. MHD plays a significant role in various industrial applications. MHD has wide range of applications in different subject areas, such as astrophysics, geophysics, space science and communication engineering to name a few. MHD finds applications in electromagnetic pumps, controlled fusion research, crystal growth, plasma jets and chemical synthesis etc. A number of researchers study free and forced convective flows with heat and mass transfer due to its day-to-day applications in science and technology. The phenomenon of heat and mass transfer are observed in buoyancy induced motions in the atmosphere, in water bodies, quasi-solid bodies such as earth and so on. In industrial applications many transport exists where the transfer of heat and mass takes place simultaneously as a result of combined buoyancy effects due to thermal diffusion and chemical species diffusion. Also a large amount of works on heat and mass transfer have focused mainly on regular geometries, such as vertical flat plate, flat plate with inclination and rectangular ducts etc., .

The effects of porous boundaries on flow, heat and mass transfer are important due to applications in engineering design in the field of chemical and geophysical sciences. Permeable porous plates are used in the filtration process and also for hot bodies to keep its temperature constant and to make the heat in solution of t he surface more effective. The combined effect 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 and hence received a considerable amount of attention in recent years. There are two types of chemical reactions namely homogeneous and heterogeneous. A homogeneous reaction occurs uniformly throughought the given phase, where as heterogeneous reaction takes place in a restricted region within the boundary of a phase. The effects of chemical reaction depend on whether the reaction is homogeneous or heterogeneous.

The mass fluxes can be created by the temperature gradient is called the Soret or thermo - diffusion effect. The term Soret effect most often applies to aerosol mixtures, but may also commonly refer to the phenomenon in all phases of matter. It has been used in commercial precipitators for applications similar to electro static precipitators, manufacturing of optical fiber in vapor deposition processes, facilitating drug discovery by allowing the detection of aptamer binding by comparison of the bound versus unbound motion of the target molecule. It is also used to separate different polymer particles in fluid flow fractionation. Shercliff [1], Ferraro and Plumpton [2], Cogley *et. al.*, [3] and Crammer and Pai [4] studied various importance of Magneto hydrodynamic flow. Singh and Soundalgekar [5] investigated the transient free convection in cold water past an infinite vertical porous plate. Sattar [6] discussed the free convection and mass transfer flow through a porous medium past an infinite vertical porous plate with time dependent temperature and concentration. The heat and mass transfer along a vertical plate with variable surface temperature and concentration in the presence of magnetic field was studied by Elbashbeshy [7]. Jha [8] reported the effects of applied magnetic field on transient free convective flow in a vertical channel while Hossain *et. al.,* [9] examined the radiation effect on free and forced convection flows past a porous vertical plate, including various physical aspects. Kim [10] investigated the unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate with variable suction while Geindreau and Auriault [11] examined the effect of magnetic field on slow flow through porous medium. Sharma and Mishra [12] analyzed the effect of mass transfer in unsteady MHD flow and heat transfer past an infinite porous vertical moving plate. Heat and mass transfer effects on moving plate in the presence of thermal radiation have been studied by Muthucumaraswamy [13] using Laplace transform technique while the effects of unsteady free convective MHD flow through a porous medium bounded by an infinite vertical porous plate has been studied by Ahmed [14].

Sharma and Singh [15] analyzed an unsteady MHD free convective flow and heat transfer along a vertical porous plate with variable suction and internal heat generation. Orhan Aydin and Ahmet Kaya [16] discussed mixed convection heat transfer about a permeable vertical plate in the presence of magneto and thermal radiation effects by the method of similarity variables. Raju *et. al.,* [17] investigated the Soret effect due to natural convection between heated inclined plates. Anjali Devi and Kayalvizhi [18] studied the problem of MHD flow over a stretching sheet embedded in a porous medium with radiation effect by analytical solution while the analysis of Soret and Dufour effects on steady MHD free convection flow past a semi-infinite moving vertical plate in a porous medium with viscous dissipation have been discussed by M.G. Reddy and N.B. Reddy [19]. Sri Hari Babu and Ramana Reddy [20] investigated the effects of mass transfer on MHD mixed convective flow from a vertical surface with ohmic heating and viscous dissipation whereas Senapati and Dhal [21] analyzed Magnanetic effect on mass and heat transfer of hydrodynamic flow past a vertical oscillating plate in presence of chemical reaction. Raju *et. al.,* [22] studied mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface in the presence of radiation. Sathya Narayana and Sravanthi [23] discussed the simultaneous effects of Soret and ohmic heating on MHD free convective heat and mass transfer flow of micropolar fluid with porous medium while the effects of chemical reaction on MHD free convective oscillatory flow past a porous plate with viscous dissipation and heat sink was investigated by Sekhar and Viswanath Reddy [24]. Kumar and Singh [25] analyzed the mathematical modeling of Soret and Hall effects on oscillatory MHD free convective flow of radiating fluid in a rotating vertical porous channel filled with porous medium. Balamurugan and Karthikeyan [26] dicussed steady free convection flow past a semi-infinite flat plat in the presence of magnetic field and viscous dissipation.

The effects of chemical reaction and heat source on two dimensional free convection MHD flow of a viscous incompressible fluid through a finitely long vertical wavy wall and a smooth flat wall have been studied by Devika *et. al.,* [27] using regular perturbation technique. Manglash *et. al.,* [28] examined the Soret and Hall effects on heat and mass transfer in MHD free convective flow through a porous medium in a vertical porous channel while the effects of Chemical reaction on MHD oscillatory flow through a porous plates with heat source and Soret effect have been studied by Barik *et. al.,* [29]. Madhusudhana Rao *et. al.,* [30] analyzed the unsteady MHD free convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate with heat absorption, radiation, chemical reaction and Soret effects while Jyothi *et. al.,* [31] discussed the thermo diffusion and chemical reaction effects on unsteady free convection flow past a vertical porous plate in slip-flow regime. Balamurugan and Karthikeyan [32] investigated the unsteady MHD free convective heat and mass transfer past an infinite vertical porous plate embedded in a porous medium in presence of hall current and heat source with chemical reaction. Balamurugan and Karthikeyan [33] analyzed the Soret and chemical reaction effects of heat and mass transfer of oscillatory free convective MHD rotation flow along a porous medium bounded by two vertical porous plates in the presence of hall current by using the singular perturbation technique. The objective of the present study is to analyze the chemical reaction, Soret and radiation effects on heat and mass transfer past an infinite vertical porous plate in presence of Ohmic heating and transverse magnetic field.

Mathematical Formulation:

Consider a steady MHD flow of an incompressible and electrically conducting viscous fluid flow along a hot, non-conducting porous vertical plate. Choose x'- axis along the plate in the upward direction and y'- axis along normal to the plate. A transverse constant magnetic field is applied that is in the direction of y'- axis. Since the motion is two dimensional and length of the plate is large enough therefore all the physical variables are independent of the variable x'. Let u' and v' be the velocity components of fluid flow along x' and y' directions respectively, that is along and perpendicular to the plate. Under the regular Boussinesq's approximation, the governing equations consisting of continuity, momentum, energy and concentration respectively are given by

(i) Equation of Continuity:

$$\frac{\partial v'}{\partial y'}=0\Rightarrow v'=-v_0 \tag{1}$$

(ii) Equation of Momentum:

$$v'\frac{\partial u'}{\partial y'}=\upsilon\frac{\partial^2 u'}{\partial y'^2}+g\beta\left(T'-T_\infty\right)+g\beta^*\left(C'-C_\infty\right)-\frac{\sigma B_0^{\,2}u'}{\rho}-\frac{\upsilon}{K'}u' \tag{2}$$

$$\frac{\partial p'}{\partial y'}=0,\ i.e., p\, is\, independent\, of\ \ y' \tag{3}$$

(iii) Equation of Energy

$$v'\frac{\partial T'}{\partial y'}=\frac{1}{\rho c_p}\left[\kappa\frac{\partial^2 T'}{\partial y'^2}+\mu\left(\frac{\partial u'}{\partial y'}\right)^2+\sigma B_0^{\,2}u'^2-\frac{\partial q_r{}'}{\partial y'}\right] \tag{4}$$

(iv) Equation of Concentration:

$$v'\frac{\partial C'}{\partial y'}=D_m\frac{\partial^2 C'}{\partial y'^2}+\frac{D_m K_T}{T_m}\frac{\partial^2 T'}{\partial y'^2}-R'\left(C'-C_\infty\right) \tag{5}$$

The radiative heat flux is taken in the following form

$$\frac{\partial q_r{}'}{\partial y'}=4\left(T'-T'_\infty\right)I' \tag{6}$$

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 wall and $e_{b\lambda}$ is Planck's function.

The boundary conditions are

$$\left.\begin{array}{ll} u'=0, T'=T_W, C'=C_W & at\ y'=0 \\ u'\to 0, T'\to T_\infty, C'\to C_\infty & as\ y'\to\infty \end{array}\right\} \tag{7}$$

Introduce the following dimensionless quantities and variables

$$y=\frac{v_0 y'}{\upsilon},\quad u=\frac{u'}{v_0},\quad T=\frac{T'-T_\infty}{T_W-T_\infty},\quad C=\frac{C'-C_\infty}{C_W-C_\infty},\quad \Pr=\frac{\mu c_p}{\kappa},\quad Sc=\frac{\upsilon}{D_m},$$
$$Gr=\frac{g\beta\upsilon\left(T_W-T_\infty\right)}{v_0^{\,3}},\quad M=\frac{\sigma B_0^{\,2}\upsilon}{\rho v_0^{\,2}},\quad Gm=\frac{g\beta'\upsilon\left(C_W-C_\infty\right)}{v_0^{\,3}},\ K=\frac{K'v_0^{\,2}}{\upsilon^2},$$
$$E=\frac{v_0^{\,2}}{c_p\left(T_W-T_\infty\right)},\quad R=\frac{R'\upsilon}{v_0^{\,2}},\quad F=\frac{4\upsilon I'}{\rho c_p v_0^{\,2}},\quad Sr=\frac{D_m K_T\left(T_w-T_\infty\right)}{\upsilon T_m\left(C_w-C_\infty\right)} \tag{8}$$

The respective non-dimensional governing equations of (2), (4) and (5) after using (8) become

$$\frac{\partial^2 u}{\partial y^2}+\frac{\partial u}{\partial y}-\left(M+\frac{1}{K}\right)u=-\left(GrT+GmC\right) \tag{9}$$

$$\frac{\partial^2 T}{\partial y^2}+\Pr\frac{\partial T}{\partial y}-F\Pr T+\Pr E\left(\frac{\partial u}{\partial y}\right)^2+\Pr EMu^2=0 \tag{10}$$

$$\frac{\partial^2 C}{\partial y^2}+Sc\frac{\partial C}{\partial y}+Sc\,Sr\frac{\partial^2 T}{\partial y^2}-ScRC=0 \tag{11}$$

The corresponding non-dimensional boundary conditions can be got by using (8) in (7)

$$\left.\begin{array}{ll} u=0,\ T=1,\ C=1 & at\ y=0 \\ u\to 0, T\to 0, C\to 0 & as\ y\to\infty \end{array}\right\} \tag{12}$$

Method of Solution:

The physical variables $u, T\ and\ C$ can be expanded in a series of powers of the Eckert number (E). This can be possible physically as E for the flow of an incompressible fluid is always less than unity.

To solve the system of partial differential equations (9) - (11), we follow the regular perturbation method using E as the perturbation parameter. Therefore the expressions for velocity, temperature and concentration are assumed in the following form.

$$\left.\begin{aligned} u(y) &= u_0(y) + E\,u_1(y) + o(E^2) \\ T(y) &= T_0(y) + E\,T_1(y) + o(E^2) \\ C(y) &= C_0(y) + E\,C_1(y) + o(E^2) \end{aligned}\right\} \tag{13}$$

Substituting the above expressions (13) in the equations (9) - (11) and equating the co - efficients of like powers of E^0 and E^1 (neglecting E^2 terms onwards), we obtain the following set of ordinary differential equations.

Zeroth Order Equations:

$$u_0'' + u_0' - (M + \frac{1}{K})u_0 = -GrT_0 - GmC_0 \tag{14}$$

$$T_0'' + \Pr T_0' - F\Pr T_0 = 0 \tag{15}$$

$$C_0'' + ScC_0' + Sc\,Sr\,T_0'' - ScRC_0 = 0 \tag{16}$$

First Order Equations:

$$u_1'' + u_1' - (M + \frac{1}{K})u_1 = -GrT_1 - GmC_1 \tag{17}$$

$$T_1'' + \Pr T_1' - F\Pr T_1 + \Pr u_0'^2 + \Pr Mu^2{}_0 = 0 \tag{18}$$

$$C_1'' + ScC_1' + Sc\,Sr\,T_1'' - ScRC_1 = 0 \tag{19}$$

The boundary conditions (12) now become

$$\left.\begin{aligned} &u_0 = 0,\ u_1 = 0,\ T_0 = 1,\ T_1 = 0,\ C_0 = 1,\ C_1 = 0 \quad at\ \ y = 0 \\ &u_0 \to 0,\ u_1 \to 0,\ T_0 \to 0,\ T_1 \to 0,\ C_0 \to 0,\ C_1 \to 0 \quad as\ \ y \to \infty \end{aligned}\right\} \tag{20}$$

The equations (14) to (19) are second order linear differential equations with constant coefficients. The solutions of these equations under the corresponding boundary conditions are

$$T_0(y) = e^{m_1 y}$$

$$C_0(y) = A_4 e^{m_3 y} + A_3 e^{m_1 y}$$

$$u_0(y) = A_9 e^{m_5 y} + A_6 e^{m_1 y} + A_7 e^{m_3 y} + A_8 e^{m_1 y}$$

$$T_1(y) = A_{17} e^{m_1 y} + A_{11} e^{2m_1 y} + A_{12} e^{2m_3 y} + A_{13} e^{2m_5 y} + A_{14} e^{(m_1+m_5)y} + A_{15} e^{(m_1+m_3)y} + A_{16} e^{(m_3+m_5)y}$$

$$C_1(y) = A_{26} e^{m_3 y} + A_{19} e^{m_1 y} + A_{20} e^{2m_1 y} + A_{21} e^{2m_3 y} + A_{22} e^{2m_5 y} + A_{23} e^{(m_1+m_5)y} + A_{24} e^{(m_1+m_3)y} + A_{25} e^{(m_3+m_5)y}$$

$$u_1(y) = A_{36} e^{m_5 y} + A_{28} e^{m_3 y} + A_{29} e^{m_1 y} + A_{30} e^{2m_1 y} + A_{31} e^{2m_3 y} + A_{32} e^{2m_5 y} + A_{33} e^{(m_1+m_5)y} + A_{34} e^{(m_1+m_3)y} + A_{35} e^{(m_3+m_5)y}$$

The values for the constants $m's$ and $A's$ are given in the Appendix.

Substituting $u_0(y)$ and $u_1(y)$ in (11), the velocity field $u(y)$ is

$$\begin{aligned} u(y) = &\left[A_9 e^{m_5 y} + A_6 e^{m_1 y} + A_7 e^{m_3 y} + A_8 e^{m_1 y}\right] + E\left[A_{36} e^{m_5 y} + A_{28} e^{m_3 y} + A_{29} e^{m_1 y} + A_{30} e^{2m_1 y}\right. \\ &\left. + A_{31} e^{2m_3 y} + A_{32} e^{2m_5 y} + A_{33} e^{(m_1+m_5)y} + A_{34} e^{(m_1+m_3)y} + A_{35} e^{(m_3+m_5)y}\right] \end{aligned} \tag{21}$$

Substituting $T_0(y)$ and $T_1(y)$ in (12), the temperature field $T(y)$ is

$$T(y) = e^{m_1 y} + E\left[A_{17} e^{m_1 y} + A_{11} e^{2m_1 y} + A_{12} e^{2m_3 y} + A_{13} e^{2m_5 y} + A_{14} e^{(m_1+m_5)y} + A_{15} e^{(m_1+m_3)y} + A_{16} e^{(m_3+m_5)y}\right] \tag{22}$$

Substituting $C_0(y)$ and $C_1(y)$ in (13), the concentration field $C(y)$ is

$$\begin{aligned} C(y) = &[A_4 e^{m_3 y} + A_3 e^{m_1 y}] + E\left[A_{26} e^{m_3 y} + A_{19} e^{m_1 y} + A_{20} e^{2m_1 y} + A_{21} e^{2m_3 y}\right. \\ &\left. + A_{22} e^{2m_5 y} + A_{23} e^{(m_1+m_5)y} + A_{24} e^{(m_1+m_3)y} + A_{25} e^{(m_3+m_5)y}\right] \end{aligned} \tag{23}$$

Skin Friction:

The non-dimensional shearing stress on the surface of a body, due to the fluid motion, is known as skin friction and is defined by the Newton's law of viscosity. The expression for the skin friction τ at the plate is given by

$$\tau = \left(\frac{\partial u}{\partial y}\right)_{y=0}$$

$$\tau = \left(\frac{\partial u_0}{\partial y}\right)_{y=0} + E\left(\frac{\partial u_1}{\partial y}\right)_{y=0}$$

$$\tau = \left[A_9 m_5 + A_6 m_1 + A_7 m_3 + A_8 m_1\right] + E\left[A_{36} m_5 + A_{28} m_3 + A_{29} m_1 + 2A_{30} m_1 + 2A_{31} m_3 + 2A_{32} m_5 + A_{33}(m_1 + m_5) + A_{34}(m_1 + m_3) + A_{35}(m_3 + m_5)\right] \quad (24)$$

Heat Flux:

The convective heat flux can be best expressed interms of Nusselt number which measures the ratio of heat actually transported across a layer to that which should be conducted if the fluid were immobilized. The expression for the Nusselt number is obtained from the gradient of the temperature. The non-dimensional form of the Nusselt number at the plate is given by

$$Nu = -\left(\frac{\partial T}{\partial y}\right)_{y=0}$$

$$Nu = -\left\{\left(\frac{\partial T_0}{\partial y}\right)_{y=0} + E\left(\frac{\partial T_1}{\partial y}\right)_{y=0}\right\}$$

$$Nu = -\left\{m_1 + E\left[A_{17} m_1 + 2A_{11} m_1 + 2A_{12} m_3 + 2A_{13} m_5 + A_{14}(m_1 + m_5) + A_{15}(m_1 + m_3) + A_{16}(m_3 + m_5)\right]\right\} \quad (25)$$

Mass Flux:

The mass flux can be expressed interms of Sherwood number which is the ratio of convective to diffusive mass transport. The expression for the Sherwood number is obtained from the gradient of the mass transfer is given by

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

$$Sh = -\left\{\left(\frac{\partial C_0}{\partial y}\right)_{y=0} + E\left(\frac{\partial C_1}{\partial y}\right)_{y=0}\right\}$$

$$Sh = -\left\{[A_4 m_3 + A_3 m_1] + E\left[A_{26} m_3 + A_{19} m_1 + 2A_{20} m_1 + 2A_{21} m_3 + 2A_{22} m_5 + A_{23}(m_1 + m_5) + A_{24}(m_1 + m_3) + A_{25}(m_3 + m_5)\right]\right\} \quad (26)$$

Results and Discussion:

The flow parameters play an important role in determining the magnitude of velocity of the flow field. The flow parameters affecting the velocity flow field are Schmidt number, Prandtl number, Grashof number, Magnetic parameter, Modified Grashof number, Radiation parameter, Porosity parameter, Chemical reaction parameter and Soret number. Figures 1-9 depict the effects of these parameters on the velocity of the flow field.

Figure 1 presents the effect of Schmidt number on the velocity field. It is observed that as the Schmidt number increases the velocity decreases. Figure 2 illustrates the effect of Prandtl number on the velocity field. It is noticed that as the Prandtl number increases the velocity decreases. Figure 3 shows the effect of Grashof number on the velocity field. It is seen that as the Grashof number increases the velocity increases. Figure 4 depicts the effect of Magnetic parameter on the velocity field. It is noticed that as the Magnetic parameter increases the velocity decreases. Physically, it is true due to the fact that the application of a transverse magnetic field to an electrically conducting fluid gives rise to a body force known as Lorentz force which tends to resist the fluid flow and slow down its motion in the boundary layer region. Figure 5 illustrates the effect of Modified Grashof number on the velocity field. It is observed that as the Modified Grashof number increases the velocity increases. Figure 6 displays the effect of Radiation parameter on the velocity field. It is seen that as the Radiation parameter increases the velocity decreases. It is due to the fact that increase in radiation parameter results in the velocity within the boundary layer, as well as decreased thickness of the velocity boundary layers. Figure 7 presents the effect of Porosity parameter on the velocity field. It is observed that as the Porosity parameter increases the velocity increases. Figure 8 discusses the effect of Chemical reaction parameter on the velocity field. It is seen that as the Chemical reaction parameter increases the velocity decreases. Figure 9 illustrates the effect of Soret number on the velocity field. It is noticed that as the Soret number increases the velocity increases. Figures 10 and 11 elucidate the temperature profiles of the flow field with the variation of the flow parameters such as Prandtl number and Radiation parameter respectively. Figure 10 shows the effect of Prandtl number on the temperature field. It is noticed that as the Prandtl number increases the temperature decreases. Figure 11 presents the effect of Radiation parameter on the temperature field. It is observed that as the Radiation parameter increases the temperature decreases. It is due to the fact that increase in radiation parameter results in the temperature within the boundary layer, as well as decreased thickness of the temperature boundary layers.

The Schmidt number, Prandtl number, Radiation parameter, Chemical reaction parameter and Soret number plays a dominant role in determining the concentration field shown in the Figures 12-16. Figure 12 discusses the effect of Schmidt number on the concentration field. It is seen that as the Schmidt number increases the concentration decreases. This is due to the fact that the concentration of the species is higher for small values of Schmidt number, as the increase of Schmidt number means decrease of molecular diffusion. Hence there is a decrease in concentration with the increase of Schmidt number. Figure 13 illustrates the effect of Prandtl number on the concentration field. It is noticed that as the Prandtl number increases the concentration decreases. Figure 14 presents the effect of Radiation parameter on the concentration field. It is observed that as the Radiation parameter increases the concentration decreases. Figure 15 illustrates the effect of Chemical reaction parameter on the concentration field. It is noticed that as the Chemical reaction parameter increases the concentration decreases. Physically, it is true due to the fact that the destructive chemical reduces the solutal boundary layer thickness and increases the mass transfer there is a decrease in the concentration of species in the boundary layer. Figure 16 depicts the effect of Soret number on the concentration field. It is seen that as the Soret number increases the concentration increases. Figure 17 shows the effect of Grashof number on the skin friction. It is noticed that as the Grashof number increases the skin friction increases. Figure 18 illustrates the effect of Prandtl number on the skin friction. It is observed that as the Prandtl number increases the skin friction decreases. Figure 19 represents the effect of Grashof number on the Nusselt number. It is seen that as the Grashof number increases the Nusselt number decreases. In Figure 20 presents the effect of Chemical reaction parameter on Sherwood number. It is observed that as the Chemical reaction parameter increases the Sherwood number increases.

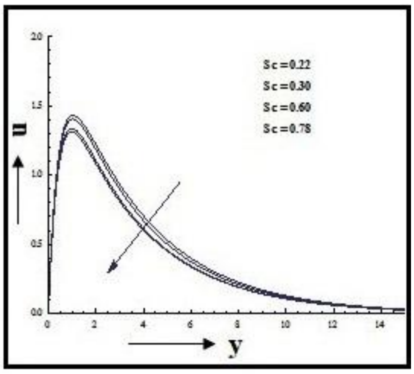

Figure 1: Effects of Schmidt number on the velocity profiles Ec =0.001, Pr=0.025, M=2, Gr=5, Gm=2, K=1, F=3, R=0.30, Sr=3

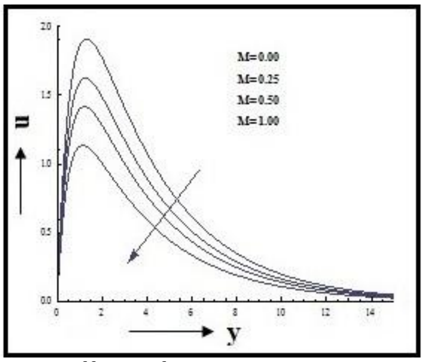

Figure 4: Effects of Magnetic parameter on the velocity profiles Ec=0.001, Pr=0.025, Gr=2, Gm=2, F=3, Sc=0.22, K=1, R=0.30, Sr=3

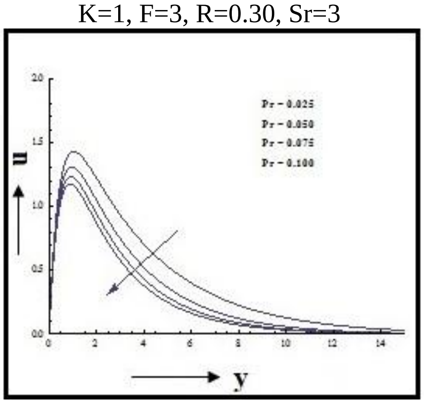

Figure 2: Effects of Prandtl number on the velocity profiles Ec=0.001, Sc=0.22, M=2,Gr=5, Gm=2, K=1, F=3 R=0.30, Sr=3

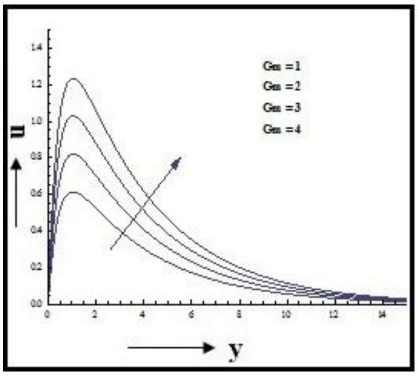

Figure 5: Effects of Modified Grashof number on the velocity profiles Ec=0.001, Pr=0.025, M=2, Gr=2, F=3, Sc=0.22, K=1,R=0.30, Sr=3

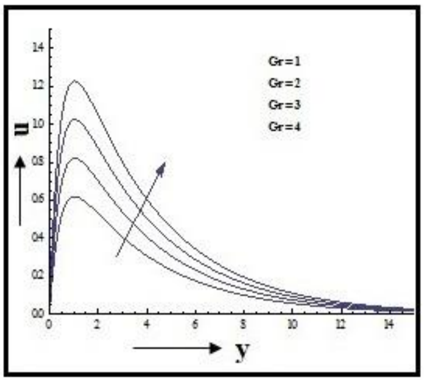

Figure 3: Effects of Grashof number on the velocity profiles Ec=0.001, Pr=0.025, M=2, F=3, Gm=2, Sc=0.22, K=1, R=0.30, Sr=3

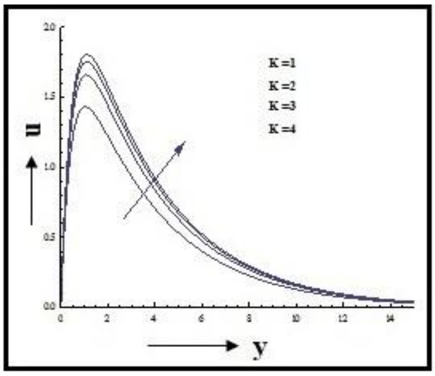

Figure 7: Effects of porosity parameter on the Velocity profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, Sc=0.22, F=3, R=0.30, Sr=3

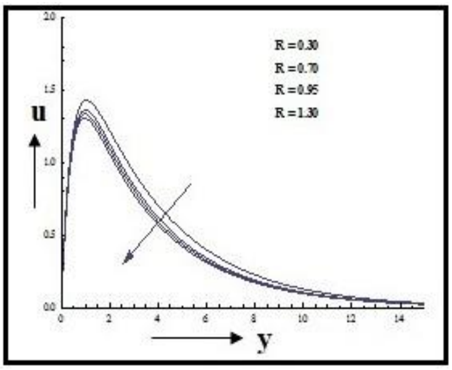

Figure 8: Effects of Chemical reaction parameter on the velocity profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, Sc=0.22, F=3, K=1, Sr=3

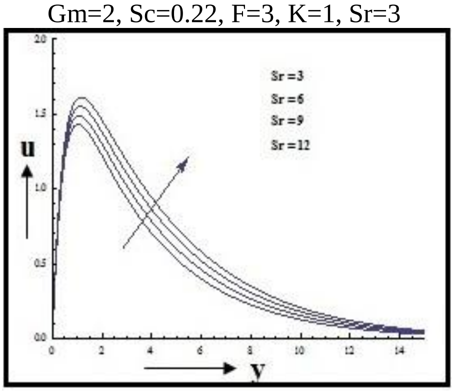

Figure 9: Effects of Soret number on the velocity profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, K=1, F=3, Sc=0.22, R=0.30

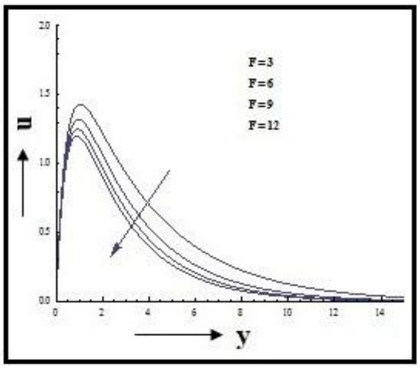

Figure 6: Effects of Radiation parameter on the velocity profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, Sc=0.22, K=1, R=0.30, Sr=3

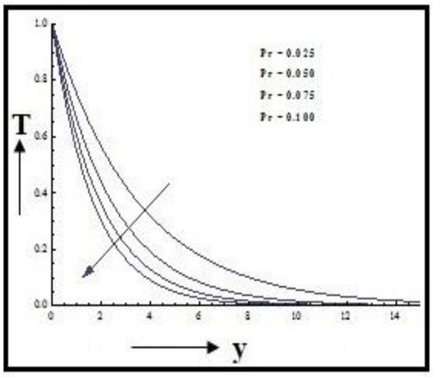

Figure 10: Effects of Prandtl number on the temperature profiles Ec=0.001, Sc=0.22, M=0.5, Gr=2, Gm=2, K=1, F=3, R=0.30, Sr=3

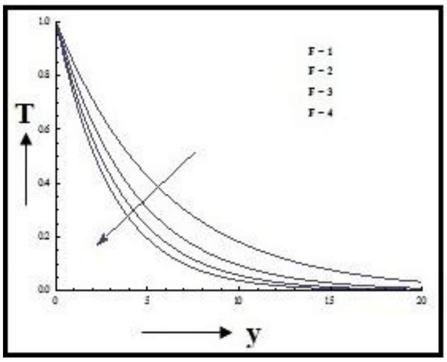

Figure 11: Effects of radiation parameter on the temperature profiles Ec=0.001, Sc=0.60, Pr=0.025, M=0.5, Gr=2, Gm=2, K=1, Sr=3, R=0.30

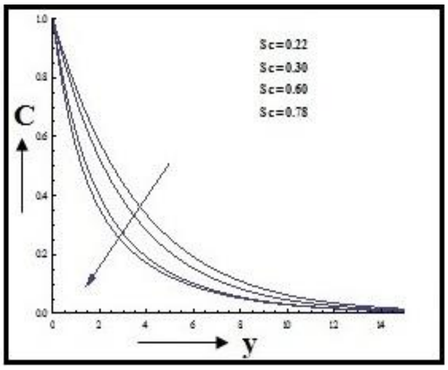

Figure 12: Effects of Schmidt number on the concentration profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, K=1, F=3, Sr=3, R=0.30

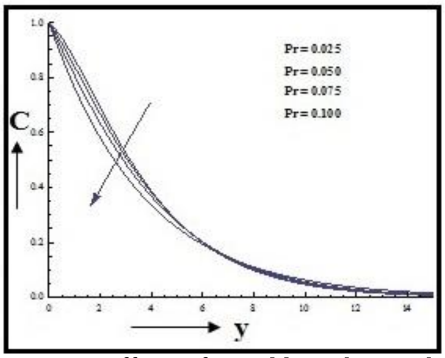

Figure 13: Effects of Prandtl number on the concentration profiles Ec=0.001, Sc=0.22, M=2, Gr=5, Gm=2, K=1, F=3, R=0.30, Sr=3

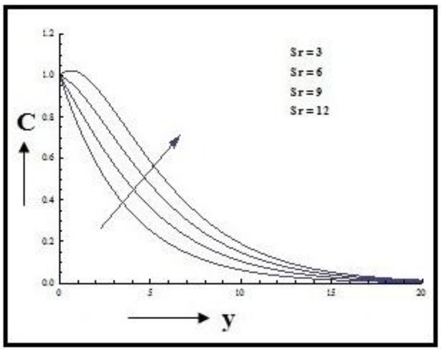

Figure 16: Effects of Soret number on the concentration profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, F=3, Sc=0.22, K=1, R=0.30

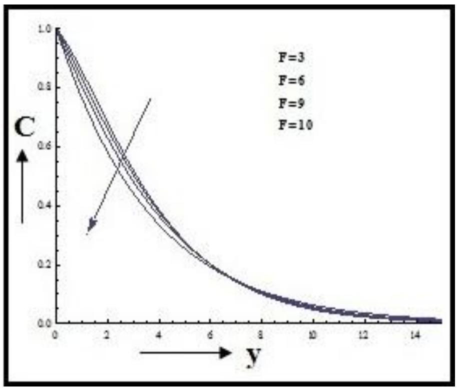

Figure 14: Effects of Radiation parameter on the concentration profiles Ec=0.001, Sc=0.22, Pr=0.025, M=2, Gr=5, Gm=2, K=1, R=0.30, Sr=3

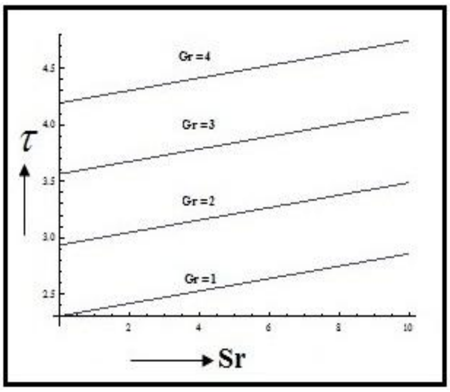

Figure 17: Effects of Grashof number on skin-friction (function of Soret number) Ec=0.001, Sc=0.22, Pr=0.025, M=2, F=3, Gm=2, K=1, R=0.30

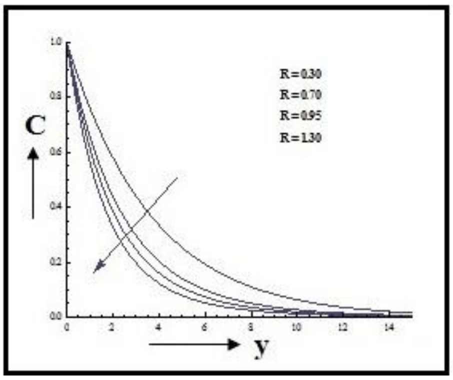

Figure 15: Effects of Chemical reaction parameter on the concentration profiles Ec=0.001, Pr=0.025, M=2, Gr=5, Gm=2, Sc=0.22, F=3, K=1, Sr=3

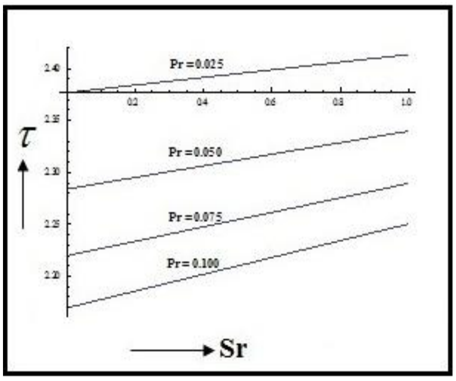

Figure 18: Effects of Prandtl number on skin-friction (function of Soret number) Ec=0.001, Sc=0.22, M=2, Gr=5, Gm=2, K=1, F=3, R=0.30

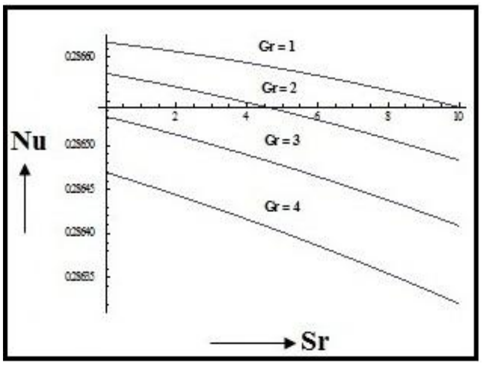

Figure 19: Effects of Grashof number on Nusselt number (function of Soret number) Ec=0.001, Pr=0.025, M=0.5, Gm=2, Sc=0.60, F=3, K=1, R=0.30

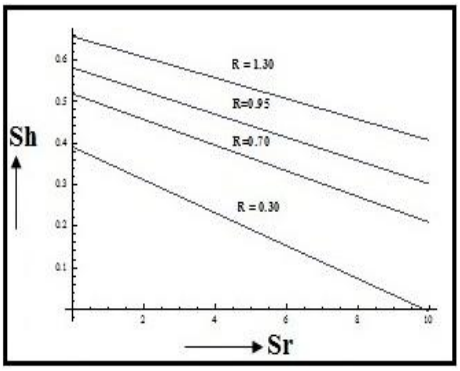

Figure 20: Effects of Chemical reaction parameter on Sherwood number (function of Soret number) Ec=0.001, Sc=0.22, M=2, Gr=5, Gm=2, K=1, F=3,

Pr=0.025

Conclusion:

The above analysis brings out the following results of physical interest on velocity temperature and concentration distribution of the flow field.

- ✓ The Schmidt number (Sc) and Prandtl number (Pr) retard the velocity of the flow fluid.
- ✓ The Grashof number (Gr) accelerates the velocity of the fluid flow but growing of magnetic parameter (M) retards the velocity.
- ✓ The modified Grashof number (Gm) accelerates the velocity of the flow field but the reverse process exists if the growing of radiation parameter (F).
- ✓ The porosity parameter (K) increases the velocity of the flow field but growing of chemical reaction parameter (R) reduces the velocity.
- ✓ The Soret number (Sr) accelerates the velocity of the flow field.
- ✓ The Prandtl number (Pr) and radiation parameter (F) reduse the temperature of the flow field.
- ✓ The Schmidt number (Sc), Prandtl number (Pr), and radiation parameter (F) decelerate the concentration distribution of the flow field.
- ✓ Growing of chemical reaction parameter (R) decreases the concentration distribution of the flow field but the reverse process exists if the growing of Soret number (Sr).
- ✓ The Grashof number (Gr) accelerates the skin friction co-efficient but growing of Prandtl number (Pr) retards the skin friction.
- ✓ Nusselt number (Nu) decreases with increase in Grashof number (Gr).
- ✓ The chemical reaction parameter (R) accelerates the Sherwood number (Sh).

Appendix:

$$m_1 = -\frac{\left[\Pr + \sqrt{\Pr^2 + 4F\Pr}\right]}{2}, \quad m_3 = -\frac{\left[Sc + \sqrt{Sc^2 + 4ScR}\right]}{2},$$

$$m_5 = -\frac{\left[1 + \sqrt{1 + 4\left(M + \frac{1}{K}\right)}\right]}{2},$$

$$A_3 = -\frac{Sc\,Sr\,m_1^2}{m_1^2 + Sc\,m_1 - Sc\,R}$$

$$A_4 = 1 - A_3$$

$$A_6 = -\frac{Gr}{m_1^2 + m_1 - \left(M + \frac{1}{K}\right)}$$

$$A_7 = -\frac{Gm\,A_4}{m_3^2 + m_3 - \left(M + \frac{1}{K}\right)}$$

$$A_8 = -\frac{Gm\,A_3}{m_1^2 + m_1 - \left(M + \frac{1}{K}\right)}$$

$$A_9 = -(A_6 + A_7 + A_8)$$

$$A_{11} = -\frac{\Pr\left(M + m_1^2\right)\left(A_6 + A_8\right)^2}{4m_1^2 + 2\Pr m_1 - F\Pr}$$

$$A_{12} = -\frac{\Pr\left(M + m_3^2\right)A_7^2}{4m_3^2 + 2\Pr m_3 - F\Pr}$$

$$A_{13} = -\frac{\Pr\left(M + m_5^2\right)A_9^2}{4m_5^2 + 2\Pr m_5 - F\Pr}$$

$$A_{14} = -\frac{2\Pr A_9 (A_6 + A_8)(M + m_1 m_5)}{(m_1 + m_5)^2 + \Pr(m_1 + m_5) - F\Pr}$$

$$A_{15} = -\frac{2\Pr A_7 (A_6 + A_8)(M + m_1 m_3)}{(m_1 + m_3)^2 + \Pr(m_1 + m_3) - F\Pr}$$

$$A_{16} = -\frac{2\Pr A_7 A_9 (M + m_3 m_5)}{(m_3 + m_5)^2 + \Pr(m_3 + m_5) - F\Pr}$$

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

$$A_{19} = -\frac{Sc\,Sr\,A_{17}\,m_1^2}{m_1^2 + Sc\,m_1 - Sc\,R}$$

$$A_{20} = -\frac{4Sc\,Sr\,A_{11}\,m_1^2}{4m_1^2 + 2Sc\,m_1 - Sc\,R}$$

$$A_{21} = -\frac{4Sc\,Sr\,A_{12}\,m_3^2}{4m_3^2 + 2Sc\,m_3 - Sc\,R}$$

$$A_{22} = -\frac{4Sc\,Sr\,A_{13}\,m_5^2}{4m_5^2 + 2Sc\,m_5 - Sc\,R}$$

$$A_{23} = -\frac{Sc\,Sr\,A_{14}(m_1 + m_5)^2}{(m_1 + m_5)^2 + Sc(m_1 + m_5) - Sc\,R}$$

$$A_{24} = -\frac{Sc\,Sr\,A_{15}(m_1 + m_3)^2}{(m_1 + m_3)^2 + Sc(m_1 + m_3) - Sc\,R}$$

$$A_{25} = -\frac{Sc\,Sr\,A_{16}(m_3 + m_5)^2}{(m_3 + m_5)^2 + Sc(m_3 + m_5) - Sc\,R}$$

$$A_{26} = -(A_{19} + A_{20} + A_{21} + A_{22} + A_{23} + A_{24} + A_{25})$$

$$A_{28} = -\frac{Gm\,A_{26}}{m_3^2 + m_3 - \left(M + \frac{1}{K}\right)}$$

$$A_{29} = -\frac{(GrA_{17} + GmA_{19})}{m_1^2 + m_1 - \left(M + \frac{1}{K}\right)}$$

$$A_{30} = -\frac{(GrA_{11} + GmA_{20})}{4m_1^2 + 2m_1 - \left(M + \frac{1}{K}\right)}$$

$$A_{31} = -\frac{(GrA_{12} + GmA_{21})}{4m_3^2 + 2m_3 - \left(M + \frac{1}{K}\right)}$$

$$A_{32} = -\frac{(GrA_{13} + GmA_{22})}{4m_5^2 + 2m_5 - \left(M + \frac{1}{K}\right)}$$

$$A_{33} = -\frac{(Gr\, A_{14} + GmA_{23})}{(m_1 + m_5)^2 + (m_1 + m_5) - \left(M + \frac{1}{K}\right)}$$

$$A_{34} = -\frac{(Gr\, A_{15} + GmA_{24})}{(m_1 + m_3)^2 + (m_1 + m_3) - \left(M + \frac{1}{K}\right)}$$

$$A_{35} = -\frac{(Gr\, A_{16} + GmA_{25})}{(m_3 + m_5)^2 + (m_3 + m_5) - \left(M + \frac{1}{K}\right)}$$

$$A_{36} = -(A_{28} + A_{29} + A_{30} + A_{31} + A_{32} + A_{33} + A_{34} + A_{35})$$

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