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Head and Mass Transfer on Unsteady MHD Free Convective Flow Pass a Semi-Infinite Vertical Plate with Soret Effect

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Abstract:
An unsteady free convective MHD flow of a viscous fluid past a semi-infinite vertical moving porous plate embedded in a porous medium is investigated with heat source, thermo diffusion (Soret effect). The constant velocity is assumed in plate to move in the direction MHD flow while the free stream velocity is assumed to follow the exponentially increasing small perturbation law. The external flow field is considered to be Soret Parameters and uniform values in the boundary layer adjacent to the vertical plate with fluid suction. This is investigated in both aiding and opposing flow by using Perturbation technique; the dimensionless governing equations are solved analytically. The effects of various parameters on the velocity, temperature and concentration fields as well as the skin friction coefficient, Nusselt Number and the Sherwood number are obtained graphically obtained.

Key words: *Heat and Mass Transfer, MHD, Porous Medium, Soret Number, Thermal Radiation*

1. Introduction

Considerable attention has been given to the unsteady free convective MHD flow of a viscous fluid .When temperature changes cause density variation of buoyancy forces acting on the fluid elements in the free convection. The free convection is atmospheric flow which is connected by different temperatures. The phenomenon of heat and mass transfer has been the object of extensive research due to its science and technology. Magneto hydrodynamic (MHD) is currently undergoing a period of great enlargement and differentiation of subject matter. The MHD heat and mass transfer processes are of interest in power engineering, metallurgy, astrophysics, and geophysics. Unsteady free convective flows in a porous medium have received much attention in recent time due to its wide applications in geothermal and oil reservoir engineering as well as other geophysical and astrophysical studies. The unsteady fluid flow past a moving plate in the presence of free convection and radiation were studied by Monsour Cogley et al.(1994), Raptis and Perdikis et al (1999) , Das et al(1996).,Grief et al(1971)., Ganeasan and Loganathan et al (2002), Mbeledogu et al.,Makinde(2007), and Abdus-Satter and Hamid Kalim et al (1996). All these studies have been confined to unsteady flow in a nonporous medium. From the previous literature survey about unsteady fluid flow, we observe that little papers were done in porous media. The effect of radiation on MHD flow and heat transfer must be considered when high temperatures are reached. EI-Hakiem et al(2000) studied the unsteady MHD oscillatory flow on free convection-radiation through a porous medium with a vertical infinite surface that absorbs the fluid with a constant velocity. Ghaly et al (2002) employed symbolic computation software Mathematica to study the effect of radiation on heat and mass transfer over a stretching sheet in the presence of a magnetic field. Raptis et al(2002) studied the effect of radiation on 2D steady MHD optically thin gray gas flow along an infinite vertical plate taking into account the induced magnetic field. Cookey et al.(2003) researched the influence of viscous dissipation and radiation on unsteady MHO free-convection flow past on infinite heated vertical plate in a porous medium with time-dependent suction. Singh et al (2004) studied MHD flow of viscous incompressible fluid past an infinite vertical plate. Abd EI-Naby et al.(2004), Kim et al (2000) studied unsteady MHD convective heat transfer past a semi-infinite vertical porous moving plate. The Soret effect arises when the mass flux contains a term that depends on the temperature gradient. The major focus of our study is the effect on free convection of the addition of a second fluid, Convection in binary fluids is considerably more complicated than that in pure fluids. Both temperature and concentration gradients' contribute to the initiation of convection and each may be stabilizing or destabilizing. Even when a concentration gradient is not externally imposed (the thermosolutal problem) it can be created by the applied thermal gradient via the Soret effect. Alan and Rahman et al (2006), examined Dufour and Soret effects on mixed convection flow past a vertical porous flat plate' with variable suction embedded,in a porous medium for a hydrogen-air mixture as the nonchemical reacting fluid pair. Emmanuel et al (2007) studied numerically the effect of thermal-diffusion and' diffusion-thermo on combined heat and mass transfer of a steady hydromagnetic convective and slip flow due to a rotating disk with viscous dissipation and Ohmic heating. Beg Anwar et al (2009). studied and combined the effects of Soret and Dufour diffusion and porous impedance on laminar magneto- hydrodynamic mixed convection heat and mass transfer of an electrically-conducting, Newtonian, Boussinesq fluid from a vertical stretching surface in a Darcian, porous medium under uniform transverse magnetic field.Heat and mass transfer for Soret and Dufour's effect on mixed convection boundary layer flow over a stretching vertical surface in a porous medium filled with a visco -elastic fluid in the presence of magnetic field. Gaikwad et al (2011) investigated the onset of double diffusive convection in a two component couple stress fluid layer with Soret and Dufour effects using both linear and non-linear stability analysis. N.Ahmed and H.Kalita et al (2012) is examined and investigate the problem of an oscillatory MHD free convective flow through a porous medium with mass transfer,soret effect and chemical reaction when the temperature as well as concentration at the plate varies periodically with time about a steady mean. In the present analysis, it is proposed to study the effect of simultaneous heat and mass transfer on the flow of viscous fluid past an impulsively started semi-infinite vertical plate with Soret effect. The closed solutions have been obtained for the velocity, temperature and concentration profile.The effects of various parameters on the velocity, temperature and concentration fields as well as the skin friction coefficient, Nusselt Number and the Sherwood number are obtained graphically obtained.

2. Formulation of the Problems

We consider two dimensional flow of incompressible, viscous, electrically conducting fluid past a semi-infinite vertical moving porous plate embedded in a uniform porous medium and subjected to a uniform transverse magnetic field in the presence of a pressure gradient has been considered with free convection with Soret effect. According to the coordinate system the x*- axis is considered along the porous plate in the upward direction and y*- axis normal to it. The fluid is assumed to be a gray, absorbing-emitting but non-scattering medium. The radiative heat flux in the x*-direction is taken negligible in comparison with that in the y*- direction. It is assumed that there is no applied voltage of which implies the absence of an electric filed. The transversely applied magnetic field and magnetic Reynolds number are very small and hence the induced magnetic field is negligible Cowling. Viscous and Darcy resistance terms are taken into account the constant permeability porous medium. The MHD term is derived from an order-of magnitude analysis of the full Navier-stokes equation. It is assumed here that the hole size of the porous plate is significantly larger than a characteristic microscopic length scale of the porous medium. A homogeneous first-order chemical reaction between the fluid and the species concentration. The chemical reactions are taking place in the flow and all thermo physical properties are assumed to be constant of the linear momentum equation which is approximation. The fluid properties are assumed to be constants except that the influence of density variation with temperature and concentration has been considered in the body-force term. Due to the semi-infinite place surface assumption furthermore, the flow variable are functions of y* and t* only. The governing equation for this investigation is based on the balances of mass, linear momentum, energy, and concentration species. Taking into consideration the assumptions made above, these equations can be written in Cartesian frame of reference, as follows:

Equation of Continuity:-

$$\frac{\partial v^*}{\partial y^*} = 0 \qquad (1)$$

Momentum Equations:-

$$\rho\left(\frac{\partial u^*}{\partial t^*} + v^* \frac{\partial u^*}{\partial y^*}\right) = \frac{\partial p^*}{\partial x^*} + \mu\frac{\partial^2 u^*}{\partial y^{*2}} - g\beta - \frac{\mu}{K^*} u^* - \sigma B_0^2 u^2 \qquad (2)$$

The Energy Equation:-

$$\frac{\partial T^*}{\partial t^*} + v^* \frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{1}{\rho C_p}\left(\frac{\partial q_r^*}{\partial y^*}\right) - \frac{Q_0}{\rho C_p}(T_w^* - T_\infty^*) \qquad (3)$$

Concentration Equation:-

$$\frac{\partial C^*}{\partial t^*} + v^* \frac{\partial C^*}{\partial y^*} = D_m\frac{\partial^2 C^*}{\partial y^{*2}} + D_r\frac{\partial^2 T^*}{\partial y^{*2}} + K_r(C_w^* - C_\infty^*) \qquad (4)$$

Where x^*, y^* and t^* are the dimensional distance and perpendicular to the plate and with respect to dimensional time. u^* and $\mathbf{v}^* = -\mathbf{v}_0(1+\varepsilon A e^{n^* t^*})$ are the components of dimensional velocities along x^* and y^*, ρ is the fluid density, μ is the viscosity, C_p is the specific heat at constant pressure, σ is the fluid electrical conductivity, B_0 is the magnetic induction, $K^*$is the permeability of the porous medium, T^* is the dimensional temperature D_M is the coefficient of chemical molecular diffusivity, D_T is the coefficient of thermal diffusivity, C^* is the dimensional concentration, K is the thermal conductivity of the fluid g is the acceleration due to gravity and q_r^*, R are the local radiative heat flux. The very Q_0 $(T_w^* - T_\infty^*)$ is assumed to the amount of heat generated or absorbed per unit volume :) is constant, which may take on either positive or negative values. The term K_r $(C_w^* - C_\infty^*)$ is assumed to the amount of heat pink generated or absorbed per unit volume. K_r is constant, which may take on either positive or negative values.

With corresponding boundary conditions:-

$$u^* = u_p^*,\ T^* = T_w^* + \varepsilon(T_w^* - T_\infty^*)e^{n^*t^*},$$
$$C^* = C_w^* + \varepsilon(C_w^* - C_\infty^*)e^{n^*t^*} \quad \text{at } y = 0 \qquad (5)$$
$$u^* \to u_\infty^* = u_0\left(1 + \varepsilon e^{n^*t^*}\right),\ T^* \to T_\infty^*,\ C^* \to C_\infty^* \quad \text{at } y \to \infty \qquad (6)$$

Where T_w^* and C_w^* are the wall dimensional temperature and concentration, respectively, C_∞^* is the free stream dimensional concentration V_0 and n^* are constants.

In the free stream, from equation (2),

$$\rho\frac{\partial u_\infty^*}{\partial t^*} = -\frac{\partial p^*}{\partial x^*} - \rho_\infty g - \frac{\mu}{K^*}u_\infty^* - \sigma B_0^2 u^2 \qquad (7)$$

Eliminating $\frac{\partial p^*}{\partial x^*}$ between equation (2) and equation (7), we obtain

$$\rho\left(\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*}\right) = (\rho_\infty - \rho)g + \rho\frac{du_\infty^*}{dt^*} + \mu\frac{\partial^2 u^*}{\partial y^{*2}} - \frac{\mu}{K^*}(u_\infty^* - u^*) - \sigma B_0^2(u_\infty^* - u^*) \qquad (8)$$

By making use the equation of state Hassaniea and Obied Allah

$$\rho_\infty - \rho = \rho\beta(T_w^* - T_\infty^*) + \rho\beta^*(C_0^* - C_\infty^*) \qquad (9)$$

Where β is the volumetric thermal expansion, β^* is the volumetric coefficient of expansion with concentration, and the density of the fluid far away the surface. Then substituting from equation (9) into equation (8) we obtain

$$\frac{\partial u^*}{\partial t^*} + v^*\frac{\partial u^*}{\partial y^*} = \frac{du_\infty^*}{dt^*} + \mu\frac{\partial^2 u^*}{\partial y^{*2}} + \rho\beta(T_w^* - T_\infty^*) + \rho\beta^*(C_w^* - C_\infty^*) + \frac{\gamma}{K^*}(u_\infty^* - u^*) - \sigma B_0^2(U_\infty^* - u^*) \qquad (10)$$

Where $\gamma = \frac{\mu}{\rho}$; is the coefficient of the kinematic energy.
The Radiative heat flux term by using The Roseland approximation is given by

$$q = \frac{4\sigma^*}{3k_1^*}\frac{\partial T^{*2}}{\partial y^*} \qquad (11)$$

Where σ^* and K_1^* respectively. The Stefen Bollzmann constant and the mean absorption coefficient. We assume that the temperature difference within the flow are sufficiently small such that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding in a Taylor Series about T_∞^* and neglecting higher order terms, thus,

$$T^{*4} \cong 4T_\infty^{*3} - 3T_\infty^{*4} \qquad (12)$$

By using equation (11) and (12), into equation (3) is reduced to

$$\frac{\partial T^*}{\partial t^*} + v^*\frac{\partial T^*}{\partial y^*} = \frac{k}{\rho C_p}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{16\sigma^* T_\infty^{*3}}{3\rho C_p k_1^*}\frac{\partial^2 T^*}{\partial y^{*2}} - \frac{Q_0}{\rho C_p}(T_w^* - T_\infty^*) \qquad (13)$$

Introducing the non-dimensional quantities and parameters

$$u^* = u\,U_0,\ v^* = v\,V_0,\ T^* = T_\infty^* + \theta(T_w^* - T_\infty^*),$$
$$C^* = C_\infty^* + \phi(C_w^* - C_\infty^*),\ U^* = U_\infty U_0,\ U_p^* = U_p U_0$$
$$K^* = \frac{kv^2}{V_0^2},\ y^* = \frac{vy}{V_0},\ G_m = \frac{v\beta^*(C_w^* - C_\infty^*)}{V_0^2 U_0}$$
$$G_r = \frac{V\beta g\left((T_w^* - T_\infty^*)\right)}{v_0^2 u_0};$$
$$p_r = \frac{V_0 C_p}{k},\ u = \frac{\sigma B_0^2 V}{\rho V_0^2},\ Q = \frac{Q_0 V}{\rho c_p V_0^2},\ R = \frac{4\sigma^* T_\infty^{*3}}{\rho V_0^2},\ S_c = \frac{V}{D_m},\ t^* = \frac{tV}{V_0^2},\ u = \frac{V_0^2}{V} \qquad (14)$$

Then substituting from equation (14) into Equations (10), (13) and (4) and taking into account equation (1) we obtain

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial u}{\partial y} = \frac{\partial u_\infty}{\partial t} + \frac{\partial^2 u}{\partial y^2} + G_r\theta + G_m\phi + N(U_\infty - u) \quad \text{———(15)}$$

$$\frac{\partial u}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial \theta}{\partial y} - \frac{1}{P_r}\left(1 + \frac{4R}{3}\right)\frac{\partial^2 \theta}{\partial y^2} - Q\theta \quad \text{———(16)}$$

$$\frac{\partial \varphi}{\partial t} - (1 + \varepsilon A e^{nt})\frac{\partial \varphi}{\partial y} = \frac{1}{S_c}\frac{\partial^2 \varphi}{\partial y^2} + S_r\frac{\partial^2 \theta}{\partial y^2} + Kr\phi \quad \text{———(17)}$$

where G_r is the Thermal Grashof Number, G_m is Solutal Grashof Number, P_r Prandth Number, M is the Magnetic field parameter, Sc is Schmidt Number, Q is the dimensionless heat generation parameter lap sorption coefficient, Sris the Soret Number, R is the Radiation Parameter respectively and $N = \left(M + \frac{1}{K}\right)$.

The dimensionless form of the boundary condition (5) and (6) become

$$u = U_p, \theta = 1 + \varepsilon\theta^{nt}, \phi = 1 + \varepsilon e^{nt} \quad at\ y = o$$
$$u \to U_\infty \to 1 + \varepsilon e^{nt}, \theta \to 0, \phi \to 0 \quad as\ y \to \infty \quad \text{———(18)}$$

3. Solution of the Problem

In order to reduce the above system of partial differential equations to a system of ordinary equations in dimensionless form, we may represent the velocity, temperature and concentration as

$$u = u_0(y) + \varepsilon e^{nt} u_1(y) + 0(\varepsilon^2)$$
$$\theta = \theta_0(y) + \varepsilon e^{nt} \theta_1(y) + 0(\varepsilon^2) \quad (19)$$
$$\phi = \phi_0(y) + \varepsilon e^{nt} \phi_1(y) + 0(\varepsilon^2)$$

Where u_0, T_0 and C_0 are mean velocity, mean temperature and mean concentration respectively.

By substituting the above equation (19) into equation (15-17), equating harmonic and non-harmonic terms and neglecting the higher order terms of $O(\varepsilon^2)$

$$u_0'' + u_0' - Nu_0 = -N - G_r\theta_0 - G_m\phi_0 \quad \text{———(20)}$$
$$u_1'' + u_1' - (N + n)u_1 = -(N + n) - Au_0' - G_r\theta_1 - G_m\theta_1 \quad \text{———(21)}$$
$$(3 + 4R)\theta_1'' + 3P_r\theta_0' - 3QP_r\theta_0 = 0 \quad \text{———(22)}$$
$$(3 + 4R)\theta_1'' + 3P_r\theta_0' - 3(n + Q)P_r\theta_1 = -3AP_r\theta_0' \quad \text{———(23)}$$
$$\phi_0'' + Sc\phi_0' - ScK_r\phi_0 = -ScS_r\phi_0'' \quad \text{———(24)}$$
$$\phi_0'' + Sc\phi_1' - Sc(K_r - n)\phi_1 = -AS_c\phi_0' - ScS_r\phi_0'' \quad \text{———(25)}$$

Where the primes denote differentiation with respect to y.

$$u_0 = u_p = u_1 = 0, \phi_0 = 1, \phi_1 = 1, \phi_0 = 1 = \phi_1 \quad at\ y = 0$$
$$u_0 \to u_1 \to 1, T_0 \to \theta_0 \to 0, \theta_1 \to 0, \phi_0 \to \phi_1 \to 0 \quad at\ y \to \infty \quad \text{———(26)}$$

Using equation (26) in Equations (20)-(24) are given by

$$u_0 = 1 + C_{15}e^{b5y} + C_{17}e^{b1y} + C_{18}e^{b5y} + C_{19}e^{b1y} \quad \text{———(27)}$$
$$u_1 = 1 + C_{20}e^{b11y} + C_{21}e^{b12y} + C_{22}e^{b9y} + C_{24}e^{b1y} + C_{25}e^{b5y} + C_{26}e^{b6y} + C_{27}e^{b3y} + C_{28}e^{b1y} + C_{29}e^{b7y}$$
$$+ C_{30}e^{b5y} + C_{31}e^{b1y} + C_{32}e^{b3y} + C_{33}e^{b1y} \quad \text{———(28)}$$

$$\theta_0 = e^{b1y} \quad \text{———(29)}$$
$$\theta_1 = C_3e^{b3y} + C_5e^{b1y} \quad \text{———(30)}$$
$$\phi_0 = C_6e^{b5y} + C_8e^{b1y} \quad \text{———(31)}$$
$$\phi_1 = C_9e^{b7y} + C_{11}e^{b5y} + C_{12}e^{b1y} + C_{13}e^{b3y} + C_{14}e^{b1y} \quad \text{———(32)}$$

In view of the above solution, the velocity, temperature and concentration distributions in boundary layer become

$$u(y,t) = \left(1 + C_{15}e^{b9y} + C_{17}e^{b1y} + C_{18}e^{b5y} + C_{19}e^{b1y}\right) + \varepsilon e^{nt}(1 + C_{20}e^{b11y} + C_{21}e^{b12y} + C_{22}e^{b9y}$$
$$+ C_{24}e^{b1y} + C_{25}e^{b5y} + C_{26}e^{b6y} + C_{27}e^{b3y} + C_{28}e^{b1y} + C_{29}e^{b7y} + C_{30}$$
$$C_{32}e^{b3y} + C_{33}e^{b1y}) \quad \text{———(33)}$$

$$\theta(y,t) = e^{b1y} + \varepsilon e^{nt}\left(C_3e^{b3y} + C_5e^{b1y}\right) \quad \text{———(34)}$$
$$\phi(y,t) = C_6e^{b5y} + C_8e^{b1y} + \varepsilon e^{nt}\left(C_9e^{b7y} + C_{11}e^{b5y} + C_{12}e^{b1y} + C_{13}e^{b3y} + C_{14}e^{b1y}\right) \quad \text{———(35)}$$

Calculation for physical quantities:-

Skin friction:-

The Skin friction due to local wall shear stress is given by

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = (C_{15}\, b_9 + C_{17}\, b_1 + C_{18}\, b_5 + C_{19}\, b_1) + \varepsilon e^{nt}(C_{20}\, b_1 + C_{21}\, b_{12} + C_{22}\, b_5 + C_{24}\, b_1 + C_{25}\, b_5 + C_{26}\, b_6 + C_{27}\, b_3 + C_{28}\, b_1 + C_{29}\, b_7 + C_{30}\, b_5 + C_{31}\, b_1 + C_{32}\, b_3 + C_{33}\, b_1) \quad (36)$$

Nusselt Number:-

The rate of heat Transfer in terms of Nusselt number Nu is given by

$$N_u = -\left(1 + \frac{4R}{3}\right)\left(\frac{\partial u}{\partial y}\right)_{y=0} = \left(1 + \frac{4R}{3}\right)[\, b_1 + \varepsilon e^{nt}(b_3 C_3 + C_5\, b_1)] \quad (37)$$

Sherwood Number:-

Mass Transfer coefficient (Sh) at the slave in terms of Amplitude and phase is given by

$$Sh = -\left(\frac{\partial \phi}{\partial y}\right)_{y=0} = [(C_6 b_5 + C_8 b_1) + \varepsilon e^{nt}(C_9 b_7 + C_{11} b_5 + C_{12} b_1 + C_{13} b_3 + C_{14} b_1)] \quad (38)$$

4. Results and Discussion

In order to attain physical insight into the problem, the numerical values of the velocity field, temperature field and concentration field are computed for different parameters like magnetic parameter, Reynolds number, suction parameter and Schmidt number. The effects of flow parameters on the skin friction, heat flux and mass flux are discussed with the help of graphs.

Figure (1) shows that Gr<0 represents cooling of the fluid of heating of the boundary surface, Gr > 0 means heating of the fluid of cooling of the boundary surface and absence of the free convection current.

Figure (2) is found that the peak value of velocity increases rapidly near the wall of the porous plate as soultal Grashof number increases, and then decays to the relevant free stream velocity.

Figure (3) denotes the velocity profiles for different values of the magnetic field parameter M. It is certain that the effect of increasing values of M parameter results in decreasing velocity distribution across the boundary layer.

As K increases in the peak value of velocity also tends to increase in Figure (4).

Figure 5(a) and 5(c) have inferred that the value of R increases the velocity and concentration increases, with an increasing in the flow boundary layer thickness.

In Figure 5(b) we observe that, as the value of R increases the temperature profiles decreases, with an increase in the thermal boundary layer thickness.

Figure 6 (a) and 6(c) show the effect of heat source (Q) on the velocity and concentration profiles. From this figure we see that the heat is generated as the buoyancy force increases which induces the flow rate to increase and hence the velocity and concentration profiles also increase.

Figure 6(b) shows that the temperature profiles decrease with an increase in heat source parameter (Q).

Figure 7(a) shows the velocity profiles across the boundary layer for different values of Prandtl number (Pr). The results show that as the Pr value increases the velocity decreases.

Figure 7(b) Figure 7(c) illustrates the concentration profiles for various values of Pr. We observe that the concentration profiles increases near the vertical porous plate as parameter Pr decreases.

Figure 8(a) we can see that the effect of increasing values of Sc results in a decreasing velocity distribution across the boundary layer.

Figure 8(b) illustrates that an decrease in Sc results in a increase of the concentration distribution, because the smaller values of Sc are equivalent to the increase the chemical Molecular diffusivity.

From Figure 9(a), we observe that velocity profiles increase with an increase of Sr. Thus we conclude that the fluid velocity rises due to greater thermal diffusion.

Figure 9(b) represents the concentration profiles for different values of Soret number (S_r) . From this figure we observe that the concentration profiles decrease significantly with an decrease of Soret number.

In Figure (10), It is observed from this figure that as R increases, the skin- friction coefficients increases.

Figure (11-12) shows that the effect of radiation parameter (R) and Pr on Nusselt number (Nu) against t. It is observed that as R and Pr increases the Nusselt number also increases.

Figure (13) depicts the effects of the Soret number (Sr) on the Sherwood number (Sh). It is clearly shown in the following table that as So increases, the Sherwood number increases whereas the Nusselt number remains unchanged.

$$b_1 = \frac{-(3+4R) - \sqrt{9Pr^2 + 12\,PrQ(3+4R)}}{2(3+4R)}$$

$$b_3 = \frac{-3Pr - \sqrt{9Pr^2 + 12(3+4R)(n+Q)Pr}}{2(3+4R)}$$

$$b_4 = \frac{-3Pr + \sqrt{9Pr^2 + 12(3+4R)(n+Q)Pr}}{2(3+4R)}$$

$$C_5 = \frac{-3A\,Pr\,b_1}{(3+4R)b_1^2 + 3\,Pr\,b_1 - 3Pr\,(n+Q)}$$

$$b_5 = \frac{-Sc - \sqrt{S_c^2 - 4Sc\,Kr}}{2}$$

$$b_6 = \frac{-Sc + \sqrt{S_c^2 - 4Sc\,Kr}}{2}$$

$$C_8 = \frac{-b_1^2 + Sc\,Sr}{b_1^2 + Sc\,b_1 + Sc\,Kr}$$

$$b_7 = \frac{-Sc - \sqrt{Sc^2 - 4Sc(Kr-n)}}{2}$$

$$C_{15} + 1 + C_{17} + C_{18} + C_{19} = 0$$

$$C_{22} = \frac{A\,C_5\,b_9}{b_9^2 + b_9 - (N+n)}$$

$$C_{24} = \frac{C_{17}\,b_1}{b_1^2 + b_1 - (N+n)}$$

$$C_{25} = \frac{C_{18}\,b_5}{b_5^2 + b_5 - (N+n)}$$

$$C_{26} = \frac{C_{19}\,b_1}{b_1^2 + b_1 - (N+n)}$$

$$C_{27} = \frac{-Gr\,C_3}{b_3^2 + b_3 - (N+n)}$$

$$C_{28} = \frac{-Gr\,C_5}{b_1^2 + b_1 - (N+n)}$$

$$C_{29} = \frac{-Gm\,C_9}{b_3^2 + b_3 - (N+n)}$$

$$C_{30} = \frac{-Gm\,C_{11}}{b_5^2 + b_5 - (N+n)}$$

$$b_8 = \frac{-Sc + \sqrt{Sc^2 - 4Sc(Kr-n)}}{2}$$

$$C_{11} = \frac{-A\,Sc\,C_6\,b_5}{b_5^2 + Sc\,b_5 + Sc\,(Kr-n)}$$

$$C_{12} = \frac{-A\,Sc\,C_8\,b_1}{b_1^2 + Sc\,b_1 + Sc\,(Kr-n)}$$

$$C_{13} = \frac{-\,Sc\,Sr\,C_3\,b_1^2}{b_3^2 + Sc\,b_3 + Sc\,(Kr-n)}$$

$$C_{14} = \frac{-\,Sc\,Sr\,C_5\,b_1^2}{b_1^2 + Sc\,b_1 + (Kr-n)\,Sc}$$

$$C_{19} = \frac{-Gm\,C_8}{b_1^2 + b_1 - N}$$

$$C_{18} = \frac{-Gm\,C_6}{b_5^2 + b_5 - N}$$

$$C_{15} + 1 + C_{17} + C_{18} + C_{19} = 0$$

$$C_{31} = \frac{-Gm\,C_{12}}{b_1^2 + b_1 - (N+n)}$$

$$C_{32} = \frac{-Gm\,C_{13}}{b_3^2 + b_3 - (N+n)}$$

$$C_{33} = \frac{-Gm\,C_{14}}{b_1^2 + b_1 - (N+n)}$$

$$C_{23} = \frac{-2\Omega\,b_{10}}{N(b_{10}^2 + b_{10} - (N+n))}$$

$$b_9 = \frac{-1 - \sqrt{1+4N}}{2}$$

$$b_{11} = \frac{-1 - \sqrt{1+4(N+n)}}{2}$$

$$b_{12} = \frac{-1 + \sqrt{1+4(N+n)}}{2}$$

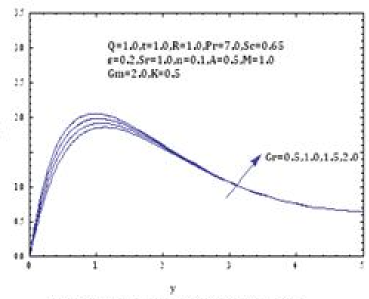

Figure 1:Velocity Profiles For different values Of Gr

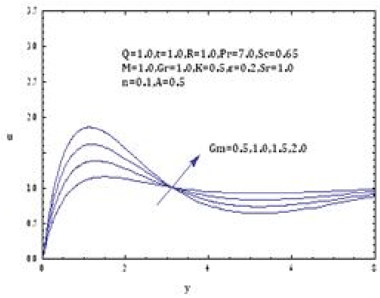

Figure 2:Velocity Profiles for different values of Gm

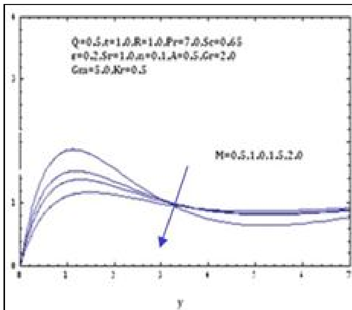

Figure 3:Velocity profiles for different values of M

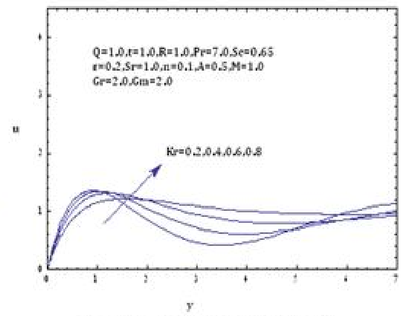

Figure 4: Velocity profiles for different values of Kr

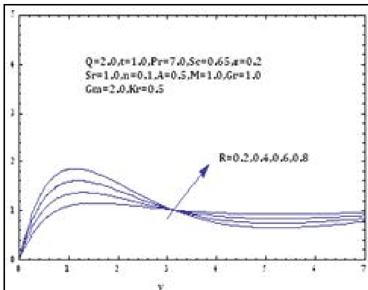

Figure 5(a):Velocity Profiles for different values of R

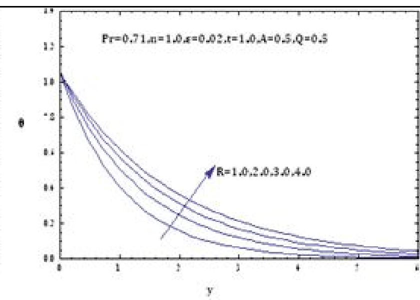

Figure 5(b): Temperature Profiles for different values of R

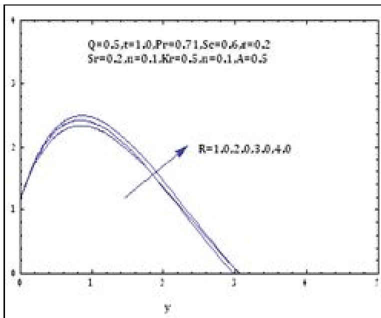

Figure 5(c): Concentration Profiles for different values of R

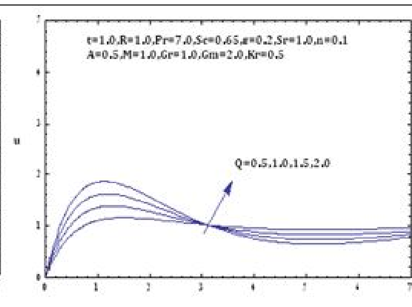

Figure 6(a): Velocity Profiles for different values of Q

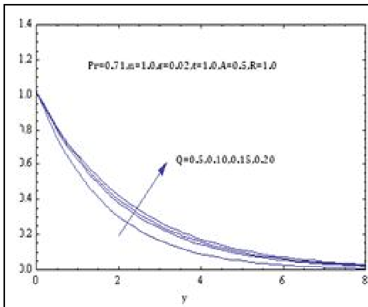

Figure 6(b):Temperature profiles for different values of Q

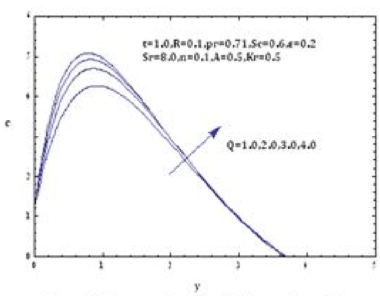

Figure 6(c): Concentration profiles for different values of Q

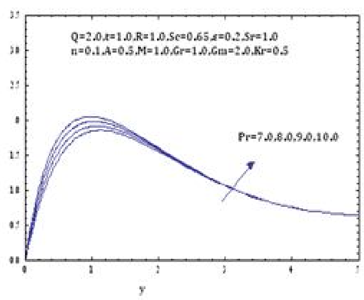

Figure 7(a):Velocity profiles for different values of Pr

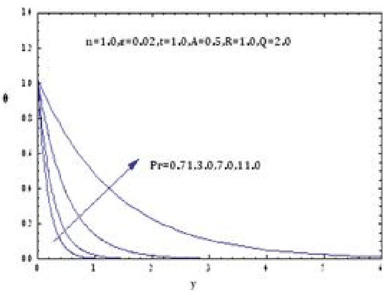

Figure 7(b):Temperature profiles for different values of Pr

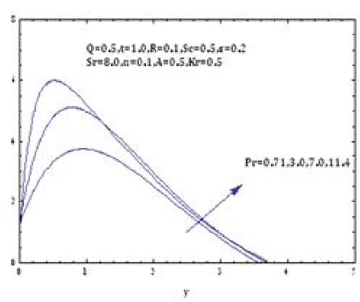

Figure 7(c):Concentration profiles for different values of Pr

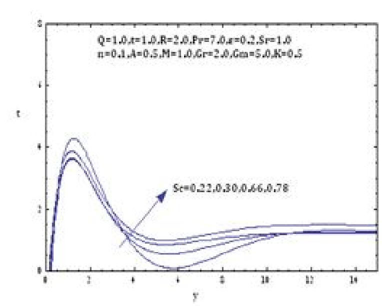

Figure 8(a):Velocity Profiles for different values of Sc

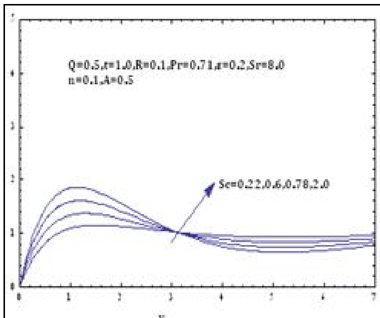

Figure 8(b):Concentration profiles for different values of Sc

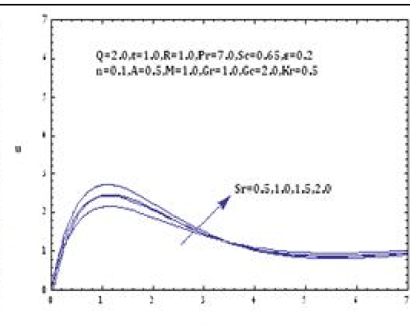

Figure 9(a):Velocity Profile for different values of Sr

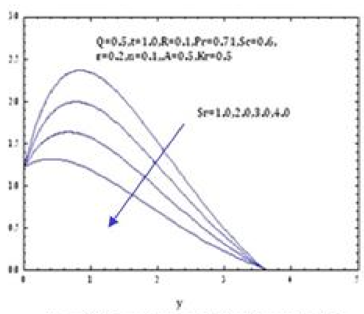

Figure 9(b): Concentration profiles for different values of Sr

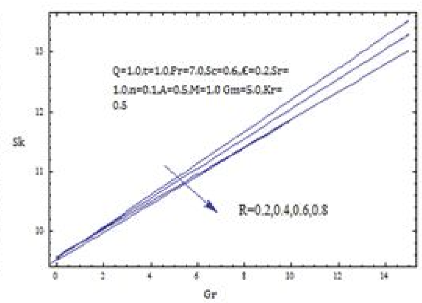

Figure 10: Skin Friction for different values of R verus Gr

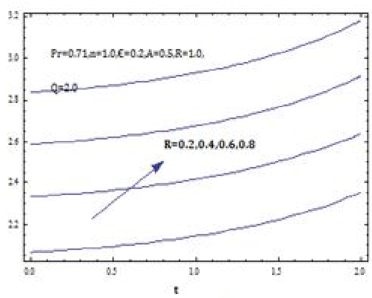

Figure:11 Nusselt number for different values of R verus t

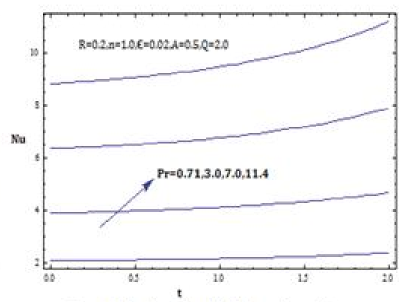

Figure:12 Nusselt number for different values of Pr verus t

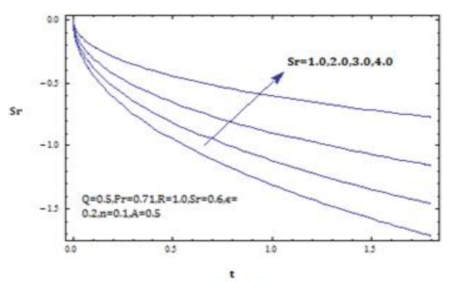

Figure13: Sherwood number fordifferent values of Sr verus t

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