Research Paper Mathematics

Hall Current Effect, Heat and Mass Transfer of MHD Flow Along a Porous Plate With Cosinusoidally Varying Temperature With Soret Effect

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ABSTRACT

This work is focused on Heat and Mass transfer effect on an unsteady free convective flow of electrically conducting viscous incompressible fluid over an infinite vertical porous plate through a porous medium in the presence of applied magnetic field with Hall Effect and thermal radiation have studied. The governing system of Partial differential equations is transformed to dimensionless equations using non dimensional variables and then solved analytically using the perturbation technique to obtain the expression for velocity, temperature and concentration. With the help of graphs, the effects of the various parameters entering into the problem on the velocity, temperature and concentration fields are discussed. Expressions for Skin friction, Nusselt number and Sherwood number are also derived.

KEYWORDS Porous medium, MHD flow, hall current, heat transfer, variable suction, soret effect.

Inroduction:

MHD flow with heat and mass transfer with chemical reaction have been a subject of interest of many researchers because if its varied applications in science and technology. Heat and Mass transfer problems with chemical reaction are important in many processes such as drying, energy transfer in a wet cooling tower etc., when the strength of the magnetic field is strong, the effect of hall current is negligible. It is of considerable importance and interest to study how the results of the hydro dynamical problems get modified by the effect of hall currents. Raptis [1] studied mathematically the case of time varying two dimensional natural convective flow of an incompressible, electrically conducting fluid along an infinite vertical porous plate embedded in a porous medium. Helmy [2] analyzed MHD unsteady free convection flow past a vertical plate embedded in a porous medium. Elabashbeshy [3] studied heat and mass transfer along a vertical plate in the presence of magnetic field. Chamkha and Khaled [4] investigated the problem of coupled heat and mass transfer by MHD free convection from an inclined plate in the presence of internal heat generation or absorption. S.Anuradha [5] studied hall current effect, heat and mass transfer of MHD flow along a porous plate with cosinusoidally varying temprature.

In recent years, the problems of free convective heat and mass transfer flows through a porous medium under the influence of magnetic field have been attracted the attention of a number of researchers because of their possible applications in many branches of science and technology, such as its applications in transportation cooling of re-entry vehicles and rocket boosters, cross-hatching on ablative surfaces and film vaporization in combustion chambers. Magnetohydrodynamics is currently undergoing a period of great enlargement and differentiation of subject matter. In light of these applications, steady MHD free convective flow past a heated vertical flat plate has been studied by many researchers such as P.S Lykoudis [6], Nanda and Mohanty [7] and R.C Chaudhary and B.K Sharma [8].

Due to the importance of Soret (thermal-diffusion) effects for the fluids with very light molecular weight as well as medium molecular weight. The Soret effect arises when the mass flux contains a term that depends on the temperature gradient. Bhavana et al [9] proposed the

Soret effect on unsteady MHD free convective flow over a vertical plate in presence of the heat source. Anand Rao et al. [10] explained the Soret and Radiation effects on unsteady MHD free convective flow past a vertical porous plate. Soret effect on MHD flow of heat and mass transfer over a vertical stretching plate in a porous medium in presences of heat source was proposed by Mohammad Ali and Mohammad Shah Alam [11]. Dufour and Soret effects on unsteady MHD free convective flow past a vertical porous plate embedded in a porous medium with mass transfer was studied by Alam et al [12].

This paper deals with the effects of magnetic field, heat and mass transfer on two dimensional laminar flow of viscous incompressible fluid past an infinite vertical porous plate. the analytical expressions for the velocity, temperature and concentration are obtained. the effects on velocity, temperature and concentration are obtained. The effects of velocity, temperature and concentration are discussed through graphs. The effects of pandtl number, schmidt number and soret number are dispalyed through tables.

Mathematical formulation:

We consider an unsteady two dimensional flow of a laminar. Free convective, viscous incompressible and electrically conducting fluid along an infinite vertical porous plate. The flow is oriented vertically upward along x' axis. The entire system is assumed to be rotating with angular velocity Ω' about y' axis. The fluid is injected with constant velocity v_0 through the porous plate. We assumed that the plate temperature, concentration and free stream velocity are varying cosinusoidally with respect to time. A strong transverse magnetic field of uniform strength B_0 IS also applied along the axis of rotation. The value of this uniform magnetic field is assumed to be unaltered by making necessary assumptions that guarantee the neglecting if induced electric and magnetic fields.

Denoting the velocity components u', v' in the x', y' directions respectively and the temperature by t', the flow in the rotating system in the presence of hall current is governed by the following equations:

$$\frac{\partial v'}{\partial y'} = 0 \quad (1)$$

$$\frac{\partial u'}{\partial t'} + v_0 \frac{\partial u'}{\partial y'} = \frac{1}{\rho}\frac{\partial p'}{\partial x'} + \nu \frac{\partial^2 u'}{\partial y'^2} + 2\Omega' v' + \frac{\sigma B_0^2 (mv' - u')}{\rho(1+m^2)} + g\beta(T' - T'_\infty) + g\beta'(C' - C'_\infty) - \frac{\nu u'}{k'} \quad (2)$$

$$\frac{\partial v'}{\partial t'} + v_0 \frac{\partial v'}{\partial y'} = \frac{1}{\rho}\frac{\partial p'}{\partial x'} + \nu \frac{\partial^2 u'}{\partial y'^2} + 2\Omega' u' + \frac{\sigma B_0^2 (mv' - u')}{\rho(1+m^2)} + g\beta(T' - T'_\infty) + g\beta'(C' - C'_\infty) - \frac{\nu u'}{k'} \quad (3)$$

$$\frac{\partial T'}{\partial t'}+v_0\frac{\partial T'}{\partial y'}=\frac{k}{\rho c_p}\frac{\partial^2 T'}{\partial y'^2}-\frac{Q_0}{\rho C_p}(T'-T'_\infty) \tag{4}$$

$$\frac{\partial C'}{\partial t'}+v_0\frac{\partial C'}{\partial y'}=D\frac{\partial^2 C'}{\partial y'^2}-D_T\frac{\partial^2 T'}{\partial y'^2} \tag{5}$$

Where $v,t',\rho,p',\sigma,T',c_p,k,g,\beta,D,Kr',C'$ are respectively kinematic viscosity, time, fluid density, modified pressure, electrical conductivity, acceleration due to gravity, coefficient of volume expansion, molecular diffusivity and permeability of the porous medium and concentration of the species.

The corresponding boundary conditions of the problem for velocity, temperature and concentration fields are:

At *y'=0,*

$$u'=u'_p,T'=(T_w^{'}-T_\infty^{'})\in e^{n't'}+T_{w,}C'=(C_w^{'}-c_\infty^{'})\in e^{n't'}+C_{w,}$$

At $y'\to\infty,$

$$u'\to U'_\infty=U_0(1+\in e^{n't'}),T'\to +T_\infty,C'\to c_\infty^{'})$$

Where *x', y'* are the dimensional distance along and perpendicular to the plate respectively. *U', v'* are the velocity components in the *x', y'* dimensions respectively. u_p' is the velocity , T_w' is the temperature of the wall, C_w' is the concentration of wall, U_∞' is the stream velocity, Q_0 is the dimensional heat absorption coefficient U_0,n are the constants.

The plate is subjected to a variable suction and from the equation of continuity:;we have

$$v'=-v_0(1+\in Ae^{n't'}) \tag{6}$$

Where A is a real positive constant and v0 is the scale of suction velocity which has a nonzero positive constant. The negative sign indicates that the suction is towards the plate. Outside the boundary layer, equation 2 gives

$$\frac{-1}{\rho}\frac{\partial p'}{\partial x'}=\frac{dU'_\infty}{dt'}+\frac{v}{k'}U'_\infty-\frac{\sigma B_0^2}{\rho}U'_\infty \tag{7}$$

On introducing the following non-dimensional quantities

$$u=\frac{u'}{U_0},\ v=\frac{v'}{U_0},\ y=\frac{v_0 y'}{v},\ U_\infty=\frac{U'}{U_0},\ U_p=\frac{u_p{}'}{U_0},\ t=\frac{t' v_0^2{}'}{v},\ n=\frac{n' v}{v^2{}_0},\ k=\frac{k' v_0^2{}'}{v_2},\ \delta=\frac{Qv}{v_0^2},$$

$$\Omega=\frac{\Omega' d^2}{v},\ Sc=\frac{v}{D},\ \Pr=\frac{v_p C_p}{k}=\frac{v}{\alpha},\ \theta=\frac{(T'-T'_\infty)}{(T'-T'_\infty}=\frac{v}{\alpha},\ \ \theta=\frac{(T'-T'_\infty)}{(T_w'-T'_\infty)},\ c=\frac{(C'-C'_\infty)}{(C_w'-C'_\infty)},$$

$$Gr=\frac{vg\beta(T_w'-T'_\infty)}{U_0 V_0^2},\ \ Gc=\frac{vg\beta(C_w'-C'_\infty)}{U_0 V_0^2},\ \ Kr=\frac{vKr'}{V_0^2}, \tag{8}$$

In equations 2-5 yields

$$\frac{\partial u}{\partial t}-(1+\in Ae^{nt})\frac{\partial u}{\partial y}=\frac{\partial U_\infty}{\partial t}+\frac{\partial^2 u}{\partial y^2}+2\Omega v+Gr\theta+GcC+\frac{M(mv-u+u)}{1+m^2}-N(u-U_\infty) \tag{9}$$

$$\frac{\partial \theta}{\partial t}-(1+\in Ae^{nt})\frac{\partial \theta}{\partial y}=\frac{1}{pr}\frac{\partial^2 \theta}{\partial y^2}-Q\theta \quad \in\in \tag{10}$$

$$\frac{\partial C}{\partial t}-(1+\in Ae^{nt})\frac{\partial C}{\partial y}=\frac{1}{Sc}\frac{\partial^2 C}{\partial y^2}+ScS0\frac{\partial^2 \theta}{\partial y^2} \tag{11}$$

The boundary conditions are then given by the following dimensionless form

$$u'=u_p{}',\quad C=1+\in e^{nt},\ \ \theta=1+\in e^{nt},\qquad at\quad y=0$$

$$U\to U'_\infty=(1+\in e^{nt}),\ \ \theta\to 0,\ \ u\to 0\qquad as\quad y\to\infty$$

Solution of the problem

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

$$u=u_0(y)+\in e^{nt}u_1(y)+o(\in^2) \tag{12}$$

$$\theta=\theta_0(y)+\in e^{nt}\theta_1(y)+o(\in^2) \tag{13}$$

$$C=C_0(y)+\in e^{nt}C_1(y)+o(\in^2) \tag{14}$$

Substituting the equations 12,13 and 14 in to the equations 9-11 and equating the harmonic and non harmonic terms neglecting the coefficient of $o(e^2)$ we get the following equations

$$u''_0 + u'_0 - (N + \frac{M}{1+m^2})u_0 = -N - Gr\theta_0 - GcC_0 - 2\Omega V_0 - \frac{Mmv_0}{1+m^2} + \frac{MU}{1+m^2} \quad (15)$$

$$u''_1 + u'_1 - (N + n + \frac{M}{1+m^2})u_1 = -Au_0^{'} - N - Gr\theta_{01} - GcC_1 - 2\Omega V_1 - \frac{Mmv_0}{1+m^2} \quad (16)$$

$$\theta''_0 + \Pr\theta'_0 - \Pr\delta\theta_0 = 0 \quad (17)$$

$$\theta''_1 + \Pr\theta'_1 - \Pr(n+\delta)\theta_1 = -\Pr A\theta_0^1 \quad (18)$$

$$C''_0 + ScC'_0 = AScS0\theta_0^{''} \quad (19)$$

$$C''_1 + ScC'_1 - Sc.n.C_1 = -ScS0\theta_{1_0^1}^{''} + AScC_0^{'} \quad (20)$$

The corresponding boundary conditions can be written as

$$u_0 = U_p, u_1 = 0, \theta_0 = 0, \theta_1 = 1, C_0 = 1, C_1 = 1 \quad at \quad y = 0$$

$$u_0 \leftarrow 1, u_1 \to 1, \theta_0 \to 0, C_0 \to 0, C_1 \to 0 \quad as \quad y \to \infty \quad (21)$$

From the above Equations we obtain for velocity, temperature and concentration as follows

$$u(y,t) = B_{16}e^{-m5y} + B_{14} + B_8 e^{-m1y} + B_9 e^{-m3y} + B_{10}e^{-m1y} + B_{11} + B_{12} + B_{13} + \in e^{nt}(B_{27}e^{-m6y} + B_{17}e^{-m5y} + B_{18}e^{-m1y} + B_{19}e^{-m3y} + B_{20}e^{-m1y} + B_{21}e^{-m2y} + B_{22}e^{-m1y} + B_{23}e^{-m3y} + B_{24}e^{-m1y} + B_{25} + B_{26})$$

$$\theta(y,t) = e^{-m1y} + \in e^{nt}(B_2 e^{-m2y} + B_1 e^{-m1y})$$

$$C(y,t) = B_4 + B_3 e^{-m2y} + \in e^{nt}((B_5 + B_6)e^{-my} + B_7 e^{-m3y})$$

Skin friction:

Knowing the velocity field, the skin friction at the plate can be obtained, which is nondimesional form is given by

$$Cf = \left[\frac{\partial u}{\partial y}\right]_{y=0} = -(B_{16}m5 + B_9 m3 + B_{10}m1 + \in ent(B_{27}m6 + B_{17}m5 + B_{18}m1 + B_{19}m3 + B_{20}m1 + B_{21}m2 + B_{2}$$

Nusselt number:

Knowing the temperature field, the rate of heat transfer coefficient can be obtained, which in non- dimensional form is given in terms of the nusselt number, is given by

$$Nu = \left[\frac{\partial\theta}{\partial y}\right]_{y=0} = -m1 - \in e^{nt}(m2B_2 + m1B_1)$$

Sherwood number:

Knowing the concentration field, the rate of mass transfer coefficient can be obtained, which in nondimensional form is given in terms of the sherwood number, is given by

$$Sh = \left[\frac{\partial C}{\partial y}\right]_{y=0} = -m2B_3 - \in e^{nt}(B_8m4 + (B_5 + B_6)m1 - B_7m3)$$

RESULT AND DISCUSSIONS:

It is observed that from figures 1 and 2 Velocity increases with the increasing Grashof number and Modified Grashof number.Figure 3 illustrates that velocity decreases with the increase in parandtl number Pr. Figures 4 exhibits that Velocity increases with the increasing n. it is observed that from Fig 5. as the increase in Magentic field decrease with the velocity. Fig 6 shows that velocity increases with the increase in permeability parameter. Fig 7 illusrates that as soret parameter increses velocity also increases.

Figure 8 illustrates the effect of n on temperature. it is stimulated from this figure that an increase to the n lead to increase of the temperature. Figure 9. shows the effect of Prandtl number Pr on Temperature. it is inferred that an increase in the Prandtl number Pr will lead to the decrease in the temperature. . Figure 10 indicates that decrease in temperature shows the increase in delta . Figure.11 displays the effect of n on the concentration profiles respectively. As the n increases the concentration increases. Figure.12 displays the effect of the schmidt number on concentration profiles. We observe that concentration profiles decreases with increasing schmidt number. Figure 13 indicates the effect of soret parameter on concentration profiles. concentration decreases with the increase in soret parameter so.

Table 1 shows the Effects of magnetic parameter on skin friction. it is observed that The skin friction decreases with the increase in magnetic parameter. Table-2. Effects of Schmidt number on sherwood number. it shows that increase in the schmidt number increses with the sherwood number. Table-3. indicates the Effects of Prandtl number on skin friction and Nusselt number. Table-4. Effects of soret number on skin friction and Nusselt number. as soret increses both skin friction and Nusselt number decreases.

GRAPHS:

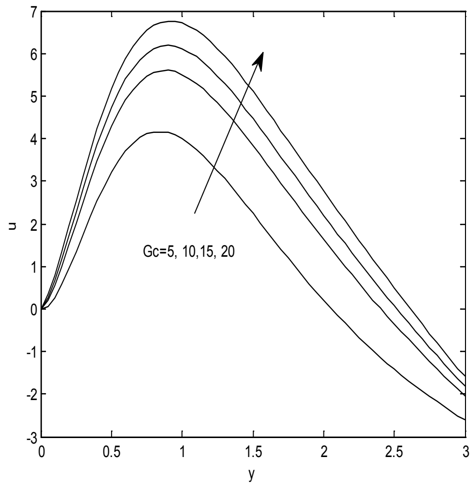

Figure 1: velocity for different values of Gc.

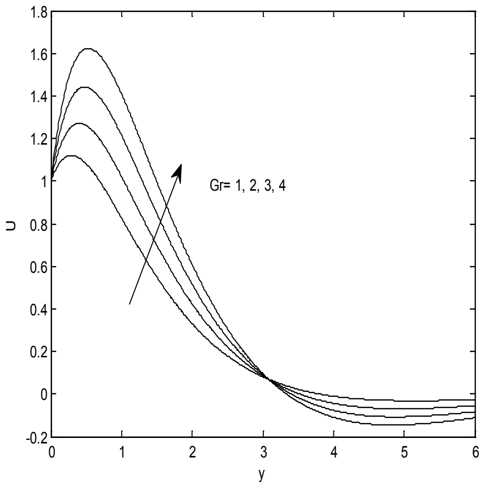

Figure 2: velocity for different values of Gr.

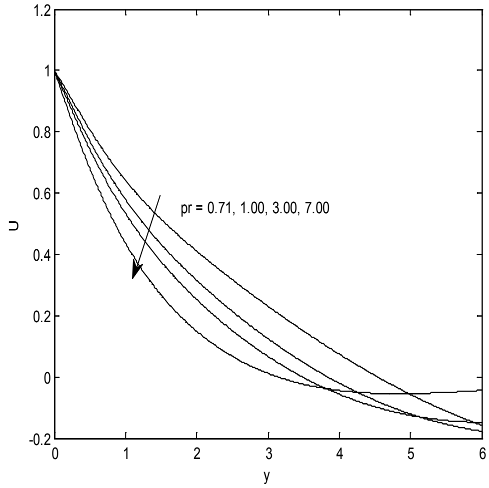

Figure 3: velocity for different values of Pr.

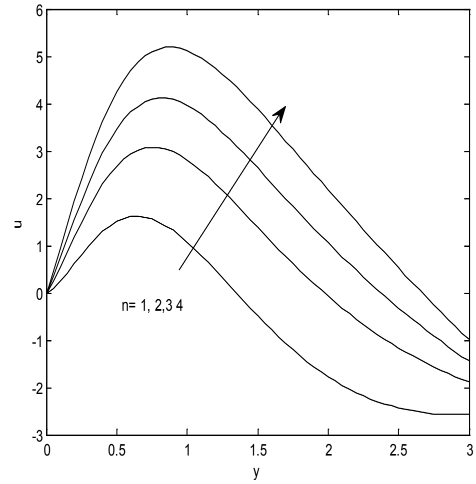

Figure 4: velocity for different values of n.

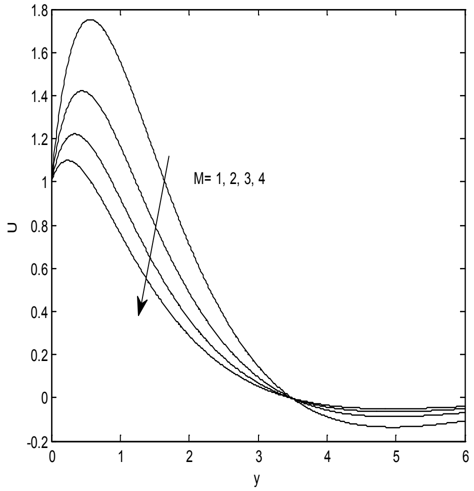

Figure 5: velocity for different values of M.

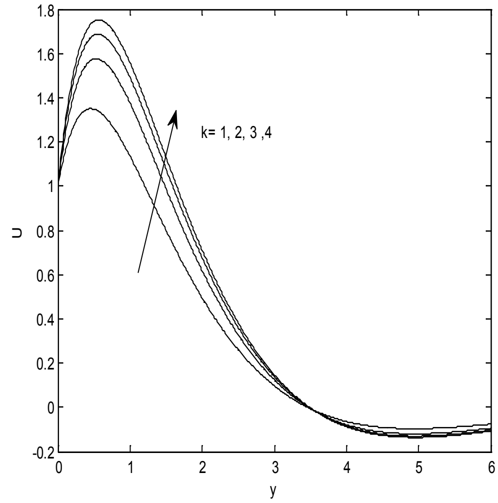

Figure 6: velocity for different values of K.

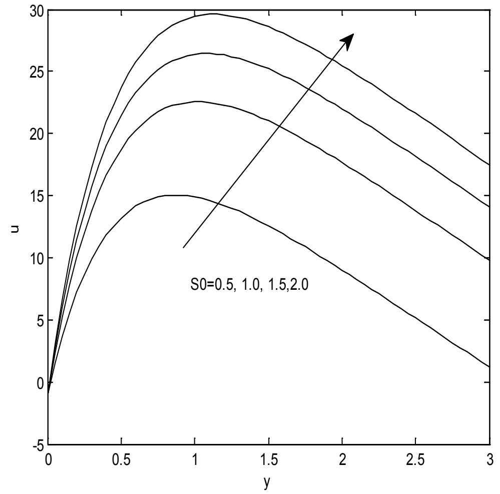

Figure 7: velocity for different values of so.

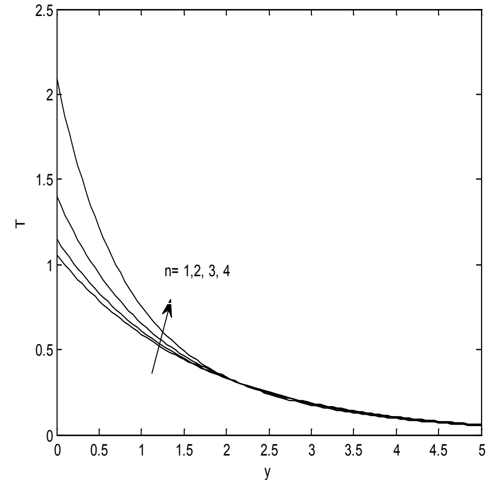

Figure 8: Temperature for different values of n.

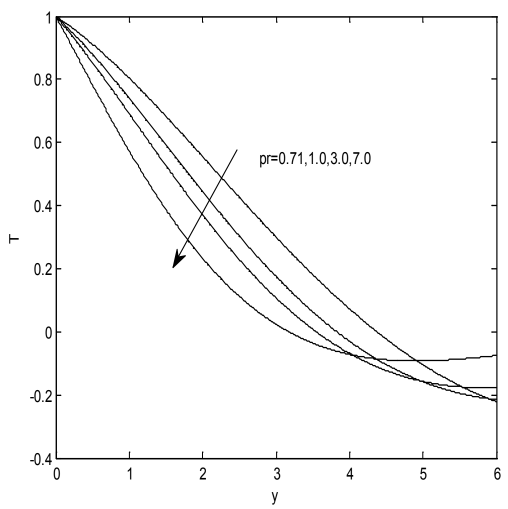

Figure 9: Temperature for different values of Prandtl number Pr.

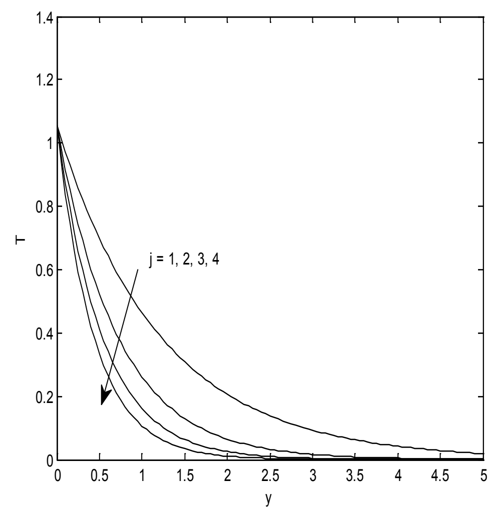

Figure 10: Temperature for different values of j (i.e. delta).

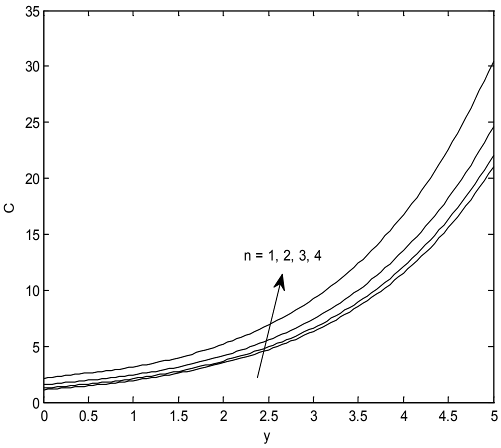

Figure 11: Concentration for different values of n.

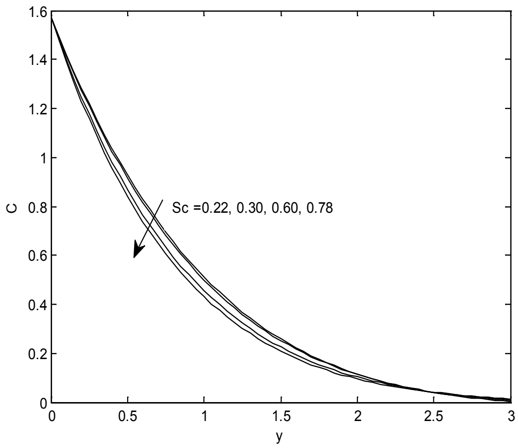

Figure 12: Concentration for different values of Sc.

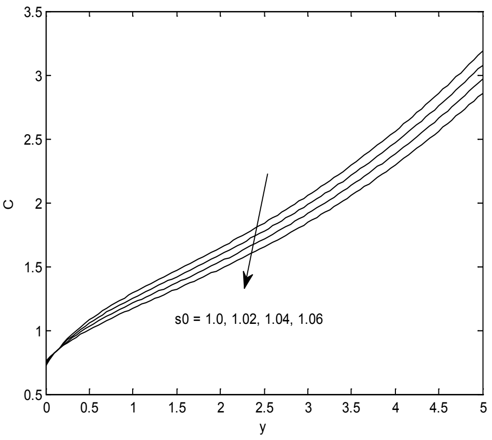

Figure 13: Concentration for different values of So.

Table-1. Effects of magnetic parameter on skin friction.

M	*Cf*
1.0	-1.6066
1.2	-2.2171
1.3	-2.248
1.4	-2.2785

Table-2. Effects of Schmidt number on sherwood number.

Sc	*Sh*
2.2	43.7925
0.30	-5.0388
0.60	-48.5259
0.78	5.7817

Table-3. Effects of Prandtl number on skin friction and Nusselt number.

Pr	*Cf*	*Nu*
0.71	-2.1391	-3.2104
1.00	-4.5614	-3.6233
5.00	-3.4384	-5.5965
7.00	-1.7317	-5.9404

Table-4. Effects of soret number on skin friction and Nusselt number.

S0	*Cf*	*sh*
0.1	118.3990	-0.6118
0.2	-66.3040	-0.8138
0.3	-332.4485	-1.0157
0.4	-680.0345	-1.2176

CONCLUSIONS:

The investigation of the problem leads to the following conclusions:

- The increase in the value of n leads to an increase in the velocity temprature and concentration distributions.
- Velocity increases with the increse in Grashof number and Modified Grashof number.
- Increase in Prandtl number, magnetic parameter and permeability parameter results in decrease in velocity.
- It is inferred that an increase in the Prandtl number Pr will lead to the decrease in the temperature.
- concentration decreases with the increase in soret parameter so.

Appendix

$$m1 = \frac{-pr + \sqrt{pr^2 + 4\Pr\delta}}{2}, \quad m2 = \frac{-pr + \sqrt{pr^2 + 4\Pr(n+\delta)}}{2}, \quad B_1 = \frac{prAm1}{m1^2 - prm1 - pr(n+\delta),}$$

$$B_2 = 1 - B_1, \quad m3 = Sc, \quad B_3 = \frac{-ScS0m1^2}{m1^2 - Scm1}, \quad B_4 = 1 - B_3, \, m4 = \frac{-sc + \sqrt{Sc^2 + 4Scn}}{2},$$

$$B_5 = \frac{scs0m1^2}{m1^2 - scm1 - scn}, \quad B_6 = \frac{-AScB_3}{m1^2 - Scm1 - Scn}, \quad B_7 = \frac{AScB_4 m3}{m3^2 - scm3 - scn}, \quad B_8 = 1 - B_5 - B_6,$$

$$m5 = \frac{-1 + \sqrt{1 + 4A1}}{2}, \quad B_9 = \frac{-Gr}{m1^2 - m1 - A1}, B_{10} = \frac{-GcB_4}{m3^2 - m3 - A1}, \quad B_{11} = \frac{-GcB_4}{m1^2 - m1 - A1},$$

$$B_{12} = \frac{-2\Omega V_o}{A1}, \quad B_{13} = \frac{-MmV_0}{(1+m^2)(-A1)}, B_{14} = \frac{-MV}{(1+m^2)(-A1)}, \quad B_{15} = \frac{N}{A1}, \quad A1 = N + \frac{M}{1+m^2},$$

$$A2 = N + n + \frac{M}{1+m^2}, \; B_{17} = \frac{-Am5B_{15}}{m5^2 - m5 - A2}, \quad B_{18} = \frac{-Am1B_8}{m1^2 - m1 - A2}, \quad B_{19} = \frac{-Am3B9}{m3^2 - m3 - A2},$$

$$B_{20} = \frac{-Am1B_{10}}{m1^2 - m1 - A2}, B_{21} = \frac{-GrB_2}{m2^2 - m2 - A2}, \; B_{22} = \frac{-GrB_1}{m1^2 - m1 - A2}, \; B_{23} = \frac{-GcB_4}{m3^2 - m3 - A2},$$

$$B_{24} = \frac{-GcB_3}{m1^2 - m1 - A2}, B_{25} = \frac{2\Omega V_1}{(1+m^2)A2}, B_{26} = \frac{MmV_1}{(1+m^2)A2},$$

$$B_{27} = 1 - B_{16} - B_{17} + B_{18} + B_{19} + B_{20} + B_{21} + B_{22} + B_{23} + B_{24} + B_{25},$$

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