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Magneto Hydrodynamic Convective Double Diffusive Fluid Flow Past a Vertical Plate with Varying Temperature and Concentration

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Abstract

This manuscript presents the influence of variable boundary of temperature and concentration of a double diffusive unsteady MHD natural convection heat and mass transfer flow past an accelerated vertical porous plate in the presence of thermal radiation and chemical reaction. The dimensionless governing equations along with the relevant boundary conditions are solved numerically by using finite difference method. The effects of pertinent physical parameters on velocity, temperature and concentration are discussed with the help of graphical representations. With the aid of the expression of velocity, concentration and temperature distributions, variations in skin friction, the rate of heat transfer in the form of Nusselt number and the rate of mass transfer in the form of Sherwood number are also analyzed. The velocity decreases with an increase in magnetic parameters and porosity parameter. The temperature increases with an increase in the Dufour number. Concentration falls down under the influence of Schmidt number and chemical reaction.

Keywords: MHD, Double diffusion, Free convection, Thermal radiation, Porous medium, Variable temperature and variable concentration.

1. INTRODUCTION

The phenomenon of magneto hydrodynamic flow with heat transfer has been a subject of great interest in view of its possible applications in many branches of science, technology and also industries. Convection heat transfer from vertical surfaces and embedded in porous media has been the subject of many investigations. This is due to the fact that these flows have many engineering and geophysical applications such as geothermal reservoirs, drying of porous solids, thermal insulation and enriched oil recovery, groundwater purification and underground energy transportation. Natural convection flow involving heat transfer occurs frequently in an environment where difference between land and air temperature can give rise to complicated flow patterns. The studies of magnetic field effects on free convection flow are often found important in liquid metals, ionized gases and electrolytes. In astrophysics and geophysics, it is applied to study the stellar graphics, solar structures, interstellar matter, propagation of radio waves through the ionosphere etc. Recently, it is of great interest to study the magnetic field effects and other physical parameters on the temperature distribution and heat transfer when the fluid is not only an electrical conductor but also when it is capable of emitting and gripping thermal radiation. Umamaheswar et al. [2] Studied MHD convective heat and mass transfer flow of a Newtonian fluid past a vertical porous plate with chemical reaction, radiation absorption and thermal diffusion. Reddy et al. [5] examined radiation and chemical reaction effects on MHD flow along a moving vertical porous plate. Reddy et al [7] examined unsteady MHD free convection flow of a visco-elastic fluid past a vertical porous plate in the presence of thermal radiation, radiation absorption, heat generation/absorption and chemical reaction. Sharma [9] studied an unsteady effect on MHD free convective and mass transfer flow through porous medium with constant suction and constant heat flux in rotating system. G.S. Seth and Md. S. Ansari [10] discussed MHD natural convection flow past an impulsively moving vertical plate with ramped wall temperature in the presence of thermal diffusion with heat absorption. Seshaiah et al. [14] discussed the effects of chemical reaction and radiation on unsteady MHD free convective fluid flow embedded in a porous medium with time-dependent suction with temperature gradient heat source. Raju et al [17] examined radiation and mass transfer effects on a free convection flow through a porous medium bounded by a vertical surface. Reddy et al. [20] studied an unsteady MHD radiative and chemically reactive free convection flow near a moving vertical plate in porous medium. Raju et al. [23] discussed MHD thermal diffusion natural convection flow between heated inclined plates in porous medium. Bhargava et al. [26] formulated, an oscillatory chemically-reacting MHD free convection heat and mass transfer in a porous medium with Soret and Dufour effects. Narayana and Sibanda [27] studied Soret and Dufour effects on free convection along a vertical wavy surface in a fluid saturated Darcy porous medium. Chandra Reddy et al. [30], examined magentohydrodynamic convective double diffusive laminar boundary layer flow past an accelerated vertical plate. In this study they explained in detail about the importance and applications of Soret and Dufour effects in significant areas of science and technology. Study of free and forced convection flow in an inclined channel was conducted by Krishnaiah et al. [31]. Combined constant heat and mass flux effect on MHD free convective flow through a porous medium bounded by a vertical surface in the presence of chemical reaction and radiation was examined by Reddy and Raju [32]. Diffusion thermo and thermal diffusion effects on MHD free convection flow of Rivlin- Ericksen fluid past a semi-infinite vertical plate were studied by Redddy et al. [33].

In this manuscript, we extend the work of Reddy et al. [30], in the presence of variable temperature and variable concentration boundary layers. This is not a simple extension to that work but we also include the influence of homogeneous first order chemical reaction. The novelty of this study is consideration of variable temperature and variable concentration effects in the presence of homogeneous chemical reaction, thermal diffusion and diffusion thermo effects, thermal radiation, heat absorption, MHD and porous medium etc. The coupled nonlinear governing equations along with boundary conditions are solved by finite difference method and the results are presented through graphs and tables.

2. NOMENCLATURE

C	Concentration [g/m]
*C*p	Specific heat at constant pressure [J.kg^{-1} K^{-1}]
D	molecular diffusivity
D_1	thermal diffusivity
Df	Dofour number
F	radiation parameter
G	Acceleration due to gravity [m.s^{-2}]
Gr	Thermal Grashof number
Gm	modified Grashof number
K	porosity parameter
Kc	Chemical reaction
M	magnetic parameter
Nu	Nusselt number
Pr	Prandtl number
Q	heat absorption parameter
Sc	Schmidt number
Sh	Sherwood number
So	Soret number
t	Time [s]
u	Velocity of the plate [m.s^{-1}]
y	Coordinate axis normal to the plate[m]
Greek symbols	
β	Volumetric coefficient of thermal expansion [K^{-1}]
μ	Coefficient of viscosity [Pa.s]
ν	Kinematic viscosity [m^2.s^{-1}]
ρ	Density of the fluid [kg.m^{-3}]
τ	skin friction
σ	Electrical conductivity [ohm^{-1} s^{-1}]
θ	Temperature [K]
κ	thermal conductivity [W.m^{-1}.K^{-1}]
Subscript	
S	Surface of the plate
∞	Conditions in the free stream

3. MATHEMATICAL FORMULATION

We consider a viscous incompressible, electrically conducting, heat absorbing and radiating Newtonian fluid flow past an infinite vertical porous plate in the presence of diffusion thermo and thermo diffusion. A magnetic field of uniform strength is applied perpendicular to the plate. Let x^*-axis be taken along the plate in the vertically upward direction and the y^*-axis be taken perpendicular to the plate. At time $t \leq 0$, the plate is maintained at the temperature higher than ambient temperature T_∞ and the fluid is at rest. At time $t > 0$, the plate is linearly accelerated with increasing time in its own plane and the temperature decreases with time as $T = 1/(1+at)$. Similarly the species concentration decreases with time t. It is assumed that the effect of viscous dissipation is negligible by usual Boussineq's and boundary layer approximation. Based on the above considerations the unsteady flow is governed by the following equations.

$$\frac{\partial u^1}{\partial t^1} + v\frac{\partial u^1}{\partial y^1} = \upsilon\frac{\partial^2 u^1}{\partial y^{1^2}} + g\beta_T(T^1 - T_\infty) + g\beta_C(C^1 - C_\infty) - \frac{\sigma B_0^2 u^1}{\rho} - \frac{\upsilon u^1}{k} \tag{1}$$

$$\rho C_p \frac{\partial T^1}{\partial t^1} = k_T\frac{\partial^2 T^1}{\partial y^{1^2}} + Q^1(T^1 - T^1_\infty) - \frac{\partial q_r^1}{\partial y^1} + \frac{Dmk_T\rho}{C_s}\frac{\partial^2 C^1}{\partial y^{1^2}} \tag{2}$$

$$\frac{\partial C^1}{\partial t^1} = D\frac{\partial^2 C^1}{\partial y^{1^2}} + D_1\frac{\partial^2 T^1}{\partial y^{1^2}} - Kc(C^1 - C^1_\infty) \tag{3}$$

The corresponding initial and boundary conditions are;

$$u^1 = 0,\ T^1 = T^1_\infty,\ C^1 = C^1_\infty,\ \text{for all }\ y^1, t^1 \le 0$$

$$t^1 \ge 0:\ \ u^1 = U_0 a^1 t^1,\ T^1 = T^1_\infty + (T^1_w - T^1_\infty)e^{a^1 t^1},$$

$$C^1 = C^1_\infty + (C^1_w - C^1_\infty)e^{a^1 t^1},\ at\ \ y^1 = 0$$

$$u^1 \to 0,\ T^1 \to T_\infty,\ \ C^1 \to C_\infty \quad as\ \ y^1 \to \infty \tag{4}$$

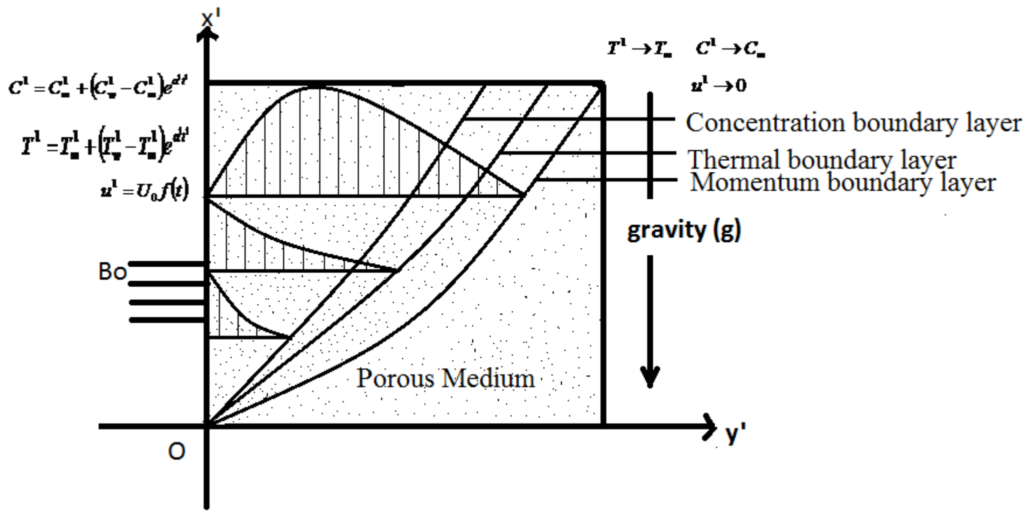

Figure 1: Physical model of the problem

$$G_r = \frac{\upsilon g \beta_T (T^1_w - T^1_\infty)}{U_0^3}$$, (Grashof number)

$$Gm = \frac{\upsilon g \beta_C (C^1_w - C^1_\infty)}{U_0^3}$$, (Solutal Grashof number)

$$M = \frac{\sigma B_0^2 \upsilon}{\rho U_0^2}$$,(Magnetic parameter)

$$K = \frac{U_0^2 k}{\upsilon^2}$$, (Porosity parameter)

$$\Pr = \frac{\upsilon \rho C_P}{k_T}$$ (Prandtl number)

$Q = \dfrac{Q^1 v^2}{k_T U_0^2}$ (Heat source parameter)

$Df = \dfrac{Dmk}{\upsilon C_S C_P}\left(\dfrac{C_w^1 - C_\infty^1}{T_w^1 - T_\infty^1}\right)$ (Dufour number)

$F = \dfrac{4\upsilon I^1}{\rho C_p U_0^2}$ (Radiation Parameter)

$S0 = \dfrac{D_1}{\upsilon}\left(\dfrac{C_w^1 - C_\infty^1}{T_w^1 - T_\infty^1}\right)$ (Soret number)

$Sc = \dfrac{\upsilon}{D}$ (Schmidt number)

$K_C = \dfrac{k_C \upsilon}{U_0^2}$ (Chemical reaction parameter)

The non-dimensional quantities are as follows:

$$y = \frac{U_0 y^1}{v};\ t = \frac{U_0^2 t^1}{v};\ u = \frac{u^1}{U_0};\ a = \frac{a^1 v}{U_0^2};\ \theta = \frac{T^1 - T_\infty^1}{T_w^1 - T_\infty^1};\ C = \frac{C^1 - C_\infty^1}{C_w^1 - C_\infty^1};\ \frac{\partial q_r^1}{\partial y^1} = 4(T^1 - T_\infty^1) I^1 .$$

Introducing the non-dimensional quantities the equations (1)-(3) reduces to following form

$$\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + Gr\,\theta + Gm\,C - M\,u - \frac{1}{K}u \tag{5}$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial y^2} + \frac{1}{\Pr}Q\theta - F\theta + Df\,\frac{\partial^2 C}{\partial y^2} \tag{6}$$

$$\frac{\partial C}{\partial t} = \frac{1}{S_C}\frac{\partial^2 C}{\partial y^2} + S_0\,\frac{\partial^2 \theta}{\partial y^2} - K_C C \tag{7}$$

The corresponding initial and boundary conditions are

$$\begin{aligned} &u = 0, \theta = 0, C = 0 \quad \text{for all} \quad y, t \le 0 \\ &t > 0; u = at, \theta = e^{at}, C = e^{at} \ \text{ at } \ y = 0 \\ &u = 0, \theta = 0, C = 0 \ \text{ as } \ y \to \infty \end{aligned} \tag{8}$$

4. METHOD OF SOLUTION

Equations (5)-(7) are linear partial differential equations and are to be solved with the initial and boundary conditions (8). In fact the exact solution is not possible for this set of equations and hence we solve these equations by finite-difference method. The equivalent finite difference schemes of equations for (5)-(7) are as follows:

$$\frac{u_{i,j+1}-u_{i,j}}{\Delta t}=Gr\,\theta_{i,j}+Gm\,C_{i,j}+\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}}{(\Delta y)^2}-M\,u_{i,j}-\frac{1}{K}u_{i,j} \tag{9}$$

$$\frac{\theta_{i,j+1}-\theta_{i,j}}{\Delta t}=\frac{1}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}-\frac{Q}{\Pr}\theta_{i,j}-F\theta_{i,j}+Df\,\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2} \tag{10}$$

$$\frac{C_{i,j+1}-C_{i,j}}{\Delta t}=\frac{1}{S_C}\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}+S_0\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}-K_C C_{i,j} \tag{11}$$

Equations (9) – (11) can also be written as follows:

$$u_{i,j+1}=u_{i,j}+Gr\,\theta_{i,j}\Delta t+Gm\,C_{i,j}\Delta t+\frac{u_{i-1,j}-2u_{i,j}+u_{i+1,j}}{(\Delta y)^2}\Delta t-M\,u_{i,j}\Delta t-\frac{1}{K}u_{i,j}\Delta t \tag{12}$$

$$\theta_{i,j+1}=\theta_{i,j}+\frac{\Delta t}{\Pr}\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}-\frac{Q}{\Pr}\theta_{i,j}\Delta t-F\theta_{i,j}\Delta t+Df\,\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}\Delta t \tag{13}$$

$$C_{i,j+1}=C_{i,j}+\frac{\Delta t}{S_C}\frac{C_{i-1,j}-2C_{i,j}+C_{i+1,j}}{(\Delta y)^2}+S_0\frac{\theta_{i-1,j}-2\theta_{i,j}+\theta_{i+1,j}}{(\Delta y)^2}\Delta t-K_C C_{i,j}\Delta t \tag{14}$$

Here, the suffix i corresponds to y and j to time. The mesh system is divided by taking $\Delta y = 0.05$. From the initial condition in (8), we have the following equivalent:

$$u(i,0)=0,\ \theta(i,0)=0, C(i,0)=0 \text{ for all } i \tag{15}$$

The boundary conditions from (8) are expressed in finite-difference form as follows

$$\begin{gathered} u(0,j)=at, \theta(0,j)=\frac{1}{1+t}, C(0,j)=\frac{1}{1+t} \text{ for all } j \\ u(i_{\max},j)=0, \theta(i_{\max},j)=0, C(i_{\max},j)=0 \text{ for all } j \end{gathered} \tag{16}$$

(Here i_{max} was taken as 200).

The velocity at the end of time step viz, u(i, j+1)(i=1,200) is computed from (12) in terms of velocity, temperature and concentration at points on the earlier time-step. After that θ (i, j +1) is computed from (13) and thenC (i, j +1) is computed from (14). The procedure is repeated until t = 0.5 (i.e. j = 500). During computation Δt was chosen as 0.0001.

Skin-friction:
The skin-friction in non-dimensional form is given by the relation

$$\tau=-\left(\frac{du}{dy}\right)_{y=0}, \text{ where } \tau=\frac{\tau^1}{\rho U_0^2}$$

Rate of heat transfer:
The dimensionless rate of heat transfer in terms of Nusselt number is given by

$$Nu=-\left(\frac{d\theta}{dy}\right)_{y=0}$$

Rate of mass transfer:
The dimensionless rate of mass transfer in terms of Sherwood number is given by

$$Sh = -\left(\frac{dC}{dy}\right)_{y=0}$$

5. RESULTS AND DISCUSSION

To gain a perspective of the physics of the flow regime, we have studied numerically the effects of Hartmann number(M), Grashoff number (Gr), modified Grashoff number (Gm), Prandtl number (Pr), porous permeability(K) , heat absorption parameter (Q), radiation parameter (F), Schmidt number (Sc), Soret number (So), Dufour number (Df) and Chemical reaction (Kc) on the velocity, temperature, concentration, shear stress function, Nusselt number and Sherwood number. In order to validate of our study we have compared with the result of previous literature by Chandra et al [30]. The results of this comparison are found to be in very good agreement.

Figures 2-5 demonstrate the variations of the fluid velocity under the efects of different parameters. Figure 4 shows the effect of magnetic parameter on velocity distribution. It is noticed that the velocity decreases with increasing values of magnetic parameter. It is known fact that the application of transverse magnetic field which is applied normal to the flow, results in a flow-resistive force called the Lorentz force which acts in the opposite direction of the flow. This force has the effect of slowing the motion of the fluid.This result is in good agreement with the results of Chandra et al. [30]. Figures 2 & 3 depict the influence of Grashof number and modified Grashof number on velocity. It can be seen that the velocity increases for rising values of both the numbers. This is due to the fact that the buoyancy which is acting on the fluid particles due to gravitational forces that enhances the fluid velocity. Figure 4 displays the effect of magnetic parameter on velocity; it shows that the velocity decreases with an increase of magnetic parameters. Figure5 displays the effect of porous permeability parameter on velocity. It is observed that as the porosity parameter value increases the velocity decreases. Physically, an increase in the permeability of porous medium leads to the rise in the flow of fluid through it.When the holes of the porous medium become large, the resistance of the medium may be neglected. In their study Harikrishna et al. [8] concluded that the velocity decreases with an increase in the values of porosity parameter. Figures 6&7 displays the effect of Prandtl number & heat source parameter on temperature . It is observed that the temperature decreases with increasing values of Prandtl number and heat source parameter. This is because this in turn means fluid of low Prandtl number has high thermal diffusivity hence attains higher temperature in steady state, with more buoyancy force i.e. more fluid velocity with respect to a comparatively higher Prandtl fluid. Figure 8 exhibits the variation of the temperature with the influence of Dufour number. It is noticed that the temperature increases with an increase in the Dufour number. Figure 9 shows the variation of the temperature by effect of radiation parameter. It is noticed that temperature decreases with the radiation parameter increases. Figures 10 & 11 show the variations of the concentration with the influence of Schmidt number and chemical reaction, the concentration decreases with an increase of Schmidt number and chemical reaction. Figure 12 shows the variation of the Concentration with the Soret number. It is clear that the concentration increases with an increase in the Soret number.

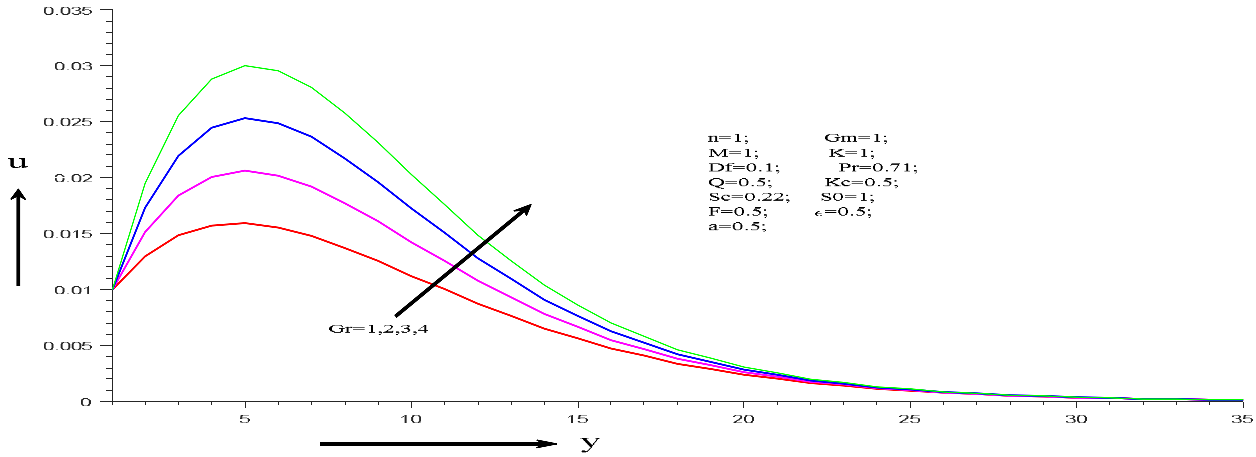

Figure 2: Effect of Grashof number on velocity

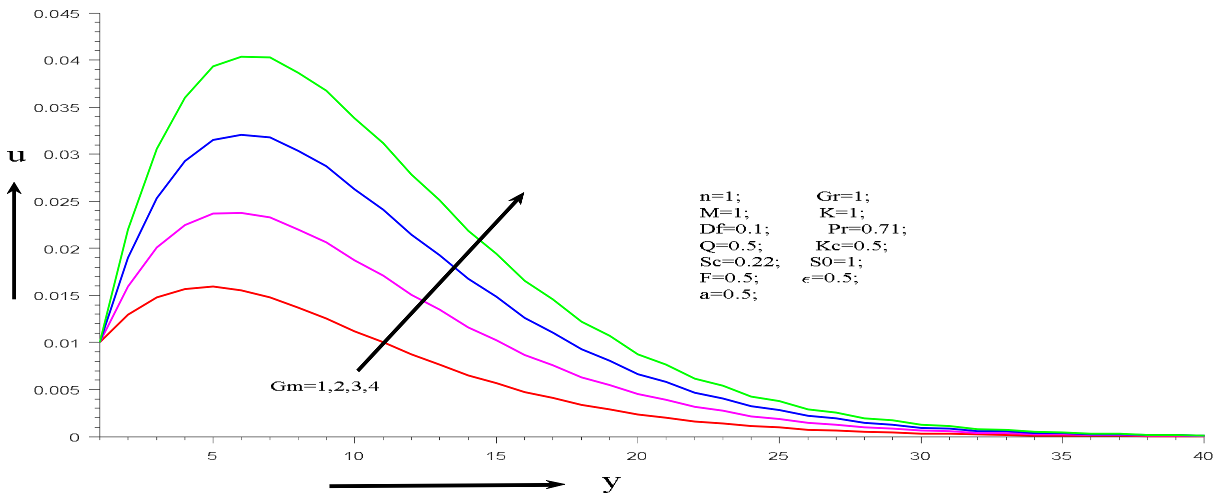

Figure 3: Effect of Modified Grashof number on velocity

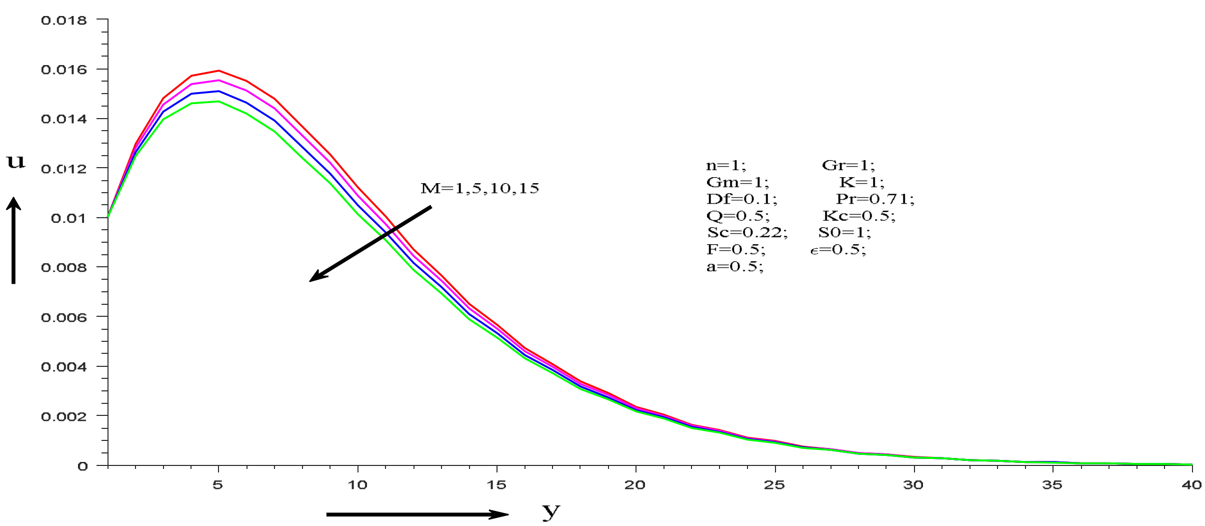

Figure 4: Effect of Magnetic parameter on velocity

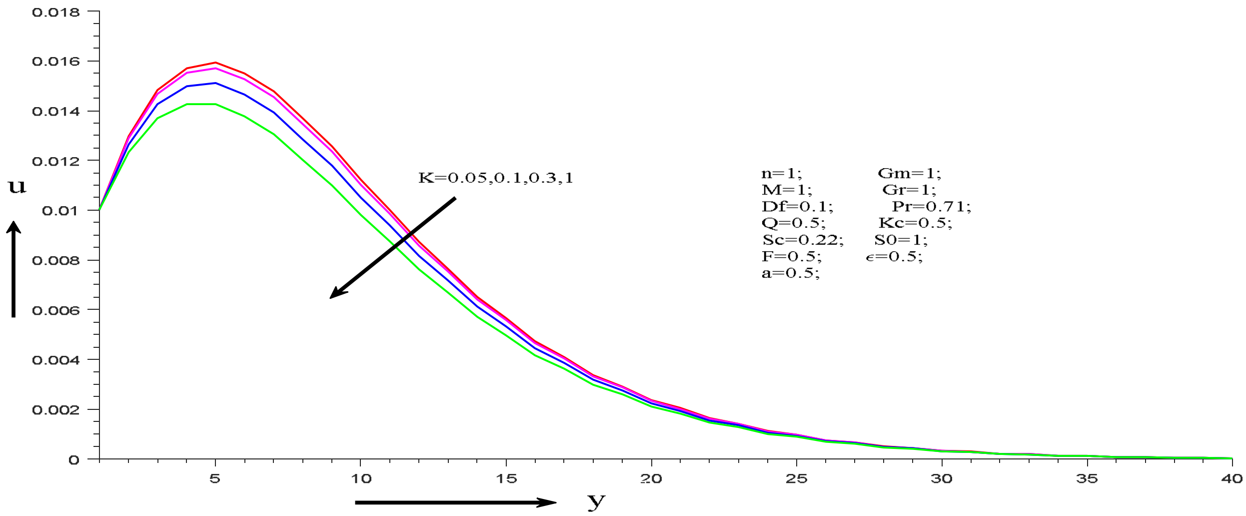

Figure 5: Effect of Porous permeability parameter on velocity

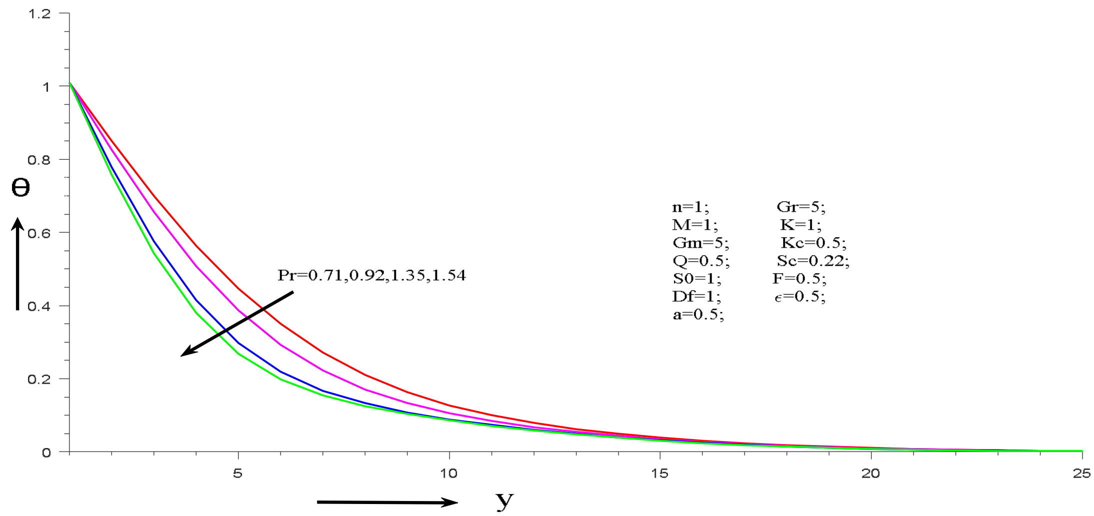

Figure 6: Effect of Prandtl number on Temperature

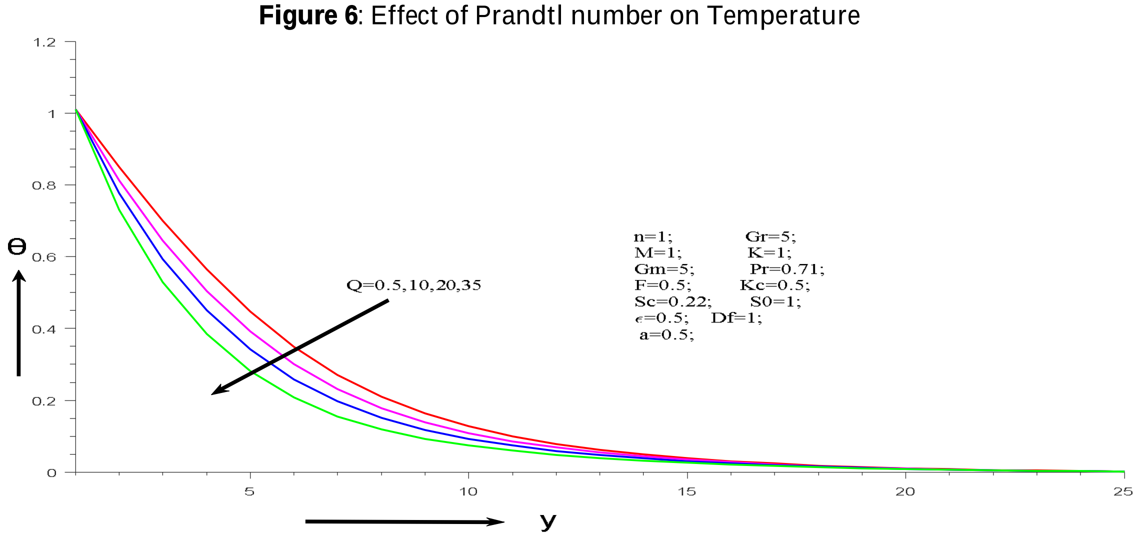

Figure 7: Effect of Heat source parameter on Temperature

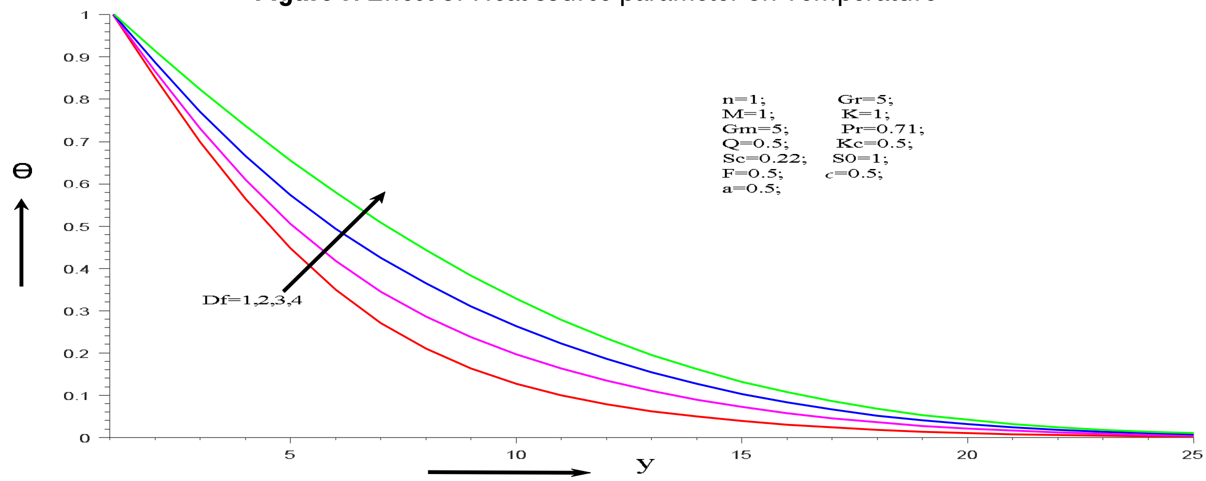

Figure 8: Effect of Dufour number on Temperature

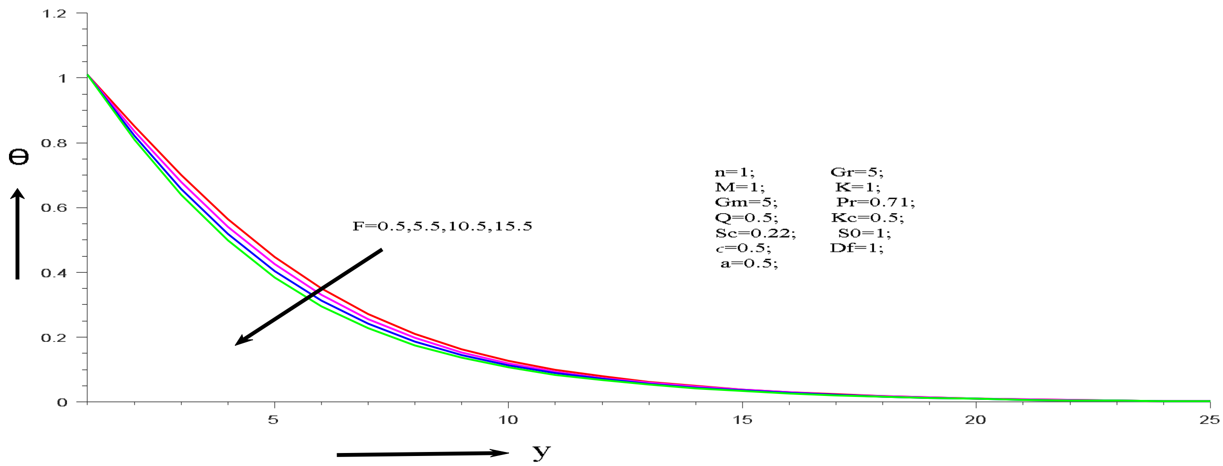

Figure 9: Effect of Radiation parameter number on Temperature

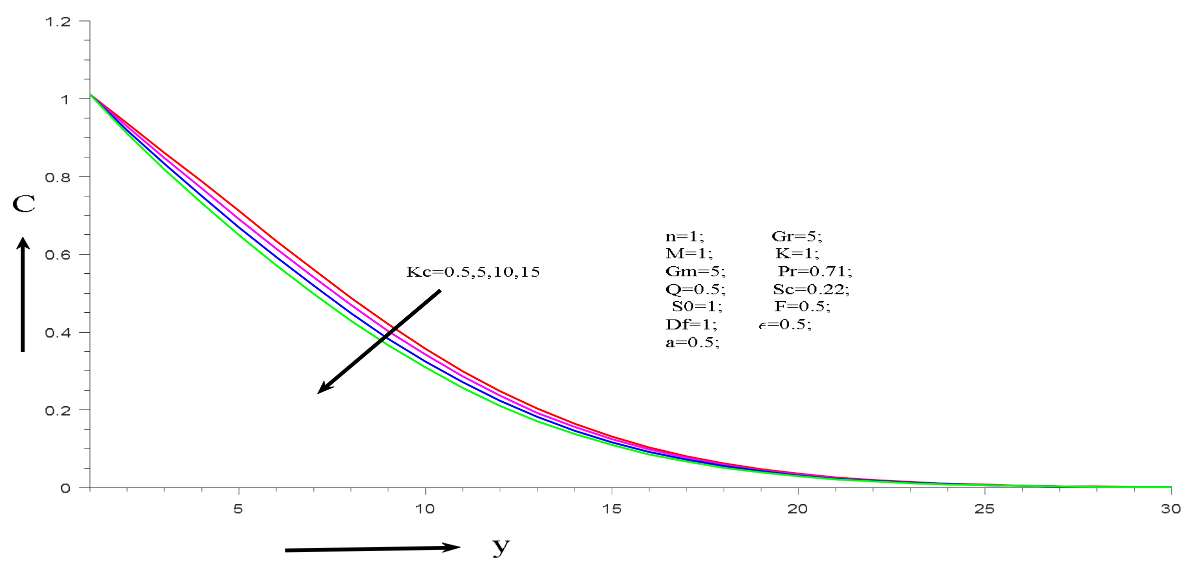

Figure 10: Effect of Chemical reactionon Concentration

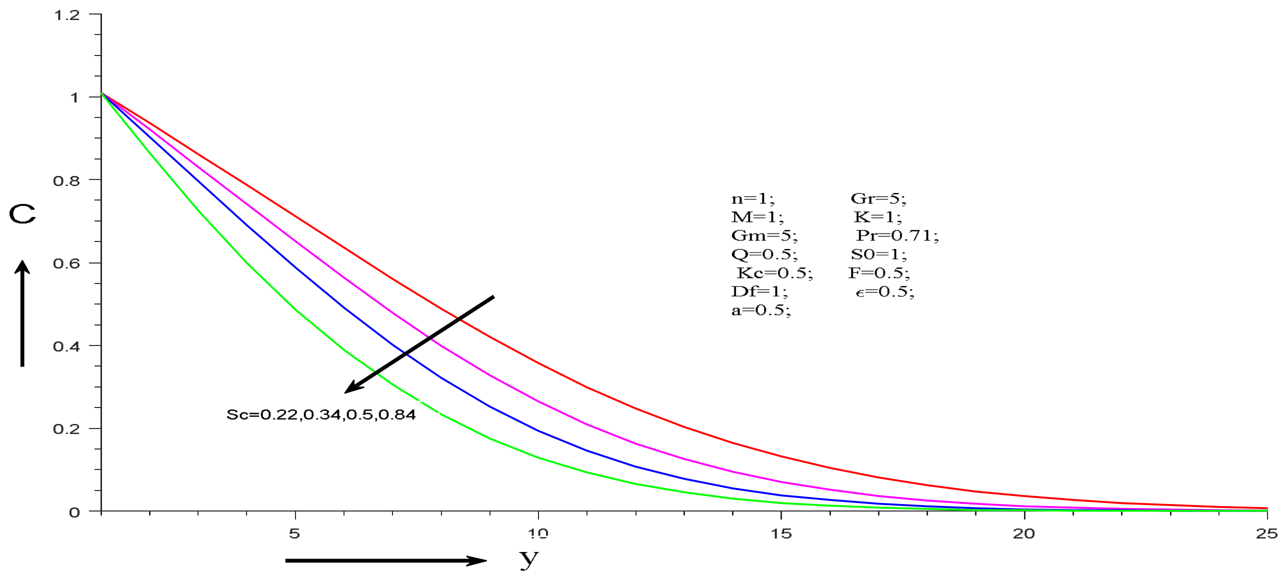

Figure 11: Effect of Schmidt number on Concentration

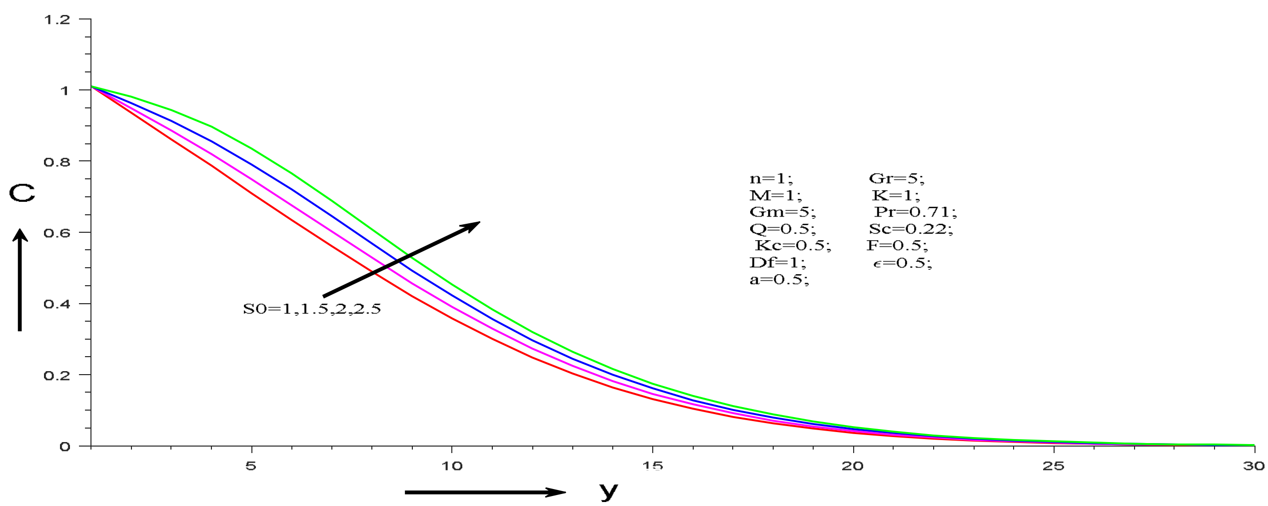

Figure 12: Effect of Soret number on Concentration

We also record numerical values of the surface skin friction (τ), Nusselt number (Nu) and Sherwood number (Sh) in tabular form. Table 1 displays the variations in skin friction. The skin friction decreases with an increase in magnetic parameter whereas it increases under the influence of porosity parameter. An increase in the Grashof number and modified Grashof number increases the skin friction. It can be noticed from table 2 that the Nusselt number enhances with rising values of radiation parameter, heat absorption parameter and Prandtl number. Increasing values of Dufour number results in decreasing the Nusselt number. Table 3 shows that Sherwood number increases for rising values of Schmidt number and chemical reaction but falling of the Sherwood number leads to an increase in the values of the Soret number.

Table: 1. Variations in skin friction

Gr	Gm	M	K	T
1	1	1	1	0.0166
2	1	1	1	0.0285
3	1	1	1	0.0403
1	3	1	1	0.0551
1	5	1	1	0.0936
1	7	1	1	0.1320
1	1	5	1	0.0166
1	1	10	1	0.0165
1	1	25	1	0.0164
1	1	1	0.01	0.0159
1	1	1	0.02	0.0163
1	1	1	0.03	0.0165

Table: 2 Variations in Nusselt Number

Pr	Q	F	Df	Nu
0.71	0.5	0.5	1	20.3884
0.85	0.5	0.5	1	22.3049
0.92	0.5	0.5	1	23.1186
0.71	1	0.5	1	20.3925
0.71	2	0.5	1	20.4008
0.71	3	0.5	1	20.4095
0.71	0.5	1	1	20.3913
0.71	0.5	3	1	20.4030
0.71	0.5	5	1	20.4147
0.71	0.5	0.5	2	17.3550
0.71	0.5	0.5	3	13.9134
0.71	0.5	0.5	4	10.0489

Table: 3 Variations in Sherwood number

Sc	So	Kc	Sh
0.22	1	0.5	7.3424
0.34	1	0.5	9.8811
0.5	1	0.5	13.1697
0.22	1.5	0.5	5.5129
0.22	2	0.5	3.5792
0.22	2.5	0.5	1.5395
0.22	1	1	7.3458
0.22	1	2	7.3527
0.22	1	3	7.3595

6. CONCLUSIONS

The non-dimensional governing equations of the problem are solved by using finite difference method. The variations in the velocity, temperature and concentration with the effects of various parameters encountered in the problem are studied through graphs. Also the effects some of the above parameters on skin friction, Nusselt number and Sherwood number are observed. The following are some of the notable conclusions:

- The fluid velocity increases with the increasing values of Grashof number, and modified Grashof number.
- The velocity decreases with an increase of magnetic parameters and porosity parameter.
- The temperature decreases with increasing values of Prandtl number and heat source parameter.
- The temperature increases with an increase in the Dufour number.
- Increasing values of Soret number results in the rising of the concentration.
- Concentration falls down under the influence of Schmidt number and chemical reaction.

- The skin friction decreases with an increase in magnetic parameter whereas it increases under the influence of porosity parameter.
- When the Grashof number and modified Grashof number increases the skin friction increases.
- The Nusselt number enhances with rising values of radiation parameter ,heat absorption parameter and Prandtl number.
- Increasing values of Dufour number results in decreasing the Nusselt number.
- Sherwood number increases for rising values of Schmidt number and chemical reaction.
- Falling of the Sherwood number results in an increase in the values of Soret number.

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