# Soret and Dufour Effects on hydro magnetic heat and mass transfer over a vertical plate in a porous medium with a convective surface boundary condition and chemical reaction

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## ABSTRACT

This paper examined the hydro magnetic boundary layer flow with heat and mass transfer over a vertical plate in the presence of magnetic field with Soret and Dufour effects, chemical reaction and a convective heat exchange at the surface with the surrounding has been studied. The similarity solution is used to transform the system of partial differential equations and an efficient numerical technique is implemented to solve the reduced system by using the Runge-Kutta fourth order method with shooting technique. A comparison study with the previous results shows a very good agreement. The results are presented graphically and the conclusion is drawn that the flow field and other quantities of physical interest are significantly influenced by these parameters.

**Key words**: vertical plate, convective boundary condition, chemical reaction, heat And mass transfer, magnetic field, similarity solution.

## 1. INTRODUCTION

The use of magnetic field that influences heat generation/absorption process in electrically conducting fluid flows has important engineering applications. See for instance, Moalem[11], Chakrabarti et al. [4], Vajravelu et al. [18], Chiam[5], Chamkha et al.[6], Chandran et al. [7] and Seddeek[14]. This interest stems from the fact that hydromagnetic flows and heat transfer have been applied in many industries. For example, in many metallurgical processes such as drawing of continuous filaments through quiescent fluids, and annealing and tinning of copper wires, the properties of the end product depend greatly on the rate of cooling involved in these processes. Most of the existing analytical studies for this problem are based on the constant physical properties of the ambient fluid. However, it is known that these properties may change with temperature. To accurately predict the flow and heat transfer rates it is necessary to take into account this variation of viscosity. Seddeek et al. [16] introduced the effect of an axial magnetic field on the flow and heat transfer. Also, Seddeek et al. [15] have analyzed the effects of variable viscosity with magnetic field on the flow and heat transfer.

The effect of radiation on free convection flow of fluid with variable viscosity from a porous plate is discussed Anwar Hossain et al [3]. The fluid considered in that paper is an optically dense viscous incompressible fluid of linearly varying temperature dependent viscosity. Salem [13] discussed coupled heat and mass transfer in Darcy-Forchheimer Mixed convection from a vertical flat plate embedded in a fluid saturated porous medium under the effects of radiation and viscous dissipation. Paresh Vyas&Ashutosh Ranjan[12] discussed the dissipative MHD boundary-layer flow in a porous medium over a sheet stretching nonlinearly in the presence of radiation. Seddeek and Almushigeh[17] studied the Effects of radiation and variable viscosity on MHD free convective flow and mass transfer over a stretching sheet with chemical reaction.

In all these studies Soret / Dufour effects are assumed to be negligible. Such effects are significant when density differences exist in the flow regime. For example when species are introduced at a surface in fluid domain, with different (lower) density than the surrounding fluid, both Soret and Dufour effects can be significant. Also, when heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are of more intricate nature. It has been found that an energy flux can be generated not only by temperature gradients but by composition gradients as well. The energy flux caused by a composition gradient is called the Dufour or diffusion-thermo effect. On the other hand, mass fluxes can also be created by temperature gradients and this is called the Soret or thermal-diffusion effect. The thermal-diffusion (Soret) effect, for instance, has been utilized for isotope separation, and in mixture between gases with very light molecular weight (H2, He) and of medium molecular weight (N2, air), the diffusion-thermo (Dufour) effect was found to be of a considerable magnitude such that it can not be ignored (Eckert and Drake [9]). In view of the importance of these above mentioned effects, Dursunkaya and Worek (Dursunkaya and Worek [8]) studied diffusion-thermo and thermal-diffusion effects in transient and steady natural convection from a vertical surface, whereas Kafoussias and Williams (Kafoussias and Williams [10]) presented the same effects on mixed free-forced convective and mass transfer boundary layer flow with temperature dependent viscosity. Recently, Alam et al. [1] who studied the Dufour and Soret effects on heat and mass transfer for flow past a semi-infinite vertical plate.

Alam and Rahman [2] studied the effects of the Dufour and Soret parameters on mixed convection in a flow past a vertical plate embedded in a porous medium.

However, the interaction of Soret and Dufour effects on steady MHD free convection flow in a porous medium with viscous dissipation has received a little attention. Hence, the object of the present chapter is to analyze Soret and Dufour Effects on Similarity solution of hydro magnetic heat and mass transfer over a vertical plate in a porous medium with a convective surface boundary condition and chemical reaction. The governing equations are transformed by using similarity transformation and the resultant dimensionless equations are solved numerically using the Runge-Kutta method with shooting technique. The effects of various governing parameters on the velocity, temperature, concentration, skin-friction coefficient, Nusselt number and Sherwood number are shown in figures and tables and analyzed in detail.

## 2. MATHEMATICAL ANALYSIS

Let us consider a steady, laminar, hydromagnetic coupled heat and mass transfer by mixed convection flow over a vertical plate in a porous medium. The fluid is assumed to be Newtonian, electrically conducting and its property variations due to temperature and chemical species concentration are limited to fluid density. The density variation and the effects of the buoyancy are taken into account in the momentum equation (Boussinesq's approximation). In addition, there is no applied electric field and all of the Hall effects and Joule heating are neglected. Since the magnetic Reynolds number is very small for mast fluid used in industrial applications, we assumed that the induced magnetic field is negligible.

Let the x-axis be taken along the direction of plate and y-axis normal to it. If u, v, T and C are the fluid x-component of velocity, y-component of velocity, temperature and concentration respectively, then under the Boussinesq and boundary-layer approximations, the governing equations for this problem con be written as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}(u-U_\infty)+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty)-\frac{\nu}{K'}u \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_m k_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2}+\frac{\nu}{c_p}\left(\frac{\partial u}{\partial y}\right)^2 \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y^2}+kr^2(C-C_\infty) \tag{4}$$

where ν is the fluid kinematics viscosity, $\rho$ - the density, $\sigma$ - the electric conductivity of the fluid, $\beta_T$ and $\beta_c$ - the coefficients of thermal and concentration expansions respectively, $k$ - the thermal conductivity, $C_\infty$ - the free stream concentration, $B_0$ - the magnetic induction, , $U_\infty$ - t the free stream velocity , *D*- the mass diffusivity and g is the gravitational acceleration, $K'$ - the permeability of the porous medium, *Kr*-the chemical reaction rate constant.
The boundary conditions at the plate surface and for into the cold fluid may be written as

$$u(x,0)=v(x,0)=0, \qquad -\kappa\frac{\partial T}{\partial y}(x,0)=h[T-T_w(x,0)], \qquad C_w(x,0)=Ax^\lambda+C_\infty ,$$

$$u(x,\infty)=U_\infty, T(x,\infty)=T_\infty, C(x,\infty)=C_\infty ,$$

$$u(x,\infty)=U_\infty, T(x,\infty)=T_\infty, C(x,\infty)=C_\infty . \tag{5}$$

Where h is the plate heat transfer coefficient, L is the plate characteristic length, $C_w$ is the species concentration at the plate surface, $\lambda$ is the plate surface concentration exponent and $\kappa$ is the thermal conductivity coefficient. The stream function $\Psi$ , satisfies the continuity equation (1) automatically with

$$u=\frac{\partial\psi}{\partial y}, v=-\frac{\partial\psi}{\partial x}. \tag{6}$$

A similarity solution of Equations (1)-(6) is obtained by defying an independent variable $\eta$ and a dependent variable 'f 'in terms of the stream function $\Psi$ as

$$\eta = y\sqrt{\frac{U_\infty}{\upsilon x}}, \quad \psi = \sqrt{\upsilon x U_\infty}\, f(\eta). \tag{7}$$

The dimensionless temperature and concentration are given as

$$\theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, \qquad \phi(\eta) = \frac{C - C_\infty}{C_w - C_\infty} \tag{8}$$

Where $T_w$ is the temperature of the hot fluid at the left surface of the plate. Substituting the equations (6)-(8) in to Equations (1)-(5), we obtain

$$f''' + \frac{1}{2} ff'' - Ha(f' - 1) + Gr\,\theta + Gc\,\phi - Kf' = 0 \tag{9}$$

$$\theta'' + \frac{1}{2}\Pr f\theta' + \frac{1}{2}\Pr Du\phi'' + \frac{1}{2}\Pr Ecf''^2 = 0 \tag{10}$$

$$\phi'' + \frac{1}{2} Scf\phi' + \frac{1}{2} ScSr\theta'' - \kappa r^2 Sc\phi = 0 \tag{11}$$

$$f(0) = 0, f'(0) = 0, \theta'(0) = Bi\,[\theta(0) - 1], \phi(0) = 0 \tag{12}$$

$$f'(\infty) = 1, \theta(\infty) = \phi(\infty) = 0. \tag{13}$$

Where the prime symbol represents the derivative with respect to $\eta$ and

$Ha = \dfrac{\sigma B_0^2 x}{\rho U_\infty}$ (The Magnetic field parameter), $Gr = \dfrac{g\beta_T (T_w - T_\infty)x}{U_\infty{}^2}$ (The thermal Grashof number), $Gc = \dfrac{g\beta_c (C_w - C_\infty)x}{U_\infty^2}$ (The solutal Grashof number), $Du = \dfrac{D_m k_T (C_w - C_\infty)}{c_s c_p (T_w - T_\infty)}$ (The Dufour number), $Sr = \dfrac{D_m k_T (T_w - T_\infty)}{\nu T_m (C_w - C_\infty)}$ (The Soret number), $Ec = \dfrac{U_\infty^2}{c_p (T_w - T_\infty)}$ (The Eckert number), $Bi = \dfrac{h}{k}\sqrt{\dfrac{\upsilon x}{U_\infty}}$ (Convective heat transfer parameter), $\Pr = \dfrac{\upsilon}{\alpha}$ (The Prandtl number), $Sc = \dfrac{\upsilon}{D_m}$ (The Schmidt number), $kr^2 = \dfrac{\kappa r^2 2x}{U_\infty}$ (The chemical reaction rate constant), $K = \dfrac{2\upsilon x}{K' U_\infty}$ (the permeability parameter).

It is noteworthy that the local parameters $Bi$, $Ha$, $Gr$ and $Gc$ in Equations (9)-(13) are functions of x. However, in order to have a similarity solution all the parameters $Bi$, $Ha$, $Gr$, $Gc$, Du, Sr, Ec must be constant and we therefore assume

$$h = cx^{-\frac{1}{2}}, \sigma = ax^{-1}, \beta_T = bx^{-1} \text{ and } \beta_c = dx^{-1} \tag{14}$$

Where a, b, c, d are constants

Other physical quantities of interest in this problem such as the skin friction parameter $C_f = 2(\mathrm{Re})^{-\frac{1}{2}} f''(0)$, the plate surface temperature $\theta(0)$, Nusselt number $Nu = -(\mathrm{Re})^{\frac{1}{2}}\theta'(0)$ and the Sherwood number $Sh = -(\mathrm{Re})^{\frac{1}{2}}\phi'(0)$ (where $Re = \dfrac{Ut}{\nu}$ is the Reynolds number) can be easily computed. For local similarity case, integration over the entire plate is necessary to obtain the total skin friction, total heat and mass transfer rate.

## 2. SOLUTION OF THE PROBLEM

The set of coupled non-linear governing boundary layer equations (9)-(11) together with the boundary conditions (12&13) are solved numerically by using Runge-Kutta fourth order technique along with shooting method. First of all, higher order non-linear differential Equations (9)-(11) are converted into simultaneous linear differential equations of first order and they are further transformed into initial value problem by applying the shooting technique (Jain *et al.*[6]). The resultant initial value problem is solved by employing Runge-Kutta fourth order technique. The step size $\Delta\eta$=0.05 is used to obtain the numerical solution with decimal place accuracy as the criterion of convergence. From the process of numerical computation, the skin-friction coefficient, the Nusselt number and the Sherwood number, which are respectively proportional to $f''(0), -\theta'(0)$ and $-\phi'(0)$, are also sorted out and their numerical values are presented in a tabular form.

## 3. RESULTS AND DISCUSSION

The governing equations (9)-(11) subject to the boundary conditions (12)-(13) are integrated as described in section 3. Numerical results are reported in the tables 1-2. The prandtl numberwas taken to be Pr=0.72 which corresponds to air,the value of Schmidt number (Sc) were chosen to be Sc=0.24,0.62, 0.78,2.62, representing diffusing chemical species of most common interest in air like $H_2$ , $H_2O, NH_3$ and Propyl Benzene respectively. Attention is focused on positive value of the buoyancy parameters that is, Grashof number Gr>0(which corresponds to the cooling problem)and solutal Grashof number Gc>0(which indicates that the chemical species concentration in the free stream region is less then the concentration at the boundary surface).In order to benchmark our numerical results, we have compared the plate surface temperature $\theta(0)$ and the local heat transfer rate at the plate surface $\theta'(0)$ in the absence of both magnetic field and buoyancy forces for various values of *Bi* with those of Gnaneswar Reddy and Bhaskar Reddy []and found them in excellent agreement as demonstrated in table 1.From table 2, it is important to note that the local skin friction together with the local heat and mass transfer rate at the plate surface increases with increasing intensity of buoyancy forces (Gr,Gc),magnetic field (Ha) , convective heat change parameter (Bi), Eckert number (Ec), Dufour number (Du) and Soret number (Sr)..However, an increase in the Schmidt number (Sc), Permeability parameter (K) and chemical parameter ( $\kappa r$ ) causes a decrease in both skin friction and surface heat transfer rate and an increase in the surface mass transfer rate.

**Effects of parameter variation on velocity profiles**:

The effects of various parameters on velocity profiles in the boundary layer are depicted in Figures 1-9. It is observed from Figures 1-9, that the velocity starts from a zero value at the plate surface and increase to the free stream value far away from the plate surface satisfying the far field boundary condition for all parameter values.

In Figure 1 the effect of increasing the magnetic field strength on the momentum boundary layer thickness is illustrated. It is now a well established fact that the magnetic field presents a damping effect on the velocity field by creating drag force that opposes the fluid motion, causing the velocity to decease. However, in this case an increase in the *Ha* only slightly slows down the motion of the fluid away from the vertical plate surface towards the free stream velocity, while the fluid velocity near the vertical plate surface increases. Similar trend of slight increase in the fluid velocity near the vertical plate is observed with an increase in convective heat transfer parameter *Bi*. Figures 3,4,7,8 &9 shows the variation of the boundary-layer velocity with the buoyancy forces parameters (*Gr*, *Gc*), Eckert number (*Ec*) and Dufour number (*Du*). In both cases an upward acceleration of the fluid in the vicinity of the vertical wall is observed with increasing intensity of buoyancy forces.

Further downstream of the fluid motion decelerates to the free stream velocity. Figures 5 and 6 shows that a slight decrease in the fluid velocity with an increase in the Schmidt number (*Sc*), Permeability parameter (*K*) and Chemical parameter ( $\kappa r$ ).

**Effects of parameter variation on temperature profiles**:

Generally, the fluid temperature attains its maximum value at the plate surface and decreases exponentially to the free stream zero value away from the plate satisfying the boundary condition. This is observed in Figures 10-20. From these figures, it is interesting to note that the thermal boundary layer thickness decreases with an increase in the intensity of magnetic field (Ha), the buoyancy forces (Gr,Gc), permeability parameter (Pr) and Soret number (Sr). Moreover, the fluid temperature increases with an increase in the Schmidt number (Sc), the convective heat exchange at the plate surface (Bi), chemical parameter ( $\kappa r$ ), Eckert number (Ec), Permeability parameter (K) and Dufour number (Du) leading to an increase in thermal boundary layer thickness.

**Effects of parameter variation on concentration profiles**:

Figures 21-29 depict chemical species concentration profiles against span wise coordinate η for varying values physical parameters in the boundary layer. The species concentration is highest at the plate surface and decrease to zero far away from the plate satisfying the boundary condition. From these figures, it is noteworthy that the concentration boundary layer thickness decreases with an increase in the magnetic field intensity (Ha), the buoyancy forces (Gr,Gc), Schmidt number (Sc),Eckert number (Ec), Dufour number (Du), and chemical parameter ( $\kappa r$ )and Moreover, the fluid concentration increases with an increase in the Permeability parameter(K) and Soret number (Sr), leading to an increase in thermal boundary layer thickness.

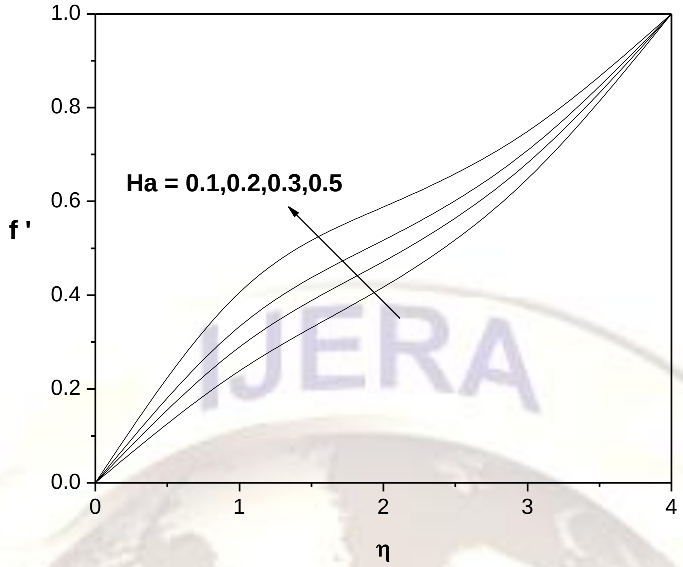


**Fig.1: Variation of the velocity component $f'$ with *Ha* for Pr=0.71, Sc=0.6, Gr=Gc=Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01,K=0.5.**

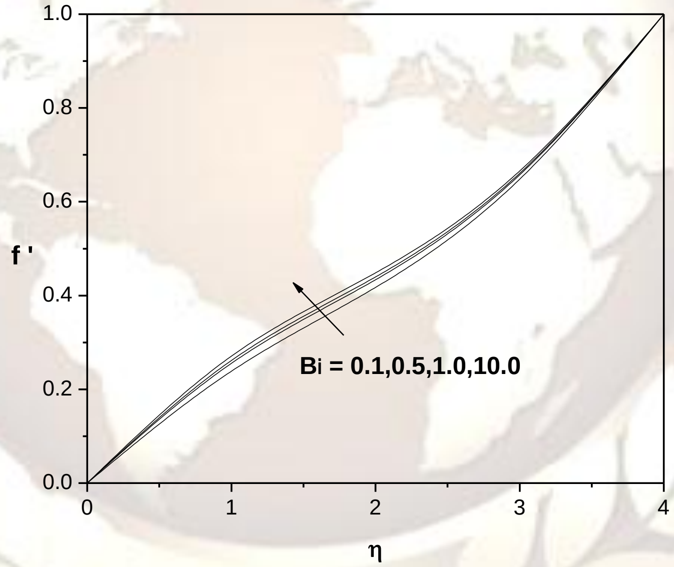


**Fig.2: Variation of the velocity component $f'$ with *Bi* for Pr=0.71, Sc=0.6, Gr=Gc =Ha=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01 K=0.5.**

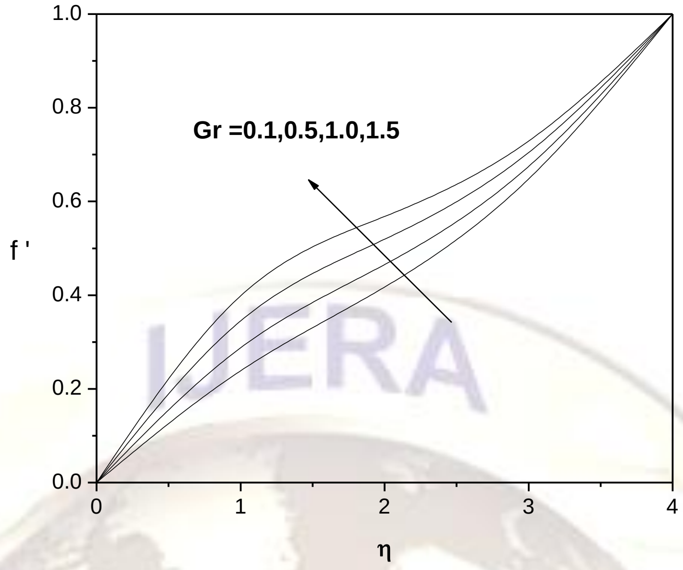


**Fig.3: Variation of the velocity component $f'$ with *Gr* for Pr=0.71, Sc=0.6, Gc =Ha=Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

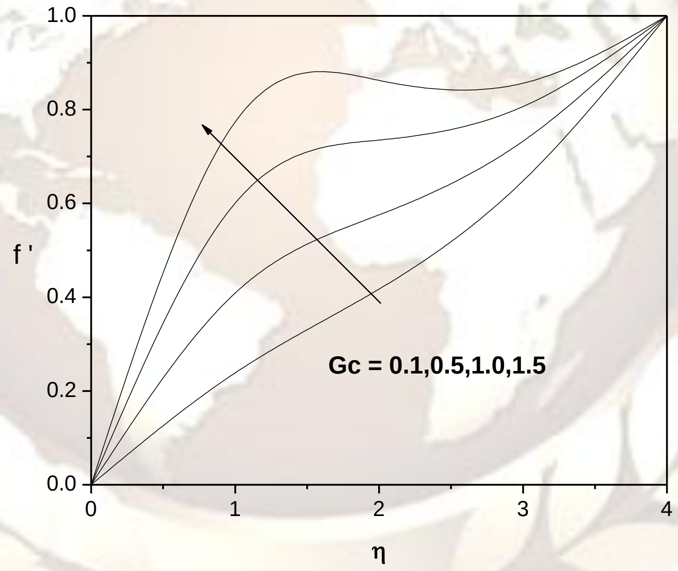


**Fig.4: Variation of the velocity component $f'$ with Gc for Pr=0.71, Sc=0.6, Gr=Ha=Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

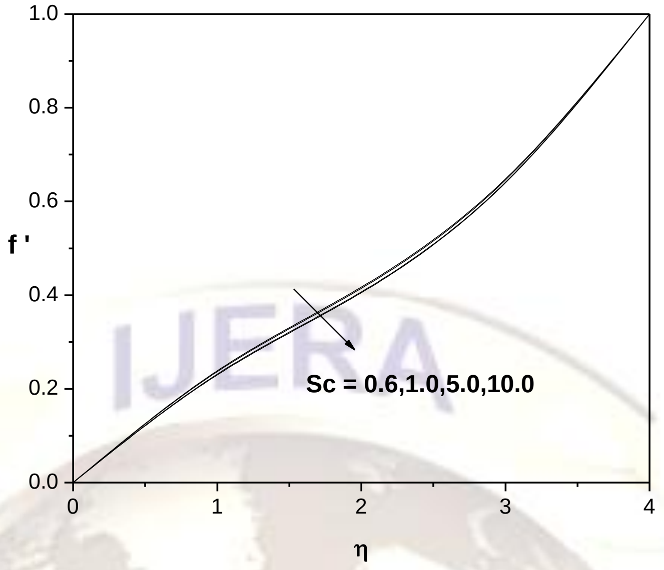


**Fig.5: Variation of the temperature with Sc for Pr=0.71,Gr=Gc=Ha=Bi=0.1,Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

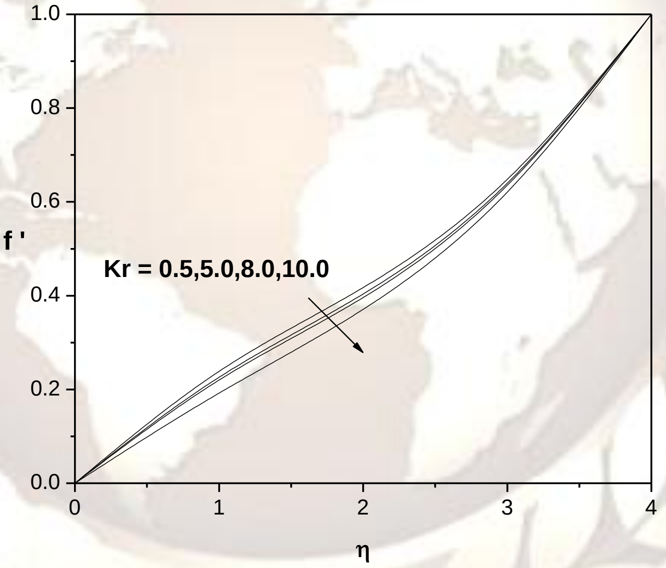


**Fig .6: Variation of the velocity component $f'$ with *Kr* for Pr=0.71 , Sc=0.6,Gr=Gc=Ha=Bi=0.1,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

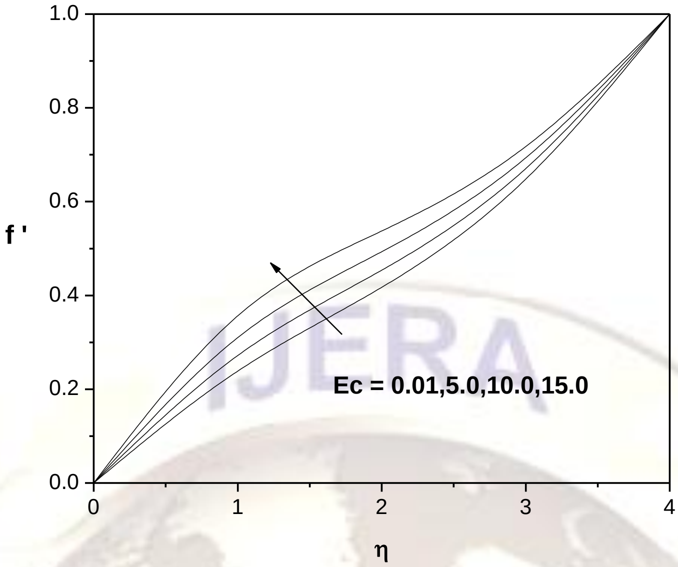


**Fig.7: Variation of the velocity component $f'$ with *Ec* for Pr=0.71, Sc=0.6,Gr=Gc =Ha=Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, K=0.5.**

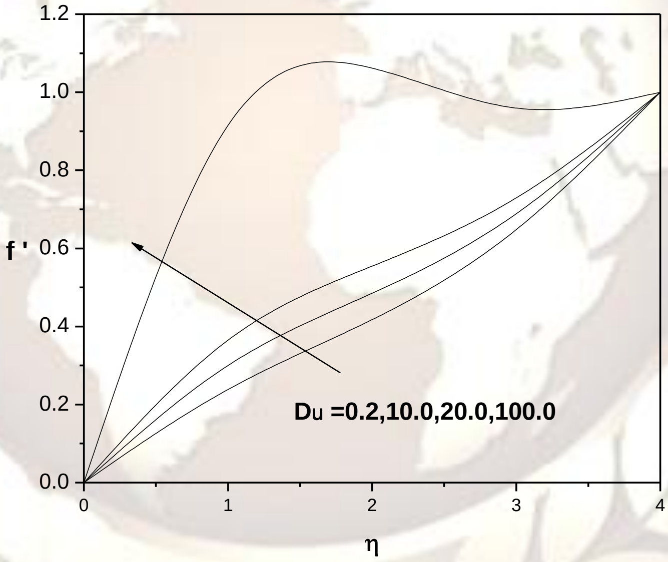


**Fig.8: Variation of the velocity component $f'$ with *Du* for Pr=0.71, Sc=0.6, Gr=Gc=Ha=Bi=0.1, Kr=0.5, Sr=1.0, Ec=0.01, K=0.5.**

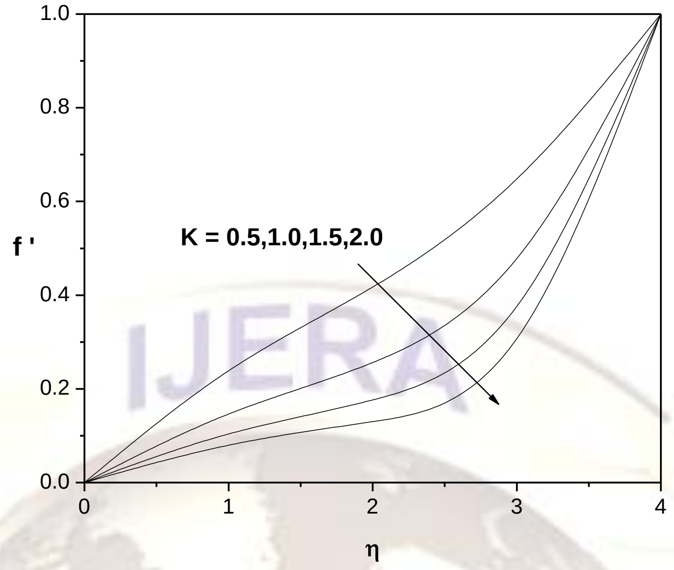


**Fig.9: Variation of the velocity component $f'$ with $K$ for Pr=0.71 , Sc=0.6,Gr=Gc=Ha=Bi=0.1,Kr=0.5,Du=0.2, Ec=0.01,Sr=1.0.**

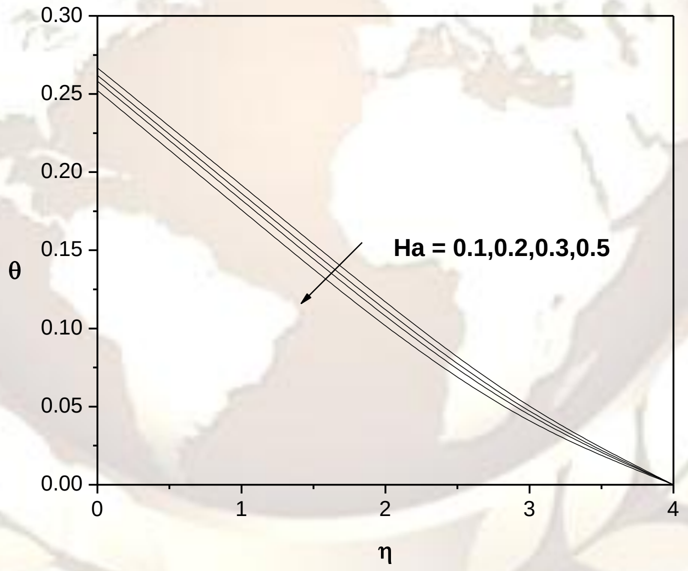


**Fig.10: Variation of the temperature θ with *Ha* for Pr=0.71, Sc=0.6, Gr=Bi=Gc=0.1, Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

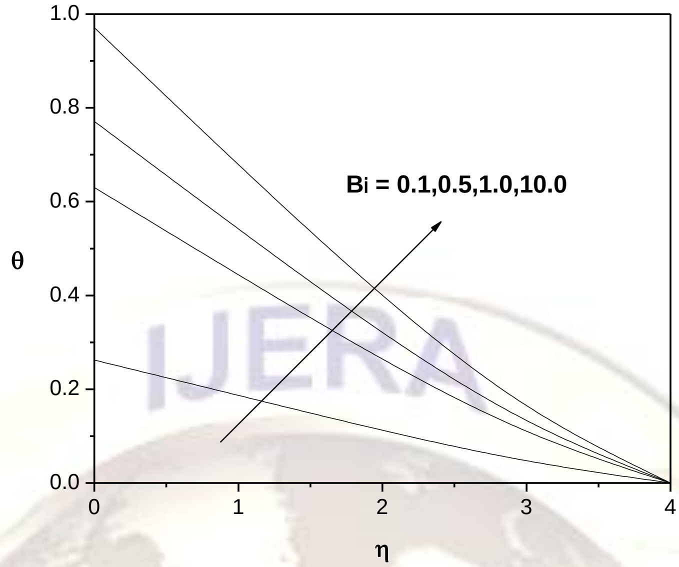


**Fig.11: Variation of the temperature θ with *Bi* for Pr=0.71, Sc=0.6, Gr=Gc=Ha=0.1, Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

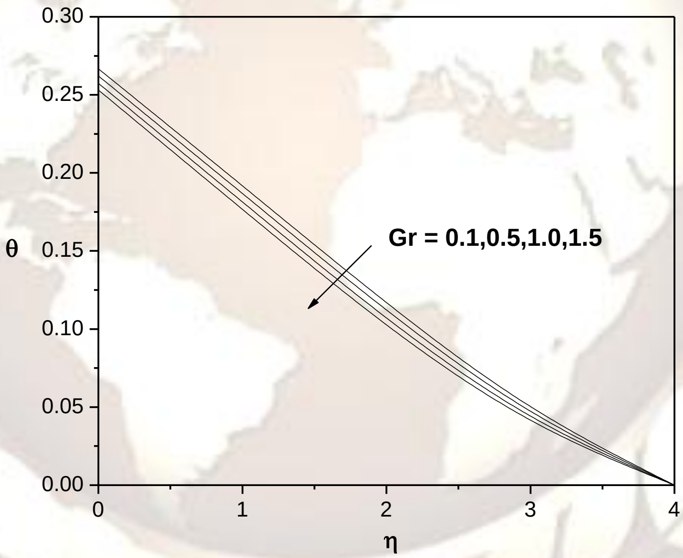


**Fig.12: Variation of the temperature θ with *Gr* for Pr=0.71, Sc=0.6, Gc=Bi=Ha=0.1, Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

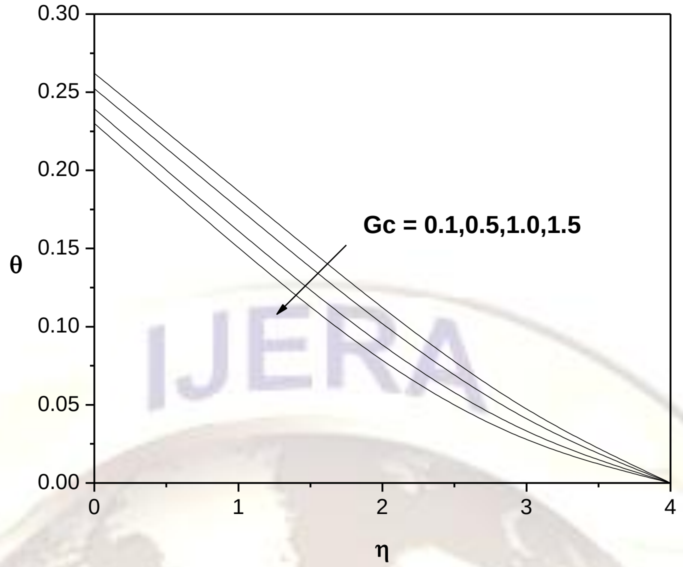


**Fig.13: Variation of the temperature θ with *Gc* for Pr=0.71, Sc=0.6, Gr=Bi=Ha=0.1, Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

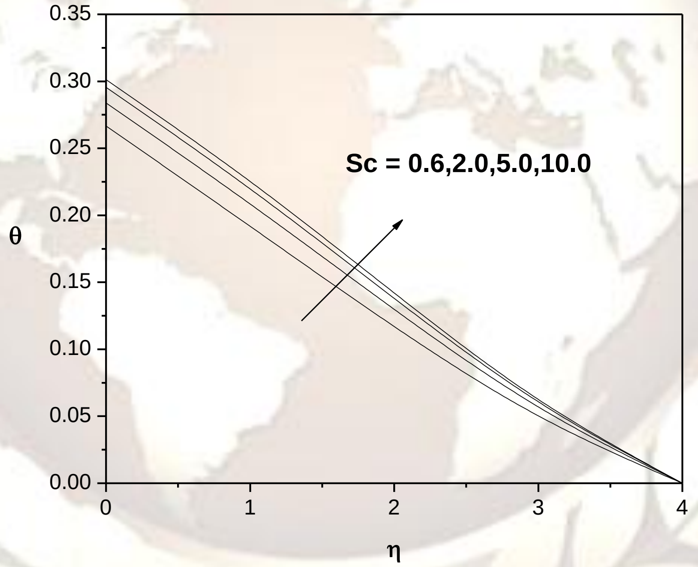


**Fig.14: Variation of the temperature θ with *Sc* for Pr=0.71, Gr=Bi=Gc=Ha=0.1, Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

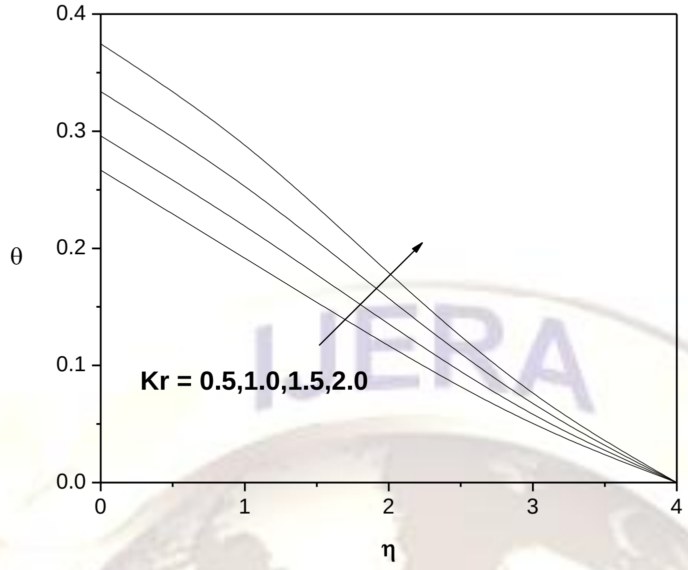


**Fig.15: Variation of the temperature θ with *Kr* for Pr=0.71, Sc=0.6, Gr=Bi=Ha=Bi=0.1, Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

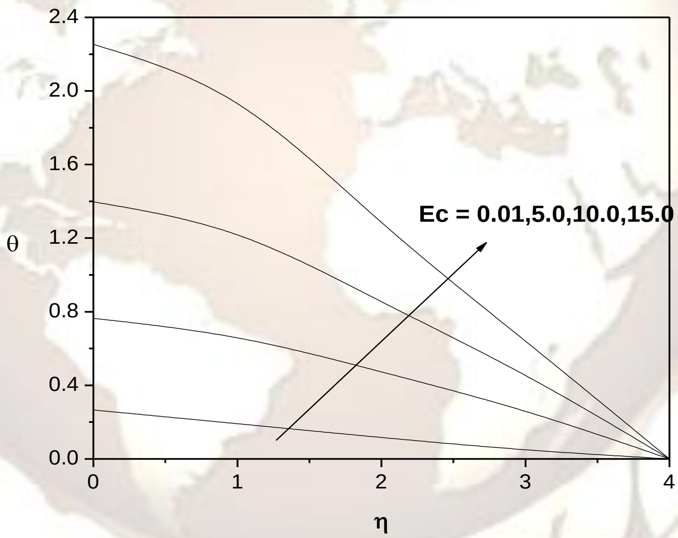


**Fig.16: Variation of the temperature θ with *Ec* for Pr=0.71, Sc=0.6,**

**Gr=Bi=Ha=Gc=0.1, Kr=0.5,Du=0.2,Sr=1.0, K=0.5.**

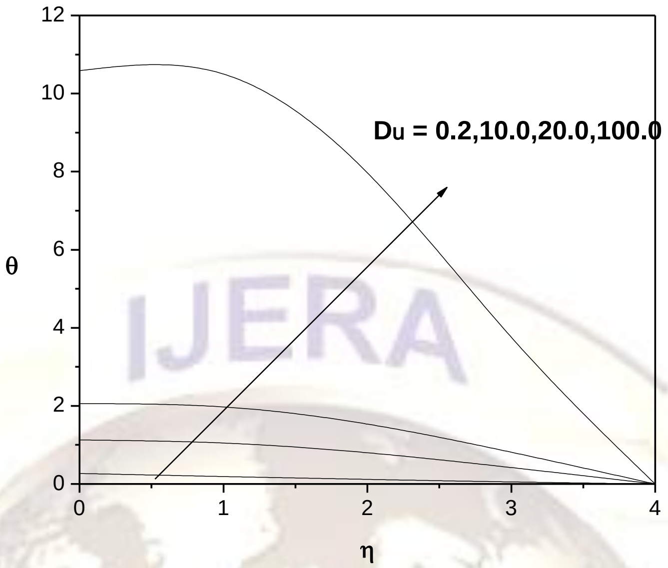


**Fig.17: Variation of the temperature θ with *Gc* for Pr=0.71, Sc=0.6, Gr=Bi=Ha=0.1, Kr=0.5, Sr=1.0, Ec=0.01, K=0.5.**

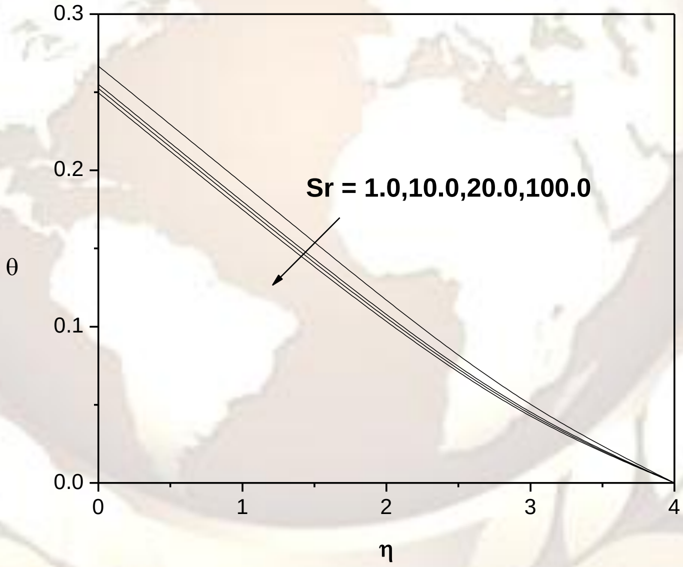


**Fig.18: Variation of the temperature θ with Sr for Pr=0.71, Sc=0.6, Gr=Bi=Gc =Ha=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

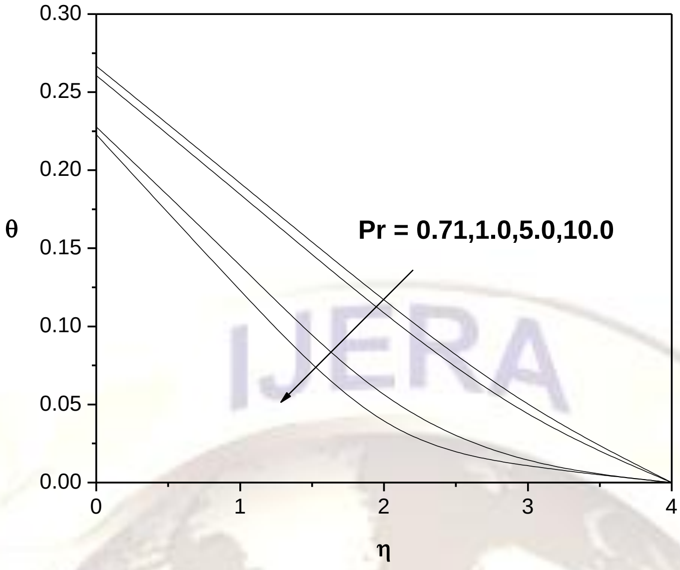


**Fig.19: Variation of the temperature θ with *Pr* for Sc=0.6, Gr=Bi=Ha=Gc =0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

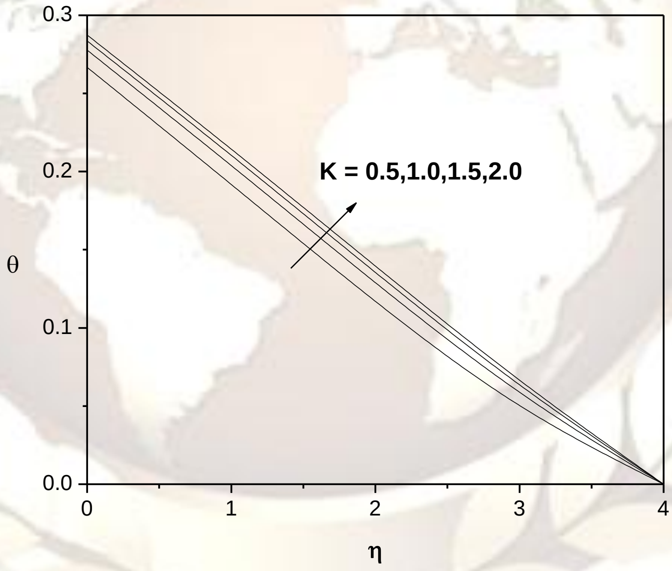


**Fig.20: Variation of the temperature θ with *K* for Sc=0.6,Pr=0.71, Gr=Bi=Ha=Gc =0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01.**

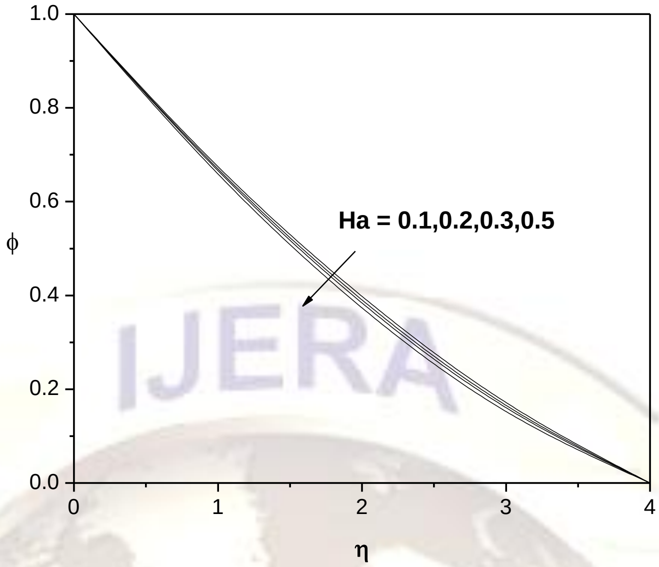


**Fig.21: Variation of the concentration $\phi$ with *Ha* for Pr=0.71 , Sc=0.6,Gr=Gc=Bi=0.1,Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01, K=0.5.**

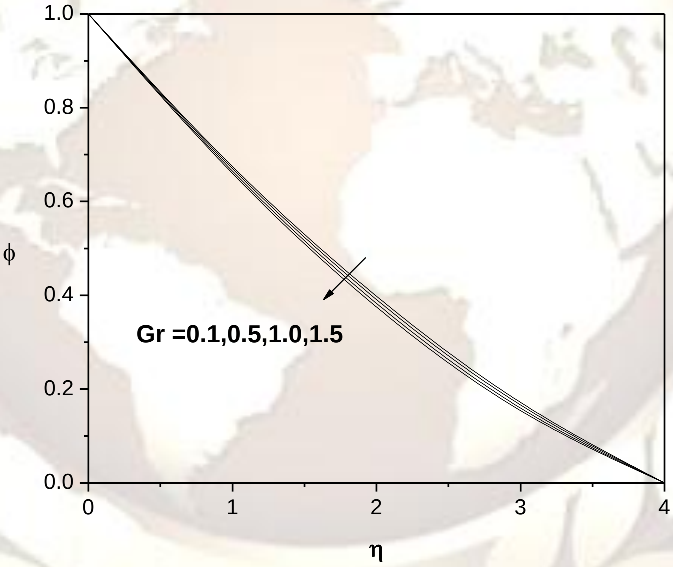


**Fig.22: Variation of the concentration $\phi$ with *Gr* for Pr=0.71, Sc=0.6, Ha=Gc =Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

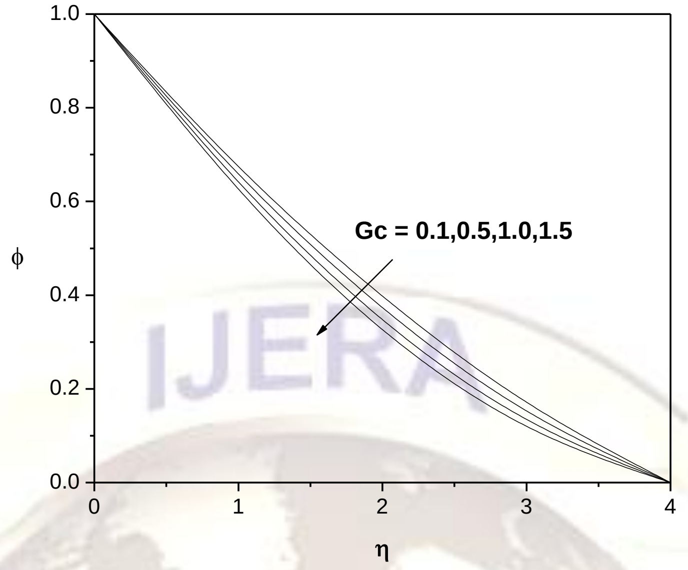


**Fig.23: Variation of the concentration $\phi$ with *Gc* for Pr=0.71, Sc=0.6, Gr=Ha=Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

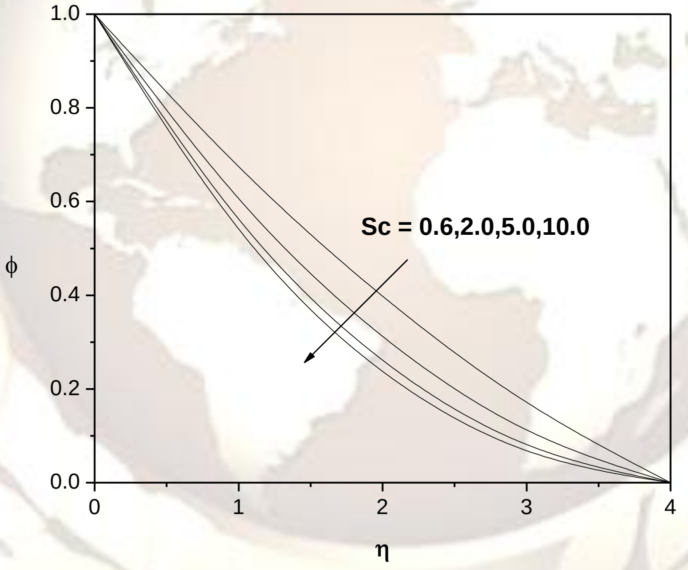


**Fig.24: Variation of the concentration $\phi$ with *Sc* for Pr=0.71, Gr=Gc =Ha=Bi=0.1, Kr=0.5, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

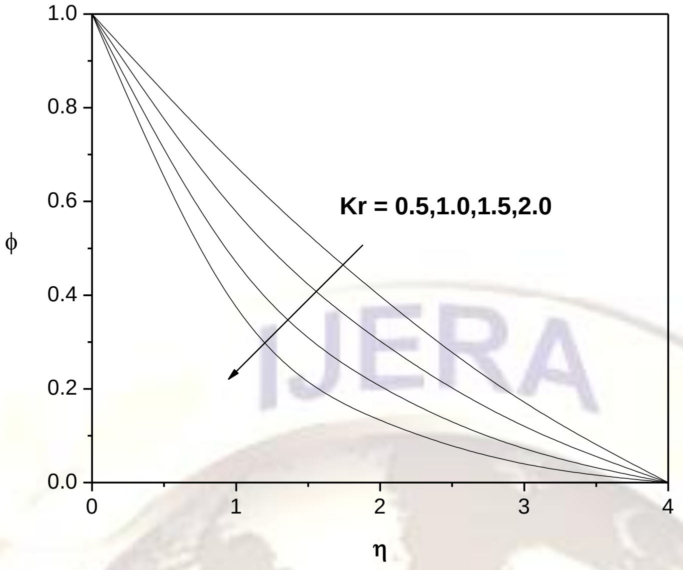


**Fig.25: Variation of the concentration $\phi$ with *Kr* for Pr=0.71, Sc=0.6, Gr=Gc =Bi=Ha=0.1, Du=0.2, Sr=1.0, Ec=0.01, K=0.5.**

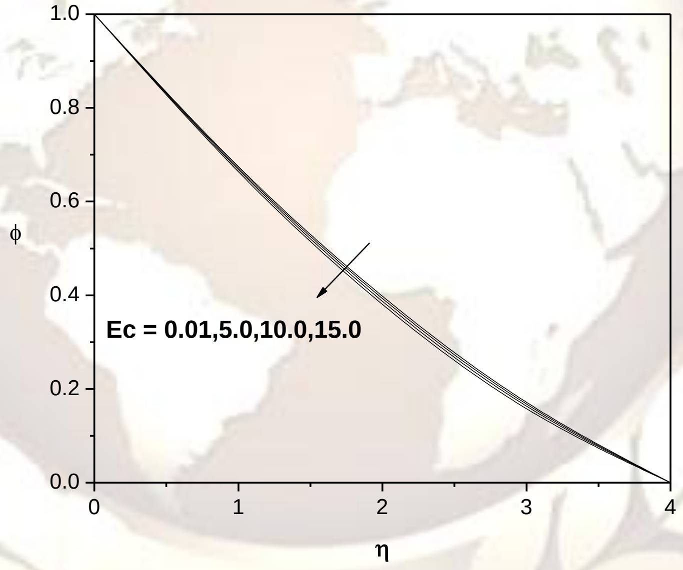


**Fig.26: Variation of the concentration $\phi$ with *Ec* for Pr=0.71, Sc=0.6, Gr=Gc=Bi=Ha=0.1, Kr=0.5, Du=0.2, Sr=1.0, K=0.5.**

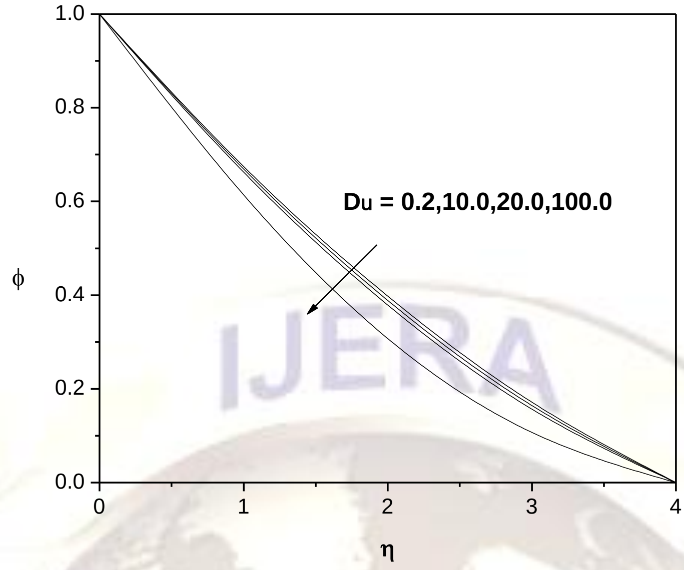


**Fig.27: Variation of the concentration $\phi$ with *Du* for Pr=0.71, Sc=0.6, Gr=Gc =Bi=Ha=0.1, Kr=0.5, Sr=1.0, Ec=0.01, K=0.5.**

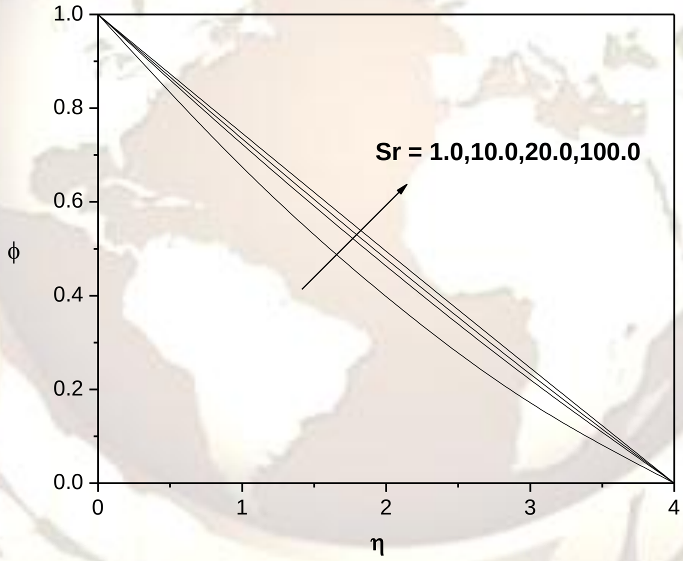


**Fig.28: Variation of the concentration $\phi$ with *Sr* for Pr=0.71, Sc=0.6, Gr=Gc =Bi=Ha=0.1, Kr=0.5, Du=0.2, Ec=0.01, K=0.5.**

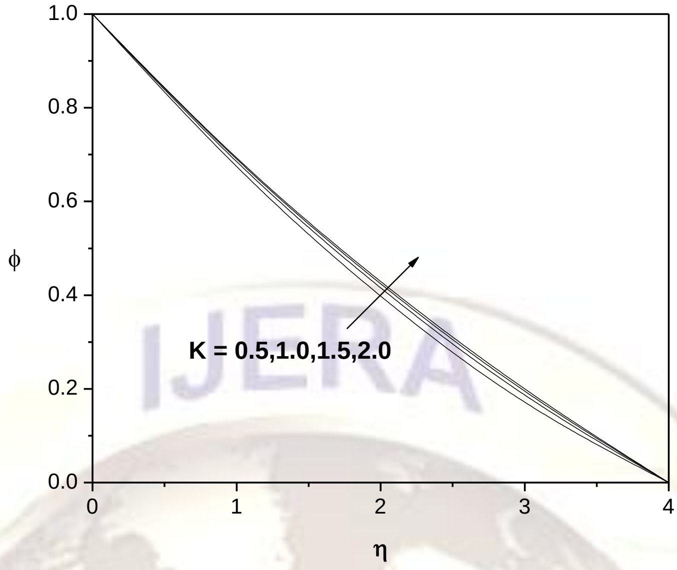


**Fig.29: Variation of the concentration $\phi$ with *Sr* for Pr=0.71, Sc=0.6, Gr=Gc =Bi=Ha=0.1, Kr=0.5, Du=0.2, Ec=0.01, Sr=1.0.**

**Table 1** Variation of $C_f$, *Nu*, *Sh* at the plate with $Bi$, $Ha$, $Gr$, $Gc$, Sc, *Sr*, $\kappa r$, *Du*, *Ec*, *K* for Pr=0.71

| *Bi* | *Gr* | *Gc* | *Ha* | *Sc* | *Sr* | $\kappa r$ | *Du* | Ec | *K* | $C_f$ | *Nu* | *Sh* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.638318 | 0.0733297 | 0.351852 |
| 1.0 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.723986 | 0.228733 | 0.354117 |
| 10 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.757636 | 0.291273 | 0.354999 |
| 0.1 | 0.5 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.818864 | 0.0737785 | 0.356671 |
| 0.1 | 1.0 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 1.03285 | 0.0742668 | 0.36224 |
| 0.1 | 0.1 | 0.5 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 1.28736 | 0.0747697 | 0.368389 |
| 0.1 | 0.1 | 1.0 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 2.05918 | 0.0760655 | 0.386606 |
| 0.1 | 0.1 | 0.1 | 0.4 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 1.12507 | 0.0745047 | 0.365044 |
| 0.1 | 0.1 | 0.1 | 0.6 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 1.26275 | 0.0747754 | 0.368397 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.7 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.637189 | 0.0731323 | 0.363117 |
| 0.1 | 0.1 | 0.1 | 0.1 | 2.6 | 1.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.627216 | 0.0712492 | 0.470637 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 2.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.640114 | 0.0736382 | 0.334249 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 3.0 | 0.5 | 0.2 | 0.01 | 0.5 | 0.641402 | 0.0738556 | 0.321843 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 1.0 | 0.2 | 0.01 | 0.5 | 0.627309 | 0.0703933 | 0.520561 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 1.5 | 0.2 | 0.01 | 0.5 | 0.616241 | 0.0666127 | 0.736631 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.4 | 0.01 | 0.5 | 0.642213 | 0.0716136 | 0.351973 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.6 | 0.01 | 0.5 | 0.646112 | 0.0698955 | 0.352095 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.02 | 0.5 | 0.638521 | 0.0732398 | 0.351858 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.04 | 0.5 | 0.638925 | 0.0730599 | 0.351871 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 1.0 | 0.443232 | 0.0722271 | 0.341281 |
| 0.1 | 0.1 | 0.1 | 0.1 | 0.6 | 1.0 | 0.5 | 0.2 | 0.01 | 1.5 | 0.352108 | 0.0716304 | 0.336089 |

**Table 2** computations showing comparison with Alam & Rahman(2006) results for Numerical values of the skin-friction coefficient $C_f$ , Nusselt number *Nu* and Sherwood number *Sh* for *Gr* □ □1.0,*Gc* □ □0.1 ,*Ha* □ □0.1 , *Kr* □ □ 0.5,*Bi* □ □ 0.5,Sc=0.22,Pr=0.71,Ec=0.01, K=0.25.

| Du | Sr | Alam & Rahman(2006) | | | Present work | | |
|---|---|---|---|---|---|---|---|
| | | $C_f$ | *Nu* | *Sh* | $C_f$ | *Nu* | *Sh* |
| 0.030 | 2.0 | 1.6795 | 0.5310 | 0.1292 | 1.83703 | 0.209131 | 0.307543 |
| 0.037 | 1.6 | 1.6758 | 0.5299 | 0.1605 | 1.83723 | 0.209041 | 0.309597 |
| 0.050 | 1.2 | 1.6724 | 0.5285 | 0.1921 | 1.83786 | 0.20888 | 0.311808 |
| 0.060 | 1.0 | 1.6712 | 0.5275 | 0.2077 | 1.83844 | 0.208757 | 0.31298 |
| 0.075 | 0.8 | 1.6707 | 0.5263 | 0.2233 | 1.83941 | 0.208574 | 0.314208 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0.120 | 0.5 | 1.6723 | 0.5230 | 0.2470 | 1.8426 | 0.208029 | 0.316157 |
| 0.600 | 0.1 | 1.7218 | 0.4908 | 0.2817 | 1.8799 | 0.202223 | 0.3195 |

## CONCLUSIONS:

This paper studied hydromagnetic mixed convection heat and mass transfer over a vertical plate subjected to convective heat exchange with the surrounding in the presence of magnetic field and chemical reaction. The governing equations are approximated to a system of non-linear ordinary differential equations by similarity transformation. Numerical calculations are carried out for various values of the dimensionless parameters of the problem. A comparison with previously published work is performed and excellent agreement between the results is obtained. The results are presented graphically and the conclusions are drawn that the flow field and other quantities of physical interest are significantly influenced by these parameters. The results for the prescribed skin friction, local heat and mass transfer rate at the plate surface are presented and discussed. It was found that the local skin-friction coefficient, local heat and mass transfer rate at the plate surface increases with an increase in intensity of magnetic field, buoyancy forces, convective heat exchange parameter, Soret number, Eckert number, Dufour number and chemical parameter.

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