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EFFECTS OF SORET AND MAGNETIC FIELD ON UNSTEADY FLOW OF A RADIATING AND CHEMICAL REACTING FLUID: A FINITE DIFFERENCE APPROACH

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ABSTRACT

The present study deals with the effects of magnetic field and Soret number variation on unsteady laminar boundary layer flow of a radiating and chemically reacting incompressible viscous fluid along a semi-infinite vertical plate. The governing boundary layer equations are solved numerically, using Crank-Nicholson method. The Roseland approximation is used to describe the radiative heat flux in the energy equation. Computations are performed for wide range of the governing flow parameters, viz. the thermal Grash of number, Solutal Grash of number, Magnetic parameter, Soret number, Prandtl number and thermal radiation parameter. The variations of these different flow parameters on velocity, temperature and concentration fields are discussed graphically. Also, the results of skin friction coefficient, Nusselt number and Shear wood number for various flow parameters are discussed. From this study, it is found that, an increase in the soret number leads to an increase in the velocity, concentration of the fluid.

KEYWORDS: Thermal Diffusion (Soret), Magnetic Field, Chemical Reaction, Crank, Nicholson Method, Radiative Heat Flux

INTRODUCTION

There has been renewed interest in studying MHD flow and heat transfer in porous media due to the effect of magnetic field on the boundary layer flow control and on the performance of many systems using electrically conducting fluids. In addition, this type of flow finds applications in many engineering problems such as MHD generators, plasma studies, nuclear reactions and geo thermal energy extractions. Several authors have dealt with flow and mass transfer over a vertical porous plate with variable suction, heat absorption/ generation, radiation and chemical reaction. Actually, many processes in engineering areas occur at high temperature and knowledge of radiation heat transfer becomes very important for the design of the pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for air craft, missiles, satellites and space vehicles are examples of such engineering areas.

Perdikis *et al* [3] illustrated the heat transfer of a micro polar fluid in the presence of radiation. Takhar, *et al* [2] considered the effects of Radiation on Free-convection flow of a radiation gas past a semi infinite vertical plate in the presence of magnetic field. Raptis [6] studied the effect of radiation on the flow of a micro-polar fluid past a continuous moving plate. Elbashbeshby [7] and kim *et al* [8] have reported on the radiation effects on the mixed convection flow of micro-polar fluid. Chamkha *et al* [9] analyzed the radiation effects on free convection flow past a semi infinite vertical plate with mass transfer. Ganesan and Loganathan [10] studied radiation and Mass transfer effects on a flow of an incompressible viscous fluid past a moving cylinder. Ramachandra Prasad *et al* [15] considered the effects Radiation and Mass transfer on two dimensional flow past an infinite vertical plate. Kandasamy *et al* [11] studied the non linear MHD flow with heat and mass transfer characteristics of an incompressible viscous, electrically conducting fluid on a vertical stretching surface with chemical reaction and thermal stratification effects. They also reported a numerical solution for the steady laminar boundary layer flow over a wall of the wedge with suction or injection in the presence of species concentration and mass diffusion [12]. Prakash and Ogulu [14] have studied the effect of thermal radiation, time-dependent suction and chemical reaction on the two-dimensional flow of an incompressible Boussinesq fluid. Chaudhary and Preethi Jain [16] studied the effect of radiation on mixed convection flow of a magneto-micro polar fluid past a vertical porous plate through a porous medium with variable permeability in slip-flow regime. Ibrahim *et al* [17] studied the effect of the chemical reaction and radiation absorption on transient hydro-magnetic natural convention flow with wall transpiration and heat source.

In the above all stated studies thermal diffusion effect (commonly known as Soret effect) has been neglected. Eckert *et al* [1] have pointed out this, thermal diffusion effect, when utilized for is otrope separation in mixtures between gases with very light molecular weight (like hydrozen, helium) and medium molecular weight (like nitrogen, air) the thermal diffusion effect was found to be of magnitude which can't be neglected. Also when the radiative heat transfer takes place the fluid involved can be electrically conducting in the sense that it is ionized owing to high operating temperature. Accordingly it is of interest to examine the effect of magnetic field on the flow.

Hence based on the above discussion the **object of the present paper** is to study the effects of **Magnetic field** and **Soret number** variation on unsteady laminar boundary layer flow of a viscous incompressible electrically conducting fluid along semi infinite vertical plate, in the presence of thermal and concentration boundary effects. According to the **Non-linearity** which appears in the momentum equation due to temperature and mass coupling with the energy and mass equations. So the governing equations (dimensionless form) with the corresponding boundary conditions are solved numerically using Crank-Nicolson method, which is more economical from computational view point.

MATHEMATICAL FORMULATION

An unsteady two-dimensional, laminar, boundary layer flow of a viscous, incompressible, electrically conducting fluid along a semi-infinite vertical plate, in the presence of thermal and concentration buoyancy effects has been considered. The x'-axis taken along the plate in the vertically upward direction and y'-axis normal to it. A magnetic field of uniform strength applied along y'-axis. Further, due to the semi-infinite plane surface assumption, the flow variables are functions of normal distance y' and t' only. A time dependent suction velocity is assumed normal to the plate. Now, under the usual Boussinesq's approximation, the governing boundary layer equations are:

Continuity

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

Momentum

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

Energy

$$\frac{\partial T}{\partial t'}+v'\frac{\partial T}{\partial y}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y'^2}-\frac{1}{\rho c_p}\frac{\partial q_r}{\partial y'} \tag{3}$$

Mass Transfer

$$\frac{\partial C}{\partial t'}+v'\frac{\partial C}{\partial y}=\upsilon\frac{\partial^2 C}{\partial y'^2}+\frac{D_m k_T}{T_m}\frac{\partial^2 T}{\partial y'^2}-k_r^2 C \tag{4}$$

The radiative flux q_r by using the Roseland approximation [3-5, 13], is given by

$$q_r=-\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y'} \tag{5}$$

The boundary conditions suggested by the physics of the problem are

$$u'=U_0,\ T=T_W+\varepsilon(T_W-T_\infty)e^{n't'},\ C=C_W+\varepsilon(C_W-C_\infty)e^{n't'}\quad at\ \ y'=0$$

$$u'\to 0,\quad T\to T_\infty,\quad C\to C_\infty\qquad as\ \ y'\to\infty \tag{6}$$

It has been assumed that the temperature differences within the flow are sufficiently small and T^4 may be expressed as a linear function of the temperature T. This is accomplished by expanding T^4 in a Taylor series about T_∞ and neglecting higher order terms, we have

$$T^4\approx 4T_\infty^3 T-3T_\infty^4 \tag{7}$$

Using Eqs (5) and (7), Eq. (3) gives

$$\frac{\partial T}{\partial t'}+v'\frac{\partial T}{\partial y'}=\frac{k}{\rho c_p}\frac{\partial^2 T}{\partial y'^2}-\frac{16\sigma^* T_\infty^3}{3\rho c_p k^*}\frac{\partial^2 T}{\partial y'^2} \tag{8}$$

Integration of continuity Eq (1) for variable suction velocity normal to the plate gives

$$v'=-U_0\left(1+\varepsilon Ae^{n't'}\right) \tag{9}$$

Where A is the suction parameter and εA is less than unity. Here U_0 is mean suction velocity, which is a non-zero positive constant and the minus sign indicates that the suction is towards the plate. It is now convenient to introduce the following dimensionless parameters:

$$u=\frac{u'}{U_0},\quad t=\frac{U_0^2 t'}{\upsilon},\quad n=\frac{\upsilon n'}{U_0^2},\quad y=\frac{y^* U_0}{\upsilon}$$

$$\theta = \frac{T - T_\infty}{T_w - T_\infty}, \quad \phi = \frac{C - C_\infty}{C_w - C_\infty}, \quad S_0 = \frac{D_m k_T (T_w - T_\infty)}{\upsilon T_m (C_w - C_\infty)}$$

$$Gr = \frac{g\beta \upsilon (T_w - T_\infty)}{U_0^3}, \; Gm = \frac{g\beta^* \upsilon (C_w - C_\infty)}{U_0^3}, \; M = \frac{\sigma B_0^2 \upsilon}{\rho U_0^2} \tag{10}$$

$$k_r^2 = \frac{k_r^{'2} \upsilon}{U_0^2}, \quad N_R = \frac{16\sigma^* T_\infty^3}{3k^* k}, \quad \Pr = \frac{\mu C_p}{k}, \quad Sc = \frac{\upsilon}{D}$$

In view of Eqs. (5), (7), (8), (9) and (10), the governing Eqs (1)-(4) reduce to the following dimensionless form:

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial u}{\partial y} = \frac{\partial^2 u}{\partial y^2} + Gr\theta + Gm\phi - Mu \tag{11}$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial \theta}{\partial y} = \left(\frac{1 + N_R}{Pr}\right)\frac{\partial^2 \theta}{\partial y^2} \tag{12}$$

$$\frac{\partial \phi}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)\frac{\partial \phi}{\partial y} = \frac{1}{Sc}\frac{\partial^2 \phi}{\partial y^2} + S_0 \frac{\partial^2 \theta}{\partial y^2} - k_r^2 \phi \tag{13}$$

With the boundary conditions

$$u = 1, \quad \theta = 1 + \varepsilon e^{nt}, \quad \phi = 1 + \varepsilon e^{nt} \quad \text{at } y = 0$$

$$u \to 0, \quad \theta \to 0, \quad \phi \to 0 \quad \text{as } y \to \infty \tag{14}$$

To convert the condition (14) $y \to \infty$ to $\eta \to 1$, changing the independent variable y to η by using the transformation, $\eta = 1 - e^{-y}$ in the equations (10), (11), (12) and (13), we get

$$\frac{\partial u}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)(1 - \eta)\frac{\partial u}{\partial \eta} = \left((1 - \eta)^2 \frac{\partial^2 u}{\partial \eta^2} - (1 - \eta)\frac{\partial u}{\partial \eta}\right) + Gr\theta + Gm\phi - Mu \tag{15}$$

$$\frac{\partial \theta}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)(1 - \eta)\frac{\partial \theta}{\partial \eta} = \frac{1 + N_R}{Pr}\left((1 - \eta)^2 \frac{\partial^2 \theta}{\partial \eta^2} - (1 - \eta)\frac{\partial \theta}{\partial \eta}\right) \tag{16}$$

$$\frac{\partial \phi}{\partial t} - \left(1 + \varepsilon A e^{nt}\right)(1 - \eta)\frac{\partial \phi}{\partial \eta} = \frac{1}{Sc}\left((1 - \eta)^2 \frac{\partial^2 \phi}{\partial \eta^2} - (1 - \eta)\frac{\partial \phi}{\partial \eta}\right) + S_0\left((1 - \eta)^2 \frac{\partial^2 \theta}{\partial \eta^2} - (1 - \eta)\frac{\partial \theta}{\partial \eta}\right) - k_r^2 \phi \tag{17}$$

With boundary conditions

$$\begin{aligned} &u = 1: \quad \theta = 1 + \varepsilon e^{nt}, \quad \phi = 1 + \varepsilon e^{nt} \quad at \quad \eta = 0 \\ &u \to 0: \; \theta \to 0, \qquad \theta \to 1 + \varepsilon e^{nt} \quad as \quad \eta \to 1 \end{aligned} \tag{18}$$

METHOD OF SOLUTION

By applying **Crank-Nicholson method** on governing Eqs (15) to (17), following system of equations are obtained:

$$-P_3\, r\, u_{i-1}^{j+1} + (1+2P_3\, r)u_i^{j+1} - P_3\, r\, u_{i+1}^{j+1} = E_i^j \tag{19}$$

$$-P_3P_4\, r\, \theta_{i-1}^{j+1} + (1+2P_3P_4\, r)\theta_i^{j+1} - P_3P_4\, r\, \theta_{i+1}^{j+1} = F_i^j \tag{20}$$

$$-\frac{P_3 r}{Sc}\phi_{i-1}^{j+1} + \left(1+\frac{2P_3 r}{Sc}\right)\phi_i^{j+1} - \frac{P_3 r}{Sc}\phi_{i+1}^{j+1} = H_i^j \tag{21}$$

Where

$$E_i^j = P_3 r\, u_{i-1}^j - (1-P_1P_2\, rh - 2P_3 r + P_2 rh - M\, k)u_i^j + (P_1\, P_2 rh + P_3 r - P_2 rh)u_{i+1}^j + Gr\, k\theta_i^j + Gm\, k\phi_i^j$$

$$F_i^j = P_3P_4 r\, \theta_{i-1}^j + (1-P_1P_2 rh - 2P_3P_4 r + P_2P_4 rh)\theta_i^j + (P_1P_2 rh + P_3P_4 r - P_2P_4 rh)\theta_{i+1}^j$$

$$H_i^j = \frac{P_3 r}{Sc}\phi_{i-1}^j + \left(1+P_1P_2\, rh - \frac{2P_3 r}{Sc} + \frac{P_2 rh}{Sc} - k_r^2 k\right)\phi_i^j + \left(\frac{P_3 r}{Sc} - P_1\, P_2 rh - \frac{P_2 rh}{Sc}\right)\phi_{i+1}^j + (2P_3 rS_0 - S_0P_1 rh)\theta_{i+1}^j + (S_0P_1 rh - 4P_3 rS_0)\theta_i^j + 2P_3 rS_0\theta_{i-1}^j$$

$$P_1 = 1+\in Ae^{nt},\ P_2 = 1-i\,h,\ P_3 = \frac{(1-i\,h)^2}{2},\ P_4 = \frac{1+N_R}{\Pr}$$

Here r = k/h^2 and h, k are mesh sizes along η and time direction respectively. Index i refers to space and j for time. Numerical solutions for the above equations are obtained by using Thomas Algorithm. In order to prove the convergence of finite difference scheme, the computation is carried out for slightly changed values of h and k, running same C-Program. Negligible change is observed in the values of u, θ and ϕ and also after each cycle of iteration the convergence checking is performed, i.e. $\left|u^{n+1}-u^n\right| < 10^{-8}$ is satisfied at all points. Thus, it is concluded that, the finite difference scheme is convergent and stable.

Skin-Friction

The Skin friction coefficient τ is given by

$$\tau = \left.\frac{\partial u}{\partial y}\right|_{y=0} = (1-\eta)\left.\frac{\partial u}{\partial \eta}\right|_{\eta=0} \tag{22}$$

Nusselt Number

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

$$Nu = \left.\frac{\partial \theta}{\partial y}\right|_{y=0} = (1-\eta)\left.\frac{\partial \theta}{\partial \eta}\right|_{y=0} \tag{23}$$

Sherwood Number

The coefficient of Mass transfer which is generally known as Sherwood

number, Sh, is given by

$$Sh = \left.\frac{\partial \phi}{\partial y}\right|_{y=0} = (1-\eta)\left.\frac{\partial \phi}{\partial \eta}\right|_{\eta=0} \tag{24}$$

RESULTS AND DISCUSSIONS

In the present work, the numerical solutions have been conducted to investigate the influence of the Soret number, thermal radiation parameter, chemical reaction parameter, thermal Grash of number, Solutal Grash of number, Magnetic Parameter and Prandtl number on the development of the velocity, temperature and concentration profiles as well as the skin-friction coefficient, Nusselt number and Sherwood number.

Figure (1) depicts the effect of magnet field on velocity field u. It is observed that the velocity decreases as the value of M increases. This result qualitatively agrees with the expectations, since the magnet field exerts a retarding force on the free convection flow.

The influence of the Soret number S_0 on velocity and concentration profiles are plotted in **figures (2) & (4)** respectively. The Soret number S_0 defines the effect of the temperature gradients inducing significant mass diffusion effects. From the graphs, it is found that an increase in the Soret number S_0 results in an increase in the velocity and concentrations of the fluid.

The influence of the thermal Grash of number Gr and Solutal Grash of number **Gm**, on velocity field **u** is presented in **figure 3**. As expected, it is observed that there is rise in the velocity due to the enhancement of thermal buoyancy force. The Solutal Grash of number **Gm** defines the ratio of the species buoyancy force to the viscous hydrodynamic force. As expected, the fluid velocity increases and peak value is more distinctive due to increase in the species buoyancy force.

Figure 5 illustrates the behavior of concentration of the fluid for various values of chemical reaction parameter **Kr**. It is observed that an increase in the value of **Kr** leads to decrease in the concentration of the fluid. A distinct velocity escalation occurs near the wall after which profiles decay smoothly to the stationary value in free stream. Chemical reaction, therefore boosts momentum transfer i.e. accelerates the flow.

Figure 6 illustrate the temperature profile for various values of the prandtl number $\Pr$ and radiation parameter N_R. The Prandtl number defines the ratio of momentum diffusivity to thermal diffusivity. It is observed that an increase in the prandtl number results a decrease of the thermal boundary layer.]

The reason is that smaller values of $\Pr$ are equivalent to increasing the thermal conductivities, and therefore heat is able to diffuse away from the heated plate more rapidly than for higher values of $\Pr$. Hence in the case of smaller Prandtl numbers as the boundary layer is thicker and the rate of heat transfer is reduced. Also, it is observed that an increase in the thermal radiation parameter, increases the thermal boundary layer.

Tables (1), (2) and (3) show the numerical values of the Skin-friction, Nusselt number and Sherwood number. From the tables, it is concluded that

- Skin –friction increases, as the values of S_0 and N_R increase but it decreases in the presence of Magnetic field.
- An increase in the S_0 leads to increase in the Sherwood number but an increase in Sc, it decreases.
- Nusselt number increases in the presence of thermal radiation while it decreases as the value of Pr increases.

CONCLUSIONS

Numerical investigations for **Soret effect** on unsteady laminar boundary layer flow of a radiating and chemically reacting incompressible viscous fluid along a semi-infinite vertical plate, in the presence of magnetic field are studied. Graphical results for the velocity profiles, temperature profiles, species concentration profiles and the tabular values of Skin-friction, Nusselt number and Sherwood number are presented and discussed for various parametric conditions. From this study the following conclusions have been drawn.

- There is rise in the velocity due to the enhancement of thermal buoyancy force and the species buoyancy force.
- Chemical reaction boosts the momentum transfer i.e. accelerates the fluid flow.
- The velocity and concentration of the fluid increased with the increase of Soret number.
- Magnetic field reduces the velocity field. Temperature of the fluid increases with the increase of thermal radiation parameter.
- Skin-friction and Sherwood number increased with the increase of Soret number.

Table 1

Nomenclature		
ρ	-	Density
C_p	-	Specific heat at constant pressure
ν	-	Kinematic viscosity
k	-	Thermal conductivity
U	-	Mean velocity
Sc	-	Schmidt number
T	-	Temperature
k_r^2	-	Chemical reaction rate constant
ϵ	-	Small reference parameter << 1
Pr	-	Prandtl number
Gr	-	Free convection parameter due to temperature
Gm	-	Free convection parameter due to concentration
S_0	-	Soret number
A	-	Suction parameter
n	-	A constant exponential index

Table 1: Contd.,

D	-	Molar diffusivity
N_R	-	Thermal radiation parameter
β	-	Coefficient of volumetric thermal expansion of the fluid
β^* M σ D_m K_T T_m	-	Volumetric coefficient of expansion with concentration Magnetic parameter Electrical conductivity Mass diffusion coefficient Thermal diffusion ratio Mean fluid temperature

Table 2: Effects of Gr, Gm, Pr, Sc, Kr, NR, So and M on Skin-Friction Coefficient

Gr	Gm	Pr	Sc	Kr	N_R	So	M	τ
5.0	5.0	0.71	0.24	0.5	0.5	0.0	0.0	1.202
5.0	5.0	0.71	0.24	0.5	0.5	0.0	2.0	0.557
5.0	5.0	0.71	0.24	0.5	0.5	2.0	2.0	0.8394
5.0	5.0	0.71	0.24	0.5	1.0	2.0	2.0	0.9183
5.0	5.0	0.71	0.6	0.5	0.5	2.0	2.0	0.7601
5.0	5.0	7.0	0.24	0.5	0.5	2.0	2.0	0.3156
5.0	10.0	0.71	0.24	0.5	0.5	2.0	2.0	2.6542
10.0	5.0	0.71	0.24	0.5	0.5	2.0	2.0	2.0447

Table 3: Effects of N_R and Pr on Nusselt Number

N_R	Pr	Nu
0.0	0.71	-1.4771
0.5	0.71	- 1.1621
0.5	7.0	- 4.2655
0.5	11.4	-5.3251

Table 4: Effects of Sc, Kr and So on Sherwood Number

Sc	Kr	So	Sh
0.24	0.5	0.0	-0.5931
0.24	0.5	2.0	-0.1156
0.24	1.0	2.0	-0.1858
0.6	0.5	2.0	-0.00291

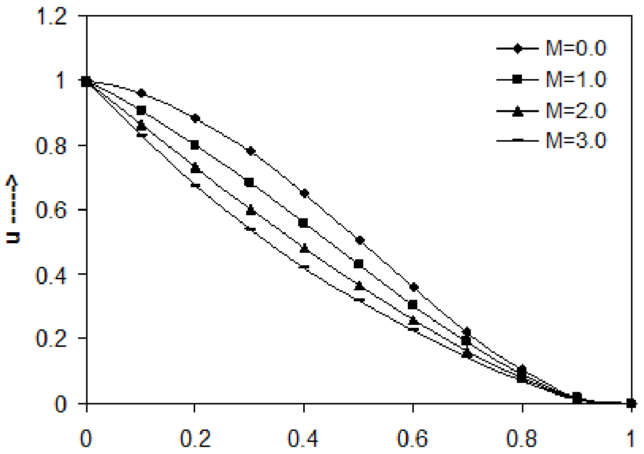

Figure 1: Effect of Magnetic Field (M) on Velocity Field u
(Gr=2.0, Gm=2.0, NR=0.5, Pr=0.71, Sc=0.3, Kr=0.5, So=2.0, A=0.3, $_{E=0.01}$ and t=1.0)

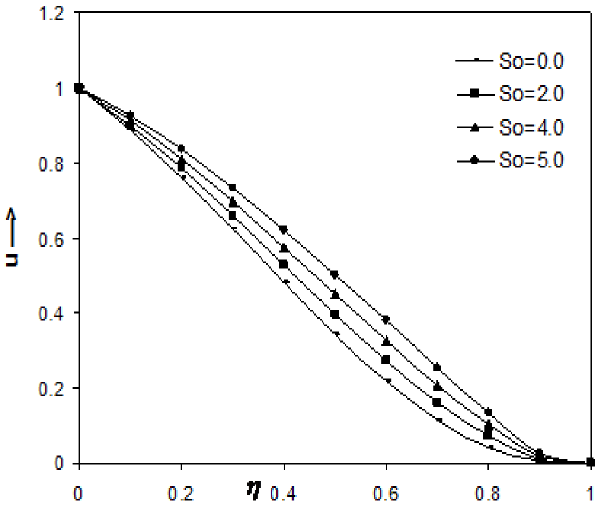

Figure 2: Effect of Soret Number on Velocity Filed u
(Gr=2.0, Gm=2.0, NR=0.5, Pr=0.71, Sc=0.3, Kr=0.5, n=0.1, A=0.3 and t=1.0)

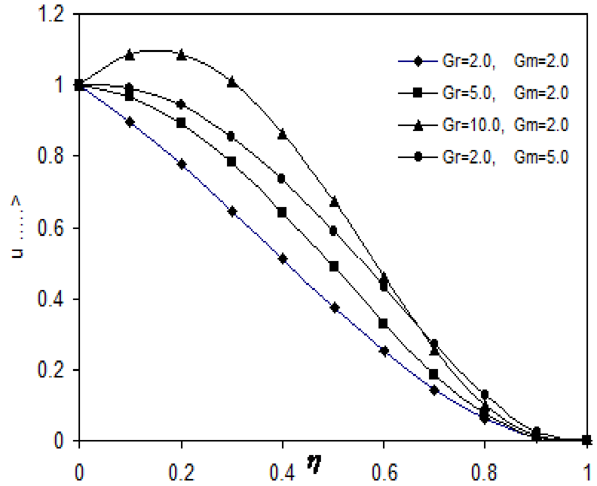

Figure 3: Effect G Rash of Modified Grash of Number on Velocity Field u
(M=2.0, So=2.0, NR=0.5, Pr=0.71, Sc=0.3, Kr=0.5, n=0.1, $_E$=0.01, A=0.3 and t=1.0)

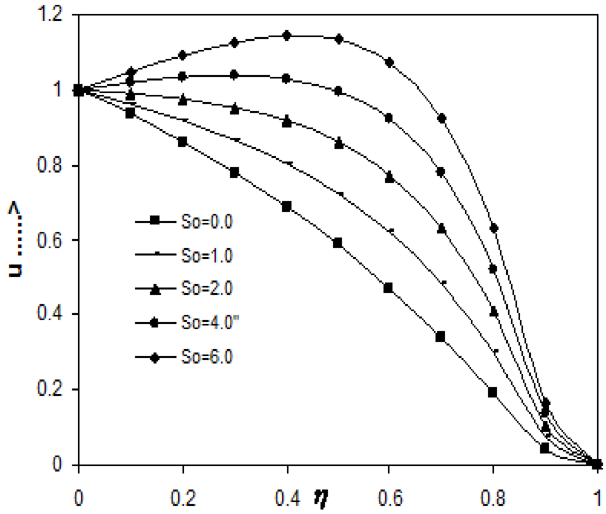

Figure 4: Effect of Soret Number on Concentration Field C
(Kr=0.5, Sc=0.3, n=0.1, $_E$=0.01 and t=1.0)

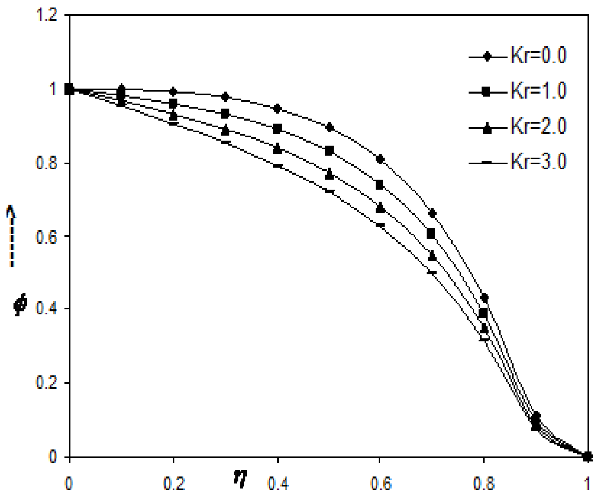

Figure 5: Effect of Chemical Reaction Parameter on Concentration Field (S0=2.0, Sc=0.3, n=0.1, A=0.3, $_E$=0.01 and t=1.0)

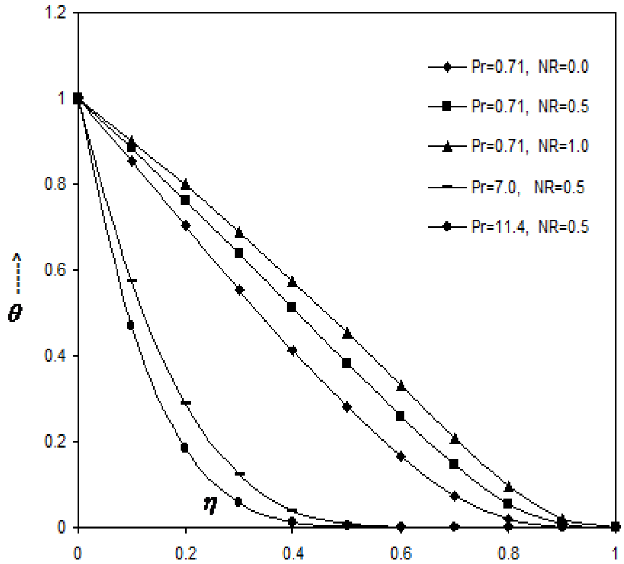

Figure 6: Effect of Thermal Radiation and Prandtl Number on Temperature Field

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