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Research Article

EFFECTS OF THERMAL STRATIFICATION ON CHEMICAL REACTING FLUID FLOW OVER A VERTICAL STRETCHING SURFACE WITH SORET AND DUFOUR EFFECTS

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ABSTRACT

This paper aims to study the influence of thermal stratification on nonlinear MHD flow with heat and mass transfer characteristics of an incompressible, viscous, electrically conducting and Boussinesq fluid on a vertical stretching surface with Dufour and soret effects. A magnetic field is applied transversely to the direction of the flow. The basic equations governing the flow, heat transfer, and concentration are reduced to a set of non linear ordinary differential equations by using appropriate transformation for variables. The non linear ordinary differential equations are first linearised using Quasi-linearization and solved numerically by an implicit finite difference scheme. Then the system of algebraic equations is solved by using Gauss-Seidal iterative method. The effects of physical parameters on the velocity, temperature, and concentration profiles are illustrated graphically. Velocity, Temperature and concentration profiles drawn for different controlling parameters reveal that the flow field is influenced appreciably by the presence of thermal stratification, chemical reaction, and magnetic field.

INTRODUCTION

Magneto hydrodynamic flows have applications in meteorology, solar physics, cosmic fluid dynamics, astrophysics, geophysics and in the motion of earth's core. In addition from the technological point of view, MHD free convection flows have significant applications in the field of stellar and planetary magnetospheres, aeronautical plasma Flows, chemical engineering and electronics. Raptis [1] (Raptis 1986) 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. Elabashbeshy [2] (Elabashbeshy 1997) studied heat and mass transfer along a vertical plate in the presence of magnetic field. Chamkha and Khaled [3] (Chamkha and Khaled 2001) investigated the problem of coupled heat and mass transfer by magneto hydrodynamic free convection from an inclined plate in the presence of internal heat generation or absorption.

In the combined heat and mass transfer processes, it is known that the thermal energy flux resulting from concentration gradients is referred to as the dufour or diffusion–thermal effect. Similarly, the soret or thermo diffusion effect is the contribution to the mass fluxes due to temperature gradients. The dufour and soret effects may be significant in the areas of geosciences and chemical engineering. Kafoussias and Williams [4] employed the finite difference method to examine the dufour and soret effects on mixed free-forced convective heat and mass transfer along a vertical surface, various other influences that have been considered include magnetic field [5], variable suction [6], and chemical reaction [7]. In many mixed flows of practical importance in nature as well as in many engineering devices, the environment is thermally stratified. The discharge of hot fluid into enclosed regions often results in a stable thermal stratification with lighter fluid overlying denser fluid. The thermal stratification effects of heat transfer over a stretching surface is of interest in polymer extrusion processes where the object, after passing through a die, enters the fluid for cooling below a certain temperature. The rate at which such objects are cooled has an important bearing on the properties of the final product. In the process of cooling the fluids, the momentum boundary layer for linear stretching of sheet was first studied by Crane [8].

The present trend in the field of chemical reaction analysis is to give a mathematical model for the system to predict the reactor performance. A large amount of research work has been reported in this field. In particular, the study of heat and mass transfer with chemical reaction is of considerable importance in chemical and hydrometallurgical industries. In order to study

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the thermal stratification effects over the above-mentioned problem, an attempt has been made have to analyze the nonlinear hydro magnetic flow with heat and mass transfer over a vertical stretching surface with chemical reaction and thermal stratification effects.

In the past decades, the penetration theory of Highie 1935 had been widely applied to unsteady state diffusional problems with and without chemical reaction. As far as we can ascertain, all the solutions with chemical reaction were obtained for the case of a semi-infinite body of liquid, although physical absorption into a finite film was considered. Among some of the interesting problems which were studied is the analysis of laminar forced convection mass transfer with homogeneous chemical reaction, [9]. The effect of different values of Prandtl number of the fluid along the surface was analyzed by Gebhart [10].

Regarding the combined heat and mass transfer processes, much attention has also been done on the Soret and Dufour effects on the convective transport phenomena. Cheng [11] used the cubic spline collocation method to study the Soret and Dufour effects on heat and mass transfer by natural convection from a cone in porous media. Recently, Tai and Char [12] employed the differential quadrature method (DQM) to attack the problem of Soret and Dufour effects on free convection flow of non-Newtonian fluids along a vertical plate in porous media in the presence of thermal radiation. The effects of Soret and Dufour on the couple heat and mass transfer by MHD mixed convection of a power-law fluid over an inclined plate was examined by Pal and Chatterjee [13]. Soret and Dufour effects have been found to appreciably influence the flow field in mixed convection boundary layer over a vertical surface embedded in a porous medium [14]. Chamkha and Ben-Nakhi [15] considered the mixed convection flow with thermal radiation along a vertical permeable surface immersed in a porous medium in the presence of Soret and Dufour effects. El-Aziz [16] have investigated the combined effects of thermal-diffusion and diffusion-thermo on MHD heat and mass transfer over a permeable stretching surface with thermal radiation.

Viscous dissipation which, appears as a source term in the fluid flow generates appreciable temperature, gives the rate at which mechanical energy is converted into heat in a viscous fluid per unit volume. However in the existing convective heat transfer literature on the non-Newtonian fluids, the effect of the viscous dissipation has been generally disregarded. Gnaneswara and Bhasker Reddy [17] have studied the effects of soret and dufour on steady MHD free convection flow in a porous medium with viscous dissipation. Kishan and Shashidar Reddy [18] have studied the MHD effects on non-Newtonian power-law fluid past a continuously moving porous flat plate with heat flux and Viscous Dissipation.

Mathematical Formulation

Let us consider two dimensional laminar boundary layer flows over a stretching plate in an incompressible electrically conducting fluid, where the x-axis is along the stretching plate and y-axis perpendicular to it, the applied magnetic field B_0 is transversely to x-axis. The magnetic Reynolds number of the flow is taken to be small enough so that the induced magnetic field can be neglected. Under the usual boundary layer approximations, the governing equations of continuity, momentum and energy under the influence of externally imposed transverse magnetic field are:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \qquad \text{--- (1)}$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\beta(T-T_\infty)+g\beta^*(C-C_\infty)-\frac{\sigma\beta_0^2 u}{\rho} \qquad \text{--- (2)}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\propto\frac{\partial^2 T}{\partial y^2}+\frac{D_m K_T}{c_s c_p}\frac{\partial^2 C}{\partial y^2}+Q(T_\infty-T)+\frac{\mu}{\rho c_p}\left(\frac{\partial u}{\partial y}\right)^2 \qquad \text{--- (3)}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}+\frac{D_m K_T}{T_m}\frac{\partial^2 T}{\partial y^2}-K_1 C \qquad \text{--- (4)}$$

The boundary conditions are

$$u=U(x)=ax,\ v=0,\ T=T_w(x),\ C=C_w(x) \text{ at } y=0 \qquad \text{--- (5)}$$

$$u=0, T=T_\infty(x)=(1-n)T_0+nT_w(x), C=C_\infty \text{ as } y\to\infty \qquad \text{--- (6)}$$

Where a is dimensional constant and n is a constant which is the thermal stratification parameter and is such that $0\leq n\leq 1$. The n defined as thermal stratification parameter is equal to $\frac{m_1}{m_1+1}$ of Nakayama and koyama [19] where m_1 is constant. T_0 is constant reference temperature say, $T_\infty(0)$. The suffixes w and ∞ denote surface and ambient conditions

As in Acharya et al. [20] the following change of variables are introduced:

$$\Psi=\left(\nu x U(x)\right)^{1/2} f(\eta)$$
$$\eta=\left(U(x)\,/\,\nu x\right)^{1/2} y \qquad \text{--- (7)}$$

The velocity components are given by

$$u=\frac{\partial\Psi}{\partial y}, v=-\frac{\partial\Psi}{\partial x} \qquad \text{--- (8)}$$

It can be easily verified that the continuity eq. (1) is identically satisfied. Similarity solutions exist if we assume that $U(x)=ax$ and introduce the non dimensional form of temperature and concentration as

$\theta(\eta)=\frac{T-T_\infty}{T_w-T_\infty}$

$\varphi(\eta)=\frac{C-C_\infty}{C_w-C_\infty}$

$Re_x=\frac{Ux}{\nu}$ is Reynolds number

$Gr_x=\frac{\nu g\beta(T_w-T_\infty)}{U^3}$ is Grashof number

$Gc_x=\frac{\nu g\beta^*(C_w-C_\infty)}{U^3}$ is modified Grashof number

$P_r=\frac{\mu C_p}{K}$ is Prandtl number

$S_c=\frac{\nu}{D}$ is Schmidt number

$M^2=\frac{\sigma\beta_0^2}{\rho a}$ is magnetic parameter

$\gamma=\frac{\nu k_1}{U^2}$ is Chemical reaction parameter

$S=\frac{XQ}{U}$ is Heat source parameter

$E_c=\frac{U^2}{C_p(T_w-T_\infty)}$ is Eckert number

In this work, temperature variation of the surface is taken into account and is also given by the power-law temperature, $T_w-T_\infty=Nx^n$ where N and n are constants. Also concentration variation is given by $C_w-C_\infty=N_1x^{n_1}$ where N_1 and n_1 are constants. The nonlinear equations and boundary conditions are obtained as

$$f''' + Gc_x Re_x \varphi + Gr_x Re_x \theta - (f')^2 - \left(\frac{M^2}{Re_x}\right) f' + ff'' = 0 \quad \text{--- (9)}$$

$$\theta'' - P_r f'\left(\theta + \frac{n}{(1-n)}\right) + p_r D_u \varphi'' + P_r f\theta' - P_r S\theta + P_r E_c (f'')^2 = 0 \quad \text{--- (10)}$$

$$\varphi'' - S_c(\varphi \gamma Re_x + f'\varphi) + S_c f\varphi' + S_c S_r \theta'' = 0 \quad \text{--- (11)}$$

The boundary conditions are given by

$$f(0) = 0, f'(0) = 1, \theta(0) = 1, \varphi(0) = 1, f'(\infty) = 0,$$
$$\theta(\infty) = 0, \varphi(\infty) = 0 \quad \text{--- (12)}$$

The set of governing Equations (9) - (11) is highly nonlinear, so it is difficult to obtain closed form solution. Hence these equations together with the boundary conditions (12) are solved numerically using finite difference technique. The momentum equation is first linearized using Quasi-linearization technique and then these linear ordinary differential equations are transformed into a system of linear equations by using implicit Finite difference Scheme. Now the computation procedure is employed to obtain the numerical solutions in which first the momentum equation is solved to obtain the values of f using which the solution of energy and concentration equations are solved under the given boundary conditions (12) using Thomas algorithm for various parameters entering into the problem and computations were carried out by using The numerical solutions of f are considered as (n+1)th order iterative solutions and F are the nth order iterative solutions. After each cycle of iteration the convergence check is performed, and the process is terminated when $|F - f| < 10^{-4}$

RESULTS AND DISCUSSIONS

A parametric study is performed to explore the Dufour soret effects and effects of magnetic field parameter, Thermal stratification, Chemical reaction and Eckert number. In order to get a clear insight of the physical problem, numerical results are displayed with the help of graphical illustrations. The effect of magnetic field parameter on dimensionless velocity profiles with constant chemical reaction parameter, Eckert number, Dufour and soret numbers and thermal Stratification parameters are presented in Fig. 1.

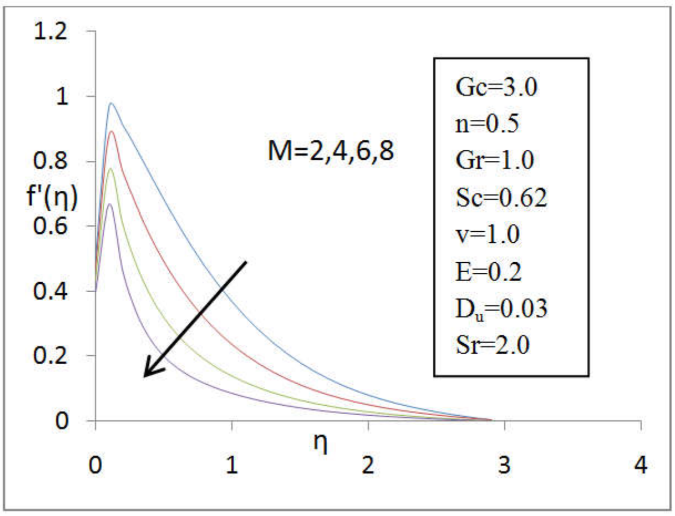

Fig 1 Velocity profiles for different magnetic parameter

It is observed that the velocity of the fluid decreases with the increase in magnetic field parameter. The dimensionless concentration profiles for different values of magnetic field with constant chemical reaction parameter and thermal stratification parameter are demonstrated in Fig. 2.

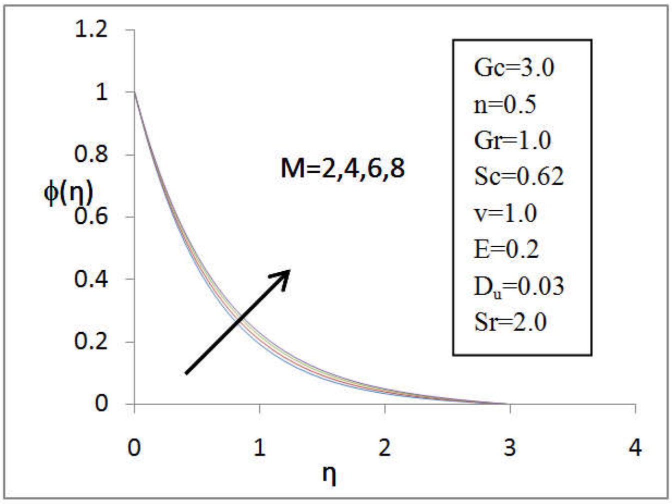

Fig 2 Magnetic effect over concentration profiles

It is seen that the concentration of the fluid rises with the increase of magnetic parameter. Fig. 3 depicts the dimensionless velocity profiles for different values of thermal stratification parameter with constant Eckert number, Dufour and soret numbers, chemical reaction parameter and the uniform magnetic field.

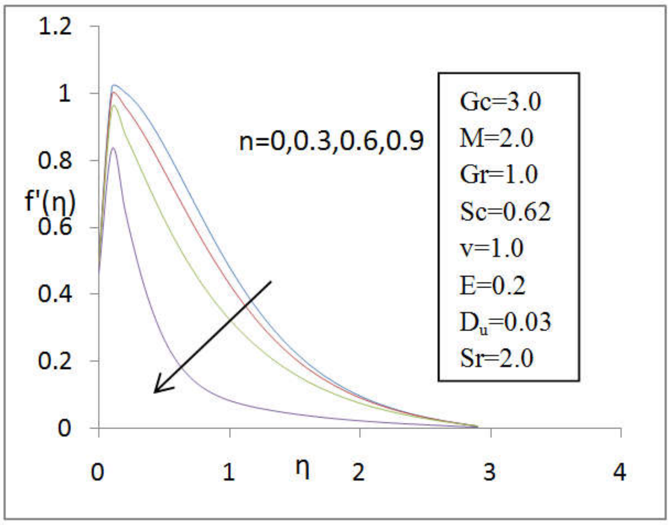

Fig 3 Thermal Stratification effects over the velocity profiles

It is observed that the velocity of the fluid decreases with the increase of thermal stratification parameter. Fig. 4 demonstrates the dimensionless concentration profiles for different values of thermal stratification parameter with constant chemical reaction parameter and the uniform magnetic field.

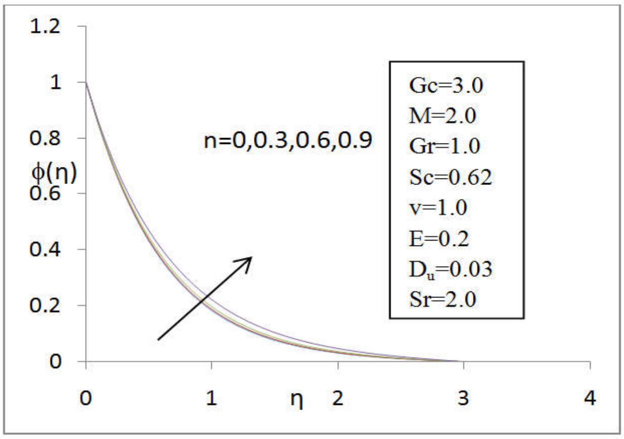

Fig 4 Thermal Stratification effects over concentration profiles

It is seen that the concentration increases with the increase of thermal stratification parameter. The dimensionless velocity profiles for different values of chemical reaction parameter with uniform magnetic field, constant thermal stratification parameter and Eckert number, Dufour and soret numbers are depicted in Fig. 5.

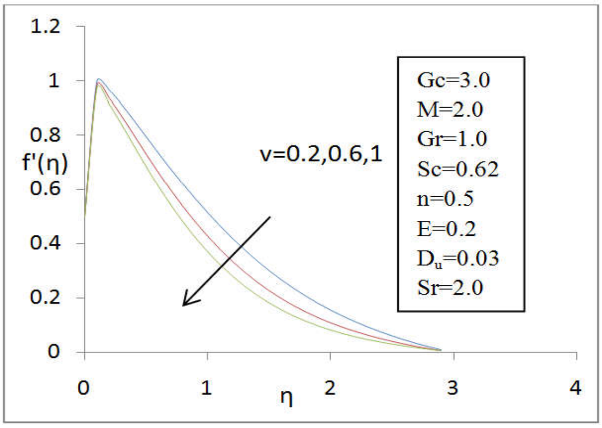

Fig 5 Chemical reaction effects over the velocity profiles

It is observed that the velocity of the fluid decreases with the increase of chemical reaction parameter. The concentration of the fluid decreases with the increase of chemical reaction parameter and this is noted through Fig. 6.

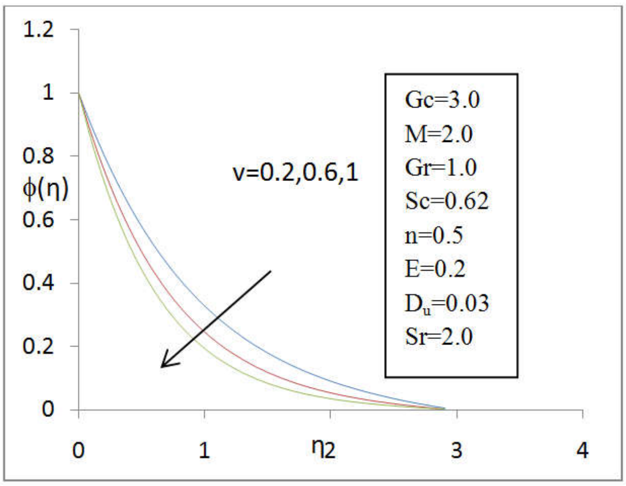

Fig 6 Chemical reaction effects over the Concentration profiles

The dimensionless temperature profiles for different values of thermal stratification parameter with constant Eckert number, Dufour and soret numbers, chemical reaction parameter and the uniform magnetic field are shown in Fig. 7.

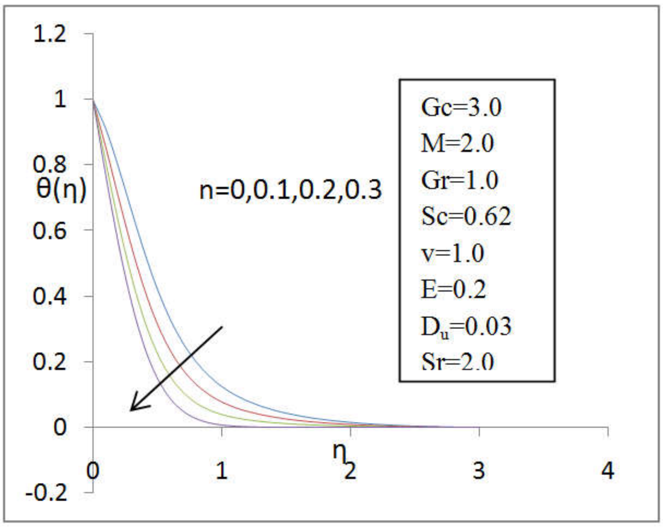

Fig 7 Thermal Stratification effects over the Temperature profiles

It is clear that the temperature of the fluid decreases with the increase of thermal stratification parameter. The dimensionless temperature profiles for different values of chemical reaction parameter with uniform magnetic field and constant Eckert number, Dufour and soret numbers, thermal stratification parameter are displayed in Fig. 8.

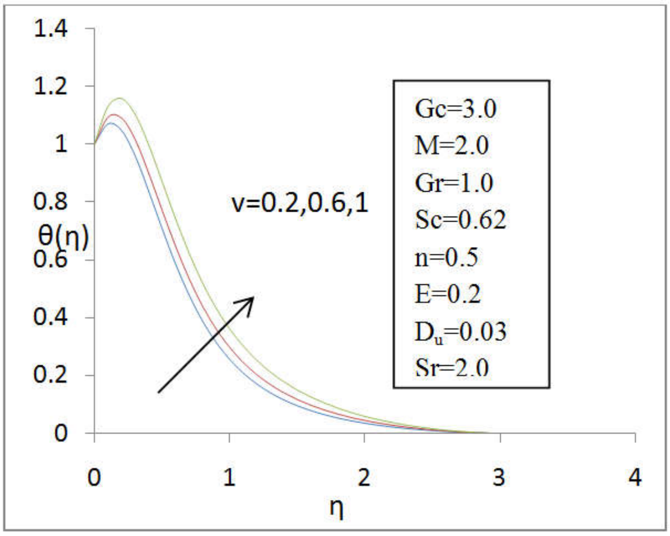

Fig 8 Chemical reaction over the Temperature profiles

It is seen that the temperature of the fluid increases with the increase of chemical reaction parameter. The dimensionless temperature profiles for different values of Eckert number with uniform magnetic field, constant chemical reaction parameter and thermal stratification parameter are demonstrated in Fig. 9. It is seen that the temperature of the fluid rises with the increase of Eckert number. The dimensionless temperature profiles for different values of magnetic field with constant chemical reaction parameter, Eckert number and thermal stratification parameter are demonstrated in Fig. 10.

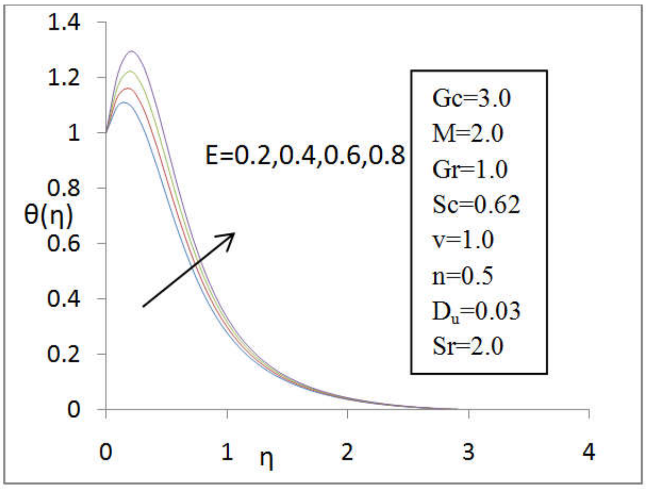

Fig 9 Viscous dissipation effects over the Temperature profiles

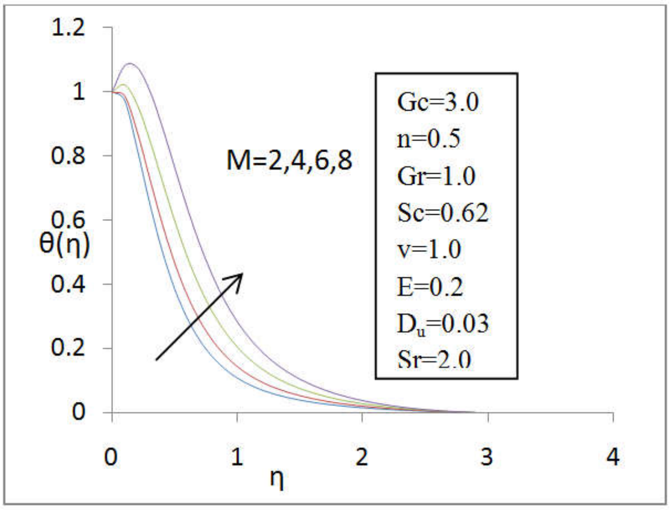

Fig 10 Magnetic effects over the Temperature profiles

It is seen that the temperature of the fluid rises with the increase of magnetic parameter.

The effects of Soret and Dufour numbers on velocity profiles and temperature profiles are shown in Fig.11 and Fig.12 respectively.

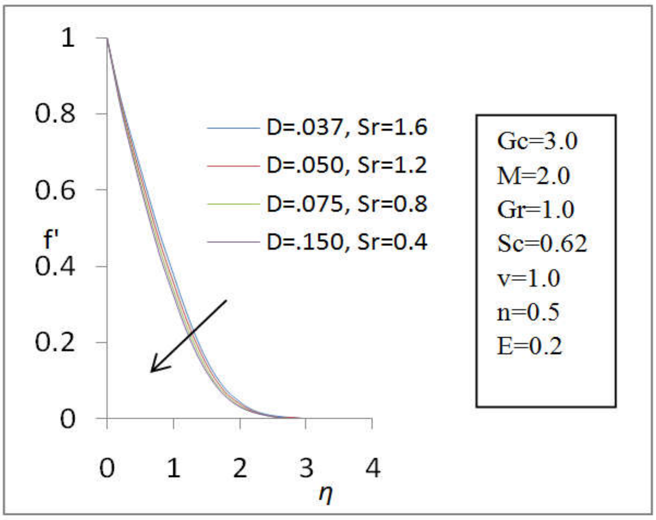

Fig 11 Dufour and soret effects over the velocity profiles

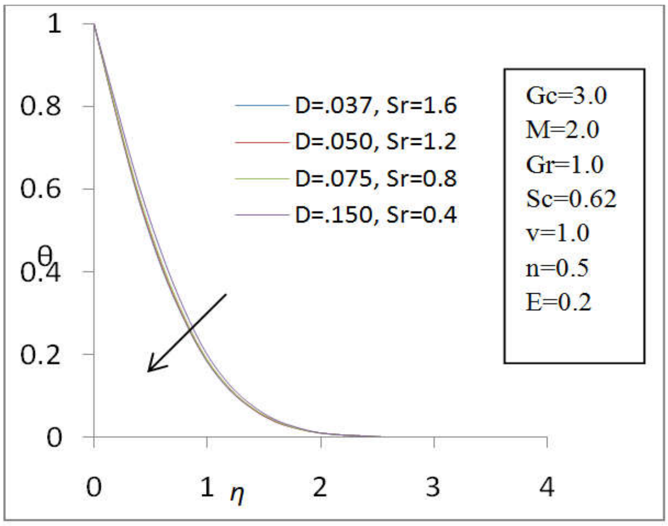

Fig 12 Dufour and soret effects over the temperature profiles

As there is an increase in the Dufour number or a decrease in the Soret number, the velocity and temperature decreases. Here the variation in the profiles is very low. The variation in concentration profiles with the change in Soret and Dufour number is displayed in Fig. 13. The concentration increases as there is an increase in Dufour number or decrease in Soret number.

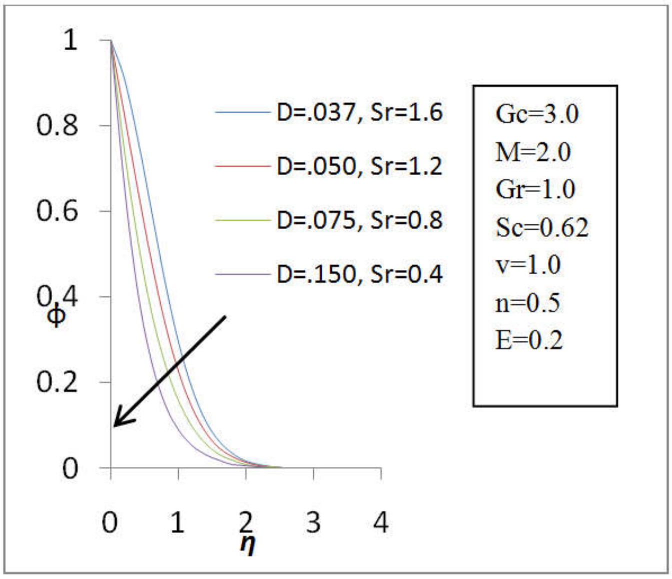

Fig 13 Dufour and soret effects over the concentration profiles

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