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RESEARCH ARTICLE

SORET AND DUFOUR EFFECTS ON MHD BOUNDARY LAYER FLOW OVER A VERTICAL PLATE WITH CONVECTIVE SURFACE BOUNDARY CONDITION AND CHEMICAL REACTION

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ABSTRACT

This paper analyses the Soret and Dufour effects on an hydromagnetic two dimensional convective boundary layer flow of a viscous incompressible chemical reacting fluid over a vertical plate with convective surface boundary condition and has been studied. The similarity transformation is used to transform the system of partial differential equations into ordinary differential equations. An efficient numerical technique is implemented to solve the resultant system, using Runge-kutta fourth order method along with shooting technique. 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. Also, comparision with the previous results shows a very good agreement.

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INTRODUCTION

The free convection processes involving the combined mechanism of heat and mass transfer are encountered in many natural processes, in many industrial applications and in many chemical processing systems. The study of free convective mass transfer flow has become the object of extensive research as the effects of heat transfer along with mass transfer effects are dominant features in many engineering applications such as rocket nozzles, cooling of nuclear reactors, high sinks in turbine blades, high speed aircrafts and their atmospheric re-entry, chemical devices and process equipments. Ibrahim and Makind (2011) studied free convection heat and mass transfer problems neglecting Dufour and Soret effects on the basis that they are of smaller order of magnitudes. Subhashini *et al.* (2011) studied new similarity solution of steady mixed convection boundary layer flow over a permeable surface for convective boundary condition. Gebhart and Pera (1971) obtained the steady state solution for natural convection on a vertical plate with variable surface temperature and variable mass diffusion using similarity variables. Soundalgekar *et al.*(1979) analyzed the problem of free convection effects on Stokes problem for a vertical plate under the action of transversely applied magnetic field. MHD flow problems have become in view of its significant applications in industrial manufacturing processes such as plasma studies, petroleum industries Magnetohydrodynamics power generator cooling of clear reactors, boundary layer control in aerodynamics. Many authors have studied the effects of magnetic field on mixed, natural and force convection heat and mass transfer problems. Chamka (2003) has analyzed MHD flow over a uniformly stretched vertical permeable surface in presence of heat generation/absorption and a chemical reaction. Rajput and Pradeep (2011) have studied the effect of a uniform transverse magnetic field on the unsteady transient free convection flow of an incompressible viscous electrically conducting fluid between two infinite vertical parallel plates with constant temperature and Variable mass diffusion. Elbashbeshy (1997) studied heat and mass transfer along a vertical plate under the combined buoyancy effects of thermal and species diffusion, in the presence of the magnetic field. The problem of steady laminar magneto hydrodynamic(MHD) mixed convection heat transfer about a vertical plate is solved numerically by Orhan Aydin and Ahmet Kaya (2009) taking into account the effect of ohmic heating and viscous dissipation. In many transport processes in nature and in industrial applications in which heat and mass transfer with heat radiation is a consequence of

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buoyancy effects caused by diffusion of heat and chemical species. The study of such processes is useful for improving a number of chemical technologies, such as polymer production and food processing. In nature the presence of pure air or water is impossible. Some foreign mass may be present either naturally or mixed with air or water. The present trend in the field of chemical reaction with viscosity 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 chemical reaction, heat and mass transfer with heat radiation is of considerable importance in chemical and hydrometallurgical industries. Chemical reaction can be codified as either heterogeneous or homogeneous processes. This depends on whether they occur at an interface or as a single phase volume reaction. Anjalidevi and Kandasamy (1999) considered the chemical reaction between species A and B to be of first order, homogenous and with a constant rate. Ibrahim and Makind (2011) examined chemically reacting MHD boundary layer flow of heat and mass transfer past a low- heat-resistant sheet moving vertically downwards in a viscous electrically conducting fluid permeated by a uniform transverse magnetic field. Adeniyan and Adigun (2012) examined the effects of a chemical reaction on stagnation point MHD flow over a vertical plate with convective boundary conditions but neglected the energy due to pressure force. Muthucumaraswamy *et al.* (2006) studied study of chemical reaction effects on vertical plate with variable temperature. Unsteady free convection flow past a vertical plate with chemical reaction under different temperature condition on the plate is elucidated by Bhaben Ch. Neog *et al.* (2012) and Rajesh. *et al.* (2010). Das *et al.* (1994) considered the effects of first order chemical reaction on the flow past an impulsively started infinite vertical plate with constant heat flux and mass transfer. . The effect of chemical reaction on free convective flow and mass transfer of a viscous, incompressible and electrically conducting fluid over a stretching sheet was investigated by Afify (2004) in the presence of transverse magnetic field. When heat and mass transfer occur simultaneously in a moving fluid, the relation 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 gradient and this is the Soret or thermal–diffusion effect. These effects are considered as second-order phenomena, on the basis that they are of smaller order of magnitude than the effects described by Fourier's and Fick's laws, but they may become significant in areas such geosciences or hydrology. Gnaneswara Reddy and Bhaskar Reddy (2010) presented Soret and Dufour effects on steady MHD free convection flow past a semi – infinite moving vertical plate in a porous medium with viscous dissipation. In view of the importance of diffusion-thermo effect, Jha and Singh (1990) presented an analytical study for free convection and mass transfer flow past an infinite vertical plate moving impulsively in its own plane taking Soret effects into account. Srinivasulu and Bhaskar Reddy (2012) studied the Thermo-diffusion and Diffusion-thermo effects on MHD boundary layer flow past an exponential stretching sheet with thermal radiation and viscous dissipation. Halima Usman, Ime Jimmy Uwanta (2013) study the effect of thermal conductivity on MHD heat and mass transfer flow past an infinite vertical plate taking into account the Dufour and Soret effects. However, to the best of authors' knowledge, so far no attempt has been made to analyze the Soret and Dufour Effects on MHD boundary layer flow over a vertical plate with convective surface boundary condition and chemical reaction. Hence, this problem is investigated. The governing boundary layer equations are reduced to a system of ordinary differential equations using similarity transformations and the resulting equations are then solved numerically using Runge - Kutta fourth order method along with shooting technique. A parametric study is conducted to illustrate the influence of various governing parameters on the velocity, temperature, concentration, skin-friction coefficient, Nusselt number and Sherwood number and discussed in detail.

Mathematical analysis

A steady two dimensional laminar mixed convection flow of a viscous incompressible electrically conducting and chemically reacting fluid over a vertical plate, is considered. A uniform magnetic field is applied perpendicular to the plate and the magnetic Reynolds number is assumed to be small so that the induced magnetic field can be neglected in comparision with the applied magnetic field. In addition, it is assumed that the input electric field and Joule heatings are negligible. The x-axis is taken along the direction of the plate and y–axis normal to it. Now under the usual Boussinesq and boundary layer approximations, the governing equations for this problem can be written as

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\upsilon\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}(U-U_\infty)+g\beta_T(T-T_\infty)+g\beta_c(C-C_\infty) \qquad \text{……. (2)}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\frac{\partial^2 T}{\partial y^2}+\frac{D_M K_T}{C_s C_p}\frac{\partial^2 C}{\partial y^2} \qquad \text{………(3)}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}+\frac{D_M K_T}{T_M}\frac{\partial^2 T}{\partial y^2}+{k_r}^2(C-C_\infty) \quad \text{….}$$
(4)

The boundary conditions for the velocity, temperature and concentration fields are

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

at $y=0$

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

at $y=\infty$ …………..(5)

where *u, v, T* and *C* are the fluid *x*-component of velocity, *y*-component of velocity, temperature and concentration respectively, υ - the kinematics viscosity, ρ - the density, σ - the electric conductivity of the fluid, β_T and β_c - the coefficients of thermal and concentration expansions respectively, α - the thermal diffusivity, C_∞ - the free stream concentration, B_0 - the magnetic induction, D_m - the mass diffusivity and g is the gravitational acceleration. T_w is the temperature of the hot fluid at the surface of the plate C_w is the species concentration at the plate surface. K' - the permeability of the porous medium, k- the thermal conductivity and C_∞ - the free stream concentration. To transform equations (2)-(4) into a set of ordinary differential equations, the following similarity transformations and dimensionless variables are introduced.

$$\eta = y\sqrt{\frac{U_\infty}{\upsilon x}}, \psi = \sqrt{\upsilon x U_\infty}\, f(\eta), \theta(\eta) = \frac{(T - T_\infty)}{(T_w - T_\infty)}$$

$$\phi(\eta) = \frac{(C - C_\infty)}{(C_w - C_\infty)}, \quad Ha = \frac{\sigma B_0^2 x}{\rho U_\infty}, \; Gr = \frac{g\beta_T (T_w - T_\infty)x}{U_\infty^2},$$

$$Gc = \frac{g\beta_c (C_w - C_\infty)x}{U_\infty^{\,2}}, \; Pr = \frac{\upsilon}{\alpha}, \; Sc = \frac{\upsilon}{D_m}, \; K = \frac{\upsilon}{(K'B)},$$

$$Du = \frac{D_M K_T (C_w - C_\infty)}{c_s c_p \upsilon (T_w - T_\infty)}, \; Sr = \frac{D_M K_T (T_w - T_\infty)}{T_M \upsilon (c_w - c_\infty)}, \; K_r^{\,2} = \frac{k_r^{\,2} x}{U_\infty} \quad \ldots\ldots\ldots (6)$$

where $f(\eta)$ is the dimensionless stream function, $\theta(\eta)$ - the dimensionless temperature, $\phi(\eta)$ - the dimensionless concentration, η - the similarity variable, *M*- the magnetic parameter, *Gr*-the local temperature Grashof number, *Gc*- the local solutal Grashof number, *Pr*- the Prandtl number, *Sc*- the Schmidt number, *K* - the permeability parameter, ψ - the stream function. *Sr*- the Soret number*, Du*- the Dufour number , T_w - the temperature of the hot fluid at the left surface of the plate and K_r - chemical reaction parameter. The stream function ψ satisfies the continuity equation (1) identically with

$$u = \frac{\partial \psi}{\partial y} \quad \text{and} \quad v = -\frac{\partial \psi}{\partial x} \quad \ldots\ldots\ldots\ldots\ldots(7)$$

A similarity solution of equations (1)-(6) is obtained by defining an independent variable η and a dependent variable f interms of the stream function ψ as

$$\psi = \sqrt{\upsilon x U_\infty}\, f(\eta), \eta = y\sqrt{\frac{U_\infty}{\upsilon x}} \quad \ldots\ldots\ldots..(8)$$

substituting the equations (6)-(8) in to the equations (1)- (4), we obtain

$$f''' + \frac{1}{2} f f'' - Ha\,(f' - 1) + G_r \theta + G_c \phi = 0 \quad ..(9)$$

$$\theta'' + \frac{1}{2} P_r f \theta' + P_r D_u \phi'' = 0 \quad \ldots\ldots(10)$$

$$\phi'' + \frac{1}{2} S_c f \phi' + S_r S_c \theta'' - k_1 S_c \phi = 0 \quad \ldots.(11)$$

The corresponding boundary conditions are

$$f(0) = 0, f'(0) = 0, \theta'(0) = B_i[\theta(0) - 1], \phi(0) = 1$$

$$f'(\infty) = 1, \theta(\infty) = 0, \phi(\infty) = 0 \quad ..(12)$$

where the prime symbol represents the derivative with respect to η and Ha – the magnetic field parameter, G_r- the thermal Grashof number, G_c - the solute Grashof number, B_i - the convective heat transfer parameter, Pr - the Prandtl number, S_c - the Schmidt number , kr^2 - the chemical reaction rate constant.

It is note worthy that the local parameters B_i, Ha, G_r and G_c in equations (9)-(13) are functions of x . However in order to have a similarity solution all the parameters B_i, Ha, G_r and G_c must be constant and we therefore assume

$$h = cx^{\frac{-1}{2}}, \sigma = ax^{-1}, \beta_T = bx^{-1} \text{and } \beta_C = dx^{-1}, k_r = ex^{\frac{-1}{2}} \quad \ldots\ldots\ldots\ldots\ldots (13)$$

where a,b,c,d and e are constants.

Other physical quantities of interest in this problem such as the skin friction parameter $\tau = f''(0)$,the plate surface temperature $\theta(0)$, Nusselt number $Nu = -\theta'(0)$ and the Sherewood number $Sh = -\phi'(0)$ 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.

Solution of the problem

Equations (9)-(11) are coupled non linear ordinary differential equations. These equations together with boundary conditions (12) and (13) are solved numerically by using Runge-Kutta fourth order method along with shooting technique. First of all higher order non linear differential equations are converted into simultaneous differential equations of first order and they are transformed into initial value problem by applying the shooting technique (Jain *et al.*, 1985). The resultant initial value problem is solved by employing Runge-Kutta fourth order technique. The step size $\Delta\eta = 0.5$ is used to obtain 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 Sherewood number, which are respectively proportional to $f''(0), -\theta'(0)$ and $-\phi'(0)$ are also sorted out and their numerical values are presented in tabular form.

RESULTS AND DISCUSSION

The governing equations (9)-(11) subject to the boundary conditions are solved as described in section 3. Numerical results are reported in Tables 1-2. The Prandtl number was 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. 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 $\theta'(0)$. To find out the solution of this problem, we have placed an infinite vertical plate in a finite length in the flow. Hence, we solve the entire problem in a finite boundary. However, in the graphs, values vary from 0 to 4, and the velocity, temperature, and concentration tend to zero as y tends to 4. This is true for any value of y. Thus, we have considered finite length. Figures 1-9 illustrates the parameter variation on velocity profiles.

From the Fig. 1 it is noticed that velocity increases on increasing the magnetic field parameter *Ha*. Increase in the velocity is observed from the Fig. 2 on increasing the chemical reaction parameter *Kr*. The effects of buoyancy parameters on velocity are illustrated in Fig. 3 and Fig. 4, it is found that buoyancy parameter effects the increase in the velocity of the fluid. Decrease in the velocity is noticed on increasing the Prandtl number and Schmidt number as shown in Fig. 5 and Fig. 6. The effect of Dufour number on velocity is shown in the Fig.7. It is seen that the velocity is increases on increasing the Dufour number *Du*. Where as decrease in the velocity is observed on increasing the Soret number *Sr* from the Fig. 8. The effect of convective heat transfer parameter *Bi* is illustrated in Fig. 9. It is found that the velocity is increased with the increase of *Bi*. Fig. 10 shows the effect of increase in the magnetic field strength on the temperature of the fluid. It is observed that the temperature of the fluid decreases on increasing magnetic field strength parameter *Ha*.

Table 1. Comparision of present results for $f''(0)$,- $\theta'(0)$ and - $\phi'(0)$ at the plate for different values of *Ha, Gr, Gc, Bi, Pr, Sc* and *Kr* for *Du* = *Sr* = 0 with that of Gangadhar *et al*. (2012)

Ha	*Gr*	*Gc*	*Bi*	*Pr*	*sc*	*Kr*	Gangadhar K et.al [21]			Present work		
							$f''(0)$	$-\theta'(0)$	$-\phi'(0)$	$f''(0)$	$-\theta'(0)$	$-\phi'(0)$
0.1	0.1	0.1	0.1	0.72	0.62	0.5	0.57598	0.0776174	0.612399	0.583817	0.0722248	0.612975
0.2	0.1	0.1	0.1	0.72	0.62	0.5	0.658281	0.0779432	0.615829	0.665375	0.0725919	0.616301
0.3	0.1	0.1	0.1	0.72	0.62	0.5	0.731627	0.0782038	0.618686	0.738157	0.0728853	0.619078
0.5	0.1	0.1	0.1	0.72	0.62	0.5	0.859832	0.0786024	0.623268	0.865546	0.0733335	0.623541
0.1	0.2	0.1	0.1	0.72	0.62	0.5	0.599426	0.0777244	0.613495	0.614722	0.0723912	0.614429
0.1	0.3	0.1	0.1	0.72	0.62	0.5	0.622447	0.0778274	0.614564	0.644947	0.0725499	0.615839
0.1	0.4	0.1	0.1	0.72	0.62	0.5	0.645069	0.0779267	0.615607	0.674539	0.0727015	0.617208
0.1	0.5	0.1	0.1	0.72	0.62	0.5	0.667313	0.0780226	0.616626	0.703543	0.0728467	0.61854
0.1	0.1	0.2	0.1	0.72	0.62	0.5	0.663436	0.0779781	0.616182	0.671129	0.0726374	0.616687
0.1	0.1	0.3	0.1	0.72	0.62	0.5	0.749072	0.0783102	0.61981	0.756652	0.0730176	0.620251
0.1	0.1	0.4	0.1	0.72	0.62	0.5	0.833048	0.0786176	0.623298	0.84054	0.0733696	0.623682
0.1	0.1	0.5	0.1	0.72	0.62	0.5	0.915499	0.0789032	0.626659	0.922926	0.0736969	0.62699
0.1	0.1	0.1	0.2	0.72	0.62	0.5	0.590922	0.127027	0.613098	0.597729	0.118263	0.613134
0.1	0.1	0.1	0.3	0.72	0.62	0.5	0.601181	0.161342	0.613577	0.607296	0.150259	0.613233
0.1	0.1	0.1	0.4	0.72	0.62	0.5	0.608672	0.186599	0.613925	0.614289	0.173817	0.6133
0.1	0.1	0.1	0.5	0.72	0.62	0.5	0.614386	0.205979	0.61419	0.619627	0.191899	0.613348
0.1	0.1	0.1	0.1	0.24	0.62	0.5	0.582628	0.0739646	0.612779	0.586011	0.0717583	0.613009
0.1	0.1	0.1	0.1	1.0	0.62	0.5	0.573284	0.0791446	0.612247	0.582853	0.0723666	0.612988
0.1	0.1	0.1	0.1	1.5	0.62	0.5	0.569816	0.0811729	0.612054	0.581606	0.0724183	0.613059
0.1	0.1	0.1	0.1	2.72	0.62	0.5	0.56512	0.0841079	0.611802	0.580173	0.0718728	0.613388
0.1	0.1	0.1	0.1	0.72	0.24	0.5	0.592694	0.0777305	0.417922	0.596406	0.0752549	0.417796
0.1	0.1	0.1	0.1	0.72	0.78	0.5	0.571082	0.0775849	0.679227	0.580299	0.0711773	0.680272
0.1	0.1	0.1	0.1	0.72	1.5	0.5	0.556583	0.0774919	0.92152	0.570674	0.0673469	0.925462
0.1	0.1	0.1	0.1	0.72	2.62	0.5	0.544757	0.0774213	1.20178	0.564325	0.0628387	1.21206
0.1	0.1	0.1	0.1	0.72	0.62	1.0	0.564496	0.0775452	0.816906	0.576357	0.0690255	0.81825
0.1	0.1	0.1	0.1	0.72	0.62	1.5	0.556661	0.0774972	0.984181	0.571774	0.0663921	0.986069
0.1	0.1	0.1	0.1	0.72	0.62	2.0	0.55088	0.0774628	1.12846	0.568769	0.0641116	1.13077
0.1	0.1	0.1	0.1	0.72	0.62	10	0.521628	0.0773102	2.49301	0.564683	0.0423712	2.49869

Table 2. Variations of $f''(0)$,- $\theta'(0)$ and - $\phi'(0)$ at the plate for different values of Du, Sr and Kr for Ha, Gr, Gc, Bi= 0.1 , Pr 0.72 and Sc= 0.62

Du	*Sr*	*Kr*	*$f''(0)$*	$-\theta'(0)$	$-\phi'(0)$
0.2	0.1	0.1	0.591518	0.0668142	0.614343
0.3	0.1	0.1	0.599219	0.0613866	0.615714
0.4	0.1	0.1	0.606922	0.0559418	0.617089
0.5	0.1	0.1	0.614626	0.0504797	0.618467
0.1	0.2	0.1	0.583911	0.0722227	0.613152
0.1	0.3	0.1	0.584006	0.0722205	0.613332
0.1	0.4	0.1	0.5841	0.0722183	0.613516
0.1	0.5	0.1	0.584196	0.072216	0.613702
0.1	0.1	1.0	0.576357	0.0690255	0.81825
0.1	0.1	1.5	0.571774	0.0663921	0.986069
0.1	0.1	2.0	0.568769	0.0641116	1.13077
0.1	0.1	10.0	0.564683	0.0423712	2.49869

Parameter variation on velocity profiles

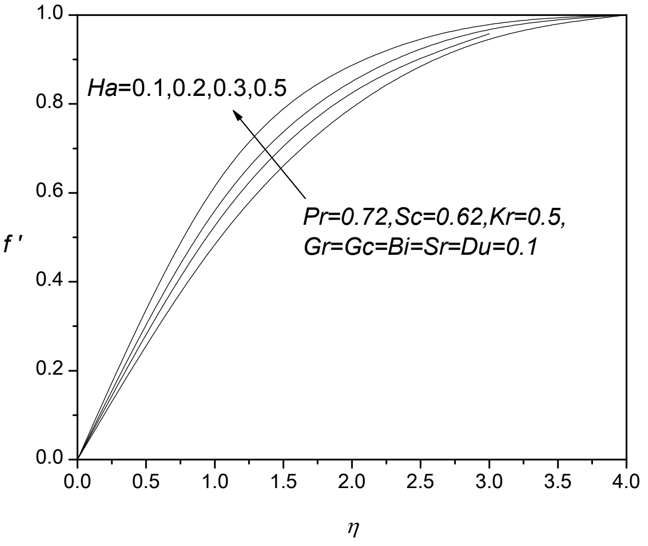

Fig. 1. Velocity profiles for different Ha

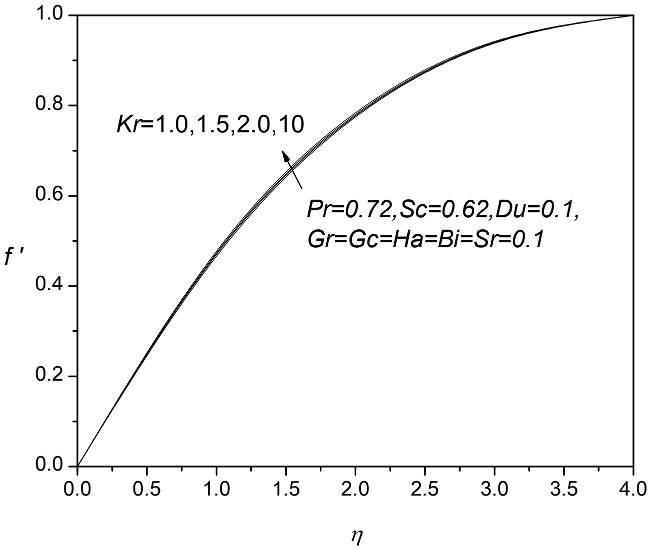

Fig. 2. Velocity profiles for different Kr

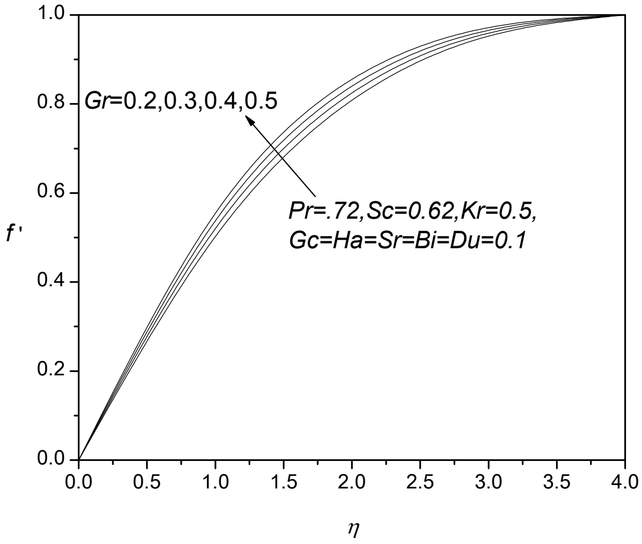

Fig. 3. Velocity profiles for different Gr

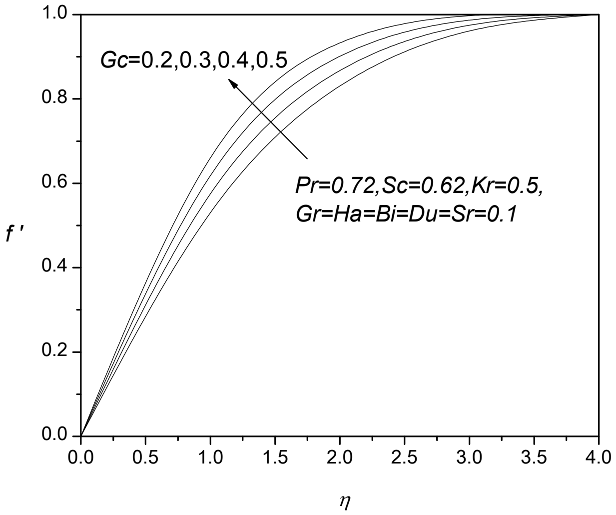

Fig. 4. Velocity profiles for different Gc

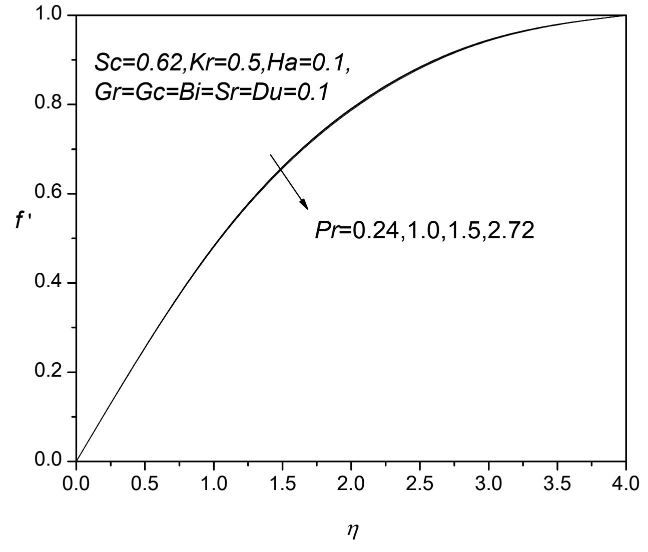

Fig. 5. Velocity profiles for different Pr

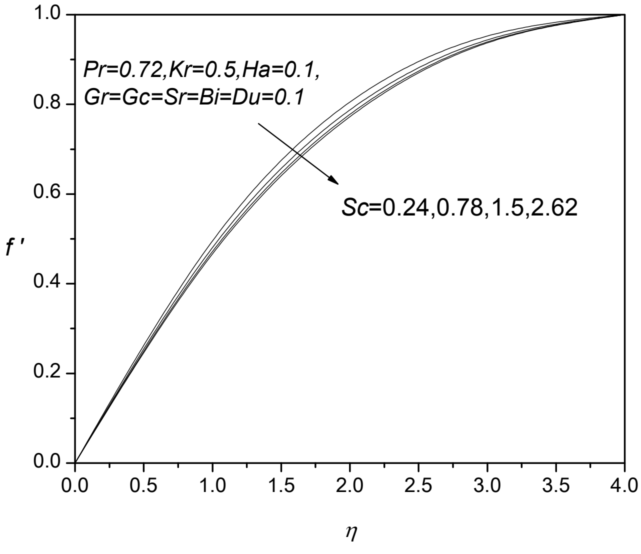

Fig. 6. Velocity profiles for different Sc

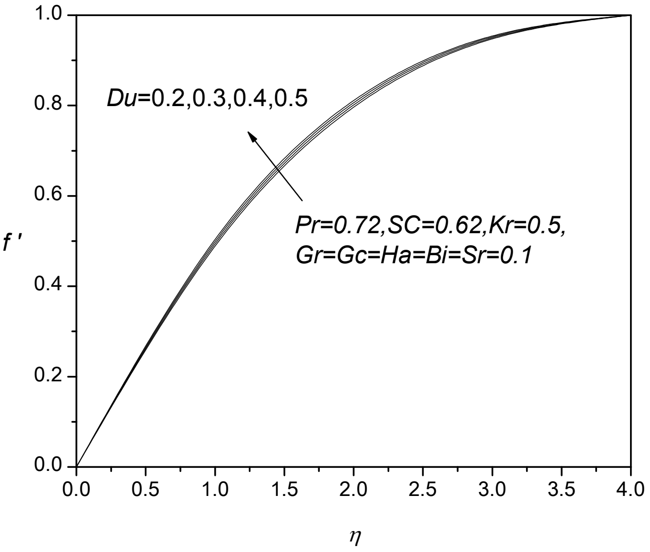

Fig. 7 velocity profiles for different Du

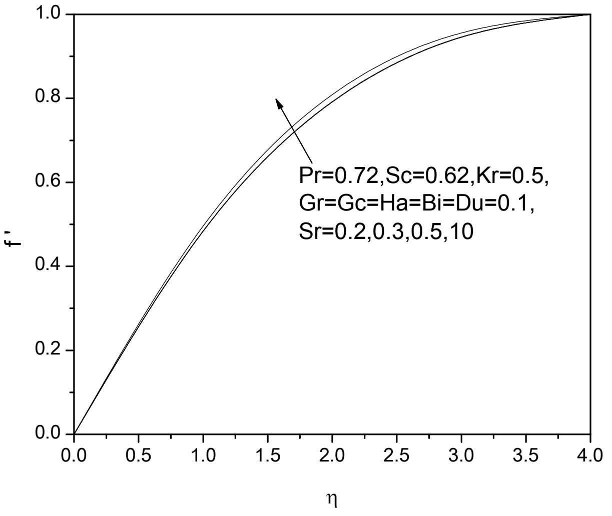

Fig. 8 velocity profiles for different Sr

Parameter variation on temperature profiles

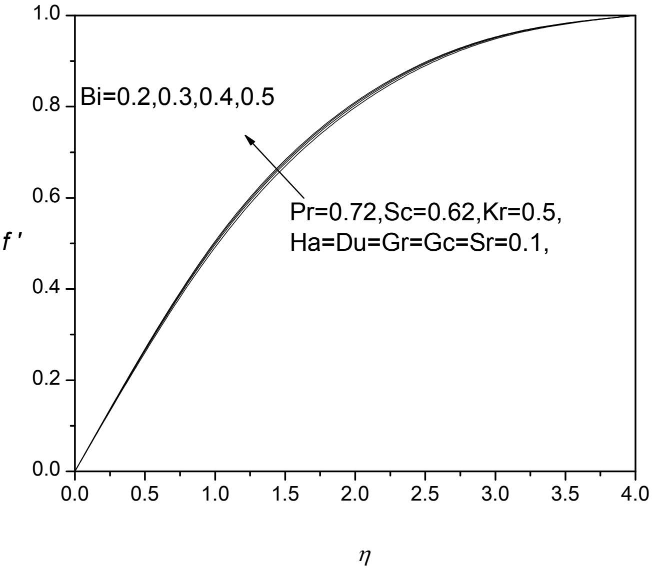

Fig. 9. Velocity profiles for different Bi

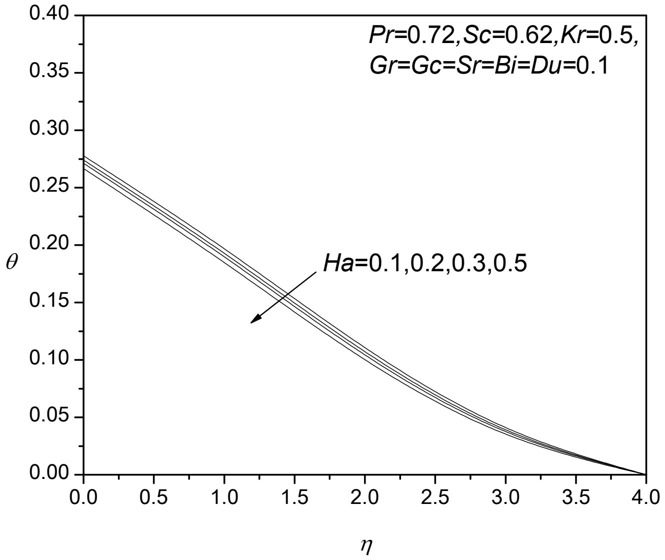

Fig. 10. Temperature profiles for different Ha

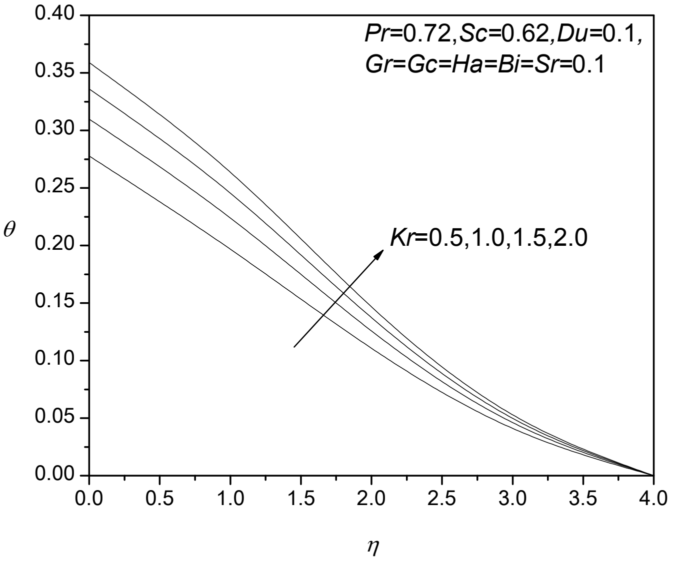

Fig. 11. Temperature profiles for different Kr

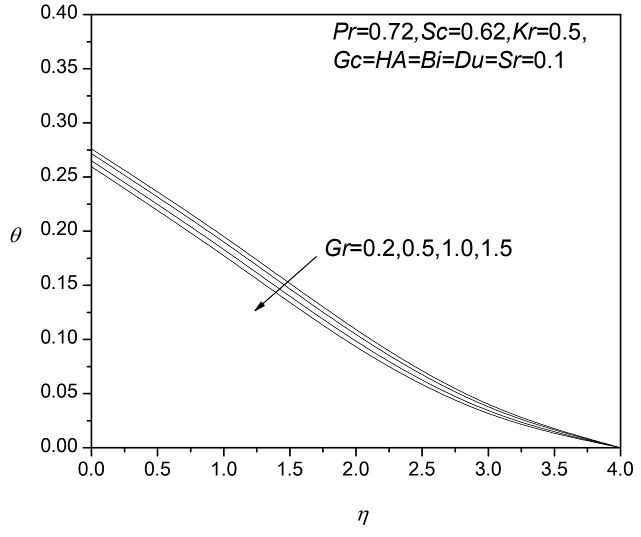

Fig. 12. Temperature profiles for different Gr

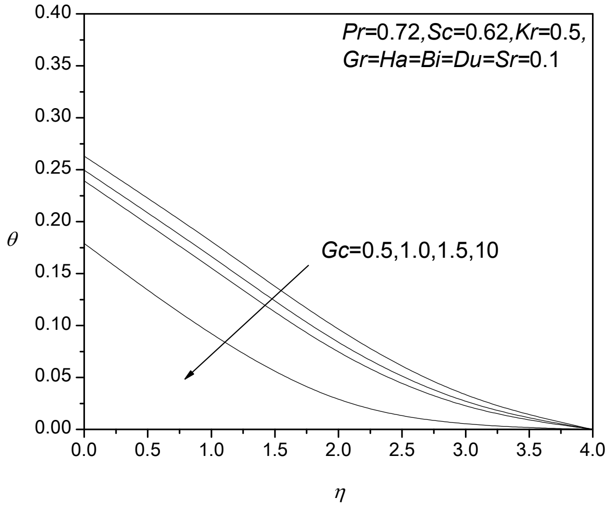

Fig. 13. Temperature profiles for different Gc

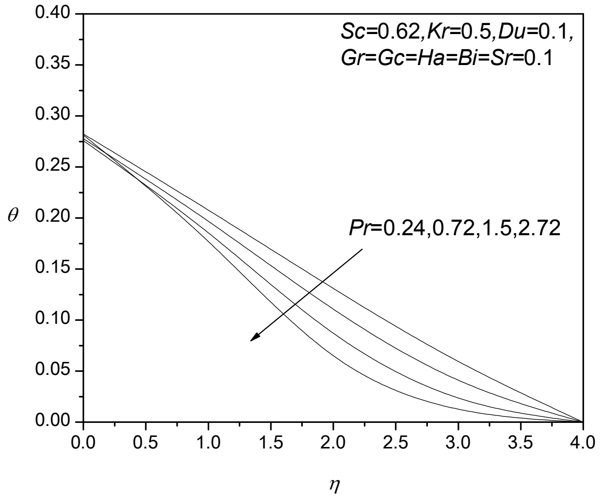

Fig. 14. Temperature profiles for different Pr

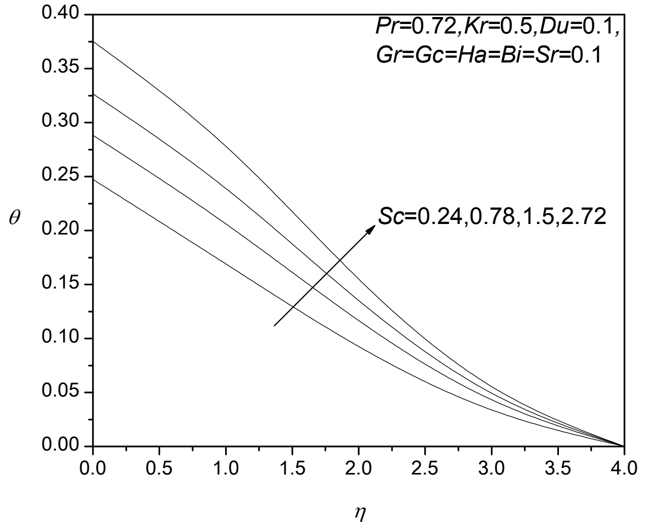

Fig. 15. Temperature profiles for different Sc

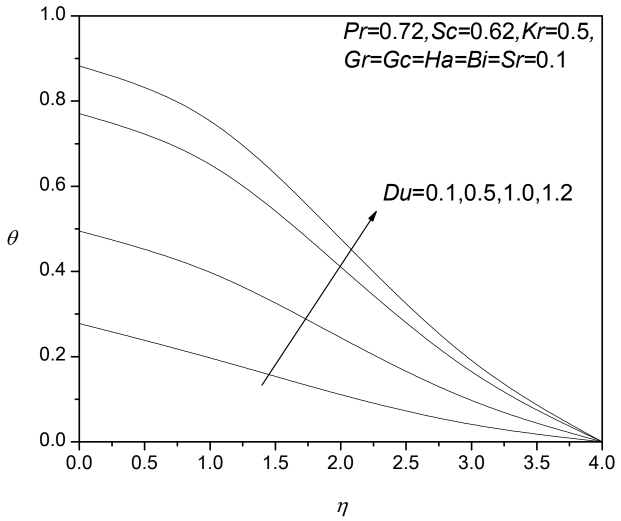

Fig. 16. Temperature profiles for different Du

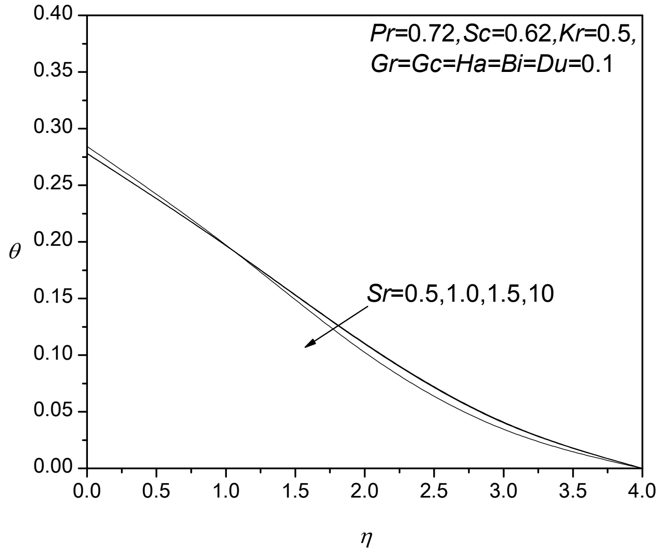

Fig. 17. Temperature profiles for different Sr

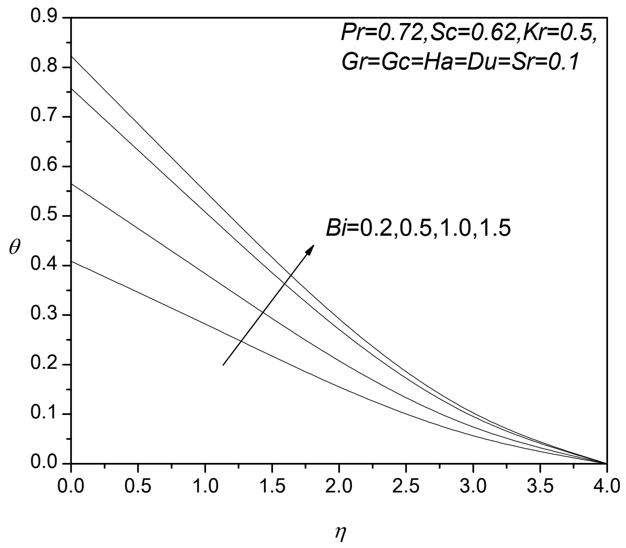

Fig. 18. Temperature profiles for different Bi

Parameter variation on concentration profiles

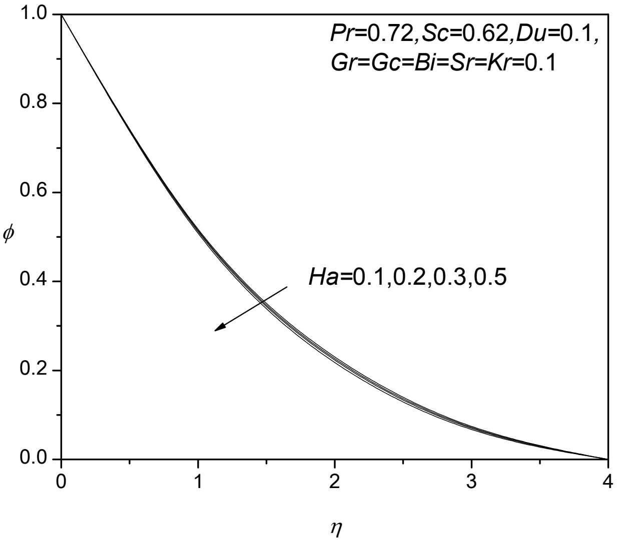

Fig. 19. Concentration profiles for different Ha

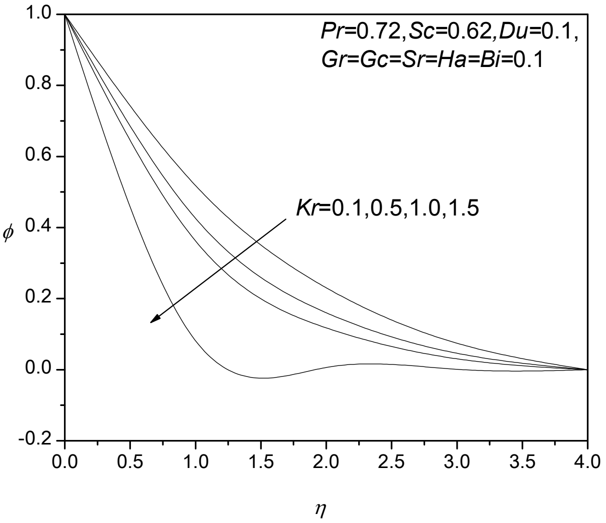

Fig. 20. Concentration profiles for different Kr

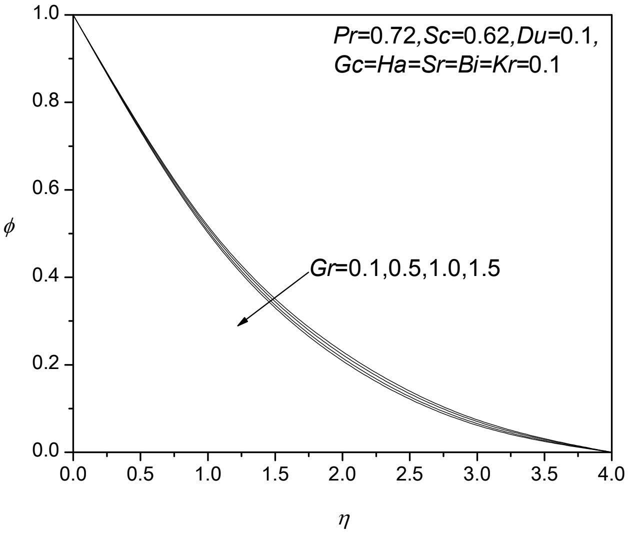

Fig. 21. Concentration profiles for different Gr

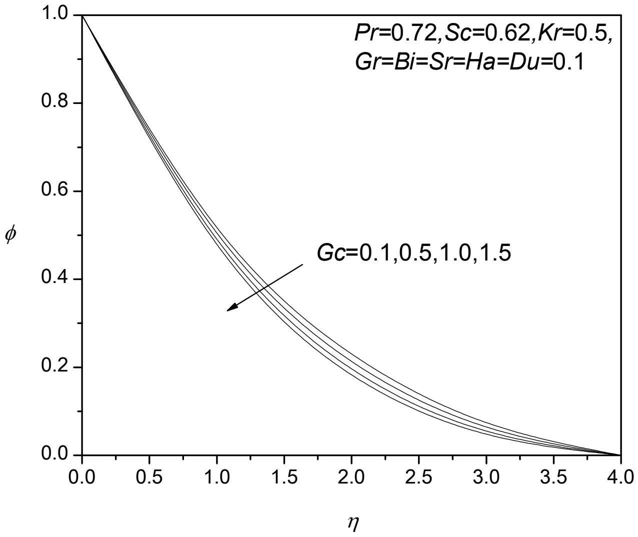

Fig. 22. Concentration profiles for different Gc

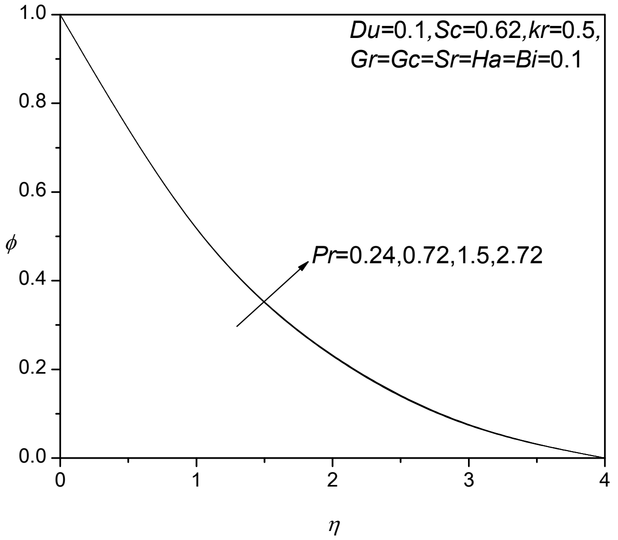

Fig. 23. Concentration profiles for different Pr

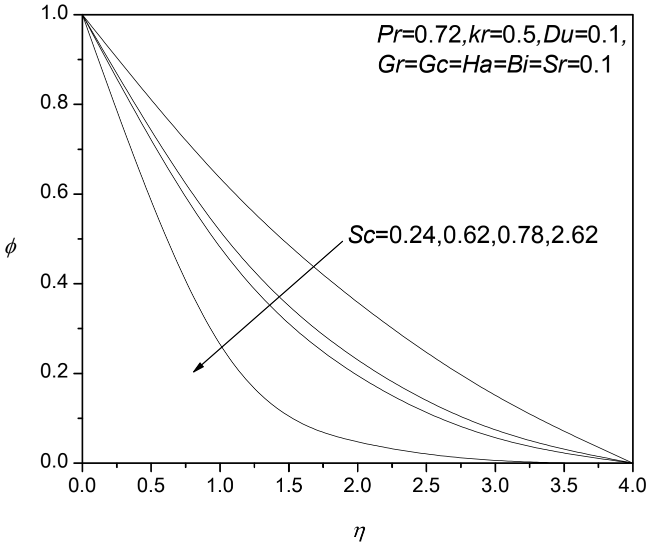

Fig. 24. Concentration profiles for different Sc

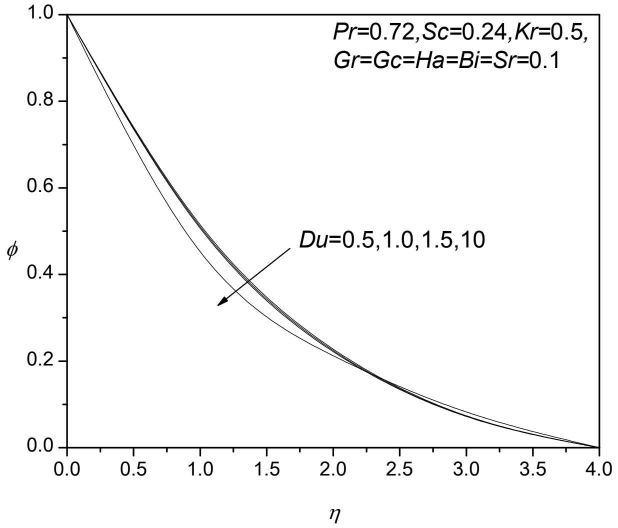

Fig. 25. Concentration profiles for different Du

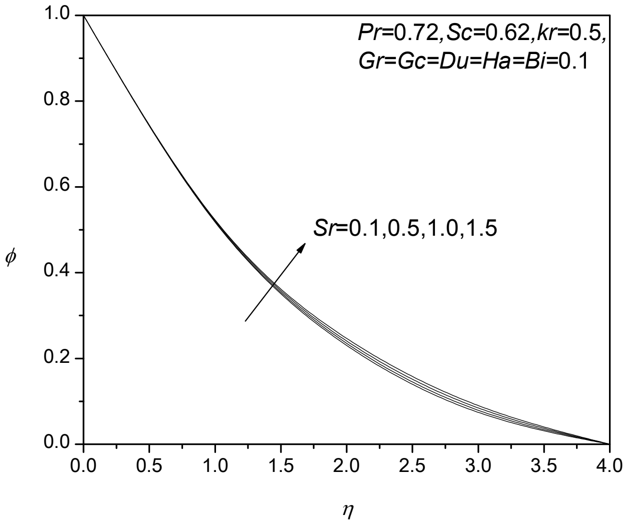

Fig. 26. Concentration profiles for different Sr

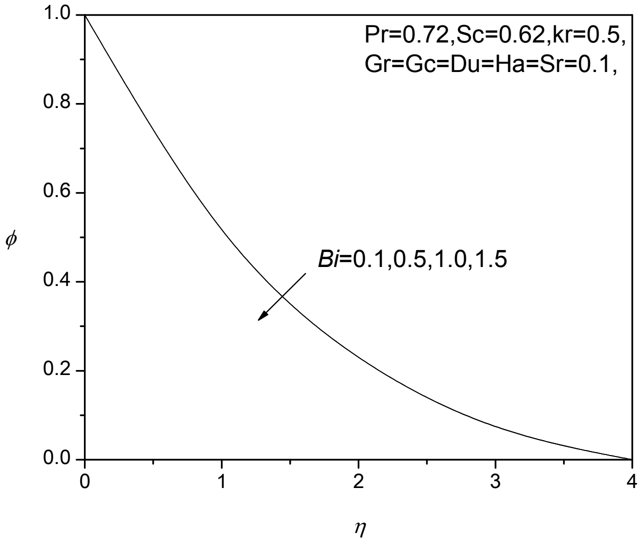

Fig. 27. Concentration profiles for different Bi

Variation of temperature on increasing *Kr* (Chemical reaction rate) is shown in Fig. 11. It is noticed that the temperature of the fluid increases on increasing *Kr*. The effect of *Gr* (Thermal Grashof number) on temperature of the fluid is illustrated in the Fig. 12. Decrease in temperature of the fluid is observed on increasing *Gr*. Fig. 13 depicts the temperature variation on varying solute Grashof number *Gc*. Decrease in temperature is observed on increasing *Gc*. The effect of Prandtl number *Pr* on temperature is shown in Fig. 14. From the figure it is found that temperature decreases on increasing *Pr*. The effect of *Sc*(The Schmidt number) on temperature is shown Fig. 15. It is noticed that on increasing *Sc* the temperature also increases. Fig. 16 shows the variance of temperature for different *Du* (Dufour Number). Increase in the temperature is observed on increasing *Du* in this figure. The effect of Soret number *Sr* on temperature is illustrated in Fig. 17. It is found from the figure that temperature falls down on increasing Sr. The variance of temperature for different *Bi*(The Convective heat transfer parameter) is depicted in Fig.18. Increase in temperature is observed from this figure on increasing *Bi*. The effect of *Ha*(Magnetic field strength parameter) on concentration of the fluid is shown in Fig. 19. It is noticed from the figure that the concentration of the fluid is decreasing on increasing *Ha*. Fig. 20 shows the effect of *Kr* on concentration of the fluid. It is found from the figure that on increasing *Kr* concentration decreases. The variance of concentration for different *Gr*(The Thermal Grashof number) is depicted in Fig. 21. Decrease in concentration is noticed on increasing *Gr*. Fig. 22 illustrates the variation of concentration for different *Gc*(Solute Grashof number). It is observed that concentration decreases on increase in *Gc*. The effect of Prandtl number Pr on concentration is shown in Fig. 23. Increase in concentration is observed on increase in *Pr*. The effect of *Sc*(Schmidt number) on concentration of the fluid is shown in the Fig. 24. It is noticed that on increasing *Sc* the concentration of the fluid is decreasing. The variance of concentration for different *Du* (Dufour number) is depicted in the Fig. 25. It is found from the figure that the concentration decreases on increase in *Du*. Fig. 26 shows the concentration variance for different *Sr*(Sorret number). Increase in concentration is observed on increasing *Sr*. The effect of *Bi*(The Convective heat transfer parameter) on concentration of the fluid is illustrated in the Fig. 27. Decrease in concentration of the fluid is noticed from the figure on increasing *Bi*.

Conclusion

From the present study we arrive at the following significant observations. By comparing the present results with previous work, it is found that there is a good agreement. Velocity profiles increases on increasing the parameters *Ha, Kr, Gr, Gc, Bi* and *Du* whereas velocity decreases on increasing te parameters *Pr* and *Sc*. There is slight or no influence of Soret number on velocity. Temperature of the fluid increases on increasing the parameters *Kr, Sc, Du* and *Bi* but the temperature decreases on increasing the parameters *Ha, Gr, Gc, Pr* and *Sr*. Concentration profiles increases on increasing the parameters Pr and Sr whereas concentration of the fluid decreases on increasing the parameters *Ha, Kr, Gr,Gc,Sc, Du* and *Bi.* Skin friction coefficient and the Sherwood number increases with the increase in the Dufour number while Nusselt number decreases. The increase in the skin friction coefficient and the Nusselt number are observed with the increase in the Soret number where as the Sherwood number decreases. Skin fraction coefficient and Nusselt number decreases where as sherewood number increases on increasing chemical reaction parameter.

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