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MHD DOUBLE DIFFUSIVE CONVECTIVE FLOW PAST A LOW - HEAT - RESISTANCE SHEET WITH SORET - DUFOUR EFFECTS UNDER CHEMICALLY REACTION

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Abstract—*In this manuscript an attempt has been taken to understand the variation in velocity, temperature and concentration for double diffusive MHD chemically reacting free convective fluid flow past a low heat resistance sheet after inclusion of soret and dufor parameter. The boundary layer flow in viscous media is presented in terms of physical model which is transformed in the set of Coupled Ordinary differential equation using similarity transformation. The set of differential equation solved numerically using spectral collocation method. The main emphasis is given on the Varity of physical parameters while change in soret and dufor parameter. The velocity, temperature and stream function is plotted w.r.t to different physical parameter w.r.t the soret and dufor parameters. The internal heating is neglected in this work since it has no meaning when the solutal is dominated over heat effect. A detailed study is made in this work for physical parameter to understand the physical changes while inclusion soret & duffor parameter*

Keywords*: MHD, Double diffusive, Sorer-Duffor.*

1. INTRODUCTION

Heat and mass transfer play an important role in manufacturing industries for the design of fins, steel rolling, nuclear power plants, gas turbines and various propulsion devices for aircraft, combustion and furnace design, materials processing, energy utilization, temperature measurements. . A number of studies have been reported in the literature focusing on the problem of mixed convection about different surface geometries in porous media Extensive reviews on this subject can be found in the books by Ingham and Pop (2005), Vafai (2005), Nield and Bejan (2006).

It is well known that most fluids which are encountered in chemical and allied processing applications do not satisfy the classical Newton's law and are accordingly known as non-Newtonian fluids. Due to the important applications of non-Newtonian fluids in biology, physiology, technology, and industry, considerable efforts have been directed toward the analysis and understanding of such fluids.

Bejan and Khair (1985) studied the buoyancy induced heat and mass transfer from a vertical plate embedded in a saturated porous medium. Rami. Y. Jumah et al. (2013) studied the coupled heat and mass transfer for non-Newtonian fluids. Kumari (2001) analyzed the effect of variable viscosity on free and mixed convection boundary layer flow from a horizontal surface in a saturated porous medium. Postelnicu et al. (2001) investigated the effect of variable viscosity on forced convection over a horizontal flat plate in a porous medium with internal heat generation. Seddeek (2005), studied the effects of chemical reaction, variable viscosity, and thermal diffusivity on mixed convection heat and mass transfer through porous media. Mohamed E- Ali (2006) studied the effect of variable viscosity on mixed convection along a vertical plate. Alam et al (2006) analyzed the study of the combined free - forced convection and mass transfer flow past a vertical porous plate in a porous medium with heat generation and thermal diffusion

Coupled heat and mass transfer by natural convection in a fluid saturated porous medium has received great attention during the last decades due to the importance of this process which occurs in many engineering, geophysical and natural systems of practical interest such as geothermal energy utilization, thermal energy storage and recoverable systems and petroleum reservoirs. When heat and mass transfer occurs simultaneously between the fluxes, the driving potential is of more intricate nature, as 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. Temperature gradients can also create mass fluxes, and this is the Soret or thermal-diffusion effect. The Dufour and Soret effects were neglected in many reported research studies, since they are of a smaller order of magnitude than the effects described by Fourier's and Fick's laws. Anghel et al(2000) investigated the Dufour and Soret effects on free convection boundary layer over a vertical surface embedded in a porous medium . M. B. K. Moorthy et al (2012) studied Soret and Dufour effects on natural convection flow past a vertical surface in a porous medium with variable viscosity

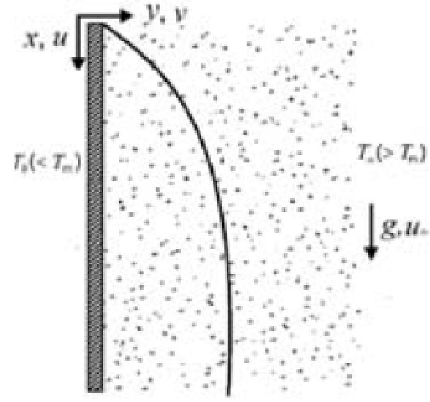
Recently Shyam et al.(2010) examined the Soret and Dufour effects on the MHD natural convection over a vertical surface embedded in a Darcy porous medium in the presence of thermal radiation. Numerical investigation of Dufour and Soret effects on unsteady MHD natural convection flow past vertical plate embedded in non-Darcy porous medium was investigated by Al-Odat and Al- Ghamdi(2012). Ali-Chamkha and Mansour(2011) examined the effect of chemical reaction, thermal radiation, and heat generation or absorption on the unsteady MHD free convective heat and mass transfer along an infinite vertical plate. Soret and Dufour Effects on Mixed Convection from an Exponentially Stretching Surface was discussed by Srinivasacharya and Ram Reddy(2011). Bég*et al. (2009)* used the finite element method to analyze reactive micropolar magneto-convective boundary layers from a nonlinear stretching surface in porous media with applications in liquid metal flows with inclusions. Makinde and Bég (2010) studied Bejan number effects in reactive hydromagnetic channel flow, also describing criticality in the solutions. In above studies Soret–Dufour effects were assumed to be negligible. However, when chemical species are introduced at a surface in fluid domain, with different (lower) density than the surrounding fluid, both Soret (thermo-diffusion) and Dufour (diffusion-thermal) effects can be influential. The effect of diffusion-thermo and thermal diffusion of heat and mass has been developed from the kinetic theory of gases by Chapman and Cowling (1952) and Hirshfelder*et al. (1954)*. They explained the phenomena and derived the necessary formulae to calculate the thermal diffusion coefficient and the thermal-diffusion factor for monatomic gases or for polyatomic gas mixtures Bhargava et al. (2009) used finite element and finite difference techniques to simulate periodic chemically-reacting hydromagnetic natural convection double-diffusive boundary layers in porous media with Soret and Dufour effects. Bég et al. (2009) presented a numerical study of free convection magneto hydrodynamic heat and mass transfer from a stretching surface to a saturated porous medium with Soret and Dufour effects. Recently O. D. Makind , et al (2012) investigated the hydro magnetic flow and mass diffusion of chemical species with first- and higher-order reactions of an electrically conducting fluid over a moving vertical plate considering diffusion-thermo (Dufour) and thermal-diffusion (Soret) effects with convective heat exchange at the plate surface.

Many researchers have done credible work in the mention fields. Chamkha et al. (2008) studied MHD mixed convection radiation interaction along a permeable surface immersed in a porous medium in the presence of Soret and Dufour effects. Prabhu et al. (2005) considered the effects of chemical reaction, heat and mass transfer on MHD flow over a vertical stretching surface with heat source and thermal stratification effects. Postelnicu (2007) studied the influence of chemical reaction on heat and mass transfer by natural convection from vertical surfaces in porous media by considering Soret and Dufour effects. Ibrahim et al. (2008) analyzed the effects of chemical reaction and radiation absorption on the unsteady MHD free convection flow past a semi infinite vertical permeable moving plate with heat source and suction. Unsteady natural convective power-law fluid flow past a vertical plate embedded in a non-Darcian porous medium in the presence of a homogeneous chemical reaction was studied by Chamkha(2010).

S. Kapoor et al (2011) considered two-dimensional laminar natural convection flow and heat transfer of a viscous incompressible, electrically conducting fluid past a vertical impermeable flat plate in presence of a uniform transverse magnetic field in porous media Recently Pal and Mondal (2012) studied the influence of chemical reaction and thermal radiation on mixed convection heat and mass transfer over a stretching sheet in Darcy porous medium with Soret and Dufour effects. D. Srinivasacharya (2015) made an attempt to obtain similarity solutions for mixed convection heat and mass transfer along a vertical plate embedded in a power-law fluid saturated porous medium. It is established that similarity solutions are possible only when variation in the temperature and concentration flux are linear functions of the distance from the leading edge measured along the plate. S.Rawat et al (2012) focused to develop a mathematical model for the comparative study of combined effects of free conve active heat and mass transfer on the steady two dimensional, laminar fluid flow past a moving permeable vertical surface subjected to a transverse uniform magnetic field. B. Madhusudhanara et al (2012) 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

2. MATHEMATICAL MODEL

Let us consider the problem of cooling of a low-heat-resistance sheet that moves downwards in a viscous fluid when the velocity of the fluid far away from the plate is equal to zero. The variation of surface temperature are linear. The flow configuration and coordinate system is shown in Fig.1. All the fluid properties are assumed to be constant except for the density variations in the buoyancy force term of linear momentum. The magnetic Reynolds number is assumed to be small, so that the induced magnetic field is neglected. Electric field is assumed to exists and both viscous and magnetic dissipation are neglected. The Hall Effect, viscous dissipation and the joule heating term are neglected. Under these assumption along with the Bousineque approximation, the boundary layer equation for the problem.



3. GOVERNING EQUATION

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0 \quad (1)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\left(\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_\infty)+g\beta(S-S_\infty)-J\times B \quad (2)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\kappa\frac{\partial^2 T}{\partial y^2}+\frac{\sigma k_T}{c_s c_p}\frac{\partial^2 S}{\partial y^2} \quad (3)$$

$$u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}=\sigma\frac{\partial^2 S}{\partial y^2}+\frac{\sigma k_T}{T_m}\frac{\partial^2 T}{\partial y^2}+\Gamma S \quad (4)$$

Where J is Current density, Γ is the chemical reaction rate parameter.

Neglecting the displacement current, the Maxwell equation and Ohm's law becomes

$$divB=0, CurlB=\mu_e J, CurlE=-\frac{\partial B}{\partial t} \quad (5)$$

Where B is magnetic field strength

$J=\sigma\,(E+V\times B)$ (6)

Where σ is electrical conductivity

and μ_e is the magnetic permeability

E is the electric field

The imposed and induced electric field are assume to be negligible under the assumption of low magnetic Reynolds number

$$J\times B=-\sigma\mu_e^2 H_0^2 u \quad (7)$$

i.e equation reduce to

$$\frac{\partial u}{\partial x}+\frac{\partial u}{\partial y}=0 \quad (8)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\left(\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_\infty)+g\beta(S-S_\infty)-\sigma\mu_e^2 H_0^2 u \quad (9)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\kappa\frac{\partial^2 T}{\partial y^2}+\frac{\sigma k_T}{c_s c_p}\frac{\partial^2 S}{\partial y^2} \quad (10)$$

$$u\frac{\partial S}{\partial x}+v\frac{\partial S}{\partial y}=\sigma\frac{\partial^2 S}{\partial y^2}+\frac{\sigma k_T}{T_m}\frac{\partial^2 T}{\partial y^2}+\Gamma S \quad (11)$$

Subject to the boundary conditions

$$u=0,\ \ v=0,\ \ T=T_0, S=S_0 \text{ at } y=0 \quad (12)$$

$$u\to 0,\ \ T\to\infty, S\to\infty \text{ as } y\to\infty, \quad (13)$$

$$\psi=[g\beta(T-T_\infty)v^2x_0^3]^{\frac{1}{4}}f(\eta), \quad (14)$$

$$T=T_\infty+(T-T_\infty)\left[\frac{x_0}{x_0-x}\right]^3\theta(\eta), \quad (15)$$

$$S=S_\infty+(S-S_\infty)\left[\frac{x_0}{x_0-x}\right]^3\emptyset(\zeta) \quad (16)$$

$$\eta=\left[\frac{g\beta(T-T_\infty)x_0^3}{v^2}\right]\frac{y}{(x_0-x)}, \quad (17)$$

$$\zeta=\left[\frac{g\beta(S-S_\infty)x_0^3}{v^2}\right]\frac{y}{(x_0-x)} \quad (18)$$

$$f'''-(f'+M)f'+Gr\theta+Gc\emptyset=0, \quad 19)$$

$$\frac{1}{\Pr}\theta''-3f'\theta+3Du\emptyset''=0. \quad (20)$$

$$\frac{1}{\mathrm{Sc}}\emptyset''-3f'\emptyset+3Sr\theta''-Kr\emptyset=0 \quad (21)$$

The boundary conditions becomes

$$f(0)=0,\ \ f'(0)=0,\ \ f'(\infty)\to 0, \quad (22)$$

$$\theta(0)=1,\ \ \theta'(0)=0\ \ \theta(\infty)\to 0, \quad (23)$$

$$\emptyset(0)=1, \emptyset'(0)=0\ \ \emptyset(\infty)\to 0 \quad (24)$$

4. NUMERICAL COMPUTATION

The Spectral collocation method is adopted to find the numerical solution of the nonlinear coupled differential Equations (19)-(21) under the boundary condition (22)-(24) The comparison is also made with the finite difference technique which is available in literature.

The equation (19)-(21) may be written as

$$\frac{d^3f}{d\eta^3}-\left(\frac{df}{d\eta}+M\right)\frac{df}{d\eta}+Gr\theta+Gc\emptyset=0 \quad (25)$$

$$\frac{1}{Pr}\frac{d^2\theta}{d\eta^2}-3\frac{df}{d\eta}\theta+3Du\frac{d^2\emptyset}{d\eta^2}=0 \quad (26)$$

$$\frac{1}{Sc}\frac{d^2\emptyset}{d\eta^2}-3\frac{df}{d\eta}\emptyset+3Sr\frac{d^2\theta}{d\eta^2}-Kr\emptyset=0 \quad (27)$$

η ζ are the dimensionless y-coordinate

Kr is the local dimensionless chemical reaction rate parameter.

$Pr=\frac{\vartheta}{\alpha}$ is the Prandtl Number, $Sc=\frac{v}{D}$ is the Schmidt Number,

θ is the dimensionless temperature and $\emptyset$ is the dimensionless concentration.

f is the dimensionless stream function,

To approximate the field variables Suppose f and θ by Chebyshev polynomials the range [0,4] of the independent variable, η is mapped in to [-1,1] by using the function $2-2\xi=\eta$

Here the maximum value of η is fixed to be 4 for the sake of connivance of the solution of flow dynamics

The governing equation (25)-(27) and the corresponding boundary condition in terms of Chebyshevξ

$$\frac{d^3f}{-2d\xi^3}+\frac{1}{2}\left(\frac{df}{-2d\xi}+M\right)\frac{df}{d\xi}+Gr\theta+Gc\emptyset=0 \quad (28)$$

$$-\frac{1}{Pr}\frac{d^2\theta}{2d\xi^2}-\frac{3}{2}\frac{df}{d\xi}\theta-\frac{3}{2}Du\frac{d^2\emptyset}{d\xi^2}=0 \quad (29)$$

$$-\frac{1}{2\,Sc}\frac{d^2\emptyset}{d\xi^2}+\frac{3}{2}\frac{df}{d\xi}\emptyset-\frac{3}{2}Sr\frac{d^2\theta}{d\xi^2}-Kr\emptyset=0 \quad (30)$$

The boundary conditions becomes

$$\theta=f=\emptyset=0\ at\ \xi=1\ and\ \frac{df}{d\xi}=\frac{d\theta}{d\xi}=\frac{d\emptyset}{d\xi}=0\ at\ \xi=-1 \quad (31)$$

Now the equations becomes

$$-\frac{1}{2}\sum_{k=0}^{n}C_{jk}f_k+\frac{1}{2}\left(-\frac{1}{2}\sum_{k=0}^{n}A_{jk}f_k+M\right)\sum_{k=0}^{n}A_{jk}f_k+Gr\theta+Gc\emptyset=0 \quad (32)$$

$$-\frac{1}{2Pr}\sum_{k=0}^{n}B_{jk}\theta_k-\frac{3}{2}\sum_{k=0}^{n}A_{jk}f_k\,\theta-\frac{3}{2}Du\sum_{k=0}^{n}B_{jk}\emptyset_k=0 \quad (33)$$

$$-\frac{1}{2\,Sc}\sum_{k=0}^{n}B_{jk}\emptyset_k+\frac{3}{2}\sum_{k=0}^{n}A_{jk}f_k\,\emptyset-\frac{3}{2}Sr\sum_{k=0}^{n}B_{jk}\theta_k-Kr\emptyset=0 \quad (34)$$

Where j=1,2,3…n-1

$$A_{jk}=\begin{cases}\dfrac{c_j(-1)^{k+j}}{c_k(\xi_j-\xi_k)}, & j\neq k\\ \dfrac{\xi_j}{2(1-\xi_j^2)}, & 1\le j=k\le n-1\\ \dfrac{2n^2+1}{6}, & j=k=0\\ -\dfrac{(2n^2+1)}{6}, & j=k=n\end{cases}$$

And $B_{jk}=A_{jm}A_{mk}$

$$C_{jk}=B_{jm}A_{mk}$$

In the above

$$c_j=\begin{cases}2, & j=0,n\\ 1, & 1\le j\le n-1\end{cases}$$

And$\xi_j=\frac{cos\pi j}{n}, for\ 0\le j\le n$are chebyshev collocation points .

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

Where a, b, c, d are constants

5. RESULT AND DISSCUSSION

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, Grash of number Gr>0(which corresponds to the cooling problem) and solutal Grash of number Gc>0(which indicates that the chemical species concentration in the free stream region is less then the concentration at the boundary surface

Effects of parameter variation on velocity profiles:

The effects of various parameters on velocity profiles in the boundary layer are depicted in Figures 1-6.9. 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 (*M*) 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. Figures 6.3,6.4,6.7,6.8&6. 9shows the variation of the boundary-layer velocity with the buoyancy forces parameters (*Gr*,*Gc*), Dufour number (*Du*) and Soret number (*Sr*). In the above 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. Figure 5 and 6 shows a slight decrease in the fluid velocity with an increase in the Schmidt number (*Sc*) and chemical reaction parameter (κr).

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 10-19. From these figures, it is interesting to note that the thermal boundary layer thickness decreases with an increase in the intensity of magnetic field *M*, the buoyancy forces (*Gr*,*Gc*), prandtl number parameter (*Pr*) and Soret number (*Sr*). Moreover, the fluid temperature increases with an increase in the Schmidt number (*Sc*), chemical reaction parameter (κr), and Dufour number (*Du*) leading to an increase in thermal boundary layer thickness.

Effects of parameter variation on concentration profiles:

Figures 20-27 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*),, Dufour number (*Du*)and chemical reaction parameter (κr)and Moreover, the fluid concentration increases with an increase in the Soret number (*Sr*)leading to an increase in thermal boundary layer thickness.

6. CONCLUSION

From the above study we conclude the following

i) The Spectral collocation method gives much similar result as we obtained in Finite difference method
ii) Every profile (Velocity or temperature and concentration) has shows an asymptomatic behavior and converges for the large value of η
iii) The soret and duffor effected the velocity, temperature and concentration profile significantly
iv) The species concentration is highest at the plate surface and decrease to zero far away from the plate satisfying the boundary condition
v) The magnetic is effect cursively in presence of soret and dufor parameter, the thermal boundary layer thickness decreases with an increase in the intensity of magnetic field *M*,
vi) 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
vii) Increasing Schmidt number reduces mass transfer function both in the reactive and non-reactive flow cases, although mass transfer function values are always higher for any Sc value in the non-reactive case (Kr = 0).

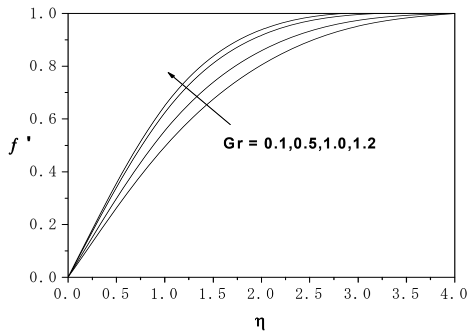


Fig.2: Variation of the velocity component f' with *Gr* for Pr=0.72, Sc=0.62, Gc =M=0.1, Kr=0.5, Du=0.2, Sr=1.0.

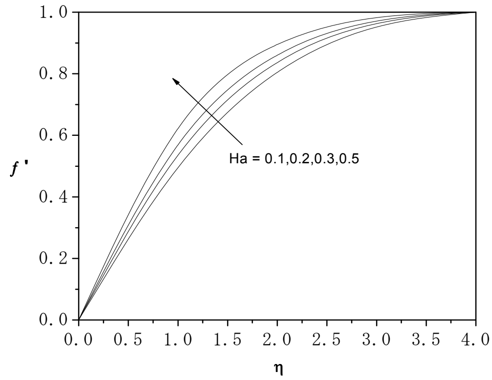


Fig.3: Variation of the velocity component f' with *Ma* for Pr=0.72, Sc=0.62, Gr=Gc=0.1, Kr=0.5, Du=0.2, Sr=1.0

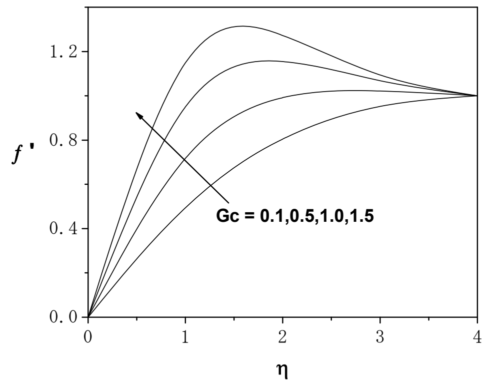


Fig.4: Variation of the velocity component f' with Gc for Pr=0.72, Sc=0.62, Gr=M=0.1, Kr=0.5, Du=0.2, Sr=1.0.

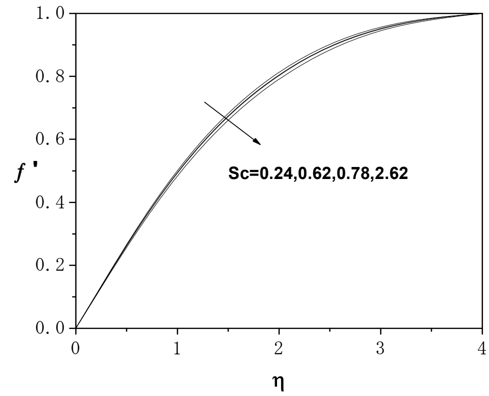


Fig.5: Variation of the temperature with Sc for Pr=0.72,Gr=Gc=M=0.1,Kr=0.5,Du=0.2, Sr=1.0

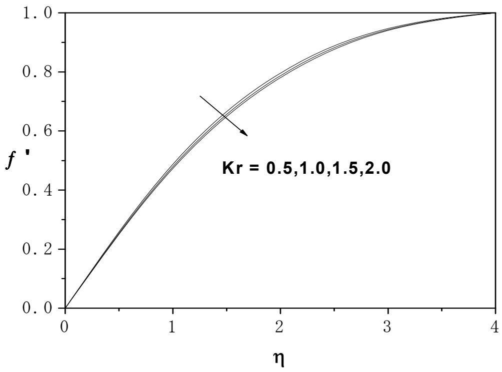


Fig .6: Variation of the velocity component f' with *Kr* for Pr=0.72 ,Sc=0.62, Gr=Gc=M=0.1,Du=0.2,Sr=1.0.

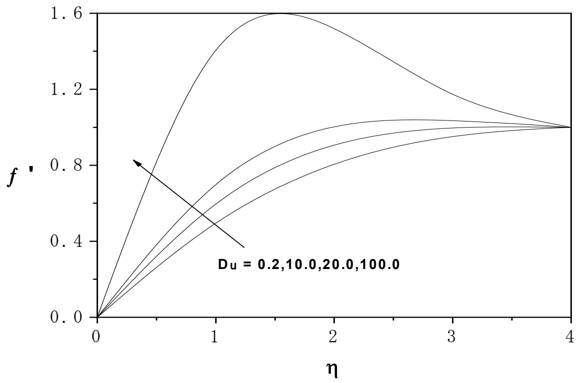


Fig.7: Variation of the velocity component f' with *Du* for Pr=0.72 ,Sc=0.62, Gr=Gc= M=0.1 ,Kr=0.5,Sr=1.0

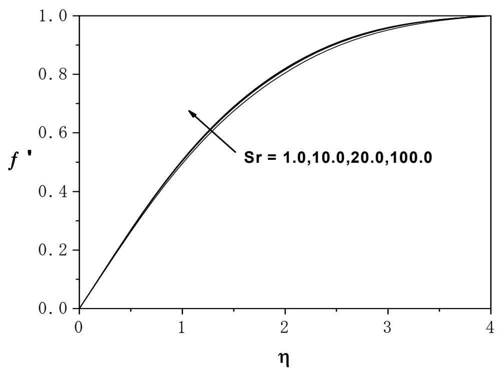


Fig.8: Variation of the velocity component f' with *Sr* for Pr=0.72 ,Sc=0.62, Gr =Gc=M=0.1, Kr=0.5,Du=0.2.

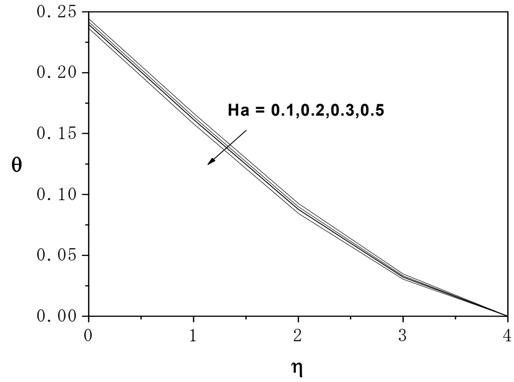


Fig.9: Variation of the temperature θ with Mfor Pr=0.72,Sc=0.62,Gr=Gc=0.1, Kr=0.5,Du=0.2,Sr=1.0.

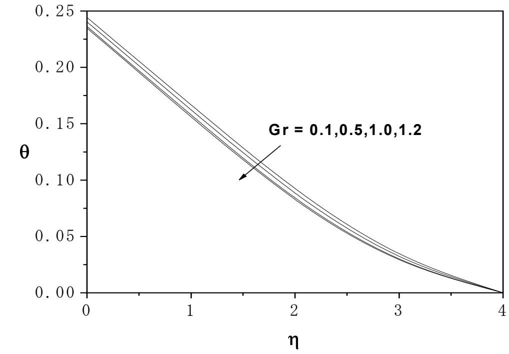


Fig.10: Variation of the temperature θ with *Gr* for Pr=0.72, Sc=0.62,Gc=M=0.1, Kr=0.5,Du=0.2,Sr=1.0.

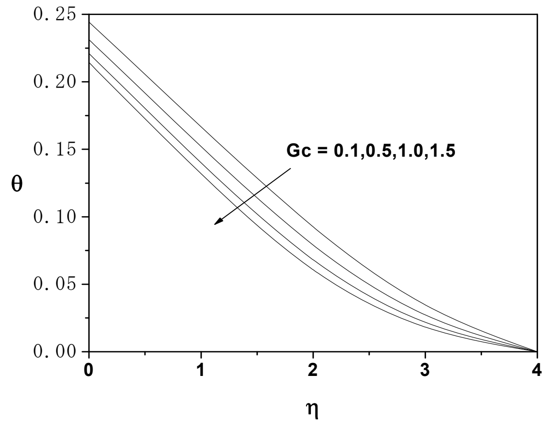


Fig.11: Variation of the temperature θ with *Gc* for Pr=0.72, Sc=0.62,Gr=Sr=M=0.1, Kr=0.5, Du=0.2, Sr=1.0.

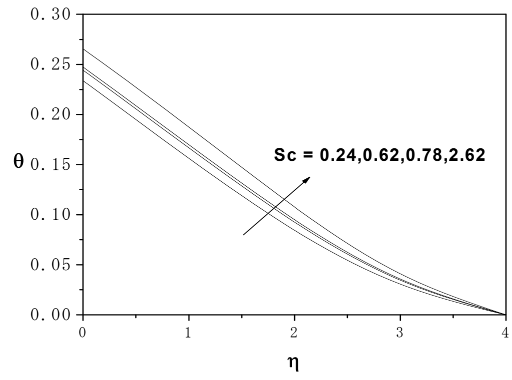


Fig.12: Variation of the temperature θ with *Sc*for Pr=0.72,Gr=Gc=M=0.1, Kr=0.5,Du=0.2,Sr=1.0,Ec=0.01.

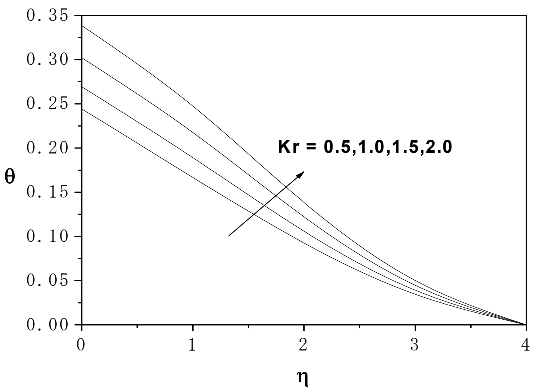


Fig.13: Variation of the temperature θ with *Kr* forPr=0.72,Sc=0.62,Gr=M=0.1, Du=0.2,Sr=1.0.

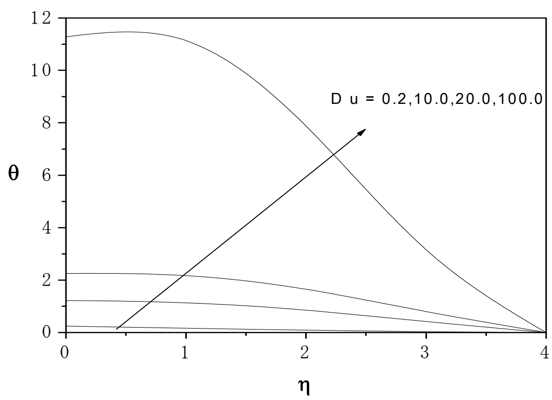


Fig.14: Variation of the temperature θ with *Gc*for Pr=0.72,Sc=0.62,Gr=SM=0.1, Kr=0.5, Sr=0.1

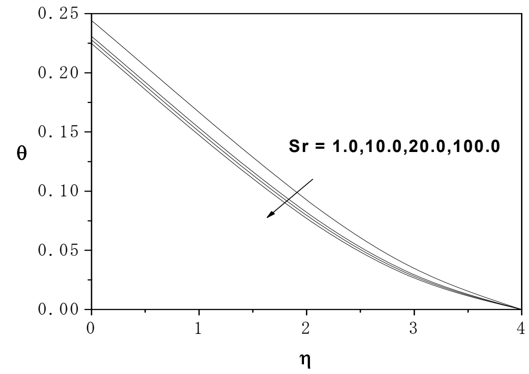


Fig.15: Variation of the temperature θ with Srfor Pr=0.72, Sc=0.62,Gr=Gc =M =0.1, Kr=0.5, Du=0.2, Sr=1.0,

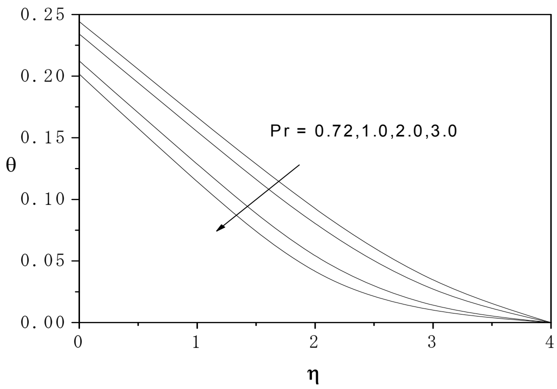


Fig.16: Variation of the temperature θ with *Pr*for Sc=0.62,Gr=M=Gc =0.1, Kr=0.5, Du=0.2, Sr=1.0.

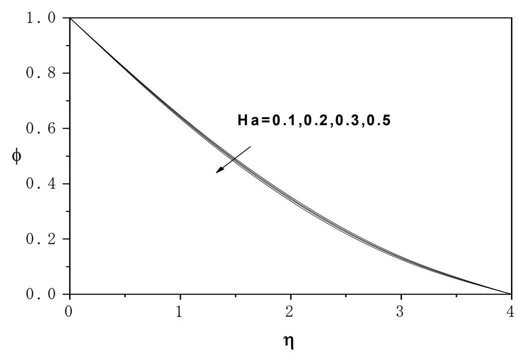


Fig.17: Variation of the concentration ϕ with M for Pr=0.72,Sc=0.62, Gr=Gc=0.1, Kr=0.5, Du=0.2, Sr=1.0

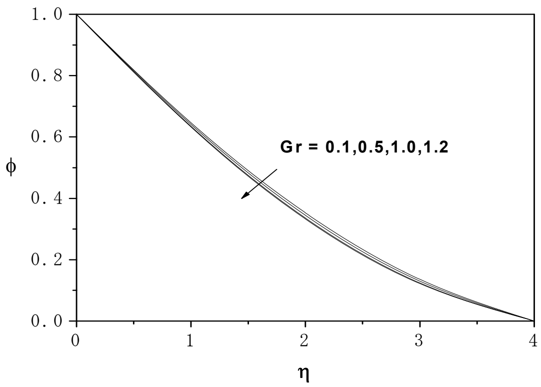


Fig.18: Variation of the concentration ϕ with *Gr* for Pr=0.72 ,Sc=0.62, M= Gc=0.1, Kr=0.5, Du=0.2,Sr=1.0

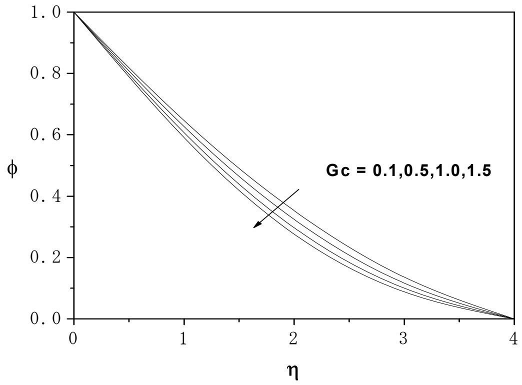


Fig.19: Variation of the concentration ϕ with *Gc* for Pr=0.72 ,Sc=0.62 ,Gr=M=0.1, Kr=0.5,Du=0.2, Sr=1.0

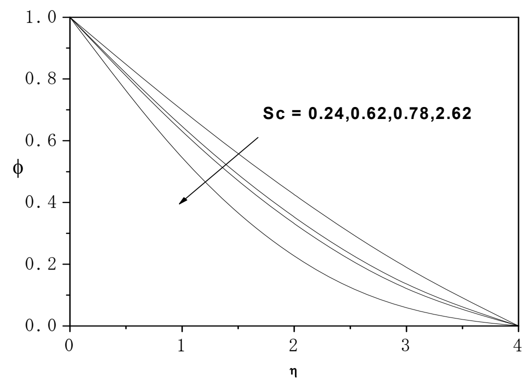


Fig.20: Variation of the concentration ϕ with *Sc* for Pr=0.72, Kr=0.5 ,Gr=Gc=M=0.1, Du=0.2 ,Sr=1.0

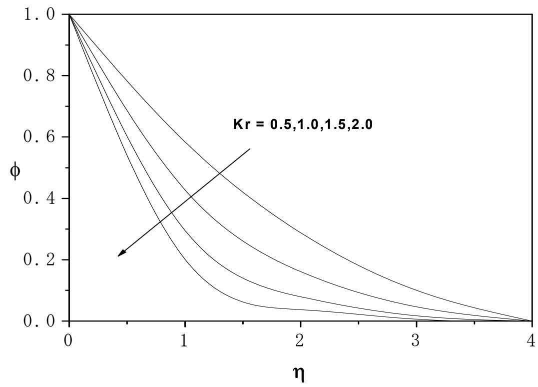


Fig.21: Variation of the concentration ϕ with *Kr* for Pr=0.72, Du=0.2,Sc=0.62,Gr=Gc=M=0.1, Sr=1.0,

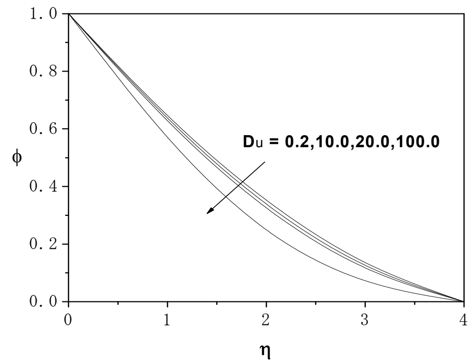


Fig.22: Variation of the concentration ϕ with *Du* for Pr=0.72, Kr=0.5, Sc=0.62,Gr=Gc=M=0.1, Sr=1.0.

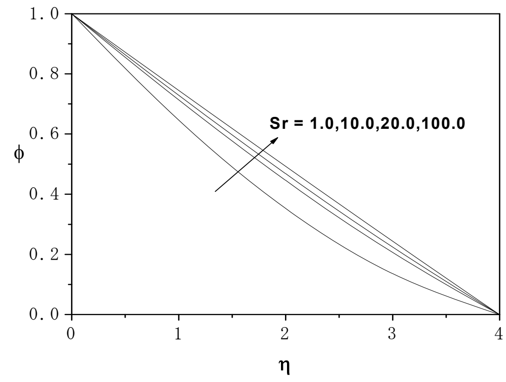


Fig.23: Variation of the concentration ϕ with *Sr* for Pr=0.72, Sc=0.62, Gr=Gc =M=0.1, Kr=0.5, Du=0.2.

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