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Ascendancy of Thermophoresis with Chemical Reaction on MHD Fluid Flow along an Inclined Surface in Presence of Heat and Mass Deportation

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Abstract

Ramifications of two dimensional viscous MHD incompressible fluid cavorted by an inclined surface in perseverance of chemical reaction, thermophoresis and heat source have been explored. The concurrent upshots of constant heat and mass flux in consideration of uniform magnetic field is also taken into account. The suction velocity at the surface is expected to be constant. Numerical technique has been explicated to solve the problem. The pertinent properties of overall structure of the fluid motion are elucidated with graphical illustrations. Application of this type of study has been interjected in industrial and chemical processes.

Keywords: Thermophoresis, MHD, Shearing stress, Nusselt number, Sherwood number

1. INTRODUCTION

In fluid dynamics, viscous fluid flow across a porous medium in existence of magnetic field has numerous applications in engineering, industries, polymer industries, food processing industries etc. Evaluation of flow across a porous surface in occurrence of heat source, chemical reaction and thermophoresis has lots of major applications in heat exchanger fouling, aerosol reactors, optical fibre etc. Srinivasa Rao et al.[1] have discussed hall current effect along with heat source and thermophoresis on dissipative aligned MHD convective flow embedded in a porous medium. Debnath et al.[2] have studied the shear thickening and shear thinning cases of fluid motion in presence of thermophoresis and diffusion thermo effect. Helal et al.[3],Animasaun et al.[4], Kabir et al.[5], Deka et al.[6],Raju et al.[7] etc. have worked on various fluid properties along with thermophoresis. Besides them, Seethamahalaskshmi et al.[8], Umemura et al.[9], Hossain et al.[10],Sivashankaran et al.[11],Alam et al.[12], Bhuvaneswari et al.[13], Kandasamy et al.[14] etc also have introduced lots of fluid properties in their researches. Apart from them Kandasamy et al.[15], Prakash et al.[16], Kandasamy et al.[17], Kandasamy et al.[18], H. Kumar et al.[19],S. Mathanrao et al.[20] have contributed various phenomenon of fluid and the outcomes acquired by them are really commendable.

The objective of this paper is to analyze the consequences of chemical reaction, heat source and thermophoresis on a steady two dimensional fluid flow through a porous medium cavorted by an inclined surface with constant suction velocity under the influence of magnetic field applied normal to the direction of flow. MATLAB'S built in solver bvp4c is used to solve the differential equations and the results are depicted by graphical illustration.

2. MATHEMATICAL FORMULATION

Consider two dimensional steady viscous MHD fluid stream across a porous surface cavorted by an inclined surface in account of chemical reaction and thermophoresis. Suppose the fluid is transmitted along $\bar{x}$ direction and $\bar{y}$ axis is taken normal to it .The effect of magnetic Reynolds number has considered to be very small. We are also neglect the action of induced magnetic field. Except body forces, all the forces acting on the fluid are presumed to be constant. Since the plate is infinite in length, therefore all the variables are functions of y only. Using boundary layer approximation, the governing equations are composed as:

Equation of continuity:

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

$$\text{i.e,} \quad \bar{v} = \text{Constant} = -v_0 \tag{2}$$

where, $v_0 > 0$

Equation of Momentum:

$$-v_0 \frac{\partial \bar{u}}{\partial \bar{y}} = \nu \frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + g\cos\phi\beta(\bar{T} - \bar{T}_\infty) + g\cos\phi\beta_1(\bar{C} - \bar{C}_\infty) - \left(\frac{\sigma B_0^2}{\rho}\right)\bar{u} - \frac{\nu}{k}\bar{u} \tag{3}$$

Equation of Energy:

$$-v_0 \frac{\partial \bar{T}}{\partial \bar{y}} = \frac{\lambda}{\rho C_p}\frac{\partial^2 \bar{T}}{\partial \bar{y}^2} + \frac{\nu}{C_p}\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 + \frac{Q_h}{\rho C_p}(\bar{T} - \bar{T}_\infty) \tag{4}$$

Equation of Concentration:

$$-v_0\frac{\partial\bar{C}}{\partial\bar{y}} = D\frac{\partial^2\bar{C}}{\partial\bar{y}^2} + k_c(\bar{C}-\bar{C}_\infty) - \frac{\partial}{\partial\bar{y}}[V_T(\bar{C}-\bar{C}_\infty)] \tag{5}$$

where $\bar{u}$ and $\bar{v}$ are fluid velocity components along and perpendicular to the surface, ν is kinematic viscosity , g is acceleration due to gravity, ϕ is inclination of the plate, β is the coefficient of volume expansion for heat transfer, β_1 is the volumetric coefficient of expansion with species concentration, $\bar{T}$ fluid temperature, $\bar{T}_\infty$ far field temperature, $\bar{C}$ species concentration, $\bar{C}_\infty$ far field temperature, σ fluid electric conductivity, B_0 magnetic field component along $\bar{y}$-axis, k permeability of porous medium, λ thermal conductivity, ρ density of fluid, C_p specific heat at constant pressure, Q_h heat generation coefficient, D chemical molecular diffusivity, k_c chemical reaction parameter, V_T thermophoretic velocity.

The relevant boundary conditions:

$$\bar{y}=0:\ \ \bar{u}=0,\qquad \frac{\partial\bar{T}}{\partial\bar{y}} = -\frac{q}{\lambda},\qquad \frac{\partial\bar{C}}{\partial\bar{y}} = -\frac{m}{D},$$

$$\bar{y}\to\infty:\ \ \bar{u}=0,\ \ \bar{T}=\bar{T}_\infty,\ \ \bar{C}=\bar{C}_\infty, \tag{6}$$

The non-dimensional parameters are defined by

$$f(\eta)=\frac{\bar{u}}{v_0},\ \eta=\frac{v_0\bar{y}}{\nu},\ Pr=\frac{\mu C_p}{\lambda},\ Sc=\frac{\nu}{D},\ \theta=\frac{(\bar{T}-\bar{T}_\infty)v_0\lambda}{q\nu},\ C=\frac{(\bar{C}-\bar{C}_\infty)v_0\lambda}{m\nu},\ \alpha=\frac{v_0^2k}{\nu^2},Gr=\frac{g\beta q\nu^2}{v_0^4\lambda},$$

$$Gm=\frac{g\beta_1 m\nu^2}{v_0^4 D},\ M=\frac{\sigma B_0^2\nu}{\rho v_0^2},\ E=\frac{\lambda v_0^3}{q\nu C_p},\ Kr=\frac{\nu k_c}{v_0^2},\ Q=\frac{Q_h\nu}{\rho C_p v_0^2} \tag{7}$$

where, $f(\eta)$ is velocity, η is the distance, Pr is the Prandtl number,Sc the is Schmidt number, θ is the dimensionless temperature, C is the dimensionless concentration, α is the permeability parameter, Gr is the Grashof number, Gm is the solutal Grashof number, M is the magnetic field parameter, E is the Eckert number, Kr is the chemical reaction parameter, Q is the heat source parameter

The thermophoretic velocity is written as

$$V_T = -\frac{k'\nu}{T_r}\frac{\partial\bar{T}}{\partial\bar{y}} \tag{8}$$

where T_r is some reference temperature and $k'$is the thermophoretic coefficient which ranges in values from 0.2 to 1.2 and is defined as

$$k' = \frac{2C_s\left(\frac{\lambda}{\lambda_p}+C_tK_n\right)\left[1+K_n\left(C_1+C_2e^{-C_3/K_n}\right)\right]}{(1+3C_mK_n)\left(1+2\lambda/\lambda_p+2C_tK_n\right)} \tag{9}$$

where $C_1, C_2, C_3, C_m, C_s, C_t$ are constants, λ and λ_p are the thermal conductivities of the fluid and diffused particles respectively, and K_n is the Knudsen number.

The thermophoretic parameter τ can be defined as

$$\tau = -\frac{k'(\bar{T}-\bar{T}_\infty)}{T_r} \tag{10}$$

The non-dimensional equations are:

$$f'' + f' - (M + \alpha^{-1})f = -(Gr^*\theta + Gm^*C) \tag{11}$$

$$\theta'' + Pr\theta' + QPr\theta = -EPr(f')^2 \tag{12}$$

$$C'' + Sc(1 + \tau\theta^{-1})C' + Sc(Kr - \tau\theta^{-1}\theta'')C = 0 \tag{13}$$

Where $Gr^* = Grcos\phi$ and $Gm^* = Gmcos\phi$ and prime denotes differentiation w.r.t η.

The transformed boundary conditions are:

$$\eta = 0 : f = 0, \theta' = -1, C' = -1$$
$$\eta \to \infty: f \to 0, \theta \to 0, C \to 0 \tag{14}$$

3. METHOD OF SOLUTION

The non-linear coupled ordinary differential equations (11) to (13) are expounded numerically using MATLAB'S built in solver bvp4c with the support of boundary conditions (14).

4. RESULTS AND DISCUSSION

To elucidate the physical situation of this problem, we have to represent the profiles for velocity, temperature and concentration for various fluid parameters such as Magnetic parameter(M),solutal Grashof number(Gm),thermal Grashof number(Gr) ,Chemical reaction parameter(Kr),Permeability parameter(α), angle of inclination(ϕ),Heat source parameter(Q),Thermophoretic parameter(τ),Prandtl number(Pr),Schimdt number(Sc) etc. Consider a set of fixed values for the parameters like M=1,Gm=3,Kr=0.7,α=1,Q=.75,τ=1,Pr=.7,Sc=0.8, $\phi = \frac{\pi}{4}$,Gr=12; unless otherwise stated .The apropos flow mannerism are exemplified graphically for varied flow parameters intricate in the solutions. Fig 1 to 6 have illustrated the shapes of fluid velocity f against the displacement η for numerous values of M, Gm, α, ϕ, Kr and Gr respectively. It is remarked from the figures that the flow velocity rises speedily near the surface but the speed diminishes as the fluid moves far away from the surface. From Fig 1, the sequel of magnetic field parameter(M) lessens the fluid velocity all over the boundary layer region because the existence of magnetic field in an electrically conductive fluid commences a force exclaimed Lorentz force, which performs against the flow if the magnetic field is solicited in normal direction, as in the current problem. This category of resistive force slows down the fluid velocity. Fig 2 represents the effect on velocity with Gm. An increasing order of velocity profiles are observed for increases the values of Gm. Fig 3 excels the rising nature of velocity profile for variations of permeable parameter α. In Fig 4, when we accelerate ϕ , velocity is declined. A diminishing trend of velocity is perceived for development of Kr (Fig 5). Fig 6 discloses the velocity sketch for Gr. It is noticed that velocity elevates for advancement of Gr.

Fig 7 to 9 manifest the temperature θ portrait against η for numerous values of Q, E and Pr respectively. The variations of Q and E accelerate the temperature but the reverse situation appears when Pr shows disparity.

Fig 10 to 12 encapsulate the profiles of concentration C versus η for diverse values of τ, Kr and Sc respectively. A reduction trend is descried for τ and Sc(Fig 10 and 12) but a rising nature is detected in case of Kr(Fig 11).

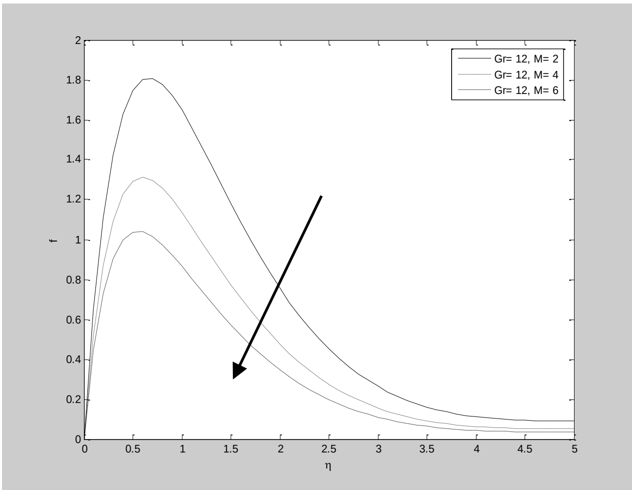

Fig. 1: Velocity profiles f against η for M

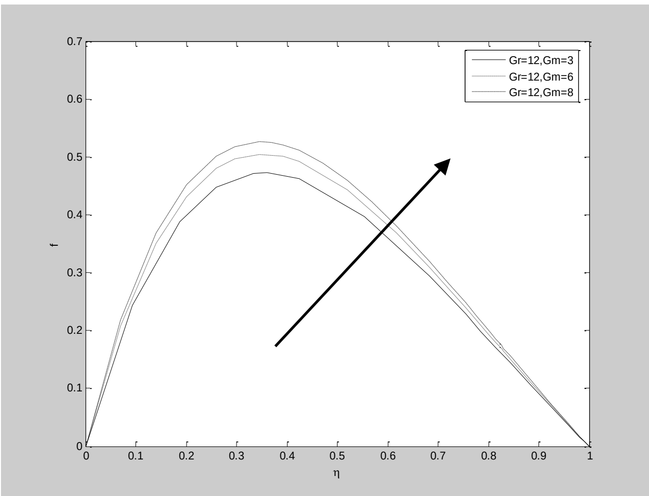

Fig. 2: Velocity profiles f against η for Gm

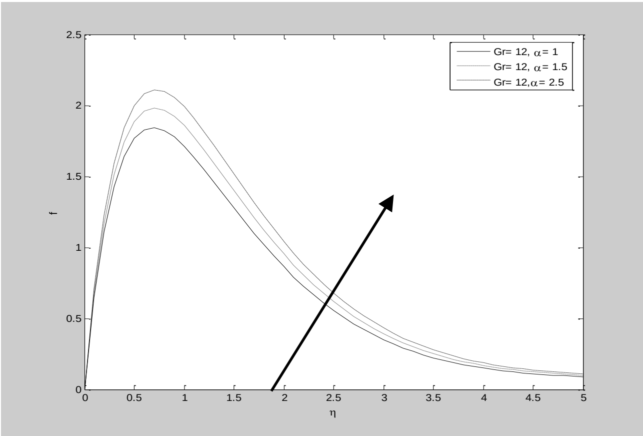

Fig. 3: Velocity profiles f against η for α

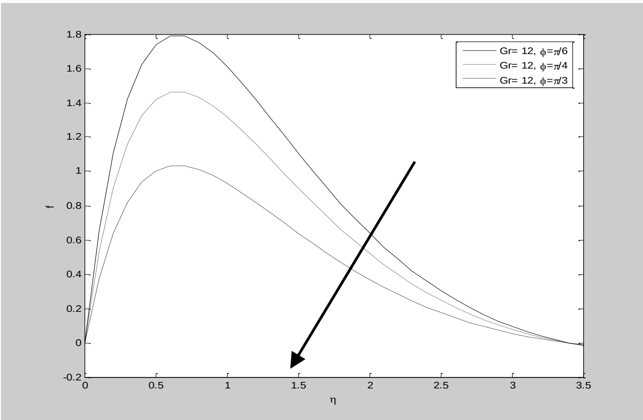

Fig. 4: Velocity profiles f against η for ϕ

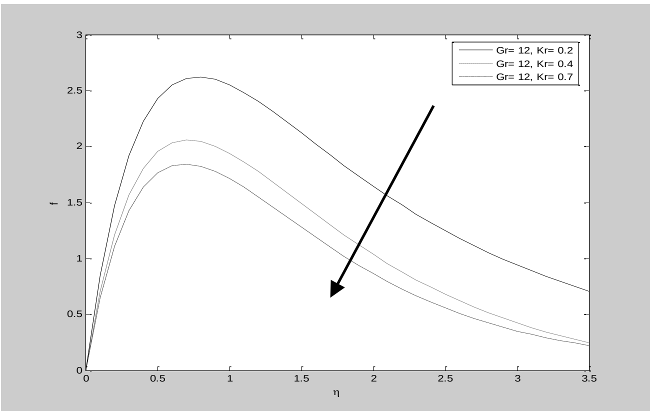

Fig.5: Velocity profiles f against η for Kr

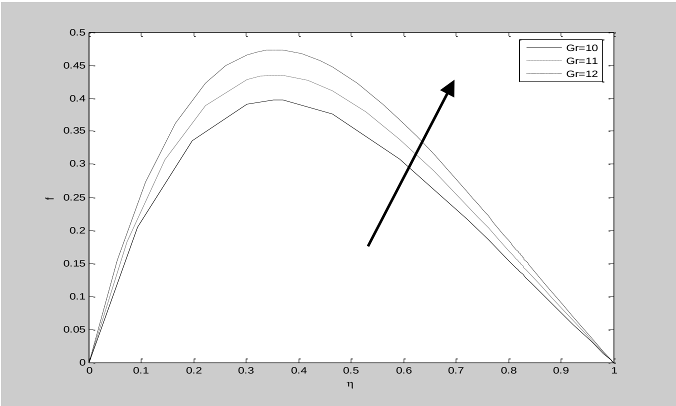

Fig. 6: Velocity profiles f against η for Gr

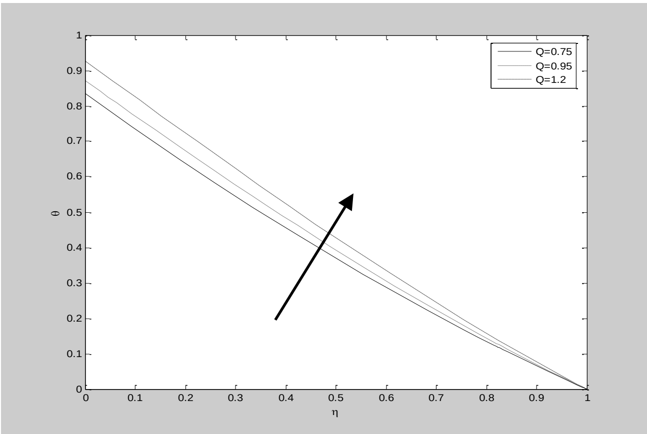

Fig. 7: Temperature profiles θ against η for Q

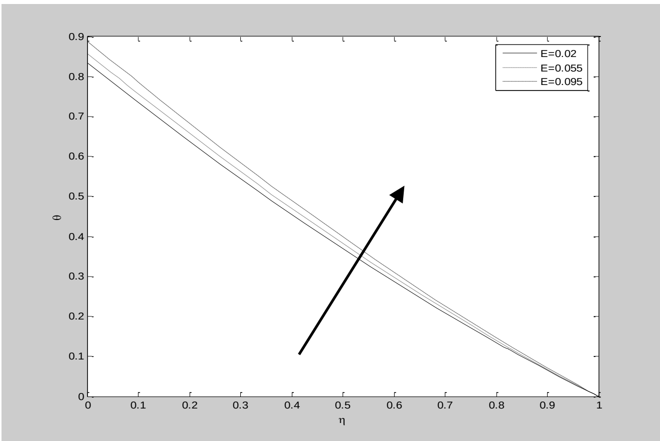

Fig. 8: Temperature profiles θ against η for E

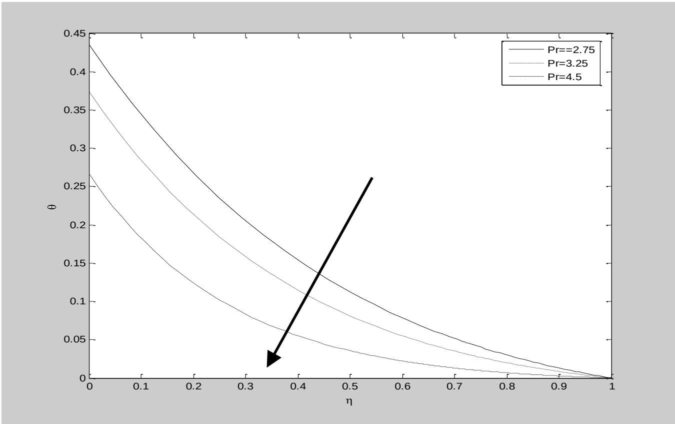

Fig. 9: Temperature profiles θ against η for Pr

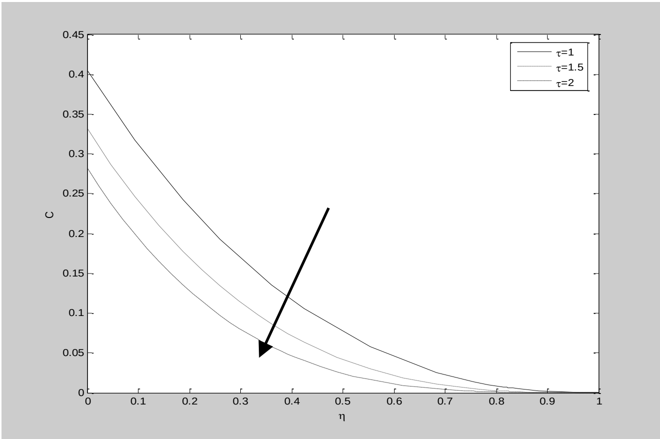

Fig. 10: Concentration profiles C against η for τ

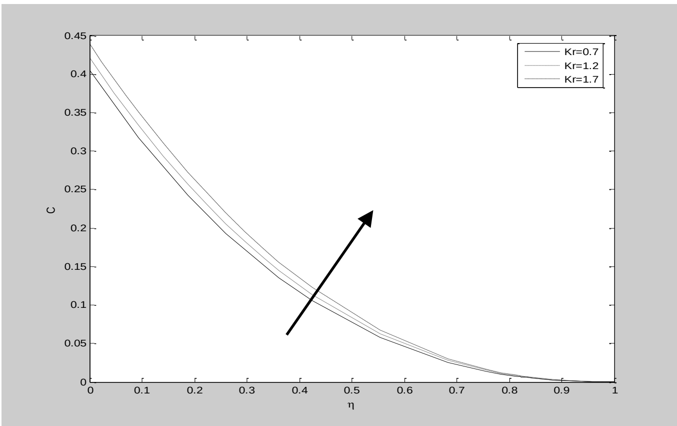

Fig. 11: Concentration profiles C against η for Kr

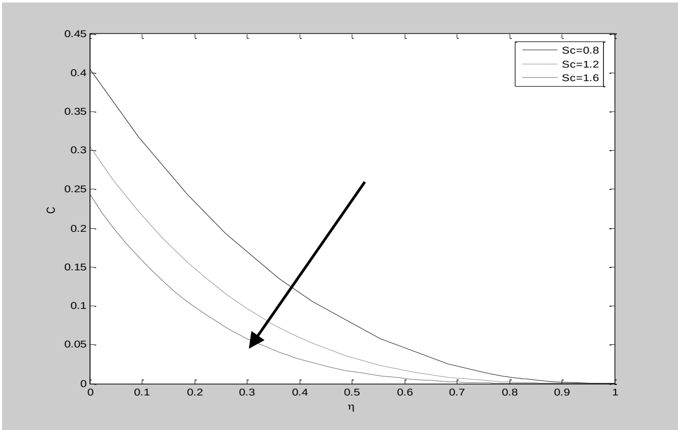

Fig. 12: Concentration profiles C against η for Sc

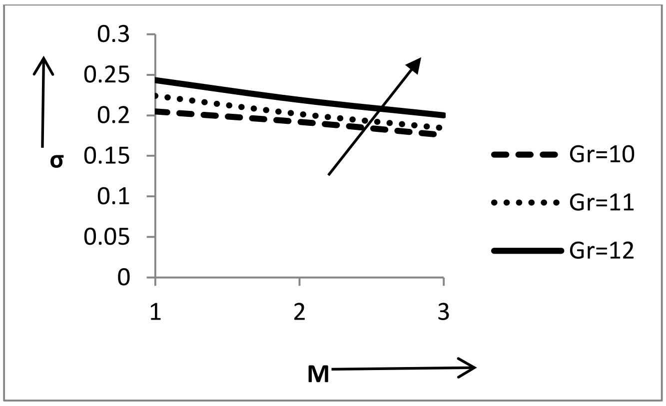

Fig. 13: Shearing stress σ against M

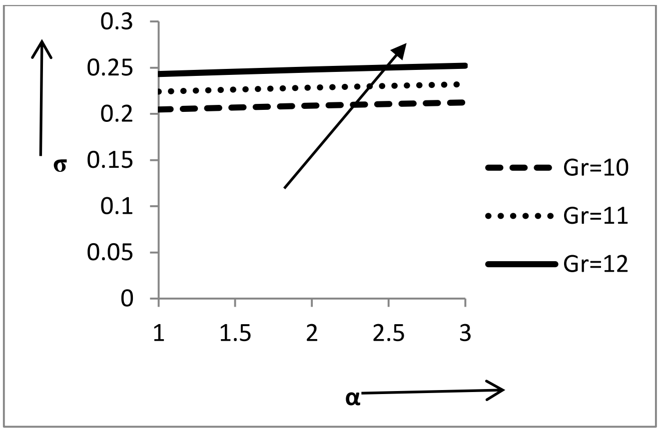

Fig. 14: Shearing stress σ against α

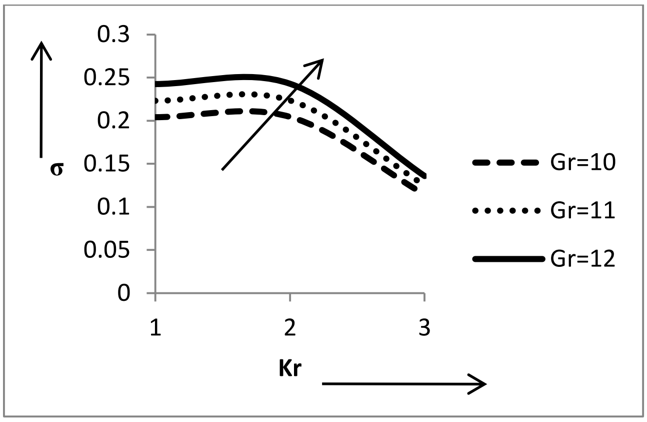

Fig. 15: Shearing stress σ against Kr

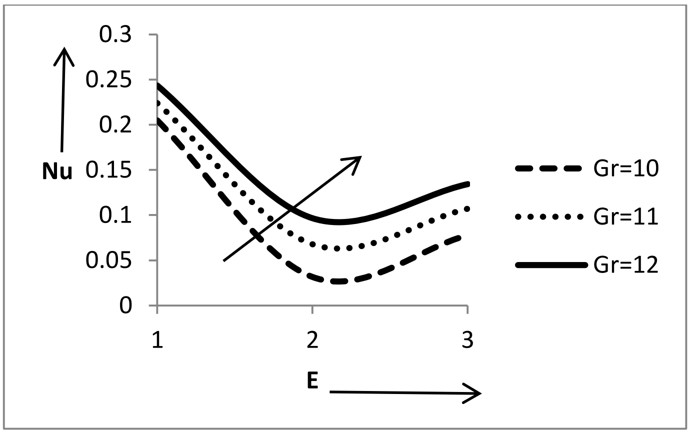

Fig. 16: Nusselt number Nu against E

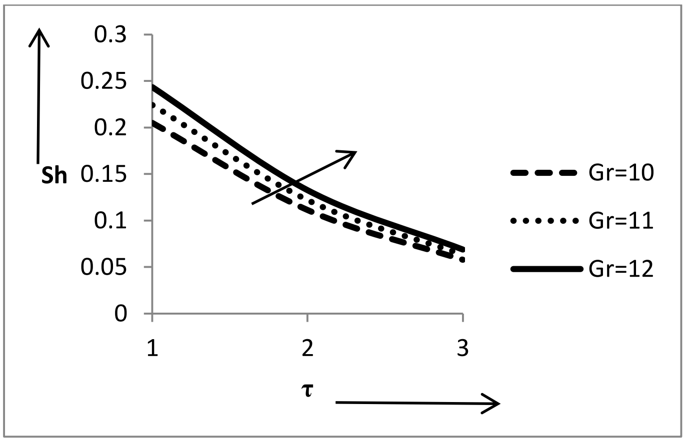

Fig. 17: Sherwood number Sh against τ

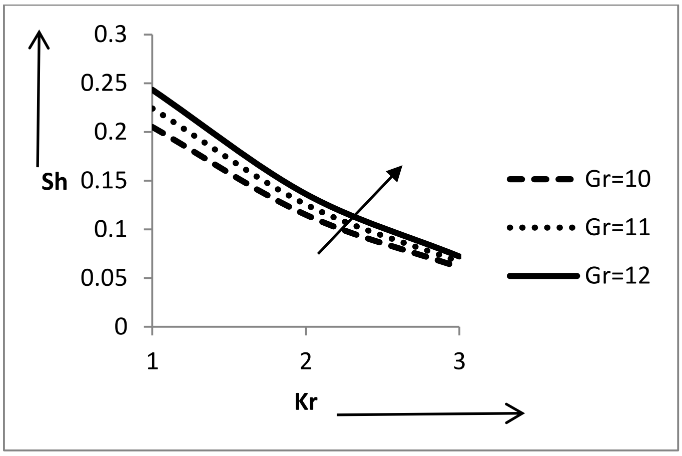

Fig. 18: Sherwood number Sh against Kr

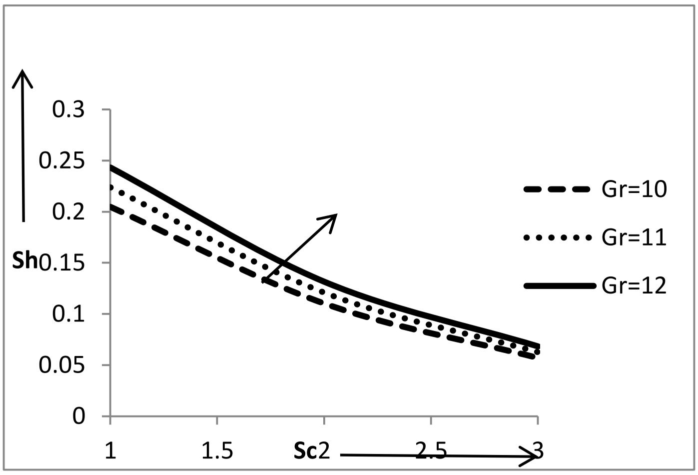

Fig. 19: Sherwood number Sh against Sc

Fig 13 to 15 delineate upshots of thermal Grashof number (Gr) on shearing stress against M, α and Kr discretely. The shearing stress enhances with the hike of the physical parameters in all the cases.

With the growth of Gr, the rising trend of Nusselt number(Nu) versus Eckert number(E) is perceived (Fig 16).

Fig 17 to 19 excel the ascent of Sherwood number (Sh) against τ, Kr and Sc sequentially with the magnification of Gr .

5. CONCLUSION

The salient features of this study are listed below:

- The fluid motion is impeded due to the implementation of magnetic field, inclination of the plate, chemical reaction but expedites under the exertion of thermal Grashof number, solutal Grashof number and permeability effect.
- The fluid temperature is retarded under the influence of Prandtl number but rises due to the application of heat generation coefficient and Eckert number.
- The variations of Schmidt number and thermophoretic parameter diminish the concentration of the fluid but opposite trend is perceived in case of chemical reaction parameters.
- The magnitude of the drag force on the plate against magnetic parameter, inclination of the plate and permeability parameter excel expansion under the impact of thermal Grashof number.
- The effect of thermal Grashof number causes the rate of heat transfer from plate to the fluid to expand.
- The mass flux surges under the sequels of thermophoretic parameter, chemical reaction parameter and Schmidt number.

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