Journal of Positive School Psychology
2022, Vol. 6, No. 5, 697 – 706
http://journalppw.com

RADIATION AND MASS TRANSFER EFFECTS ON MHD FREE CONVECTION FLOW OVER AN INCLINED PLATE

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Abstract

The present investigation is exact analyses of combined effects of chemical reaction and radiation on the MHD free convection flow of an electrically conducting incompressible viscous fluid over an inclined plate embedded in a porous medium. The impulsively started plate with variable temperature and mass diffusion is considered. The dimensionless momentum equation coupled with the energy and mass diffusion equations are analytically solved by using the perturbation technique. The effects of pertinent parameters on velocity, temperature and concentration profiles are graphically demonstrated whereas the differences in skin friction, Nusselt number and Sherwood number are presented in tables.

Keywords: Radiation, Chemical reaction, inclined plate, Heat and Mass transfer and MHD.

INTRODUCTION

The free convection flow over vertical surfaces immersed in porous media has paramount importance due to its prospective applications in geohydrology, soil physics and filtration of solids form liquid, biological systems and chemical engineering etc. In view of this Bear J [1] focused on Dynamics of Fluid in Porous Media. Nield D A [2] studied Convection in a porous medium with inclined temperature gradient: An additional result. Ali et al. [5] investigated unsteady magnetohydrodynamic oscillatory flow of viscoelastic fluids in a porous channel with heat and mass transfer. I Khan et al. [6] analyzed effects of hall current and mass transfer on the unsteady MHD flow in a porous channel. A N A Osman et al [7] studied analytically the thermal radiation and chemical reaction effects on unsteady MHD free convection flow in a porous medium wit heat source/sink by taking the porous medium effect. S Shafie [8] provided an exact analysis to the study of the magnetohydrodynamic free convection flow of an incompressible viscous fluid past an infinite vertical oscillating plate with uniform heat flux. And in further research, Samiulhaq et al. [9] studied the MHD free convection flow in a porous medium with thermal diffusion and ramped wall temperature.

Thermal radiation on fluid stream has great significance when the environment is at higher temperature. Higher thermal radiation increases convective flow and enhances the thermal condition on liquid (fluid) in the boundary layer. However, thermal radiation and heat transfer are also of great significance in the design of numerous progressive energy conversion systems if and only if it controls at a high temperature. It is routine experience for heat to flow from one object to another. When a hot body falls on cold body, heat will be transferred and the temperature of the hot body will drop when the cold becomes hot. Investigators in the field of fluid mechanics have extensively worked in this area. The authors Sharma and Gupta [10] focused on the analytical study of MHD boundary layer flow and heat transfer towards a porous electrically stretching sheet in presence of thermal radiation. A Jimoh et al. [11] investigated the numerical study of unsteady free convective heat transfer in Walters-B investigated the numerical study of unsteady free convective heat transfer in viscoelastic flow over an inclined stretching sheet with heat source and magnetic field. F I Alao et.al. [12] discussed effects of thermal radiation, Soret and Dufour on an unsteady heat and mass transfer flow of a chemically reacting fluid past a semi-infinite vertical plate with viscous dissipation. S S Manna et al. [13] also studied the effects of radiation on unsteady MHD free convective flow past an oscillating vertical porous plate embedded in a porous medium with oscillatory heat flux. One of the researchers' attentions was also drawn to the effect of heat and mass transfer flows. Ch Kesavaiah et al. [14] have been studied effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction.

Chemical Reaction is a progression that includes reorganization of the molecular or ionic structure of a substance, as distinct from a change in physical form or a nuclear reaction. Here two categories of such reactions namely one is homogeneous reaction which occurs uniformly all through a given phase of a flow and heterogeneous reaction which takes place in a particular region or within the boundary of a phase. In view of the above Karunakar Reddy et al. [15] considered MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction. The authors Srinathuni Lavanya and Chenna Kesavaiah [16] investigated heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction. Mallikarjuna Reddy et al. [17] analyzed effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates. The authors Bhavana and Chenna Kesavaiah [18] have been studied perturbation solution for thermal diffusion and chemical reaction effects on MHD flow in vertical surface with heat generation. The authors Chenna Kesavaiah and Venkateswarlu [19] worked out chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, Srinathuni Lavanya et al. [20] has considered radiation effect on unsteady free convective MHD flow of a viscoelastic fluid past a tilted porous plate with heat source. Omeswar Reddy et al. [21] investigated thermo diffusion, heat and mass transfer analysis of MHD viscoelastic fluid flow towards a vertically inclined plate by perturbation technique. Mallikarjuna Reddy et al. [22] has been considered radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source. The author Chenna Kesavaiah [23] analyzed radiative flow of MHD Jeffery fluid over a stretching vertical surface in a porous medium. The authors (Bijoy Krishna Taid and Nazibuddin Ahmed [24] studied MHD free convection flow across an inclined porous plate in the presence of heat source, Soret effect, and chemical reaction affected by viscous dissipation Ohmic heating. Chenna Kesavaiah et al. [25] investigated Radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source. Rami Reddy et al. [26] has been studied Hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source. Chenna Kesavaiah and Venkateswarlu [27] focused Chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves. The same related investigations are studied by various authors Lawal K K et al. [28], Jyotsna Rani et al. [30], Ramakrishna S B et Al. [31], Nagaraju et al. (29, 34, 35 and 38), Ilias M R et al. [33], Srihar Babu V et al. [37], Omeshwar Reddy V et al. [32 and 39].

Sunita Rani et al. [40] also investigated on Variation of Eckert number on hydrodynamic convective fluid flow in the presence of thermal radiation. Sunita Rani et al. [41] also studied about Jeffrey Fluid Performance on MHD Convective Flow Past a Semi-Infinite Vertically Inclined Permeable Moving Plate in Presence of Heat and Mass Transfer: a Finite Difference Technique.

View of all above investigations the present study is exact analyses of combined effects of radiation and chemical reaction on the MHD free convection flow of an electrically conducting incompressible viscous fluid over an inclined plate embedded in a porous medium. The impulsively started plate with variable temperature and mass diffusion is considered.

Formulation of the problem

We consider the unsteady flow of an incompressible viscous fluid past an infinite inclined plate with variable heat and mass transfer. The axis is taken along the plate with the angle inclination to the vertical and axis is normal to the plate. The viscous fluid is taken to be electrically conducting and fills the porous half space . A uniform magnetic field is applied in the direction transversely to the plate. The applied magnetic field is considered to be strong enough so that the induced magnetic field due to the fluid motion is weak and can be ignored. Cramer and Pai [3] started that, this hypothesis is physically justified for semi ionized fluids and metallic liquid because of their small magnetic Reynolds number. Initially, both the fluid and the plate are at rest with constant temperature and the constant concentration . At time plate is given a sudden jerk, and the motion is induced in the direction of flow against the gravity with uniform velocity . The temperature and concentration of the plate are raised linearly with respect to time. It is also assumed that the viscous dissipation is negligible and the fluid is thick gray absorbing – emitting radiation but non-scattering medium. Since the plate is infinite in the plane, all physical variables are functions of and only. The physical model and coordinates system is shown in figure (1).

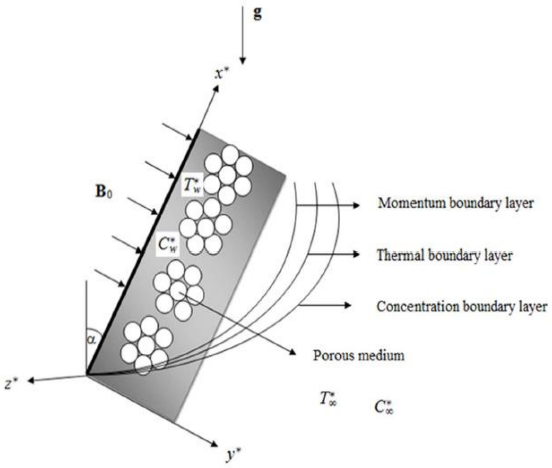

Figure (1): *Physical model and coordinates system*

In sight of the above hypotheses, as well as the usual Boussinesq approximation, the governing equations reduce

$$\frac{\partial u\left(y^*t^*\right)}{\partial t^*}=\frac{\partial^2 u^*\left(y^*t^*\right)}{\partial y^{*2}}-\left(\frac{\sigma B_0^2}{\rho}+\frac{\nu}{k}\right)u^*\left(y^*t^*\right)$$
$$+g\,\beta_T\left(T^*-T_\infty{}^*\right)\cos\alpha+g\,\beta_C\left(C^*-C_\infty{}^*\right)\cos\alpha \qquad (1)$$

$$\rho c_p\frac{\partial T^*}{\partial t^*}=k_1\frac{\partial^2 T^*}{\partial y^{*2}}-\frac{\partial q_r}{\partial y^*} \qquad (2)$$

$$\frac{\partial C^*}{\partial t^*}=D\frac{\partial^2 C^*}{\partial y^{*2}}-k_2\left(C^*-C_\infty{}^*\right) \qquad (3)$$

where u^* is the axial velocity of the fluid along the plate in the x' - direction, u^* are the dimensional distance along and perpendicular to the plate and $\nu=\frac{\mu}{\rho}$.

The initial and boundary conditions are:

$$u^*\left(y^*,0\right)=0, T\left(y^*,0\right)=T_\infty^*, C\left(y^*,0\right)=C_\infty^*,\quad y^*>0$$
$$u^*\left(\infty,t^*\right)=0, T^*\left(\infty,t^*\right)=T_\infty{}^*, C^*\left(\infty,t^*\right)=C_\infty{}^*, t^*>0 \qquad (4)$$

where following $A=\frac{u_0^2}{\nu}$ Magyari and Pantokratoras [4], we adopt the Rosseland approximation for radiative flux q_r namely

$$u^*\left(0,t^*\right)=u_0$$

$$T\left(0,t^*\right)=T_\infty^*+\left(T_w^*+T_\infty^*\right)At^*,$$

$$C\left(0,t^*\right)=C_\infty^*+\left(C_w^*+C_\infty^*\right)At^*,\qquad t^*>0$$

$$q_r=-\frac{4\sigma_0}{3k_3}\frac{\partial T^{*4}}{\partial y^*}$$

(5)

We consider that the temperature differences within the flow are sufficiently small such that T^{*4} may be expressed as a linear function of the temperature. This is accomplished by expanding T^{*4} in a Taylor series about $T_\infty{}^*$ and neglecting the higher order terms, we get

$$T^{*4}\cong 4T^*{}_\infty{}^4T'-3T^{*4}_\infty$$

(6)

Using equation (5) and (6) into equation (2) yields

$$\rho c_p\frac{\partial T^*}{\partial t^*}=k_1\left(1+\frac{16\sigma_0T_\infty^{*3}}{3k_1k_3}\right)\frac{\partial^2T^*}{\partial y^{*2}}$$

(7)

On introducing the following non – dimensional quantities

$$y=\frac{u_0y^*}{\nu},u=\frac{u^*}{u_0},\ t=\frac{t^*u_0{}^2}{\nu},\ \theta=\frac{T^*-T_\infty{}^*}{T_w^*-T_\infty{}^*},\ \phi=\frac{C^*-C_\infty{}^*}{C_w^*-C_\infty{}^*}$$

(8)

Equations (1), (3) and (7) reduces

$$\frac{\partial u}{\partial t}=\frac{\partial^2u}{\partial y^2}-\left(M+\frac{1}{K}\right)u+Gr\,\theta\,\cos\alpha+Gc\,\phi\cos\alpha$$

(9)

$$\Pr\frac{\partial\theta}{\partial t}=\left(1+N\right)\frac{\partial^2\theta}{\partial y^2}$$

(10)

$$\frac{\partial\phi}{\partial t}=\frac{1}{Sc}\frac{\partial^2\phi}{\partial y^2}-\gamma\,\phi \qquad (11)$$

where

$$M=\frac{\sigma B_0{}^2\nu}{\rho u_0{}^2},\ \frac{1}{K}=\frac{\nu^2}{u_0{}^2k},\ \ Gr=\frac{g\beta_T\nu\left(T_w^*-T_\infty^*\right)}{u_0{}^3},\ \gamma=\frac{k_2\nu}{u_0{}^2}$$

$$Gm=\frac{g\beta_C\nu\left(C_w^*-C_\infty^*\right)}{u_0{}^3},\Pr=\frac{\mu c_p}{\kappa},N=\frac{16\sigma_0T_\infty^{*3}}{3k_1k_3},Sc=\frac{\nu}{D}$$

The corresponding initial and boundary conditions (4) become

$$t\le 0:u\left(y,t\right)=0,\theta\left(y,t\right)=0,\phi\left(y,t\right)=0,\quad y>0$$

$$t>0:u\left(0,t\right)=1,\theta\left(0,t\right)=t,\phi\left(0,t\right)=t$$

$$u\left(y,t\right)\to 0,\theta\left(y,t\right)\to 0,\phi\left(y,t\right)\to 0,\quad y\to\infty$$

(12)

Technique of solution

Equation (9) – (11) are coupled, non – linear partial variously equations and these cannot be solved in closed – form using the initial and boundary conditions (9). However, these equations can be reduced to a set of ordinary variously equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighbourhood of the fluid in the neighbourhood of the plate as

$$u=u_0\left(y\right)+\varepsilon e^{at}u_1\left(y\right)$$

$$\theta=\theta_0\left(y\right)+\varepsilon e^{at}\theta_1\left(y\right)$$

$$\phi=\phi_0\left(y\right)+\varepsilon e^{at}\phi_1\left(y\right)$$

(13)

Substituting (13) in Equation (9) – (11) and equating the harmonic and non – harmonic terms, we obtain

$$u_0{}''+\beta_2u_0=-Gr\,\theta_0\cos\alpha-Gm\phi_0\cos\alpha$$

(14)

$$u_1{}''-\left(\beta_2+at\right)u_1=-Gr\,\theta_1\cos\alpha-Gm\phi_1\cos\alpha$$

(15)

$$\Pr\left(1+N\right)\theta_0{}''=0$$

(16)

$$\theta_1''-\beta_1\theta_1=0$$

(17)

$$\phi_0''-Sc\,\gamma\,\phi_0=0$$

(18)

$$\phi_1''-Sc\left(\gamma+at\right)\phi_1=0$$

(19)

The corresponding boundary conditions can be written as

$$u_0 = 0, u_1 = 1,\ \theta_0 = t, \theta_1 = 0, \phi_0 = t, \phi_1 = 0 \qquad at\ y = 0$$

$$u_0 = 0, u_1 = 0,\ \theta_0 = 0, \theta_1 = 0, \phi_0 = 0, \phi_1 = 0 \qquad as\ y \to \infty \tag{20}$$

where $\beta_1 = \Pr\left(\frac{at}{1+N}\right), \beta_2 = \left(M + \frac{1}{K}\right)$

Solving Equations (14) – (19) under the boundary conditions (20) and we obtain the velocity, temperature and concentration distributions in the boundary layer as

$$\phi_0 = t\ e^{m2y}; \phi_1 = 0$$

$$\theta_0 = t\Pr\left(1+N\right); \theta_1 = 0$$

$$u_0 = Z_1 + Z_2 e^{m2y} + Z_3 e^{-\sqrt{\beta_2}y}; u_1 = 0$$

In view of the equation (13) becomes

$$u = Z_1 + Z_2 e^{m2y} + Z_3 e^{-\sqrt{\beta_2}y}$$

$$\theta = t\Pr\left(1+N\right)$$

$$\phi = t\ e^{m2y}$$

Coefficient of Skin-Friction

The coefficient of skin-friction at the vertical porous surface is given by

$$C_f = \left(\frac{\partial u}{\partial y}\right)_{y=0} = m_2 Z_2 - \sqrt{\beta_2} Z_3$$

Coefficient of Heat Transfer

The rate of heat transfer in terms of Nusselt number at the vertical porous surface is given by

$$N_u = \left(\frac{\partial T}{\partial y}\right)_{y=0} = 0$$

Sherwood number

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = t\ m_2$$

RESULTS AND DISSCUSSIONS

The outcomes are presented graphically for various parameters rotation parameter $\left(\gamma\right)$, modified Grashof number $\left(Gc\right)$,Prandtl number$\left(\Pr\right)$, Schmidt number$\left(Sc\right)$, Chemical reaction parameter $\left(\gamma\right)$ and time $\left(t\right)$. In this observation the values of the Prandtl number are chosen to represents air $\left(\Pr = 0.71\right)$; Schmidt number are chosen to represents oxygen $\left(Sc = 0.60\right)$, The velocity profiles, concentration, skin friction and Sherwood number are shown from figures (2) – (11). Figures (2) and (3) shown velocity profiles for various values of chemical reaction parameter $\left(\gamma = 1, 2, 3, 4\right)$ and Schmidt number $\left(Sc = 0.60, 0.78, 0.94, 2\right)$, it is observed that increasing values of chemical reaction parameter and Schmidt number the velocity decreases. The velocity profiles various values of time $\left(t = 1, 2, 3, 4\right)$ are predicted in figure (4); it is clearly shown that the velocity increases with increasing values of time. The velocity variations for various values of the magnetic parameter $\left(M = 1, 2, 3, 4\right)$ are show in figure (5). Form this figure we observed that an increasing values of magnetic parameter the velocity decreases. For various values of thermal Grashof number and modified Grashof number $\left(Gm = 5, 10, 15, 20\right)$ are give an exhibition of the velocity profiles in figure (6), we noticed that the velocity increase with increasing values of modified Grashof number. The velocity profiles observed for various values of rotation parameter $\left(\alpha = \frac{\pi}{6}, \frac{\pi}{5}, \frac{\pi}{4}, \frac{\pi}{3}\right)$ are shown in figure (7), it is clear that the velocity decreases with increasing values of rotation parameter. The concentration profiles are shown from figures (8) – (9). From figures (8) and figure (9) observed that the concentration profiles for various values of chemical reaction parameter $\left(\gamma = 1, 2, 3, 4\right)$ and Schmidt number $\left(Sc = 0.60, 0.78, 0.94, 2\right)$, we observed that an increasing Prandtl number the concentration profiles decreases in both the parameters. The skin friction coefficient shown in figure (10) for various values of magnetic parameter $\left(M = 1, 2, 3, 4\right)$ versus thermal modified Grashof number $\left(Gm\right)$ which is clear that an increasing values of rotation parameter the skin friction coefficient decreases. From figure (11) observed that Sherwood number for various values of chemical reaction $\left(\gamma = 0.5, 1, 1.5, 2\right)$ parameter versus Schmidt number, we observed that an increasing Schmidt number the Sherwood number decreases.

Conclusions:

In this article, the combined effects of chemical reaction and radiation on the MHD free convection flow of an electrically conducting incompressible viscous fluid over an inclined plate embedded in a porous medium has been studied. The governing equations are solved for the velocity and concentration profiles by using perturbation technique in terms of dimensionless parameters. In the analysis of the flow the following conclusions are made:

- The velocity decreases with an increase in the magnetic parameter *M* and Rotation parameter ‘α’
- The velocity increases with an increase in the time t and Grashof number *Gm*.
- The velocity, as well as concentration, decreases with an increase in the Schmidt number *Sc* and Chemical reaction parameter *Kr(γ)*.
- Skin friction decreases with an increase in the magnetic parameter *M*.
- Sherwood number decreases with an increase in the Chemical reaction parameter *Kr*.

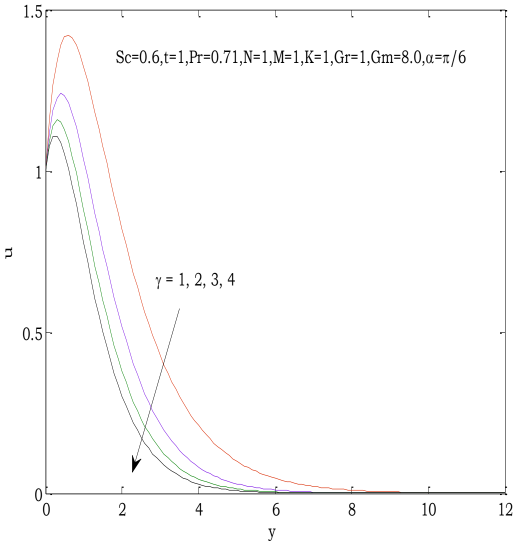

Figure (2): Velocity profiles for different values of Kr

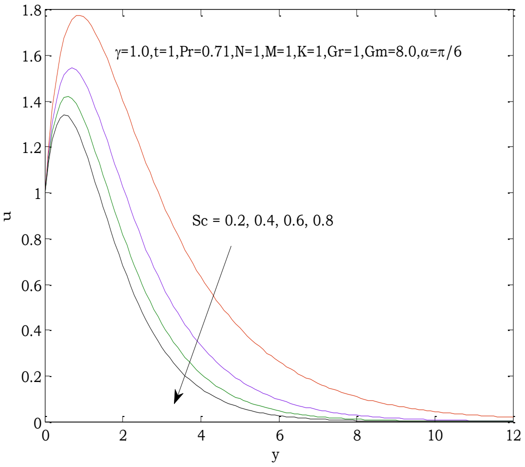

Figure (3): Velocity profiles for different values of Sc

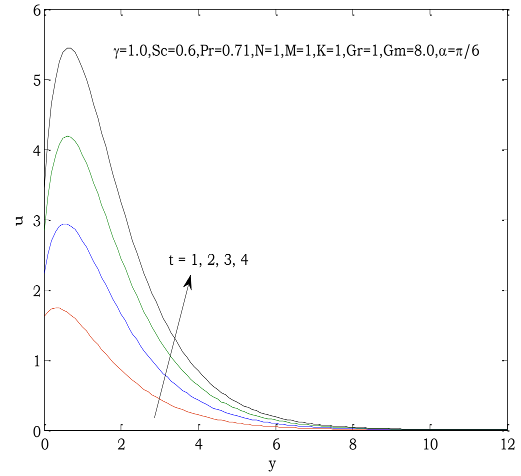

Figure (4): Velocity profiles for different values of t

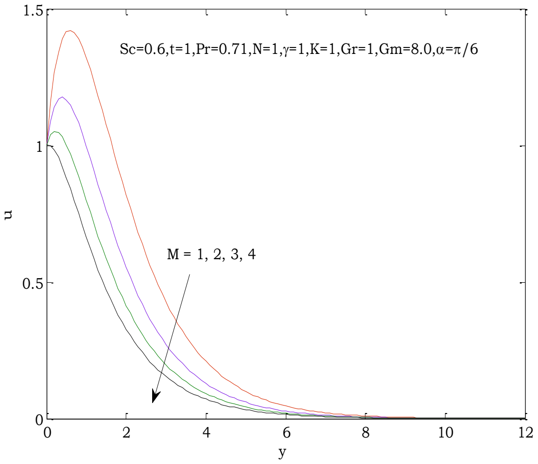

Figure (5): Velocity profiles for different values of M

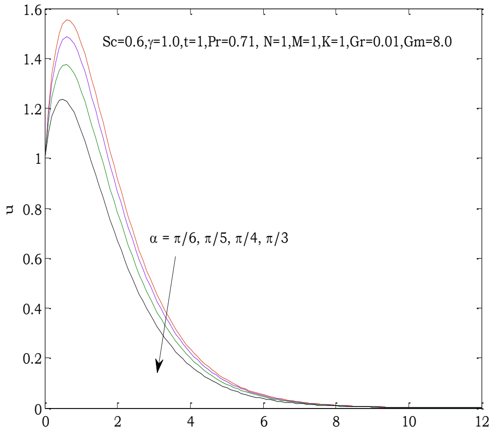

Figure (7): Velocity profiles for different values of α

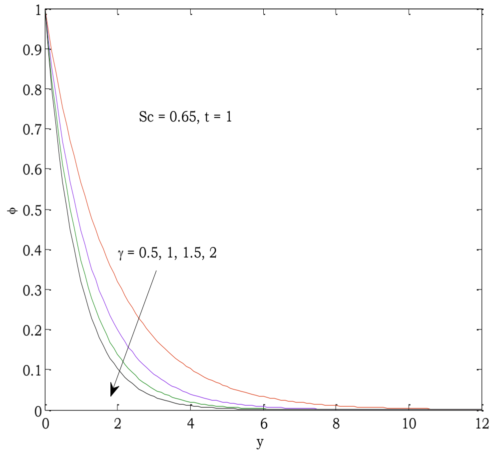

Figure (8): Concentration profiles for different values of Kr

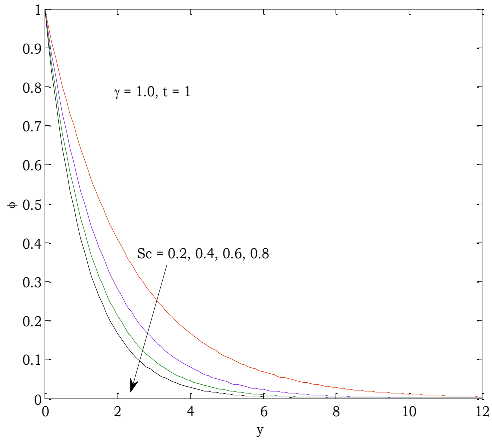

Figure (9): Concentration profiles for different values of Sc

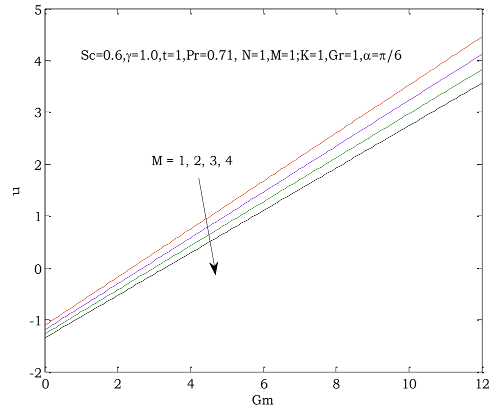

Figure (10): Skin friction for different values of M

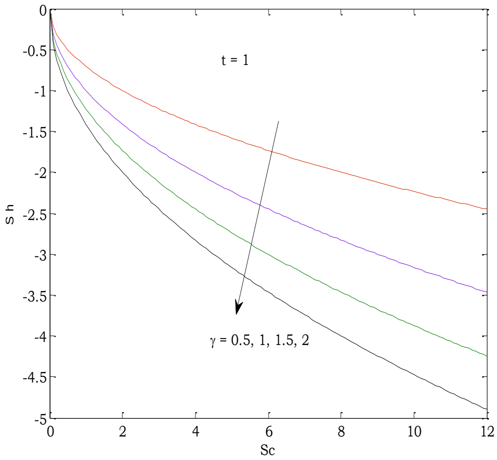

Figure (11): Sherwood number for different values of Kr

APPENDIX

$$m_2 = -\sqrt{Sc\,\gamma}, Z_1 = -\frac{t\,Gr\cos\alpha\Pr\left(1+N\right)}{\beta_2},$$

$$Z_2 = -\frac{tGm\cos\alpha}{m_2{}^2-\beta_2}, Z_3 = \left(1-Z_1-Z_2\right)$$

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