DUFOUR AND CHEMICAL REACTION EFFECTS ON TWO DIMENSIONAL INCOMPRESSIBLE FLOW OF A VISCOUS FLUID OVER MOVING VERTICAL SURFACE

Anita Tuljappa[1], V. Nagaraju[2], G. Rami Reddy[3], Dr. Nookala Venu[4]
[1]Department of Mathematics, Vijayanagara Srikrishna Devaraya University, Ballari, Karnataka,Pin-583105, India
Email: anita.birapur@gmail.com
[2]Department of Basic Sciences & Humanities, Vignan Institute of Technology and Science, Deshmukhi (V), Pochampally (M), Yadadri-Bhuvanagiri (Dist), TS-508284, India
Email: vellanki.nagsra@gmail.com
[3]Department of Mathematics, Malla Reddy Engineering College (Autonomous), Dulapally (V), Kompally (M), Medchal Malkajgiri (Dist), TS-500100, India
Email: dr.g.ramireddy76@gmail.com
[4]Department of Electronics and Communication Engineering,
Balaji Institute of Technology and Science (Autonomous), Narsampet, Warangal, TS -506331, India
Email: venunookala@gmail.com

ABSTRACT

The extensive variety of issues include reactions kinetics, simulations and optimizations of different models of reactors including basic explorations of the processes of temperature and mass and momentum transfer that taken places with chemical reaction. Based on this criteria, it is discussed the impacts of the Dufour consequences on natural convective heat and mass transfer for the unsteady two dimensional boundary layer flow through a vertical surface. The resultant governing boundary layer equations are nonlinear and coupled form of partial differential equations which are solved analytically using two-term harmonic and non-harmonic function. The effects of different physical parameters on the velocity, temperature and concentration fields as well as skin friction are discussed in detail.

KEYWORDS: MHD, Porous medium, Vertical surface, Chemical reaction
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INTRODUCTION

The combined heat and mass transfer with natural convective fluid flow though an inundated permeable medium has most imperative applications in the geothermal and geophysical industrial engineering they are, the extraction of geothermal energy, the migration of wetness in fibrous insulations, underground disposal of nuclear wastes, and the distribution of chemical pollutants in saturated soils. As well, the temperature and mass transport is concurrently distressing each other that would cause the cross diffusion effects. The heat transport reasoned with the concentration gradient is known as Dufour effects. Towards attained most significant concepts of costs and energies, intensification of heat transport played an extremely requisite role. In view of the above (Omowaye et.al. 2015)Considered Dofour and Soret effects on steady MHD convective flow of a fluid in a porous medium with temperature dependent viscosity: Homotopy analysis approach, (Dursunkaya et.al. 1992) observed Diffusion thermo and thermal diffusion effects in transient and steady natural convection form a vertical surface, (Gbadeyan et.al. 2018)Considered Soret and Dufour effects on heat and mass transfer in chemically reacting MHD flow through a wavy channel, (Mabood et.al. 2015) Observed MHD stagnation point flow and transfer impinging on stretching sheet with chemical reaction and transpiration, (Tasawar Hayat et.al. 2018) presented Numerical investigation of MHD flow with Soret and Dufour effect.(Jena et.al. 2018) Chemical reaction effect on MHD viscoelastic fluid flow over vertical stretching sheet with heat source/sink, (Tripathy et.al. 2015)studied chemical reaction effects on MHD free convective surface over a moving vertical plate through porous medium, for more information we refereed Applied Numerical Methods by (Carnahan et.al. 1996), (Rajput et.al. 2011) discussed radiation and chemical reaction effect on free convection MHD flow through a porous medium bounded by vertical surface, (Reddy et. al. 2013) considered chemical reaction and radiation effects on MHD free convection flow through a porous medium bounded by a vertical surface with constant heat and mass flux, (Sudershan Reddy et. al. 2012) studied radiation and chemical reaction effects on free convection MHD flow through a porous medium bounded by vertical surface.

The present developments in the field of science and technology are levitating the demands for exceptional characteristic packed together machines with the better performances, speed and accurate rolling, and extended life span. Therefore, the scholars and scientists congregated to working on the thermal organization of heat transport machines. The curiosity of combined hat and mass transport with natural convection in a fluid saturated porous medium intervenes in countless manufacturing, technical and industrial companies such as hydro-geological, earth sciences, electronically applications getting cold through fans, terrestrial heat power exploitations, petroleum repositories, and invent of steel, underrating and atomic strength factories. An extensive version of the existing in sequence is granted in the modern researchers (Neild and Bejan, 2006) and (Ingham and Pop, 2005). Current years, substantial emphasis committed towards investigate the hydromagnetic flow for heat and mass transport since for claims through physics of the earth, aeronautical studies, and engineering in chemistry. (Makinde, 2010) premeditated the MHD boundary layer flow with heat and mass transport past a moving vertical plate in the occurrence of magnetic field. (Palani and Srikanth, 2009) explored the hydromagnetic flow of an electrically conducting fluid across a semi-infinite vertical plate under the effect of magnetic field. (Duwairi, 2005) observed viscous and Joule-heating outcomes on compelled convective flow from disseminate isothermal surface. The result of viscous dissipation is frequently distinguished by the Eckert number and it is performed an extremely imperative responsibility in geo-scientific flow and in atomic industry has been studied by (Alim et. al, 2007). This is addition performs an essential task in natural convection into a variety of proceedings on huge measures or for bulky heavenly bodies. The results of suction on boundary sheet flow also have superior influence in excess of the industrial functioning and have made extensively deliberated by abundant leading scientists. Multiple creators have explored the results of viscous dissipation and constant suction in distinct plane this embodiment. (Uwanta, 2012) explained the consequences of chemical substance retort and emission for heat and mass transport over a semi-infinite vertical permeable plate with invariable flux and diffusion. (Mansour et. al, 2008) deliberated an impact of chemical reaction and viscous dissipation for hydromagnetic free convection flow. The end product of compound response and heat and mass transfer along a sequence with heat source and absorption or inoculation by (Kandasamy et. al, 2005) A hypothetical study on the control of emission for a steady natural convective heat and mass transport through an isothermal stretching sheet by the occurrence of unvarying magnetic field with viscous dissipation effect has been studied by (Govardan et. al, 2012)

A typical chemical reaction is always dependent on a decent quantity of activation energy no matter it is linear or binary, to start off. The Arrhenius equation is therefore, necessary for a model involving chemical reaction to calculate the amount of this activation energy. This equation describes the variation of temperature within the system due to the chemical reaction phenomena. Several industrial applications are linked with fluid flow analysis based on chemical reaction due to which researchers have adopted this factor frequently in their models.(Hamid and Khan, 2018) has been given impacts of binary chemical reaction with activation energy on unsteady flow of magneto-Williamson nanofluid, (Dhlamini et. al, 2019) experimental study onactivation energy and binary chemical reaction effects in mixed convective nanofluid flow with convective boundary conditions.

In a decades, some of the authors shown their research motivation in a Varity of problems considered and observed the physical behaviours of various parameters introduced and solved given their opinions, some of them, (Ch Kesavaiah et. al, 2013) has been studied the effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium, Srinathuni Lavanya and D Chenna Kesavaiah, 2017) considered heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction,(Chenna Kesavaiah and Sudhakaraiah, 2014) motivated study on effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Chenna Kesavaiah and Satyanarayana, 2013) gave their opinion onMHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction,(ChKesavaiah et. al, 2012) detailed information on radiation absorption, chemical reaction and magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux, (Karunakar Reddy et. al, 2013) expressed their ideas on MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, (Chenna Kesavaiah et. al, 2013) motivated study on natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (ChKesavaiah et. al, 2012) observed that the radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, (Mallikarjuna Reddy et. al, 2018) shown the effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (ChennaKesavaiah et. al, 2013) measured the radiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source,(Chenna Kesavaiah and Venkateswarlu, 2020) given out line on chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Chenna Kesavaiah et. al, 2018) has been considered MHD free convection heat and mass transfer flow past an accelerated vertical plate through a porous medium with effects of hall current, rotation and Dufour effects, (Chenna Kesavaiah et. al, 2021) expressed the radiative MHD Walter’s Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, (Bang ChuolNhial et. al. 2022) motivated study onhall current, rotation and chemical reaction effects on MHD free convection flow past an accelerated vertical plate through a porous medium,(Bang ChuolNhial et. al. 2022) detailed information has been given radiation and mass transfer effects on MHD free convection flow over an inclined plate, (Nagaraju et. al. 2019) observed MHD viscoelastic fluid flow past an infinite vertical plate in the presence of radiation and chemical reaction,(Nagaraju et. al. 2018) studied radiation effects on MHD convective heat and mass transfer flow past a semi-infinite vertical moving porous plate in the presence of chemical reaction.

FORMULATION OF THE PROBLEM

We considered the steady, two-dimensional laminar, incompressible flow of a chemically reacting, viscous fluid on a continuously moving vertical surface in the presence of a uniform magnetic field and Dufour effect, uniform heat and mass flux effects issuing a slot and moving with uniform velocity in a fluid at rest. Let $x-$ axisbe taken along the direction of motion of the surface in the upward direction and $y-$ axis is normal to the surface are shown in figure (1).

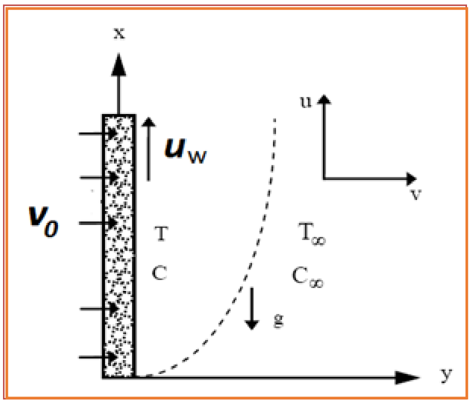

Fig. (1): Geometry of the problem

The temperature and concentration levels near the surface are raised uniformly. The induced magnetic field, viscous dissipation is assumed to be neglected. Now, under the usual Boussinesq's approximation, the flow field is governed by the following equations.

Continuity equation

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

Momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}-\frac{\nu}{K_p}u \qquad (2)$$
$$g\beta\left(T'-T'_\infty\right)+g\beta^*\left(C'-C'_\infty\right)$$

Energy equation

$$\rho C_p\left(u\frac{\partial T'}{\partial x}+v\frac{\partial T'}{\partial y}\right)=k\frac{\partial^2 T'}{\partial y^2} \qquad (3)$$
$$+\frac{D_M K_T}{C_s C_p}\frac{\partial^2 C'}{\partial y^2}$$

Diffusion equation

$$u\frac{\partial C'}{\partial x}+v\frac{\partial C'}{\partial y}=D\frac{\partial^2 C'}{\partial y^2}-Kr'\left(C'-C'_\infty\right) \qquad (4)$$

The initial and boundary conditions

$$\left.\begin{array}{l} u=u_w, v=-v_0\ const, <0 \\ \dfrac{\partial T}{\partial y}=-\dfrac{q}{k}, \qquad \dfrac{\partial C}{\partial y}=-\dfrac{j''}{k} \end{array}\right\} at \quad y=0 \qquad (5)$$
$$u\to 0, T\to T'_\infty, C\to C'_\infty \qquad as \quad y\to\infty$$

Where u, are velocity components in x and y directions respectively. g is the acceleration due to gravity, β is volumetric coefficient of thermal expansion, β^* is the volumetric coefficient of expansion with concentration, is the temperature of the fluid, C' is the species concentration, T'_w is the wall temperature, C'_w is the concentration at the plate, T'_∞ is the free steam temperature far away from the plate, C'_∞ is the free steam concentration in fluid far away from the plate, ν is the kinematic viscosity, Du is the species diffusion coefficient, Kr is the chemical reaction parameter. The term is assumed to be the amount of heat generated or absorbed per unit volume. Q_0 is a constant, which may take on either positive or negative values. When the wall temperature T'_w exceeds the free steam temperature T'_∞, the source term represents the heat source $Q_0>0$ when and heat sink when $Q_0<0$. The first term and second term on the right hand side of the momentum equation (2) denote the thermal and concentration buoyancy effects respectively.

In order to write the governing equations and the boundary conditions the following non-dimensional quantities are introduced.

$$Y=\frac{yv_o}{\nu},\quad U=\frac{u}{u_w},\quad k=\frac{K_p v_0^2}{\nu^2}$$

$$T=\frac{T'-T'_\infty}{\left(\dfrac{q\nu}{kv_0}\right)},Sc=\frac{\nu}{D},\mathrm{Pr}=\frac{\mu C_p}{k}$$

$$C=\frac{C'-C'_\infty}{\left(\dfrac{j''\nu}{kv_0}\right)},\quad Gr=\frac{\nu g\beta\left(\dfrac{q\nu}{kv_0}\right)}{u_w v_0^2} \quad (6)$$

$$M=\frac{\sigma B_0^2\nu}{\rho},\quad Du=\frac{D_M K_T j''}{c_s c_p \nu q\rho C_p}$$

$$Gc=\frac{\nu g\beta^*\left(\dfrac{j''\nu}{kv_0}\right)}{u_w v_0^2},Kr=\frac{Kr'\nu}{v_0^2}$$

In view of (6) the equations (2) – (4) are reduced to the following non-dimensional form

$$\frac{d^2U}{dY^2}+\frac{dU}{dY}-\left(M+\frac{1}{k}\right)U=-GrT-GrC \quad (7)$$

$$\frac{d^2T}{dY^2}+\mathrm{Pr}\frac{dT}{dY}=-Du\,\mathrm{Pr}\frac{d^2C}{dY^2} \quad (8)$$

$$\frac{d^2C}{dY^2}+Sc\frac{dC}{dY}-KrSc\,C=0 \quad (9)$$

Corresponding initial and boundary conditions in non-dimensional form are

$$U=1,\frac{\partial T}{\partial Y}=-1,\frac{\partial C}{\partial Y}=-1\ \ at\ \ Y=0 \quad (10)$$
$$U\to 0,T\to 0,C\to 0\quad as\ \ Y\to\infty$$

where Gr is the thermal Grashof number, Gc is the solutal Grashof number, M is the magnetic parameter, k is the permeability parameter, Pr is the fluid Prandtl number, Du is the Dufour number , Sc is the Schmidt number and Kr is the chemical reaction parameter.

METHOD OF SOLUTION

The study of ordinary differential equations (7), (8) and (9) along with their initial and boundary conditions (10) have been solved by using the method of ordinary linear differential equations with constant coefficients. We get the following analytical solutions for the velocity, temperature and concentration

$$U=\left(L_1+L_3\right)e^{m_2 y}+L_2e^{m_4 y}+L_4e^{m_6 y}$$

$$T=J_1e^{m_2 y}+J_2e^{m_4 y}$$

$$C=-\frac{1}{m_2}e^{m_2 y}$$

Skin friction

$$\tau=\left(\frac{\partial U}{\partial y}\right)_{y=0}=m_2\left(L_1+L_3\right)+m_4L_2+m_6L_4$$

Nusselt number

$$Nu=\left(\frac{\partial T}{\partial y}\right)_{y=0}=m_2J_1+m_4J_2$$

Sherwood number

$$Sh=\left(\frac{\partial C}{\partial y}\right)_{y=0}=-1$$

RESULTS AND DISCUSSION

In order to analyze the results are carried out for various values of thermal Grashof number (Gr), solutal Grashof number (Gc), magnetic parameter (M), permeability parameter (k), Prandtl number (Pr), Dufour number (Du) , Schmidt number (Sc) and Chemical reaction parameter (Kr) for various values of Gr = 5.0, Kr = 1.0, Sc= 0. 84, Pr= 0.72, Du=1.0, M=1.0, K=1.0, Gc=5.0 Figs. (2 and 3) disclosed the consequence of thermal and solute Grashof number on the fluid velocity. The Grashof number means the qualified outcome of the heat buoyancy force for the viscous hydrodynamic force through the boundary layer, at the same time as the mass Grashof number established the proportion for the concentration buoyancy force to the viscous hydrodynamic force. As accepted the fluid velocity enhances through good quality of the strengthening of thermal and solute buoyancy forces. The resulting velocity delivery increases quickly after that to the porous surface and this decline effortlessly for the gratuitous flow area. The momentous velocity transversely the boundary layer enlarges through an enhancing in Gr and/or Gm. Therefore, boundary layer thickness augments with boost up in Gr and/or Gm. The repeal tendency is observed with ever-mounting in Dufour parameter illustrated in Fig. (4). Dufour parameter narrates a consequence for the thermal gradients provoking noteworthy mass diffusion consequences. A raise in Dofour parameter, enhance the momentum transport through the boundary layer, hence, the velocity enlarges in complete fluid region. For unlike quantities of the permeability parameter K for velocities and is conspired through Fig. (5). Evidently, the growing quantities of K be probable to rising of the velocity on the porous walls and hence development in the momentum boundary layer thickness. Inferior the permeability lesser noteworthy the fluid velocity is respected inside the vertical surface employed by the fluid. The outcome of chemical reaction parameter on velocity is observed in Fig. (6), it is notice that an increasing chemical reaction parameter the velocity increases. Hence, this is found that disparaging chemical reaction make ineffective the resistive Lorentz force in increasing the resultant velocity throughout the fluid region. Fig. (7) explored that, the influence of the magnetic field parameter M for the resultant velocity distribution. The profiles are parabolise character. The velocity transversely the boundary layer trim downs through an amplifying in the Hartmann number M, this participates a principal responsibility to shrink in the layer width caused by Lorentz forces. Fig. (8) Portrayed the resultant velocity within the boundary layer augments with escalating in Prandtl number. Rising the values of Prandtl number trend to reduces the velocity and so pick up the rate of the momentum boundary layer thickness. It is explored by Fig. (9).That for the velocity with the different values of Schmidt number. On increases in Schmidt numberbe predisposed to reduce of the velocity and boost up the momentum boundary layer thickness. The impacts from Prandtl number (Pr), Dufour number (Du)on the temperatures of the fluid surrounded by the vertical channel is shown in Fig. (10) and Fig. (11). It is observed that, a raise in Prandtl number decline the fluid temperature throughout the fluid region shown in fig (10). Identical manners are noticed with growing in Dufour parameter (Du) in fig. (11). The Dufour parameter (Du) connotes the involvement of the attentiveness gradients for the caloric energy discharge during the flow. This is observed as Dufour parameter amplifies and is monotonically raise in temperature distribution.The concentration interpretation with the parameters like, the chemical reaction parameter (Kr) and Schmidt number (Sc) are publicized from Fig. (12) and (13). The concentration accentuate with heighten in chemical reaction parameter during the fluid medium Fig. (12). It is depicted the transient flow pattern for the variation of chemical reaction parameter with time. The concentration at the left plate is high and it gradually decreases towards the right plate. It is perceived that, from fig. (13)Concentration field lessens through widening in Sc during the fluid region. The Schmidt number discriminates the proportion of thickness of viscous to the solute diffusivity. The Schmidt number is defining the virtual efficiency of momentum and mass transfer through dispersions in the velocity and solutal boundary layers. It is found that, an amplifying in the values of Sc induced the absorption of spices and those boundary layer thicknesses to diminish expansively. From figure (14), we observed that the skin friction for various values of chemical reaction parameter versus Grashof number, it is clear that an increasing in chemical reaction parameter, the results also rises in the vertical surface.

CONCLUSIONS

We analysed the effect of diffusion - thermo (Dufour) on MHD free convective heat and mass transfer two-dimensional steady boundary layer flow of a viscous incompressible electrically conducting fluid through a porous medium with variable permeability over a vertical surface in the presence of first order chemical reaction and oscillatory suction. The governing unsteady boundary layer problems are solved numerically.

The main conclusions of this study are as follows:

- Velocity profiles of the fluid increases with increasing values of Grashof number.
- Velocity profiles of the fluid increases with increasing values of modified Grashof number.
- Velocity profiles of the fluid increases with increasing values of Dufour number
- Velocity profiles of the fluid increases with increasing values of porous permeability number.
- Temperature profiles decreases with increases in Dufour number and Prandtl number.
- Concentration profiles decreases with increasing values of Schmidt number and chemical reaction parameter.
- Skin friction increases with increasing values of porous permeability parameter versus Grashof number.

APPENDIX

$$\beta = \left(M + \frac{1}{K} \right),$$

$$m_2 = -\left(\frac{Sc + \sqrt{Sc^2 + 4KrSc}}{2} \right),\ m_4 = -\left(\Pr\right),$$

$$m_6 = -\left(\frac{1 + \sqrt{1 + 4\beta}}{2} \right)$$

$$J_1 = \left(\frac{Du \Pr m_2}{m_2^2 + \Pr m_2} \right), J_2 = -\left(\frac{1 + J_1 m_2}{m_2} \right)$$

$$L_1 = -\left(\frac{GrJ_1}{m_2^2 + m_2 - \beta} \right), L_2 = -\left(\frac{GrJ_2}{m_4^2 + m_4 - \beta} \right)$$

$$L_3 = \frac{1}{m_2}\left(\frac{Gc}{m_2^2 + m_2 - \beta} \right), L_4 = \left(1 - L_1 - L_2 - L_3\right)$$

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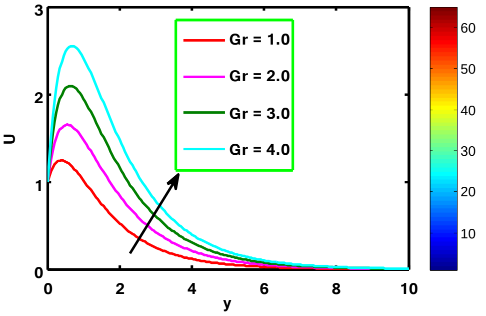

Fig. (2): Velocity Profiles for different values of Gr

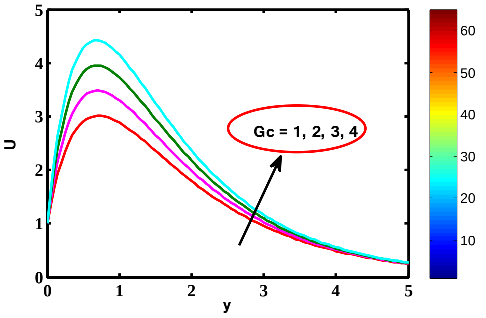

Fig. (3): Velocity Profiles for different values of Gc

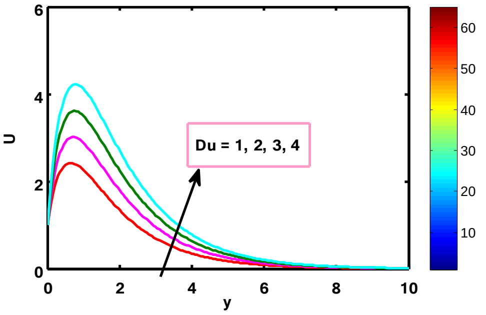

Fig. (4): Velocity Profiles for different values of Du

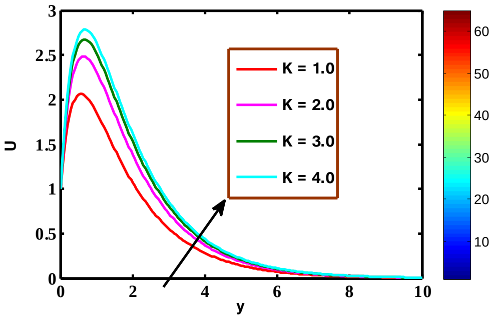

Fig. (5): Velocity Profiles for different values of K

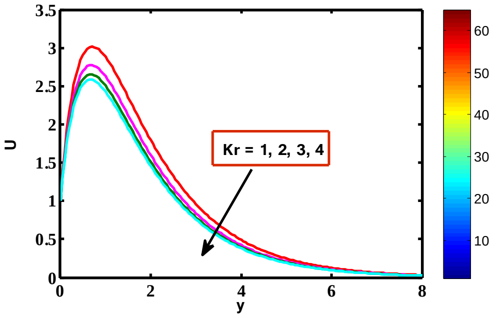

Fig. (6): Velocity Profiles for different values of Kr

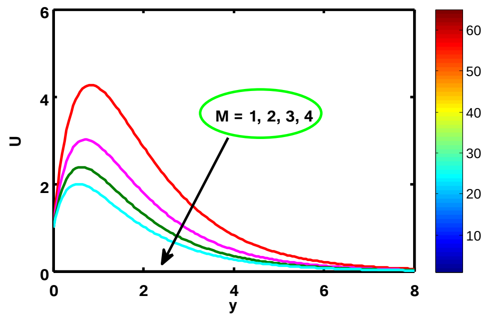

Fig. (7); Velocity profiles for different values of M

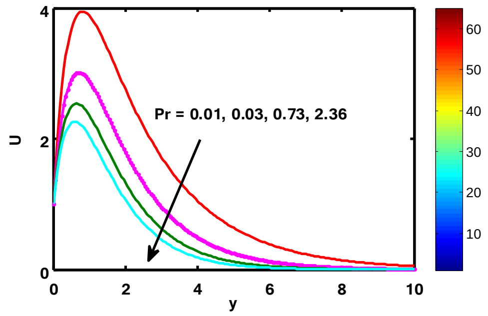

Fig. (8): Velocity Profiles for different values of Pr

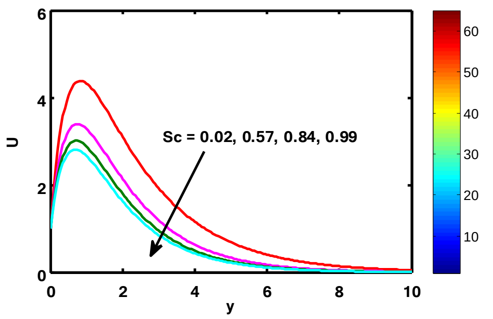

Fig. (9): Velocity Profiles for different values of Sc

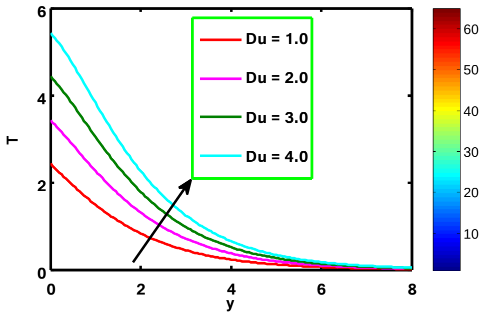

Fig. (10): Temperature profiles for different values of Du

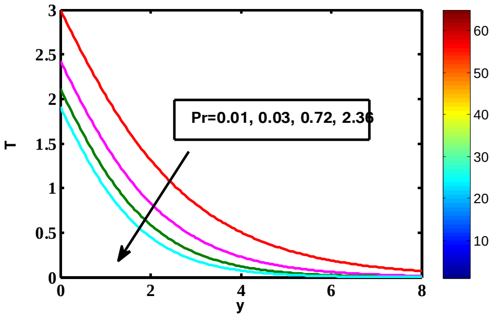

Fig. (11): Temeprature Profiles for different values of Pr

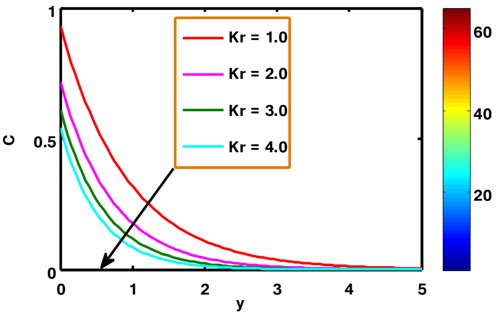

Fig. (12): Concentration profiles for different values of Kr

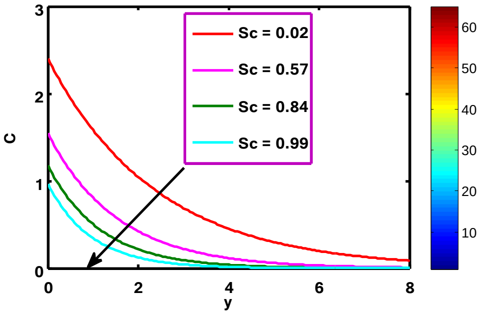

Fig. (13): Concentration profiles for different values of Sc

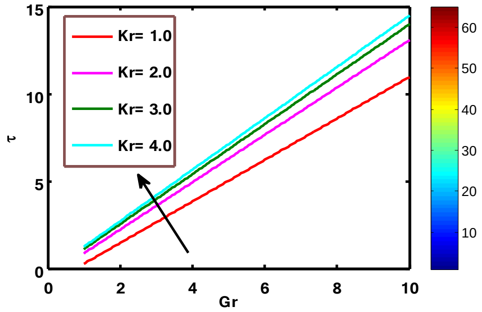

Fig. (14): Skin friction for different values of K versus Gr