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Radiation Absorption, Chemical Reaction and Magnetic Filed Effects On The Free Convection And Mass Transfer Flow Through Porous Medium With Constant Suction And Constant Heat Flux

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ABSTRACT: An attempt has been made to study the effect of the steady two - dimensional free convection heat and mass transfer flow electrically conducting and chemically reacting fluid through a porous medium bounded by a vertical infinite surface with constant suction velocity and constant heat flux in the presence of a uniform magnetic field is presented. The governing equations are couples and non linear. These equations are solved by perturbation technique. The effect of Grashof number for heat transfer $Gr > 0$ corresponds to externally cooled plate and $Gr < 0$ specified condition for externally heated plate). Grashof number for heat transfer (Gr), Mass Grashof number (Gm), Schmidt number (Sc), permeability parameter (K), heat source parameter (ϕ), radiation absorption parameter (Q_l), Magnetic number (M) and Chemical reaction parameter (Kr) taking two cases viz. Case(I): when $Gr > 0$, (i.e. flow on cooled plate) and Case(II) $Gr < 0$ (i.e. flow on heated plate). All numerical calculation are done with respect to air $\left(\Pr = 0.71 \ at \ 20^\circ C\right)$. The effects of the above mentioned parameters on skin friction coefficient at the surface are also presented.

Keywords: Conducting fluid, porous medium, free convection, chemical reaction and heat absorption.

INTRODUCTION

Convective flows with simultaneous heat and mass transfer under the influence of a magnetic field and
chemical reaction arises in many transport processes both naturally and artificially in many branches of science and engineering applications. This phenomenon plays an important role in the chemical industry, power and cooling industry for drying, chemical vapour deposition on surfaces, cooling of nuclear reactors and petroleum industries. Natural convection flow occurs frequently in nature. It occurs due to temperature differences, as well as due to concentration differences or the combination of these two, for example in atmospheric flows, there exists differences in water concentration and hence the flow is influenced by such concentration difference.

Convective flow in porous media has been widely studied in the recent years due to its wide applications in engineering as post accidental heat removal in nuclear reactors, solar collectors, drying processes, heat exchangers, geothermal and oil recovery, building construction, etc. Porous media are widely used in high temperature heat exchangers, turbine blades, jet nozzles, ect. In practice cooling of porous structure is achieved by forcing the liquid or gas through capillaries of solid. Actually, they are used to insulate a heated body to maintain its temperature. Porous media are considered to be useful in diminishing the natural free convection which would otherwise occur intensely on a vertical heated surface. In order to make heat insulation of surface more effect in heat and mass transfer. Study of origin of flow through porous media is heavily based on Darcy's experimental law. By using Darcy's law, Yamamoto and Yoshida [26] considered suction and injection flow with convective acceleration through a plane porous wall specifically for the flow outside a vertex layer. Chawla and Singh [5] studied oscillatory flow past a porous bed. The effect of variable permeability on combined free and forced convection in porous media was studied by Chandrasekhar and Namboodiri [4]. Heat and mass transfer in a porous medium was discussed by Bejan and Khair [2]. The above problem was studied in presence of buoyancy effect by

Trevisan and Bejan [25]. Lai and Kulacki [12] studied the effect of variable viscosity on convective heat transfer along a vertical surface in a saturated porous medium. Convection in a porous medium with inclined temperature gradient was investigated by Nield [14]. Shateyi et.al. [22] Magnetohydrodynamic flow past a vertical plate with radiative heat transfer.

Combined heat and mass transfer problems with chemical reaction are of importance in many processes and have, therefore, received a considerable amount of attention in recent years. In processes such as drying, evaporation at the surface of a water body, energy transfer in a wet cooling tower and the flow in a desert cooler, heat and the mass transfer occur simultaneously. Possible applications of this type of flow can be found in many industries, For example, in the power industry, among the methods of generating electric power is one in which electrical energy is extracted directly from a moving conducting fluid. Many practical diffusive operations involve the molecular diffusion of a species in the presence of chemical reaction within or at the boundary. There are two types of reactions. A homogeneous reaction is one that occurs uniformly throughout a give phase. The species generation in a homogeneous reaction is analogous to internal source of heat generation. In contrast, a heterogeneous reaction takes place in a restricted region or within the boundary of a phase. It can therefore be treated as a boundary condition similar to the constant heat flux condition in heat transfer. The study of heat and mass transfer with chemical reaction is of great practical importance to engineers and scientists because of its almost universal occurrence in many branches of science and engineering. Muthucumaraswamy and Ganesan [13] studied the effect of the chemical reaction and injection on flow characteristics in an unsteady upward motion of an isothermal plate. Deka *et al.* [6] studied the effect of the first-order homogeneous chemical reaction on the process of an unsteady flow past an infinite vertical plate with a constant heat and mass transfer.

The study of heat generation/absorption effects in moving fluids is important in view of several physical problems, such as fluids undergoing exothermic or endothermic chemical reaction. Due to the fast growth of electronic technology, effective cooling of electronic equipment has become warranted. The cooling of electronic equipment ranges from individual transistors to main frame computers, from energy suppliers to telephone switch boards and thermal diffusion effects has been utilized for isotopes separation in the mixture between gases with very light molecule weight (hydrogen and helium) and medium molecular weight. Chamkha [3] studied the MHD flow of a numerical of uniformly stretched vertical permeable surface in the presence of heat generation / absorption and a chemical reaction. Muthucumaraswamy and Ganesan [19] investigated the effects of a chemical reaction on the unsteady flow past an impulsively started semi-infinite vertical plate which subjected to uniform heat flux. Acharya et.al [1] Magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux. Dulal Pal *et al* [7] studied Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction. Stanford Shateyi and Sandile Motsa [24] Unsteady Magnetohydrodynamic convective heat and mass transfer past an infinite vertical plate in a porous medium with thermal radiation, heat generation/absorption and chemical reaction. Kesavaiah et.al [10] 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.

Seethamahalakshmi et.al [20] effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical moving in a porous medium with heat source and suction. Singh et.al [23] a study of the effect of chemical reaction and radiation absorption on MHD convective heat and mass transfer flow past a semi-infinite vertical moving plate with time dependent suction. Prakash *et al.* [16] studied the transient MHD free convection of a chemically reacting micro-polar fluid along with mass transfer in the presence of transverse magnetic field and variable suction. The problem of the unsteady free convection flow of water near 40C in the laminar boundary layer over a vertical moving porous plate is investigated by Rapits and Pedrikis [18]. In his pioneering work, Rajeswari *et al.* [17] included the effects of chemical reaction on heat and mass transfer in non - linear MHD boundary layer flow with vertical porous surface in the presence of suction. Sharma and Singh *et al.* [21] have discussed in detail the effect of variable thermal conductivity in MHD fluid flow over a stretching sheet considering heat source and sink parameter. Ch Kesavaiah and Venkataramana [11] A study of some convective flows with heat transfer effects.

In spite of all the previous studies, to investigate the free convection heat and mass transfer flow of a viscous incompressible and electrically conducting and chemically reacting fluid through porous medium (assumed highly porous) bounded by vertical infinite surface with constant suction velocity and constant heat flux in the presence of radiation absorption under the action of uniform magnetic field applied normal to the direction of flow.

FORMULATION OF THE PROBLEM

We consider steady two dimensional motion of incompressible, electrically conducting and chemical reacting fluid through a porous medium with heat generation/absorption occupying semi-infinite region of space bounded by a vertical infinite surface under the action of uniform magnetic field applied normal to the direction of the flow. The effect of induced magnetic field is not strong enough to cause Joule heating Sapunkov [19] (electrical dissipation). Hence, the term due to electrical dissipation is neglected in energy equation (3). The x-axis is taken along the surface in the upward direction and y-axis is taken normal to it. The fluid properties are assumed constant except for the influence to density in the body force term. As the bounding surface is infinite in length, all the variables are functions of y only. Hence, by the usual boundary layer approximation the basic equations for steady flow through highly porous medium are

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

$$v\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\,\beta(T-T_\infty)+g\beta^*(C-C_\infty)-\left(\frac{\sigma B_0^2}{\rho}\right)u+\left(\frac{\nu}{k}\right)u \tag{2}$$

$$v\frac{\partial T}{\partial y}=\frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{Q_0}{\rho C_p}\left(T-T_\infty\right)+Q_l'\left(C-C_\infty\right) \tag{3}$$

$$v\frac{\partial C^*}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-Kr'\left(C-C_\infty\right) \tag{4}$$

Where u and v are the velocity components along and perpendicular to the surface, g is the acceleration due to gravity, T the temperature of the fluid near the plate, T_∞ the free stream temperature, C concentration, β the coefficient of thermal expansion, β^* is the volumetric coefficient of expansion of the spices concentration, k the thermal conductivity, C_p the specific heat of constant pressure, B_0 the magnetic field coefficient, μ viscosity of the fluid, ρ the density, σ the magnetic permeability of fluid V_0 constant suction velocity, ν the kinematic viscosity and D chemical molecular diffusivity.

SOLUTION OF THE PROBLEM

The equation of continuity (1) gives

$$v=-v_0 \text{ (Constant)} \tag{5}$$

where $v_0>0$ corresponds to steady suction velocity (normal) at the surface. In view of equation (5), equations (2), (3) and (4) are reduced to

$$v_0\frac{\partial u}{\partial y}=\nu\frac{\partial^2 u}{\partial y^2}+g\,\beta(T-T_\infty)+g\beta^*(C-C_\infty)-\left(\frac{\sigma B_0^2}{\rho}\right)u+\left(\frac{\nu}{k}\right)u \tag{6}$$

$$v_0\frac{\partial T}{\partial y}=\frac{\lambda}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{Q_0}{\rho C_p}\left(T-T_\infty\right)+Q_l'\left(C-C_\infty\right) \tag{7}$$

$$v_0\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}-Kr'\left(C-C_\infty\right) \tag{8}$$

The relevant boundary conditions are

$$u=0, T=T_w, C=C_\infty \quad for \ all \ y \ t\le 0$$
$$u=0, T_y=-q/\lambda, C_y=m/D \ y=0, t>0 \qquad (9)$$
$$u\to 0, \ T\to T_\infty, C\to C_\infty \ y\to\infty, t>0$$

Introducing the following non-dimensional quantities in equations (6), (7) and (8) and asterisk

$$f(\eta)=\frac{u}{v_0}, \ \eta=\frac{v_0 y}{\nu}, \ M=\frac{\sigma B_0^2 \nu}{v_0^2\rho}$$
$$\theta=\frac{(T-T_\infty)v_0\lambda}{q\nu}, C=\frac{(C-C_\infty)v_0 D}{m\nu}$$
$$Gr=\frac{\rho\beta g\nu^2(T_w-T_\infty)}{v_0^3\mu}, \qquad Sc=\frac{\nu}{D} \qquad (10)$$
$$Gm=\frac{\rho\beta^* g(C-C_\infty)}{v_0^3}, \ Kr=\frac{Kr' m\nu}{DV_0^2}$$
$$\Pr=\frac{\mu C_p}{\lambda}, \qquad Q_0=\frac{\phi V_0^2\rho C_p}{\nu}$$
$$Q_l'=\frac{QqV_0^2 D}{m\nu\lambda}, \qquad \alpha=\frac{V_0^2 K}{\nu^2}$$

where Gr is Grashof number, Gm is mass Grashof number, $\Pr$ is Prandtl number, M is Magnetic number, Sc is Schmidt number, Kr is Chemical reaction parameter, Q_l is radiation absorption parameter, ϕ is heat source parameter,

where q is the heat flux term per unit area and m is the mass flux per unit area.

We get

$$f''+f'-f\left(\alpha^{-1}+M\right)=-Gr\theta-GrC \qquad (11)$$

$$\Pr\theta'=\theta''-\Pr\phi\theta-\Pr Q_l C \qquad (12)$$

$$C''+ScC'-KrSc=0 \qquad (13)$$

Where prime denotes differentiation with respect to η

The corresponding boundary condition in dimensionless form are reduced to

$$\eta=0: \quad f=0, \quad \theta'=-1, C'=-1$$
$$\eta\to\infty: f\to 0, \quad \theta\to 0, \quad C\to 0 \qquad (14)$$

The physical variables f, θ *and* C can be expanded in the power of (ε). This can be possible physically as ε for the flow of an incompressible fluid is always less than unity. It can be interpreted physically as the flow due to the Joules dissipation is super imposed on the main flow. Hence we can assume

$$f(\eta)=f_0(\eta)+\varepsilon f_1(\eta)+0\left(\varepsilon^2\right)$$
$$\theta(\eta)=\theta_0(\eta)+\varepsilon\theta_1(y)+0\left(\varepsilon^2\right) \qquad (15)$$
$$C(\eta)=C_0(\eta)+\varepsilon C_1(\eta)+0\left(\varepsilon^2\right)$$

Using equation (15) in equations (11)–(13) and equating the coefficient of like powers of ε, we have

$$f_0''+f_0'-\left(\alpha^{-1}+M\right)f_0=-Gr\,\theta_0-GmC_0 \quad (16)$$
$$\theta_0''-\Pr\,\theta_0'-\Pr\phi\theta_0=\Pr Q_l C_0 \qquad (17)$$
$$C_0''+ScC_0'-KrC_0=0 \qquad (18)$$
$$f_1''+f_1'-\left(\alpha^{-1}+M\right)f_1=-Gr\,\theta_1-GmC_1 \qquad (19)$$
$$\theta_1''-\Pr\theta_1'-\Pr\phi\theta_1=\Pr Q_l C_1 \qquad (20)$$
$$C_1''+ScC_1'-KrC_1=0 \qquad (21)$$

and the corresponding boundary conditions are

$$\eta=0: \begin{cases} f_0=0, \quad f_1=0, \quad \theta_0'=-1 \\ \theta_1'=0, \ C_0'=-1, C_1'=0 \end{cases}$$
$$y\to\infty: \begin{cases} f_0\to 0, \ f_1\to 0, \ \theta_0\to 0 \\ \theta_1\to 0, \ C_0\to 0, C_1\to 0 \end{cases} \qquad (22)$$

Solving equations (16) to (21) with the help of (22) we get

$$f_0=A_3e^{m_2y}+A_4e^{m_6y}+A_5e^{m_2y}+A_6e^{m_{10}y}$$
$$f_1=0 \qquad (23)$$

$$\theta_0=A_1e^{m_2y}+A_2e^{m_6y}, \ \theta_1=0 \qquad (24)$$

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$$C_0 = -\frac{1}{m_2} e^{m_2 y}, C_1 = 0 \qquad (25)$$

$$f = A_3 e^{m_2 y} + A_4 e^{m_6 y} + A_5 e^{m_2 y} + A_6 e^{m_{10} y}$$

$$\theta = A_1 e^{m_2 y} + A_2 e^{m_6 y}$$

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

Skin – friction:

The skin-friction coefficient at the plate is given by

$$\tau = \left(\frac{\partial f}{\partial \eta}\right)_{\eta=0} = m_2 A_3 + m_6 A_4 + m_2 A_5 + m_{10} A_6$$

Heat Transfer:

The rate of heat transfer in terms of Nusselt number at the plate is given by

$$Nu = \left(\frac{\partial \theta}{\partial \eta}\right)_{\eta=0} = m_2 A_1 + m_6 A_2$$

RESULTS AND DISCUSSION

Using equations (14), (22), (23), (24), (25) & (26) we find required equations for velocity, temperature and concentration. During the course of numerical calculation of velocity, temperature and spices concentration functions the values of Prandtl number $\Pr$ is chosen to be 0.17 which represents air at $20^\circ C$. The values of Schmidt number Sc are chosen is such a way that they represent the diffusing chemical spices of most common interest in air. (For examples, the values of Schmidt number for H_2, H_2O, NH_3 and propyl benzene in air is 0.22, 0.60, 0.78 and 2.62 respectively. Perry [15]). Here Grashof number for heat transfer $Gr < 0$ corresponds to an externally heated plate as the free convection currents are carried towards the plate. $Gr > 0$ Corresponds to an externally cooled plate. As the species concentration is assumed to be very low, these only positive values are chosen.

The fluid velocity, temperature and concentrations variations in case of externally cooled surface are shown in Figures (1), (2) and (3) for various values of Schmidt number (Sc). It is observed that for heavier diffusing foreign spices, i.e., increasing Schmidt number reduction in velocity level both in magnitude and extent and thinning of thermal boundary layer occurs. Substantial increase in velocity distribution profiles is observed near the plate with decreasing Schmidt number (lighter diffusing particle): Comparison of solid curves $(Gr = 10.0)$ and broken curves $(Gr = 5.0)$ for a particular foreign species indicate that greater cooling results in an increase in velocity and thermal boundary layer thickness. Comparison of velocity distribution curves shows that curves fall gradually after attaining maximum value near the plate or on the plate, where as temperature distribution profiles falls from maximum value on the plate. The concentration distribution decreases where as Schmidt number increases. Figure (4) and (5) shows the effects of velocity and temperature distribution against y variations in heat absorption parameter Q_l, we observe that an increasing the heat absorption parameter Q_l the velocity and temperature distribution increases.

Figure (6) shows the velocity profiles across the boundary layer for different values of Prandtl number Pr. The results show that the effect of increasing values of Pr results in a increasing the velocity. Typical variation of the temperature profiles along the span wise coordinate *y* are shown in Figure (7) for different values of Prandtl number Pr. The results show that an increase of Prandtl number results in a increasing; The physical reason is that the high Prandtl number fluid has a relatively the thermal boundary layer thickness and more uniform temperature distribution across the boundary layer. Thus, results in a reduction in the thermal boundary layer and an increase in the convection heat transfer at wall. The influences of chemical reaction parameter Kr on the velocity and temperature profiles across the boundary layer are presented in Figures (8) and (9). We see that the velocity and temperature distribution across the boundary layer increases with increasing of Kr. For different values of the chemical reaction parameter Kr, the concentration profiles plotted in Figure (10). It is obvious that the influence of increasing values of Kr, the concentration distribution across the boundary layer decreases. Figure (11) depicts the effect of permeability α on velocity distribution externally cooled plate with increasing permeability parameter. However, substantial increase occurs near the plate. The effect of heat generation ϕ on the velocity profiles is shown in Figure (12). From this figure we see that the heat is generated the buoyancy force increases which induces the flow rate to increase giving rise to the decrease in the velocity profiles. Figure (13) shows the variation of temperature profiles for different values of ϕ. It is seen from this figure that temperature profiles decrease with an increasing of heat generation parameter ϕ. For different values of the magnetic field parameter *M*, the velocity profiles are plotted in Figure (14). It is obvious that the effect of increasing values of *M* parameter results in decreasing velocity distribution across the boundary layer because of the application of transfer magnetic field will result a restrictive type force (Lorentz force) similar to drag force which tends to resist the fluid flow and thus reducing its velocity.

Figures (15) – (21) exhibits variations of velocity profiles of the fluid for different values of Sc in case of externally heated plate $(Gr < 0)$. The velocity of fluid layer decreases in magnitude for thicker diffusing species and substantial decrease in observed near the plate. Here also thinning effect in thermal boundary layer is observed for smaller values of Sc. For a particular value of Sc greater heating causes decrease in fluid velocity and increase in thermal boundary layer thickness. Comparing the curves of Figure (1) and Figure (15), it is conclude that cooling results increase in velocity while heating results decrease in velocity. The effects of variations in the parameters $\phi, \alpha, Kr, Q_l, \Pr$ shows from figures (16) – (20), we conclude that increases in $\phi, \alpha, Kr, Q_l, \Pr$ the velocity decreases. The reverse effect can be observed form figure (15) for variation in M .

It is inferred from Table I that skin friction coefficient increases both for externally cooled plate and externally heated plate with increasing Sc but the magnitude being negative for $Gr < 0$ Similarly, increasing Grashof number for mass transfer skin friction coefficient decreases for both the cases and magnitude being negative for $Gr < 0$ (Table II). The porosity of the medium has considerable effect on skin friction increases for externally heated plate and decreases for externally heated plate (Table III). Finally increasing magnetic field skin friction coefficient decreases (Table IV).

Table I

Variation of skin friction coefficient at the plate with Schmidt Number for

$$\Pr = 0.71, \alpha = 0.5, Q_l = 0.5, Kr = 0.5, M = 1.0$$

$(\tau)_0$		
Sc	$Gr = 10.0$	$Gr = -10.0$
0.22	3.3975	-10.9876
0.60	4.1345	-9.87650
0.78	3.8757	-9.87690
2.62	9.3546	-4.56430

Table II

Variation of skin friction coefficient at the plate with Gm for

$$\Pr = 0.71, Sc = 0.22, Kr = 0.5, Q_l = 0.5$$

$(\tau)_0$		
Gm	$Gr = 10.0$	$Gr = -10.0$
0.1	4.8604	-8.9276
0.2	3.4345	-10.8765
0.3	2.1757	-12.8034
0.4	1.0546	-15.0678

Table III

Variation of skin friction at the plate with permeability parameter α where

$$\Pr = 0.71, Sc = 0.22, Gm = 2.0, Kr = 0.5, Q_l = 0.5$$

$(\tau)_0$

α	$Gr = 10.0$	$Gr = -10.0$
1.0	3.3604	-10.7276
2.0	4.1345	-15.1265
3.0	4.5004	-17.8034
4.0	4.6868	-19.5678

Table IV

Variation of skin friction at the plate with magnetic number M where

M	$(\tau)_0$
0.5	4.1614
1.0	3.3345
2.0	2.6464
3.0	2.4278
4.0	2.8196
5.0	1.9261
6.0	1.8765
7.0	1.6623

$$\Pr = 0.71, Sc = 0.22, Gm = 2.0$$
$$\alpha = 1.0, Q_l = 0.5, Kr = 0.5$$

We now summaries the following main conclusions can be drawn from the present paper:

1. Presence of foreign species reduces the velocity as well as thermal boundary layer and further reduction occurs with increasing Schmidt number in case of externally cooled plate.
2. Velocity of fluid layer decreases and thickness of thermal boundary layer increases with increasing Schmidt number in case of externally heated plate.
3. Porosity of the medium has considerable effect on velocity distribution. The profiles increase with increases in permeability parameter.
4. Application of magnetic field causes decrease in velocity profiles.
5. The concentration decreases with increasing the chemical reaction parameter
6. Both the velocity and temperature profiles increase with increasing values of radiation absorption parameter.

These results might find wide applications in engineering, such as geothermal system, heat exchangers, and nuclear waste depositors.

APPENDIX

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

$$m_6 = -\left(\frac{\Pr + \sqrt{\Pr^2 + 4\Pr\phi}}{2}\right)$$

$$m_{10} = -\left(\frac{1 + \sqrt{1 + 4B_1}}{2}\right), B_1 = \left(\alpha^{-1} + M\right)$$

$$A_1 = -\frac{\Pr Q_l}{m_2^{\ 3} - \Pr m_2^{\ 2} - \Pr m_2\phi}$$

$$A_2 = -\frac{1}{m_6}\left(1 + A_1 m_2\right)$$

$$A_3 = -\frac{GrA_1}{m_2^{\ 2} + m_2 - B_1}, A_4 = -\frac{GrA_2}{m_6^{\ 2} + m_6 - B_1}$$

$$A_5 = \frac{Gr}{m_2^{\ 3} + m_2^{\ 2} - B_1}, \ A_6 = -\left(A_3 + A_4 + A_5\right)$$

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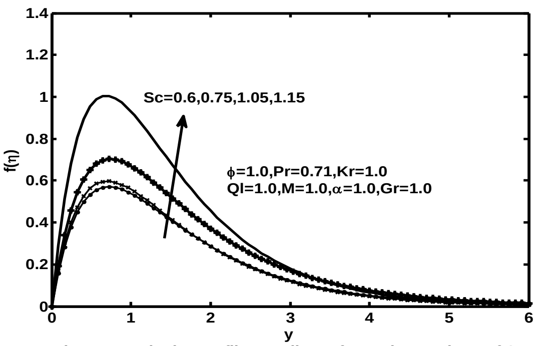

Figure 1. Velocity Profiles agaibst η for various values of Sc

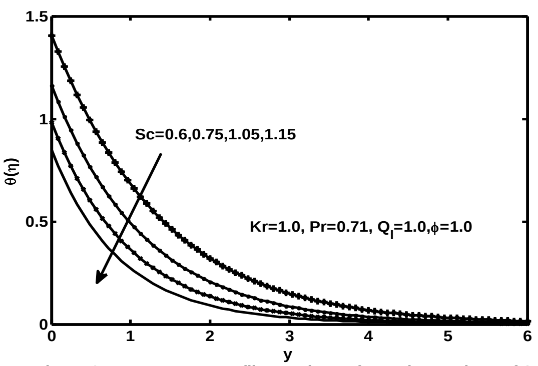

Figure 2. Temperature profiles against η for various values of Sc

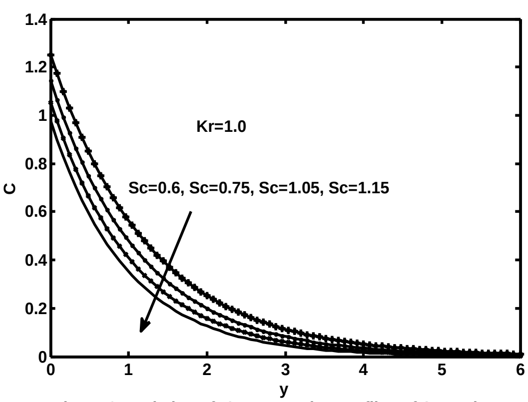

Figure 3. Variation of Concentration profiles of Sc against η

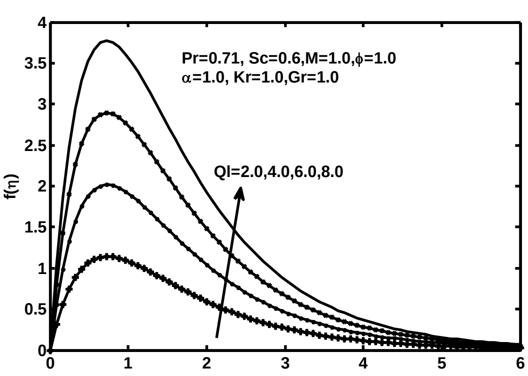

Figure 4. Velocity profiles against η various values of Q_l

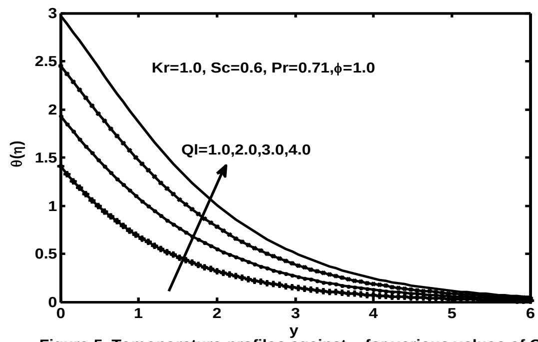

Figure 5. Temeperature profiles against η for various values of Q_l

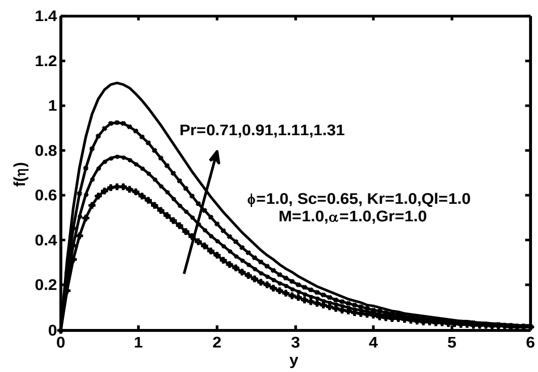

Figure 6. Velocity profiles against η various values of Pr

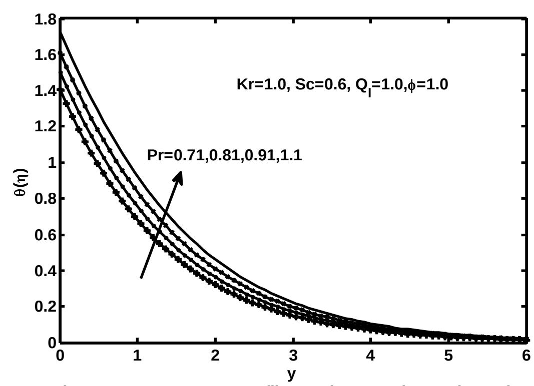

Figure 7. Temeperature profiles against η various values of Pr

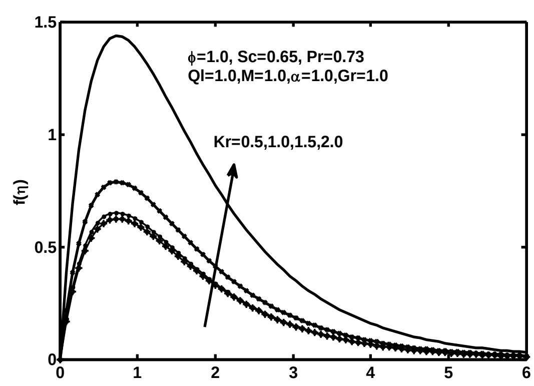

Figure 8. Velocity profiles against η various values of Kr

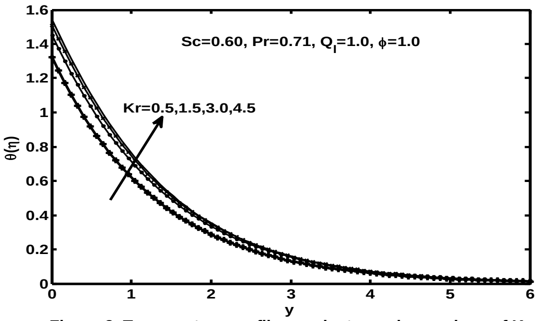

Figure 9. Temperature profiles against η various values of Kr

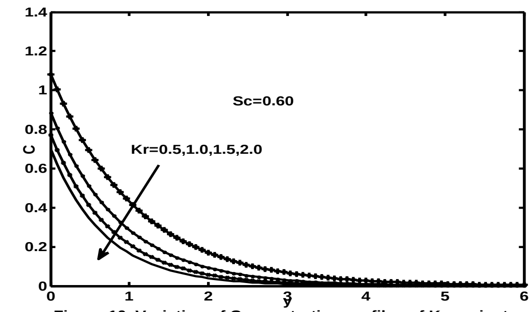

Figure 10. Variation of Concentration profiles of Kr against η

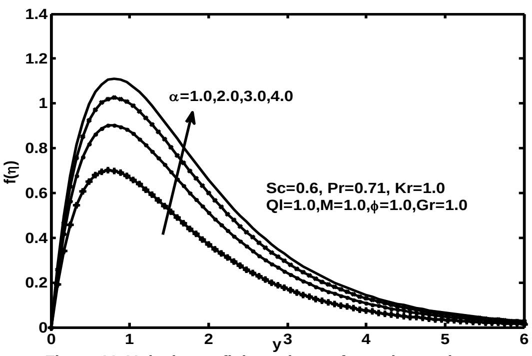

Figure 11. Velocity profiels against η for various valueos α

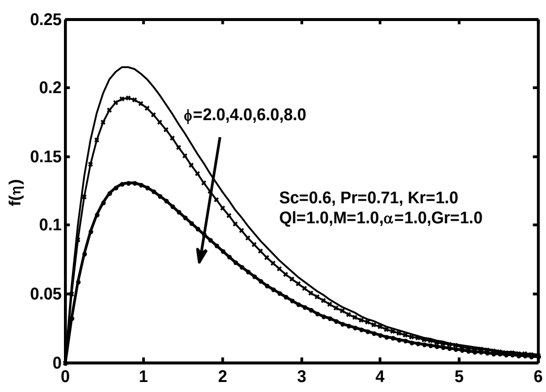

Figure12. Velocity profiles against η for various values of ϕ

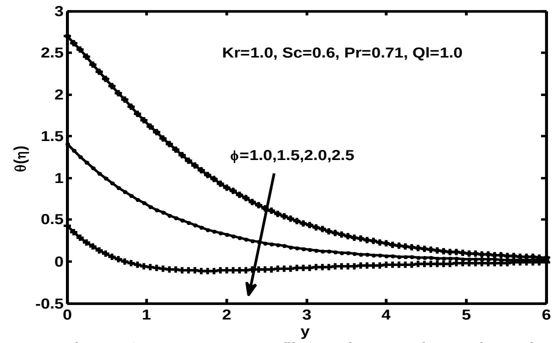

Figure 13. Temperature profiles against η various values of ϕ

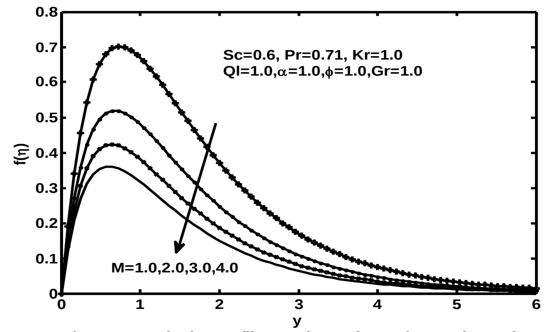

Figure 14. Velocity profiles against η for various values of M

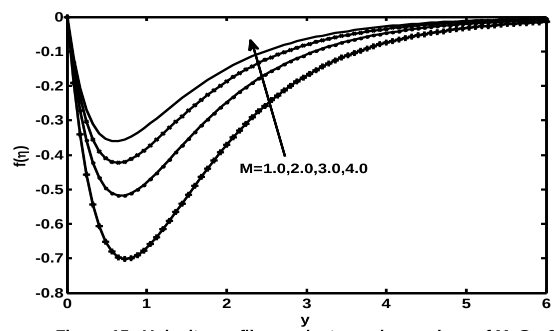

Figure 15. Velocity profiles against η various values of M, Gr<0

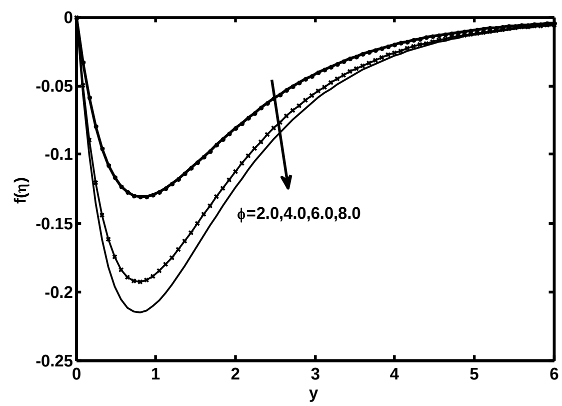

Figure 16. Velocity profiles against η various values of ϕ, Gr<0

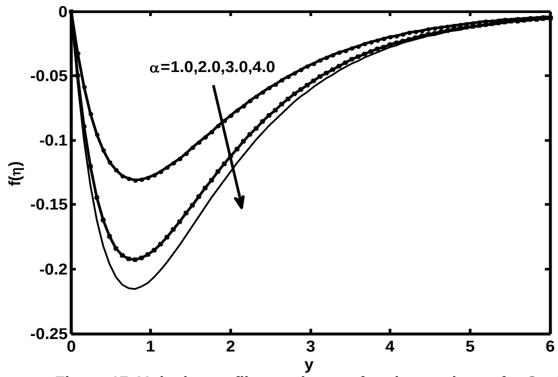

Figure 17. Velocity profiles against η of various values of α,Gr<0

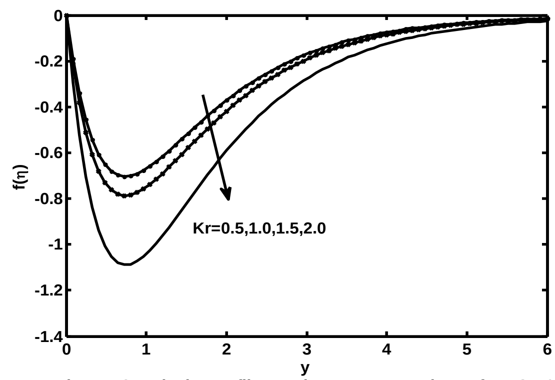

Figure 18. Velocity profiles against η varous values of Kr, Gr<0

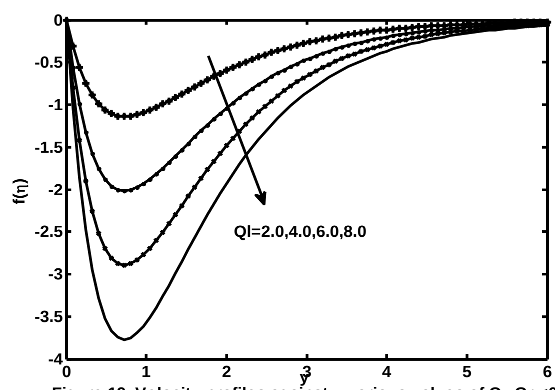

Figure 19. Velocity profiles against η various values of Q_l, Gr <0

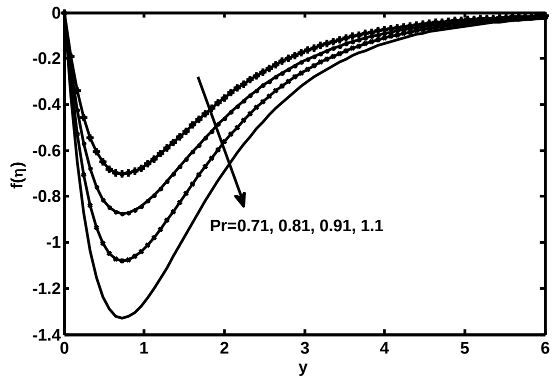

Figure 20. Velocity profiles against η for various values of Pr, Gr <0

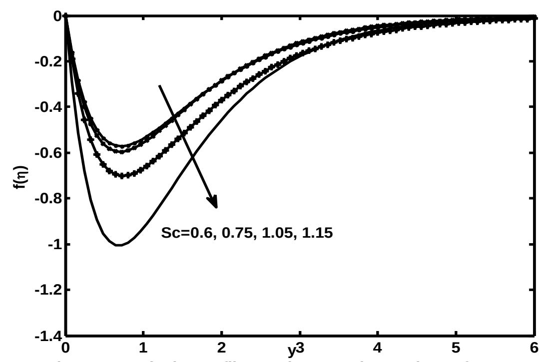

Figure 21. Velocity profiles against η various values of Sc, Gr<0