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# Effects of Variable Viscosity and Thermal Conductivity and Magnetic Field Effect on the Free Convection and Mass Transfer Flow through Porous Medium with Constant Suction/Heat Flux.

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**ABSTRACT:** Here effects of variable viscosity and thermal conductivity and magnetic field effect on the free convection and mass transfer flow through porous medium with constant suction/heat flux is studied The boundary layer equations are transformed in to ordinary differential equations with similarity transformations. The effects of variable viscosity and thermal conductivity on velocity profile, temperature profile and concentration profiles are investigated by solving the governing transformed ordinary differential equations with the help of Runge-Kutta shooting method and plotted graphically.
**Keywords:** Variable viscosity, thermal conductivity, magnetic field.
MSC(2000): 47.10AD

## I. INTRODUCTION:

The study of porous media is given much interest due to its wide use in high temperature heat exchangers, turbine blades, jet nozzles etc. In practice cooling of porous structure is achieved by forcing the liquid or gas through capillaries of solid. They are used to insulate a heated body to maintain its temperature.

In order to make heat insulation of surface more effective, it is necessary to study the free convection flow through a porous medium and to estimate its effect in heat and mass transfer. In most of the investigations done earlier on the free convection and mass transfer flow of a viscous fluid through porous medium, the viscosity and the thermal conductivity of the fluid were assumed to be constant. However, it is known [1] that these physical properties can change significantly with temperature and when the variable viscosity and thermal conductivity are taken into account, the flow characteristic are substantially changed to the constant cases.

Thermal conductivity is a physical property of a substance which accounts for the heat conducting ability of a substance and depends not only on the particular substance but also on the state of that substance. The value of thermal conductivity determines the quantity of heat passing per unit time per unit area at a temperature drop of $1^0$c per unit length. Thermal conductivity of a fluid changes with temperature. Fourier's Law of heat conduction states that the rate of heat transfer is linearly proportional to the temperature gradient. Viscosity is that property of fluid which resists relative motion of its adjacent layer. It is a measure of internal fluid friction due to which there is resistance of fluid, in general it is a function of temperature.

Chawla and Singh [2] studied oscillatory flow past a porous bed. The steady two dimensional flow of viscous fluid through a porous medium bounded by a porous surface subject to a constant suction velocity by taking of free convection currents (both velocity and temperature fields are constant along x –axis) was studied by Raptis [3]. Yamamoto and Yoshida [4] considered suction and injection flow with convective acceleration through a plane porous wall especially for the flow outside a vortex layer.

The effect of variable permeability on combined free and forced convection in porous media was studied by Chandra Sekhara and Namboodiri [5]. Heat and Mass transfer in a porous medium was discussed by Bejan and Khair [6]. The free convection effect on the flow on an ordinary viscous fluid past an infinite vertical porous plate with constant suction and constant heat flux was investigated by Sharma [7].

The steady two dimensional flow through a porous medium bounded by a vertical infinite surface with constant section velocity and constant heat flux (where both velocity and temperature fields are constant along x-axis) was studied by Sharma [8]. Hazarika [9] has studied heat transfer due to flow of viscous Newtonian fluid between two parallel circular disks of infinite extent. Pop. Gorla and Rashid [10] studied the effect of variable viscosity on laminar boundary flow and heat transfer due to a continuous moving flat plate.

The objective of the present study is to investigate the effects of variable viscosity & thermal conductivity on the free convection and mass transfer flow of a viscous incompressible and electrically conducting fluid through a porous medium (assumed highly porous) bounded by vertical infinite surface with constant suction velocity & constant heat flux in presence of a uniform magnetic field.

## II. MATHEMATICAL FORMULATION:

In the present study, we consider steady two dimensional motion of viscous incompressible electrically conducting fluid through a porous medium occupying semi-infinite region of space bounded by vertical infinite surface under the action of uniform magnetic field. The effect on induced magnetic field is neglected. Magnetic field is not strong enough to cause Joule heating (electrical dissipation). Hence, the term due to electrical dissipation is neglected. The x-axis is taken along the surface in the upward direction and y-axis is taken normal to it. 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:

*Equation* of continuity:

$$\frac{\partial v}{\partial y} = 0 \quad \text{--- (4.2.1)}$$

$$\Rightarrow v = constant = -v_0 \text{ (say)}$$

Equation of motion:

$$-v_0 \frac{\partial u}{\partial y} = \frac{1}{\rho}\frac{\partial \mu}{\partial y}\frac{\partial u}{\partial y} + \frac{\mu}{\rho}\frac{\partial^2 u}{\partial y^2} + g\beta(T - T_\infty)$$

$$+ g\beta^*(C - C_\infty) - \left(\frac{\sigma\beta^2{}_0}{\rho}\right)u - \left(\frac{v_\infty}{k}\right)u \quad \text{--- (4.2.2)}$$

Equation of Energy:

$$-v_0 \frac{\partial T}{\partial y} = \frac{1}{\rho C_p}\left[\frac{\partial \lambda}{\partial y}\frac{\partial T}{\partial y} + \lambda\frac{\partial^2 T}{\partial y^2}\right] + \frac{\mu}{\rho C_p}\left(\frac{\partial u}{\partial y}\right)^2 \; --- (4.2.3)$$

*Equation* of Mass Transfer:

$$-v_0 \frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} \quad \text{--- (4.2.4)}$$

The appropiate boundary conditions are:

$$\left.\begin{array}{lll} u=0,\ T=T_w, & C=C_w & \text{for all } y,t \le 0 \\ u=0,\ T_y = -\dfrac{q}{\lambda_\infty}, & C_y = -\dfrac{m}{D_\infty}, & y=0,t>0 \\ u=0,\ T=T_\infty, & C=C_\infty, & y \to \infty, t>0 \end{array}\right\rangle \quad \text{---(4.2.5)}$$

Where u and v are the corresponding velocity components along and perpendicular to the surface,

$\mu \rightarrow$ Viscosity

$\nu_\infty \rightarrow$ The Kinetic viscosity at $\infty$

$g \rightarrow$ The acceleration due to gravity

$\beta \rightarrow$ The co-efficient of volume expansion for the heat transfer.

$\beta^* \rightarrow$ The volumetric co-efficient of expansion with species concentration,

$T \rightarrow$ The temperature of the fluid,

$T_\infty \rightarrow$ The fluid temperature at $\infty$

$\lambda \rightarrow$ The thermal conductivity,

$\rho \rightarrow$ The density of the fluid

$C_p \rightarrow$ Specific heat at constant pressure

$C \rightarrow$ The specific concentration

$C_\infty \rightarrow$ The specific concentration at $\infty$

$D \rightarrow$ The chemical molecular diffusivity

$D_\infty \rightarrow$ Molecular diffusivity at $\infty$

$\kappa \rightarrow$ The permeability of porous medium

$V_0 > 0$, Corresponds to steady suction velocity (normal) at the surface.

Following Lai and Kulacki [1] we assumed the viscosity and thermal conductivity of fluid to be an inverse linear function of temperature as:

$$\left.\begin{aligned} \frac{1}{\mu} &= \frac{1}{\mu_\infty}\left[1+\gamma(T-T_\infty)\right] \\ \frac{1}{\lambda} &= \frac{1}{\lambda_\infty}[1+\gamma_1(T-T_\infty)] \end{aligned}\right\} \qquad \ldots(4.2.6)$$

Under the above assumption and considering the following substitutions

$$\mu = \frac{-\mu_\infty \theta e}{\theta - \theta e} \quad , \qquad \lambda = \frac{-\lambda_\infty \theta_r}{\theta - \theta_r}$$

$f(\eta) = u/v_0$ (Velocity)

$\eta = v_0 y / \nu_\infty$ (Distance)

$\Pr = \mu_\infty C_p / \lambda_\infty$ (Prandtl Number)

$Sc = \nu_\infty / D_\infty$ (Schmidt Number)

$\theta = (T - T_\infty) v_0 \lambda_\infty / q\nu_\infty$ (Temperature)

$C^* = (C - C_\infty) v_0 D_\infty / m\nu_\infty$ (Species concentration)

$\alpha = v_0^{\ 2}\,k / \nu_\infty^{\ 2}$ (Permeability Parameter)

$Gr = g\beta q \nu_\infty^{\ 2} / v_0^4 \lambda_\infty$ (Grashof number for heat transfer)

$Gm = g\beta^* m\nu_\infty^2 / v_0^4 D_\infty$ (Grashof number for mass transfer)

$M = \sigma B_0^2 \nu_\infty / \rho v_0^2$ (Magnetic number)

$E = \lambda_\infty v_0^3 / q\nu_\infty C_p$ (Eckert number)

$\theta e = \dfrac{T_e - T_\infty}{T_w - T_\infty}$ (Viscosity parameter)

$\theta r = \dfrac{T_r - T_\infty}{T_w - T_\infty}$ (Thermal conductivity parameter)

$q \rightarrow$ The heat flux per unit area

$m \rightarrow$ The mass flux per unit area

in equations (4.2.2), (4.2.3) and (4.2.4) and dropping asterisk we get.

$$f'' = \frac{\theta - \theta e}{\theta e}\left[\left\{1 + \frac{\theta e\,\theta'}{(\theta - \theta e)^2}\right\} f' - f(\alpha^{-1} + M) + Gr\theta + GmC\right] \qquad \ldots(4.2.7)$$

$$\theta'' = \frac{\theta - \theta r}{\theta r}\left[\left\{\frac{\theta r\,\theta'^2}{(\theta - \theta r)^2}\right\} + \Pr\theta' - \Pr E\,\frac{\theta e f'^2}{\theta - \theta e}\right] \qquad \ldots(4.2.8)$$

$$C'' = \left[\frac{\theta'}{\theta - \theta e} + Sc\left(\frac{\theta - \theta e}{\theta e}\right)\right] C' \qquad \ldots(4.2.9)$$

Where Prime denotes differentiation with respect to $\eta$.

The Corresponding boundary conditions become

$$\left.\begin{array}{llll} \eta = 0, & f = 0 & \theta = -1, & C = -1 \\ \eta \rightarrow \infty, & f = 0, & \theta \rightarrow 0, & C \rightarrow 0 \end{array}\right\} \qquad \ldots(4.2.10)$$

The skin friction co-efficient $C_f$ & Nusselt number $N_u$ in this problem are given by

$$C_f = \frac{\mu\left(\frac{\partial u}{\partial y}\right)_{y=0}}{\rho \upsilon_0^{\ 2}}$$

$$= -\frac{\theta_c}{1-\theta_c}\left[f'(0)\right] \qquad \ldots \quad (4.2.11)$$

$$N_{u_0} = \frac{L\,k\left(\frac{\partial T}{\partial y}\right)_{y=0}}{k_\infty\left(T_w - T_\infty\right)}$$

$$= -\frac{\theta_r}{1-\theta_r}\left[\theta'(0)\right] \qquad \ldots \quad (4.2.12)$$

## III. METHOD OF SOLUTIONS:

To solve the above BVP, the Range Kutta shooting method is applied. In this method the BVP is converted to an initial value problem (IVP) by estimating the missing initial values to a desired degree of accuracy by an iterative scheme. Hazarika [9] showed that though there is no guarantee of convergence of the iterative scheme, yet the method is convergent if the initial guesses for the missing initial values are on opposite sides of the true value. The convergence is rapid and agrees well with other methods.

## IV. RESULTS AND DISCUSSION:

We have studied the flow pattern changes with the viscosity parameter and conductivity parameter. In the previous studies the viscosity and thermal conductivity are assumed to be constant. But our result shows that the flow pattern is influenced by the variable viscosity and thermal conductivity parameter. In this paper the system of differential equations governed by the respective boundary conditions is solved numerically by applying an efficient numerical technique base on the common Runge- Kutta shooting method and an iterative procedure. The whole numerical scheme can be programmed and applied easily. It is experienced that the convergence of the iteration process is quite rapid

The estimated values of the missing initial values are arranged in different tables for various values of the parameters $\theta_{e,}$ $\theta_r$ ranging from -15 to -2. The viscosity parameter $\theta_{e,}$ as well as conductivity parameter $\theta_r$ are negative for liquids. The concept of the parameter $\theta_{e,}$ was first introduced by Ling and Dybbs [11] in their study of connective flow in porous medium.

We have obtained the velocity and temperature distribution for various values of $\theta_{e,}$ $\theta_r$. The results of the problem are presented graphically

Table 4.4.1 displays the variation of numerical values of skin friction co-efficient $C_f$, Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values of Ec and Pr=0.71, Gm=2.00, Gr=10.00 , α=1.00 , M=1.00, $\theta_r$= -10.00, $\theta_c$= -10.00. Here it is observed that the values of f'(o), C'(o), increases for increasing values of Ec and the values of θ'(o) decreases for increase of Ec The skin friction co-efficient increases and Nusselt number decreases for increasing values of Ec.

From the table 4.4.2 displays the variation of numerical values of skin friction co-efficient $C_f$, Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values Pr and E=0.01, Gm=2.00, Gr=10.00, α=1.00 ,M=1.00, $\theta_r$= -10.00, $\theta_e$= -10.00.

Here it is observed that the values of f'(o), C'(o) decreases for increasing values of Pr and the values of θ'(o) increases for increase of Pr. The skin friction co-efficient decreases and Nusselt number increases for increasing values of Pr.

The table 4.4.3 shows the variation of numerical values of skin friction co-efficient $C_f$, Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values $\theta_c$ and Pr=0.71, E=0.01, Gm=2.00, Gr=10.00, α=1.00, M=1.00, $\theta_r$= -10.00 .

Here it is observed that the values of f'(o), C'(o) decrease for increasing values of $\theta_c$ and the values of θ'(o) increases for increase of $\theta_e$. The skin friction co-efficient decreases and Nusselt number Nu increases for increasing values of $\theta_c$ .

Table 4.4.4 displays the numerical values of skin friction co-efficient $C_f$, Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values of $\theta_r$ and Pr=0.71, E=0.01, Gm=2.00, Gr=10.00, α=1.00 M=1.00, $\theta_e$= -10.00.

The table shows that values of f'(o), C'(o) increases for increasing values of thermal conductivity parameter $\theta_{r..}$ The values of θ'(o) increases for increase of the values of the parameter. The values of skin friction co-efficient and Nusselt number increases for increasing values of thermal conductivity parameter.
Our observations are as below:-

From the fig. 4.4.1a, we have seen that velocity profile decreases as viscosity Parameter increases, in case of Gr>0 (externally cooled plate.)Fig. 4.4.1b shows that the velocity profile increases with increase of viscosity parameter in case of externally heated plate (Gr<0). Fig. 4.4.2 exhibits the variation of temperature profile for various values of viscosity parameter; It is seen that this temperature profile decreases when viscosity parameter increases. Again from the fig. 4.4.3, it is observed that temperature profile decreases as thermal conductivity parameter increases.

From fig.4.4.4, it is found that concentration profile decreases when viscosity parameter increases.
Fig. 4.4.5. shows the variation of concentration profile for various values of Schmidt number. Concentration profile increases as Schmidt Number increases
Fig 4.4.6. represents that the velocity decreases for increasing values of magnetic field parameter

## V. CONCLUSIONS:

We now summarize some important observations:-
The presented analysis has shown that the fluid flow field is influenced by the variable viscosity & thermal conductivity within the boundary layer.
(1)The fluid velocity decreases (for externally cooled plate) and increases (for externally heated plate) as viscosity parameter increases.
(2) Temperature decreases for increase of both viscosity & thermal conductivity parameter.
(3) The Species concentration layer thickness decreases with viscosity Parameter.
(4) The concentration profile increases as Schmidt Number increases.
Therefore, we can conclude that to predict more accurate results, the variable viscosity and thermal conductivity effects have to be taken into consideration on the problem.
The results discussed above can be applied to engineering & industrial problems for desired final product.

Table 4.4.1. estimated numerical values of skin friction co-efficient $C_f$, Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values of Ec and Pr=0.71, Gm=2.00, Gr=10.00 , α=1.00, M=1.00 , $\theta_r$= -10.00, $\theta_e$= -10.00

| Ec | f'(o) | c'(o) | θ'(o) | $C_f$ | Nu |
|---|---|---|---|---|---|
| 0.10 | -2.221960 | 1.370219 | 0.442554 | -2.127793 | -0.957620 |
| 0.20 | -1.989103 | 1.431935 | 0.400797 | -1.912452 | -0.961465 |
| 0.30 | -1.830134 | 1.475902 | 0.371902 | -1.764511 | -0.964143 |
| 0.40 | -1.709772 | 1.510741 | 0.349734 | -1.651996 | -0.966208 |
| 0.50 | -1.612903 | 1.540162 | 0.331650 | -1.561128 | -0.967900 |
| 0.60 | -1.531670 | 1.566099 | 0.316273 | -1.484713 | -0.969342 |
| 0.70 | -1.461481 | 1.589690 | 0.302792 | -1.418529 | -0.970611 |
| 0.80 | -1.399411 | 1.611665 | 0.290691 | -1.359881 | -0.971752 |
| 0.90 | -1.343482 | 1.632526 | 0.279618 | -1.306938 | -0.972799 |
| 1.00 | -1.292282 | 1.652639 | 0.269320 | -1.258391 | -0.973774 |
| 1.10 | -1.244760 | 1.672285 | 0.259607 | -1.213263 | -0.974696 |
| 1.20 | -1.200101 | 1.691692 | 0.250329 | -1.170792 | -0.975578 |
| 1.30 | -1.157643 | 1.711057 | 0.241365 | -1.130360 | -0.976432 |
| 1.40 | -1.116830 | 1.730561 | 0.232607 | -1.091442 | -0.977268 |
| 1.50 | -1.077161 | 1.750377 | 0.223957 | -1.053566 | -0.978095 |
| 1.60 | -1.038165 | 1.770688 | 0.215321 | -1.016283 | -0.978922 |
| 1.70 | -0.999366 | 1.791695 | 0.206600 | -0.979137 | -0.979758 |
| 1.80 | -0.960238 | 1.813641 | 0.197679 | -0.941624 | -0.980615 |
| 1.90 | -0.920151 | 1.836833 | 0.188422 | -0.903134 | -0.98150 |

Table 4.4.2. estimated numerical values of skin friction co-efficient $C_f$ , Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values of Pr and E=0.01, Gm=2.00, Gr=10.00, α=1.00 M=1.00, $\theta_r$= -10.00, $\theta_e$= -10.00

| Pr | f'(o) | C'(o) | θ'(o) | $C_f$ | Nu |
|---|---|---|---|---|---|
| 0.10 | -0.266465 | 1.868639 | 0.094391 | -0.263974 | -0.990649 |
| 0.20 | -0.588189 | 1.793377 | 0.151599 | -0.579405 | -0.985067 |
| 0.30 | -0.931372 | 1.710039 | 0.212740 | -0.911970 | -0.979169 |
| 0.40 | -1.297399 | 1.618231 | 0.277986 | -1.262308 | -0.972953 |
| 0.50 | -1.687498 | 1.517612 | 0.347469 | -1.630832 | -0.966420 |
| 0.60 | -2.102596 | 1.407940 | 0.421252 | -2.017604 | -0.959578 |
| 0.70 | -2.543152 | 1.289107 | 0.499306 | -2.422210 | -0.952444 |
| 0.80 | -3.008945 | 1.161197 | 0.581474 | -2.843597 | -0.945048 |
| 0.ss90 | -3.498842 | 1.024536 | 0.667445 | -3.279925 | -0.937432 |
| 1.00 | -4.010605 | 0.879735 | 0.756723 | -3.728464 | -0.929651 |
| 1.10 | -4.540746 | 0.727713 | 0.848620 | -4.185552 | -0.921776 |
| 1.20 | -5.084536 | 0.569690 | 0.942273 | -4.646690 | -0.913887 |
| 1.30 | -5.636178 | 0.407128 | 1.036678 | -5.106770 | -0.906070 |
| 1.40 | -6.189182 | 0.241644 | 1.130767 | -5.560427 | -0.898411 |
| 1.50 | -6.736849 | 0.074886 | 1.223484 | -6.002458 | -0.890989 |
| 1.60 | -7.272824 | -0.091589 | 1.313869 | -6.428238 | -0.883871 |
| 1.70 | -7.791546 | -0.256414 | 1.401124 | -6.834016 | -0.877106 |
| 1.80 | -8.288561 | -0.418479 | 1.484648 | -7.217079 | -0.870728 |
| 1.90 | -8.760653 | -0.576952 | 1.564040 | -7.575771 | -0.864750 |

Table 4.4.3. estimated numerical values of skin friction co-efficient $C_f$ , Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values of $\theta_c$ and Pr=0.71 , E=0.01, Gm=2.00 ,Gr=10.00, α=1.00, M=1.00 , $\theta_r$= -10.00

| $\theta_c$ | f(o) | c'(o) | θ'(o) | $C_f$ | Nu |
|---|---|---|---|---|---|
| -15.00 | -2.458288 | 1.310898 | 0.484387 | -2.381387 | -0.953799 |
| -14.00 | -2.476679 | 1.306062 | 0.487633 | -2.393318 | -0.953504 |
| -13.00 | -2.497993 | 1.300463 | 0.491392 | -2.407009 | -0.953162 |
| -12.00 | -2.522989 | 1.293904 | 0.495797 | -2.422884 | -0.952762 |
| -11.00 | -2.552700 | 1.286117 | 0.501027 | -2.441495 | -0.952288 |
| -10.00 | -2.588607 | 1.276721 | 0.507341 | -2.463617 | -0.951716 |
| -9.00 | -2.632858 | 1.265161 | 0.515111 | -2.490325 | -0.951012 |
| -8.00 | -2.688732 | 1.250594 | 0.524906 | -2.523178 | -0.950127 |
| -7.00 | -2.761469 | 1.231673 | 0.537629 | -2.564505 | -0.948980 |
| -6.00 | -2.860002 | 1.206111 | 0.554818 | -2.617923 | -0.947435 |
| -5.00 | -3.000843 | 1.169683 | 0.579301 | -2.689264 | -0.945242 |
| -4.00 | -3.218233 | 1.113627 | 0.616908 | -2.788214 | -0.941894 |
| -3.00 | -3.596189 | 1.016305 | 0.681840 | -2.930211 | -0.936168 |
| -2.00 | -4.409099 | 0.805224 | 0.820052 | -3.126963 | -0.924210 |
| -1.00 | -7.384618 | -0.033216 | 1.318910 | -3.184521 | -0.883477 |

Table 4.4.4. estimated numerical values of skin friction co-efficient $C_f$ , Nusselt Number Nu and missing initial values of f'(o), C'(o), θ'(o) for various values of $\theta_r$ and Pr=0.71 , E=0.01, Gm=2.00 ,Gr=10.00, α=1.00 M=1.00 , $\theta_e$ = -10.00

| $\theta_r$ | f(o) | c'(o) | th'(o) | Cf | Nu |
|---|---|---|---|---|---|
| -15.00 | -2.791015 | 1.253762 | 0.547048 | -2.646253 | -0.964813 |
| -14.00 | -2.760827 | 1.257187 | 0.541071 | -2.619115 | -0.962790 |
| -13.00 | -2.726537 | 1.261075 | 0.534306 | -2.588246 | -0.960522 |
| -12.00 | -2.687249 | 1.265530 | 0.526586 | -2.552821 | -0.957963 |
| -11.00 | -2.641792 | 1.270685 | 0.517694 | -2.511760 | -0.955052 |
| -10.00 | -2.588607 | 1.276721 | 0.507341 | -2.463617 | -0.951716 |

Fig. 4.4..1a. Velocity profile for different values of viscosity parameter θe ,α=1.0, M = 1.0, Gr= 0.5, Gm =0.2

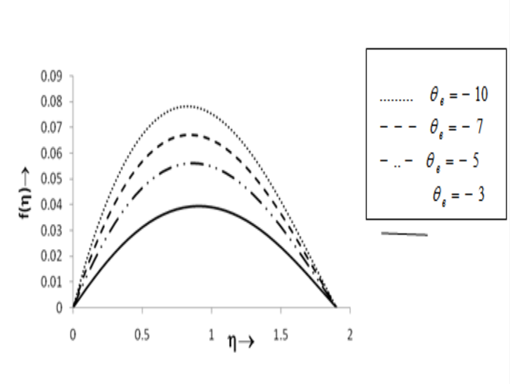
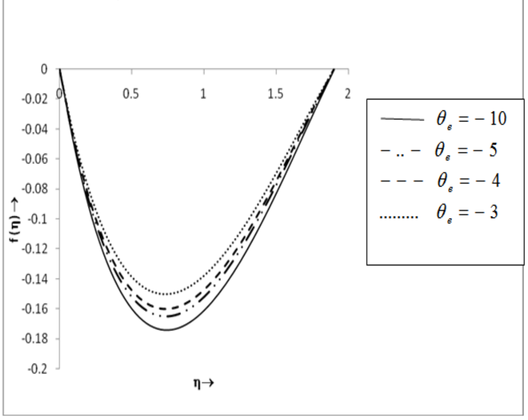



Fig 4.4..1b. Velocity profile for different values of viscosity parameter and M=1.0, α=1.0, Gr=-0.5, Gm=0.2



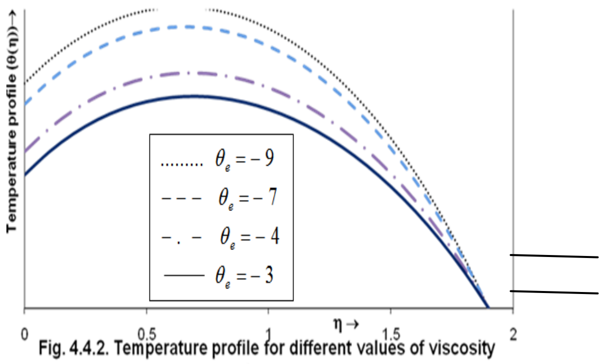
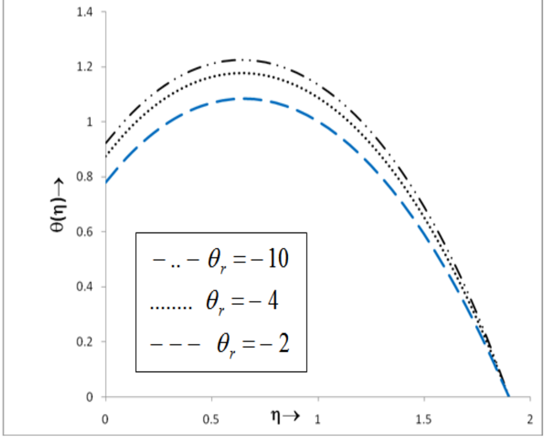




Fig. 4.4.2. Temperature profile for different values of viscosity parameter θe and Pr=0.71, E=0.02, θr=-10

Fig.4.4.3. Temperature profile θ(η) for various values of thermal conductivity parameter θr and Pr=0.71, E=0.02, θe=-10



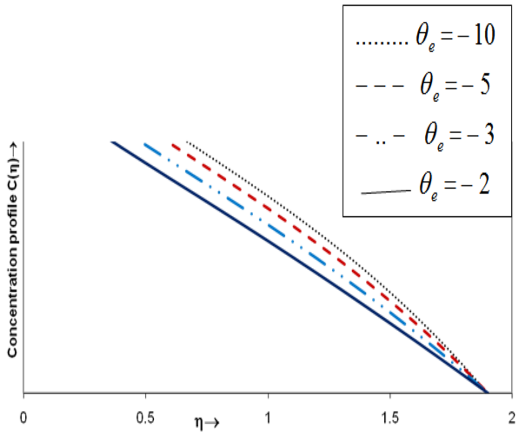




**Fig. 4.4.4. Concentration profile for different values of viscosity parameter, Sc=.75**

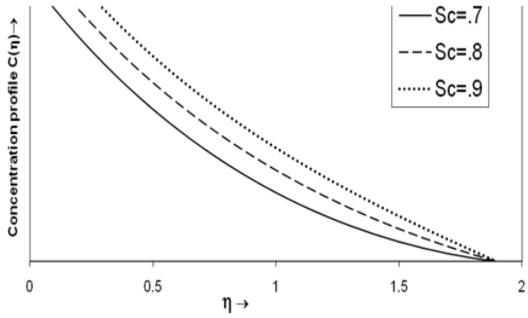



Fig. 4.4.5. Concetration profile for various values of schmidt number and Θe=–10

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