International Journal of Mathematics and Statistics Invention (IJMSI)
E-ISSN: 2321 – 4767 P-ISSN: 2321 - 4759
www.ijmsi.org Volume 1 Issue 1 ‖ Aug. 2013‖ PP-01-11

Unsteady Magnetopolar free Convection flow embedded in a Porous Medium with Radiation and variable Suction in a Slip flow Regime

D. Chaudhary[1], H. Singh[2], N.C. Jain[3]
(Department of Mathematics, University of Rajasthan Jaipur-302004, India)

ABSTRACT: *The objective of this paper is to study the effects of different parameters on an unsteady magnetopolar free convection flow of an incompressible fluid in the presence of thermal radiation and uniform magnetic field of strength B_0 through a porous medium in slip flow regime. The suction velocity is considered to be variable and the fluid is assumed to be gray; emitting absorbing but non scattering medium. The governing boundary layer equations with the boundary conditions are first converted into dimensionless form by non-similar transformations, and then resulting system of coupled non-linear partial differential equations are solved by series expansion method. The expressions for velocity (u), angular velocity (ω), temperature (θ), concentration (C), skin friction (C_f) and rate of heat transfer (Nu) are obtained. The results obtained have been presented, separately in two basic fluids air (Pr=0.71, Sc=0.22) and water (Pr=7, Sc=0.61), numerically through graphs to observe the effects of different parameters and the physical aspect of the problem. We observe that on decreasing Gr (thermal Grashof number), skin friction drops in air but rises in water. Also we notice that the rate of heat transfer rises on decreasing h_2 (jump parameter).*

KEYWORDS: *Free convection, Mass transfer, Polar fluid, Radiation, temperature jump, Unsteady.*

I. INTRODUCTION

The problem of fluid flow in an electromagnetic field has been studied for its importance in geophysics, metallurgy, aerodynamics and extrusion of plastic sheets and other engineering processes such as in petroleum engineering, chemical engineering, composite or ceramic engineering and heat exchangers. Many investigations dealing with heat and mass transfer over a vertical porous plate with variable suction, heat absorption/generation have been reported involving heat transfer occurring frequently in the environment. Sahoo et al. [1] have studied MHD unsteady free convection flow past an infinite vertical plate with constant suction and heat sink. Revankar [2] studied free convection effects on flow past an impulsively started or oscillating infinite vertical plate. Magyari et al. [3] have discussed analytic solution for unsteady free convection in porous media. Muthukumaraswamy et al. [4] studied the flow past an impulsively started isothermal vertical plate with variable mass diffusion. Geindreau and Auriault [5] studied the Magnetohydrodynamic flows in porous media. Kandasamy et al. [6] have studied thermophoresis and variable viscosity effects on MHD mixed convective heat and mass transfer past a porous wedge in the presence of chemical reaction.

Radiative convective flows are frequently encountered in many scientific and environmental processes, such as astrophysical flows, water evaporation from open reservoirs, heating and cooling of chambers and solar power technology. Several researchers have investigated radiative effects on heat transfer in non porous and porous medium utilizing the rosseland or other radiative flux model. Raptis and Perdikis [7] studied the unsteady flow through a highly porous medium in presence of radiation. Sanyal and Adhikari [8] studied the effects of radiation on MHD vertical channel flow. Prasad and Reddy [9] studied the radiation effects on an unsteady MHD convective heat and mass transfer flow past a semi infinite vertical permeable moving plate embedded in a porous medium.

Aero et al. [10] derived and solved the flow equations of the fluid in which angular velocity of the fluid particles was considered. These fluids are known as polar fluids in the literature and are more general than ordinary fluids. The dynamics of polar fluid has attracted considerable attention during the last few decades because traditional Newtonian fluids cannot precisely describe the characteristics of fluid flow with suspended particles. Lukaszewicz [11] gave a detailed study of such fluids. The theory of micropolar fluid and thermo micropolar fluid has been developed by Eringen [12,13] and they can be used to explain the characteristics of certain fluids such as exotic lubricants, colloidal suspensions, or polymeric fluids, liquid crystals and animal blood. The micropolar fluids exhibit certain microscopic effects arising from local structure and microrotation of fluid elements. Patil and Kulkarni [14] studied the effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation. Rahman and Sattar [15] studied MHD convective flow of a micropolar fluid past a continuously moving vertical porous plate in the presence of heat generation/absorption. Ogulu [16] studied the influence of radiation/absorption on unsteady free convection and mass transfer flow of a polar fluid in the presence of uniform magnetic field. Kim [17] studied unsteady MHD convection flow of a polar fluid past a vertical moving porous plate in a porous medium.

The problem of the slip flow regime is very important in this era of modern science,technology and vast ranging industrialization. In many practical applications, the particle adjacent to a solid surface no longer takes the velocity of the surface. The particle at the surface has a finite tangential velocity and slips along the surface. The flow regime is called the slip flow regime and its effect cannot be neglected. The fluid slippage phenomenon at the solid boundaries appear in many applications such as micro channels or Nano channels and in applications where a thin film of light oils is attached to the moving plates or when the surfaces are coated with special coating to minimize the friction between them. Derek et al. [18] studied apparent fluid slip at hydrophobic micro channel walls. Mehmood and Ali [19] studied the effects of slip conditions on unsteady MHD oscillatory flow of a viscous fluid in planer channel. Mansour et al. [20] studied fluctuating thermal and mass diffusion on unsteady MHD convection of a micro polar fluid through a porous medium past a vertical plate in slip flow regime. Jain and Gupta [21] studied unsteady magneto polar free convection flow in slip flow regime with variable permeability and constant heat flux. Sharma [22] studied fluctuating thermal and mass diffusion on unsteady free convection flow past a vertical plate in slip flow regime.

In the present paper, the objective is to investigate the effects of radiation parameter (R), magnetic parameter (M), permeability parameter (K), slip parameter(h_1), temperature jump parameter(h_2), rotational parameter (α_1), couple stress parameter (β_1) and thermal and mass Grashof numbers (Gr and Gc resp.) on the unsteady free convective magnetopolar flow with variable suction velocity and jump in temperature in a slip flow regime. The effects, on velocity (u), angular velocity (ω),temperature(θ),concentration(C), skin friction (C_f) and rate of heat transfer (Nu), of all the parameters are shown graphically.

II. FORMULATION OF THE PROBLEM

Consider the problem of an unsteady two-dimensional, MHD free convective, heat and mass transfer flow with radiation of a polar fluid through a porous medium over a vertical plate with slip boundary condition for velocity field and jump for temperature field. A transfer magnetic field of strength B_0 is applied. The plate is moving in its own plane with velocity $U_0(1+\in \bar{e}^{nt})$.

the plate. The permeability of the porous medium is considered to be constant and the suction velocity is considered to be of the form :

$V = -V_0(1 + A \in \bar{e}^{nt})$

Under these conditions and using the Boussinesq's approximation, governing equations of the flow are given by:

Continuity equation:

$$\frac{\partial v}{\partial y} = 0, \qquad \text{...(1)}$$

Linear momentum:

$$\frac{\partial u}{\partial t} + V\frac{\partial u}{\partial y} = g\beta\,(T - T_\infty) + g\beta'(C - C_\infty) + (\nu + \nu_r)\frac{\partial^2 u}{\partial y^2} - \frac{\nu}{K}u + 2\nu_r\frac{\partial \omega}{\partial y} - \frac{\sigma B_0^2}{\rho}u\ , \qquad \text{...(2)}$$

Angular momentum:

$$\frac{\partial \omega}{\partial t} + V\frac{\partial \omega}{\partial y} = \frac{\gamma}{I}\left(\frac{\partial^2 \omega}{\partial y^2}\right) \ , \qquad \text{...(3)}$$

Energy equation:

$$\frac{\partial T}{\partial t} + V\frac{\partial T}{\partial y} = \frac{\kappa}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q_r}{\partial y} \ , \qquad \text{....(4)}$$

Concentration equation:

$$\frac{\partial C}{\partial t} + V\frac{\partial C}{\partial y} = D\frac{\partial^2 C}{\partial y^2} \ . \qquad \text{...(5)}$$

where u, ω, T and C are velocity, angular velocity, temperature and concentration of the fluid particles. g is acceleration due to gravity, β is coefficient of volumetric expansion, β' is coefficient of species concentration expansion, ρ, ν, ν_r, κ, C_p, σ, D, K are density, kinematic viscosity, rotational kinematic viscosity, thermal conductivity, specific heat at constant pressure, electrical conductivity, mass diffusivity and

permeability of the porous medium respectively. I is a scalar constant equal to moment of inertia of unit mass and
$\gamma = C_a + C_d$
where C_a and C_d are coefficient of couple stress viscosities.

The initials and boudary conditions are as follows :

$$y = 0: \quad u = U_0(1+\epsilon\, e^{nt}) + L_1\frac{\partial u}{\partial y}, \; \omega = -\frac{1}{2}\frac{\partial u}{\partial y}, \; T = T_w + \xi\frac{\partial T}{\partial y}, \; C = C_w,$$

$$y \to \infty: u \to 0, \omega \to 0, T \to T_\infty, C \to C_\infty \qquad \ldots(6)$$

The local radiant for the case of an optically thin gray gas is expressed by :

$$\frac{\partial q_r}{\partial y} = -4a^*\sigma^*(T_\infty^4 - T^4) \qquad \ldots(7)$$

we assume that the temperature difference within the flow is 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_∞ and neglecting the higher order, thus :

$$T^4 \cong 4T_\infty^3 T - 3T_\infty^4 \qquad \ldots(8)$$

by using equations (8) in (7) we obtain:

$$\frac{\partial q_r}{\partial y} = -16a^*\sigma^* T_\infty^3(T_\infty - T) \qquad \ldots(9)$$

where σ^* is Stefan-Boltzmann constant and a^* is absorption coefficient.

On introducing the following non-dimensional quantities :

$$y^* = \frac{V_0 y}{\nu}, \quad t^* = \frac{V_0^2 t}{\nu}, \quad u^* = \frac{u}{V_0}, \quad n^* = \frac{n\nu}{V_0^2},$$

$$\omega^* = \frac{\nu\omega}{V_0 u_0}, \quad \theta = \frac{T - T_\infty}{T_w T_\infty}, \quad C^* = \frac{C - C_\infty}{C_w - C_\infty},$$

equations (2) to (5), substituting (9) in (4), in non-dimensional form after dropping the asteriks are :

$$\frac{\partial u}{\partial t} - (1 + A\epsilon\, e^{nt})\frac{\partial u}{\partial y} = \theta Gr + CGc + (1+\alpha_1)\frac{\partial^2 u}{\partial y^2} + 2\alpha_1\frac{\partial \omega}{\partial y} - \left[M + \frac{1}{K}\right]u \qquad \ldots(10)$$

$$\frac{\partial \omega}{\partial t} - (1 + A\epsilon\, e^{nt})\frac{\partial \omega}{\partial y} = \frac{1}{\beta_1}\frac{\partial^2 \omega}{\partial y^2} \qquad \ldots(11)$$

$$\frac{\partial \theta}{\partial t} - (1 + A\epsilon\, e^{nt})\frac{\partial \theta}{\partial y} = \frac{1}{Pr}\frac{\partial^2 \theta}{\partial y^2} - \frac{R}{Pr}\theta \,, \qquad \ldots(12)$$

$$\frac{\partial C}{\partial t} - (1 + A\epsilon\, e^{nt})\frac{\partial C}{\partial y} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} \,, \qquad \ldots(13)$$

with corresponding boundary conditions as :

$$\left.\begin{array}{l} y = 0: u = (1+\epsilon\, e^{nt}) + h_1\frac{\partial u}{\partial y}, \; \omega = -\frac{1}{2}\frac{\partial u}{\partial y}, \; \theta = 1 + h_2\frac{\partial \theta}{\partial y}, \; C = 1 \,, \\ y \to \infty: u \to 0, \; \omega \to 0, \; \theta \to 0, \; C \to 0 \,. \end{array}\right\} \qquad \ldots(14)$$

Where

$K^* = \frac{V_0^2 K}{\nu^2}$ (permeability parameter),

$M = \frac{\sigma B_0^2 \nu}{\rho V_0^2}$ (magnetic parameter),

$h_1 = \frac{L_1 V_0}{\nu}$ (velocity slip parameter),

$h_2 = \frac{\xi V_0}{\nu}$ (temperature jump parameter),

$Gr = \frac{\nu g\beta(T_w - T_\infty)}{V_0^2 U_0}$ (thermal Grashof number),

$Gc = \frac{\nu g\beta(C_w - C_\infty)}{V_0^2 U_0}$ (mass Grashof number),

$\alpha_1 = \frac{\nu_r}{\nu}$ (rotational viscosity parameter),

$\beta_1 = \frac{I\nu}{\gamma}$ (couple stress parameter),

$Sc = \frac{\nu}{D}$ (Schmidt number),

$Pr = \frac{\mu C_p}{\kappa}$ (Prandtl number),

$R = \frac{16a^*\sigma^*\nu^2 T_\infty^3}{V_0^2 \kappa}$ (radiation parameter),

$L_1 = ((2 - m_1)/m_1)L$, m_1 being the maxwell's reflexion coefficient and L the free path.

$\xi = \left(\frac{2-a}{a}\right)\left(\frac{1.996\eta}{(\eta+1)}\right)\frac{L}{Pr}$, a is the thermal accomodation coefficient and η is the gas constant and L the free path.

III. SOLUTION OF THE PROBLEM

Since ∈ is a small quantity, we reduce the system of partial differential equations to ordinary differential equations by assuming :

$$f(y,t) = f_0(y) + \in \bar{e}^{nt} f_1(y) + O(\epsilon^2) + \cdots \qquad ...(15)$$

where f stands for u, ω, θ and C.

Substituting equation (15) in equations (10) to (13) and equating the like terms terms, neglecting the coefficient of $O(\in^2)$ and higher orders, we get :

$$u_0'' + \frac{1}{(1+\alpha_1)}u_0' - \frac{\left(M+\frac{1}{K}\right)}{(1+\alpha_1)}u_0 = \frac{1}{(1+\alpha_1)}\left(-\theta_0 Gr - C_0 Gc - 2\alpha_1\omega_0'\right), \qquad ...(16)$$

$$u_1'' + \frac{1}{(1+\alpha_1)}u_1' - \frac{\left(M+\frac{1}{K}-n\right)}{(1+\alpha_1)}u_1 = \frac{1}{(1+\alpha_1)}\left(-Au_0' - \theta_1 Gr - C_1 Gc - 2\alpha_1\omega_1'\right) \qquad ...(17)$$

$$\omega_0'' + \beta_1\omega_0' = 0 \quad , \qquad ...(18)$$

$$\omega_1'' + \beta_1\omega_1' + n\beta_1\omega_1 = -A\beta_1\omega_0' \ , \qquad ...(19)$$

$$\theta_0'' + Pr\theta_0' - R\theta_0 = 0 \, , \qquad ...(20)$$

$$\theta_1'' + Pr\theta_1' - (R - nPr)\theta_1 = -APr\theta_0', \qquad ...(21)$$

$$C_0'' + ScC_0' = 0 \quad , \qquad ...(22)$$

$$C_1'' + ScC_1' + nScC_1 = -AScC_0' \ , \qquad ...(23)$$

here primes denote differentiation with respect to y.

The corresponding boundary conditions can be written as :

$$\left.\begin{aligned} y = 0: \ & u_0 = 1 + h_1 u_0', \ \omega_0 = -\frac{1}{2}u_0', \ \theta_0 = 1 + h_2\theta_0', \ C_0 = 1 \\ & u_1 = 1 + h_1 u_1', \ \omega_1 = -\frac{1}{2}u_1', \ \theta_1 = h_2\theta_1', \ C_1 = 0, \\ y \to \infty: \ & u_0 \to 0, \ \omega_0 \to 0, \ \theta_0 \to 0, \ C_0 \to 0 \\ & u_1 \to 0, \ \omega_1 \to 0, \ \theta_1 \to 0, \ C_1 \to 0. \end{aligned}\right\} \qquad ...(24)$$

Solving equations (16) to (23) with satisfying boundary conditions (24), and substituting back in (15), we get :

$$u = \{m_7 e^{x_9 y} + b_1 e^{x_3 y} + b_2 \bar{e}^{Scy} + b_3 \bar{e}^{\beta_1 y}\} + \epsilon\bar{e}^{nt}\{m_8 e^{x_{11} y} + b_4 e^{x_9 y} + b_{14} e^{x_3 y} + b_{15}\bar{e}^{Scy} + b_{16}\bar{e}^{\beta_1 y} + b_8 e^{x_5 y} + b_{10} e^{x_7 y} + b_{12} e^{x_1 y}\}$$

,

$$\omega = m_1\bar{e}^{\beta_1 y} + \in \bar{e}^{nt}\left[m_2 e^{x_1 y} + b_{17}\bar{e}^{\beta_1 y}\right],$$

$$\theta = m_3 e^{x_3 y} + \in \bar{e}^{nt}\left[m_4 e^{x_5 y} + b_{18} e^{x_3 y}\right],$$

$$C = m_5\bar{e}^{Scy} + \in \bar{e}^{nt}\left[m_6 e^{z_7 y} + b_{19}\bar{e}^{Scy}\right].$$

IV. SKIN FRICTION

Knowing the velocty field, the non dimensional skin friction (C_f) at the plate is given by:

$$C_f = \frac{\tau_w}{\rho U_o V_o},$$

$$C_f = (1+\alpha_1)\left[\left(m_7 x_9 + b_1 x_3 - b_2 Sc - b_3 \beta_1\right) + \epsilon\, \bar{e}^{nt}\left(m_8 x_{11} + b_4 x_9 + b_{14} x_3 - b_{15} Sc - b_{16}\beta_1 + b_8 x_5 + b_{10} x_7 + b_{12} x_1\right)\right].$$

...(25)

V. NUSSELT NUMBER

Another important physical parameter of interest viz. Nusselt number in dimensionless form is :

$$Nu = \left(\frac{\partial\theta}{\partial y}\right)_{y=0},$$

$$Nu = -\left[m_3 x_3 + \epsilon \bar{e}^{nt}\left(m_4 x_5 + b_{18} x_3\right)\right] \quad \ldots(26)$$

Where

$$x_1, x_2 = \frac{-\beta_1 \mp \sqrt{\beta_1^2 - 4n\beta_1}}{2}, \qquad x_3, x_4 = \frac{-Pr \mp \sqrt{Pr^2 + 4R}}{2},$$

$$x_5, x_6 = \frac{-Pr \mp \sqrt{Pr^2 + 4(R - nPr)}}{2}, \qquad x_7, x_8 = \frac{-Sc \mp \sqrt{Sc^2 + 4nSc}}{2},$$

$$x_9, x_{10} = \frac{-1 \mp \sqrt{1 + 4\left(M + \frac{1}{K}\right)(1+\alpha_1)}}{2(1+\alpha_1)}, \qquad x_{11}, x_{12} = \frac{-1 \mp \sqrt{1 + 4\left(M + \frac{1}{K} - n\right)(1+\alpha_1)}}{2(1+\alpha_1)},$$

$$b_1 = \frac{-m_3 Gr}{(1+\alpha_1)(x_3 - x_9)(x_3 - x_{10})}, \qquad b_2 = \frac{-m_5 Gc}{(1+\alpha_1)(Sc + x_9)(Sc + x_{10})},$$

$$b_3 = \frac{2\alpha_1 m_1 \beta_1}{(1+\alpha_1)(\beta_1 + x_9)(\beta_1 + x_{10})}, \qquad b_4 = \frac{-A m_7 x_9}{(1+\alpha_1)(x_9 - x_{11})(x_9 - x_{12})},$$

$$b_5 = \frac{-A b_1 x_3}{(1+\alpha_1)(x_3 - x_{11})(x_3 - x_{12})}, \qquad b_6 = \frac{-A b_2 Sc}{(1+\alpha_1)(Sc + x_{11})(Sc + x_{12})},$$

$$b_7 = \frac{A b_3 \beta_1}{(1+\alpha_1)(\beta_1 + x_{11})(\beta_1 + x_{12})}, \qquad b_8 = \frac{-m_4 Gr}{(1+\alpha_1)(x_5 - x_{11})(x_5 - x_{12})},$$

$$b_9 = \frac{AP m_3 x_3 Gr}{(1+\alpha_1)(x_3 - x_5)(x_3 - x_6)(x_3 - x_{11})(x_3 - x_{12})}, \qquad b_{10} = \frac{-m_6 Gc}{(1+\alpha_1)(x_7 - x_{11})(x_7 - x_{12})},$$

$$b_{11} = \frac{-A m_5 Gc Sc^2}{(1+\alpha_1)(Sc + x_7)(Sc + x_8)(Sc + x_{11})(Sc + x_{12})}, \qquad b_{12} = \frac{-2\alpha_1 m_2 x_1}{(1+\alpha_1)(x_1 - x_{11})(x_1 - x_{12})},$$

$$b_{13} = \frac{2A m_1 \alpha_1 \beta_1^3}{(1+\alpha_1)(\beta_1 + x_1)(\beta_1 + x_2)(\beta_1 + x_{11})(\beta_1 + x_{12})}, \qquad b_{14} = b_5 + b_9,$$

$$b_{15} = b_6 + b_{11}, \qquad b_{16} = b_7 + b_{11},$$

$$b_{17} = \frac{A m_1 \beta_1^2}{(\beta_1 + x_1)(\beta_1 + x_2)}, \qquad b_{18} = \frac{-APr\, m_3 x_3}{(x_3 - x_5)(x_3 - x_6)},$$

$$b_{19} = \frac{A m_1 Sc^2}{(Sc + x_7)(Sc + x_8)}, \qquad m_1 = -\frac{1}{2}\left[m_7 x_9 + b_1 x_3 - b_2 Sc - b_3 \beta_1\right],$$

$$m_2 = -b_{17} - \frac{1}{2}\left[\begin{array}{c} m_8 x_{11} + b_4 x_9 + \\ b_{14} x_3 - b_{15} Sc - b_{16}\beta_1 + b_8 x_5 + b_{10} x_7 + b_{12} x_1 \end{array}\right],$$

$$m_3 = \frac{1}{(1 - h_2 x_3)}, \qquad m_4 = \frac{b_{18}(1 - h_2 x_3)}{(h_2 x_5 - 1)},$$

$$m_5 = 1, \qquad m_6 = -b_{19},$$

$$m_7 = \frac{1 - b_1(1 - x_3 h_1) - b_2(1 + h_1 Sc) - b_3(1 + h_1 \beta_1)}{(1 - h_1 x_9)}, \qquad m_8 = \frac{\begin{array}{c} 1 + b_4(h_1 x_9 - 1) + b_{14}(h_1 x_3 - 1) - b_{16}(h_1 \beta_1 + 1) \\ + b_8(h_1 x_5 - 1) + b_{10}(h_1 x_7 - 1) + b_{12}(h_1 x_1 - 1) \end{array}}{(1 - h_1 x_{11})}.$$

VI. RESULTS AND DISCUSSION

In order to understand the physical importance of the flow and to find the effects of different paramerters, calculations have been carried out for velocity, angular velocity, temperature,concentration,skin friction and the rate of heat transfer, for different values of the permeability parameter (K), the magnetic parameter (M), the thermal Grashof number (Gr), the mass Grashof number (Gc), the velocity slip parameter (h_1),the temperature jump parameter (h_2), the rotational viscosity parameter (α_1), the couple stress parameter (β_1), the prandtl number (Pr), the schmidt number(Sc). Result are also shown for particular cases of no slip (h_1=0) and for no jump in temperature (h_2=0). ε= 0.1, n=0.1 are considered to be fixed.

In figures 1 and 2,the velocity distribution is plotted against y for air (Pr=0.71 , Sc=0.22) and for water (Pr=7 , Sc=0.61) fixing t=1, A=0.5 and R =0.2. For both air and water, we observe that on decreasing K , Gr and Gc velocity decreases where as on decreasing M and h_2 velocity increases. It is specially observed that on decreasing h_1 velocity decreases near the plate but rises up as we move away from the plate for both the basic fluids. Results differ for α_1 and β_1. For air on decreasing α_1 velocity rises near the plate but drops as we move away and on increasing β_1 velocity drops where as for water on decreasing α_1 velocity drops and on increasing β_1 velocity rises near the plate but then drops. Results are specially observed for the case of no slip (h_1=0) and no jump in temperature (h_2=0) for both the basic fluids air and water.

Angular velocity distribution is plotted against y for air (Pr=0.71, Sc= 0.22) and water (Pr=7, Sc=0.61) in figures 3 and 4, fixing t=1, A=0.5 and R=0.2.It is observed that on decreasing K, Gr and Gc velocity increases whereas on decreasing M, h_1, h_2, α_1 and β_1 velocity decreases. Cases for no slip (h_1=0) and no jump in temperature (h_2=0) are also observed for both the basic fluids.

In figure 5, temperature profiles are plotted against y for both air (Pr=0.71, Sc=0.22) and water (Pr=7, Sc=0.61) fixing t=1. We observe that as R, A and h_2 decrease, temperature increases. Also for negative of radiation (absorption) temperature rises.

Concentration profiles are plotted against y in figure 6, fixing t=1. We notice that increasing value of schmidt number, decreases the concentration of the fluid. Here, we may say that concentration is highest for hydrogen (Sc=0.22) but least for Propyl benzene (Sc=2.62). Also, we notice that increasing the value of A, concentration of the fluid falls.

In figures 7 and 8, skin friction is plotted against K for both the basic fluids air (Pr=0.71, Sc=0.22) and water (Pr=7, Sc=0.61) respectively. We notice that for both air and water, on decreasing M and h_1 skin friction increases where as on decreasing Gc and R skin friction drops. Results differ for h_2, α_1, β_1 and Gr. For air, if h_2 decreases skin friction increases on the other hand decreasing α_1, β_1 and Gr drops the skin friction. For water, decrease in h_2 tends the skin friction to drop where as decrease in α_1, β_1 and Gr increases the skin friction. Also for negative of radiation (absorption) skin friction drops further.

Nusselt number is plotted against t for both basic fluids air (Pr=0.71, Sc=0.22) and water (Pr=7, Sc=0.61) in figure 9. We notice that when R decreases Nusselt number decreases on the other hand decrease in h_2 tends the Nusselt number to rise. Also for negative of radiation (absorption) Nusselt number falls further.

REFERENCES

[1]. Sahoo,P.K., Dutta, N. and Biswal, S., 2003. Magnetohydrodynamic unsteady free convection flow past an infinite vertical plate with constant suction and heat sink, Ind. J. pure. App. Math. vol 34(1), pp. 145-155.

[2]. Revankar, S.T., 2000. Free convection effects on the flow past an impulsively started or oscillating infinite vertical plate, Mechanics Research comm., vol 27, pp.241-246.

[3]. Magyari, E., Pop, I. and Keller, B., 2004. Analytic solution for unsteady free convection in porous media, J. Eng. Math., pp. 93-104.

[4]. Muthukumaraswamy, R., Ganesan, P. and Soundalgekar, V.M.,2001. The study of the flow past an impulsively started isothermal vertical plate with variable mass diffusion, J. Energy, Heat and Mass transfer, vol 23, pp. 63-72.

[5]. Geindreau, C. and Auriault, J.L., 2002. Magnetohydrodynamic flow in porous media, J. Fluid Mech., vol 466, pp. 343-363.

[6]. Kandasamy, R., Muhaimin, I. and Khami's, A.B., 2009. Thermophoresis and variable viscosity effects on MHD mixed convective heat and mass transfer past a porous wedge in the presence of chemical reaction, Heat Mass transfer, vol 45, pp. 703-712.

[7]. Raptis, A. and Perdikis, C., 2004. Unsteady flow through a highly porous medium in the presence of radiation, Transport in porous media, vol 57, pp.171-179.

[8]. Sanyal, D.C. and Adhikari, A., 2006. Effects of radiation on MHD vertical channel flow, Bull. Cal. Math. Soc., vol 98(5), pp. 487-497.

[9]. Prasad, V.R. and Reddy, N.B., 2008. radiation effects on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium, J. Energy, Heat and Mass Transfer, vol 30, pp. 57-78.

[10]. Aero, E.L. et al., 1965. A symmetric hydrodynamics, J. Appl. Math. Mech.,vol 29, pp. 333-346.

[11]. Lukaszewicz,G.,1999. Micropolar fluids:Theory and Applications, Modeling ans simulations in science, Engineering and technology, Birkhauser, Boston, Mass, USA.

[12]. Eringen, A.C., 1966. Theory of micropolar fluids, J. Math. and Mech., vol 16, pp. 1–18.

[13]. Eringen, A.C., 1972. Theory of thermo-micro-polar fluids, J. Math. Analysis and App., vol 38, pp. 480–496.

[14]. Patil, P.M. and Kulkarni, P.S., 2008. Effects of chemical reaction on free convective flow of a polar fluid through a porous medium in the presence of internal heat generation, Int. J. thermal sci., vol 47(8), pp. 1043-1054.

[15]. Rahman, M.M and Sattar, M.A., 2006. MHD convective flow of a micropolar fluid past a continuously moving vertical porous plate in the presence of heat generation/absorption, J. of heat transfer, vol 128(2), pp. 142-152.

[16]. Ogulu, A., 2005. The influence of radiation/absorption on unsteady free convection and mass transfer flow of a polar fluid in the presence of a uniform magnetic field, Int. J. heat and mass transfer, vol 48(23-24), pp. 5078-5080.

[17]. Kim, Y.J., 2001. Unsteady MHD convection flow of a polar fluid past a vertical moving porous plate in a porous medium, Int. J. heat and mass transfer, vol 44(15), pp. 2791-2799.

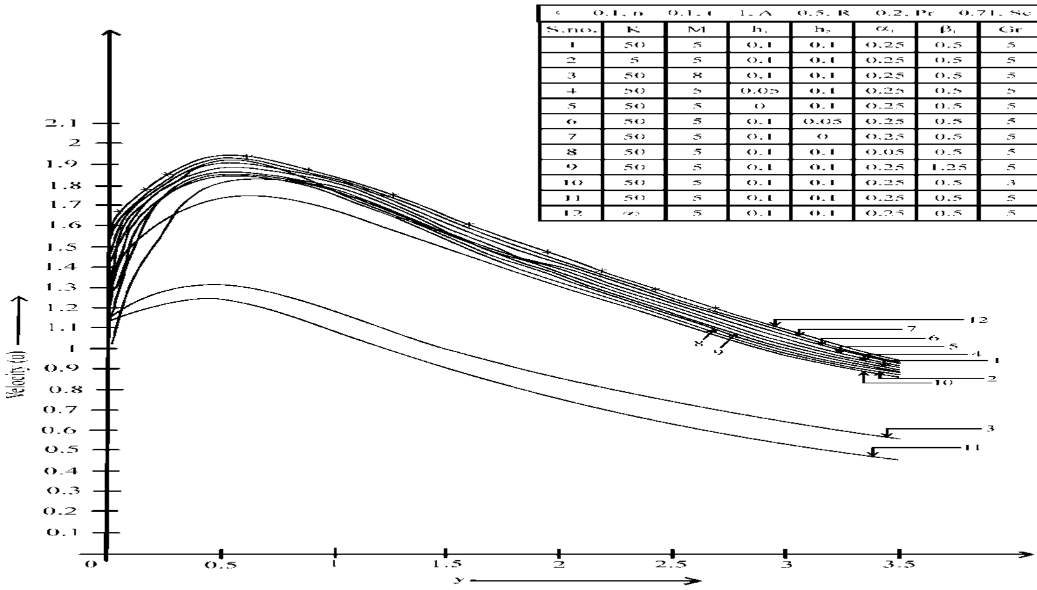
[18]. Derek, C., Tretheway, D.C. and Meinhart, C.D., 2002. Apparent fluid slip at hydrophobic micro channels walls, Physics of Fluid, vol 14, pp. L9-L12.

[19]. Mehmood, A. and Ali, A., 2007. The effect of slip conditions on unsteady MHD oscillatory flow of a viscous fluid in a planer channel, Romanian J. Phy., vol 52, pp.85-91.

[20]. Mansour, M.A., Mohamed, R.A., Abd-Elaziz, M.M. and Ahmed, S.E., 2007. Fluctuating thermal and mass diffusion on unsteady MHD convection of a micro polar fluid through a porous medium past a vertical plate in slip-flow regime, Int. J. App. Math. Mech., vol 3, pp. 99-117.

[21]. Jain, N.C. and Gupta, P., 2007. Unsteady magneto polar free convection flow in slip flow regime with variable permeability and constant heat flux, Journal of Energy, Heat and Mass Transfer, vol 29, pp. 227-240.

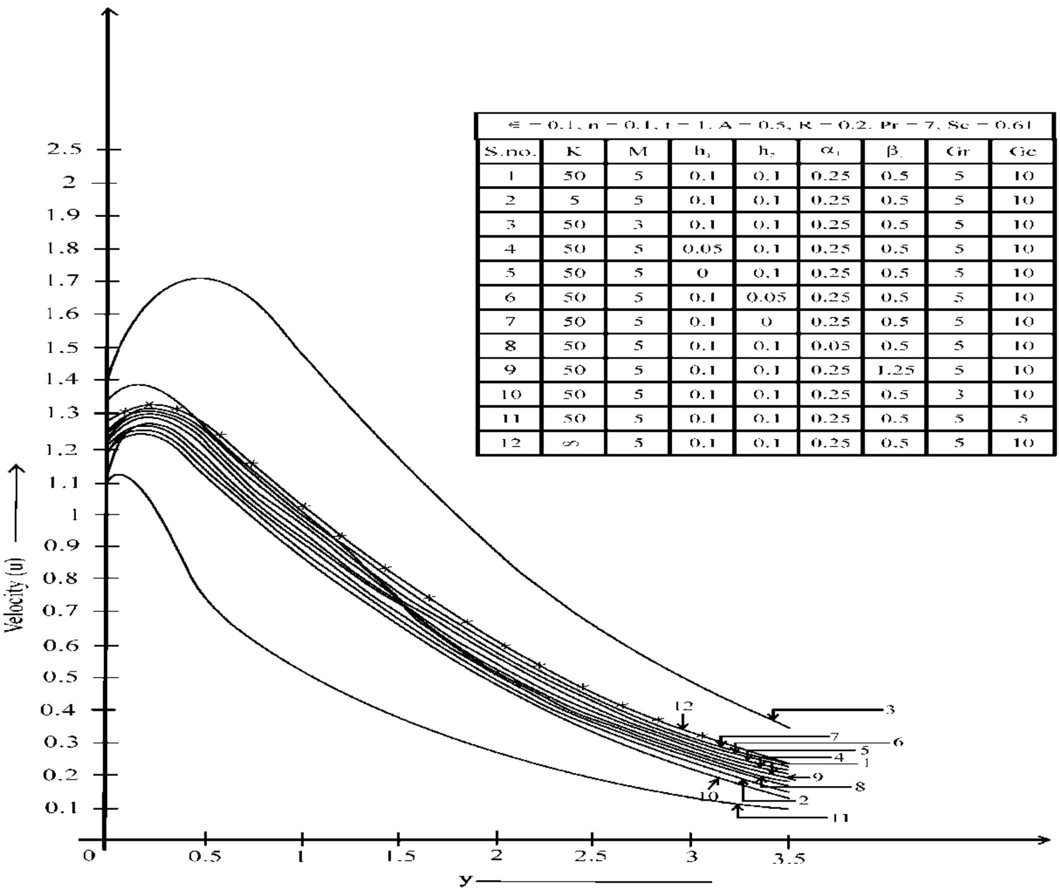
[22]. Sharma, P.K., 2005. Fluctuating thermal and mass diffusion on unsteady free convection flow past a vertical plate in slip-flow regime, Latin American App. Research, vol 35, pp. 313-319.



$\in = 0.1, n = 0.1, t = 1, A = 0.5, R = 0.2, Pr = 0.71, Sc = 0.22$

S.no.	K	M	h_1	h_2	α_1	β_1	Gr	Gc
1	50	5	0.1	0.1	0.25	0.5	5	10
2	5	5	0.1	0.1	0.25	0.5	5	10
3	50	8	0.1	0.1	0.25	0.5	5	10
4	50	5	0.05	0.1	0.25	0.5	5	10
5	50	5	0	0.1	0.25	0.5	5	10
6	50	5	0.1	0.05	0.25	0.5	5	10
7	50	5	0.1	0	0.25	0.5	5	10
8	50	5	0.1	0.1	0.05	0.5	5	10
9	50	5	0.1	0.1	0.25	1.25	5	10
10	50	5	0.1	0.1	0.25	0.5	3	10
11	50	5	0.1	0.1	0.25	0.5	5	5
12	∞	5	0.1	0.1	0.25	0.5	5	10

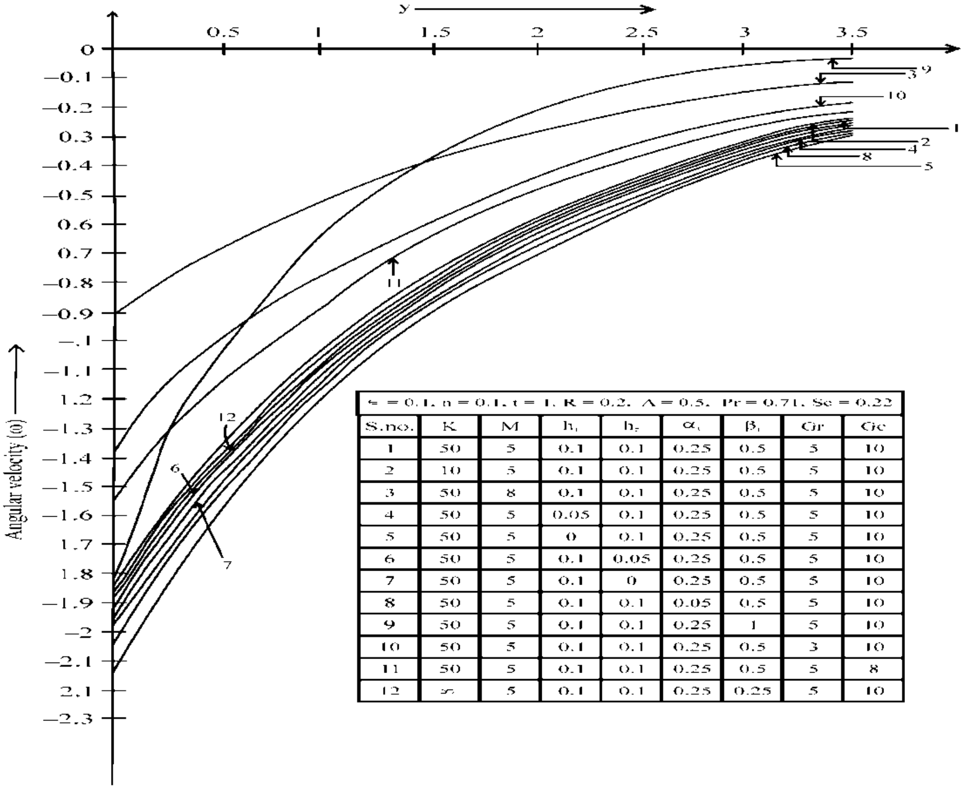
Figure 1: Velocity profiles in air plotted against y for different values of K, M, h_1, h_2, α_1, β_1, Gr and Gc.



$\in = 0.1, n = 0.1, t = 1, A = 0.5, R = 0.2, Pr = 7, Sc = 0.61$

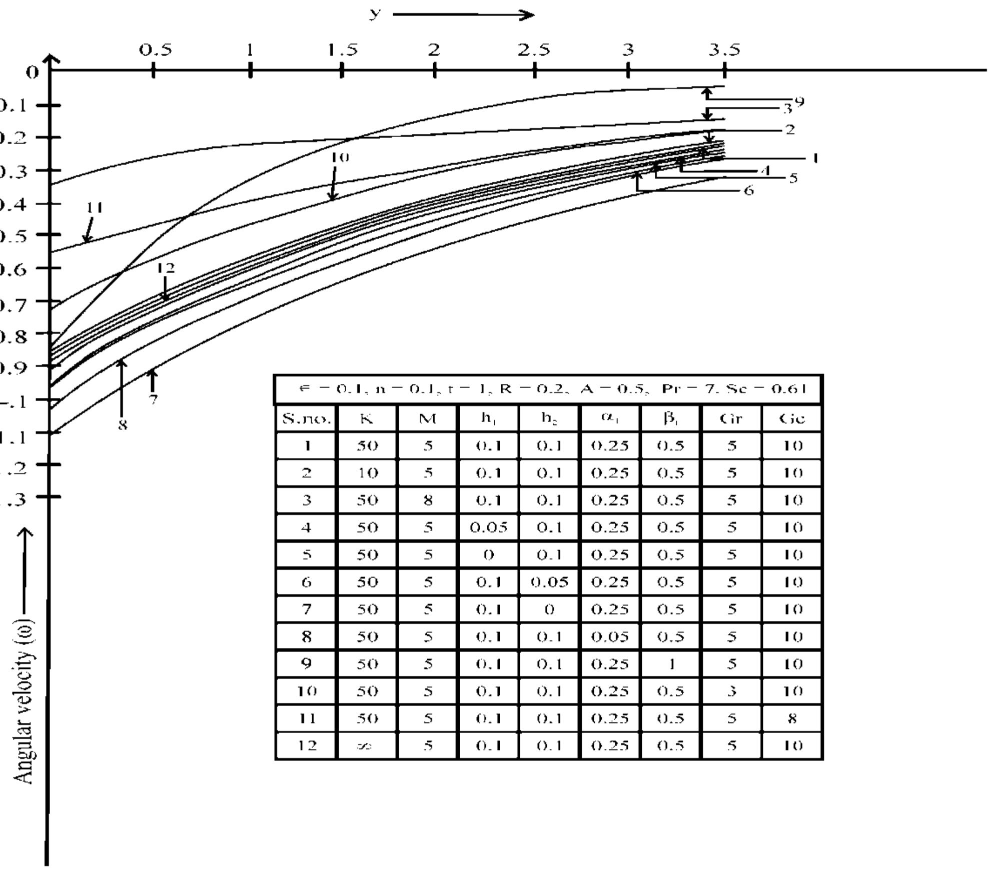
S.no.	K	M	h_1	h_2	α_1	β_1	Gr	Gc
1	50	5	0.1	0.1	0.25	0.5	5	10
2	5	5	0.1	0.1	0.25	0.5	5	10
3	50	3	0.1	0.1	0.25	0.5	5	10
4	50	5	0.05	0.1	0.25	0.5	5	10
5	50	5	0	0.1	0.25	0.5	5	10
6	50	5	0.1	0.05	0.25	0.5	5	10
7	50	5	0.1	0	0.25	0.5	5	10
8	50	5	0.1	0.1	0.05	0.5	5	10
9	50	5	0.1	0.1	0.25	1.25	5	10
10	50	5	0.1	0.1	0.25	0.5	3	10
11	50	5	0.1	0.1	0.25	0.5	5	5
12	∞	5	0.1	0.1	0.25	0.5	5	10

Figure 2: Velocity profiles in water plotted against y for different values of K, M, h_1, h_2, α_1, β_1, Gr and Gc.



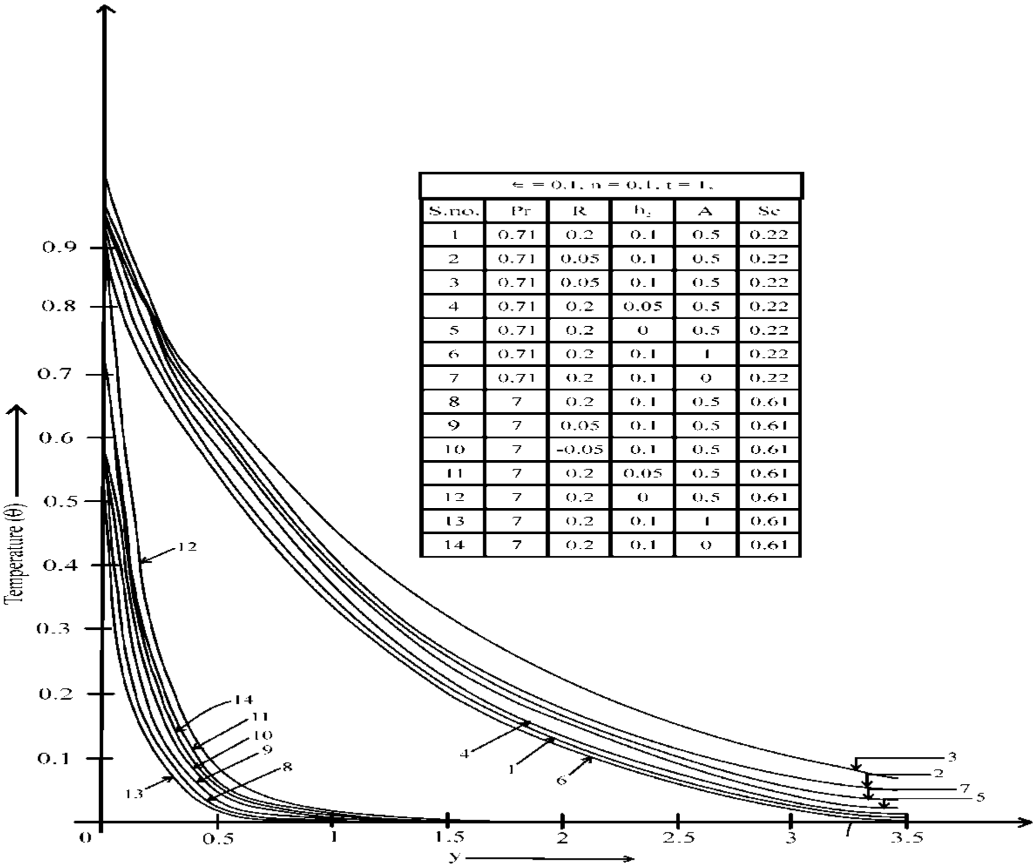
$\epsilon = 0.1,\ n = 0.1,\ t = 1,\ R = 0.2,\ A = 0.5,\ Pr = 0.71,\ Sc = 0.22$								
S.no.	K	M	h_1	h_2	α_1	β_1	Gr	Gc
1	50	5	0.1	0.1	0.25	0.5	5	10
2	10	5	0.1	0.1	0.25	0.5	5	10
3	50	8	0.1	0.1	0.25	0.5	5	10
4	50	5	0.05	0.1	0.25	0.5	5	10
5	50	5	0	0.1	0.25	0.5	5	10
6	50	5	0.1	0.05	0.25	0.5	5	10
7	50	5	0.1	0	0.25	0.5	5	10
8	50	5	0.1	0.1	0.05	0.5	5	10
9	50	5	0.1	0.1	0.25	1	5	10
10	50	5	0.1	0.1	0.25	0.5	3	10
11	50	5	0.1	0.1	0.25	0.5	5	8
12	∞	5	0.1	0.1	0.25	0.25	5	10

Figure 3: Angular velocity profiles in air plotted against y for different values of K, M, h_1, h_2, α_1, β_1, Gr and Gc.



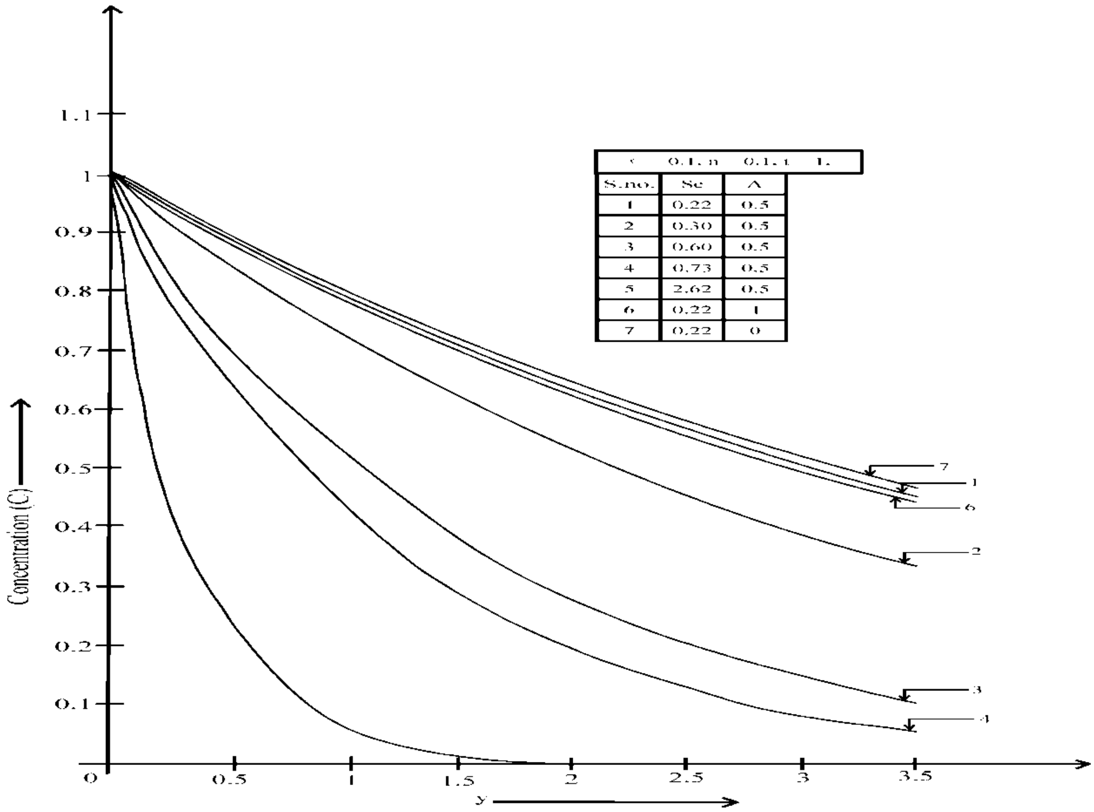
$\epsilon = 0.1,\ n = 0.1,\ t = 1,\ R = 0.2,\ A = 0.5,\ Pr = 7,\ Sc = 0.61$								
S.no.	K	M	h_1	h_2	α_1	β_1	Gr	Gc
1	50	5	0.1	0.1	0.25	0.5	5	10
2	10	5	0.1	0.1	0.25	0.5	5	10
3	50	8	0.1	0.1	0.25	0.5	5	10
4	50	5	0.05	0.1	0.25	0.5	5	10
5	50	5	0	0.1	0.25	0.5	5	10
6	50	5	0.1	0.05	0.25	0.5	5	10
7	50	5	0.1	0	0.25	0.5	5	10
8	50	5	0.1	0.1	0.05	0.5	5	10
9	50	5	0.1	0.1	0.25	1	5	10
10	50	5	0.1	0.1	0.25	0.5	3	10
11	50	5	0.1	0.1	0.25	0.5	5	8
12	∞	5	0.1	0.1	0.25	0.5	5	10

Figure 4: Angular velocity profiles in water plotted against y for different values of K, M, h_1, h_2, α_1, β_1, Gr and Gc.



$\epsilon = 0.1, n = 0.1, t = 1.$					
S.no.	Pr	R	h_2	A	Sc
1	0.71	0.2	0.1	0.5	0.22
2	0.71	0.05	0.1	0.5	0.22
3	0.71	0.05	0.1	0.5	0.22
4	0.71	0.2	0.05	0.5	0.22
5	0.71	0.2	0	0.5	0.22
6	0.71	0.2	0.1	1	0.22
7	0.71	0.2	0.1	0	0.22
8	7	0.2	0.1	0.5	0.61
9	7	0.05	0.1	0.5	0.61
10	7	-0.05	0.1	0.5	0.61
11	7	0.2	0.05	0.5	0.61
12	7	0.2	0	0.5	0.61
13	7	0.2	0.1	1	0.61
14	7	0.2	0.1	0	0.61

Figure 5: Temperature profiles plotted against y of different values of Pr, R, h_2, A and Sc.



ϵ = 0.1, n = 0.1, t = 1.		
S.no.	Sc	A
1	0.22	0.5
2	0.30	0.5
3	0.60	0.5
4	0.73	0.5
5	2.62	0.5
6	0.22	1
7	0.22	0

Figure 6: Concentration profiles plotted against y for different values Sc and A.

ϵ 0.1, n 0.1, j 1, Pr 0.71, Sc 0.22, A 0.5.								
S.no.	M	h_1	h_2	α_1	β_1	Gr	Gc	R
1	5	0.1	0.1	0.25	0.5	5	10	0.05
2	4	0.1	0.1	0.25	0.5	5	10	0.05
3	5	0.05	0.1	0.25	0.5	5	10	0.05
4	5	0	0.1	0.25	0.5	5	10	0.05
5	5	0.1	0.05	0.25	0.5	5	10	0.05
6	5	0.1	0	0.25	0.5	5	10	0.05
7	5	0.1	0.1	0.1	0.5	5	10	0.05
8	5	0.1	0.1	0.25	1	5	10	0.05
9	5	0.1	0.1	0.25	0.5	3	10	0.05
10	5	0.1	0.1	0.25	0.5	5	8	0.05
11	5	0.1	0.1	0.25	0.5	5	10	0
12	5	0.1	0.1	0.25	0.5	5	10	-0.05

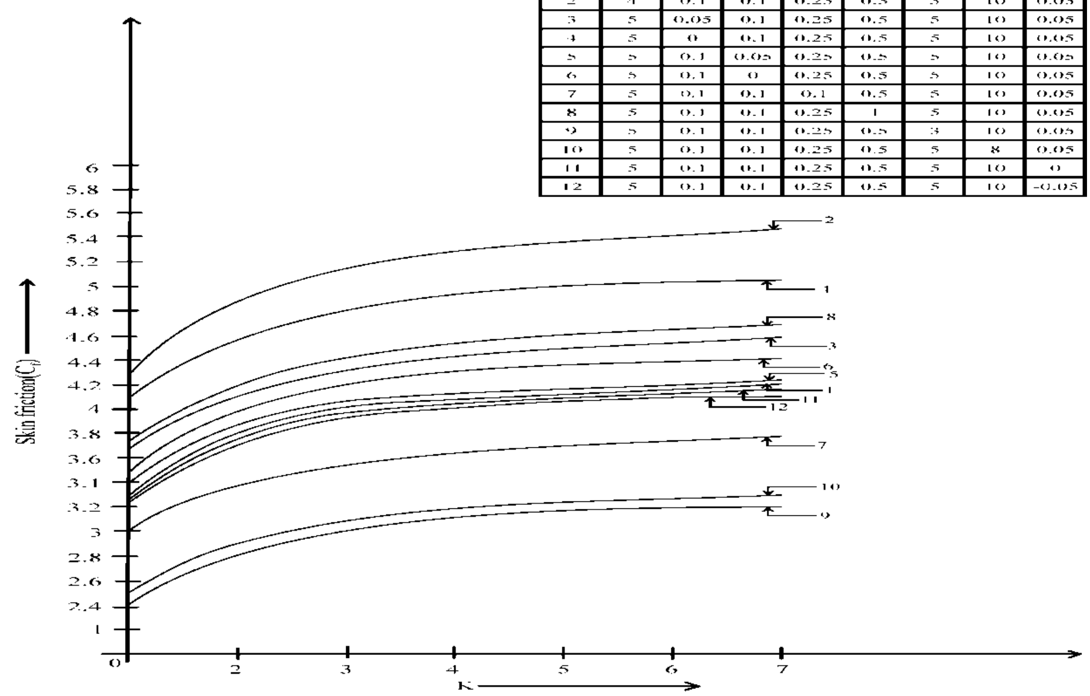
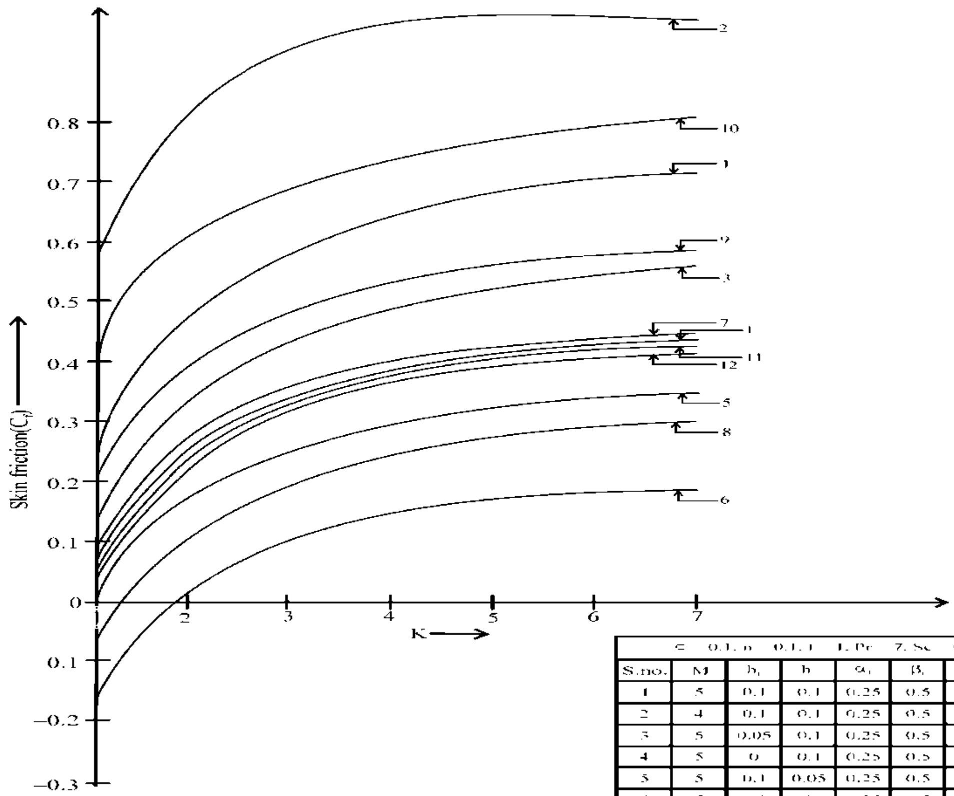


Figure 7: Skin friction in air plotted against K for different values of M, h_1, h_2, α_1, β_1, Gr, Gc and R.



ϵ 0.1, n 0.1, j 1, Pr 7, Sc 0.61, A 0.5,								
S.no.	M	h_1	h	α_1	β_1	Gr	Gc	R
1	5	0.1	0.1	0.25	0.5	5	10	0.05
2	4	0.1	0.1	0.25	0.5	5	10	0.05
3	5	0.05	0.1	0.25	0.5	5	10	0.05
4	5	0	0.1	0.25	0.5	5	10	0.05
5	5	0.1	0.05	0.25	0.5	5	10	0.05
6	5	0.1	0	0.25	0.5	5	10	0.05
7	5	0.1	0.1	0.1	0.5	5	10	0.05
8	5	0.1	0.1	0.25	0.1	5	10	0.05
9	5	0.1	0.1	0.25	0.5	3	10	0.05
10	5	0.1	0.1	0.25	0.5	5	11	0.05
11	5	0.1	0.1	0.25	0.5	5	10	0
12	5	0.1	0.1	0.25	0.5	5	10	-0.05

Figure 8: Skin friction in water plotted against K for different values of M, h_1, h_2, α_1, β_1, Gr, Gc and R.

$\epsilon = 0.1, n = 0.1, t = 1, A = 0.5.$			
S.no.	Pr	R	h_2
1	0.71	0.2	0.1
2	0.71	0.05	0.1
3	0.71	0	0.1
4	0.71	-0.05	0.1
5	0.71	0.2	0.1
6	0.71	0.2	0
7	7	0.2	0.1
8	7	0.05	0.1
9	7	0	0.1
10	7	-0.05	0.1
11	7	0.2	0.05
12	7	0.2	0

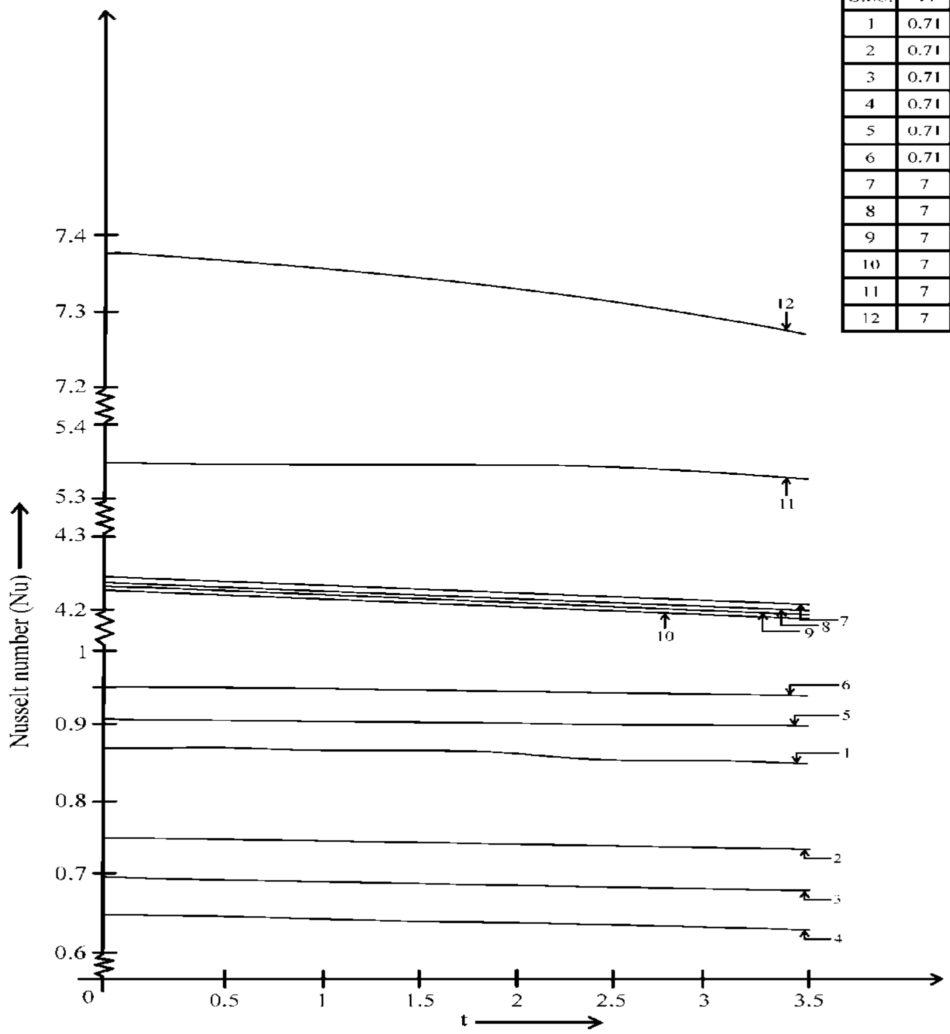


Figure 9: Nusselt number plotted against t for different values of Pr, R and h_2.