Available online at http://scik.org
J. Math. Comput. Sci. 2 (2012), No. 2, 172-188
ISSN: 1927-5307

UNSTEADY MHD FREE CONVECTIVE VISCOELASTIC FLOW AND MASS TRANSFER THROUGH POROUS MEDIUM

NOUSHIMA HUMERA.G [1*], M.V RAMANA MURTHY [2] AND RAFIUDDIN [3]

[1]Department of Mathematics,Methodist College of Engg and Tech,Abids,Hyd
[2]Department of Computer Science,King Abdul Aziz Univ,Rabigh,UAE
[3]Department of Humanities and Appl.Sci,CVR College of and Engg and Tech ,Ibrahim Patnam,India.

Abstract: Analysis of unsteady two-dimensional free convective flow and mass transfer through an incompressible electrically conducting viscoelastic fluid in 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 discussed. The effects of Grashoff number, modified Grashoff number, Schmidt number, Eckert number, permeability parameter, phase angle and magnetic number on velocity, temperature and concentration profiles are discussed and shown graphically. Also effects of various physical parameters are considered on skin friction coefficient, Nusselt number and mass transfer coefficient at the surface.

Keywords : walters liquid b, free convection, skin friction, nusselt number and mass transfer coefficient.
AMS Subject Classification : 47H17,47H05,47H09.

1.Introduction

*Corresponding author
E-mail address: noushimahg@yahoo.com (N. Humera.G), mv.rm50@gmail.com(M.V R. Murthy), rafiuddin2008@gmail.com (Rafiuddin)
Received December 02, 2011

It is necessary to study free convection flow through porous medium to make heat insulation of surface more effective to estimate its effect in heat and mass transfer. Raptis et.al[1] studied two dimensional flow of viscous fluid through a porous medium bounded by porous surface subjected to constant suction velocity by taking account of free convection currents.Bejan&Khai[2]discussed heat and mass transfer in porous medium. Sharma [3] investigated free convective effect on flow of an ordinary viscous fluid past and infinite vertical porous plate with constant suction and constant heat flux.Achary et.al[4]studied the effect of magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux. Bansood [5] studied boundary layer solution of convective heat and mass transfer from a horizontal surface in a non-Darcy porous media.A.K Singh[6]studied MHD free convective and mass transfer flow with heat source and thermal diffusion. A.K Singh et.al [7] studied heat and mass transfer in MHD flow of a viscou fluid past a vertical plate under oscillatory suction velocity . Y.J Kim[8] studied heat and mass transfer in MHD micropolar flow over a vertical moving porous plate in a porous medium.Alam et.al [9] studied Dufour and Soret effects on unsteady MHD free convection and mass transfer flow past a vertical porous plate in a porous medium.N.P Singh et.al[10]studied MHD free convection and mass transfer flow past a flat plate. Noushima et.al[11] studied MHD unsteady free convective Walter`s memory flow with constant suction and heat sink. Noushima et.al [12] studied unsteady viscoelastic memory flow and heat transfer over a continuous porous moving horizontal surface.

In this paper, we have extended the problem of Sarangi and Bose [13] to the viscoelastic fluid, whose constitutive equation is given by (Walters liquid model B) mixture of polymethyl mehacrylate and pyridine at $25\,^{0}C$ containing 30.5 g polymer per liter behaves very nearly as the Walters liquid [14 &15].

Nomenclature:

B_0	applied magnetic field,	T	the fluid temperature,
B_1	viscoelastic parameter,	T_∞	is the free stream temperature, time,
C_p	specific heat at constant pressure,	t^*	is time,
C^*	the species concentration,	u and v are the corresponding velocity	

C_∞^* the species concentration at ∞,

C_f Skin friction coefficient,

D the chemical molecular diffusivity,

g the acceleration due to gravity,

k_0 the permeability of porous medium,

components along and perpendicular to the surface,

$v_0 > 0$ corresponds to steady suction velocity(normal) at the surface,

Greek Alphabets

β^* the coefficient of volume expansion for the heat transfer,

β^{**} is the volumetric coefficient of expansion with species concentration,

ρ the density of the fluid,

σ electrical conductivity,

ν the kinematic viscosity,

ε is a small parameter i:e $\varepsilon <<1$

κ the thermal conductivity,

1.Materials and Methods

Unsteady two dimensional motion of viscoelastic incompressible electrically conducting fluid through a porous medium 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 flow is considered. The effect of induced magnetic field is neglected.The magnetic Reynolds number is assumed to be very small. Further, magnetic field is not strong enough to cause Joule heating (electrical dissipation).Hence, the term due to electrical dissipation is neglected in energy equation (1.3).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 the influence of density in body force term.As the bounding surface is infinite in length,all the variable are functions of y only.Hence,by usual boundary layer approximation the basic equation for unsteady flow through highly porous medium are :

$$\partial v / \partial y = 0 \Rightarrow v = -v_0 (1 + \varepsilon e^{i \omega t}) \tag{1.1}$$

$$\partial u / \partial t + v \, \partial u / \partial y = \nu \, \partial^2 u / \partial y^2 + g \beta^* (T - T_\infty) + g \beta^{**} (C^* - C_\infty^*)$$

$$- B_1 (\partial^3 u / \partial t \partial y^2 + v \ \partial^3 u / \partial y^3) - (\sigma B_0^2 / \rho) u - (\nu / k_0) u \quad (1.2)$$

$$\partial T / \partial t + v \partial T / \partial y = (\kappa / \rho C_p) \partial^2 T / \partial y^2 + (\nu / C_p)(\partial u / \partial y)^2 \quad (1.3)$$

$$\partial C^* / \partial t + v \partial C^* / \partial y = D \partial^2 C^* / \partial y^2 \quad (1.4)$$

Subscript denotes the derivative.

The corresponding boundary conditions are :

$$\left.\begin{array}{l} u = 0, T = T_\infty, C^* = C_\infty{}^* \text{ for all } y \text{ and } t \le 0 \\ u = 0, dT/dy = -q/\kappa, dC^*/dy = m^{\cdot}/D, y = 0 \text{ and } t > 0 \\ u = 0, T = T_\infty, C^* = C_\infty{}^*, y \to \infty \text{ and } t > 0 \end{array}\right\} \quad (1.5)$$

where q is the heat flux per unit area and $m^{\cdot}$ is the mass flux per unit area.

Introducing the following non-dimensional quantities :

$$f(\eta, t) = u / v_0, \ \eta = v_0 y / \nu, \ Pr = \mu C_p / \kappa, \ Sc = \nu / D;$$

$$\theta(\eta, t) = (T - T_\infty) v_0 \kappa / q \nu, \ C = (C^* - C_\infty{}^*) v_0 D / m^{\cdot} \nu \ ;$$

$$k_0 = v_0^2 \kappa / \nu u^2, \ Gr = g \beta^* q \nu^2 / v_0^4 \kappa, \ Gm = g \beta^{**} m^{\cdot} \nu^2 / v_0^4 D;$$

$$M = \sigma B_0^2 \nu / \rho v_0^2, \ Ec = \kappa v_0^3 / q \nu Cp, \ t = v_0^2 t^* / \nu, \ R_m = B_1 v_0^2 / \nu^2$$

into equations (1.2), (1.3), (1.4) and using (1.1), we get

$$f^{11} + R_m \{ (1 + \varepsilon e^{i\omega t}) f^{111} - f^{11}{}_t \} + (1 + \varepsilon e^{i\omega t}) f^1$$

$$- (1 / k_0 + M) f - f_t = - Gr \theta - Gm C \quad (1.6)$$

$$\theta^{11} + (1 + \varepsilon e^{i\omega t}) \Pr \theta^{1} - \Pr \theta_{t} = - \Pr Ec (f^{1})^{2} \quad (1.7)$$

$$C^{11} + (1 + \varepsilon e^{i\omega t}) Sc\, C^{1} = Sc\, C_{t} \quad (1.8)$$

where prime denotes differentiation with respect to η ,suffix t denotes differentiation with respect to time.

The corresponding boundary conditions in non-dimensional form are :

$$\left.\begin{array}{l} \eta = 0 : f = 0 , \theta^{1} = -1 , C^{1} = -1 \\ \eta \to \infty : f = 0 , \theta \to 0, C \to 0 \end{array}\right\} \quad (1.9)$$

Since the Eckert number Ec is very small for incompressible fluid flows,therefore $f(\eta,t)$, $\theta(\eta,t)$ and $C(\eta,t)$ can be expanded in power of Ec as given below:

$$F(\eta,t) = F_{0}(\eta,t) + Ec\, F_{1}(\eta,t) + O(Ec^{2}) \quad (1.10)$$

where F stands for f , θ , C.Substituting equation (1.10) into equations (1.6),(1.7) and (1.8) ,equating the coefficients of like power of Ec and neglecting higher order terms in Ec, we find :

$$f_{0}^{11} + R_{m} \{ (1 + \varepsilon e^{i\omega t}) f_{0}^{111} - f_{0}^{11}{}_{,t} \} + (1 + \varepsilon e^{i\omega t}) f_{0}^{1}$$

$$- (1/k_{0} + M) f_{0} - f_{0,t} = - Gr\, \theta_{0} - Gm\, C_{0} \quad (1.11)$$

$$\theta_{0}^{11} + (1 + \varepsilon e^{i\omega t}) \Pr \theta_{0}^{1} = \Pr \theta_{0,t} \quad (1.12)$$

$$C_{0}^{11} + (1 + \varepsilon e^{i\omega t}) Sc\, C_{0}^{1} = Sc\, C_{0,t} \quad (1.13)$$

$$f_{1}^{11} + R_{m} \{ (1 + \varepsilon e^{i\omega t}) f_{1}^{111} - f_{1}^{11}{}_{,t} \} + (1 + \varepsilon e^{i\omega t}) f_{1}^{1}$$

$$- (1/k_{0} + M) f_{1} - f_{1,t} = - Gr\, \theta_{1} - Gm\, C_{1} \quad (1.14)$$

$$\theta_1^{11} + (1 + \varepsilon e^{i\omega t}) \Pr \theta_1^{1} = \Pr \theta_{1,t} + \Pr (f_0^{1})^2 \tag{1.15}$$

$$C_1^{11} + (1 + \varepsilon e^{i\omega t}) Sc\, C_1^{1} = Sc\, C_{1,t} \tag{1.16}$$

The corresponding boundary conditions are reduced to :

$$\left.\begin{array}{l} \eta = 0 \ : f_0 = f_1 = 0 , \theta_0^{1} = -1 , \theta_1^{1} = 0 , C_0^{1} = -1 , C_1^{1} = 0 \\ \\ \eta \to \infty : f_0 = f_1 = 0 , \theta_0 \to 0, \theta_1 \to 0, C_0 \to 0, C_1 \to 0 \end{array}\right\} \tag{1.17}$$

Now, separating steady and unsteady parts by using

$$G = G_0 + \varepsilon e^{i\omega t} G_1 \tag{1.18}$$

where G stands for f_0, f_1 ,θ_0 ,θ_1, C_0 and C_1 into the equations (1.11) to (1.16) and equations the like power of $O(\varepsilon)$,we get :

$$R_m\, f_{00}^{111} + f_{00}^{11} + f_{00}^{1}$$

$$- (1 / k_0 + M) f_{00} = - G r\, \theta_{00} - G m\, C_{00} \tag{1.19}$$

$$\theta_{00}^{11} + \Pr \theta_{00}^{1} = 0 \tag{1.20}$$

$$C_{00}^{11} + Sc\, C_{00}^{1} = 0 \tag{1.21}$$

$$R_m\, f_{10}^{111} + f_{10}^{11} + f_{10}^{1}$$

$$- (M + 1 / k_0) f_{10} = - G r\, \theta_{10} - G m\, C_{10} \tag{1.22}$$

$$\theta_{10}^{11} + \Pr \theta_{10}^{1} + \Pr (f_{00}^{1})^2 = 0 \tag{1.23}$$

$$C_{10}^{11} + Sc\, C_{10}^{1} = 0 \tag{1.24}$$

$$R_m \{ f_{00}^{111} + f_{01}^{111} - i\omega f_{01}^{11}\} + f_{01}^{11} - i\omega f_{01} + f_{00}^{1} + f_{01}^{1}$$

$$-(1/k_0 + M) f_{01} = -Gr\,\theta_{01} - Gm\,C_{01} \qquad (1.25)$$

$$\theta_{01}^{11} + Pr\,\theta_{01}^{1} - Pr\,i\omega\,\theta_{01} = -Pr\,\theta_{00}^{1} \qquad (1.26)$$

$$C_{01}^{11} + Sc\,C_{01}^{1} - Sc\,i\omega\,C_{01} = -Sc\,C_{00}^{1} \qquad (1.27)$$

$$R_m\{f_{10}^{111} + f_{11}^{111} - i\omega f_{11}^{11}\} + f_{11}^{11} + f_{10}^{1} + f_{11}^{1}$$

$$-i\omega f_{11} - (1/k_0 + M) f_{11} = -Gr\,\theta_{11} - Gm\,C_{11} \qquad (1.28)$$

$$\theta_{11}^{11} + Pr\,\theta_{10}^{1} + Pr\,\theta_{11}^{1} - Pr\,i\omega\,\theta_{11} = -2\,Pr\,f_{00}^{1} f_{01}^{1} \qquad (1.29)$$

$$C_{11}^{11} + C_{11}^{1} - Sc\,i\omega\,C_{11} = -Sc\,C_{10}^{1} \qquad (1.30)$$

The corresponding boundary conditions are :

$$\left.\begin{array}{l} \eta = 0 : \; f_{00} = f_{01} = f_{10} = f_{11} = 0, \\ \quad \theta_{00}^{1} = -1, \theta_{01}^{1} = \theta_{10}^{1} = \theta_{11}^{1} = 0, \\ \quad C_{00}^{1} = -1, C_{01}^{1} = C_{10}^{1} = C_{11}^{1} = 0 \\ \\ \eta \to \infty : f_{00} \to f_{01} \to f_{10} \to f_{11} \to 0 \\ \quad \theta_{00} \to \theta_{01} \to \theta_{10} \to \theta_{11} \to 0, \\ \quad C_{00} \to C_{01} \to C_{10} \to C_{11} \to 0, \end{array}\right\} \qquad (1.31)$$

the equations (1.19),(1.22),(1.25) and (1.28) are coupled nonlinear third order differentiation equations due to presence of viscoelasticity of the fluid.Since the Magnetic Reynolds number is very small, therefore can be expanded using Beard and Walters rule[16]

$$H = H_0 + R_m H_1 + O(R_m^{\,2})$$

where $H = f_{00}, f_{01}, f_{10}, f_{11}, \theta_{00}, \theta_{01}, \theta_{10}, \theta_{11}, C_{00}, C_{01}, C_{10}, C_{11}.$

The equation are ordinary linear second –order differential equations.

Through straight forward Algebra,the solution of f_{000}, f_{010} , f_{011} , f_{100},, f_{110}, f_{001} , f_{101}, f_{011}, f_{111}, θ_{000},θ_{100}, θ_{010}, θ_{110} , θ_{00},θ_{001}, θ_{101} , θ_{011} , θ_{111} ,C_{000}, C_{100}, C_{010}, C_{110}, ,C_{001}, C_{101}, C_{011}, C_{111} are found.

The corresponding boundary conditions are :

$$
\left.
\begin{array}{l}
\eta = 0 \; : \\
f_{000} = f_{010} = f_{011} = f_{100} = f_{110} = f_{011} = f_{101} = f_{011} = f_{111} = 0 , \\
\theta_{000}{}^{1} = -1, \theta_{010}{}^{1} = \theta_{011}{}^{1} = \theta_{110}{}^{1} = \theta_{110}{}^{1} = \theta_{101}{}^{1} = \theta_{111}{}^{1} = \theta_{001}{}^{1} = 0 ; \\
C_{000}{}^{1} = -1, C_{010}{}^{1} = C_{011}{}^{1} = C_{100}{}^{1} = C_{110}{}^{1} = C_{011}{}^{1} = C_{101}{}^{1} = 0 \\
C_{111}{}^{1} = 0 \\
\eta \to \infty : \\
f_{000} \to f_{010} \to f_{011} \to f_{100} \to f_{110} \to f_{011} \to f_{101} \to f_{111} \to 0 \\
\theta_{000} \to \theta_{010} \to \theta_{011} \to \theta_{100} \to \theta_{110} \to \theta_{011} \to \theta_{101} \to \theta_{111} \to 0,
\end{array}
\right\} \quad (1.32)
$$

$C_{000} \to C_{010} \to C_{011} \to C_{100} \to C_{110} \to C_{011} \to C_{101} \to C_{111} \to 0$,

The expression of velocity, temperature and concentration distribution are found and not presented here for the sake of brevity.Throughout the computations the value of R_m is taken as 0.05.

2.Skin Friction, Rate of Heat and Mass Transfer :

The skin friction coefficient at the surface is given by

$$C_f = [\tau_{xy} / \rho v_0^2]_{y=0} = (\partial f / \partial y)_{y=0}$$

The rate of heat transfer at the surface is given by

$$Nu = (\partial \theta / \partial y)_{y=0}$$

The mass transfer coefficient at the surface is given by

$$Sh = (\partial C / \partial y)_{y=0}$$

3.RESULTS AND DISCUSSION

Table 1 depicts the skin friction coefficient at the surface for the different values of Prandtl number,Grashoff number, Schmidt number,Hartmann number Modified Grashoff number,permeability parameter and phase angle. For both the cases, cooled surface and extremely heated plate. It is observed that, skin friction coefficient increases due to increase in the Eckert number,Grashoff number ,modified Grashoff number, permeabilityparameter and phase angle while it decreases with the increases of Schmidt number or Hartmann number. In case of extremely heated plate the skin friction coefficient increases due to increase in Hartmann number, modified Grashoff number, while it decreases with the increase of permeability parameter,Grashoff number,Eckert number ,Schmidt number.

Table 2 depicts the rate of heat transfer at the surface for the different values of Prandtl number,Grashoff number,Schmidt number,Hartmann number,Modified Grashoff number, number, permeability parameter and phase angle. For both cases, cooled and extremely cooled and extremely heated surface. It is observed, Nusselt number increases due to increase in the Schmidt number or Hartmann number, while it decreases with increase in Eckert number, Grashoff number, modified Grashoff number permeability parameter and phase angle.In case of extremely heated plate, the Nusselt number increases due to increase in Eckert number, modified Grashoff number and permeability parameter while it decreases with the increase of Grashoff number, Schmidt number, Hartmann number and phase angle.

Table 3 depicts the rate of mass transfer at the surface for the different values of Schmidt number and phase angle. It is observed from Table 3 that mass transfer coefficient is more for Helium,Water Vapour,Oxygen,Ammonia and phase angle than Hydrogen.

Figure 1 shows fluid velocity for extremely cooled surface for different values of Schmidt number, Hartmann number, phase angle, Eckert number, Grashoff number,modified Grashoff number and permeability paramet It is observed from Figure 1that for extremely cooled surface fluid velocity decreases due to increase in Schmidt number,Hartmann number, phase angle, while it increases with the increase of the Eckert number, Grashoff number,modified Grashoff number and permeability parameter .

Figure 2 shows that fluid velocity for extremely heated surface for different values of modified Grashoff number, Eckert number, Hartmann number , phase angle, permeability parameter, Grashoff number, Schmidt number.It is observed that for extremely cooled surface fluid velocity increases due to increase in modified Grashoff number,Eckert number, phase angle or Hartmann number, while with the increase in the Schimdt number, Grashoff number and permeability parameter fluid velocity decreases .

Figure 3 and 4 shows fluid temperature for extremely cooled surface ,for different values of Schmidt number,Hartmann number, phase angle,Eckert number, Grashoff number, modified Grashoff number and permeability parameter It is observed that for extremely cooled surface fluid temperature decreases due to increase in Schmidt number,Hartmann number or phase angle, while it increases with the increase in the Eckert number, Grashoff number, modified Grashoff number and permeability parameter.

Figure 5 and 6 shows fluid temperature for extremely heated surface for different values of Grashoff number, Eckert number, Schimdt number, permeability parameter,modified Grashoff number,Hartmann number and phase angle . It is observed that for extremely heated surface fluid temperature increases due to increases in Grashoff number, Eckert number, Schimdt number and permeability parameter, while it decreases due to increase in modified Grashoff number.It is noted that with the increase in Hartmann number the fluid temperature decreases and decreases as phase angle increases.

Figure 7 shows concentration field for different values in Schmidt number for the gases Hydrogen, Helium, Water Vapour, Oxygen and Ammonia. It is observed that concentration field decreases slowly and steadily for Hydrogen,Helium and phase angle but decreases rapidly for Oxygen and Ammonia in comparison to Water Vapour. Thus Hydrogen can be used for maintaining effective concentration field and Water Vapour can be used for maintaining normal concentration field.

Table 1

Values of skin friction coefficient at the surface when Pr = 0.71

S.No	Pr	Gr	Ec	Sc	M	Gm	k_0	ω	ωt	C_f
1	0.71	5.0	0.01	0.60	1.0	1.0	1.0	5.0	π/6	5.8421
2	0.71	5.0	0.01	0.60	4.0	1.0	1.0	5.0	π/6	3.7176
3	0.71	5.0	0.01	0.70	1.0	1.0	1.0	5.0	π/6	5.6117
4	0.71	5.0	0.02	0.60	1.0	1.0	1.0	5.0	π/6	6.1903
5	0.71	5.0	0.01	0.60	1.0	4.0	1.0	5.0	π/6	10.1357
6	0.71	10.	0.01	0.60	1.0	1.0	1.0	5.0	π/6	11.6446
7	0.71	5.0	0.01	0.60	1.0	1.0	2.0	5.0	π/6	6.7660
8	0.71	5.0	0.01	0.60	1.0	1.0	1.0	5.0	π/3	5.8858
9	0.71	-5	-0.01	0.60	1.0	1.0	1.0	5.0	π/6	-3.3202
10	0.71	-5	-0.02	0.60	1.0	1.0	1.0	5.0	π/6	-2.2139
11	0.71	-5	-0.01	0.60	1.0	4.0	1.0	5.0	π/6	-3.5276
12	0.71	-5	-0.01	0.60	1.0	1.0	2.0	5.0	π/6	-3.3066
13	0.71	-5	-0.01	0.60	1.	1.0	1.0	5.0	π/6	-0.0563
14	0.71	-5	-0.01	0.60	4.0	1.0	1.0	5.0	π/6	-8.0373
15	0.71	-10	-0.01	070	1.0	1.0	1.0	5.0	π/6	-3.7092
16	0.71	-5	-0.01	0.60	1.0	1.0	1.0	5.0	π/3	-3.3759

Table 2

Values of Nusselt number at the surface when Pr = 0.71

S.No	Pr	Gr	Ec	Sc	M	Gm	k_0	ω	ωt	Nu
1	0.71	5.0	0.01	0.60	1.0	1.0	1.0	5.0	π/6	-1.4034
2	0.71	5.0	0.01	0.60	4.0	1.0	1.0	5.0	π/6	-1.1074
3	0.71	5.0	0.01	0.70	1.0	1.0	1.0	5.0	π/6	-1.3849
4	0.71	5.0	0.02	0.60	1.0	1.0	1.0	5.0	π/6	-1.8191
5	0.71	5.0	0.01	0.60	1.0	4.0	1.0	5.0	π/6	-2.1353
6	0.71	10.	0.01	0.60	1.0	1.0	1.0	5.0	π/6	-2.3207
7	0.71	5.0	0.01	0.60	1.0	1.0	2.0	5.0	π/6	-2.7285
8	0.71	5.0	0.01	0.60	1.0	1.0	1.0	5.0	π/3	-1.4294
9	0.71	-5	-0.01	0.60	1.0	1.0	1.0	5.0	π/6	-0.5705
10	0.71	-5	-0.02	0.60	1.0	1.0	1.0	5.0	π/6	-0.1541
11	0.71	-5	-0.01	0.60	1.0	4.0	1.0	5.0	π/6	-0.1352
12	0.71	-5	-0.01	0.60	1.0	1.0	2.0	5.0	π/6	0.7545
13	0.71	-5	-0.01	0.60	1.	1.0	1.0	5.0	π/6	-1.1318
14	0.71	-5	-0.01	0.60	4.0	1.0	1.0	5.0	π/6	-1.0283
15	0.71	-10	-0.01	070	1.0	1.0	1.0	5.0	π/6	-1.1472
16	0.71	-5	-0.01	0.60	1.0	1.0	1.0	5.0	π/3	-0.5954

Table 3

Values of Sherwood number at the surface,for different values of Schmidt number and phase angle.

S.No	Sc	ωt	Sh
1	0.22	π/6	-0.9874
2	0.30	π/6	-0.9829
3	0.60	π/6	-0.9667
4	0.66	π/6	-0.9635
5	0.78	π/6	-0.9571
6	0.22	π/3	-0.9836

No	Gr	Ec	Sc	M	Gm	k_0	ωt
I	5.0	0.01	0.60	1.0	1.0	1.0	π/6
II	5.0	0.01	0.60	4.0	1.0	1.0	π/6
III	5.0	0.01	0.70	1.0	1.0	1.0	π/6
IV	5.0	0.02	0.60	1.0	1.0	1.0	π/6
V	5.0	0.01	0.60	1.0	4.0	1.0	π/6
VI	10.0	0.01	0.60	1.0	1.0	1.0	π/6
VII	5.0	0.01	0.60	1.0	1.0	2.0	π/6
VIII	5.0	0.01	0.60	1.0	1.0	1.0	π/3

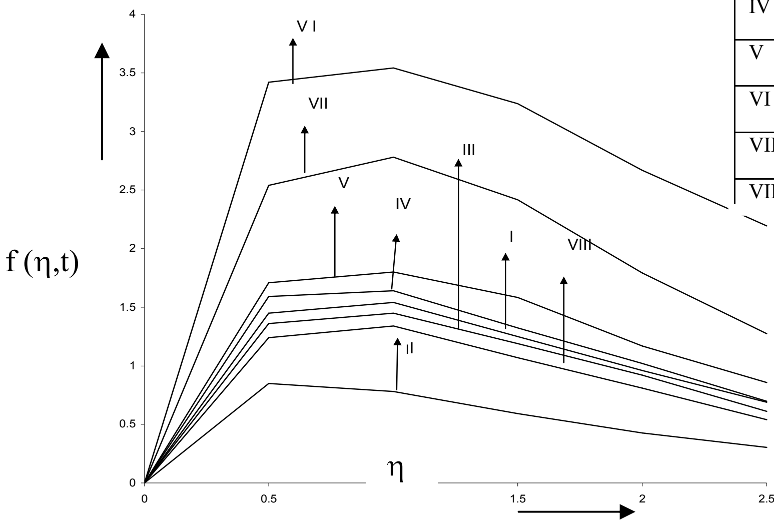


Fig 1 : Velocity distribution η versus when Pr = 0.71

No	Gr	Ec	Sc	M	Gm	k_0	ωt
I	-5.0	-0.01	0.60	1.0	1.0	1.0	π/6
II	-5.0	-0.01	0.60	4.0	1.0	1.0	π/6
III	-5.0	-0.01	0.70	1.0	1.0	1.0	π/6
IV	-5.0	-0.02	0.60	1.0	1.0	1.0	π/6
V	-5.0	-0.01	0.60	1.0	4.0	1.0	π/6
VI	-10.	-0.01	0.60	1.0	1.0	1.0	π/6
VII	-5.0	-0.01	0.60	1.0	1.0	2.0	π/6
VIII	-5.0	-0.01	0.60	1.0	1.0	1.0	π/3

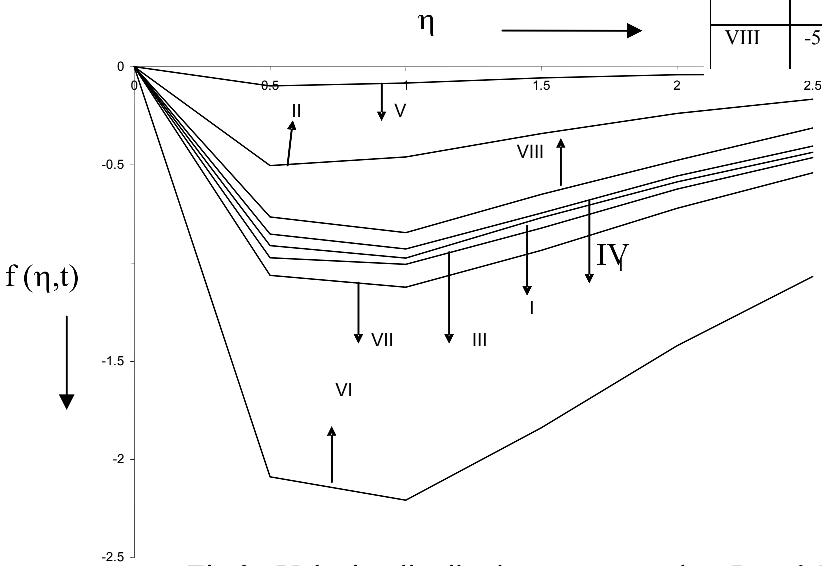
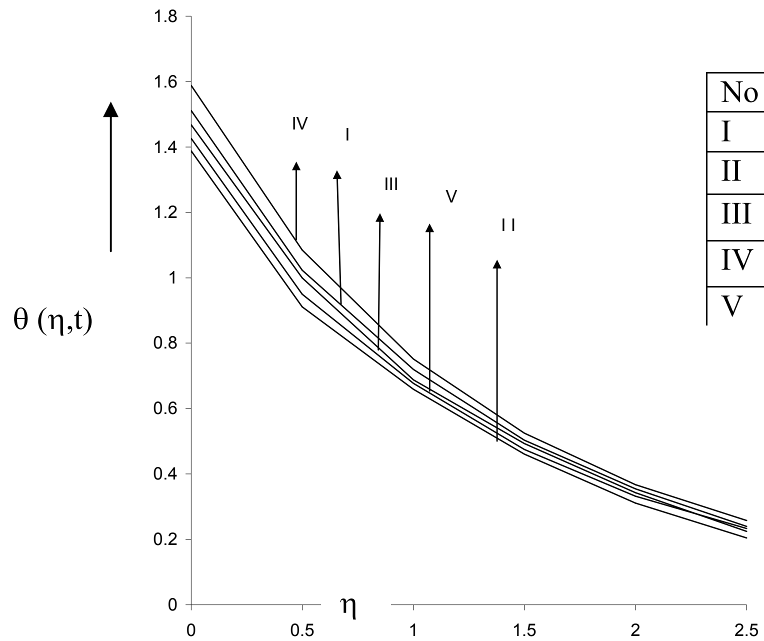
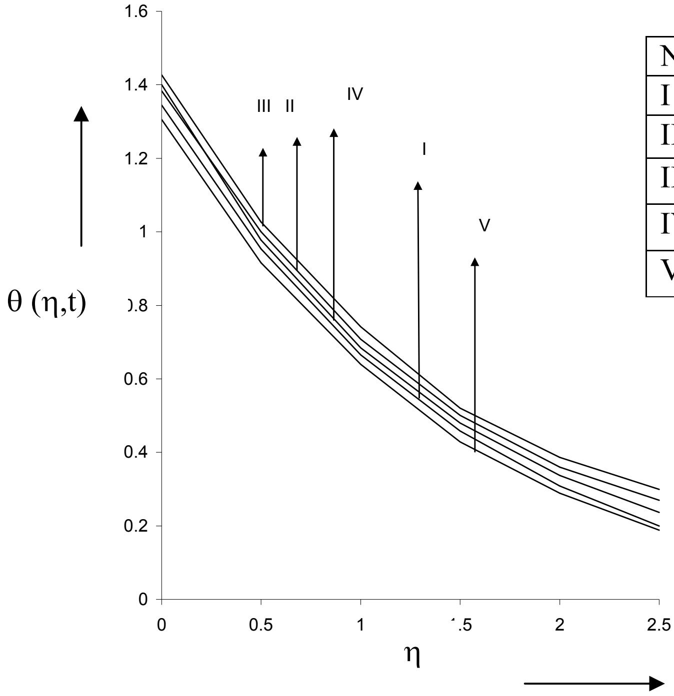


Fig 2 : Velocity distribution η versus when Pr = 0.71



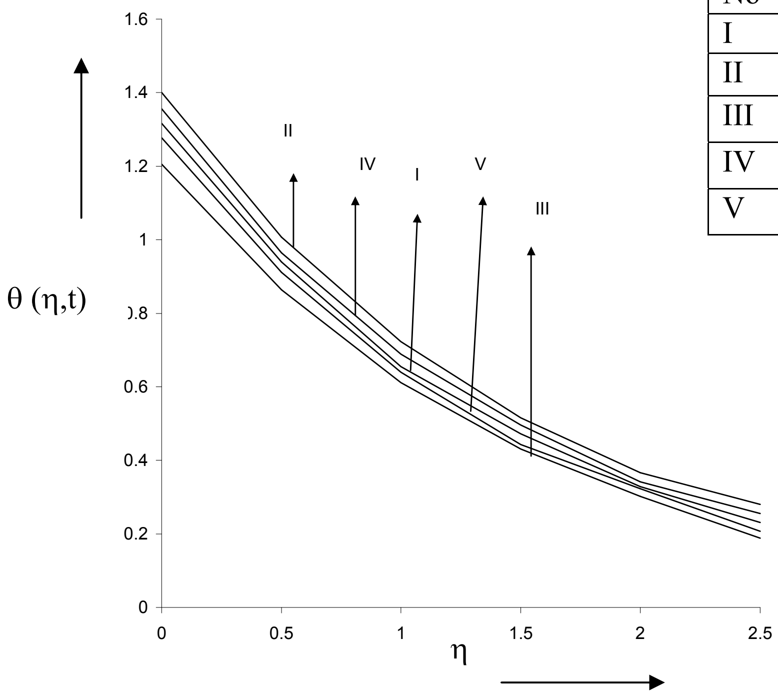
No	Ec	Sc	M	ωt
I	0.01	0.60	1.0	π/6
II	0.01	0.60	4.0	π/6
III	0.01	0.70	1.0	π/6
IV	0.02	0.60	1.0	π/6
V	0.01	0.60	1.0	π/3

Fig 3 : Temperature distribution η versus when Pr = 0.71, Gr = 5.0, Gm = 1.0 and k_0 = 1.0



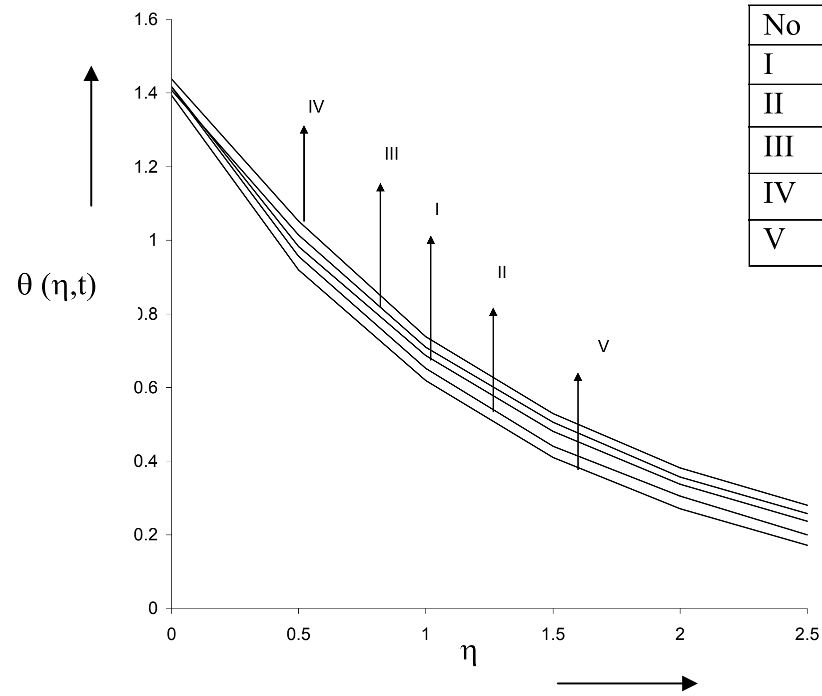
No	Gr	Gm	k_0	ωt
I	5.0	1.0	1.0	π/6
II	5.0	4.0	1.0	π/6
III	10.0	1.0	1.0	π/6
IV	5.0	1.0	2.0	π/6
V	5.0	1.0	1.0	π/3

Fig 4 : Temperature distribution η versus when Pr = 0.71, Ec = 0.01, Sc = 0.60 and M = 1.0



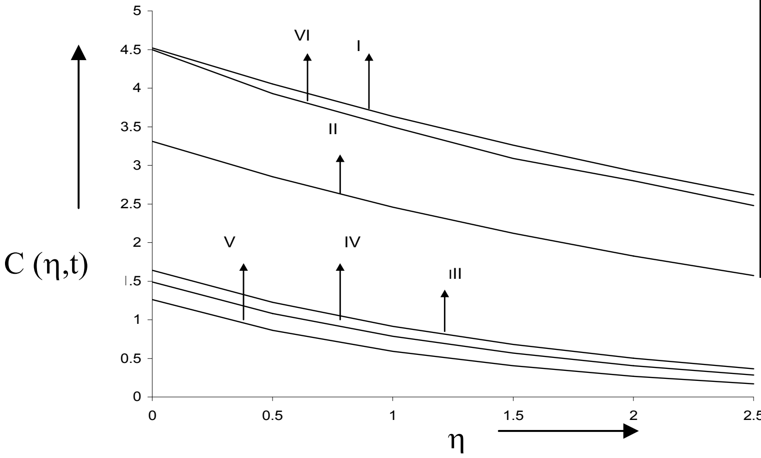
No	Ec	Gm	k_0	ωt
I	-0.01	1.0	1.0	π/6
II	-0.02	1.0	1.0	π/6
III	-0.01	4.0	1.0	π/6
IV	-0.01	1.0	2.0	π/6
V	-0.01	1.0	1.0	π/3

Fig 5 : Temperature distribution η versus when Pr = 0.71, Gr = 5.0, Sc = 1.0 and M = 1.0



No	Gr	Sc	M	ωt
I	-5.0	0.60	1.0	π/6
II	-5.0	0.60	4.0	π/6
III	-5.0	0.70	1.0	π/6
IV	-10.0	0.60	1.0	π/6
V	-5.0	0.60	1.0	π/3

Fig 6 : Temperature distribution η versus when Pr = 0.71, Ec = -0.01, Gm = 1.0 and k_0 = 1.0



No	Gas	Sc	ωt
I	Hydrogen	0.22	π/6
II	Helium	0.30	π/6
III	Water Vapour	0.60	π/6
IV	Oxygen	0.66	π/6
V	Ammonia	0.78	π/6
VI	Hydrogen	0.22	π/3

Fig 7 : Concentration distribution for different values of Schimdt number

REFERENCES

[1] A.Raptis,C.Peredikis and Tzivanidis.,"Free convection flow through a porous medium bounded by a vertical surface",J.Phys.D.Apply.Phys,14,(1981), pp.99-102.

[2]. A.Bejan and K.R Khair(1985),"Heat and mass transfer by natural convection in a porous medium ",*.Int.J.Heat and Mass Transfer*,28,(1985),pp.909-916.

[3] P.R Sharma,(1992).,"Free convection effects on the flow past a porous medium bounded by a

vertical infinite surface with constant suction and constant heat flux”, *J.PhysD.Appl.Phys.England*(U.K), 25,(1992),pp.162-166.

[4].Acharya, Dash ,Singh.,”Magnetic field effects on the free convection and mass transfer flow through porous medium with constant suction and constant heat flux “, *Indian J.Pure Appl*,31,(2000),pp.1.

[5] V.J Bansood,.”Boundary layer solution of convective heat and mass transfer from a horizontal surface in a non-Darcy porous media“, *J.Energy ,Heat and Mass Transfer,*23,issue 4,(2001), pp.379-391.

[6] Atul Kumar Singh.,.” MHD free convection and mass transfer flow with heat source and thermal diffussion“, *J.Energy ,Heat and Mass Transfer*,23,issue 2,June,(2001),pp.227-249.

[7] Atul Kumar Singh , Ajay Kumar Singh and N.P Singh,”Heat and mass transfer in MHD flow of a viscous fluid past a vertical plate under oscillatory suction “, *Ind.J.Pure and Appl.Maths,*vol 34 (3) ,(2003) pp.429-442.

[8]. Y.J Kim,”Heat and mass transfer in MHD micropolar flow over a vertical moving porous plate in a porous medium “, *Transport in Porous Media*,56,1,(2004)pp.17-37.

[9] M.S Alam,M.M Rahman and M.A Samad,”Dufour and Soret effects on unsteady MHD free convection and mass transfer flow past a vertical porous plate in porous medium “,*Nonlinear Analysis* : *Modelling and Control*,11,3,(2006) ,pp.217-226.

[10] N.P Singh,Ajay Kumar Singh and Atul Kumar Singh.,”MHD free convection and mass transfer flow past a flat plate“, *Arabian J.Sci and Engg*,32,14,(2007),pp.93-115.

[11] G.Noushima Humera,M.V Ramana Murthy, Rafiuddin and M ChennaKrishna Reddy,”MHD unsteady free convective Walter’s memory flow with constant suction and heat sink “, *J.Engg and Appl.Sci*,vol 2,No 5,(2007) p.12-16.

[12] G.Noushima Humera.,M.V Ramana Murthy, Rafiuddin and M ChennaKrishna Reddy,”Unsteady viscoelastic memory flow and heat transfer over a continuous porous moving horizontal surface “,J.Ind.Acad.Math,vol 30,No 2,(2008),p.325-331.

[13] K.C Sarangi and C.B Jose, “Unsteady MHD free convective flow and mass transfer through a porous medium with constant suction and constant heat flux “, *J.Ind.Acad.Maths*,26,1,(2004),pp.115-126.

[14] K.Walters,” The motion of an elastico-viscous liquid contained between coaxial cylinders“, *Quart.J.Maths.Appl.Mech*,13,6,(1960),p.444-462.

[15] K.Walters,”Non-Newtonian effects in some elastico-viscous liquid whose behaviour at small rates of shear is characterized by a general linear equation of state,” *Quart.J.Maths.Appl.Mech*,1,(1962),p.479.

[16] D.W Beard and K. Walter,K.,” Elastico-viscous boundary layer flow two dimensional flow near a stagnation point“, *Camb.Phil.Soc*,60,(1964)pp.667.