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MHD Oscillatory Flow of a Visco Elastic Fluid in a Porous Channel with Chemical Reaction

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ABSTRACT: *An analysis of first order homogeneous chemical reaction and heat source on MHD oscillatory flow of a visco-elastic fluid through a channel filled with saturated porous medium are reported. The present visco-elastic fluid model is working to suggest rheological liquids encountered in biotechnology (medical creams) and chemical engineering. This rheological model introduces additional terms into the momentum equation. It is assumed that the fluid has small electric conductivity and the electromagnetic force produced is very small. The dimensionless governing equations are solved analytically using regular perturbation method. The effects of various parameters on velocity, temperature and concentration fields are presented graphically and discussed.*

Keywords: *MHD, oscillatory flow, visco-elastic fluid, chemical reaction, thermal radiation, heat source.*

I. INTRODUCTION

The study of non Newtonian fluid flows has gained the attention of engineers and scientist in recent times due to its important application in various branches of science, engineering, and technology: particularly in chemical and nuclear industries, material processing, geophysics, and bio-engineering. In view of these applications an extensive range of mathematical models has been developed to simulate the diverse hydrodynamic behavior of these non-Newtonian fluids. In particular different visco-elastic fluid models (like the Rivlin-Ericksen second order model. Oldroyd model, Johnson-Seagalman model) have been presented by many investigators in a diverse range of geometries using various types of analytical and computational schemes (see for instance [1-4]). The Fluids which exhibit the elasticity property of solids and viscous property of liquids are called visco-elastic fluids. These fluid flows are encountered in numerous areas of petrochemical, biomedical and environmental engineering including polypropylene coalescence sintering [5], dynamically-loaded journal bearings [6], blood flow [7] and geological flows [8].

The study of visco-elastic fluids through porous media has become the basis of many scientific and engineering applications. This type of flow is of great importance in the petroleum engineering concerned with the movement of oil, gas and water through reservoir of oil or gas field to the hydrologist in the study of the migration of underground water and to the chemical engineering for the purification and filtration processes and in the cases like drug permeation through human skin. The principles of this subject are very useful in recovering the water for drinking and irrigation purposes. Many research workers [9-14] have paid their attention towards the application of visco-elastic fluid flow of different category through porous medium in channels of various cross-sections. Rajgopal [15] analyzed the Stoke's problem for a non-Netonian fluid. Hossain and Takhar [16] studied the radiation effects on mixed convection along a vertical plate with uniform surface temperature. Heat transfer enhancement for the power-law fluids through a parallel-plate double-pass heat exchangers with external recycle was examined by Gwo et.al [17]. Pascal [18] studied the rheological effects of non-Newtonian behavior of displacing fluids on stability of a moving interface in radial oil displacement mechanism in porous media. Nakayama and Koyama [19] examined the buoyancy-induced flow of non- Newtonian fluids over a non isothermal body of arbitrary shape in a fluid-saturated porous medium. Mehta and Rao [20-21] studied the buoyancy-induced flow of non-Newtonian fluids over a non isothermal horizontal/vertical plate embedded in a porous medium.

The flow of the conducting fluid is effectively changed by the presence of the magnetic field and the magnetic field is also perturbed due to the motion of the conducting fluid. This phenomenon is therefore interlocking in character and the discipline of this branch of science is called Magneto hydrodynamics (MHD). Influence of the magnetic field on the non-Newtonian fluid flow has wide applications in chemical engineering, metallurgical engineering, and various industries. Researchers have considerable interest in the study of flow phenomenon between two parallel plates. Because of its occurrence in rheometric experiments to determine the constitutive properties of the fluid, in lubrication engineering, and in transportation and processing encountered in chemical engineering, the flow on non-Newtonian visco-elastic fluid is worthwhile to investigate. Many research workers [22-25] have paid their attention towards the application of visco-elastic fluid flow through various types of channel under the influence of magnetic field. Makinde and Osalusi [26] have been discussed a MHD steady flow in a channel with slip at permeable boundaries. Singh [27] obtained an exact solution of an oscillatory MHD flow in a channel filled with porous medium. Rahman and Sarkar [28] analyzed the unsteady MHD flow of a dusty visco-elastic Oldroyd fluid under time varying body force through a rectangular channel. Singh and Singh [29] studied MHD flow of a dusty visco-elastic (Oldroyd B- liquid) through a porous medium between two parallel plates inclined to the horizon. Mishra et al. [30] investigated a flow and heat transfer of a MHD visco-elastic fluid in a channel with stretching walls. Masood Khan [31] studied the Rayleigh–Stokes problem for an edge in a viscoelastic fluid with a fractional derivative model. The reaction produced in a porous medium was extraordinarily in common, such as the topic of PEM fuel cells modules and the polluted underground water because of discharging the toxic substance, etc. Recently many researchers [32-35] studied the effects of chemical reaction on various flow fields by using analytical methods. Muthuraj and Srinivas [36] extend the work of reference [37] by considering heat transfer effects on MHD oscillator flow in an asymmetric wavy channel.

The main objective of this paper is to extend the work of reference [37] in three directions: (i) to consider the MHD oscillatory flow of a visco-elastic fluid in a channel (ii) to consider the heat source effect, (iii) to include the chemical reaction. The governing equations of the flow are solved analytically and the effects of various flow parameters on the flow field have been discussed. The organization of the remnants of the paper is as follows. In Sec.2, we describe the model with its governing equations and boundary conditions. Here we also describe the solution method briefly. In Sec.3, we present results and discussion. Finally, in Sec.4, we summarize our results and present our conclusions.

II. MATHEMATICAL ANALYSIS

We consider an unsteady oscillatory flow of visco-elastic fluid through a planar channel with chemical reaction, thermal radiation and heat source in the presence of transverse magnetic field. It is assumed that the fluid has small electrical conductivity and the electromagnetic force produced is very small. Also, it is assumed that there is no applied voltage, so that the electric field is absent, the concentration of the diffusivity species in the binary mixture is assumed to be very small in comparison with the other chemical species which are present, and hence Soret and Dufour effects are negligible. The x-axis is taken along the lower plate and a straight line perpendicular to that as the y-axis. Assuming a Bounssinesq incompressible fluid model, the equations governing motion are given as

$$\frac{\partial u}{\partial t} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \upsilon_1 \frac{\partial^2 u}{\partial y^2} + \upsilon_2 \frac{\partial^3 u}{\partial y^2 \partial t} - \frac{\upsilon_1 u}{k} - \frac{\sigma_e B_0^2 u}{\rho} + g\beta_T\left(T - T_0\right) + g\beta_C\left(C - C_0\right) \tag{2}$$

$$\frac{\partial T}{\partial t} = \frac{k}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - \frac{1}{\rho C_p}\frac{\partial q}{\partial y} + Q\frac{\left(T - T_0\right)}{\rho C_p} \tag{3}$$

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2} - K_r (C - C_0) \tag{4}$$

The boundary conditions for velocity, temperature and species concentration fields are given as follows

$$u = 0, \quad T = T_w, \quad C = C_w, \quad on \quad y = 1 \tag{5}$$

$$u = 0, \quad T = T_0, \quad C = C_0, \quad on \quad y = 0$$

Here we assume that the fluid is optically thin with a relativity low density and radiative heat flux is according to the Ref [38] is given by

$$\frac{\partial q}{\partial y} = 4\alpha^2 (T_0 - T_w)$$

We now introduce the non dimensionless variables as follows.

$$R_e = \frac{Ua}{\upsilon_1}, \ \bar{x} = \frac{x}{a}, \ \bar{y} = \frac{y}{a}, \ \bar{u} = \frac{u}{U}, \ \theta = \frac{T - T_0}{T_w - T_0}, \ H^2 = \frac{a^2 \sigma_e B_0^2}{\rho \upsilon_1}, \ \bar{t} = \frac{tU}{a},$$
$$\bar{P} = \frac{aP}{\rho \upsilon_1 U}, \ D_a = \frac{K}{a^2}, \ G_r = \frac{g\beta_T (T_w - T_0) a^2}{\upsilon_1 U}, \ G_c = \frac{g\beta_C (C_w - C_0) a^2}{\upsilon_1 U}, \tag{6}$$

$$P_e = \frac{Ua\rho C_p}{k},\ N^2 = \frac{4\alpha^2 a^2}{k},\ \ S^2 = \frac{1}{D_a},\ E = \frac{Qa^2}{k},\ J = \frac{K_r a}{U},$$

$$C = \frac{C - C_0}{C_w - C_0},\ S_c = \frac{D}{aU}.$$

The dimensionless governing equations together with the appropriate boundary conditions (neglecting bar symbols) can be written as

$$R_e \frac{\partial u}{\partial t} = -\frac{\partial P}{\partial x} + \frac{\partial^2 u}{\partial y^2} - (S^2 + H^2)u + G_r\theta + \gamma \frac{\partial^3 u}{\partial y^2 \partial t} + G_c C \tag{7}$$

$$P_e \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial y^2} + E\theta \tag{8}$$

$$\frac{\partial C}{\partial T} = S_c \frac{\partial^2 C}{\partial y^2} - JC \tag{9}$$

The dimensionless boundary conditions are

$$u = 0,\quad \theta = 1,\quad C = 1 \quad on \qquad y = 1 \tag{10}$$
$$u = 0,\quad \theta = 0,\quad C = 0 \quad on \quad y = 0$$

III. METHOD OF SOLUTION

To solve equations (7), (8), (9) for purely oscillatory flow.

Let $\frac{\partial P}{\partial x} = \lambda e^{i\omega t},\ u(y,t) = u_0(y)e^{i\omega t},\ \theta(y,t) = \theta_0(y)e^{i\omega t},\ C(y,t) = C_0(y)e^{i\omega t}$ (11)

Substituting equation (11) in equations (7), (8) and (9) we get

$$(1 + i\omega\gamma)\frac{\partial^2 u_0}{\partial y^2} - m_2^2 u_0 = -\lambda - G_r\theta_0 - G_c C_0 \tag{12}$$

$$\frac{d^2\theta_0}{dy^2} + m_1^2\theta_0 = 0 \tag{13}$$

$$\frac{d^2 C_0}{dy^2} - m_3^2 C_0 = 0 \tag{14}$$

Subject to the boundary conditions

$$u_0 = 0,\quad \theta_0 = 1,\quad C_0 = 1 \quad on \qquad y = 1 \tag{15}$$
$$u_0 = 0,\quad \theta_0 = 0,\quad C_0 = 0 \quad on \quad y = 0$$

The analyzed solutions of equations (12)-(14) with satisfy boundary conditions (15) are given by

$$u(y,t) = \left[\begin{array}{l} \frac{G_r}{m_1^2 L^2 + m_2^2}\left(\frac{\sin m_1 y}{\sin m_1} - \frac{\sinh \frac{m_2}{L} y}{\sinh \frac{m_2}{L}}\right) + \frac{G_c}{m_3^2 L^2 - m_2^2}\left(\frac{\sinh \frac{m_2}{L} y}{\sinh \frac{m_2}{L}} - \frac{\sinh m_3 y}{\sinh m_3}\right) + \\ \frac{\lambda}{m_2^2}\left(\frac{\sinh \frac{m_2}{L} y}{\sinh \frac{m_2}{L}}\right)(\cosh m_2 - 1) + \frac{\lambda}{m_2^2}(1 - \cosh m_2 y) \end{array}\right] e^{i\omega t}$$

$$\theta(y,t) = \left(\frac{\sin m_1 y}{\sin m_1}\right)e^{i\omega t}$$

$$C(y,t)=\left(\frac{\sinh m_3 y}{\sinh m_3}\right)e^{i\omega t}$$

The non dimensional stress tensor σ at wall $y=0$ is given by

$$\sigma=\frac{\bar{\sigma}}{\frac{\mu_1 U}{a}}\left[\frac{\partial u}{\partial y}+\gamma\frac{\partial^2 u}{\partial y\partial t}\right]_{y=0}$$

$$\sigma=\left[\begin{array}{l}\dfrac{G_r}{m_1^2L^2+m_2^2}\left(\dfrac{m_1}{\sin m_1}-\dfrac{\frac{m_2}{L}}{\sinh\frac{m_2}{L}}\right)+\dfrac{G_c}{m_3^2L^2-m_2^2}\left(\dfrac{\frac{m_2}{L}}{\sinh\frac{m_2}{L}}-\dfrac{m_3}{\sinh m_3}\right)+\\ \dfrac{\lambda}{Lm_2}\dfrac{1}{\sinh\frac{m_2}{L}}(\cosh m_2-1)\end{array}\right](\cos\omega t-\gamma\sin\omega t)$$

The rate of heat transfer across the channels wall is given as

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

$$Nu=-\frac{m_1}{\sin m_1}\cos\omega t$$

The rate of mass transfer across the channels wall is given as

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

$$Sh=-\frac{m_3}{\sinh m_3}\cos\omega t$$

Where $m_1=\sqrt{N^2+E-i\omega P_e}$, $m_2=\sqrt{S^2+H^2+i\omega P_e}$

$m_3=\sqrt{\dfrac{J+i\omega}{S_c}}$, $L=\sqrt{1+i\omega\gamma}$

It should be mentioned that in the absence of the chemical reaction, heat source and visco elastic parameter, the relevant results obtained are deduced as the results obtained by Makinde and Mhone [37].

IV. NOMENCLATURE

$B_0(=\mu_e H_0)$	Electromagnetic induction
C_p	Specific heat at constant pressure
d	Mean half width of the channel
D_a	Darcy number
E	Heat source parameter
g	Gravitational force
G_r	Grashof number
G_c	Modified Grashof number
H_0	Intencity of magnetic field
H	Hartmann number
J	Chemical reaction parameter

k	Thermal conductivity
K	Porous medium permeability coefficient
N	Radiation parameter
Nu	Nusselt number at the wall $y=0$
P_e	Peclet number
p	Pressure
q	Radiative heat flux
R_e	Reynolds number
S_c	Schmidt number
S	Porous medium shape factor
t	Time
T	Fluid temperature,
T_0, T_w	Walls of temperature
u	Axial velocity
U	Flow mean velocity
Greek Symbols	
ρ	Fluid density
μ_e	Magnetic permeability,
θ	Fluid temperature
β_T	Coefficient of thermal expansion
β_C	Coefficient of mass expansion
μ_e	Magnetic permeability
σ_e	Conductivity of the fluid
ρ	Fluid density
υ	Kinematics viscosity coefficient
λ	Wave length
ω	Frequency of the oscillation
τ	Skin friction at the wall $y=0$
α	Mean radiation absorption coefficient

V. RESULTS AND DISCUSSION

The formulation of the effects of chemical reaction, thermal radiation and heat source on MHD oscillatory flow of a visco-elastic fluid in a porous channel has been performed in the preceding sections. This enables us to carry out the numerical calculations in the distribution of the equations of momentum, energy and diffusion, which govern the flow fluid, are solved by using regular perturbation method. The effects of various variables like chemical reaction parameter J, the Schmidt number S_c, Hartmann number H, visco-elastic parameter γ, porous medium shape factor S etc on velocity, temperature and concentration profiles has been discussed with the help of graphs plotted against y.

The velocity profiles for different values of Grashof number G_r and Modified Grashof number G_c are described in figs. 1 and 2. It is observed that an increasing in G_r leads to a rise in the values of velocity. In addition the curves show the peak value of velocity increase rapidly near the wall of the porous plate as Modified Grashof number G_c increase and then decays to the relevant free stream velocity. Figs. 3 and 4.respectively represent the dimensionless velocity u and temperature θ profiles for different values of radiation parameter N. It is seen from these figures that both the velocity and temperature profiles increase with increase of radiation parameter N. The influence of chemical reaction parameter J on velocity and species concentration profiles across the boundary layer are presented in figs. 5 and 6. We note from fig. 5. that there is decrease in horizontal velocity profiles with increase in chemical reaction parameter J. The increase of the chemical reaction parameter J leads to decrease the boundary layer thickness and to enhance the heat transfer rate in the presence of thermal and solutal buoyancy force. It is also observed that the peak value attains near the porous boundary surface. We noticed from fig. 6. that there is marked effect of increasing the value of chemical reaction parameter on concentration distribution in the boundary layer. Further, it is observed that increasing value of the chemical reaction decrease the concentration of species in the boundary layer, this is due to the fact that destructive chemical reduces the solutal boundary layer thickness and increases the mass transfer.

For different values of Schmidt number S_c, the velocity profiles are plotted in fig. 7. It is obvious that the effect of increasing values of S_c, results in a decreasing velocity distribution across the boundary layer. Fig. 8 shows the concentration profiles C across the boundary layer for various values of Schmidt number S_c. The figure shows that an increasing in S_c results in an increasing the concentration distribution C. The influence of Peclet number P_e on velocity u and temperature θ profiles have been illustrated in figs. 9 and 10. It is observed that an increase in P_e results a decrease in velocity u. But in temperature profile θ, as temperature increase with increasing values of P_e. Figs. 11 and 12 shows the variation of velocity and temperature profiles for different values of E. It is seen from this figs. That velocity and temperature profiles increase with an increasing of heat source parameter E.

The effects of various parameters on local skin friction coefficient τ, rate of heat transfer Nu and sherwood number Sh. Fig. 13 shows the local skin friction coefficient for different values of E and P_e keeping all the parameters fixed. From this figure we see that for fixed P_e, τ decreases as E increases. On the other hand as E increases, skin friction coefficient increases. The effect of heat source E on the rate of heat transfer from the plate for different values of N is illustrated in fig 14. From here we see that for fixed E the rate of heat transfer from the heated surface decreases with the increases of N. On the other hand as E value increases, the rate of heat transfer decreases. Fig. 15 deals with the variation of Sherwood number for different values of S_c and J. This figure revels that for fixed S_c, Sh increases with the increase of J. On the other hand as S_c value increases, the Sherwood number coefficient increases. Figs. 16 and 17 present the effect of Hartmann number H on velocity and skin friction coefficient profiles for both Newtonian and Non-Newtonian fluid conditions respectively. Increasing the Hartmann number H has the tendency to decrease the velocity and skin friction. In addition, it is seen that the fluid velocity and skin friction are lower for Non Newtonian fluids than for Newtonian fluids.

VI. CONCLUSIONS

We analyze the effects of chemical reaction, thermal radiation and heat source on MHD oscillatory visco-elastic flow in a channel filled with porous medium. The equations of momentum, energy and diffusion which govern the flow field are solved by using a regular perturbation method. The behaviors of velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number has been discussed for variations in the governing parameters. From the present calculations we may conclude the following conclusions.

1. The magnetic parameter H retards the velocity of the flow field at all points, due to the magnetic pull of the Lorentz force acting on the flow field.
2. The fluid motion is retarded due to chemical reaction. Hence the consumption of chemical species causes a fall in the concentration field which in turn diminishes the buoyancy effects due to concentration gradients. Hence the flow field is retarded.
3. Due to chemical reaction the concentration of the fluid decreases. This is because, the consumption of chemical species leads to a fall in the species concentration field.
4. The magnitude of skin friction at the plate is found to decrease due to increasing H.
5. The rate of mass transfer Sh increase due to increase in *J* and rate of heat transfer Nu decrease due to increase in *N*.
6. The analytical results obtained in this work are more generalized form of Makinde and Mhone [37] and can be taken as a limiting case by taking $J\rightarrow0$, $E\rightarrow0$, $\gamma\rightarrow0$.

It is hoped that the results obtained will not only provide useful information for applications but also serve as a complement to the previous studies.

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GRAPHS

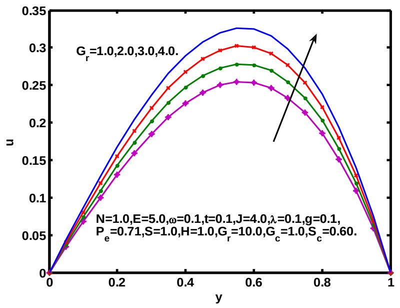


Fig: 1 Effect of G_r on velocity

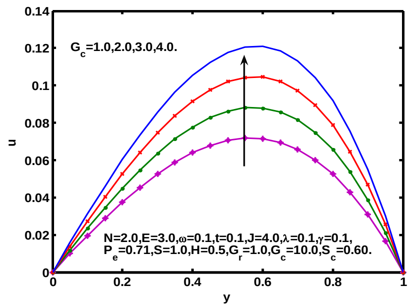


Fig: 2 Effect of G_c on velocity

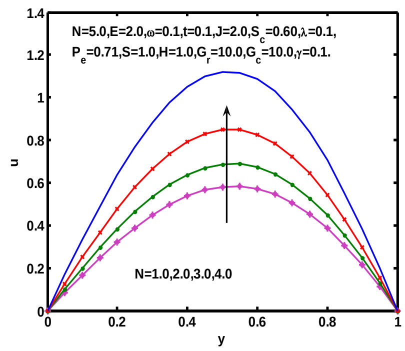


Fig: 3 Effect of N on velocity

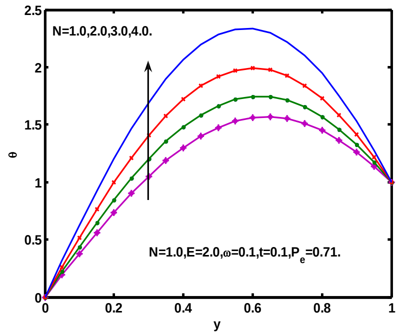


Fig: 4 Effect of N on Temperature

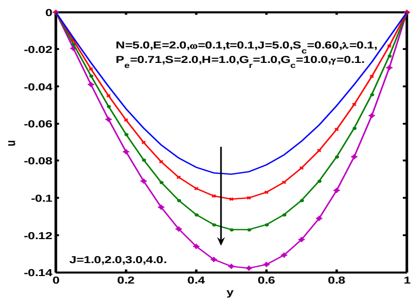


Fig: 5 Effect of J on velocity

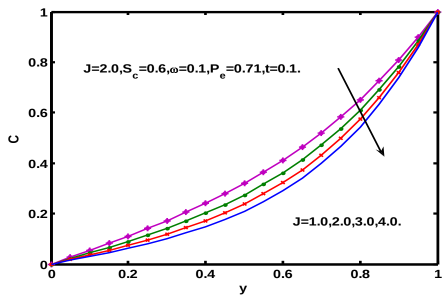
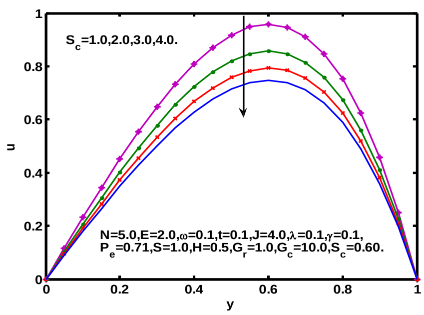


Fig: 6 Effect of J on Concentration



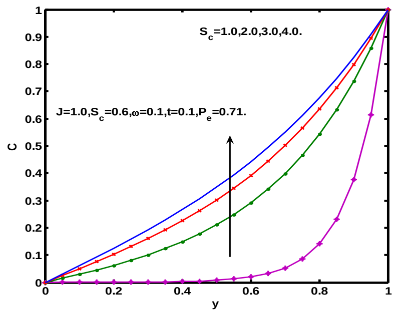
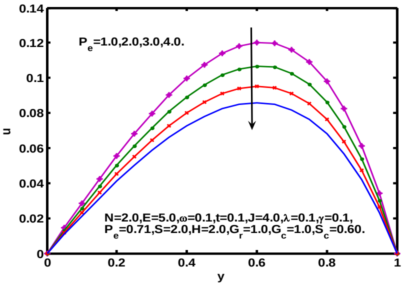


Fig: 7 Effect of S_c on velocity **Fig: 8 Effect of S_c on concentration**



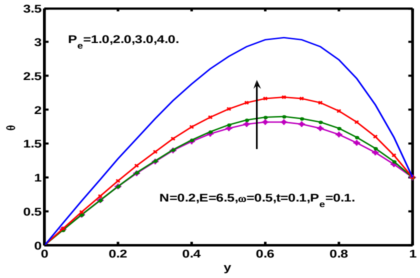
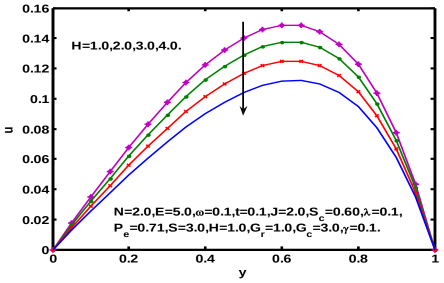


Fig: 9 Effect of P_e on velocity **Fig: 10 Effect of P_e on Temperature**



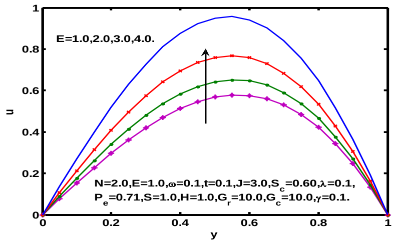
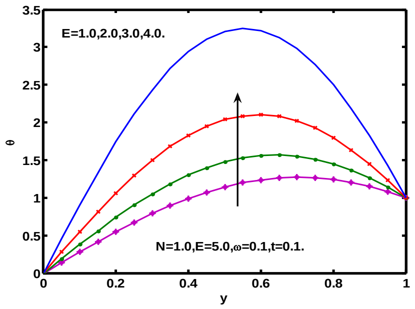


Fig: 11Effect of H on velocity **Fig: 12 Effect of E on velocity**



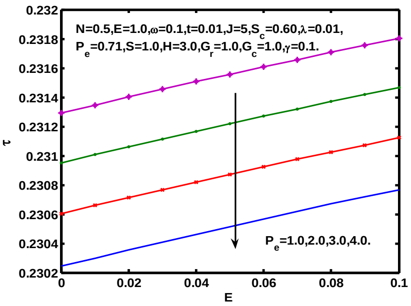
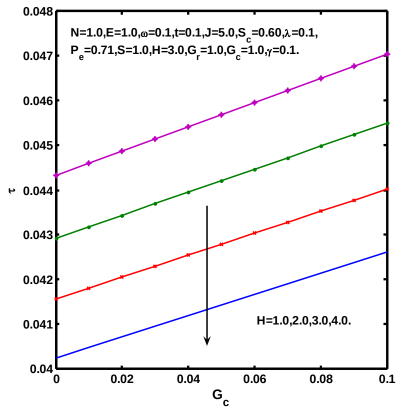


Fig: 13 Effect of E on Temperature **Fig: 14 Skin frictions for P_e verses E**



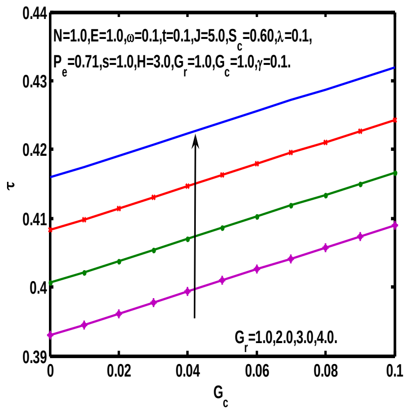


Fig: 15 Skin frictions for H versus G_c **Fig: 16 Skin frictions for G_r verses G_c**

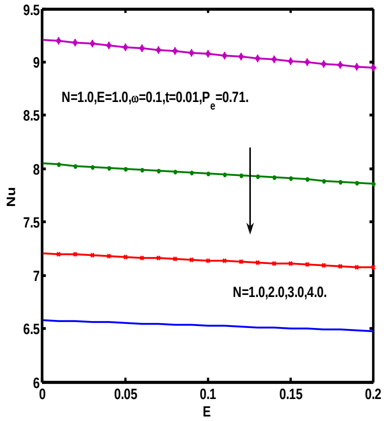


Fig: 17Nusselt number for N **verses** E

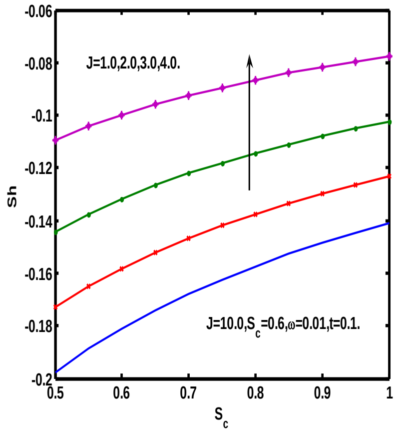


Fig: 18 Sherwood number for J **verses** S_c

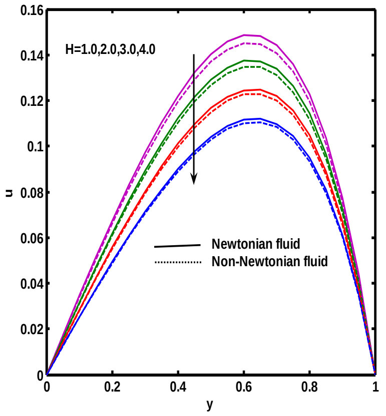


Fig: 19 Effect of H **on velocity**

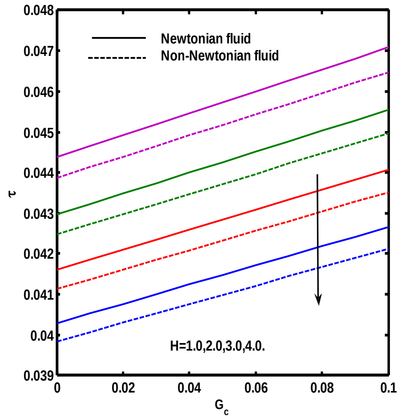


Fig: 20 Skin frictions for H **versus** G_c