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Effect of Radiation and Thermo-Diffusion on Convective Heat and Mass Transfer Flow of a Viscous Fluid in a Vertical Rotating Channel

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ABSTRACT: *In this Paper, we analyse the effect of radiation and thermo-diffusion on convective heat and mass transfer flow of a viscous fluid in a vertical rotating channel. The left wall at z=0 is maintained at an oscillatory temperature while the right wall is maintained at constant temperature. By employing an asymptotic method the equations governing the flow and heat transfer are solved. The velocity, temperature dissipations and concentration are analysed for a different parametric values. The shear stress, rate of heat and mass transfer on the boundaries are evaluated numerically for different variations.*

KEYWODS: *Radiation, Thermo diffusion, Convective Heat, Viscous Fluid.*

I. INTRODUCTION:

Free convection and mass transfer flow in porous medium have received considerable attention due to its numerous application in geophysical and energy related problems. Such types of applications include natural circulation in isothermal reservoirs, aquifers porous insulation in heat storage bed, grain storage, extraction of thermal energy and thermal insulation design. Studies associated with flow through porous medium in a rotating environment have some relevance in a geophysical, geothermal. Many aspects of motion in rotating frame of reference of terrestrial and planetary atmosphere are influenced by the effects of rotation of the medium. In the last several years considerable attention has been given to the study of the Hydro magnetic thermal convection due to its numerous applications in geophysics and astrophysics. It is well known that in the geothermal region, gases are electrically conduction and that they undergo the influence of magnetic fluid. Gill and Cosal (8) theoretically investigated the natural convection effects in forced horizontal flows. Jana(9) considered the effect of wall conductance as convective horizontal channel flow. Yen (20) considered the same effect on magneto hydrodynamic heat transfer in a channel and has shown that the wall conductance entirely destabilizing influence on the flow, whereas the magnetic field stabilizes the flow.

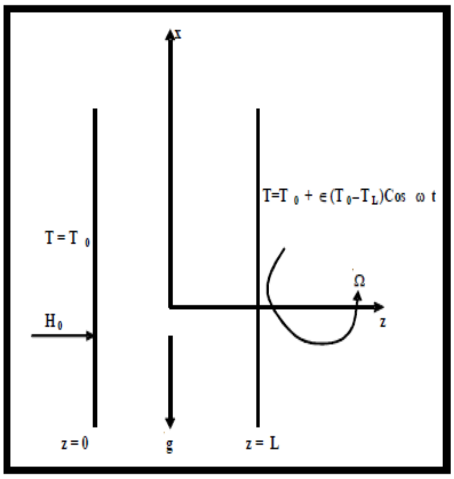
Nanda and Mohanti (14) studied the effect of magnetic field in a rotating channel. Soundalgekar and Bhat(18) investigated the MHD flow and heat transfer in viscous electrically conducting fluid in rotating channel with conducting fluid. The rotating viscous flow equation yield a layer known as Eckman boundary layer after the Swedish oceanographer V.W.Eckman who discovered it. Attempts to observe the structure of the Eckman layer in the surface layers of the sea have been successful. Eckman layers are easy to produce and observe in the laboratory. Such boundary layers or similar ones, are required to connect principally geotropic flow in the interior of the fluid to the horizontal boundaries where conditions like a prescribed horizontal stress or no slip on a solid bottom are given. In a similar way other kinds of various boundaries have been studies so as to connect geotropic flow to vertical boundaries (for example a vertical well along which the depth varies) on which boundary conditions consistent with geotropic flow are given.

Mahendra Mohan (12) discussed the free and forced convections in rotating Hydromagnetic viscous fluid between two finitely conduction parallel plates maintained at constant temperature gradients. In view of many scientific and engineering applications of fluids flow through porous media, Mahendra Mohan and Srivastava (13) studied the combined free and forced convection flow of an incompressible viscous fluid in a parallel plates channel bounded below by a permeable bed and rotating with a constant angular velocity about an axis perpendicular to the length of the plates. Rao etal.,(15) made an investigation of the combined free and forced convective effects on an unsteady Hydro magnetic viscous incompressible flow in a rotating porous channel. This analysis has been extended to porous boundaries by Sarojamma and Krishna(16). An initial value investigation of the hydro magnetic and convective flow of a viscous electrically conducting fluid through a porous medium in a rotating parallel plates channel has been made by Krishna et al.,(11).

In all these papers the viscous dissipative effect has not been considered. But the viscous dissipation has its importance when the natural convection flow fixed is of extreme size or the temperature is low or in higher gravity field. G.S. Seth and Ghosh (17) has investigated to the unsteady hydromagnetic flow of viscous incompressible electrically conducting fluid in rotating channel under the influence of periodic pressure gradient and of uniform magnetic field, which in inclined with the axes of rotation. The problem of steady laminar micro polar fluid flow through porous walls of different permeability had been discussed by R.S. Agarwal and C. Dhanpal (1) . Steady and unsteady hydro magnetic flow of viscous incompressible electrically conducting fluid under the influence of constant and periodic pressure gradient in the presence of include magnetic field had been investigated by S.K. Ghosh (17) to study the effect of slowly rotating systems with low frequency of oscillation when the conductivity of the fluid is low and the applied magnetic field is weak. El-Mistikawy et al.,(5) were discussed the rotating disk flow in the presence of strong magnetic field and weak magnetic field. Later Hazem Ali Allia(7) developed the MHD flow of incompressible, viscous and electrically conducting fluid above an infinite rotating porous disk was extended to flow starting impulsively from rest. Circar and Mukherjee (4) have analyzed the effect of mass transfer and rotation on flow pasta porous plate in a porous medium with variable suction in a slip flow regime. Balasubramanyam (2) and Reddy (19) have investigated convective Heat and Mass Transfer flow in Horizontal rotating fluid under different conditions. Recently Singh and Mathew (10) have studied on oscillatory free convective MHD flow in a rotating vertical porous channel with heat sources.

II. MATHEMATICAL ANALYSIS:

We consider the unsteady flow of a viscous electrically conducting fluid through a porous medium in a vertical channel bounded by insulating porous plates at a distance'd' apart in presence of temperature dependant heat sources. A constant injection velocity w_0 is applied at the stationary plate z = 0. The origin is assumed to be at the plate z = 0 and the channel is oriented vertically along x – axis. The channel rotates with an angular velocity $\bar{w}$ about the z – axis. A uniform magnetic field of strength H_0 is applied normal to the walls. Assuming the magnetic Reynolds number to be small we neglect the induced field. Since the plates are infinite in extent all the physical variables except pressure depend on z and t only. Assuming the Boussinesq approximation the equations governing the unsteady flow on heat and mass transfer are



Configuration of the Problem

Equation of continuity

$$\frac{\partial w}{\partial z} = 0 \tag{2.1}$$

Equation of linear momentum

$$\frac{\partial u}{\partial t} - 2\Omega v = \frac{1}{\rho} - \frac{1}{\rho}\frac{\partial p}{\partial x} - \rho\bar{g} - \frac{\sigma . \mu^2 H_0^2}{\rho_0} u \tag{2.2}$$

$$\frac{\partial v}{\partial t} + 2\Omega u = \frac{-1}{\rho}\frac{\partial p}{\partial z} - \frac{\sigma\mu^2 H_0^2}{\rho_0} v \tag{2.3}$$

Equation of energy

$$\rho_0 C_P \left(\frac{\partial T}{\partial t}\right) = K_f \frac{\partial^2 T}{\partial z^2} + Q(T_L - T) - \frac{\partial}{\partial y}(q_r) \tag{2.4}$$

Equation of diffusion

$$\frac{\partial C}{\partial t} = D_1 \frac{\partial^2 C}{\partial z^2} + K_{11} \frac{\partial^2 \theta}{\partial z^2} \tag{2.5}$$

Equation of state

$$\rho - \rho_0 = -\beta\rho_0 (T - T_0) - \beta^* \rho_0 (C - C_0) \tag{2.6}$$

where u, v are velocity components along x and y direction respectively.
P is pressure, ρ is density, Ω is Rotating velocity, $\bar{\Omega}$ is angular velocity,
σ is electrical conductivity, μ is Magnetic permeability, C_P is specific heat at constant pressure, T is the Temperature, C is concentration, g Acceleration due to gravity, Q is strength of the heat source, q_r is radiative heat flux, K_f is Thermal conductivity, K_{11} is cross diffiusivity, β is co-efficient of volume expansion,β^* is volumetric coefficient of expansion with mass fraction, andD_1 is the chemical molecular diffusivity.
The boundary conditions are

$$u = 0,\ v = 0,\ T = T_0 + \in(T_0 - T_L)\ \text{coswt},\ C = C_0 - \in(C_0 - C_L)\ \text{coswt at } z = 0$$

and

$$u' = U(t) = U_0(1 + \in \text{coswt}),\ v = 0, \quad T = T_L, \quad C = C_L \text{ on } z = L \tag{2.7}$$

By applying Rosseland approximation (Brewester) [3] the radiative heat flux q_r is given by

$$q_r = -\left(\frac{4\sigma^*}{3\beta_R}\right)\frac{\partial}{\partial y}\left[T'^4\right] \tag{2.8}$$

where σ^* is the Stephan – Boltzmann constant
β_R is the mean absorption coefficient.
Expanding T'^4 about T_e in Taylor Series

$$T'^4 = 4T_e^3 T - 3T_e^4 . \tag{2.9}$$

Using (2.8. & 2.9) in the equation of energy and using (2.6) in the equations (2.2)–(2.6)

$$\frac{\partial q}{\partial t} + 2i\Omega q = \frac{-1}{\rho}\frac{\partial P}{\partial x} + \gamma \frac{\partial^2 q}{\partial z^2} - \frac{\sigma\mu^2 H_0^2 q}{\rho_0} - \left(\frac{\mu}{K}\right)q + \beta g(T - T_0) + \beta^* g(C - C_0) \tag{2.10}$$

$$\frac{\partial T}{\partial t} = \frac{K_f}{\rho_0 C_P}\frac{\partial^2 T}{\partial z^2} + \frac{Q}{\rho_0 C_P}(T - T_0) + \frac{16\sigma^2 T_0^3}{3\beta_R}\frac{\partial^2 T}{\partial z^2} \tag{2.11}$$

$$\frac{\partial C}{\partial t} = D_1 \frac{\partial^2 C}{\partial z^2} + K_{11}\frac{\partial^2 T}{\partial z^2} \tag{2.12}$$

where q = u + iv.
On introducing non-dimensional variables

$$z' = \frac{z}{L}, \qquad t' = w^2 t,\ \theta' = \frac{T - T_L}{T_0 - T_L}, \quad C' = \frac{C - C_L}{C_0 - C_L}$$

$$u', v' = \frac{(u, v)}{U_0}, \qquad \Omega' = \frac{\Omega^2 d}{\gamma}, \qquad P' = \frac{P}{\rho_0 u_0^2}$$

The equations (2.10) – (2.12) reduces to (on dropping dashes)

$$\gamma^2 \frac{\partial q}{\partial t} = \pi + \frac{\partial^2 q}{\partial z^2} - (D^{-1})q - q_1.E^{-1}q + G(\theta + NC) \tag{2.13}$$

$$P\gamma^2 \frac{\partial \theta}{\partial t} = \frac{\partial^2 \theta}{\partial z^2} - \alpha\theta \tag{2.14}$$

$$S_C \gamma^2 \frac{\partial C}{\partial t} = \frac{\partial^2 C}{\partial z^2} + \frac{S_C . S_0}{N} \frac{\partial^2 \theta}{\partial z^2} \tag{2.15}$$

where $G = \frac{\beta g L^3}{\gamma^2}(T_0 - T_L)$ (Grashof number); $D^{-1} = \frac{L^2}{K}$ (Darcy parameter)

$P = \frac{\mu C_P}{K_f}$ (Prandatl number); $\alpha = \frac{QL^2}{K_f}$ (Heat source parameter)

$S_C = \frac{\gamma}{D_1}$ (Schmidt number); $S_0 = \frac{\beta * K_{11}}{\gamma\beta}$ (Soret parameter)

$N = \frac{\beta * (C_L - C_0)}{\beta (T_L - T_0)}$ (Buoyancy ratio); $\gamma = \frac{\omega \nu}{L^2}$ (Wormsely Number)

The Non dimensional boundary conditions are

q = 0, $\theta = 1 + \frac{\in}{2}(e^{it} + e^{-it})$, $C = 1 + \frac{\in}{2}(e^{it} + e^{-it})$ at z = 0

and $q = U(t) = 1 + \frac{\in}{2}(e^{it} + e^{-it})$, θ = 0, C = 0 at z = 1 (2.16)

III. METHOD OF SOLUTION:

In order to solve the system of equations (2.13 – 2.15) subject to the boundary conditions we assume

$$q(z,t) = q_0(z) + \frac{\in}{2}\left[q_1(z)e^{it} + q_2(z)e^{-it}\right]; \qquad \theta(z,t) = \theta_0(z) + \frac{\in}{2}\left[\theta_1(z)e^{it} + \theta_2(z)e^{-it}\right]$$

$$C(z,t) = C_0(z) + \frac{\in}{2}\left[C_1(z)e^{it} + C_2(z)e^{-it}\right] \tag{3.1}$$

Substituting (2.17) in the equations (2.13 – 2.15) and boundary conditions comparing harmonic and non harmonic terms we get

$$q_{0,zz} - M_1^2 q_0 = -G(\theta_0 + NC_0) \tag{3.2}$$

$$q_{1,zz} - \left[M_1^2 + i\gamma^2 + 2iE^{-1}\right]q_1 = -G(\theta_1 + NC_1) \tag{3.3}$$

$$q_{2,zz} - \left[M_1^2 - i\gamma^2 + 2iE^{-1}\right]q_2 = -G(\theta_2 + NC_2) \tag{3.4}$$

$$C_{0,zz} = -\frac{S_C S_0}{N}\theta_{0,zz} \tag{3.5}$$

$$C_{1,zz} - \left[iS_C . \gamma^2\right]C_1 = \frac{-S_C . S_0}{N}\theta_{1,zz} \tag{3.6}$$

$$C_{2,zz} = \frac{-S_C . S_0}{N}\theta_{2,zz} \tag{3.7}$$

$$\theta_{0,zz} - \alpha\theta_0 = 0$$

$$\theta_{1,zz} - [\alpha + iP\gamma^2]\theta_1 = 0$$

$$\theta_{2,zz} - [\alpha - iP\gamma^2]\theta_2 = 0 \tag{3.8}$$

where $\beta_1^2 = \alpha + iP\gamma^2$, $\beta_2^2 = \alpha - iP\gamma^2$

The corresponding transformed boundary conditions reduces to

$q_0 = q_1 = q_2 = 0$; $\theta_0 = \theta_1 = \theta_2 = 1$; $C_0 = C_1 = C_2 = 1$ at z = 0

and $q_0 = q_1 = q_2 = 1$; $\theta_0 = \theta_1 = \theta_2 = 0$; $C_0 = C_1 = C_2 = 0$ at z = 1 (3.9)

The solutions of the equations (3.2 – 3.4) under the boundary conditions (3.5) are

$$q_0 = a_{23}\left[ch\ (\mathrm{hz}) - \frac{\mathrm{ch}\ (M_1\mathrm{y})}{\mathrm{ch}\ \mathrm{M}_1} ch\ \mathrm{h}\right] + a_{24}\left[sh\ (\mathrm{hz}) - \mathrm{sh}\ \mathrm{h}\frac{\mathrm{sh}\ (M_1\mathrm{y})}{\mathrm{sh}\ \mathrm{M}_1}\right]$$

$$+ a_{26}\left[\frac{\mathrm{ch}\ (M_1\mathrm{y})}{\mathrm{ch}\ \mathrm{M}_1} - 1\right] + a_{25}\left[-\mathrm{y} + \frac{\mathrm{sh}\ (\mathrm{M}_1\mathrm{y})}{\mathrm{sh}\ \mathrm{M}_1}\right]$$

$$q_1 = a_{29}\left[ch\ (\beta_1\mathrm{z}) - ch\ \beta_1\frac{ch\ (\beta_3\mathrm{y})}{ch\ \beta_3}\right] + a_{30}\left[sh\ (\beta_1\mathrm{z}) - sh\ \beta_1.\frac{sh\ (\beta_3\mathrm{y})}{sh\ \beta_3}\right]$$

$$q_2 = a_{37}\left[ch\ (\beta_2\mathrm{z}) - ch\ \beta_2.\frac{ch\ (\beta_4\mathrm{y})}{ch\ \beta_4}\right] + a_{38}\left[sh\ (\beta_2\mathrm{z}) - sh\ \beta_2.\frac{sh\ (\beta_4\mathrm{y})}{sh\ \beta_4}\right]$$

$$+ a_{39}\left[ch\ (\beta_1\mathrm{z}) - ch\ \beta_1.\frac{ch\ (\beta_4\mathrm{y})}{ch\ \beta_4}\right] + a_{40}\left[sh\ (\beta_1\mathrm{z}) - sh\ \beta_1.\frac{sh\ (\beta_4\mathrm{y})}{sh\ \beta_4}\right]$$

$$\theta_0 = \frac{1}{2}\left[\frac{ch\ (\mathrm{hz})}{\mathrm{ch}\ \mathrm{h}} - \frac{sh\ (\mathrm{hz})}{\mathrm{sh}\ \mathrm{h}}\right] \qquad \theta_1 = \frac{1}{2}\left[\frac{ch\ (\beta_1\mathrm{z})}{\mathrm{ch}\ \beta_1} - \frac{sh\ (\beta_1\mathrm{z})}{\mathrm{sh}\ \beta_1}\right]$$

$$\theta_2 = \frac{1}{2}\left[\frac{ch\ (\beta_2\mathrm{z})}{\mathrm{ch}\ \beta_2} - \frac{sh\ (\beta_2\mathrm{z})}{\mathrm{sh}\ \beta_2}\right]$$

$$C_0 = -a_5 ch\ (\mathrm{hz}) + a_6 sh\ (\mathrm{hz}) + \left[\frac{-1}{2} - a_6 ch\ (\mathrm{h})\right]z + \left[\frac{1}{2} + a_5 ch\ (\mathrm{h})\right]$$

$$C_1 = a_9\left[zsh\ (\beta_1\mathrm{z}) - \mathrm{sh}\ \beta_1.\frac{ch\ (\beta_1\mathrm{z})}{ch\ \beta_1}\right] + a_{10}\left[z.ch\ (\beta_1\mathrm{z}) - \mathrm{ch}\ \beta_1.\frac{sh\ (\beta_1\mathrm{z})}{sh\ \beta_1}\right]$$

$$+ \frac{1}{2}\left[\frac{ch\ (\beta_1\mathrm{z})}{ch\ \beta_1} - \frac{sh\ (\beta_1\mathrm{z})}{sh\ \beta_1}\right]$$

$$C_2 = a_{15}\left[ch\ (\beta_2\mathrm{z}) - \mathrm{ch}\ \beta_2.\frac{ch\ (\beta_1\mathrm{z})}{ch\ \beta_1}\right] + a_{16}\left[sh\ (\beta_2\mathrm{z}) - \mathrm{sh}\ \beta_2.\frac{sh\ (\beta_1\mathrm{z})}{sh\ \beta_1}\right]$$

$$+ \frac{1}{2}\left[\frac{ch\ (\beta_1\mathrm{z})}{ch\ \beta_1} - \frac{sh\ (\beta_1\mathrm{z})}{sh\ \beta_1}\right]$$

For N=0 and M=0 the results are in good agreement with Singh & Mathew [10]

IV. SHEAR STRESS, NUSSELT NUMBER and SHERWOOD NUMBER:

The shear stress at the plates z = 0 and 1 are given by

$$(\tau)_{z=0,1} = \mu\left[\frac{\partial u}{\partial z}\right]_{z=0,1}$$

which is in non dimensional form reduces

$$(\tau)_{z=0,1} = \frac{\tau}{\left(\frac{\mu u_0}{L}\right)} = \left(\frac{\partial u}{\partial z}\right)_{z=0,1}$$

and the corresponding equations are

$$\tau(0) = a_{43} + \frac{\in}{2}[a_{44}\, e^{it} + a_{45}\, e^{-it}] \qquad \tau(1) = a_{46} + \frac{\in}{2}[a_{47}\, e^{it} + a_{48}\, e^{-it}]$$

The rate of heat transfer (Nusselt number) at the plates z = 0 and 1 is given by

$$(Nu)_{z=0,1} = \left(\frac{d\theta}{dz}\right)_{z=0,1}$$

and the corresponding expressions are

$$Nu(0) = \frac{-a_{52}h}{2} - \in[a_{53}\, e^{it} + a_{54}\, e^{-it}] \qquad Nu(1) = \frac{a_{49}h}{2} + \in[a_{50}\, e^{it} + a_{51}\, e^{-it}]$$

The rate of mass transfer [Sherwood number] at the plates z = 0 and 1 is given by

$$[Sh]_{z=0,1} = \left(\frac{dc}{dz}\right)_{z=0,1}$$

and the corresponding expressions are

$$Sh(0) = a_{56} + \frac{\in}{2}[a_{59}\, e^{it} + a_{60}\, e^{-it}] \qquad Sh(1) = a_{55} + \frac{\in}{2}[a_{56}\, e^{it} + a_{57}\, e^{-it}]$$

where a_1, a_2 - - a_{62} are the constants.

V. RESULTS AND DISCUSSION:

In this analysis we investigate the Effect of thermal radiation and thermo- diffusion on the convective heat and mass transfer flow of viscous fluid through a vertical rotating channel in the presence of heat generating sources. The actual axial flow is in the vertically downward direction and therefore u>0 represents a reversal flow.The axial velocity u is shown in Figures, for variations of G, D^{-1}, α, S_C, S_0, γ, E^{-1}.

A variation of u with Soret parameter S_0 shows that the reversal flow which occurs in the left half for S_0=0.5 shifts to right half for higher S_0=1also the reversal flow which occurs in the entire flow region for S_0=-0.5 disappears for higher S_0=-1(Fig-1). The variation of u with Wormsely number γ shows that the reversal flow appears in the left half for all values of γ and the region of the reversal flow enlarges with increase in γ. |u| enhances with increase in γ≤1.2 and depreciates with higher γ≥1.4 (Fig-2). The effect of rotation of u is shown in Figure-3. It is observed that a reversal flow which occurs in the left half of the vertical channel shrinks with increase in E^{-1} also |u| depreciates in the left half and enhances in the right half. In Fig-4,we find that |v| enhances in the left half and reduces in the right half with increase in S_0>0 while |v| enhances with increase in |S_0| in the entire flow region. In Figure -5 represents variation of v with γ. It is found that |v| enhances with increase in γ≤1.2 and reduces with higher γ≥1.4. In Figure -6we find that higher the values of E^{-1} smaller |v| in the region. In Figure- 7 we notice that the actual concentration reduces with increase in S_0>0 and enhances with higher | S_0|. The variation of C with Wormsely number γ shows that an increase in γ results in an enhancement of the actual concentration except in the region -0.6≤Z≤-0.4 (Fig -8).

The Shear stress (τ) on the walls y=±1 is shown in Tables ,for a different values of G, D^{-1}, α, N, S_C and S_0. From Tables (1&2) we find that |τ| enhances at y=+1 and depreciates at y=-1 with increase in S_C also it enhances with increase in |S_0|. It is found that the rate of heat transfer depreciates with increase in α at y = ±1. Thus the presence of heat sources reduces the rate of heat transfer at both the walls. The variation of Nu with Prandatl number P shows that the rate of heat transfer reduces with P≤1 and enhances with higher P>1 at y=-1 while at y=+1 it enhances with P≤1 and depreciates with higher P>1. The variation of Nu with Wormsely number γ indicates that |Nu| experiences an enhancement with γ at y=-1 and at y=+1 it enhances with increase in γ≤1.5 and reduces with higher γ≥2.5 (Tables 3&4).It is found that the rate of mass transfer enhances at y=+1 and reduces at y=-1 with increase in α. The variation of Sh with Soret parameter S_0 shows that |Sh| reduces with S_0>0 and enhances with S_0<0 and reversed effect is observed in the behavior of Sh at y=-1 when the molecular buoyancy force dominates over the thermal buoyancy force the rate of mass transfer enhances at y=+1 and depreciates at y=-1 when the buoyancy forces act in the same direction and for the forces act in the opposite direction a reversed effect is observed in the behavior of |Sh|. An increase in γ enhances |Sh| at y=+1 and at y=-1 it reduces with γ≤2 and enhances with higher γ≥4 (Tables 5&6).

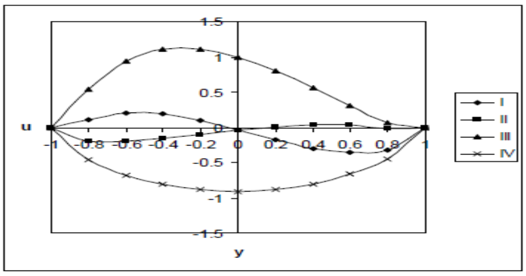


Fig. 1 : Variation of u with S_0
$G=10^3$, $D^{-1}=10^2$ $\alpha=2$ Sc=1.30 N=1 $\gamma=1$ $E^{-1}=0.5$ P=0.71

	I	II	III	IV
S_0	0.5	1	-0.5	-1

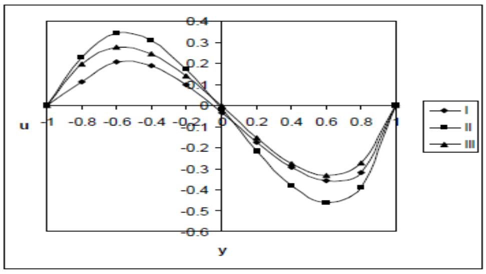


Fig. 2 : Variation of u with γ
$G=10^3$, $D^{-1}=10^2$ $\alpha=2$ Sc=1.30 $S_0=0.5$ N=1 $E^{-1}=0.5$ P=0.71

	I	II	III
γ	1	1.2	1.4

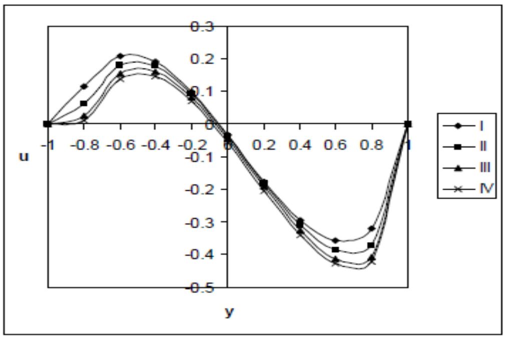


Fig. 3 : Variation of u with E^{-1}
$G=10^3$, $D^{-1}=10^2$ $\alpha=2$ Sc=1.30 $S_0=0.5$ N=1 $\gamma=1$ P=0.71

	I	II	III	IV
E^{-1}	0.5	1.5	2.5	3.5

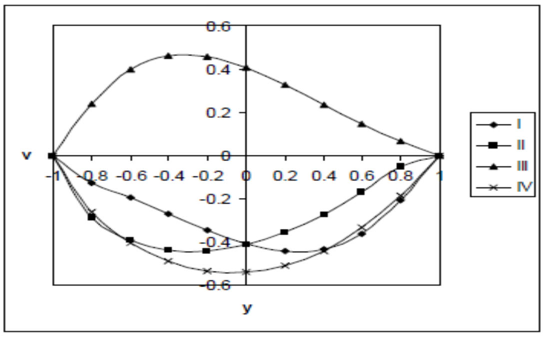


Fig. 4 : Variation of v with S_0
$G=10^3$, $D^{-1}=10^2$ $\alpha=2$ Sc=1.30 N=1 $\gamma=1$ $E^{-1}=0.5$ P=0.71

	I	II	III	IV
S_0	0.5	1	-0.5	-1

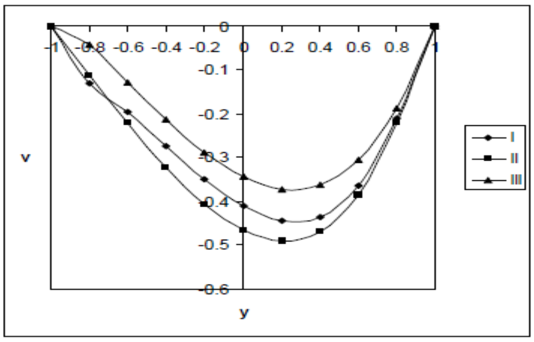


Fig. 5 : Variation of v with γ
$G=10^3$, $D^{-1}=10^2$ $\alpha=2$ Sc=1.30 $S_0=0.5$ N=1 $E^{-1}=0.5$ P=0.71

	I	II	III
γ	1	1.2	1.4

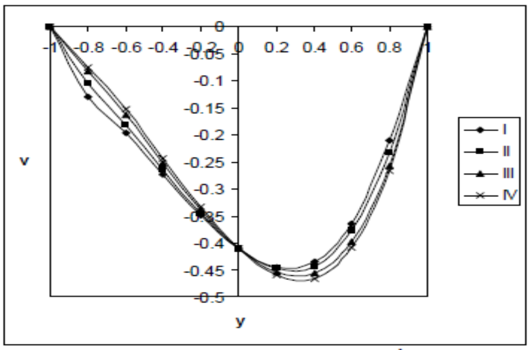


Fig. 6 : Variation of v with E^{-1}
$G=10^3$, $D^{-1}=10^2$ $\alpha=2$ Sc=1.30 $S_0=0.5$ N=1 $\gamma=1$ P=0.71

	I	II	III	IV
E^{-1}	0.5	1.5	2.5	3.5

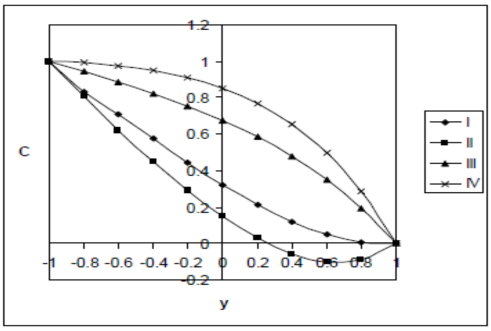


Fig. 7 : Variation of C with S_0
$G=10^3$, $D^{-1}=2$ $\alpha=2$ Sc=1.30 N=1 $\gamma=1$ $E^{-1}=0.5$ P=0.71

	I	II	III	IV
S_0	0.5	1	-0.5	-1

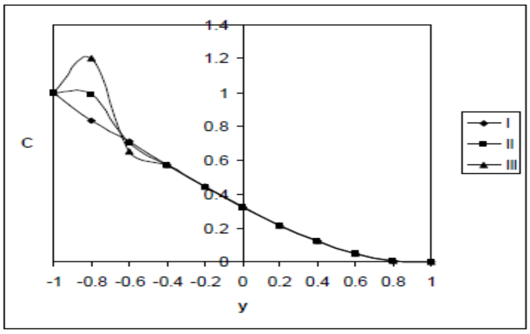


Fig. 8 : Variation of C with γ
$G=10^3$ $D^{-1}=2$ $\alpha=2$ Sc=1.30 $S_0=0.5$ N=1 $E^{-1}=0.5$ P=0.71

	I	II	III
γ	1	1.2	1.4

TABLE – 1

SHEAR STRESS (τ) AT y = +1

α =2 ,N=1, $D^{-1}=10^2$

G	I	II	III	IV	V	VI	VII
10^3	-0.02124	-0.13614	-0.35908	-0.58610	-0.77437	0.47016	0.88507
$2x10^3$	-0.04251	-0.27227	-0.71886	-1.17219	-1.54875	0.94039	1.77008
$-1x10^3$	0.02125	0.13613	0.35949	0.58608	0.77436	-0.47018	-0.88502
$-2x10^3$	0.04251	0.27227	0.71903	1.17217	1.54872	-0.94038	-1.77012
S_c	0.24	0.6	1.3	2.01	1.3	1.3	1.3
S_0	0.5	0.5	0.5	0.5	1	-0.5	-1

TABLE – 2

SHEAR STRESS (τ) AT y = -1

α =2, N=1 ,$D^{-1}=10^2$

G	I	II	III	IV	V	VI	VII
10^3	0.28713	0.22199	0.09493	-0.03305	-0.13975	0.56566	0.80091
$2x10^3$	0.57422	0.44398	0.19056	-0.06610	-0.27953	1.13141	1.60178
$-1x10^3$	-0.28711	-0.22199	-0.09534	0.03306	0.13978	-0.56570	-0.80090
$-2x10^3$	-0.57422	-0.44397	-0.19072	0.06612	0.27954	-1.13142	-1.60185
S_c	0.24	0.6	1.3	2.01	1.3	1.3	1.3
S_0	0.5	0.5	0.5	0.5	1	-0.5	-1

TABLE – 3

NUSSELT NUMBER (Nu) at y = -1

α	I	II	III	IV	V	VI
2	-0.16769	-0.16746	-0.17187	-0.17337	-0.16748	-0.17302
4	-0.07327	-0.07325	-0.07451	-0.07505	-0.07327	-0.07491
6	-0.03652	-0.03652	-0.03709	-0.03737	-0.03654	-0.03728
P	0.01	0.71	7	10	0.71	0.71
γ	1	1	1	1	1.5	3.5

TABLE – 4

NUSSELT NUMBER (Nu) at y = +1

α	I	II	III	IV	V	VI
2	0.16899	0.16924	0.16908	0.16883	0.16929	0.16922
4	0.07397	0.07403	0.07369	0.07352	0.07404	0.07361
6	0.03695	0.03698	0.03673	0.03662	0.03699	0.03666
P	0.01	0.71	7	10	0.71	0.71
γ	1	1	1	1	1.5	3.5

TABLE – 5

SHERWOOD NUMBER (Sh) AT y = +1

α	I	II	III	IV	V	VI	VII	VIII	IX
2	-0.00144	-0.00131	-0.00171	-0.00185	-0.00151	-0.00185	-0.00175	-5.1641	-5.45867
4	-0.00490	-0.00487	-0.00496	-0.00499	-0.00491	-0.00499	-0.00497	-5.41546	-6.12745
6	-0.00843	-0.00845	-0.00845	-0.00846	-0.00846	-0.00846	-0.00845	-5.90409	-7.42783
S_0	0.5	1	-0.5	-1	0.5	0.5	0.5	0.5	0.5
N	1	1	1	1	2	-0.5	-0.8	1	1
γ	1	1	1	1	1	1	1	2	4

TABLE – 6

SHERWOOD NUMBER (Sh) AT y = -1

α	I	II	III	IV	V	VI	VII	VIII	IX
2	-6.53146	-8.06309	-3.46819	-1.93655	-5.76564	-1.93655	-3.08528	-0.556	0.977
4	-6.49483	-7.99411	-3.49628	-1.99701	-5.74520	-1.99701	-3.12147	-0.555	0.978
6	-6.50159	-3.48211	-3.48211	-1.97237	-1.97237	-1.97237	-3.10467	-0.553	0.980
S_0	0.5	1	-0.5	-1	0.5	0.5	0.5	0.5	0.5
N	1	1	1	1	2	-0.5	-0.8	1	1
γ	1	1	1	1	1	1	1	2	4

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