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Effect of Chemical Reaction on Mixed Convective Heat and Mass Transfer Flow of a Viscous Electrically Conducting Fluid Through a Porous Concentric Annulus

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ABSTRACT

This paper is focused on the study of chemical reaction on mixed convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous medium. The governing equations are solved numerically by reducing the differential equations in to difference equations which are solved using Gauss-Seidel Iteration method. The velocity, temperature and concentration distributions for different parameters graphically.

Keywords: Chemical Reaction, Mixed Convection flow, Heat and Mass Transfer, Viscous eclectic fluid, Porous Medium

I. INTRODUCTION

The increasing cost of energy has lead technologists to examine measures which could considerably reduce the usage of the natural source energy (fossil). In particular design engineers require relationships between heat transfer, geometry and boundary conditions which can be utilized cost benefit analysis to determine the amount of insulation that will yield the maximum investment. Apart from this, the study of flow and heat transfer in the annular region between the concentric cylinders has applications in nuclear waste disposal research. It is known the canisters filled with radioactive rays be buried in the earth so as to isolate them from human population and is of interest to determine the surface temperature of these canisters. This surface temperature strongly depends on the buoyancy driven flow sustained by the heated surface and the possible moment of ground water past it. This phenomenon make idealized to the study of convection flow in a porous medium contained in a cylindrical annulus and extensively has been made on these lines [14,15, 16].

Free convection in a vertical porous annulus has been extensively studied by Prasad et al [16] both theoretically and experimentally. Caltagirone [3] has published a detailed theoretical study of free convection in a horizontal porous annulus including possible three dimensional and transient effects. Similar studies for fluid filled annuli are available in the literature [19]. Convection through annular regions under steady state conditions has also been discussed with the two cylindrical surfaces kept at different temperatures [8]. This work has been extended in temperature dependent convection flow [5, 7, 8] as well as convection flows through horizontal porous channel whose inner surface is maintained at constant temperature, while the other surface is maintained at circumferentially varying sinusoidal temperature [16,20,28].

Free convection flow and heat transfer in hydro magnetic case is important in nuclear and space technology [8, 12, 21, 24, 30, 31]. In particular such convection flow in a vertical annulus region in the presence of radial magnetic field has been investigated by Sastry and Bhadram [22]. Nanda and Purushotham [9] have analyzed the free convection of a thermal conducting viscous incompressible fluid induced by traveling thermal waves on the circumference of a long vertical circular cylindrical pipe. The solutions of the velocity and temperature fields are obtained using the long wave approximations. Ganapathi and Purushotham [6] have studied the unsteady flow induced by a traveling thermal wave imposed on the circumference of a long vertical cylindrical column of a fluid in a saturated porous medium. The analysis is carried out following White head [29], has made a study of the fluid flow and heat transfer in a viscous incompressible fluid confined in an annulus bounded by two rigid cylinders. The flow is generated by periodic traveling waves imposed on the outer cylinder and the inner cylinder is maintained at constant temperature.

Chen and Yuh [4] have investigated the heat and mass transfer characteristics of natural convection flow along a vertical cylinder under the combined buoyancy effects of thermal and species diffusion. The analysis is restricted to processes in which the diffusion-thermo and thermo-diffusion effects as well as the inter facial velocities from species diffusion are negligible. The surface of the cylinder is either maintained at a uniform temperature and concentration (or) subjected to uniform heat and mass flux. The conservation equations of the laminar boundary layer are solved in finite difference method. Antonio [2] has investigated the laminar flow, heat transfer in a vertical cylindrical duct by taking in to account both viscous dissipation and the effect of buoyancy. The limiting case of fully developed natural convection in porous annuli is solved analytically for steady and transient cases by E.Shaarwari and AL–Nimr [23] and AL-Nimr [1]. Philip [12] has obtained analytical solution for the annular porous media valid for low modified Reynolds number.

In this chapter we deal with the convective heat and mass transfer flow of a viscous fluid through a porous medium in an annular region between concentric cylinder r = a, and r = b in presence of heat generating sources. The outer cylinder r = b is maintained at constant temperature flux and concentration flux. By using Gauss – Seidel Iteration procedure, the governing equations are solved numerically. The effect of variation of governing parameter on the flow heat and mass transfer characteristic are discussed in detail.

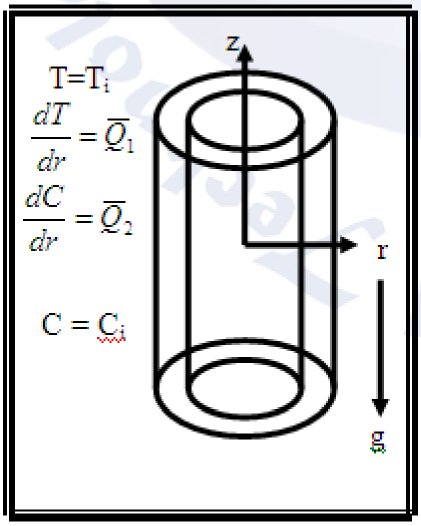

Fig.1:Schematic Diagram

II. Formulation of the Problem

We analyze the fully developed, steady laminar free convective flow of a viscous, electrically conducting fluid through a porous medium confined in an annular region between two vertical co-axial porous circular pipes in the presence of heat generating sources.. We choose the cylindrical polar coordinates system O (r , θ , z) with the inner and outer cylinders at r =a and r = b respectively. The fluid is subjected to the influence of a radial magnetic field (H_0 / r). Pipes being sufficiently long, all the physical quantities are independent of the axial coordinate z. The fluid is chosen to be of small conductivity so that the Magnetic Reynolds number is much smaller than unity and hence the induced magnetic field is negligible compared to the applied radial field. Also the motion being rotationally symmetric, the azimuthally velocity V is zero. The equation of motion governing the MHD flow through the porous medium are

$u_r + u / r = 0$ 1

$\rho_e u u_r = -p_r + \mu(u_{rr} + u_r / r - u / r^2) - (\mu / k) u$ 2

$\rho_e u w_r = -p_z + \mu(w_{rr} + w_r / r) - (\mu / k) w - \rho g - (\sigma \mu_e^2 H_0^2 a^2 / r^2) w$ 3

$\rho C_p (u T_r) = k_f (T_{rr} + T_r / r) + Q(T_e - T) + Q_1'(C - C_e)$ 4

$(u C_r) = D(C_{rr} + C_r / r) - k_1 C = 0$ 5

$\rho - \rho_e = -\beta(T - T_0) - \beta^\bullet (C - C_0)$ 6

where (u ,w) are the velocity components along 0 (r ,z) directions respectively, ρ is the density of the fluid, p is the pressure, T,C are the temperature and concentration, μ is the coefficient of viscosity, C_p is the specific heat at constant pressure, k is the porous permeability, σ isthe electrically conductivity, μ_e is the magnetic permeability andρ_e, T_e,C_e are density,temperature and concentration in the equilibrium state. Where k_f is the coefficient of thermal conductivity,D_1 is the molecular diffusivity, $\beta^\bullet$ isthe volumetric expansion with mass fraction,k_1 is chemical reaction coefficient, Q' is radiation absorption coefficientand Q is the strength of the heat generating source (suffices r and z indicate differentiation w.r.t.the variables).

The boundary conditions are

$w(a) = w(b) = 0$

$T(a) = T_i$ and $\left(\frac{dT}{dr}\right)_{r=a} = Q_1$

$C(a) = C_i$ and $\left(\frac{dC}{dr}\right)_{r=b} = Q_2$ 7

The equation of continuity gives

$r u = a u_a = b u_b$

$\Rightarrow u_b = (a / b) u_a$ 8

In the hydrostatic state, equation (2.3) gives

$-\rho_e g - p_{e,z} = 0$ 9

where ρ_e and p_e are the density and pressure in the static case and hence

$-\rho g - p_z = -(\rho - \rho_e) g - p_{d,z}$ 10

where p_d is the dynamic pressure

Also substituting (2.10) in (2.2) we find

$$\frac{\partial p_d}{\partial r} = f(r) \quad 11$$

Using the relation (8) – (11) in (1) – (4) the equations governing free convective heat transfer flow under no pressure gradient are

$$w_{rr} + (1 - a u_a / \nu) w_r / r + ((\beta g / \nu)(T - T_e)) + (\beta^\bullet g / \nu)(C - C_e) - (\sigma \mu_e^2 H_0^2 a^2 / \nu)(w / r^2) - (\nu / k) w = 0$$
12

$$T_{rr} + (1 - a u_a / \nu) T_r / r + (Q / k_f)(T_e - T) + (Q_1' / k_f)(C - C_e) = 0$$
13

$$C_{rr} + (1 - a u_a / \nu) C_r / r - k_1 C = 0 \quad 14$$

Introducing the non-dimensional variables (r', w', θ') as $r' = r / a$, $w' = w (a / \nu)$,

$$\theta = \frac{T - T_e}{T_i - T_e}, C' = \frac{C - C_e}{C_i - C_e} \quad 15$$

the equations (2.12) to (2.14) reduces to

$w_{rr} + (1 - \lambda)(1 / r) w_r - (D_2^{-1} + (M^2 / r^2)) w = -G(\theta + N C)$ 16

$\theta_{rr} + (1 - \lambda P)\theta_r / r - \alpha\theta + Q_1 C = 0$ 17

$C_{rr} + (1 - \lambda Sc) C_r / r - \gamma C = 0$ 18

where

$M = (\sigma \mu_e^2 H_0^2 a^2 / \rho \nu)^{1/2}$ Hartmann number

$G = (\beta g a^3 (T_1 - T_e)^2 / \nu^2)$ Grashof number)

$\lambda = a u_a / \nu$ Suction parameter

$D_2^{-1} = (a^2 / k)$ Darcy parameter

$P = (\mu C_p / k_f)$ Prandtl number

$\alpha = \frac{QL^2}{k_f}$ Heat Source parameter

$Sc = \frac{\nu}{D_1}$ Schmidt number

$N = \frac{\beta^\bullet k_{11}}{\beta \nu}$ Buoyancy ratio

$\gamma = \frac{k_1 a^2}{D_1}$ Chemical reaction parameter

$Q_1 = \frac{Q_1' \Delta C a^2}{k_f \Delta T}$ Radiation absorption parameter

The corresponding boundary conditions are

$w = 0$, $\theta = 1$, $C = 1$ on $r = 1$

$w(s) = 0$, $\left(\frac{d\theta}{dr}\right)_{r=s} = Q_1$, $\left(\frac{dC}{dr}\right)_{r=s} = Q_2$ 19

III. Solution of the Problem

The differential equations (2.16)-(2.18) have been discussed numerically by reducing the differential equations in to difference equations which are solved using Gauss-Seidel Iteration method. The differential equations involving θ_0,θ_1, w_0 and w_1 are reduced to the following difference equations

$$\left(1 - \frac{h(1 - \lambda P)}{2 r_i}\right)\theta_{,i-1} - (2 + \alpha)\theta_{,i} + \left(1 + \frac{h(1 - \lambda P)}{2 r_i}\right)\theta_{,i+1} + Q_1 C_{,i} = 0$$
20

$$\left(1 - \frac{h(1 - \lambda Sc)}{2 r_i}\right)C_{,i-1} - 2 C_{,i} + \left(1 + \frac{h(1 - \lambda Sc)}{2 r_i}\right)C_{,i+1} - \gamma C_{,i} = 0$$
21

$$(1-\frac{h(1-\lambda)}{2r_i})w_{,i-1}-(2+h^2(D_2^{-1}+(M^2/r^2)))w_{,i}+(1+\frac{h(1-\lambda)}{2r_i})w_{,i+1}$$
$$=-Gh^2(\theta_{,i}+NC_{,i})$$

22

where h is the step length taken to be 0.05 together with the following conditions

$$\theta_{,0}=1,\quad \theta_{,1}=m_1$$
$$w_{,0}=0,\quad w_{,1}=0$$

All the above difference equations are solved using Gauss-Seidel iterative method to the fourth decimal accuracy.

Shear Stress, Nusselt Number and Sherwood Number

The shear stress on the pipe is given by

$$\tau'=\mu(\frac{\partial w}{\partial r})_{r=a,b}$$

which in the non-dimensional form reduces to

$$\tau=\tau'/(\mu^2/a^2)=(w_r)_{r=1,s}=(w_{0,r}+E_e w_{1,r})_{r=1,s}$$

The heat transfer through the pipe to the flow per unit area of the pipe surface is given by

$$q=k_1(\frac{\partial T}{\partial r})_{r=a}$$

Which is in the non-dimensional form is

$$Nu=(\frac{qa}{k_1(T_1-T_e)})=(\frac{\partial\theta}{\partial r})_{r=1}$$

The mass transfer through the pipe to the flow per unit area of the pipe surfacein the non-dimensional form is

$$Sh=(\frac{q_1 a}{D_1(C_1-C_e)})=(\frac{\partial C}{\partial r})_{r=1}$$

IV. Results and Discussion

The mixed convective heat and mass transfer flow of viscous, electrically conducting fluid through a porous medium in a circular annular with outer cylinder maintained at constant heat and mass flux with chemical reaction and radiation is analyzed for different values of G, M, D^{-1}, α, Sc, Q, λ and α.

The axial velocity (w) is shown in figs (1-8) for different G, D^{-1}, M, λ, Sc, N,Q, α. The actual axial velocity (w) is in the vertically downward direction i.e. w < 0 is the actual flow and w > 0 represents a reversal flow. (Fig 1) represents the variation of w with G. It is found that w > 0 for G < 0 and w < 0 for G > 0. This shows that w exhibits a reversal flow for G<0 and the region of reversal flow enlarges with |G|. Also |w| experiences an enhancement with increase in |G| (><0) with maximum occurring at r =1.4. The variation of w with M and D^{-1} shows that lesser the permeability of the porous medium or higher the Lorentz force smaller |w| in the flow region (fig 2). From (fig 3) we find that the axial velocity experiences a marginal increment in |w| with increase in Sc. The variation of u with chemical reaction parameter γ shows that |w| depreciates in the degeneration reaction and enhances in the generating reaction (fig4). |w| enhances with increase in the radiation absorption parameter Q_1 (fig 5). The variation of u with heat source parameter α shows that |w| depreciates with increase in the strength of the heat generating source (fig 6). When the molecular buoyancy force dominates over the thermal buoyancy force the axial velocity enhances when the buoyancy forces, act in the same direction and for the force acting in opposite directions |w| depreciates in the entire flow region (fig7). An increasing in λ leads to an enhancement with increase in λ (fig. 8)

The non-dimensional temperature (θ) is shown in figs (9–16) for different parameter values. We follow the convention that the temperature is positive or negative according as the actual temperature is greater or lesser than the temperature on the inner cylinder. (Fig 9) represents the variation of θ with G, fixing the other parameters. It is found that actual temperature depreciates with G > 0 and enhances with G < 0. From (fig 10) we find that the actual temperature enhances with $D^{-1}\le 2\times10^2$ and depreciates with higher $D^{-1}\ge 3\times10^2$. Higher the Lorentz force smaller the actual temperature in the entire flow region. The variation of θ with buoyancy ratio N shows that when the molecular buoyancy force dominates over the thermal buoyancy force, the actual temperature depreciates when the buoyancy forces act in the same direction and for the forces acting in opposite directions it enhances in the flow region (fig 11). From (fig 12) it is found that the suction at the boundary enhances the actual temperature. The variation of θ with Schmidt number Sc reveals that lesser the molecular diffusivity larger the actual temperature (fig13). An increase in the heat source parameter α enhances the temperature in the entire flow region (fig 14). In the degenerating reaction case the actual temperature depreciates while it enhances in the generating reaction (fig15). The variation of θwith radiation absorption parameter Q_1 shows an increasing tendency with increase in θ everywhere in the flow region (fig 16).

The non-dimensional concentration (C) is shown in figs (17-24) for different G, M, D^{-1}, λ, Q,α, Sc, γ and θ. We follow the convention that the actual concentration is greater/lesser than the concentration on the inner cylinder. (Fig 17) represents the variation of C with Grashof number G. It is observed that the actual concentration reduces with G > 0 and enhances with G < 0 with maximum at r =1. The variation of C with D^{-1}, Sc, λ and α shows that the actual concentration experiences a depreciation with increase in D^{-1}, Sc, λ and α. Also it enhances with increase in Hartmann number (figs 18, 20-22). From (fig19) we find that the actual concentration reduces with increase N > 0 and enhances with N<0. The variation of C with chemical reaction parameter γ shows that the actual concentration reduces in the degenerating reaction and enhances in the generating reaction (fig. 23). From (fig 24) we find that an increase in the radiation absorption parameter Q_1 results in a depreciation in the concentration in the entire flow region.

The Shear stress (τ) at the inner and outer cylinders r = 1 & 2 are evaluated for different G, M, D^{-1}, α, λ, N, Sc, γ and Q and are shown in tables (1-6). The stress at r = 1 enhances with increase in G (><0) while at r =2 $|\tau|$ depreciates with G > 0 and enhances with G < 0. The variation of τ with M & D^{-1} shows that lesser the permeability of the porous medium or higher the Lorentz force, smaller $|\tau|$ at both the cylinders. An increase in the strength of the heat source leads to a depreciation in the stress at r = 1 & 2. The variation of τ with λ reveals that the stress depreciates at r = 1 and enhances at r = 2 with increase in the suction parameterλ (tables 1 & 2). From (tables 3 & 4) we find that when the molecular buoyancy force dominates over the thermal buoyancy force the stress at r = 1 enhances irrespective of the directions of the buoyancy forces. At r = 2 the stress depreciates for $|G| = 10^3$ and enhances with N for $|G| = 3x10^3$. An increase in the radiation absorption parameter Q_1 results in an enhancement in $|\tau|$ at both the cylinders (tables 5&6). The variation of τ with Sc shows that lesser the molecular diffusivity larger $|\tau|$ at r=1 while at r = 2 larger $|\tau|$ and for further lowering of the molecular diffusivity smaller $|\tau|$. The variation of τ with λ shows that the stress depreciates in the degenerating chemical reaction and enhances in the generating chemical reaction (tables 3 & 4).An increase in the radiation parameter Q_1results in an enhancement in the magnitude of the stress at both the cylinders (tables 5&6).

The Nusselt number (Nu) at r = 1 is shown in (tables 7 & 8). The rate of heat transfer at the inner cylinder enhances with G > 0 and depreciates with G < 0. Lesser the permeability of the porous medium or higher the Lorentz force, larger the rate of heat transfer at r = 1. An increase in the suction parameter λ depreciates Nu for all G. When the molecular buoyancy force dominates over the thermal buoyancy force. The rate of heat transfer depreciates when the buoyancy forces act in the same directions and for the forces acting in opposite directions it enhances in its magnitude for all G. The variation of Nu with Sc shows that lesser the molecular diffusivity, smaller Nu at r = 1. The variation of Nu with chemical reaction parameter γ shows an increase in $\gamma \leq 0.5$ enhances Nu for G>0 and depreciates it for G < 0 and for higher $\gamma \geq 1.3$ we notice an enhancement in Nu for all G. Also it depreciates with increase in the radiation absorption parameter Q_1(table8).

The Sherwood number (Sh) is shown in (tables 9 & 10). The rate of mass transfer at the inner cylinder r = 1 enhances in the heating case and depreciates in the cooling case. An increase in M or D^{-1} enhances $|Sh|$ at r =1. Thus lesser the permeability of the porous medium or higher the Lorentz force, larger $|Sh|$ at r = 1. An increase in the suction parameter λ reduces the rate of mass transfer. The variation of Sh with heat source parameter α reveals that the rate of mass transfer reduces in heating case and enhances in the cooling case when the molecular buoyancy force dominates over the thermal buoyancy force.The rate of mass transfer reduces for G>0 and enhances for G<0 when the buoyancy forces act in the same direction and for the forces acting in apposite direction, it reduces at r = 1 for all G. Also lesser the molecular diffusivity, smaller $|Sh|$ for all G. With respect to chemical reaction parameter γ we find that the rate of mass transfer experiences an enhancement in the degenerating chemical reaction and depreciates in the generating reaction. Also it enhances with increase in the radiation absorption parameter Q_1(table.10).

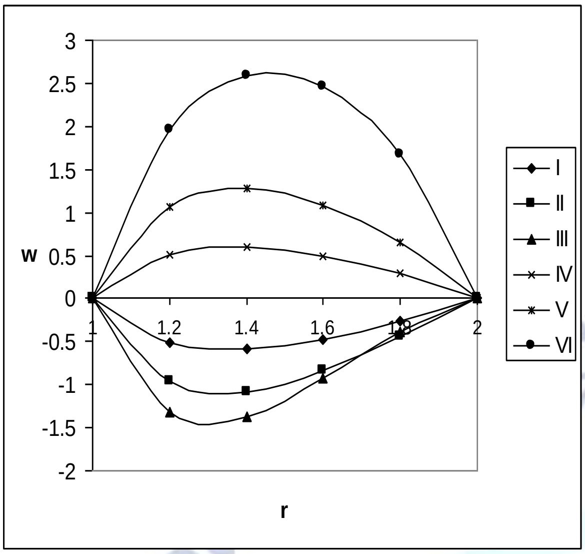

Fig. 1 : Variation of w with G

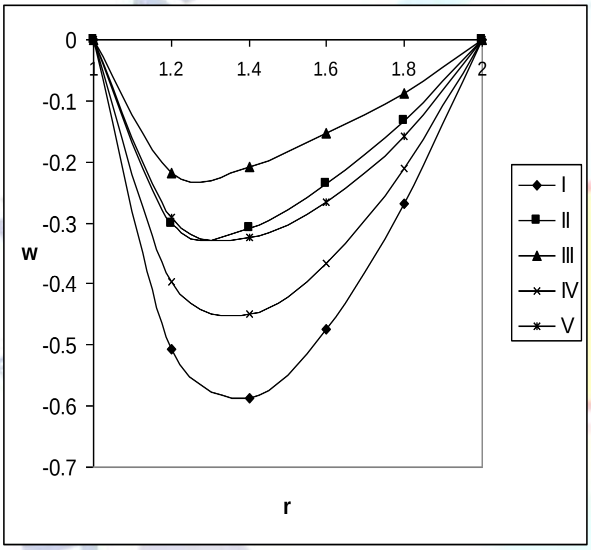

Fig. 2 : Variation of w with D^{-1}, M

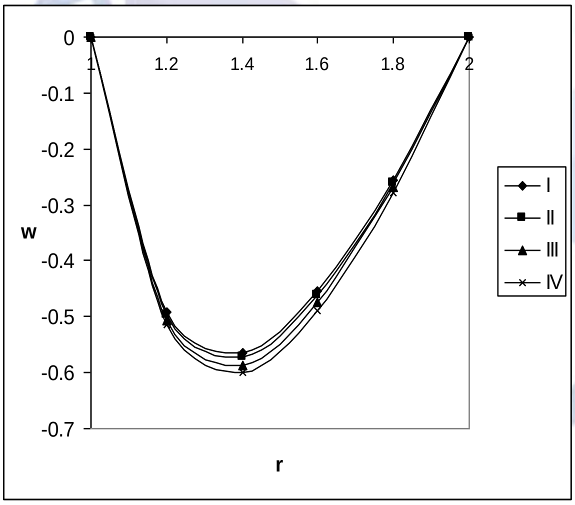

Fig. 3 : Variation of w with Sc

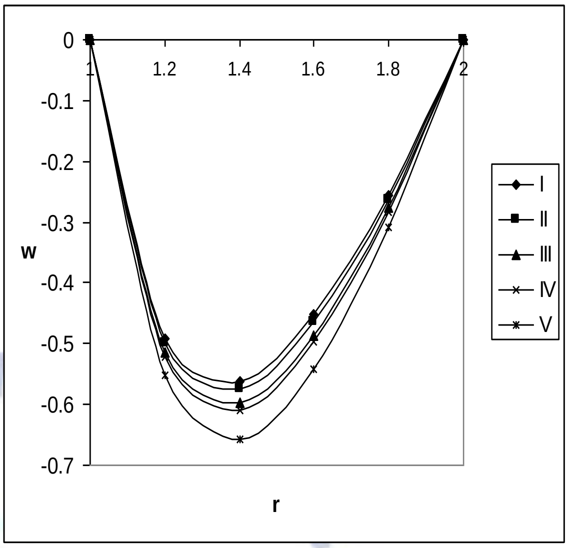

Fig. 4 : Variation of w with Q

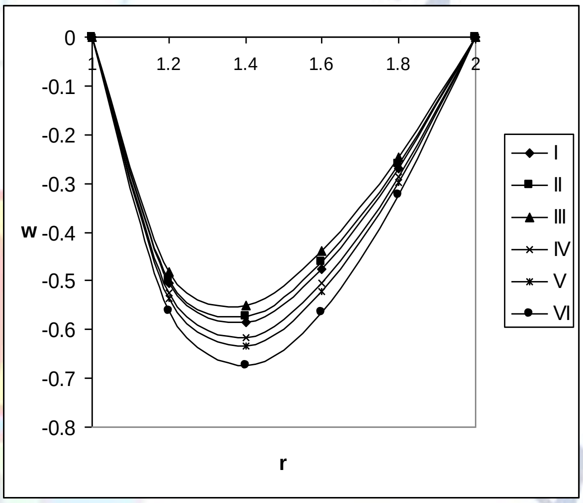

Fig. 5 : Variation of w with γ

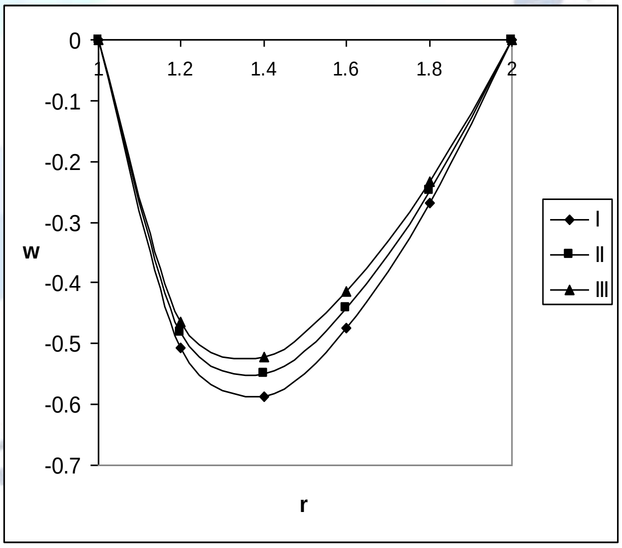

Fig. 6 : Variation of w with α

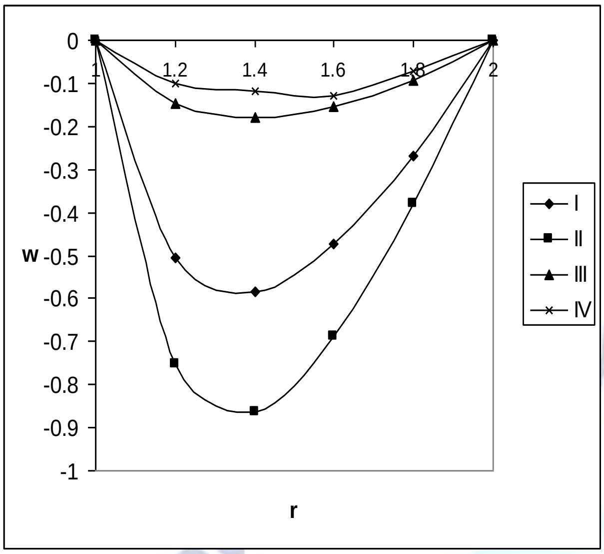

Fig. 7 : Variation of w with N

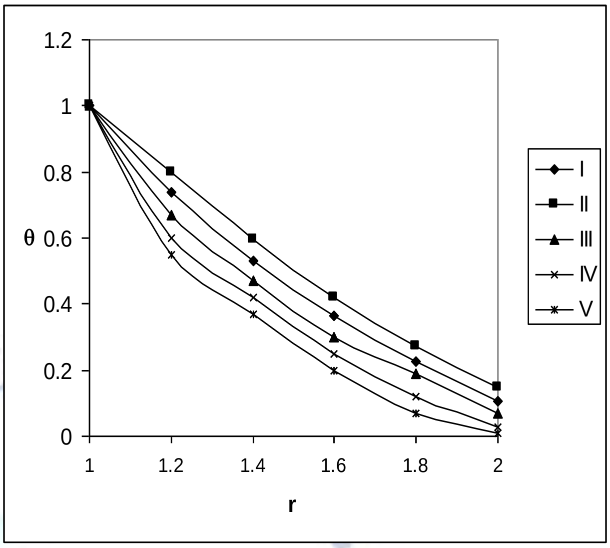

Fig. 10 : Variation of θ with D^{-1}, M

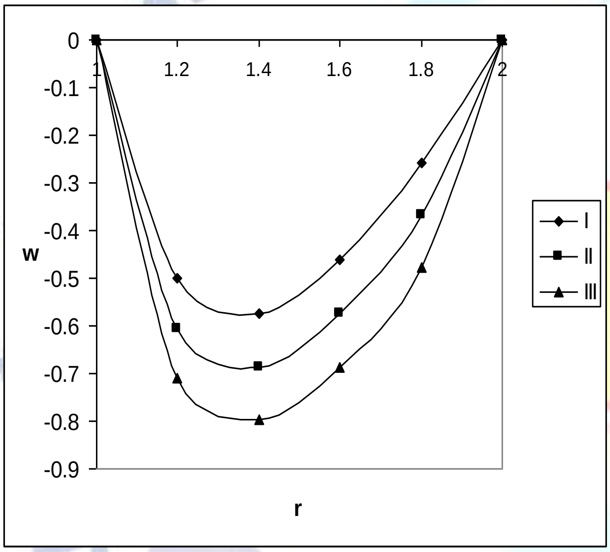

Fig. 8 : Variation of w with λ

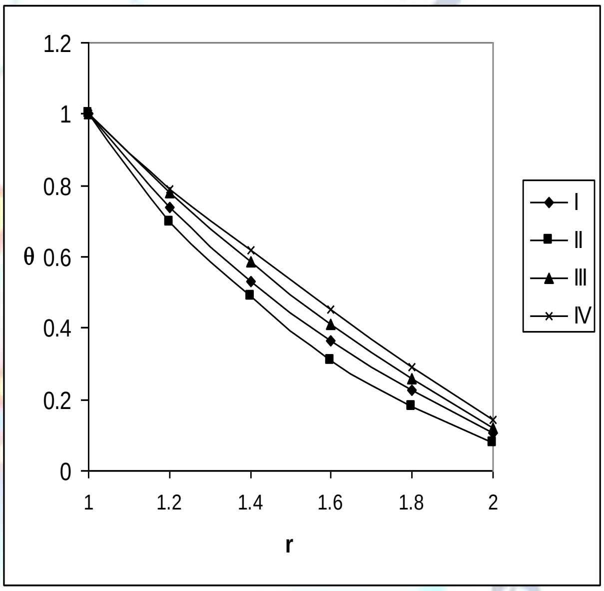

Fig. 11 : Variation of θ with N

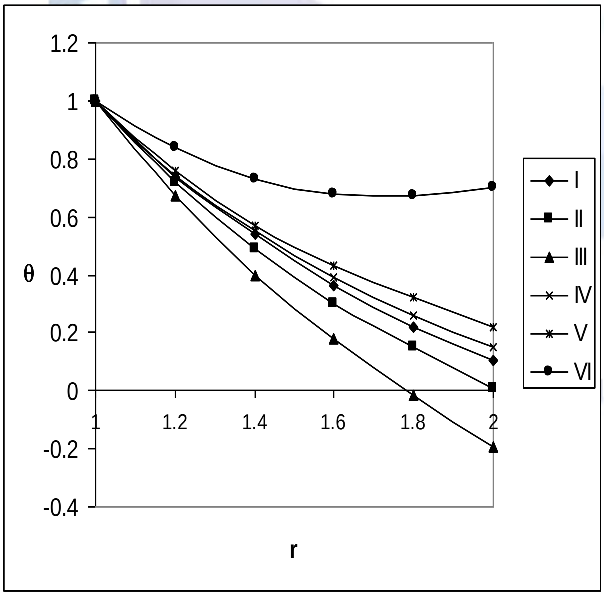

Fig. 9 : Variation of θ with G

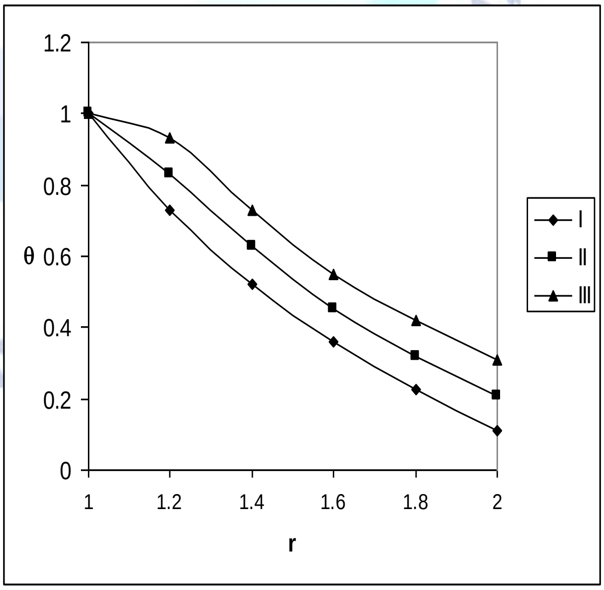

Fig. 12 : Variation of θ with λ

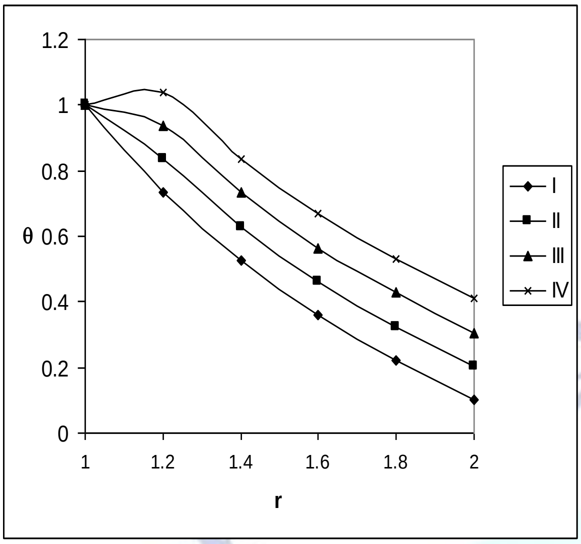

Fig. 13 : Variation of θ with Sc

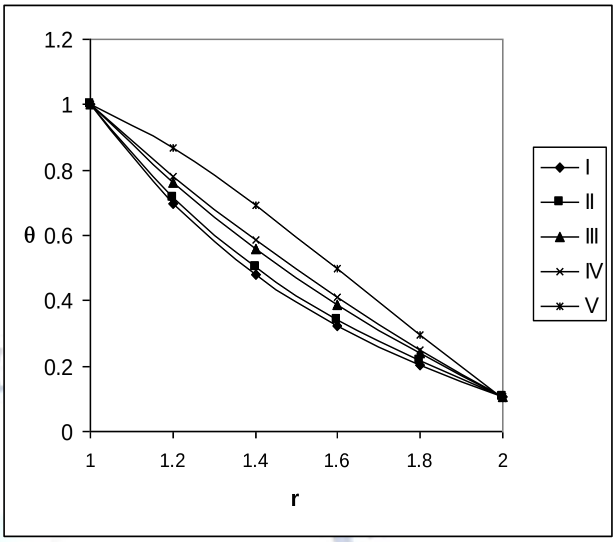

Fig. 16 : Variation of θ with Q

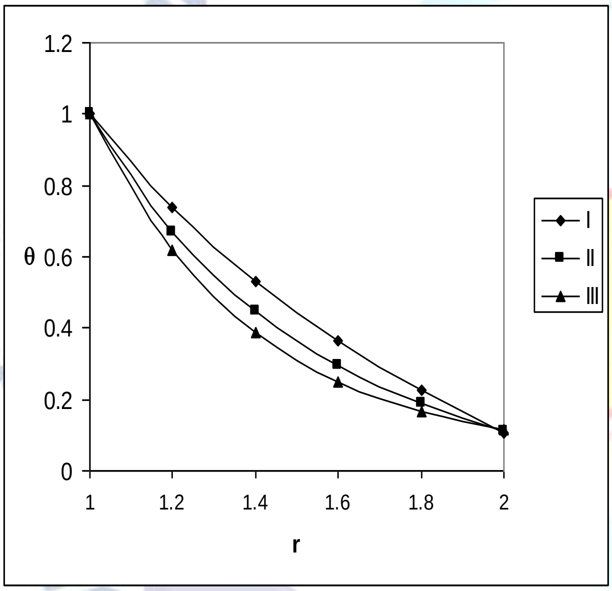

Fig. 14 : Variation of θ with α

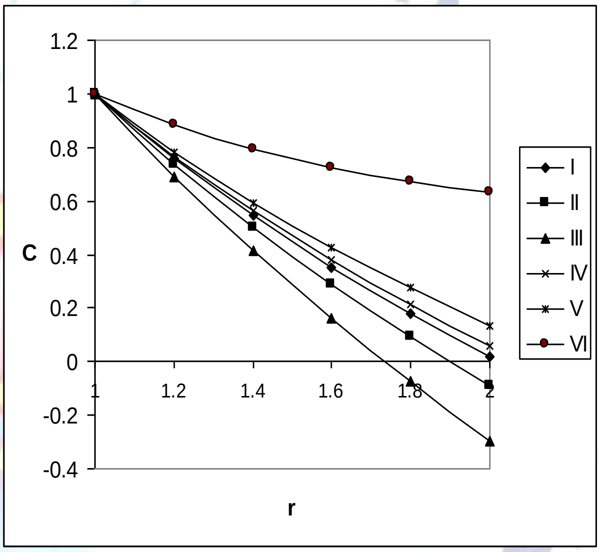

Fig. 17: Variation of C with G

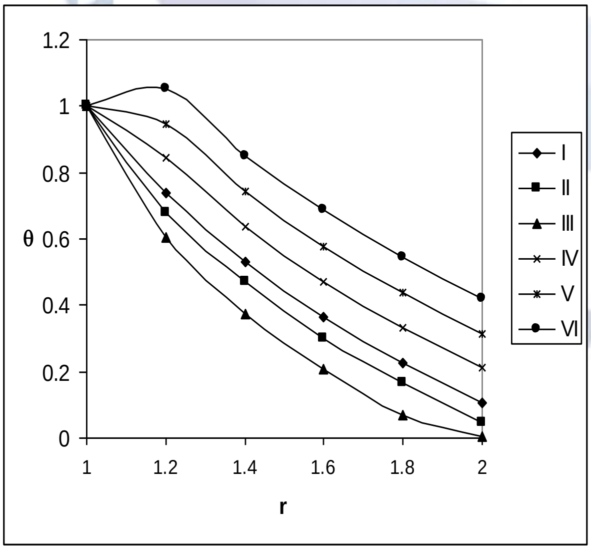

Fig. 15 : Variation of θ with γ

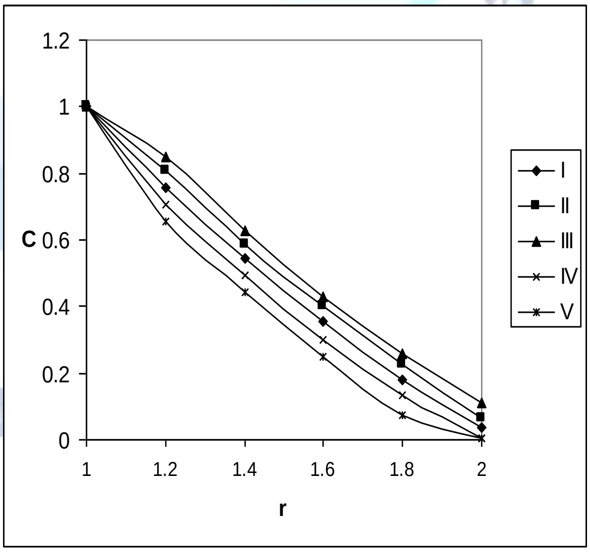

Fig. 18 : Variation of C with D^{-1}, M

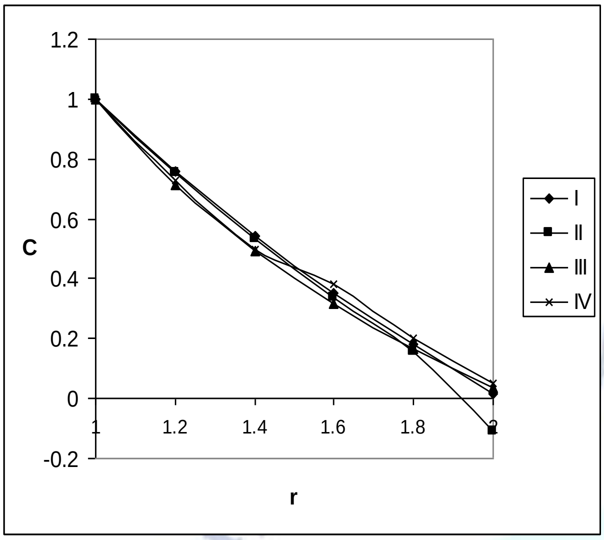

Fig. 19 : Variation of C with N

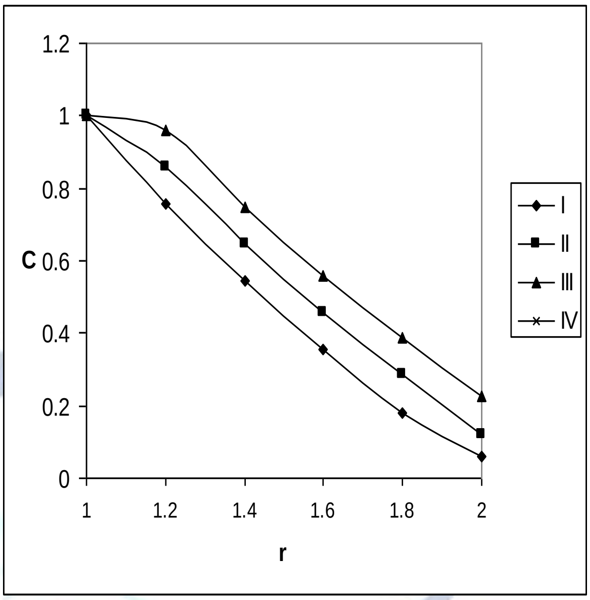

Fig. 22 : Variation of C with α

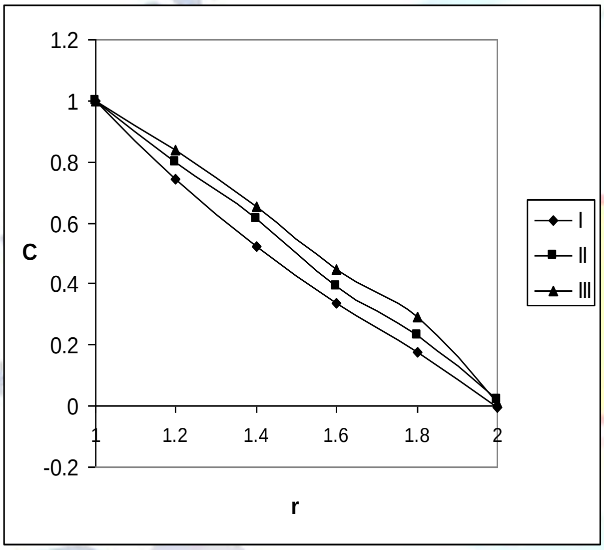

Fig. 20: Variation of C with λ

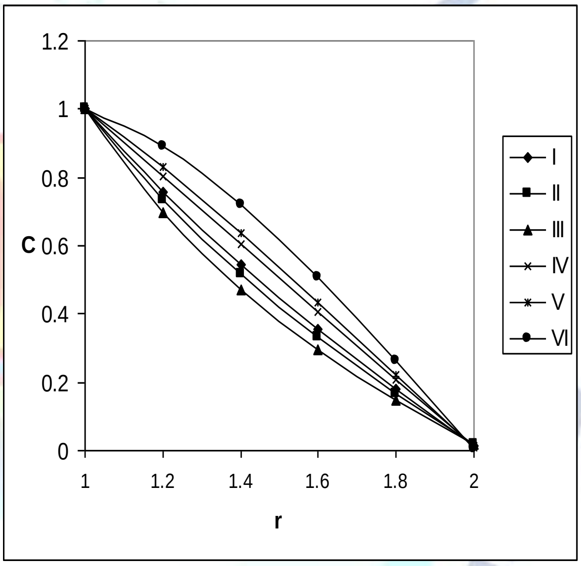

Fig. 23 : Variation of θ with γ

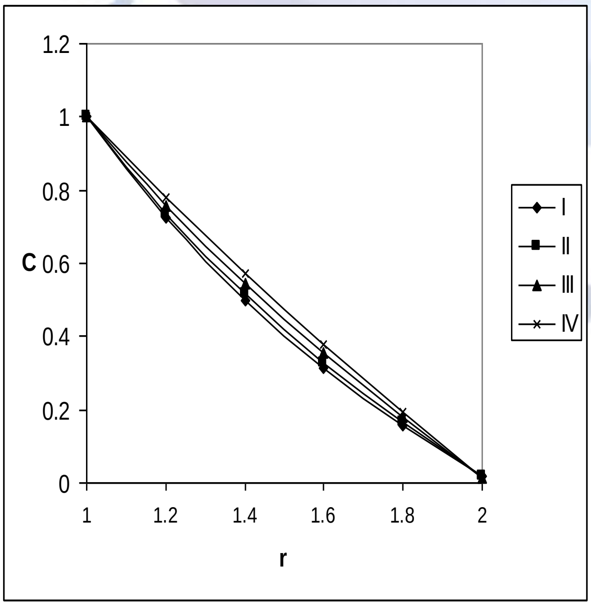

Fig. 21 : Variation of C with Sc

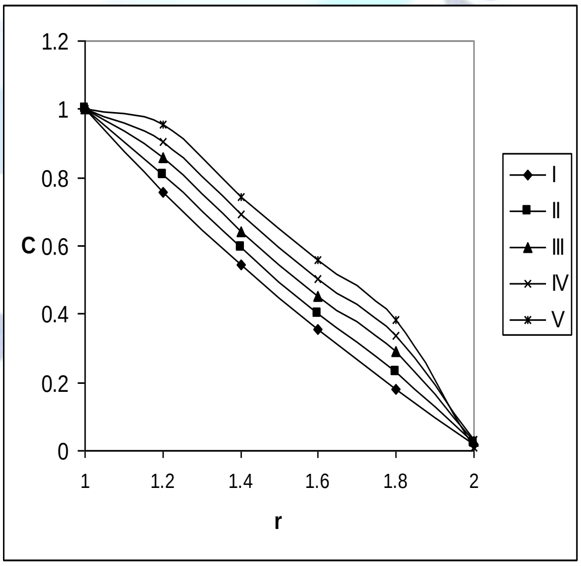

Fig. 24 : Variation of θ with Q

Table – 1

Shear stress (τ) at the inner cylinder r = 1

G	I	II	III	IV	V	VI	VII	VIII	IX	X
10	-3.7792	-3.0775	-2.3983	-3.8008	-3.7928	-3.7602	-2.9988	-2.5444	-3.6559	-3.5597
30	-10.0919	-8.3601	-6.8045	-10.757	-10.0929	-10.0748	-8.5673	-7.4274	-10.1804	-10.1134
-10	3.8264	3.1225	2.4296	3.8293	3.8275	3.8243	3.0263	2.5628	3.6891	3.5846
-30	13.4382	11.8445	8.4969	13.1641	13.2818	13.6207	9.8090	8.0094	11.9988	11.2897
M	2	4	6	2	2	2	2	2	2	2
λ	0.5	0.5	0.5	0.1	0.3	0.7	0.5	0.5	0.5	0.5
D^{-1}	10	10	10	10	10	10	20	30	10	10
α	2	2	2	2	2	2	2	2	4	6

Table – 2

Shear stress (τ) at the inner cylinder r = 2

G	I	II	III	IV	V	VI	VII	VIII	IX	X
10	1.4822	1.1836	0.9084	1.3818	1.4356	1.5205	1.0115	0.7740	1.3745	1.2938
30	0.6454	0.0169	0.4037	0.5551	0.6146	0.6452	1.2595	1.2314	1.5844	1.9744
-10	-1.6239	-1.3609	-1.0854	-1.4565	-1.5341	-1.7254	-1.1184	-0.8593	-1.4795	-1.3752
-30	-10.5555	-13.4401	-9.7325	-8.6746	-9.5088	-9.5088	-6.0549	-3.9909	-7.2367	-5.7696
M	2	4	6	2	2	2	2	2	2	2
λ	0.5	0.5	0.5	0.1	0.3	0.7	0.5	0.5	0.5	0.5
D^{-1}	10	10	10	10	10	10	20	30	10	10
α	2	2	2	2	2	2	2	2	4	6

Table – 3

Shear stress (τ) at the inner cylinder r = 1

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
10	-2.8505	-0.4649	-0.1777	-1.8639	-1.4285	-1.9214	-1.9084	-1.8637	-1.8259	-1.8259	-1.9396	-1.9506	-1.9994	-2.0741
30	-5.6341	-.9353	-0.3619	-3.7082	-1.7959	-3.8252	-3.7972	-3.7118	-3.6396	-3.8557	-3.8767	-3.8767	-3.9695	-4.1095
-10	2.8633	0.4659	0.1781	1.8708	-1.3826	1.9053	1.1914	1.8697	1.8313	1.9496	1.9578	1.9578	2.0073	2.0833
-30	5.7523	0.9405	0.3636	3.7569	-0.8301	3.8714	3.8459	3.7547	3.6774	3.9093	3.9093	3.9317	4.0326	4.1866
N	2	-0.5	-0.8	1	1	1	1	1	1	1	1	1	1	1
Sc	1.3	1.3	1.3	0.24	0.6	1.3	2.01	1.3	1.3	1.3	1.3	1.3	1.3	1.3
γ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	1.3	2.3	-0.3	-0.5	-1.3	-2.3

Table – 4

Shear stress (τ) at the inner cylinder r = 2

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII	XIV
10	1.1345	0.2258	0.1138	0.7395	1.4298	-1.3991	0.8059	0.7895	0.7403	0.6997	0.8246	0.8372	0.8939	0.9827
30	2.0449	0.4510	0.2304	1.4033	-0.7295	-1.4244	1.5364	1.5012	1.4121	1.3387	1.5636	1.5863	1.6875	1.8435
-10	-1.1729	-0.2292	-0.1149	-0.7593	-1.5706	-1.3857	-0.7983	-0.8092	-0.7586	-0.7169	-0.8452	-0.8583	-0.9163	-1.0076
-30	-2.3991	-0.4663	-0.2352	-1.5440	0.8059	-1.3773	-1.6793	-0.8092	-1.5433	-1.4591	-1.7192	-1.7453	-1.8643	-2.0503
N	1	2	-0.5	-0.8	1	1	1	1	1	1	1	1	1	1
Sc	1.3	1.3	1.3	1.3	0.24	0.6	2.01	1.3	1.3	1.3	1.3	1.3	1.3	1.3
γ	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.3	1.3	2.3	-0.3	-0.5	-1.3	-2.3

Table – 5

Shear stress (τ) at the inner cylinder r = 1

G	I	II	III	IV
10	-1.8874	-1.9503	-2.0326	-2.1155

30	-3.7576	-3.8769	-4.0349	-4.1921
-10	1.8941	1.9573	2.0407	2.1248
-30	3.8039	3.9308	4.1001	4.2703
Q	0.5	2	4	6

Table – 6
Shear stress (τ) at the inner cylinder r = 2

G	I	II	III	IV
10	0.7688	0.8309	0.9126	0.9945
30	1.4641	1.5754	1.7218	1.8657
-10	-0.7882	-0.8515	-0.9354	-1.0197
-30	-1.6034	-1.7323	-1.9044	-2.0771
Q	0.5	2	4	6

Table – 7
Nusselt number (Nu) at the inner cylinder r = 1

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
10	-1.4441	-1.4576	-1.5362	-1.4793	-1.3839	-1.4294	-1.4315	-1.9093	-2.3076	-1.4209	-1.4152	-1.3684	-1.3924
30	-1.8506	-1.9871	-1.9116	-1.8504	-1.7478	-1.6651	-1.61.34	-2.0987	-2.4158	-1.4453	-1.4396	-1.4259	-1.4474
-10	-1.3815	-1.3870	-1.5086	-1.4449	-1.3213	-1.3864	-1.3916	-1.8813	-2.289	-1.4072	-1.4016	-1.3826	-1.3906
-30	-0.4939	-0.7152	-1.0512	-0.9459	-0.7048	-1.0853	-1.2183	-1.6471	-2.1648	-1.3998	-1.3940	-0.3101	-1.3706
M	4	6	2	2	2	2	2	2	2	2	2	2	2
λ	0.5	0.5	0.1	0.3	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
D^{-1}	10	10	10	10	10	20	30	10	10	10	10	10	10
α	2	2	2	2	2	2	2	4	6	2	2	2	2
Sc	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.24	0.6	1.3	2.01

Table – 8
Nusselt number (Nu) at the inner cylinder r = 1

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
10	-1.3991	-1.4284	-1.4311	-1.4392	-1.3839	-1.3785	-1.3537	-1.3157	-1.0969	-0.4928	0.1101
30	-1.4244	-1.4959	-1.5437	-1.4596	-1.4112	-1.4066	-1.3853	-1.3536	-1.1277	-0.5365	0.0520
-10	-1.3857	-1.3826	-1.4082	-1.4273	-1.3697	-1.3641	-1.3388	-1.2993	-1.0815	-0.4727	0.1358
-30	-1.3773	-0.8301	-1.4004	-1.4194	-1.3613	-1.3557	-1.3296	-1.2896	-0.0717	-0.4606	0.1513
γ	0.3	0.5	1.3	2.3	-0.3	-0.5	-1.3	-2.3	0.5	0.5	0.5
Q	1	1	1	1	1	1	1	1	2	4	6

Table – 9
Sherwood number (Sh) at the inner cylinder r = 1

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
10	-1.2834	-1.2885	-1.2897	-1.4941	-1.3851	-1.1914	-1.2765	-1.2725	-1.2775	-1.2521	-1.4799	-1.4013	-1.1232
30	-1.6825	-1.7048	-1.7265	-1.9294	-1.8021	-1.3734	-1.5146	-1.4452	-1.5609	-1.2582	-1.5106	-1.4308	-1.1468
-10	-1.2369	-1.2243	-1.2176	-1.4632	-1.3486	-1.1294	-1.2324	-1.2316	-1.2405	-1.2432	-1.4633	-1.3865	-1.2443
-30	-0.6511	-0.5557	-0.3665	-0.9501	-0.8043	-0.4957	-0.5829	-0.4164	-0.9362	-1.2380	-1.4553	-1.3786	-1.1041
M	4	6	2	2	2	2	2	2	2	2	2	2	2
λ	0.5	0.5	0.1	0.3	0.7	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
D^{-1}	10	10	10	10	10	20	30	10	10	10	10	10	10
α	2	2	2	2	2	2	2	4	6	2	2	2	2
Sc	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.3	0.24	0.6	1.3	2.01

Table – 10
Sherwood number (Sh) at the inner cylinder r = 2

G	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
10	-1.1983	-1.2834	-1.4814	-1.7313	-1.0085	-0.9416	-0.6502	-0.2220	-1.1987	-1.1999	-1.2008
30	-1.2259	-1.4835	-1.5032	-1.7489	-1.0412	-0.9756	-0.6932	-0.2807	-1.2282	-1.2330	-1.2384
-10	-1.1841	-1.2369	-1.4696	-1.7218	-0.9929	-0.9250	-0.6309	-0.1967	-1.1842	-1.1844	-1.1846
-30	-1.1764	-1.1911	-1.4632	-1.7164	-0.9834	-0.9158	-0.6194	-0.1828	-1.1762	-1.1756	-1.1751
γ	0.3	0.5	1.3	2.3	-0.3	-0.5	-1.3	-2.3	0.5	0.5	0.5
Q	1	1	1	1	1	1	1	1	2	4	6

V. CONCLUSION:

This paper gives the effect of chemical reaction on mixed convective heat and mass transfer flow of a viscous electrically conducting fluid through a porous concentric annulus. The governing equations are solved numerically by reducing the differential equations in to difference equations which are solved using Gauss-Seidel Iteration method.

- An increasing in λ leads to an enhancement with increase in λ
- We find that an increase in the radiation absorption parameter Q_1 results in a

depreciation in the concentration in the entire flow region.

- The stress at r = 1 enhances with increase in G (><0) while at r =2 |τ| depreciates with G > 0 and enhances with G < 0.
- An increase in the strength of the heat source leads to a depreciation in the stress

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