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IMPACT OF THERMO DIFFUSION, DIFFUSION THERMO AND HALL CURRENT ON TRANSIENT MHD FLOW PAST AN OSCILLATING VERTICAL PLATE

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Abstract:

The present study is carried out to impact of thermo- diffusion, diffusion- thermo and hall current on transient MHD flow past an oscillating vertical plate. The transformed non- linear coupled, dimensionless partial differential equations describing the flow are solved with physically appropriate boundary conditions using the finite element method (FEM). The influence of relevant parameters on non-dimensional primary and secondary velocities, temperature and concentration profiles is depicted graphically and investigated in detail. The results are analyzed with the study published earlier and it creates a fine concord.

Key words: *Thermal diffusion, Diffusion- thermo, Hall current, Transient, MHD, oscillating, FEM.*

1.Introduction:

When heat and mass transfer occur simultaneously in a moving fluid, the relations between the fluxes and the driving potentials are of a more intricate nature. It has been observed that an energy flux can be generated not only by temperature gradients but also by concentration gradients. The energy flux caused by a concentration gradient is termed the diffusion-thermo (Dufour) effect. On the other hand, mass fluxes can also be created by temperature gradients and this embodies the thermal-diffusion (Soret) effect. In most of the studies related to heat and mass transfer process, Soret and Dufour effects are neglected on the basis that they are of a smaller order of magnitude than the effects described by Fouriers and Ficks laws. But these effects are considered as second order phenomena and may become significant in areas such as hydrology, petrology, geosciences, etc. Soret-Dufour and radiation effect on MHD flows arise in many areas of engineering and applied physics. The study of such flow has application in MHD generators, chemical engineering, nuclear reactors, geothermal energy, reservoir engineering and astrophysical studies. In nature, the assumption of the pure fluid is rather impossible. The presence of foreign mass in the fluid plays an important role in flow of fluid. Thermal diffusion is one of the mechanisms in the transport phenomena in which molecules are transported in a multi-component mixture driven by temperature

gradient. Siva Reddy and Anjan Kumar [1] investigated finite element analysis of heat and mass transfer past an impulsively moving vertical plate with ramped temperature. Kumar et al. [2] studied thermal diffusion effects on MHD heat and mass transfer flow past a moving vertical plate when the magnetic field relative to the fluid on to the plate. Siva Reddy et al. [3] analysed Thermal-diffusion and diffusion-thermo effects on MHD natural convective flow through porous medium in a rotating system with ramped temperature. Recently, Pal et al. [4] discussed Soret and Dufour effects on MHD convective-radiative heat and mass transfer of nano fluids over a vertical nonlinear stretching/shrinking sheet. Ojjela et al. [5] studied unsteady MHD mixed convective flow of chemically reacting and radiating couple stress fluid in a porous medium between parallel plates with Soret and Dufour effects. Shivaiah and Anand Rao [6] Soret and Dufour effects on transient MHD flow past a semi- infinite vertical porous plate with chemical reaction. Siva Reddy Sheri and Prashanthi Modugula [7] Thermal-diffusion and diffusion-thermo effects on MHD flow through porous medium past an exponentially accelerated inclined plate with variable temperature. Siva Reddy Sheri et al. [8], Soret and Dufour effects on MHD free convection flow past an impulsively moving vertical plate in the presence of Inclined Magnetic field.

Unsteady magneto hydrodynamic flow of rotating fluids, is a classical problem that has various applications in the field of aerospace, medical, manufacturing of fibbers, aerodynamics, bio fluids, MHD power generators and pumps, accelerators, aerodynamic heating, electrostatic precipitation, polymer technology, petroleum industry, purification of crude oil and fluid droplets, sprays, rotating hydro magnetic generators and vortex type MHD power generators. Garg [9] has presented on combined effects of thermal radiations and Hall current on moving vertical porous plate in a rotating system with variable temperature. Reddy et al. [10] have worked radiation and mass transfer effects on nonlinear MHD boundary layer flow of liquid metal over a porous stretching surface embedded in porous medium with heat generation. Hall effects on unsteady MHD natural convection flow of a heat absorbing fluid past an accelerated moving vertical plate with ramped wall temperature was investigated by Seth et al [11]. Ramireddy et al. [12] have studied effect of nonlinear thermal radiation on MHD chemically reacting maxwell fluid flow past a linearly stretching sheet. Unsteady heat and mass transfer from a rotating vertical cone with a magnetic field and heat generation or absorption effects were investigated by Chamkha and Mudhaf [13].

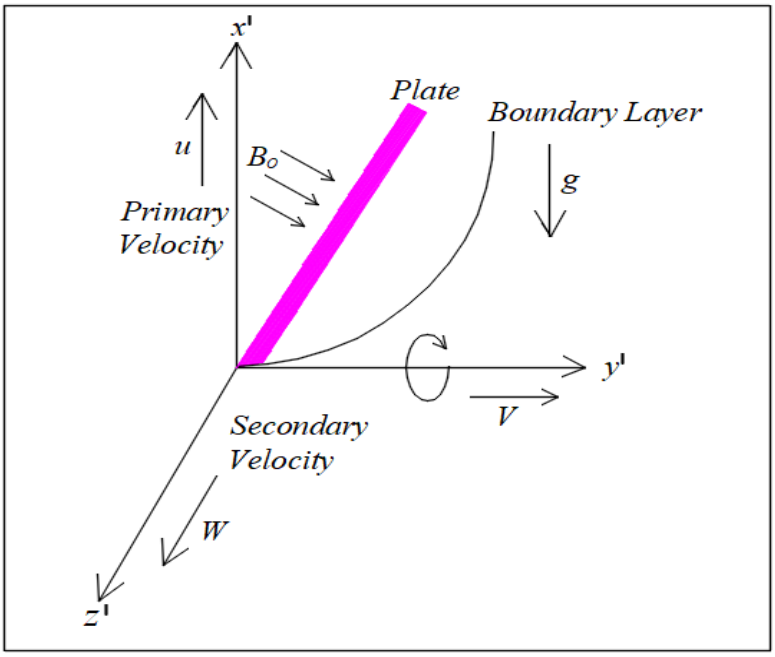
The main purpose of the present investigation is to study the thermo-diffusion, diffusion-thermo and hall current on transient MHD flow past an oscillating vertical plate. The numerical results are compared with skin friction, Nusselt number and Sherwood number and found to be in good agreement with previous results as special case of the present investigation.

2. Mathematical Formulation

In this problem we discussed viscous and MHD fluid past an oscillating plate with Hall effect. The physical model containsx', y' and z' are three mutually perpendicular axes and u', v' and w' are velocity components along three axes correspondingly. The plate is electrically non-conducting, taken along x'-axis and inclined at an angle $\boldsymbol{\alpha}$ from vertical. A magnetic field of strength $B_0$is applied transversally on the plate. Initially, assume plate and fluid have same temperature T'_∞ and concentration of the fluid is C'_∞. At time $t' > 0$, plate starts oscillating with frequency ω' in its individual plane, also temperature and

concentration of the plate and fluid is increased to T'_w and C'_w correspondingly. The Geometric model of the flow is depicted in Fig 1.

Figure 1: Geometric model of the flow



The governing equations are as under:

$$\frac{\partial u'}{\partial t'} + 2\Omega' w' = \upsilon \frac{\partial^2 u'}{\partial y'^2} - \left(\frac{\sigma {B_0}^2}{\rho}\right)\frac{(u'+mw')}{(1+m^2)} - \frac{\upsilon}{K_1'}u' + g\beta' \cos\alpha\,(T'-T'_\infty) + g\beta^* \cos\alpha\,(C'-C'_\infty) \quad (1)$$

$$\frac{\partial w'}{\partial t'} - 2\Omega' u' = \upsilon \frac{\partial^2 w'}{\partial y'^2} + \left(\frac{\sigma {B_0}^2}{\rho}\right)\frac{(mu'-w')}{(1+m^2)} - \frac{\upsilon}{K_1'}w' \quad (2)$$

$$\frac{\partial T'}{\partial t'} = \frac{k}{\rho C_p}\frac{\partial^2 T'}{\partial y'^2} - \frac{Q_0}{\rho C_p}(T'-T'_\infty) + \frac{Dk_T}{c_s C_p}\frac{\partial^2 C'}{\partial y'^2} \quad (3)$$

$$\frac{\partial C'}{\partial t'} = D\frac{\partial^2 C'}{\partial y'^2} + \frac{Dk_T}{T_m}\frac{\partial^2 T'}{\partial y'^2} \quad (4)$$

The associated initial and boundary conditions are:

$$\left.\begin{aligned} &t' \le 0 : u' = 0,\ w' = 0,\ T' = T'_\infty,\ C' = C'_\infty \ for\ every\ y' \\ &t' > 0 : u' = u_0 \cos(\omega' t'), w' = 0, T' = T'_\infty + \frac{(T'_w - T'_\infty)u_0^2 t'}{\upsilon}, \\ &\qquad C' = C'_\infty + \frac{(C'_w - C'_\infty)u_0^2 t'}{\upsilon}\ \ at\ y' = 0 \\ &u' \to 0,\ w' \to 0,\ T' \to T'_\infty,\ \ C' \to C'_\infty\ as\ y' \to \infty \end{aligned}\right\} \quad (5)$$

To write the equations (1) - (4) in non-dimension system, we introduce the given dimensionless quantities:

$$\left.\begin{aligned} &y = \frac{y'u_0}{\upsilon}, u = \frac{u'}{u_0}, w = \frac{w'}{u_0}, t = \frac{t'u_0^2}{\upsilon}, \theta = \frac{(T'-T'_\infty)}{(T'_w - T'_\infty)}, C = \frac{(C'-C'_\infty)}{(C'_w - C'_\infty)}, Pr = \frac{\mu c_p}{k}, Sc = \frac{\upsilon}{D} \\ &Du = \frac{Dk_T}{\upsilon c_s c_p}\frac{(C'_w - C'_\infty)}{(T'_w - T'_\infty)}, Sr = \frac{Dk_T}{\upsilon T_m}\frac{(T'_w - T'_\infty)}{(C'_w - C'_\infty)} M = \frac{\sigma B_0^2 \upsilon}{\rho u_0^2}, K = \frac{K_1' u_0^2}{\upsilon^2}, Gr = \frac{g\upsilon\beta'(T'_w - T'_\infty)}{u_0^3} \\ &Gm = \frac{g\upsilon\beta^*(C'_w - C'_\infty)}{u_0^3}, Q = \frac{Q_0 \upsilon}{\rho c_p u_0^2}, \omega = \frac{\omega'\upsilon}{u_0^2}, m = \omega_e \tau_e, \qquad \Omega = \frac{\Omega'\upsilon}{u_0^2} \end{aligned}\right\} \quad (6)$$

The dimension less flow model becomes:

$$\frac{\partial u}{\partial t} + 2\Omega w = \frac{\partial^2 u}{\partial y^2} - \left(\frac{M}{1+m^2}\right)(u+mw) - \frac{u}{K} + Gr\cos(\alpha)\theta + Gm\cos(\alpha)C \quad (7)$$

$$\frac{\partial w}{\partial t} - 2\Omega u = \frac{\partial^2 w}{\partial y^2} + \left(\frac{M}{1+m^2}\right)(mu - w) - \frac{w}{K} \quad (8)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\mathrm{Pr}}\frac{\partial^2 \theta}{\partial y^2} - Q\theta + \mathrm{Du}\frac{\partial^2 C}{\partial y^2} \quad (9)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} + Sr\frac{\partial^2 \theta}{\partial y^2} \quad (10)$$

Dimensionless boundary and initial conditions are:

$$\left.\begin{array}{l} t \le 0 : u = 0, w = 0,\ \theta = 0, C = 0\ for\ every\ y \\ t > 0 : u = \cos(\omega t), w = 0,\ \theta = t,\ C = t\ \ at\ \ y = 0 \\ u \to 0,\ w \to 0,\ \theta \to 0, C \to 0\ \ as\ \ y \to \infty \end{array}\right\} \quad (11)$$

Skin friction factor is expressed as

$$C_f = \frac{\tau_w}{\rho u_w^2},\ \tau_w = \left[\mu\frac{\partial u'}{\partial y'}\right]_{y'=0} = \left[\frac{\partial u}{\partial y}\right]_{y=0} \quad (12)$$

Wall couple stress at the plate is described as

$$C_w = \frac{\tau_w}{\rho w_w^2},\ w_w = \left[\mu\frac{\partial w'}{\partial y'}\right]_{y'=0} = \left[\frac{\partial w}{\partial y}\right]_{y=0} \quad (13)$$

3. Method of Solution

The FEM is a numerical technique for solving problems of engineering and mathematical physics includes structural analysis, heat transfer, fluid flow, mass transfer and electromagnetic potential. It especially deals with complicated geometries, loadings and material properties. The detailed description of this method is explained by Bathe[15] and Reddy[16]. The fundamental steps involved in FEM are

Step 1: Discretization of the infinite fluid domain into finite elements:

i. The whole domain is divided into a finite number of sub domains, which is called the discretization of the domain. Each sub domain is called an element. The collection of elements is then denoted the finite-element Mesh. The intersection of any two elements is termed an inter-element boundary. The intersection points are called the global nodes.

ii. The nodes and elements are numbered.

iii. The geometric properties needed for the problem are generated, which indicates the position of the elements.

Step 2: Derivation of element equations:

i. A typical element is isolated from the mesh and the variational formulation of the given problem over the typical element is constructed.

ii. An approximate solution of the variational problem is assumed. Substituting it into the element equations is made.

iii. The element matrix or stiffness matrix is constructed by using the element interpolation functions. The interpolation functions depend on the type of element (geometry, number of nodes and number of primary unknowns per node). These functions have to be derived or selected and are not already available in the literature.

Step 3: Assembly of Element Equations:

The algebraic equations so obtained are assembled by imposing the inter element continuity conditions (i.e., the values of the nodal variables at the nodes are identical for two or more elements). This yields a large number of algebraic equations known as the global finite element model, which governs the whole domain.

Step 4: Imposition of boundary conditions:

The initial and final boundary conditions (3.10) are imposed on the assembled equations.

Step 5: Solution of assembled equations:

The assembled equations are solved by any of the numerical technique viz. Gaussian Elimination, Gauss-Seidel, LU decomposition etc.

4. Code Validation

The existing outcomes are compared with outcomes of Rajput and Kanaujia [14]. It is detected that the attained outcomes are close convergent with the published results (see table 5.1). Also noticed from Table 5.1 that magnitude of C_f rises with the rising values of K and ωt however, reduces with rising of α, Q and Ω. The value of C_w enhances with rising in Q and ωt. Further, it diminishes if α, Ω and K are rises.

5. Results and Discussions

In this problem, we discussed and analyzing the characteristics of fluid and are examined to the effect of physical variables. These effects are established graphically. The values of skin friction for different values of parameters are shown in table. Given values of flow parameters are assumed for calculations unless or else specified in the graphs and table Gr = 12.0, Gm = 2.0, M = 1.0, K = 1.0, $m = 1.0$, $\alpha = 30^0$, $\omega t = 30^0$, $Pr = 0.71, Q = 2.0, Du = 1.0, Sc = 0.13, Sr = 1.0$ and $t = 1.0$.

Figures 2 and 3 shows the impact of thermal Grashof number Gr on primary and secondary velocity profiles. Gr is the ratio between thermal buoyancy forces to the viscous hydrodynamic force. As Gr raises both the velocity profiles are rises.

The effect of mass Grashof number Gm on primary and secondary velocity profiles is depicted in figures 4 and 5. Gm signifies the ratio of the species buoyancy force to the viscous hydrodynamic force. Observed that the velocity fields rise with rising values of Gm.

Figures 6 and 7, illustrates the influence of inclination angle (α) on primary and secondary velocity components. It is observed that an increase in inclination (increasingly sloped duct walls) evidently depresses both primary and secondary velocity magnitudes. Primary velocity overshoots are also markedly pushed closer to the wall and reduced simultaneously.

Figures 8 and 9 displays the primary and secondary velocity profiles versus non-dimensional species coordinates for distinct values of M. It is clear that a rise in M, the velocity field throughout the boundary layer decreases. A resistive-type of force called the Lorentz force has obtained with the application of a transverse magnetic field to an electrically conducting fluid, and this force has a behaviour to slow down the fluid motion in the boundary layer.

From figures 10 and 11, visualizes the evolution in primary and secondary velocity profiles with permeability of the porous medium (K) as noted earlier the Darcy model is employed in the simulations which is valid for low-speed transport. Substantial enhancement in both primary and secondary velocity components is observed with an increase in permeability of porous medium.

Figures 12 and 13 shows the effect of Hall current parameter ***m*** on primary and secondary velocity profiles respectively. We observe from figure. 12 that the primary velocity field steeply rises up to maximum peaks

as the Hall parameter increases. Figure 13, incorporates the influence of micro rotation profile approaches their classical values when the Hall parameter becomes large. This means that the secondary velocity profile increases with increasing values of Hall parameter.

A slowing down phenomenon on primary velocity and reverse tendency on secondary velocity against rotation parameter recognized from figures 14 and 15. It happens due to the reason that the Coriolis force works as a constraint in the primary fluid flow when the friction layer near the moving plate is suddenly situate into motion, Coriolis force stops the flow in the primary flow direction and generates a cross flow which is termed as secondary flow.

The primary, secondary velocities and temperature profiles for different Prandtl numbers corresponding to various substances shows in figures 16, 17 and 18. Observed from these, that both the velocities and temperature profiles diminish as a growth in Prandtl number.

Figures 19, 20 and 21 show the primary, secondary velocities and temperature field for distinct values of Q. In figures 19 and 20, when Q rises, raises the boundary layer, because when heat is absorbed, the buoyancy force raises and retards the fluid flow, therefore, reduce in the primary, secondary velocities fields. In figure 21, noticed that the temperature diminishes with rising values of Q. Since heat is absorbed, the buoyancy force reduces the temperature gradient.

Figures 22, 23 and 24 depicts the primary, secondary velocities and temperature field for distinct values of Du. The thermal energy flux due to the mass concentration gradient is called Dufour number. The primary, secondary velocities and temperature profiles rise with the rising values of Du.

The impact of the Soret number on dimensionless primary, secondary velocities and concentration fields is presented in figures 25, 26 and 27 respectively. The Soret number is the phenomenon that takes place in mixtures of particles where different types of particles act differently due to temperature gradient. It is observed that the primary, secondary velocities and concentration profile increase as the rise in the Soret number.

Figures 28, 29 and 30 shows the primary, secondary velocities and concentration fields for different values of the Schmidt number, Helium (Sc = 0.3), Steam (Sc = 0.6), Ammonia (Sc = 0.78) and Ethyl Benzene (Sc = 2.01). The Schmidt number embodies the relative effectiveness of momentum and mass diffusion in the hydrodynamic and concentration boundary layers. It is observed that primary, secondary velocities and concentration fields reduce by increases Schmidt number.

6. Conclusions

The current study explores the impact of the major findings are summarized as:

- Primary velocity decreases with the increase in $\alpha, M, \Omega, \Pr, Q$ and Sc .
- Primary velocity increases as Gr, Gm, K, m, Du and Sr increase.
- Secondary velocity decreases with the increase in $\alpha, M, \Pr, Q$ and Sc .
- Secondary velocity increases as Gr, Gm, Ω, K, m, Du and Sr increase.
- Temperature increases with the increase in Du .
- Temperature decreases with the increase in Pr and Q.
- Concentration increases with the increase in Sr

- Concentration decreases with the increase in *Sc*.

7. Tables

Table 1. Comparison of C_f and C_w when $Sr = 0$ and $Du = 0$.

8.

α (Deg.)	Q	K	Ω	ωt (Deg.)	Rajput and Kanaujia [84]		present result	
					C_f	C_w	C_f	C_w
30	5.0	0.2	2.0	30	6.1615	-1.7059	6.1615 24	-1.705916
45	5.0	0.2	2.0	30	6.0523	-1.8295	6.052317	-1.829528
30	10	0.2	2.0	30	3.9056	-0.9315	3.905631	-0.931524
30	20	0.2	2.0	30	3.8297	-0.9218	3.829723	-0.921818
30	1.0	0.1	2.0	30	2.6698	-0.6839	2.669828	-0.683927
30	1.0	0.3	2.0	30	4.5014	-1.07325	4.501417	-1.0732518
30	1.0	0.2	3.0	30	3.7852	-1.51997	3.785223	-1.5199725
30	1.0	0.2	5.0	30	3.2560	-2.4944	3.256026	-2.494419
30	1.0	0.2	2.0	45	4.4793	-0.8750	4.479325	-0.875027
30	1.0	0.2	2.0	60	5.1391	-0.7898	5.139131	-0.789825

Figures

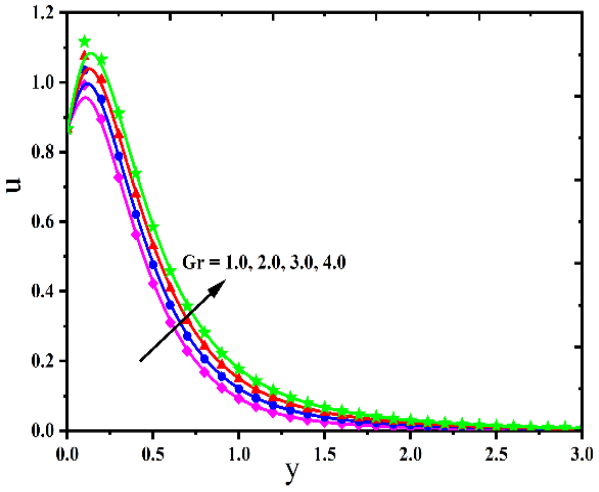


Fig 2: Influence of (*Gr*) on velocity (*u*)

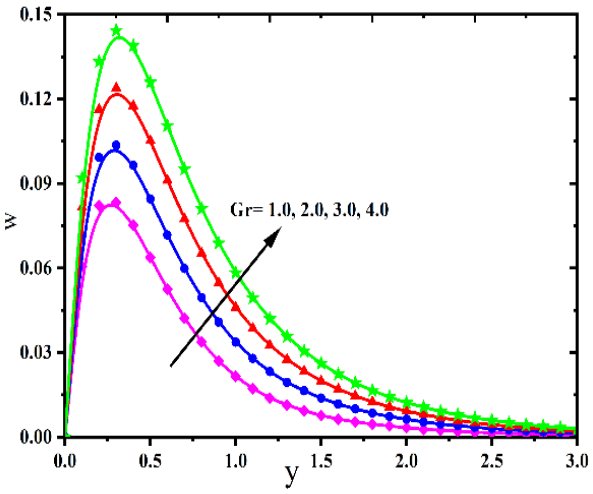


Fig 3: Influence of (*Gr*) on velocity (*w*)

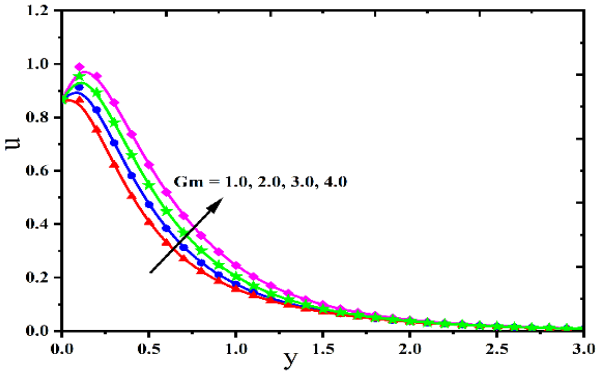


Fig 4: Influence of (*Gm*) on velocity (*u*)

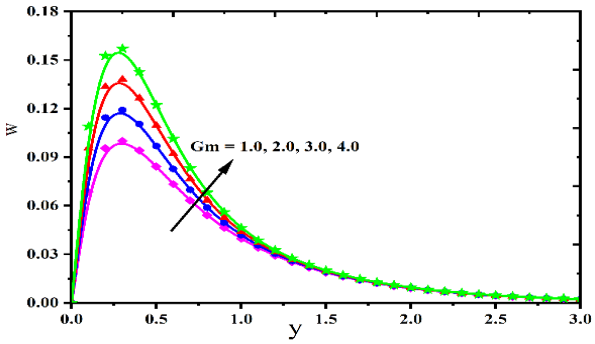


Fig 5: Influence of (*Gm*) on velocity (*w*)

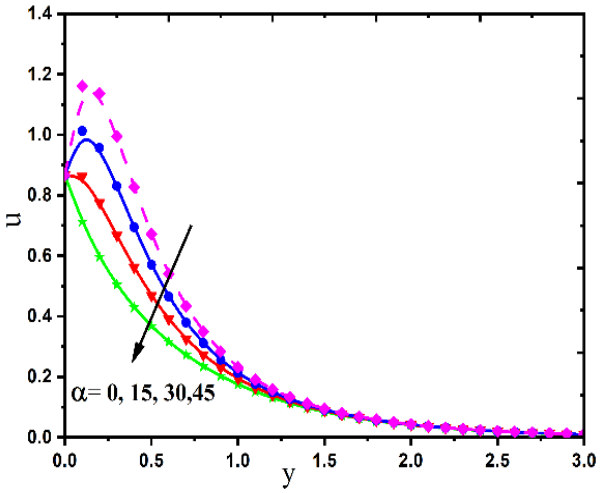


Fig 6: Influence of (α) on velocity (*u*)

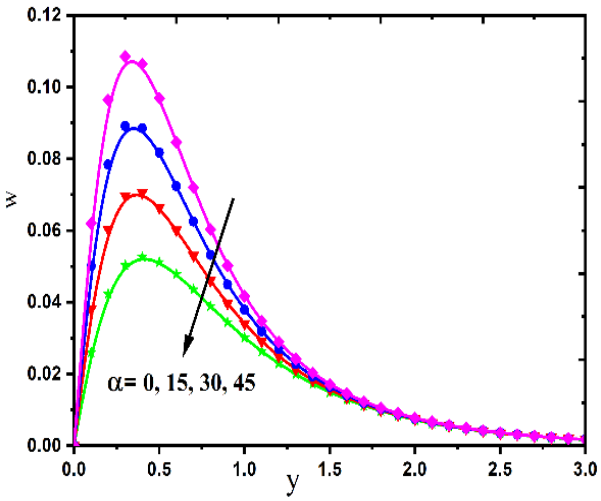


Fig 7: Influence of (α) on velocity (*w*)

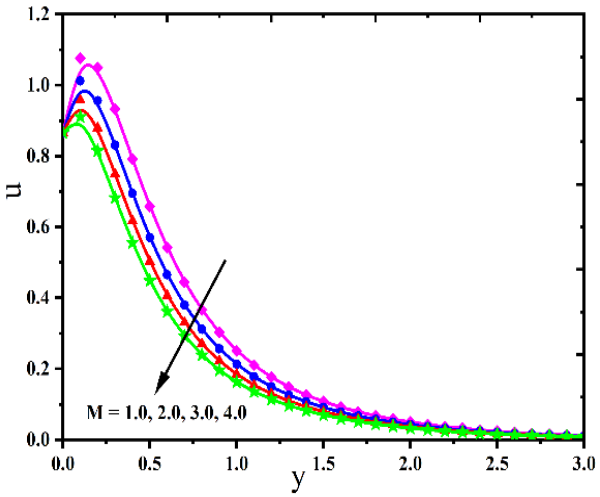


Fig 8: Influence of (*M)* on velocity (*u)*

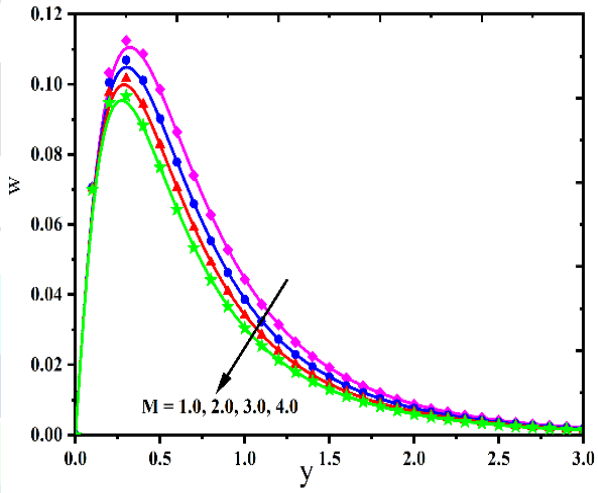


Fig 9: Influence of (*M)* on velocity (*w)*

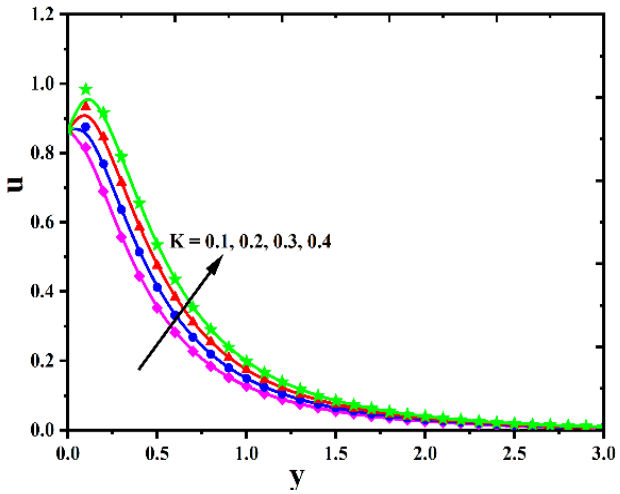


Fig10: Influnce of (*K)* on velocity (*u)*

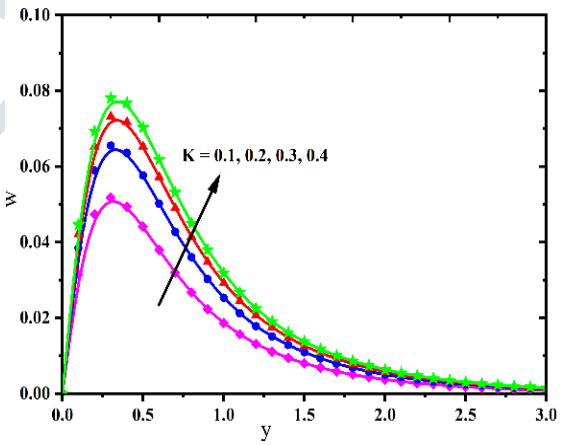


Fig 11: Influence of (*K)* on velocity (*w)*

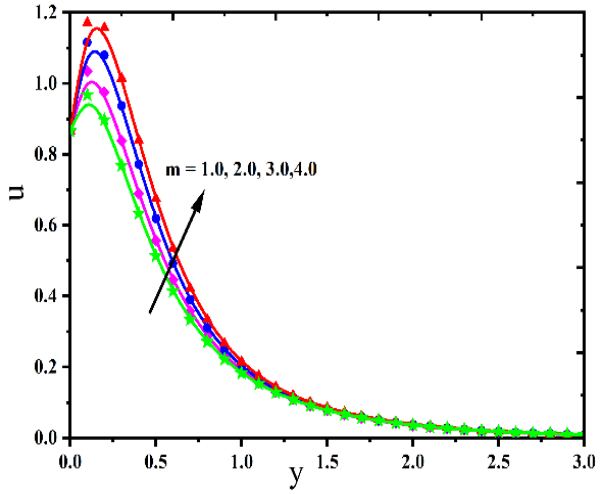


Fig 12: Influence of (*m*) on velocity (*u*)

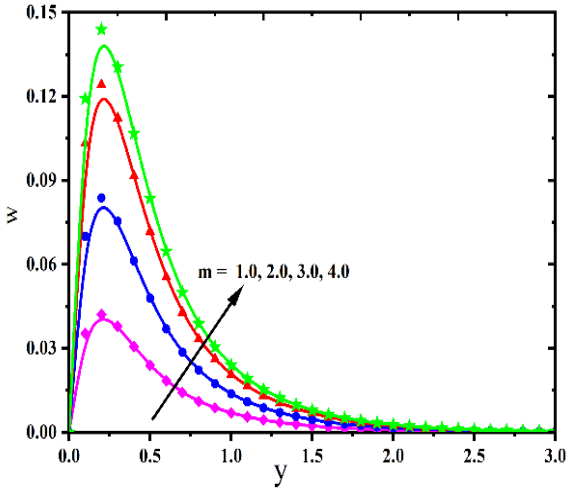


Fig 13: Influence of (*m*) on velocity (*w*)

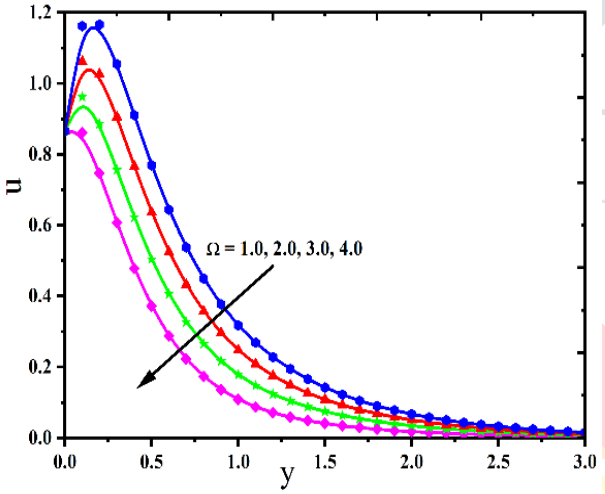


Fig 14: Influence of (Ω) on velocity (*u*)

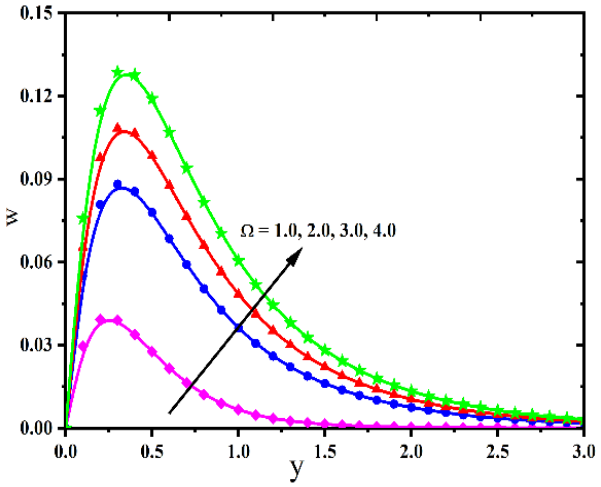


Fig 15: Influence of (Ω) on velocity (*w*)

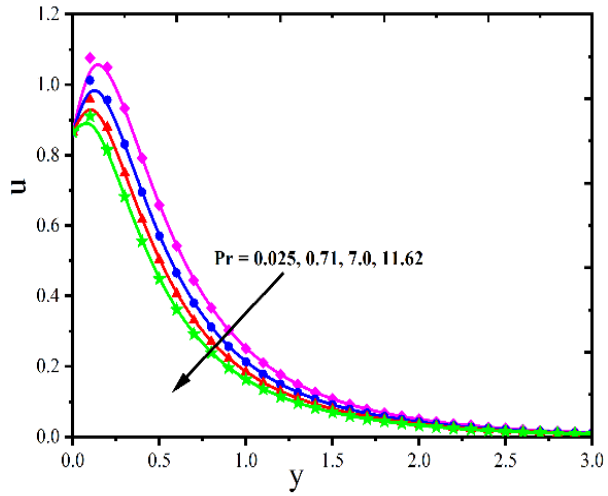


Fig 16: Influence of (*Pr*) on velocity (*u*)

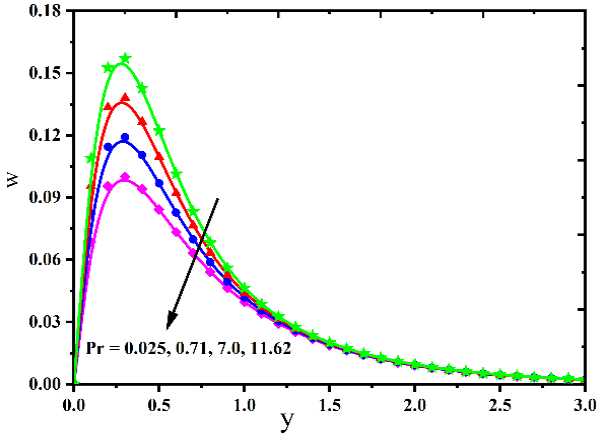


Fig17: Influence of (*Pr*) on velocity (*w*)

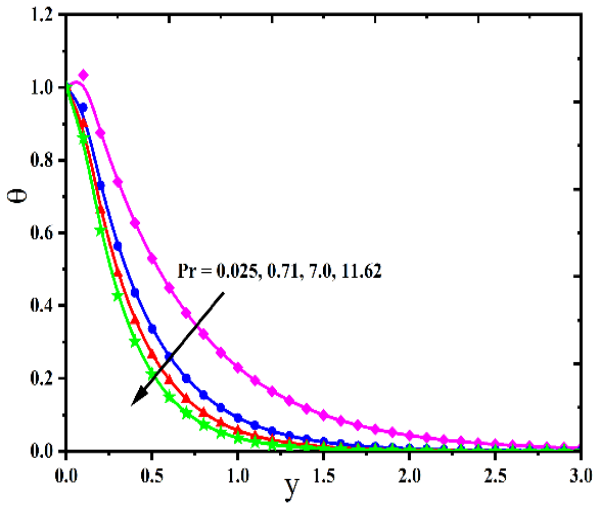


Fig18: Influence of (Pr) on temperature (θ)

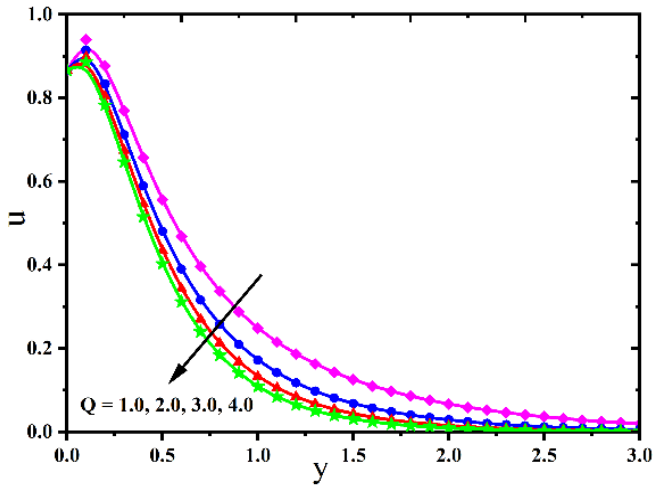


Fig19: Influence of (Q) on velocity (u)

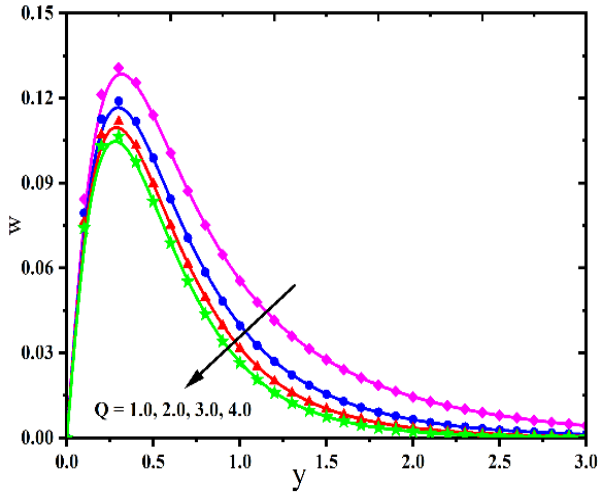


Fig 20: Influence of (Q) on velocity (w)

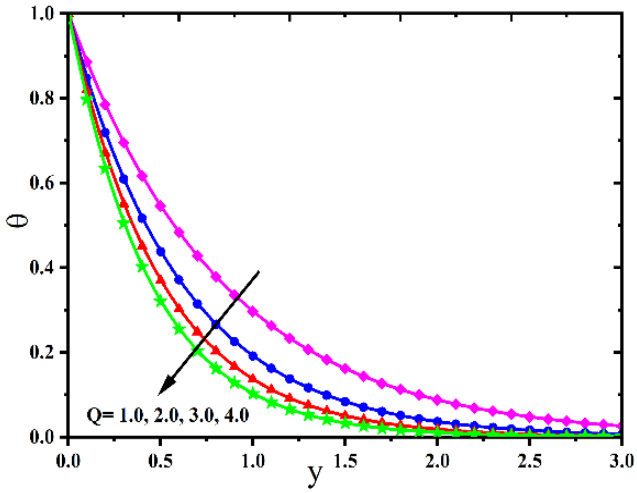


Fig 21: Influence of (Q) on temperature(θ)

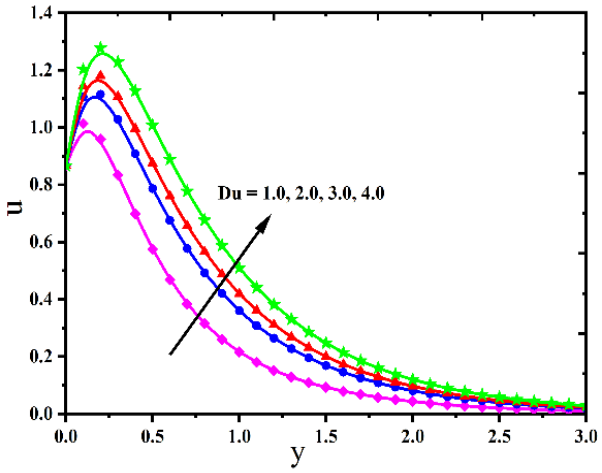


Fig 22: Influence of (Du) on velocity (u)

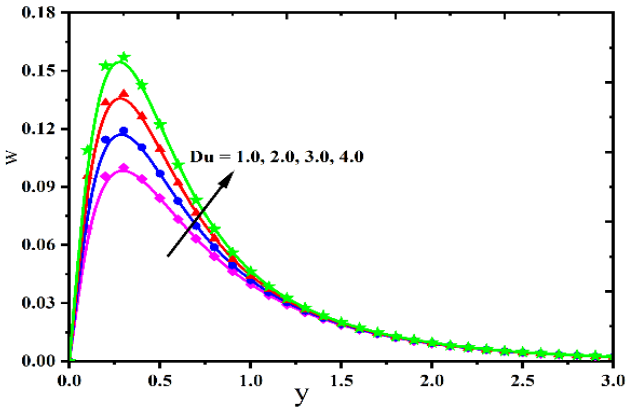


Fig 23: Influence of (Du) on velocity (w)

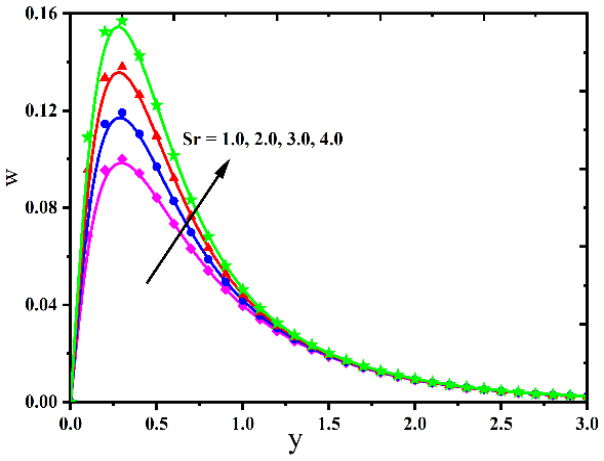


Fig 24: Influence of (*Du*) on temperature (θ)

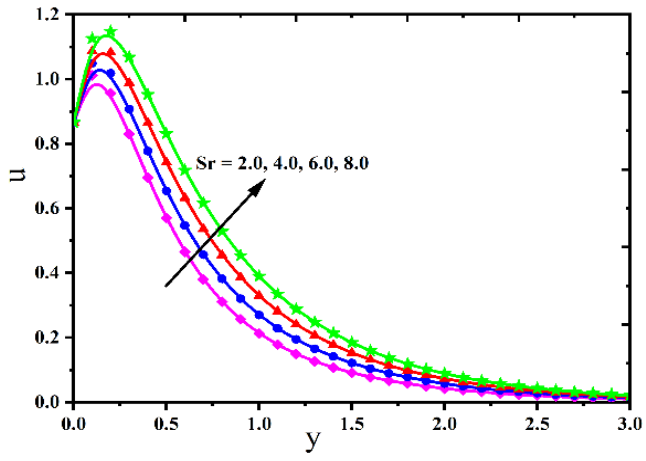


Fig 25: Influence of (*Sr*) on velocity (*u*)

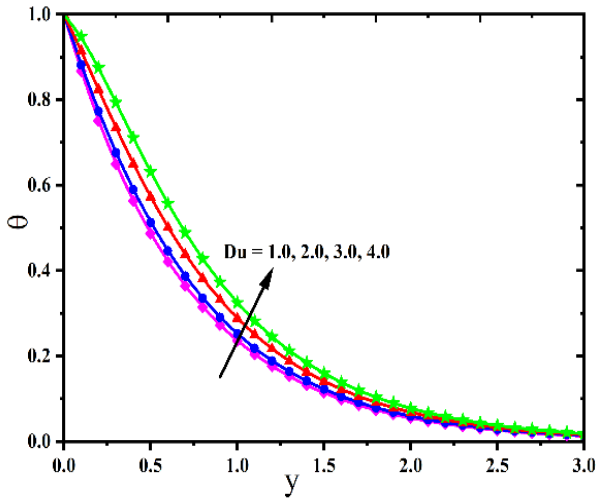


Fig 26: Influence of (*Sr*) on velocity (*w*)

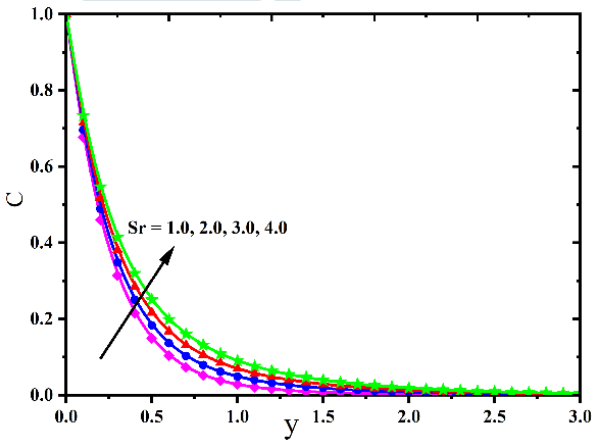


Fig 27: Influence of (*Sr*) on concentration(*C*)

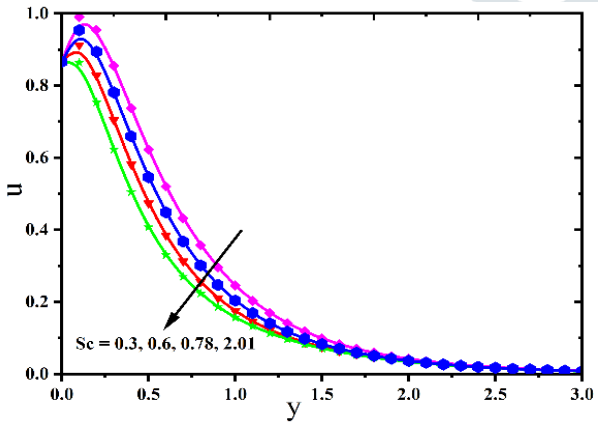


Fig 28: Influence of (*Sc*) on velocity (*u*)

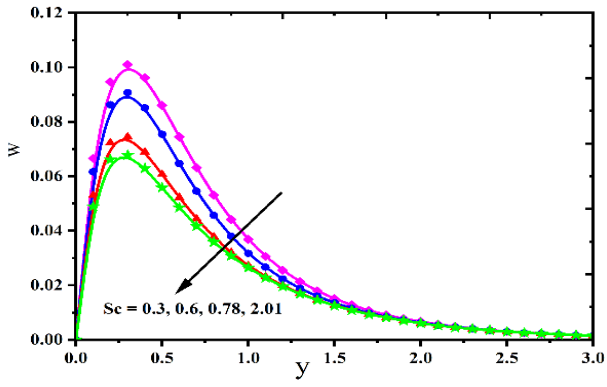


Fig 29: Influence of (*Sc*) on velocity (*w*)

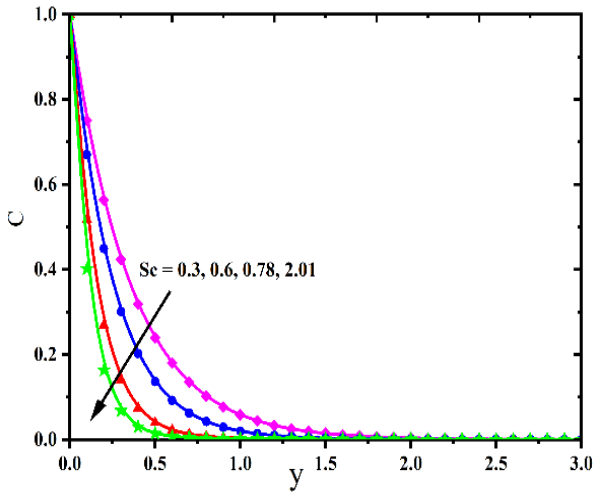


Fig 30: Influence of (*Sc*) on concentration (*C*)

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