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Influence of Viscous Dissipation on MHD unsteady flow past an Exponentially Accelerated plate through Porous Medium with Heat Source

Prof. (Dr). P. T. Hemamalini[1], and N. Suresh kumar[2]

[1]HOD, Department of science and humanities, Karpagam University,
Coimbatore- 641021. TN, India.
[2]Research Scholar in Department of Mathematics, Karpagam University,
Coimbatore-641021, TN, India.

Abstract:
An investigation of viscous dissipation possessions on MHD unsteady heat and mass transfer flow past an exponentially accelerated vertical plate all the way through a porous medium with changeable temperature with heat source has been considered the dimensionless essential equations are solved by resources of the perturbation technique. Resulting non-dimensional velocity, temperature and concentration summary are then accessible graphically for diverse standards of the parameters entering into the problem. Finally, the personal property of the pertinent parameters on the skin-friction coefficient, the speed of heat transfer (Nusselt number) and the speed of mass transfer (Sherwood number), which are of physical interest, are accessible graphically.
Keywords: Heat transfer, Mass transfer, MHD, Viscous Dissipation, Radiation, Chemical reaction, Heat source, Porous medium.

1. Introduction

The radiation released at each point of a plane surface in varied direction in to the hemisphere. It differs from other heat transfer mechanism which does not have need of a material medium. The energy transferred from side to side radiation is fast (at the rapidity of light) and necessitate no consideration in vacuum. The relocate of radiation takes place in expressions of liquid, gases and solids. The three modes of heat transfer takes place at the same time at different degree. The heat transfers from beginning to end a space that which takes place only by radiation for occurrence, the energy of sun is emitted all the way through radiation towards earth. The theoretical establishment of radiation was conventional in 1864 by physicist James clerk Maxwell, who postulated that accelerated transform or changing electric in progress give get elevated to electric and magnetic fields. These quickly moving fields are called electromagnetic bearing or electromagnetic radiation and they correspond to the energy emitted by substance as a consequence of the changes in the electronic configurations of the atoms or molecules.

2. Formulation of the Problem

The viscous dissipation in MHD consequence on unsteady stream all the way through an exponentially accelerated plate in the occurrence of porosity and heat sink is analyzed. The plate is occupied along the x- axis vertically and y-axis is measured normal to the plate. In the commencement the temperature of the plate, fluid is at T'_∞.At $t' > 0$ the plate velocity is raised to $u_0 \exp(a' t')$, the heats transmit and mass transmit of the plate rises slowly but surely with time.The stable magnetic field of strength B_0 in the existence of radiation is compulsory transversely in the y way. The changeable of the flow are the gathering of y and t' alone. The first order chemical response of first instruct is recorded in the concentration equation. The principal equations for this knowledge are based on the linear momentum, energy and species concentration equations in Cartesian frame of reference as:

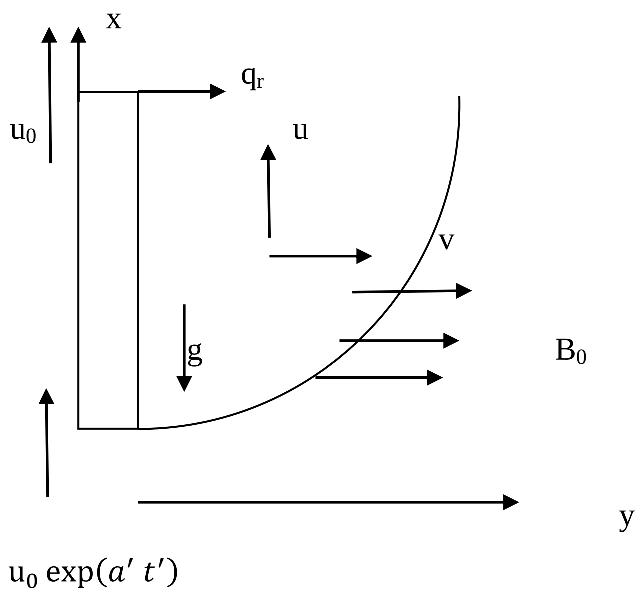

Figure.1. Physical configuration and coordinate system

The stable magnetic field of strength B_0 in the existence of radiation is compulsory transversely in the y way. The changeable of the flow are the gathering of y and $t^{'}$ alone. The first order chemical response of first instruct is recorded in the concentration equation. The principal equations for this knowledge are based on the linear momentum, energy and species concentration equations in Cartesian frame of reference as:

Then beneath common Boussinesq's estimate, the principal equations are

$$\frac{\partial u'}{\partial t'} = g\ \beta_T\,(T' - T'_\infty) + g\ \beta_C^*\,(C' - C'_\infty)$$

$$+\nu \left(\frac{\partial^2 u'}{\partial y^2}\right) - \nu \left(\frac{u'}{k'}\right) - \left(\frac{\sigma B_0^2\, u'}{\rho}\right) \qquad (1)$$

$$\rho\, C_P \frac{\partial T^{'}}{\partial t^{'}} = \kappa \frac{\partial^2 T^{'}}{\partial y^2} + \mu \left(\frac{\partial u^{'}}{\partial y}\right)^2$$

$$-\left(\frac{\partial q_r}{\partial y}\right) - Q_0\,(T' - T'_\infty) \qquad (2)$$

$$\frac{\partial C^{'}}{\partial t^{'}} = D \frac{\partial^2 C^{'}}{\partial y^2}$$

$$- K_\ell\,(C^{'} - C^{'}_\infty) \qquad (3)$$

ρ- density of the intermediate,ν- kinematic viscosity, g - gravity acceleration,σ - fluid electrical conductivity, B_O - magnetic induction, q_r - radiative heat flux. The term $Q_0(T^{'} - T^{'}_\infty)$ is unspecified to be the quantity of heat generation or experiential per unit volume, Q_O is constant which may obtain on either positive or negative values. When the plate temperature $T^{'}$ exceeds the free stream temperature $T^{'}_\infty$ the source term $Q_O > 0$ and heat sink when $Q_O < 0$. D is the chemical molecular diffusivity and q_r is the radiative flux.

The early and border line condition of the leading equation are

$$u' = 0,\ T' = T'_\infty,\ C' = C'_\infty \ \text{ for all } y,\ \ t' \le 0$$

$$u' = u_0 \exp(a'\, t'),\ \ T' = T'_\infty + (T'_w - T'_\infty) A\, t',$$

$$C' = C'_\infty + (C'_w - C'_\infty)\, A\, t' \ \text{ at } y = 0,\ \ t' > 0$$

$$u' \to 0,\ T' \to T'_\infty\,,\ C' \to C'_\infty \quad \text{as } y \to \infty, t' > 0 \quad (4)$$

where $A = \left(\frac{u_0^2}{\nu}\right)$

Introducing the similarity variables and dimensionless quantities

$$U = \left(\frac{u^{'}}{u_0}\right), t = \left(\frac{t^{'}\, u_0^2}{\nu}\right), Y = \left(\frac{y\, u_0}{\nu}\right), Sc = \left(\frac{\nu}{D}\right)$$

$$\theta = \left(\frac{T^{'} - T^{'}_\infty}{T^{'}_w - T^{'}_\infty}\right), \phi = \left(\frac{C^{'} - C^{'}_\infty}{C^{'}_w - C^{'}_\infty}\right), k = \left(\frac{u_0^2\, k^{'}}{\nu^2}\right)$$

$$Gr = \left(\frac{g\, \beta_T\, \nu\, (T^{'}_w - T^{'}_\infty)}{u_0^3}\right), \qquad Kr = \left(\frac{\nu\, K_\ell}{u_0^2}\right)$$

$$Gc = \left(\frac{g\, \beta_c^*\ \nu\, (C^{'}_w - C^{'}_\infty)}{u_0^3}\right), \qquad a = \left(\frac{a^{'}\vartheta}{u_0^2}\right)$$

$$Ec = \left(\frac{u_0^2}{k\, (T^{'}_w - T^{'}_\infty)}\right), R = \left(\frac{16\, a^*\, \nu^2\, \sigma\, T_\infty^3}{k\, u_0^2}\right)$$

$$M = \left(\frac{\sigma\, B_0^2\, \nu}{\rho\, u_0^2}\right), Pr = \left(\frac{\mu\, C_P}{\kappa}\right), Q = \left(\frac{\nu^2 Q_0}{k\, u_0^2}\right)$$

(5)

The local radiation for case of an optically thin gray gas is uttered by

$$\left(\frac{\partial q_r}{\partial y}\right) = -4\, a^* \sigma^* \left(T_\infty'^{\,4} - T'^4\right) \quad (6)$$

By presumptuous the temperature differences within the flow are adequately small, so T'^4 expressed as a linear function of temperature. by means of the Taylor sequence expanding T'^4 in term of T'_∞ and omitting higher-order expression

$$T'^4 = 4\, T_\infty'^{\,3} T' - 3\, T_\infty'^{\,4} \quad (7)$$

by means of the dimensionless quantities (5) in the equation (1), (2) and (3) we get

$$\frac{\partial \mathrm{U}}{\partial \mathrm{t}} = \mathrm{Gr}\ \theta + \mathrm{Gc}\ \phi + \frac{\partial^2 \mathrm{U}}{\partial \mathrm{Y}^2} - \left(\mathrm{M} + \frac{1}{\mathrm{k}}\right)\mathrm{U} \quad (8)$$

$$\frac{\partial \theta}{\partial \mathrm{t}} = \left(\frac{1}{\mathrm{Pr}}\right)\left(\frac{\partial^2 \theta}{\partial \mathrm{Y}^2}\right) + \left(\frac{\mathrm{Ec}}{\mathrm{Pr}}\right)\left(\frac{\partial U}{\partial Y}\right)^2 - \left(\frac{1}{\mathrm{Pr}}\right)(R+Q)\theta \quad (9)$$

$$\frac{\partial \phi}{\partial \mathrm{t}} = \left(\frac{1}{\mathrm{Sc}}\right)\left(\frac{\partial^2 \phi}{\partial \mathrm{Y}^2}\right) - \mathrm{Kr}\ \phi \quad (10)$$

via the dimensionless quantities (5) in the primary and edge condition (4) The modified border conditions are

$$\mathrm{U} = 0, \theta = 0, \phi = 0 \text{ for all } \quad \mathrm{Y} \le 0, \mathrm{t} \le 0$$

$$\mathrm{U} = \exp(\mathrm{at}), \theta = \mathrm{t}, \phi = \mathrm{t} \text{ at } \mathrm{Y} = 0, \mathrm{t} > 0$$

$$\mathrm{U} \to 0, \theta \to 0, \phi \to 0 \text{ as } \quad \mathrm{Y} \to \infty \quad \mathrm{t} > 0 \quad (11)$$

3. Method of Solution

The classification of fixed non-linear partial differential equations (8), (9) and (10) are concentrated to dimensionless appearance of ordinary equations, in stopped up from by with the preliminary and frontier situation the solution of the equations not achievable.

In view of the fact that the amplitudes of the free flow velocity temperature variation (ε << 1) is tremendously small, in the district of the fluid and plate take for granted the solutions of the velocity, temperature and concentration of the fluid as,

$$U = U_0(y) + \epsilon\, e^{nt}\, U_1(y) + o(\epsilon^2)$$

$$\theta = \theta_0(y) + \epsilon\, e^{nt}\, \theta_1(y) + o(\epsilon^2)$$

$$\phi = \phi_0(\mathrm{y}) + \epsilon\, \mathrm{e}^{\mathrm{nt}}\, \phi_1(\mathrm{y}) + \mathrm{o}(\epsilon^2) \quad (12)$$

Substituting (12) in equation (8), (9) and (10) and then harmonic and non-harmonic expressions are equated and omitting the higher order expressions of $\mathrm{o}(\epsilon^2)$,

$$U_0'' - \left(M + \frac{1}{k}\right)U_0 = -\mathrm{Gr}\ \theta_0 - \mathrm{Gc}\,\phi_0 \quad (13)$$

$$U_1'' - \left(M + \frac{1}{k} + n\right)U_1 = -\ \mathrm{Gr}\,\theta_1 - \mathrm{Gc}\,\phi_1 \quad (14)$$

$$\theta_0'' - (R+Q)\,\theta_0 = -\,Ec\, U_0'^{\,2} \quad (15)$$

$$\theta_1'' - (R+Q+n\,Pr)\,\theta_1 = -\,2Ec\, U_0' U_1' \quad (16)$$

$$\phi_0'' - \mathrm{Sc\ Kr}\ \phi_0 = 0 \quad (17)$$

$$\phi_1'' - (\mathrm{Kr} + n)\,\mathrm{Sc}\,\phi_1 = 0 \quad (18)$$

The border line situation for the above equations can be customized as

$$U_0 = \exp(\mathrm{at}), U_1 = 0, \quad \theta_0 = t$$

$$\theta_1 = 0, \quad \phi_0 = \mathrm{t}, \quad \phi_1 = 0 \text{ at } \mathrm{y} = 0$$

$$U_0 \to 0, \quad U_1 \to 0, \quad \theta_0 \to 0$$

$$\theta_1 \to 0, \quad \phi_0 \to 0, \quad \phi_1 \to 0 \text{ as } \mathrm{y} \to \infty \quad (19)$$

The accurate solutions for attached non-linear equations (13) to (18) are not achievable,

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The incompressible fluid stream the Eckert number is especially small.

So we develop U_0, U_1, θ_0, θ_1, ϕ_0, ϕ_1 in term (f_0, f_1) of E_c in the following structure

$$f_0(y) = f_{01}(y) + Ec\ f_{02}(y)$$

$$f_1(y) = f_{11}(y) + Ec\ f_{12}(y) \qquad (20)$$

Substituting (20) in equation (13) to (18) and the coefficient of E_c equated to zero, omitting E_c^2 and higher order conditions we get

$$U_{01}'' - \left(M + \frac{1}{k}\right) U_{01} = -\ Gr\ \theta_{01} - Gc\ \phi_{01} \quad (21)$$

$$U_{02}'' - \left(M + \frac{1}{k}\right) U_{02} = -\ Gr\ \theta_{02} - Gc\ \phi_{02} \quad (22)$$

$$U_{11}'' - \left(M + \frac{1}{k} + n\right) U_{11} = -\ Gr\ \theta_{11} - Gc\ \phi_{11} \quad (23)$$

$$U_{12}'' - \left(M + \frac{1}{k} + n\right) U_{12} = -\ Gr\ \theta_{12} - Gc\ \phi_{12} \quad (24)$$

$$\theta_{01}'' - (R + Q)\,\theta_{01} = 0 \qquad (25)$$

$$\theta_{02}'' - (R + Q)\,\theta_{02} = 0 \qquad (26)$$

$$\theta_{11}'' - (R + Q + n\,Pr)\,\theta_{11} = 0 \qquad (27)$$

$$\theta_{12}'' - (R + Q + n\,Pr)\,\theta_{12} = -2\,U_{01}'U_{11}' \qquad (28)$$

$$\phi_{01}'' - Sc\,Kr\,\phi_{01} = 0 \qquad (29)$$

$$\phi_{02}'' - Sc\,Kr\,\phi_{02} = 0 \qquad (30)$$

$$\phi_{11}'' - (Kr + n)\,Sc\,\phi_{11} = 0 \qquad (31)$$

$$\phi_{12}'' - (Kr + n)\,Sc\,\phi_{12} = 0 \qquad (32)$$

The respective frontier conditions

$$U_{01} = \exp(at),\ U_{02} = 0,\quad \theta_{01} = t$$

$$\theta_{02} = 0,\quad \phi_{01} = t,\quad \phi_{02} = 0$$

$$\theta_{12} = 0,\quad \phi_{11} = 0,\quad \phi_{12} = 0 \ \text{ at } \ y = 0$$

$$U_{01} \to 0,\quad U_{02} \to 0,\quad \theta_{01} \to 0$$

$$\theta_{02} \to 0,\quad \phi_{01} \to 0,\quad \phi_{02} \to 0$$

$$U_{11} \to 0,\quad U_{12} \to 0,\quad \theta_{11} \to 0$$

$$\theta_{12} \to 0,\quad \phi_{11} \to 0,\quad \phi_{12} \to 0 \ \text{ as } \ y \to \infty \qquad (33)$$

Solving equation (21) to (32) by means of the (33) border condition the Velocity, Temperature and Concentration distributions are as

$$U(y.t) = a_1 \exp(m_3 y) + a_2 \exp(m_1 y) + a_3 \exp(m_4 y) + Ec\,\{ a_4 \exp(m_3 y) + a_5 \exp(2 m_4 y) + a_6 \exp(2 m_3 y) + a_7 \exp(2 m_1 y) + a_8 \exp[(m_3 + m_4)\,y] + a_9 \exp[(m_1 + m_3) y] + a_{10} \exp[(m_1 + m_4) y] + a_{11} \exp(m_4 y) \} \qquad (34)$$

$$\theta(y.t) = t \exp(m_3 y) + Ec\,\{ b_1 \exp(2 m_4 y) + b_2 \exp(2 m_3 y) + b_3 \exp(2 m_1 y) + b_4 \exp[(m_3 + m_4)\,y] + b_5 \exp[(m_1 + m_3)\,y] + b_6 \exp[(m_1 + m_4)\,y] + b_7 \exp(m_3 y) \} \qquad (35)$$

$$C(y.t) = t \exp(m_1 y) \qquad (36)$$

4. Skin Friction

The most important attention to calculate the local wall shear stress for the velocity field in the frontier layer as

$$\tau = \left(\frac{\partial U}{\partial Y}\right)_{Y=0}$$

$$\tau = a_1 m_3 + a_2 m_1 + a_3 m_4 + Ec\,\{ a_4 m_3 + 2 a_5 m_4 + 2 a_6 m_3 + 2 a_7 m_1 +$$

$$+ a_8 (m_3 + m_4) \quad + \quad a_9 (m_1 + m_3) \}$$

$$+ \quad a_{10} (m_1 + m_4) \; + \; a_{11} m_4 \} \qquad (37)$$

5. Nusselt Number

The pace of heat transfer coefficient in non dimensional structure of Nusselt Number for the temperature meadow can be obtained as

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

$$Nu = -t\, m_3 - Ec \{2\, b_1 m_4 + 2\, b_2 m_3 + 2\, b_3 m_1 +$$

$$+ b_4 (m_3 + m_4) + b_5 (m_1 + m_3) + b_6 (m_1 + m_4)$$

$$+ b_7 m_3 \} \qquad (38)$$

6. Sherwood Number

The speed of mass transfer coefficient in non dimensional structure of Sherwood Number for the concentration meadow can be obtained as

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

$$Sh = -t\, m_1 \qquad (39)$$

Where

$$m_1 = -\sqrt{Sc\, Kr}, \quad m_2 = -\sqrt{Sc\,(Kr + n)}, \quad m_3 = -\sqrt{(R + Q)}, \quad m_4 = -\sqrt{\left(M + \frac{1}{k}\right)}$$

$$m_5 = -\sqrt{(R + Q + n\, Pr)}, \quad m_6 = -\sqrt{\left(M + \frac{1}{k} + n\right)}$$

$$a_1 = \left(\frac{-Gr\, t}{m_3^2 - m_4^2}\right), \qquad a_2 = \left(\frac{-Gc\, t}{m_1^2 - m_4^2}\right),$$

$$a_3 = (\exp(at) - a_1 - a_2)$$

$$a_4 = \left(\frac{-Gr\; b_7}{m_3^2 - m_4^2}\right), \quad a_5 = \left(\frac{-Gr\; b_1}{4\, m_4^2 - m_4^2}\right)$$

$$a_6 = \left(\frac{-Gr\, b_2}{4\, m_3^2 - m_4^2}\right), \; a_7 = \left(\frac{-Gr\, b_3}{4\, m_1^2 - m_4^2}\right)$$

$$a_8 = \left(\frac{-Gr\, b_4}{(m_3 + m_4)^2 - m_4^2}\right),$$

$$a_9 = \left(\frac{-Gr\, b_5}{(m_1 + m_3)^2 - m_4^2}\right)$$

$$a_{10} = \left(\frac{-Gr\, b_6}{(m_1 + m_4)^2 - m_4^2}\right)$$

$$a_{11} = -(a_4 + a_5 + a_6 + a_7 + a_8 + a_9 + a_{10})$$

$$b_1 = \left(\frac{-m_4^2\; a_3^2}{4\, m_4^2 - m_3^2}\right), b_2 = \left(\frac{-m_3^2\; a_1^2}{4\, m_3^2 - m_3^2}\right)$$

$$b_3 = \left(\frac{-m_1^2\; a_2^2}{4\, m_1^2 - m_3^2}\right), b_4 = \left(\frac{-2\, m_4\, m_3\, a_1 a_3}{(m_3 + m_4)^2 - m_3^2}\right),$$

$$b_5 = \left(\frac{-2\, m_1\, m_3\, a_1 a_2}{(m_1 + m_3)^2 - m_3^2}\right),$$

$$b_6 = \left(\frac{-2\, m_1\, m_4\, a_3 a_2}{(m_1 + m_4)^2 - m_3^2}\right),$$

$$b_7 = -(b_1 + b_2 + b_3 + b_4 + b_5 + b_6)$$

7. Results and Discussions

The figure (2) demonstrate that the velocity summary for heat transfer Grashof Number Gr.when the heat transfer Grashof Number Gr raised it is observed that the velocity raised. Increase the mass transfer Grashof Number Gc standards of velocity rise it is observed from figure. (3). The figure (4) illustrated the Magnetic parameter M effect on velocity (M = 0.2, 2, 5, 10), Gr = 5, Gc = 5, a = 0.5, k = 1, t = 0.2, Kr = 0.5, Ec = 0.1, R=0.2, Q = 0.1 and Sc = 0.6. From the figure velocity declined when the Magnetic field parameter raises. Because of the transverse Magnetic field, there is a resistive type force called Lorentz force that resist the fluid flow and reduces velocity of the flow. The transform in the velocity outline due to different ideology of Kr (Kr = 0.2, 2, 6, 10) are plotted in figure (5). This figure demonstrate that the velocity profile decreases rapidly as increase in Kr. Figure (6) illustrates the dimensionless velocity summary for different values of the permeability parameter of the porous medium. When increasing the permeability of porous medium k velocity profile raises rapidly.

The figure (7) shows velocity summary for the effect of time (t = 0.2, 0.4, 0.6, 0.8) and a = 0.5, Gr = 5, Gc = 5, M = 2, k = 1, Kr = 0.5, Ec = 0.1, R = 0.2, Q = 0.1 and Sc = 0.6. From the figure conclude that the velocity raises when the time increases. The acceleration parameter result for velocity profile (a = 0.2, 0.5, 0.9, 1.3), Gr = Gc = 5, M = 2, k = 1, t = 0.2, Kr = 0.5, Ec = 0.1, R = 0.2, Q = 0.1 and Sc = 0.6 is examined in figure (8). The velocity amplifies as the values of ‘a’ raises. The Eckert number Ec effect for velocity is examined in Figure (9). In the flow region velocity amplifies as Ec is increased. The Radiation parameter R outcome of the velocity field is shown in figure (10). When the radiation parameter is raises the velocity field decline. The effect of the heat sink parameter Q is presented in Figure (11). An increase in the heat sink parameter Q velocity declined within the frontier layer

Figure (12) displays that the temperature profiles θ increases as time‘t’ is increased. Figure (13) examines that divergence of temperature profile with admiration to the Radiation parameter R from this figure; it is observed that temperature decreases for the increasing principles of Radiation parameter R. This result qualitatively agrees with expectation, since the consequence of Radiation is to decrease the tempo of energy transport to the fluid, thereby decreasing the temperature of the fluid. Figure (14) depicts the temperature distribution for different values of Eckert number Ec. It is observed that the temperature boost with rising values of Ec. The heat sink parameter influence on temperature profiles plotted in figure (15). When increase the heat sink parameter Q the result is diminish in temperature.

The outcome of Thermal Grashof Number Gr and Mass Grashof Number Gc are presented in figure (16) and (17). If increasing the values of Gr and Gc the temperature diminish. Temperature profiles for Magnetic parameter (M), porous medium constraint (k), chemical reaction parameter (Kr) and Acceleration parameter (a) are represented in figures (18) - (21) respectively. It is observed that increase in M, a, Kr increases the temperature summary but it decreases with an increase of k.

In figure (22) Concentration of the fluid with esteem to time is specified. As time rises it is observed that the concentration contour increases. The concentration summary reduced when the increase the chemical reaction parameter is displayed in figure (23).The chemical reaction is a first order that reduces the fluid concentration. In figure (24) examined that Schmidt number Sc increases there is diminish in the molecular diffusivity of the fluid that leads to less concentration. The concentration report declined when increase the Sc.

Figures (25) - (32) illustrate the effect of Gr, Gc, M, k, a, Ec, Q and R on the skin-friction τ. From these figures it is observed that as Gr , Gc, k, and Ec amplify, the skin-friction coefficient increases and the trend is just inverted with respect to the magnetic parameter M, a, Q and R.

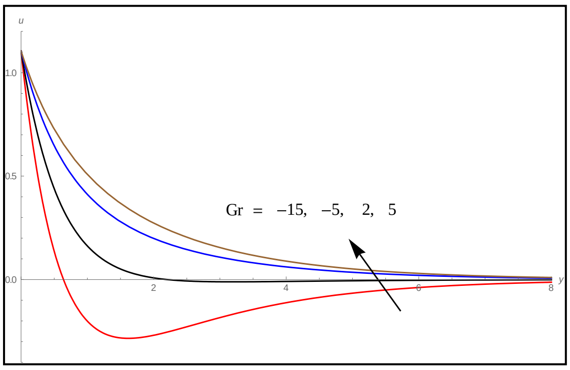
Figure (33) - (41) illustrates the effect of R, Ec, Q, Gr, Gc, M, k, Kr and the acceleration parameter ‘a’ on the Nusselt Number. As R, Q, Gr, Gc and k raises the Nusselt Number is enlarged and reversed effect happen in the remaining parameters. The consequence of Schmidt number and Chemical reaction parameter on Sherwood number presented in figure (42) and (43). As the Schmidt number, chemical reaction parameter elevates the Sherwood number is also elevate.

8. Conclusion

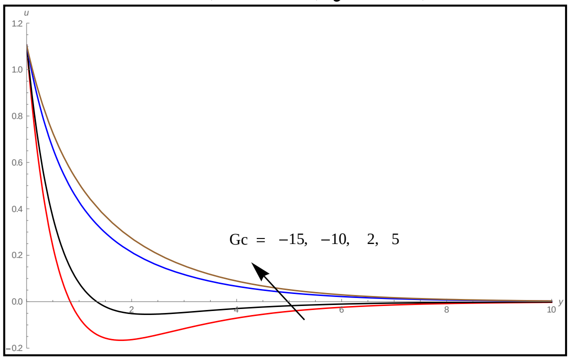
The abstract solution of an exponentially accelerated endless vertical plate in the occurrence of inconsistent temperature is considered. The dimensionless fundamental equations are resolve by using the perturbation technique. The effects of different parameters are deliberated by graphically.

- It was experimental that the velocity amplifies with rising values of Gr, Gc, k, t, a and Ec but the trend is reversed with esteem to M, Kr, R and Q.
- The Temperature raises with growing values of t, Ec, M, a and Kr and it decline when elevate the values of R, Q, Gr, Gc and k

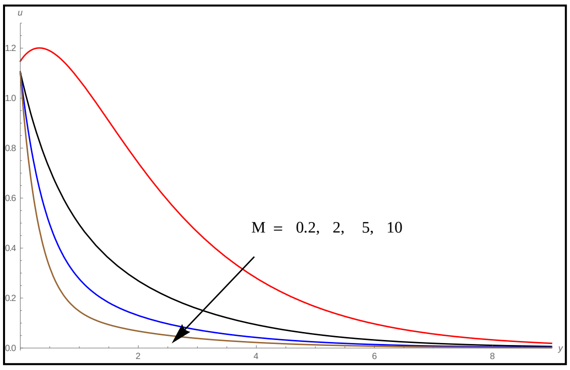
- The concentration enhances with augment in time and diminishes with increase in Kr and Sc.
- The magnitude of the skin - friction at the plate is found to be dwindle due to increasing of M, a, Q and R whereas it amplify due to increase in Gr, Gc, k and Ec.
- It is interesting to note that, Nusselt number was enhanced with the enlarge of R, Q, Gr, Gc and k while it decline with ever-increasing values of Ec, M, Kr and a.
- The rate of mass transfer (Sh) enhance due to amplify in Sc and Kr.



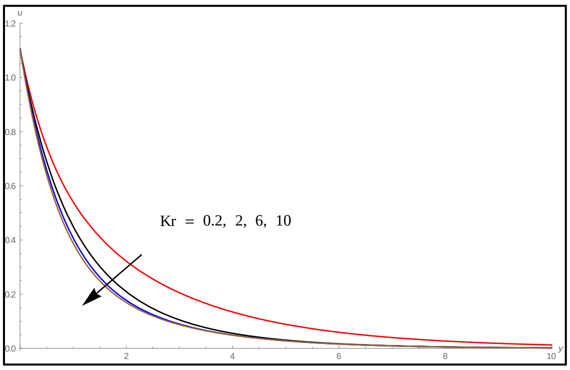
$\boldsymbol{Fig. 2: Velocity\ profiles\ for\ values\ of\ \ Gr}$
$\boldsymbol{Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2, Kr = 0.5,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



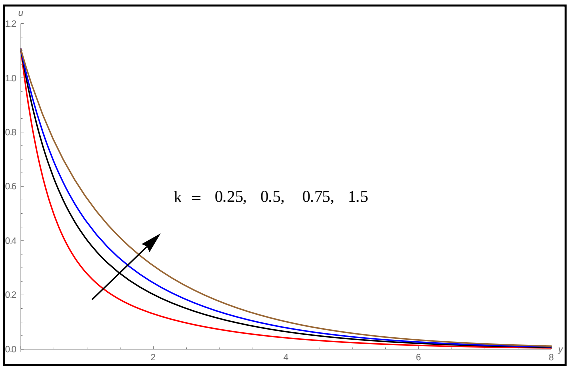
$\boldsymbol{Fig. 3: Velocity\ profiles\ for\ values\ of\ \ Gc}$
$\boldsymbol{Gr = 5, M = 2, a = 0.5, k = 1, t = 0.2, Kr = 0.5}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



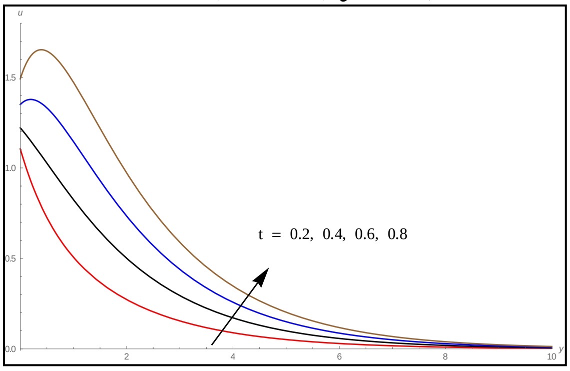
$\boldsymbol{Fig. 4: Velocity\ profiles\ for\ values\ of\ \ M}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, k = 1, t = 0.2, Kr = 0.5 Ec}$
$\boldsymbol{= 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



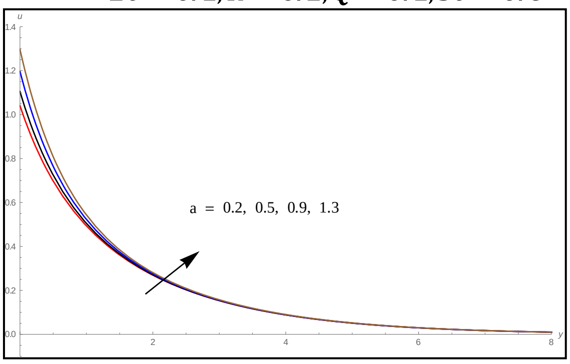
$\boldsymbol{Fig. 5: Velocity\ profiles\ for\ values\ of\ \ Kr}$
$\boldsymbol{Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



$\boldsymbol{Fig. 6: Velocity\ profiles\ for\ values\ of\ \ k}$
$\boldsymbol{Gr = 5, Gc = 5, M = 2, a = 0.5, t = 0.2, Kr = 0.5}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



$\boldsymbol{Fig. 7: Velocity\ profiles\ for\ values\ of\ \ t}$
$\boldsymbol{Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, Kr = 0.5,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



$\boldsymbol{Fig. 8: Velocity\ profiles\ for\ values\ of\ \ a}$
$\boldsymbol{Gr = 5, Gc = 5, M = 2, k = 1, t = 0.2, Kr = 0.5,}$

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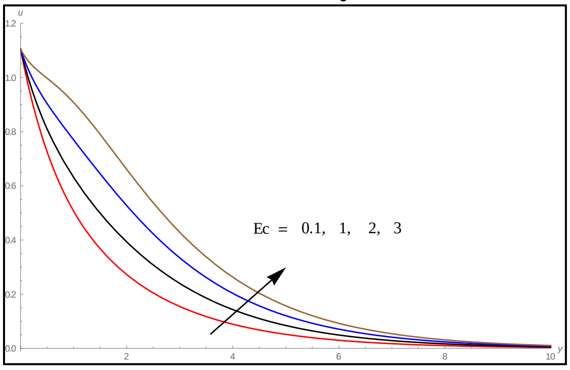
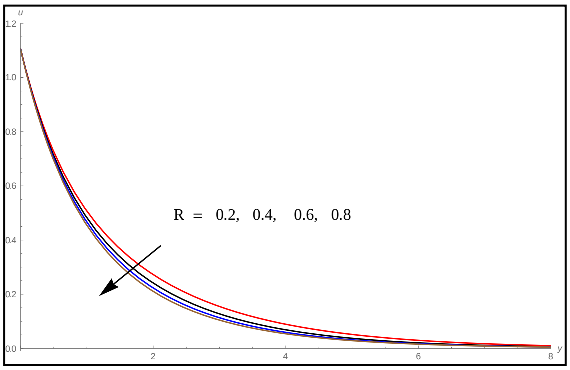
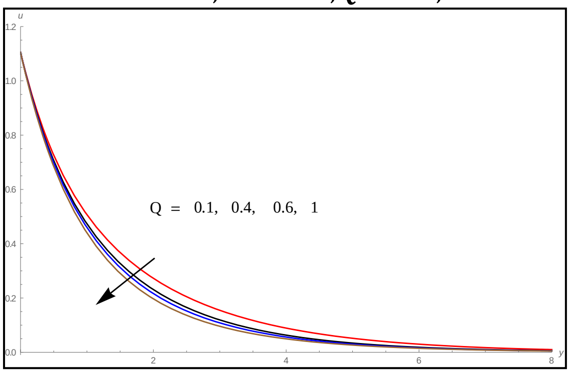
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



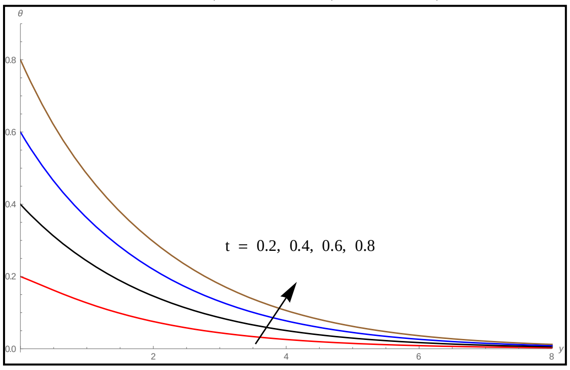
$Fig. 9$: $Velocity\ profiles\ for\ values\ of\ \ Ec$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2,$
$Kr = 0.5, R = 0.2, Q = 0.1, Sc = 0.6$



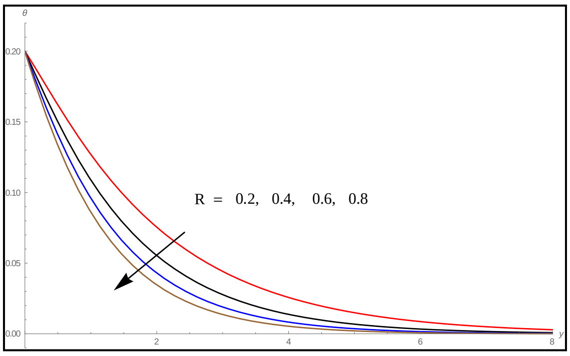
$Fig. 10$: $Velocity\ profiles\ for\ values\ of\ \ R$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2$
$Kr = 0.5, Ec = 0.1, Q = 0.1, Sc = 0.6$



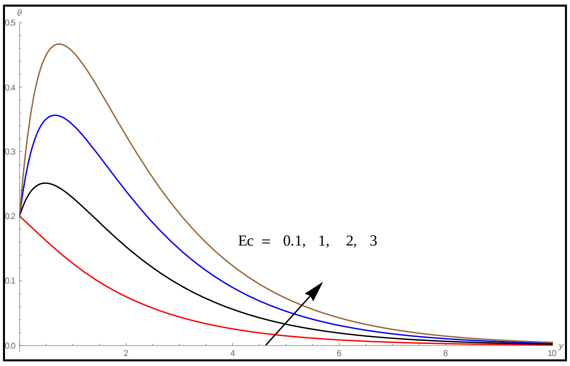
$Fig. 11$: $Velocity\ profiles\ for\ values\ of\ \ Q$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2,$
$Kr = 0.5, Ec = 0.1, R = 0.2, Sc = 0.6$



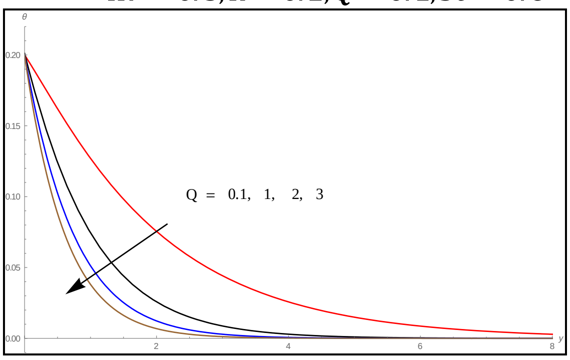
$Fig. 12$: $Temperature\ profiles\ for\ values\ of\ \ t$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



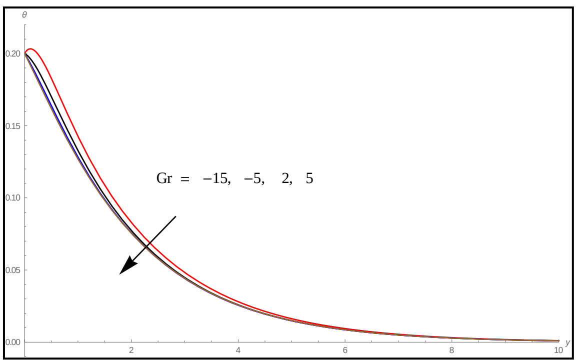
$Fig. 13$: $Temperature\ profiles\ for\ values\ of\ \ R$
$Gr = 5, Gc = 10, M = 2, k = 1, Kr = 0.5, Q = 0.2,$
$a = 0.3, Ec = 0.2, t = 1, Sc = 0.22$



$Fig. 14$: $Temperature\ profiles\ for\ values\ of\ \ Ec$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2,$
$Kr = 0.5, R = 0.2, Q = 0.1, Sc = 0.6$



$Fig. 15$: $Temperature\ profiles\ for\ values\ of\ \ Q$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2,$
$Kr = 0.5, Ec = 0.1, R = 0.2, Sc = 0.6$



$Fig. 16$: $Temperature\ profiles\ for\ values\ of\ \ Gr$
$Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$

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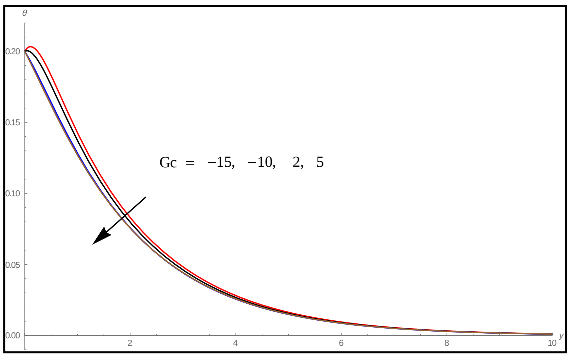
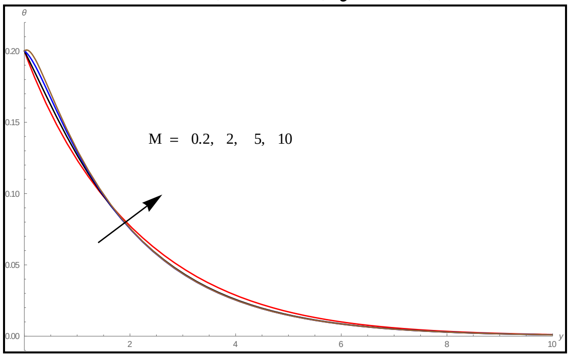
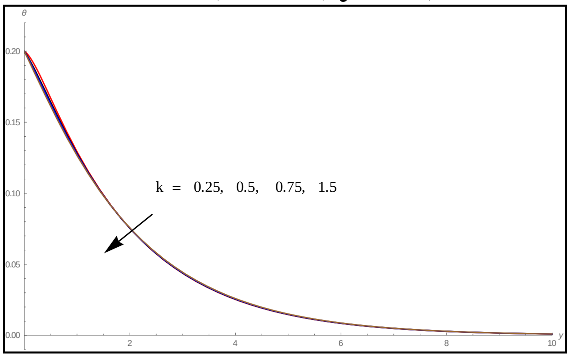


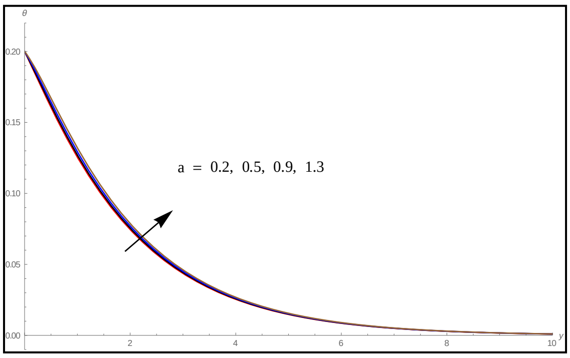
$Fig. 17$: $Temperature\ profiles\ for\ values\ of\ \ Gc$
$Gr = 5, M = 2, a = 0.5, k = 1, t = 0.2, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



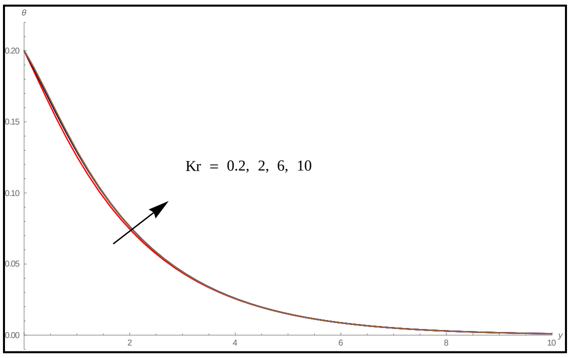
$Fig. 18$: $Temperature\ profiles\ for\ values\ of\ \ M$
$Gr = 5, Gc = 5, a = 0.5, k = 1, t = 0.2, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



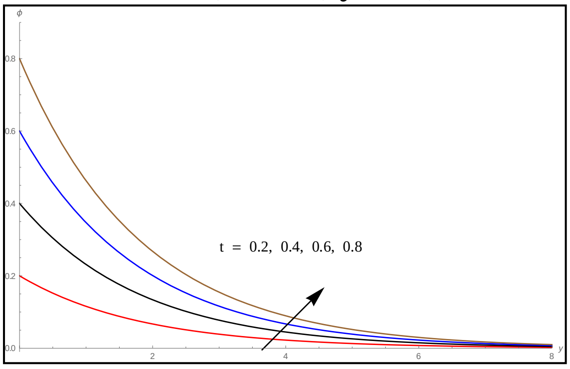
$Fig. 19$: $Temperature\ profiles\ for\ values\ of\ \ k$
$Gr = 5, Gc = 5, M = 2, a = 0.5, t = 0.2,$
$Kr = 0.5, Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



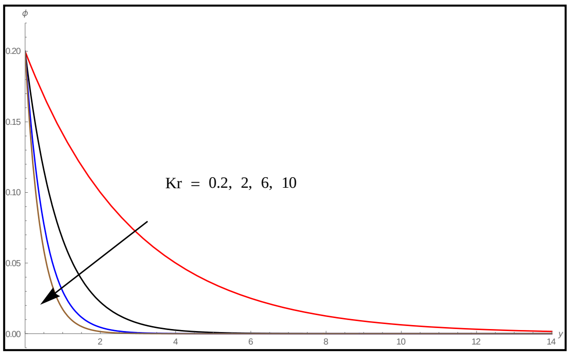
$Fig. 20$: $Temperature\ profiles\ for\ values\ of\ \ a$
$Gr = 5, Gc = 5, M = 2, k = 1, t = 0.2, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



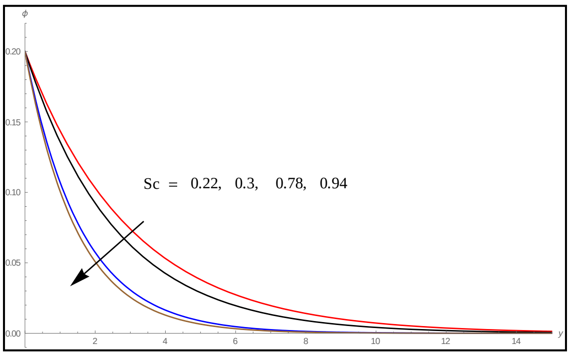
$Fig. 21$: $Temperature\ profiles\ for\ values\ of\ \ Kr$
$Gr = 5, Gc = 5, M = 2, a = 0.5, k = 1, t = 0.2,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



$Fig. 22$: $Concentration\ profiles\ for\ values\ of\ \ t$
$Kr = 0.5, Sc = 0.6$



$Fig. 23$: $Concentration\ profiles\ for\ values\ of\ \ Kr$
$t = 0.2, Sc = 0.6$



$Fig. 24$: $Concentration\ profiles\ for\ values\ of\ \ Sc$
$t = 0.2, Kr = 0.5$

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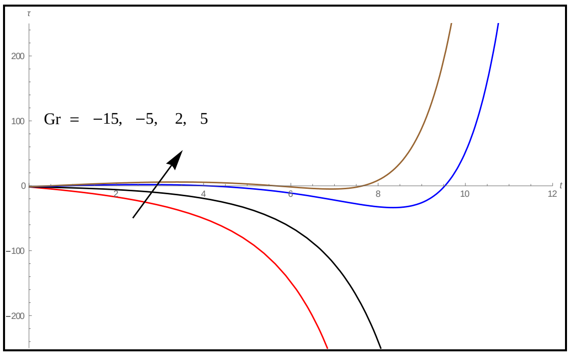
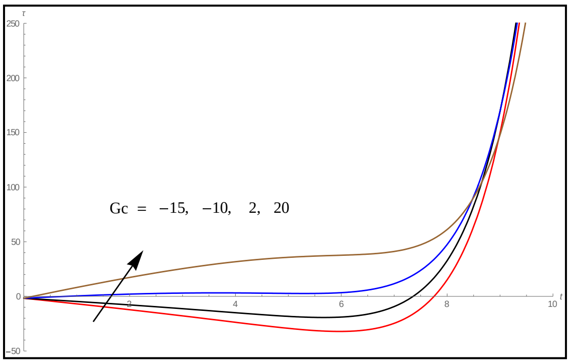
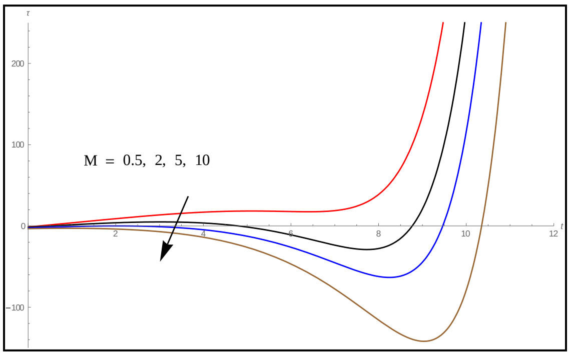


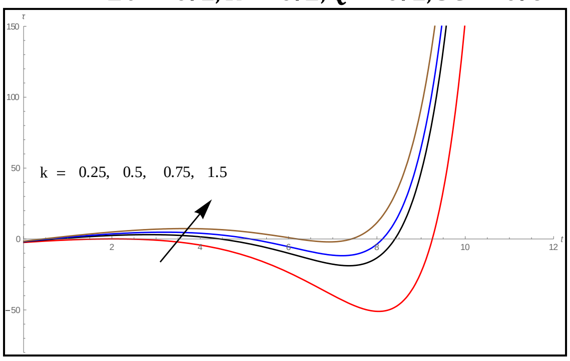
$Fig. 25$: $Skin - friction\ for\ values\ of\ \ Gr$
$Gc = 5, a = 0.5, M = 2, k = 1, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



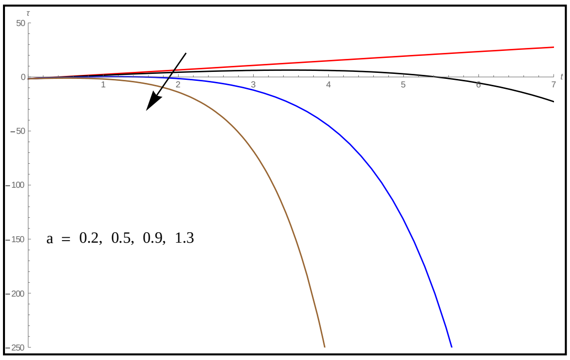
$Fig. 26$: $Skin - friction\ for\ values\ of\ \ Gc$
$Gr = 5, a = 0.5, M = 2, k = 1, Kr = 0.5$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



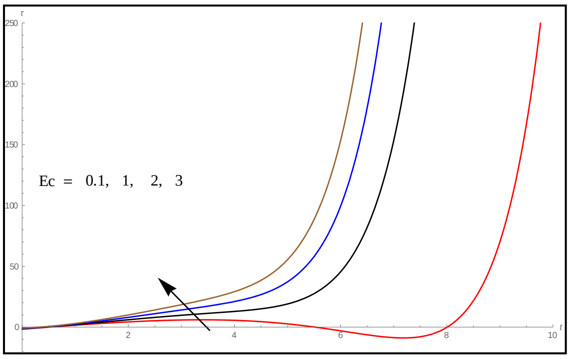
$Fig. 27$: $Skin - friction\ for\ values\ of\ \ M$
$Gr = 5, Gc = 5, a = 0.5, k = 1, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, SC = 0.6$



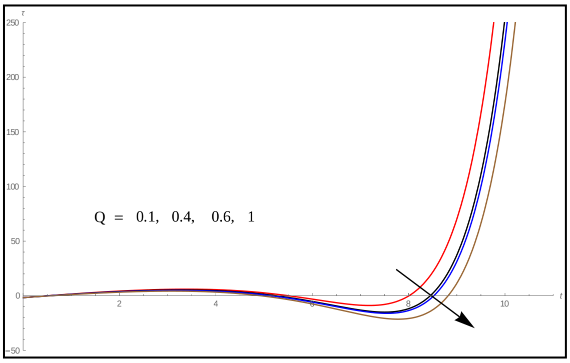
$Fig. 28$: $Skin - friction\ for\ values\ of\ k$
$Gr = 5, Gc = 5, a = 0.5, M = 2, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



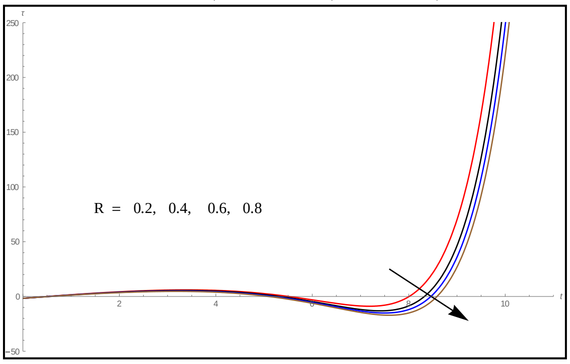
$Fig. 29$: $Skin - friction\ for\ values\ of\ a$
$Gr = 5, Gc = 5, M = 2, k = 1, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



$Fig. 30$: $Skin - friction\ for\ values\ of\ Ec$
$Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,$
$Kr = 0.5, R = 0.2, Q = 0.1, Sc = 0.6$



$Fig. 31$: $Skin - friction\ for\ values\ of\ Q$
$Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,$
$Kr = 0.5, Ec = 0.1, R = 0.2, Sc = 0.6$



$Fig. 32$: $Skin - friction\ for\ values\ of\ R$
$Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,$
$Kr = 0.5, Ec = 0.1, Q = 0.1, Sc = 0.6$

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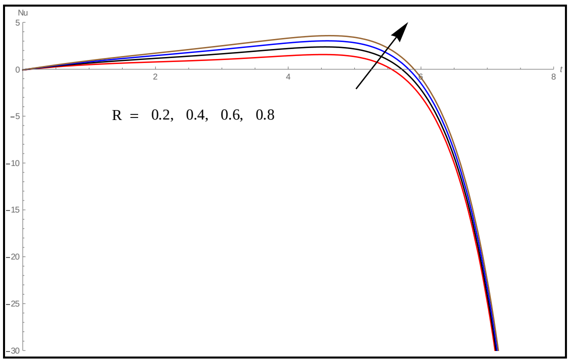
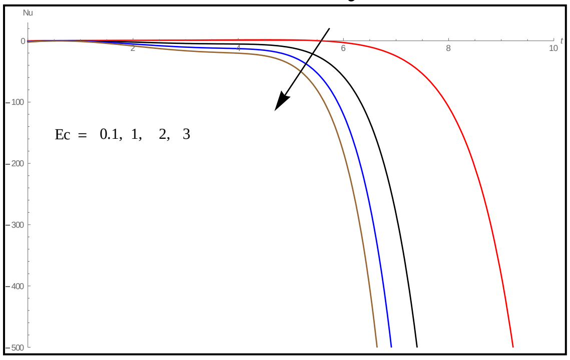
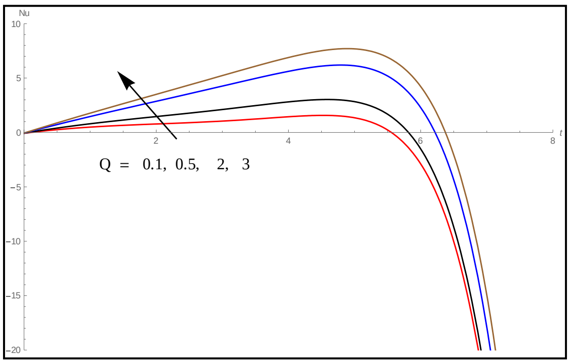


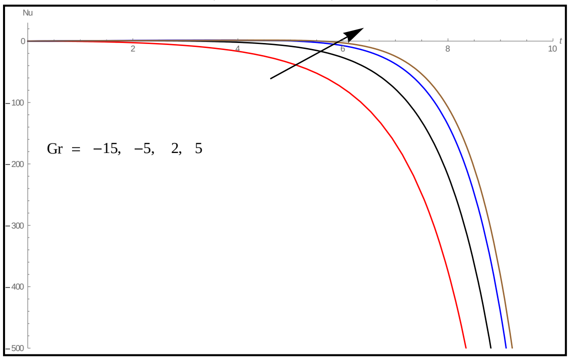
$fig.33$: $\boldsymbol{Effect\ of\ Radiation\ on\ Nusselt\ number}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,}$
$\boldsymbol{Kr = 0.5, Ec = 0.1, Q = 0.1, Sc = 0.6}$



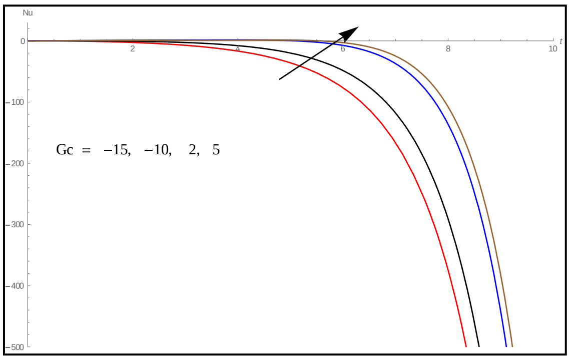
$Fig.34$: $\boldsymbol{Effect\ of\ Ec\ on\ Nusselt\ number}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,}$
$\boldsymbol{Kr = 0.5, R = 0.2, Q = 0.1, Sc = 0.6}$



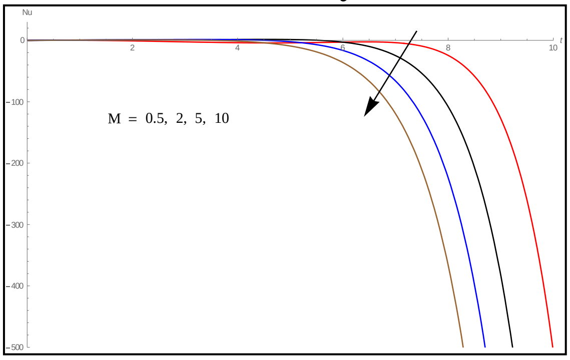
$Fig.35$: $\boldsymbol{Effect\ of\ Q\ on\ Nusselt\ number}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,}$
$\boldsymbol{Kr = 0.5, Ec = 0.1, R = 0.2, Sc = 0.6}$



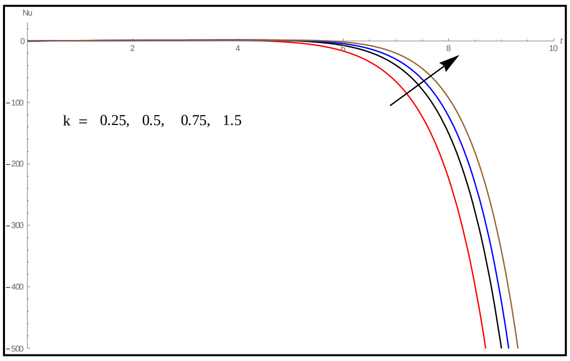
$Fig.36$: $\boldsymbol{Effect\ of\ Gr\ on\ Nusselt\ number}$
$\boldsymbol{Gc = 5, a = 0.5, M = 2, k = 1, Kr = 0.5,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



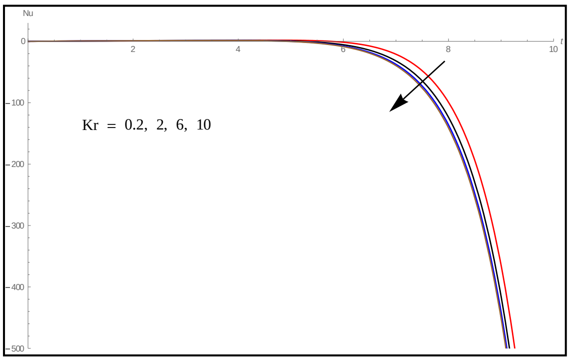
$Fig.37$: $\boldsymbol{Effect\ of\ Gc\ on\ Nusselt\ number}$
$\boldsymbol{Gr = 5, a = 0.5, M = 2, k = 1, Kr = 0.5,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



$Fig.38$: $\boldsymbol{Effect\ of\ M\ on\ Nusselt\ number}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, k = 1, Kr = 0.5,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



$Fig.39$: $\boldsymbol{Effect\ of\ k\ on\ Nusselt\ Number}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, M = 2, Kr = 0.5,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$



$Fig.40$: $\boldsymbol{Effect\ of\ Kr\ on\ Nusselt\ Number}$
$\boldsymbol{Gr = 5, Gc = 5, a = 0.5, M = 2, k = 1,}$
$\boldsymbol{Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6}$

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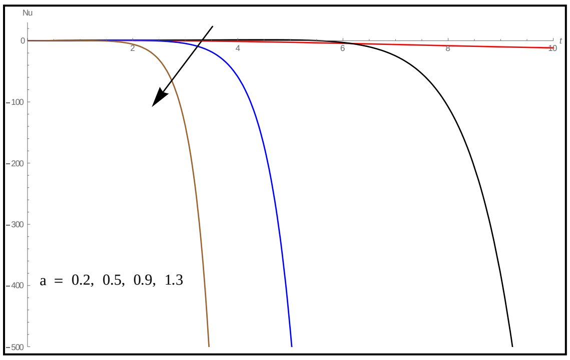
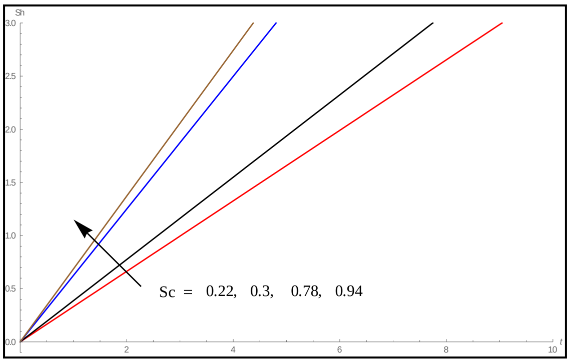
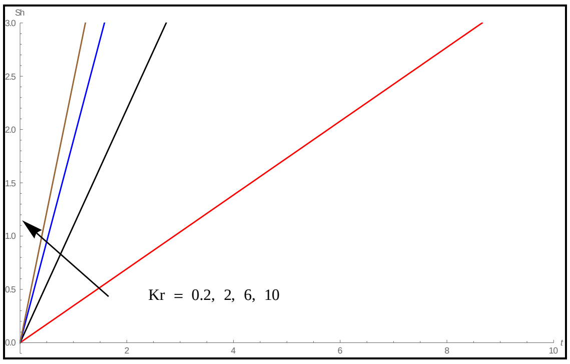


$Fig. 41$: $Effect\ of\ a\ on\ Nusselt\ Number$
$Gr = 5, Gc = 5, M = 2, k = 1, Kr = 0.5,$
$Ec = 0.1, R = 0.2, Q = 0.1, Sc = 0.6$



$Fig. 42$: $Effect\ of\ Sc\ on\ Sherwood\ Number$
$Kr = 0.5$



$Fig. 43$: $Effect\ of\ Kr\ on\ Sherwood\ Number$
$Sc = 0.6$

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