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The MHD Unsteady Flow Past an Oscillating Infinite Perpendicular Plate with Variation in Temperature through Permeable Medium considering the Heat and Mass Transfer Effects

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Abstract: The objective of this paper is to study the effect of the MHD flow past an oscillating infinite perpendicular plate through the permeable medium taking account of the variation in temperature with Heat and Mass transfer. The dimensionless governing equations are solved by the Laplace Transform technique. The velocity, temperature, concentration profiles are studied for the different physical parameters like phase angle, magnetic parameter, Thermal Grashof number, Modified Grashof number, Permeability parameter, Prandtl number, Schmidt number and time.
Keywords*: *Heat Transfer, Mass Transfer, MHD, Oscillating plate and Permeable Medium, variable temperature.

I. INTRODUCTION

The study of magneto hydrodynamics (MHD) is a part of continuum mechanics which deals the flow of an electrical fluid in existence of the electromagnetic field. MHD represents the idea of inducing currents in a conductive fluid at motion which in turn create forces in the fluids and change the magnetic field. This combines the electromagnetic and fluid dynamic theories to represent and describe the concurrent effect of the magnetic field. The most appropriate name for the phenomena would be Magneto Fluid Mechanics, but the original name MHD is still generally used for the flow analysis of incompressible electrically conducting fluids including conducting liquids and gases.

MHD finds practical use in many areas of engineering and pure science. Some examples are pumping and levitation of liquid metals, orientation and confinement of extremely hot ionized gases or plasmas as in thermonuclear fusion experiments, electric power generation from ionized gases or from heat produced in a fission reaction etc. Magnetohydrodynamic flows through the porous medium which are important in the flow of the oil through porous rocks in the many fields of the petroleum technology, purification, filtration processes in chemical engineering and the drug permeation of the human skin.

WSoundalgekar (1979) analyzed the free convection effects of the flow past a vertical oscillating plate. Soundalgekar and Akolkar (1983) studied the effect of free convection currents and mass transfer on the flow past a vertical oscillating plate. Muthucumaraswamy and Manivanna (2007) examined the Mass transfer effect on vertical Oscillating plate with Heat Flux. The Radiation and mass transfer effects on MHD free convection flow through porous medium past an exponentially accelerated vertical plate with variable temperature was analyzed by Pattnaik, Dash and Singh (2012). Saraswat Amit and Srinivastava (2013) presented the Heat and Mass Transfer effects on flow past an Oscillating infinite vertical plate with variable Temperature through porous media. Numerical study of MHD and radiation effects on flow past an Oscillating isothermal vertical plate with uniform mass flux was examined by Muthucumaraswamy and Saravanan (2014). Girish Kumar and Mohana Ramana (2015) studied the viscous dissipation effects on MHD flow past a parabolic started vertical plate with variable temperature and mass diffusion.

II. FORMULATION OF THE PROBLEM

The heat transfer and mass transfer deals on an unsteady MHD flow through an oscillating perpendicular plate with a variation in temperature in the course of permeable medium is considered. The flow is measured with the perpendicular plate and is considered to be in x-axis direction. The y-axis is perpendicular to the plate. Magnetic field with uniform strength B_0 is implemented in the y direction. The temperature of the plate is T'_∞ and the concentration C'_∞ in the beginning and starts oscillating at $t' > 0$ having the velocity $u' = u_0 \cos\omega' t'$.

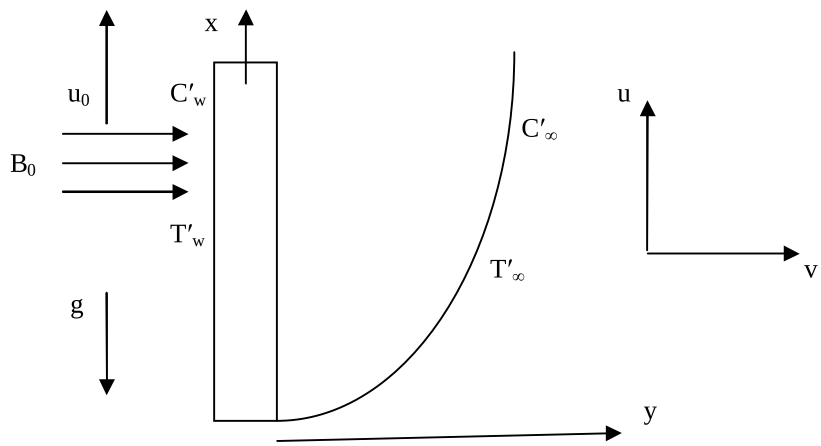

Figure.1: Physical configuration and coordinate system

Now the temperature and concentration are elevated linearly with respect to time. The physical stature of the fluid are the functions of y and t'. Using the Boussinesq's approximation, the unsteady flow is governed by the following equations:

$$\frac{\partial u'}{\partial t'} = g\ \beta_T\,(T' - T'_\infty) + g\ \beta_C^*\,(C' - C'_\infty) + \nu\left(\frac{\partial^2 u'}{\partial y^2}\right) - \nu\left(\frac{u'}{k'}\right) - \left(\frac{\sigma B_0^2\, u'}{\rho}\right) \tag{1}$$

$$\rho\, C_P \frac{\partial T'}{\partial t'} = \kappa\ \frac{\partial^2 T'}{\partial y^2} \tag{2}$$

$$\frac{\partial C'}{\partial t'} = D\,\frac{\partial^2 C'}{\partial y^2} \tag{3}$$

with the initial and boundary conditions of the flow are

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

$$u' = u_0 \cos\omega' t', \quad T' = T'_\infty + (T'_w - T'_\infty)\, A\, t', \quad C' = C'_\infty + (C'_w - C'_\infty)\, A\, t'$$

$$\text{at} \quad y = 0, \quad t' > 0$$

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

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

where ν - kinematic viscosity of the fluid, σ - electric conductivity, u_0 - velocity of the plate, B_0- constant magnetic field intensity, ρ - density, k'- permeability, g - gravitational constant, β_T - thermal expansion coefficient, β_C^* - concentration expansion coefficient, T' - temperature, C'- mass concentration, C_p - specific heat at constant pressure, D - chemical molecular diffusivity, T'_w - wall temperature, T'_∞ - free stream temperature, C'_w - species concentration at the plate surface and C'_∞ - free stream concentration.

The following non-dimensional quantities are introduced:

$$U = \left(\frac{u'}{u_0}\right), \quad t = \left(\frac{t'\, u_0^2}{\nu}\right), \quad Y = \left(\frac{y\, u_0}{\nu}\right), \quad \theta = \left(\frac{T' - T'_\infty}{T'_w - T'_\infty}\right)$$

$$\omega = \left(\frac{\nu\ \omega'}{u_0^2}\right), \quad M = \left(\frac{\sigma B_0^2\, \nu}{\rho\, u_0^2}\right), \quad Pr = \left(\frac{\mu\, C_P}{\kappa}\right), \quad Sc = \left(\frac{\nu}{D}\right),$$

$$Gr = \left(\frac{g\, \beta_T\, \nu\ (T'_w - T'_\infty)}{u_0^3}\right), \quad Gc = \left(\frac{g\, \beta_c^*\, \nu\ (C'_w - C'_\infty)}{u_0^3}\right), \quad \phi = \left(\frac{C' - C'_\infty}{C'_w - C'_\infty}\right)$$

$$k = \left(\frac{u_0^2\, k'}{\nu^2}\right), \tag{5}$$

In equations (1) to (4), leads to:

$$\frac{\partial U}{\partial t} = Gr\,\theta + Gc\,\phi + \frac{\partial^2 U}{\partial Y^2} - \left(M + \frac{1}{k}\right) U \tag{6}$$

$$\frac{\partial\theta}{\partial t} = \left(\frac{1}{Pr}\right)\left(\frac{\partial^2\theta}{\partial Y^2}\right) \tag{7}$$

$$\frac{\partial\phi}{\partial t} = \left(\frac{1}{Sc}\right)\left(\frac{\partial^2\phi}{\partial Y^2}\right) \tag{8}$$

The initial and boundary conditions in the non-dimensional form are:

$$\begin{array}{llllll} U = 0, & \theta = 0, & \phi = 0 & \text{for all} & Y, & t \le 0 \\ U = \cos\omega t, & \theta = t, & \phi = t & \text{at} & Y = 0, & t > 0 \\ U \to 0, & \theta \to 0, & \phi \to 0 & \text{as} & Y \to \infty & t > 0 \end{array} \tag{9}$$

III.METHOD OF SOLUTION

The dimensionless basic equations (6) to (8), under the initial and boundary conditions equation (9), are solved by the standard Laplace-transform procedure. The Laplace-transform of the equations (6) to (8) and the boundary conditions (9) are given by

$$\frac{d^2\bar{U}}{dY^2} - \left[S + \left(M + \frac{1}{k}\right)\right]\bar{U} = -Gr\,\bar{\theta} - Gc\,\bar{\phi} \tag{10}$$

$$\frac{d^2\bar{\theta}}{dY^2} - S\,Pr\,\bar{\theta} = 0 \tag{11}$$

$$\frac{d^2\bar{\phi}}{dY^2} - S\,Sc\,\bar{\phi} = 0 \tag{12}$$

where S is the Laplace-transformation parameter.

$$\begin{array}{llllll} \bar{U} = 0, & \bar{\theta} = 0, & \bar{\phi} = 0 & \text{for all} & Y, & t \le 0 \\ \bar{U} = \dfrac{S}{S^2 + \omega^2}, & \bar{\theta} = \dfrac{1}{S^2}, & \bar{\phi} = \dfrac{1}{S^2} & \text{at} & Y = 0, & t > 0 \\ \bar{U} \to 0, & \bar{\theta} \to 0, & \bar{\phi} \to 0 & \text{as} & Y \to \infty, & t > 0 \end{array} \tag{13}$$

Solving equations (10), (11), (12) with the help of (13), we get

$$\begin{aligned} \bar{U} = {} & \left\{\frac{S}{S^2 + \omega^2} + \frac{1}{S^2}\left[\frac{Gr}{S(Pr - 1) - \left(M + \frac{1}{k}\right)} + \frac{Gc}{S(Sc - 1) - \left(M + \frac{1}{k}\right)}\right]\right\} \times \\ & \times \exp\left(-Y\sqrt{\left[S + \left(M + \frac{1}{k}\right)\right]}\right) \\ & - \frac{1}{S^2}\left\{\left[\frac{Gr\,\exp\left(-Y\sqrt{S\,Pr}\right)}{S(Pr - 1) - \left(M + \frac{1}{k}\right)}\right] + \left[\frac{Gc\,\exp\left(-Y\sqrt{S\,Sc}\right)}{S(Sc - 1) - \left(M + \frac{1}{k}\right)}\right]\right\} \end{aligned} \tag{14}$$

$$\bar{\theta} = \left(\frac{\exp\left(-Y\sqrt{S\,Pr}\right)}{S^2}\right) \tag{15}$$

$$\bar{\phi} = \left(\frac{\exp\left(-Y\sqrt{S\,Sc}\right)}{S^2}\right) \tag{16}$$

On taking inverse Laplace-transform of equations (14), (15) and (16), we get

$$\theta = t\left[(1 + 2\eta^2 Pr)\,\mathrm{erfc}\left(\eta\sqrt{Pr}\right) - \frac{2}{\sqrt{\pi}}\left(\eta\sqrt{Pr}\right)\exp\left(-\eta^2 Pr\right)\right] \tag{17}$$

$$\phi = t\left[(1 + 2\eta^2 Sc)\,\mathrm{erfc}\left(\eta\sqrt{Sc}\right) - \frac{2}{\sqrt{\pi}}\left(\eta\sqrt{Sc}\right)\exp\left(-\eta^2 Sc\right)\right] \tag{18}$$

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$$
\begin{aligned}
U =& \left[\frac{\exp(\ i\omega t\ )}{4}\right][\exp(-2\eta a_1)\operatorname{erfc}(\eta - a_1) + \exp(2\eta a_1)\operatorname{erfc}(\eta + a_1)] \\
&+ \left[\frac{\exp(-i\omega t)}{4}\right][\exp(-2\eta a_2)\operatorname{erfc}(\eta - a_2) + \exp(2\eta a_2)\operatorname{erfc}(\eta + a_2)] \\
&+ [a_4\ (1 + t\,a_3)][\exp(\ 2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta + \sqrt{a\,t}) \\
&\qquad + \exp(-2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta - \sqrt{a\,t}\ )] \\
&- \left[\frac{a_3\ a_4\ \eta\ \sqrt{t}}{\sqrt{a}}\right][\exp(-2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta - \sqrt{a\,t}\ ) \\
&\qquad - \exp(\ 2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta + \sqrt{a\,t})] \\
&- [a_4\ \exp(\ a_3 t)]\left[\exp\left(2\eta\sqrt{(a + a_3)t}\right)\operatorname{erfc}\left(\eta + \sqrt{(a + a_3)t}\right)\right. \\
&\qquad \left. + \exp\left(-2\eta\sqrt{(a + a_3)t}\right)\operatorname{erfc}\left(\eta - \sqrt{(a + a_3)t}\right)\right] \\
&- [2\ a_4\ \operatorname{erfc}(\eta\sqrt{Pr})] \\
&- [2a_3\ a_4\ t]\left[(1 + 2\eta^2 Pr)\operatorname{erfc}(\eta\sqrt{Pr}) - \frac{2}{\sqrt{\pi}}\ (\eta\sqrt{Pr})\ \exp(-\eta^2 Pr)\right] \\
&+ [a_4\ \exp(\ a_3 t)]\ [\exp(\ 2\eta\sqrt{Pr\,a_3 t}\ )\operatorname{erfc}(\eta\sqrt{Pr} + \sqrt{a_3 t}) \\
&\qquad + \exp(-2\eta\sqrt{Pr\,a_3 t}\ )\operatorname{erfc}(\eta\sqrt{Pr} - \sqrt{a_3 t})\ ] \\
&+ [a_6\ (1 + t\,a_5)]\ [\exp(\ 2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta + \sqrt{a\,t}) \\
&\qquad + \exp(-2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta - \sqrt{a\,t}\ )\ ] \\
&- \left[\frac{a_5\ a_6\ \eta\ \sqrt{t}}{\sqrt{a}}\right][\exp(-2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta - \sqrt{a\,t}\ ) \\
&\qquad - \exp(\ 2\eta\sqrt{a\,t}\ )\operatorname{erfc}(\eta + \sqrt{a\,t})\ ] \\
&- [a_6\ \exp(\ a_5 t)]\left[\exp\left(2\eta\sqrt{(a + a_5)t}\right)\operatorname{erfc}\left(\eta + \sqrt{(a + a_5)t}\right)\right. \\
&\qquad \left. + \exp\left(-2\eta\sqrt{(a + a_5)t}\right)\operatorname{erfc}\left(\eta - \sqrt{(a + a_5)t}\right)\right] \\
&- [2\ a_6\ \operatorname{erfc}(\eta\sqrt{Sc})] \\
&- [2a_5\ a_6\ t]\left[(1 + 2\eta^2 Sc)\operatorname{erfc}(\eta\sqrt{Sc}) - \frac{2}{\sqrt{\pi}}\ (\eta\sqrt{Sc})\ \exp(-\eta^2 Sc)\right] \\
&+ [a_6\ \exp(\ a_5 t)]\ [\exp(\ 2\eta\sqrt{Sc\,a_5 t}\ )\operatorname{erfc}(\eta\sqrt{Sc} + \sqrt{a_5 t}) \\
&\qquad + \exp(-2\eta\sqrt{Sc\,a_5 t}\ )\operatorname{erfc}(\eta\sqrt{Sc} - \sqrt{a_5 t})\ ]
\end{aligned} \tag{19}
$$

where,

$$\eta = \left(\frac{Y}{2\sqrt{t}}\right),\quad a = \left(M + \frac{1}{k}\right),\quad a_1 = \sqrt{(a + i\omega)t},\quad a_2 = \sqrt{(a - i\omega)\,t}$$

$$a_3 = \left(\frac{a}{Pr - 1}\right),\quad a_4 = \left(\frac{Gr}{2\ a_3{}^2(1 - Pr)}\right),\quad a_5 = \left(\frac{a}{Sc - 1}\right)$$

$$a_6 = \left(\frac{Gc}{2\ a_5{}^2(1 - Sc)}\right)$$

IV. SKIN FRICTION

When the velocity field of the flow is known, the skin-friction at the plate in non-dimensional form is:

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

$$\tau = \left[\frac{\exp(\ i\omega t\ )}{4}\right]\left[\left(-\frac{a_1}{\sqrt{t}}\right)\operatorname{erfc}(-a_1) + \left(\frac{a_1}{\sqrt{t}}\right)\operatorname{erfc}(a_1)\right] - \left(\frac{2}{\sqrt{\pi\,t}}\right)\exp(-a_1^2)\Big]$$

$$+\left[\frac{\exp(-i\omega t)}{4}\right]\left[\left(-\frac{a_2}{\sqrt{t}}\right)\operatorname{erfc}(-a_2)+\left(\frac{a_2}{\sqrt{t}}\right)\operatorname{erfc}(a_2)\right]-\left(\frac{2}{\sqrt{\pi t}}\right)\exp(-a_2^2)\Big]$$

$$+[a_4(1+t a_3)]\left[(\sqrt{a})\operatorname{erfc}(\sqrt{a}\,t)-(\sqrt{a})\operatorname{erfc}(-\sqrt{a}\,t)\right]-\left(\frac{2}{\sqrt{\pi t}}\right)\exp[-a\,t]\Big]$$

$$-\left[\frac{a_3\,a_4}{2\sqrt{a}}\right]\left[\operatorname{erfc}(-\sqrt{a}\,t)-\operatorname{erfc}(\sqrt{a}\,t)\right]$$

$$-[a_4\exp(a_3 t)]\Big[\left(\sqrt{(a+a_3)}\right)\operatorname{erfc}\left(\sqrt{(a+a_3)\,t}\right)$$

$$-\sqrt{(a+a_3)}\operatorname{erfc}\left(-\sqrt{(a+a_3)\,t}\right)\Big]-\left(\frac{2}{\sqrt{\pi t}}\right)\exp[-(a+a_3)\,t]\Big]$$

$$-\left[2\,a_4\sqrt{\frac{Pr}{\pi t}}\right]-[2\,a_3\,a_4\,t]\,2\left[\sqrt{\frac{Pr\,t}{\pi}}\right]$$

$$+[a_4\exp(a_3 t)]\left[\left(\sqrt{Pr\,a_3}\right)\operatorname{erfc}\left(\sqrt{a_3 t}\right)\right.$$

$$\left.-\left(\sqrt{Pr\,a_3}\right)\operatorname{erfc}\left(-\sqrt{a_3 t}\right)\right]-\left(\frac{2\sqrt{Pr}}{\sqrt{\pi t}}\right)\exp[-(a_3 t)]\Big]$$

$$+[a_6(1+t a_5)]\left[(\sqrt{a})\operatorname{erfc}(\sqrt{a}\,t)\right.$$

$$\left.-(\sqrt{a})\operatorname{erfc}(-\sqrt{a}\,t)\right]-\left(\frac{2}{\sqrt{\pi t}}\right)\exp[-a\,t]\Big]$$

$$-\left[\frac{a_5\,a_6}{2\sqrt{a}}\right]\left[\operatorname{erfc}(-\sqrt{a}\,t)-\operatorname{erfc}(\sqrt{a}\,t)\right]$$

$$-[a_6\exp(a_5 t)]\Big[\left(\sqrt{(a+a_5)}\right)\operatorname{erfc}\left(\sqrt{(a+a_5)\,t}\right)$$

$$-\left(\sqrt{(a+a_5)}\right)\operatorname{erfc}\left(-\sqrt{(a+a_5)\,t}\right)\Big]-\left(\frac{2}{\sqrt{\pi t}}\right)\exp[-(a+a_5)\,t]\Big]$$

$$-\left[2\,a_6\sqrt{\frac{Sc}{\pi t}}\right]-[2\,a_5\,a_6\,t]\,2\left[\sqrt{\frac{Sc\,t}{\pi}}\right]$$

$$+[a_6\exp(a_5 t)]\left[\left(\sqrt{Sc\,a_5}\right)\operatorname{erfc}\left(\sqrt{a_5 t}\right)\right.$$

$$\left.-\left(\sqrt{Sc\,a_5}\right)\operatorname{erfc}\left(-\sqrt{a_5 t}\right)\right]-\left(\frac{2\sqrt{Sc}}{\sqrt{\pi t}}\right)\exp[-(a_5 t)]\Big] \qquad (20)$$

V. RESULTS AND DISCUSSIONS

The Velocity profiles for different Phase angles $\left(\omega t = 0, \frac{\pi}{4}, \frac{\pi}{3}, \frac{\pi}{2}\right)$, $k = 1, Gr = 2, Gc = 2, Pr = 0.71, Sc = 0.6, M = 2, t = 0.2$ are shown in Figure (2). It is observed that the Velocity reduced when raise of Phase angle ωt. Figure (3) and (4) show the Velocity profiles for different $(Gr = -15, -5, 2, 5)$, $(Gc = -15, -10, 2, 5)$, $k = 1$, $\omega t = \frac{\pi}{2}$, $Pr = 0.71$, $Sc = 0.6$, $t = 0.2$, $M = 2$.

It is understandable that the velocity amplifies when the Gr or Gc raises because of buoyancy force. The velocity profile for the Magnetic field effect is shown in fig (5) for all values of M the velocity reduced. Because of the Lorentz force, magnetic field in the electrical conducting fluid drastically decreases the velocity of the fluid.

In figure (6) represents the permeability parameter k for velocity profile. The velocity accelerated due to permeability k. The effect of velocity for time $(t = 0.2, 0.4, 0.6, 0.8)$, $Gr = 5$, $Gc = 5$, $M = 2$, $k = 1$, $Pr = 0.71$, $Sc = 0.6$, $\omega t = \pi/2$ are shown in Figure (7). It is noticed that the velocity increases gradually with respect to time. For different values of the Prandtl Number and Schmidt Number the velocity profiles are plotted in Figure (8) and (9) respectively. It is clearly shows that when Pr and Sc increases the velocity profile decrease in the boundary layer.

The temperatures graphs are considered for unlike values of time $(t = 0.2, 0.4, 0.6, 0.8)$ are presented in Figure (10). It is shows that temperature amplified with raise in time t. Figure (11) presented the temperature profiles for diverse values of Prandtl Number. It is shows that the temperature reduced as raising Prandtl Number.

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Concentration of the fluid for time is presented in Figure (12) and it is evidently shows that Concentration profile raised as increase in time. Figure (13) displays the outcome of Schmidt Number (Sc) on the concentration profiles correspondingly. It is experimental that the Concentration profiles reduce as boost the Schmidt number (Sc). These discussions in the absence of Lorentz force are found to be same with Saraswat Amit and Srivastava (2013).

VI. CONCLUSION

he examination approved for MHD flow past an oscillating endless vertical plate with changeable temperature through porous medium. The solution for the model has been solved by Laplace transformation technique. The conclusion of this study is as:

The velocity profile amplifies with increasing of Thermal Grashof Number, Modified Grashof Number, Permeability parameter and time.

The velocity profile reduces with increasing Phase angle, Magnetic field parameter, Prandtl Number and Schmidt Number.

The Temperature profile raises with increases in time. An interesting observation is noticed that the Prandt Number reduces the temperature profile.

The concentration of the fluid flow enhances as increase in time and diminishes as increase in Schmidt number.

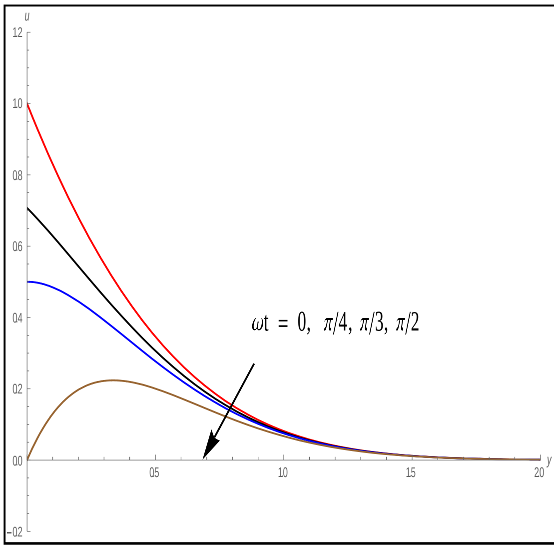

Fig. 2: Velocity profiles for different values of ωt when $\mathbf{Gr = 2, Gc = 2, M = 2, k = 1, t = 0.2, Pr = 0.71, Sc = 0.6}$

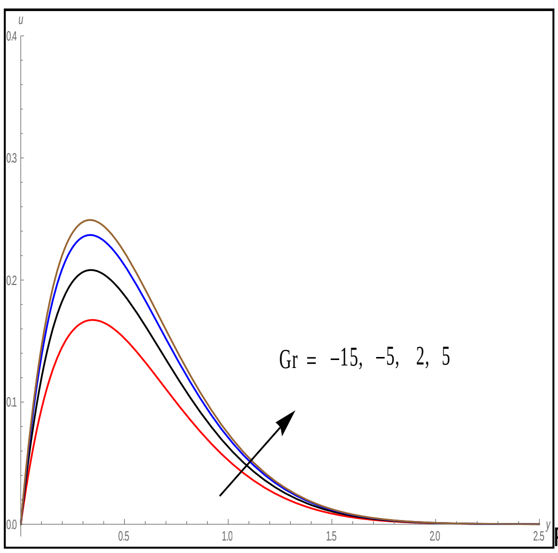

Fig. 3: Velocity profiles for different values of Gr when $\mathbf{Gc = 5, M = 2, k = 1, t = 0.2, Pr = 0.71, Sc = 0.6, \omega t = \pi/2}$

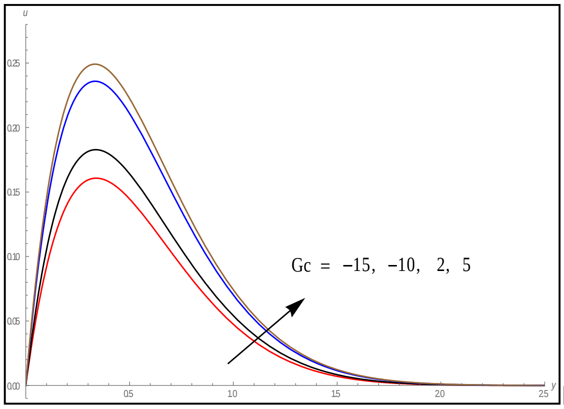

Fig. 4: Velocity profiles for different values of Gc when $\mathbf{Gr = 5, M = 2, k = 1, t = 0.2, Pr = 0.71, Sc = 0.6, \omega t = \pi/2}$

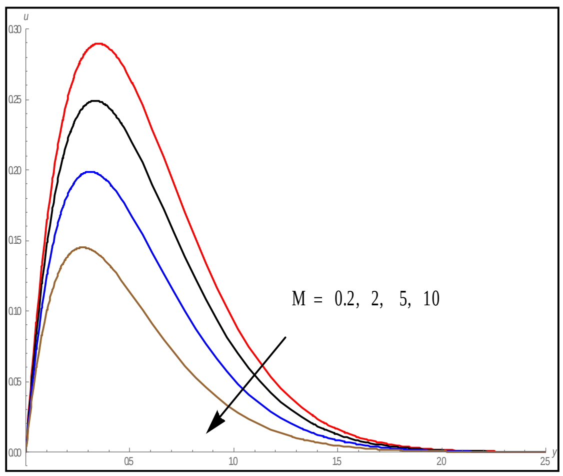

Fig. 5: Velocity profiles for different values of M when

$\mathbf{Gr = 5, Gc = 5, k = 1, t = 0.2, Pr = 0.71, Sc = 0.6, \omega t = \pi/2}$

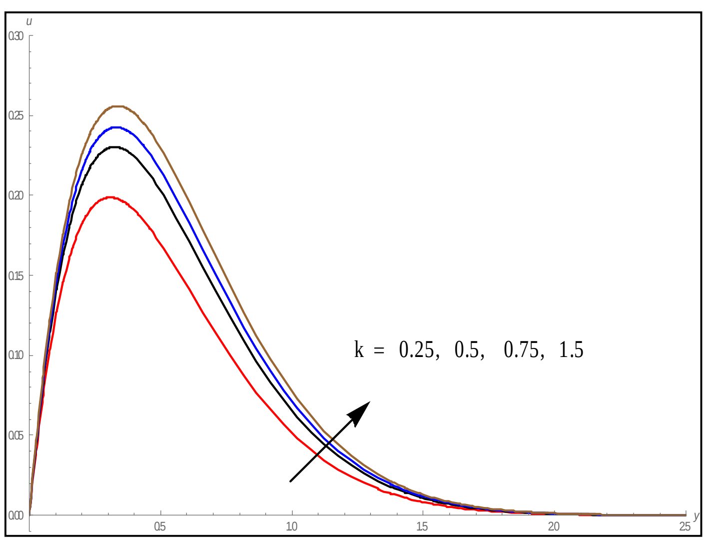

Fig. 6: Velocity profiles for different values of k when
$\mathbf{Gr = 5, Gc = 5, M = 2, t = 0.2, Pr = 0.71, Sc = 0.6, \omega t = \pi/2}$

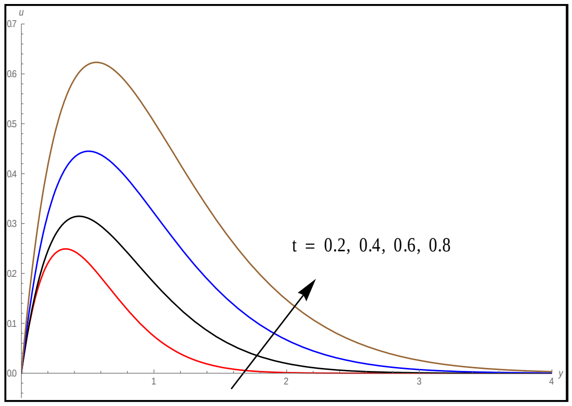

Fig. 7: Velocity profiles for different values of t when
$\mathbf{Gr = 5, Gc = 5, \mathit{M} = 2, \mathit{k} = 1, Pr = 0.71, \mathit{Sc} = 0.6, \omega t = \pi/2}$

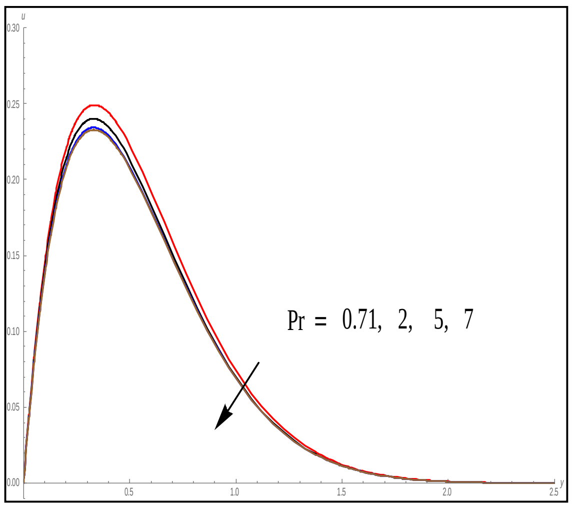

Fig. 8: Velocity profiles for different values of Pr when
$\mathbf{Gr = 5, Gc = 5, M = 2, k = 1, t = 0.2, Sc = 0.6, \omega t = \pi/2}$

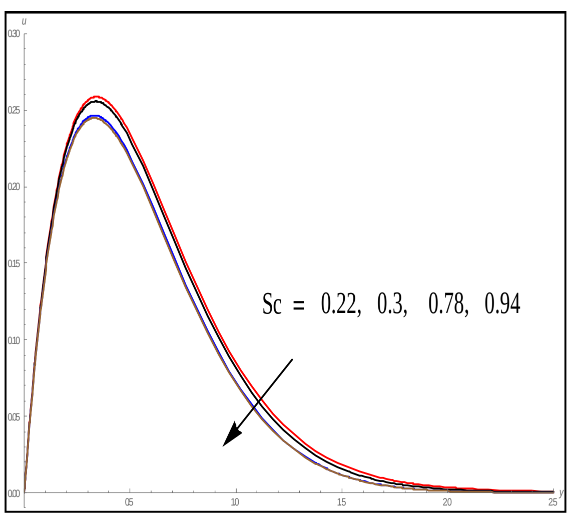

Fig. 9: Velocity profiles for different values of $\mathbf{Sc}$ when
$\mathbf{Gr = 5, Gc = 5, M = 2, k = 1, t = 0.2, Pr = 0.71, \omega t = \pi/2}$

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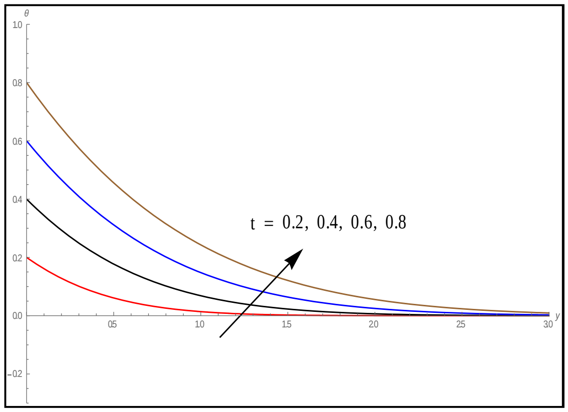

Fig. 10: Temperature profiles for values of t when $\mathbf{Pr = 0.71}$

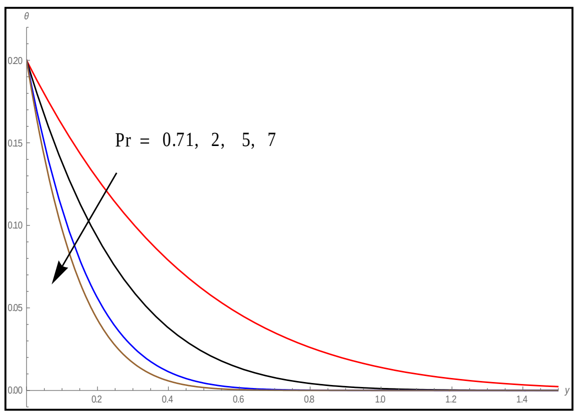

Fig. 11: Temperature profiles for values of Pr when $\mathbf{t = 0.2}$

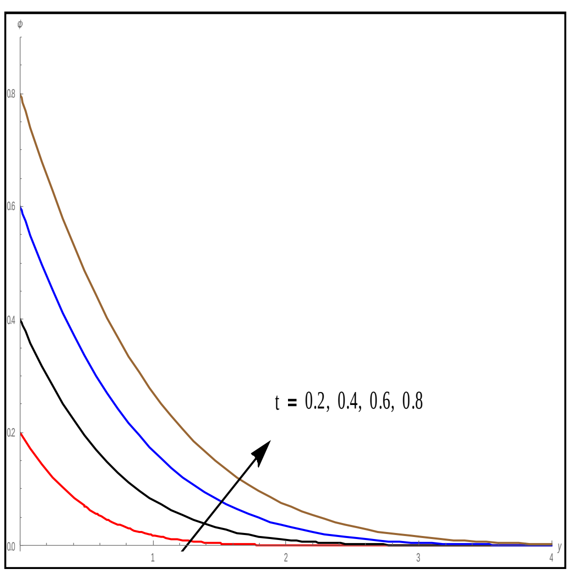

Fig12: Concentration profiles for values of t when $\mathbf{Sc = 0.6}$

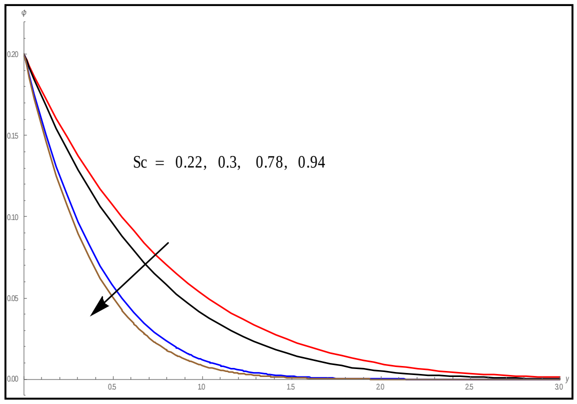

Fig. 13: Concentration profiles for values of Sc when $t = 0.2$

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