AN UNIFORM MASS DIFFUSION ON AN UNSTEADY FLOW PAST AN ACCELERATED INFINITE PERPENDICULAR PLATE WITH VARYING TEMPERATURE THROUGH THE PERMEABLE MEDIUM

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Abstract : ***The purpose of present analysis is to study the effect of the unsteady flow of an incompressible viscous fluid past an uniformly Accelerated Infinite Vertical Porous Plate through the Porous Medium taking into the account of the presence of the variable temperature, uniform mass diffuse with the Heat and Mass Transfer. The dimensionless governing equations are solved by using the Laplace Transform technique. The Velocity, temperature and concentration fields are studied for the different physical parameters like Thermal Grashof Number, Modified Grashof Number, Permeability Parameter, Prandtl Number, Schmidt Number, and time. The effect of these parameters on the Velocity field, Temperature field and Concentration distribution are studied and the results are presented graphically and discussed quantitatively.***

IndexTerms : ***Accelerated infinite Vertical Plate, Heat Transfer, Mass Transfer, Porous Medium and mass diffusion.***

I. INTRODUCTION

The flow through porous media acting an essential role in the fields of science and engineering and considered to be one of the world's most popular classic work. In many engineering and chemical process industries like petroleum, chemical engineering, ground water hydrology, soil mechanics, drainage and irrigation engineering, soil physics and soil mechanics, the flow through porous medium application can be used.

A porous medium is a martial consists of pores or voids. Sponge in one of the best example of a porous medium. The skeletal portion of the material is known as the matrix or frame. The medium can be modelled in a solid matrix penetrated by a network of channel or pores where fluid is in motion. The natural substances like soils, rocks, bones, organic tissues and artificial equipment like cement, foams and stoneware all known as permeable medium.

The flow through permeable intermediate had wide applications in mechanical, chemical, civil engineering and medicine. In various branches of engineering and science, reservoir engineering, petroleum engineering, environmental engineering, civil engineering, ground water hydrology, soil science the movement of fluid in porous medium has received significant attention. The extensive applications of heat and fluid flow through porous media Knowledge is applied in several engineering devices, mechanical, civil, chemical engineering, recently in bioengineering and bio-technology.

Soundalgekar (1979) established the free convection effects on the flow past a vertical oscillating Plate. Soundalgekar and Akolkar (1983) presented Effects of free convection currents and mass transfer on the flow past a vertical oscillating Plate.Radiation effects on mixed convection along a vertical plate with uniform surface temperature studied by Hossain and Takhar (1996). Bakier (2001) examined the thermal radiation effect on mixed convection from vertical surfaces in saturated porous media. Muthucumaraswamy (2002) investigated the effects of a chemical reaction on a moving isothermal surface with suction. Saleh et al (2010) analyzed the heat and mass transfer in MHD visco-elastic fluid flow through a porous medium over a Stretching Sheet with Chemical Reaction. Ahmed et al (2014) presented Radiation Effects on Heat and Mass Transfer over an Exponentially Accelerated Infinite Vertical Plate with Chemical Reaction. The effect of radiation on MHD mixed convection flow from a vertical plate embedded in a saturated porous media with melting studied by Mohammed (2015).

II. Formulation of the problem

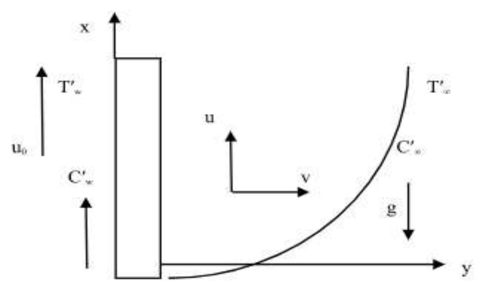

Figure.1. Physical configuration and coordinate system

This chapter decodes the uneven flow accelerated perpendicular plate with a varying temperature with a uniform mass diffusion. The approximate point of the plate in chosen to be origin of a Cartesian co-ordinates system with the plate is occupied by the side of the x-axis vertically, the y-axis perpendicular to the plate. At first the plate and fluids remain in a constant temperature T'_∞. As time increases the velocity of the plate is $u' = \left(\frac{u_0^3\, t'}{\nu}\right)$ which is accelerated in its own stature. The level of concentration, temperature raises from the plate gradually with the time t′. The substantial properties of the fluid are taken in x-direction and hence the physical stature are considered to be the function of y and time t'.

Then under the usual Boussinesq's approximation the unsteady flow equations are momentum equation, energy equation, and mass equation respectively.

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

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

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

In view if the physics of the problem, following are initial and boundary conditions

$$u' = 0,\quad T' = T'_\infty,\quad C' = C'_\infty \quad \text{for all } y,\quad t' \le 0$$
$$u' = \left(\frac{u_0^3\, t'}{\nu}\right),\quad T' = T'_\infty + (T'_w - T'_\infty)\, A\, t',\quad C' = C'_\infty + (C'_w - C'_\infty)\, A\, t' \quad \text{at } y = 0,\ t' > 0$$
$$u' \to 0,\quad T' \to T'_\infty,\quad C' \to C'_\infty,\quad \text{as } y \to \infty \quad t' > 0 \quad (4)$$

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

In order to write the governing equations and the boundary conditions in dimensionless form, the following non-dimensional parameters are introduced.

$$U = \left(\frac{u'}{u_0}\right),\quad t = \left(\frac{t'\, u_0^2}{\nu}\right),\quad Y = \left(\frac{y\, u_0}{\nu}\right),\quad \theta = \left(\frac{T' - T'_\infty}{T'_w - T'_\infty}\right),\quad Sc = \left(\frac{\nu}{D}\right)$$
$$Gr = \left(\frac{g\, \beta_T\, \nu\, (T'_w - T'_\infty)}{u_0^3}\right),\quad Gc = \left(\frac{g\, \beta_c^*\, \nu\, (C'_w - C'_\infty)}{u_0^3}\right),\quad \phi = \left(\frac{C' - C'_\infty}{C'_w - C'_\infty}\right)$$
$$Pr = \left(\frac{\mu\, C_P}{\kappa}\right),\quad k = \left(\frac{u_0^2\, k'}{\nu^2}\right), \quad (5)$$

Using the dimensionless quantities (5) in the equations (1), (2) and (3)

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

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

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

Using the dimensionless quantities (5.5) in the initial and boundary conditions

$$U = 0,\quad \theta = 0,\quad \phi = 0 \quad \text{for all } Y,\quad t \le 0$$
$$U = t,\quad \theta = t,\quad \phi = t \quad \text{at } Y = 0 \quad t > 0$$
$$U \to 0,\quad \theta \to 0,\quad \phi \to 0 \quad \text{as } Y \to \infty \quad t > 0 \quad (9)$$

III. Method of Solution

The non linear coupled partial differential equations (6), (7) and (8) along with the boundary condition (9) in exact form have been solved analytically by using usual Laplace transform technique. By taking Laplace transform on both sides of the equations,

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

$$\frac{d^2\bar{\theta}}{d\,Y^2} - S\,Pr\,\bar{\theta} = 0 \quad (11)$$

$$\frac{d^2\bar{\phi}}{d\,Y^2} - S\,Sc\,\bar{\phi} = 0 \quad (12)$$

The initial and boundary condition are:

$$\bar{U} = 0,\quad \bar{\theta} = 0,\quad \bar{\phi} = 0 \quad \text{for all } Y,\quad t \le 0$$
$$\bar{U} = \frac{1}{S^2},\quad \bar{\theta} = \frac{1}{S^2},\quad \bar{\phi} = \frac{1}{S^2} \quad \text{at } Y = 0,\quad t > 0$$
$$\bar{U} \to 0,\quad \bar{\theta} \to 0,\quad \bar{\phi} \to 0 \quad \text{as } Y \to \infty,\quad t > 0 \quad (13)$$

On solving the equations (10) - (12) with the help of (13) we get

$$\bar{U} = \frac{1}{S^2}\left[1 + \frac{Gr}{S\,(Pr - 1) - \left(\frac{1}{k}\right)} + \frac{Gc}{S\,(Sc - 1) - \left(\frac{1}{k}\right)}\right] \times \exp\left(-Y\sqrt{\left[S + \left(\frac{1}{k}\right)\right]}\right)$$
$$- \frac{1}{S^2}\left\{\left[\frac{Gr\,\exp\left(-Y\sqrt{S\ Pr}\right)}{S\,(Pr - 1) - \left(\frac{1}{k}\right)}\right] + \left[\frac{Gc\,\exp\left(-Y\sqrt{S\ Sc}\right)}{S\,(Sc - 1) - \left(\frac{1}{k}\right)}\right]\right\} \quad (14)$$

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

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

Here Laplace transforms parameter denoted by S, in equation (5.14), (5.15) and (5.16) applying inverse Laplace transform we get,

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

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

$$
\begin{aligned}
U = &\left(\frac{t}{2}\right)\left[\exp\left(2\eta\sqrt{a\,t}\right) erfc\left(\eta+\sqrt{a\,t}\right) + \exp\left(-2\eta\sqrt{a\,t}\right) erfc\left(\eta-\sqrt{a\,t}\right)\right] \\
&- \left(\frac{\eta\sqrt{t}}{2\sqrt{a}}\right)\left[\exp\left(-2\eta\sqrt{a\,t}\right) erfc\left(\eta-\sqrt{a\,t}\right) - \exp\left(2\eta\sqrt{a\,t}\right) erfc\left(\eta+\sqrt{a\,t}\right)\right] \\
&+ \left[a_4\,(1+t\,a_3)\right]\left[\exp\left(2\eta\sqrt{a\,t}\right) erfc\left(\eta+\sqrt{a\,t}\right) + \exp\left(-2\eta\sqrt{a\,t}\right) erfc\left(\eta-\sqrt{a\,t}\right)\right] \\
&- \left[\frac{a_3\,a_4\,\eta\sqrt{t}}{\sqrt{a}}\right]\left[\exp\left(-2\eta\sqrt{a\,t}\right) erfc\left(\eta-\sqrt{a\,t}\right) - \exp\left(2\eta\sqrt{a\,t}\right) erfc\left(\eta+\sqrt{a\,t}\right)\right] \\
&- \left[a_4\exp(a_3 t)\right]\left[\exp\left(2\eta\sqrt{(a+a_3)\,t}\right) erfc\left(\eta+\sqrt{(a+a_3)\,t}\right) + \exp\left(-2\eta\sqrt{(a+a_3)\,t}\right) erfc\left(\eta-\sqrt{(a+a_3)\,t}\right)\right] \\
&- \left[2\,a_4\,erfc\left(\eta\sqrt{Pr}\right)\right] \\
&- \left[2\,a_3\,a_4\,t\right]\left[(1+2\eta^2 Pr)\,erfc\left(\eta\sqrt{Pr}\right) - \frac{2}{\sqrt{\pi}}\left(\eta\sqrt{Pr}\right)\exp\left(-\eta^2 Pr\right)\right] \\
&+ \left[a_4\exp(a_3 t)\right]\left[\exp\left(2\eta\sqrt{Pr\,a_3\,t}\right) erfc\left(\eta\sqrt{Pr}+\sqrt{a_3\,t}\right) + \exp\left(-2\eta\sqrt{Pr\,a_3\,t}\right) erfc\left(\eta\sqrt{Pr}-\sqrt{a_3\,t}\right)\right] \\
&+ \left[a_6\,(1+t\,a_5)\right]\left[\exp\left(2\eta\sqrt{a\,t}\right) erfc\left(\eta+\sqrt{a\,t}\right) + \exp\left(-2\eta\sqrt{a\,t}\right) erfc\left(\eta-\sqrt{a\,t}\right)\right] \\
&- \left[\frac{a_5\,a_6\,\eta\sqrt{t}}{\sqrt{a}}\right]\left[\exp\left(-2\eta\sqrt{a\,t}\right) erfc\left(\eta-\sqrt{a\,t}\right) - \exp\left(2\eta\sqrt{a\,t}\right) erfc\left(\eta+\sqrt{a\,t}\right)\right] \\
&- \left[a_6\exp(a_5 t)\right]\Big[\exp\left(2\eta\sqrt{(a+a_5)\,t}\right) erfc\left(\eta+\sqrt{(a+a_5)\,t}\right) \\
&\qquad + \exp\left(-2\eta\sqrt{(a+a_5)\,t}\right) erfc\left(\eta-\sqrt{(a+a_5)\,t}\right)\Big] \\
&- \left[2\,a_6\,erfc\left(\eta\sqrt{Sc}\right)\right] \\
&- \left[2\,a_5\,a_6\,t\right]\left[(1+2\eta^2 Sc)\,erfc\left(\eta\sqrt{Sc}\right) - \frac{2}{\sqrt{\pi}}\left(\eta\sqrt{Sc}\right)\exp\left(-\eta^2 Sc\right)\right] \\
&+ \left[a_6\exp(a_5 t)\right]\Big[\exp\left(2\eta\sqrt{Sc\,a_5\,t}\right) erfc\left(\eta\sqrt{Sc}+\sqrt{a_5\,t}\right) \\
&\qquad + \exp\left(-2\eta\sqrt{Sc\,a_5\,t}\right) erfc\left(\eta\sqrt{Sc}-\sqrt{a_5\,t}\right)\Big] \quad (19)
\end{aligned}
$$

IV. Skin Friction

To know about the velocity field at the plate the Skin-Friction is calculated with help of the non dimensional form

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

$$
\begin{aligned}
\tau = &\left(\frac{t}{2}\right)\left[\left(\sqrt{a}\right) erfc\left(\sqrt{a\,t}\right) - \left(\sqrt{a}\right) erfc\left(-\sqrt{a\,t}\right) - \left(\frac{2}{\sqrt{\pi\,t}}\right)\exp\left(-\sqrt{a\,t}\right)\right] + \left(\frac{1}{4\sqrt{a}}\right)\left[erfc\left(-\sqrt{a\,t}\right) - erfc\left(\sqrt{a\,t}\right)\right] \\
&+ \left[a_4\,(1+t\,a_3)\right]\left[\left(\sqrt{a}\right) erfc\left(\sqrt{a\,t}\right) - \left(\sqrt{a}\right) erfc\left(-\sqrt{a\,t}\right)\right] - \left(\frac{2}{\sqrt{\pi\,t}}\right)\exp[-a\,t]\Big] \\
&- \left[\frac{a_3\,a_4}{2\sqrt{a}}\right]\left[erfc\left(-\sqrt{a\,t}\right) - erfc\left(\sqrt{a\,t}\right)\right] \\
&- \left[a_4\exp(a_3 t)\right]\left[\left(\sqrt{(a+a_3)}\right) erfc\left(\sqrt{(a+a_3)\,t}\right) - \sqrt{(a+a_3)}\,erfc\left(-\sqrt{(a+a_3)\,t}\right)\right] \\
&- \left(\frac{2}{\sqrt{\pi\,t}}\right)\exp[-(a+a_3)\,t]\Big] - \left[2\,a_4\sqrt{\frac{Pr}{\pi\,t}}\right] - \left[2\,a_3\,a_4\,t\right]2\left[\sqrt{\frac{Pr\,t}{\pi}}\right] \\
&+ \left[a_4\exp(a_3 t)\right]\left[\left(\sqrt{Pr\,a_3}\right) erfc\left(\sqrt{a_3\,t}\right) - \left(\sqrt{Pr\,a_3}\right) erfc\left(-\sqrt{a_3\,t}\right)\right] - \left(\frac{2\sqrt{Pr}}{\sqrt{\pi\,t}}\right)\exp[-(a_3 t)]\Big] \\
&+ \left[a_6\,(1+t\,a_5)\right]\left[\left(\sqrt{a}\right) erfc\left(\sqrt{a\,t}\right) - \left(\sqrt{a}\right) erfc\left(-\sqrt{a\,t}\right)\right] - \left(\frac{2}{\sqrt{\pi\,t}}\right)\exp[-a\,t]\Big] \\
&- \left[\frac{a_5\,a_6}{2\sqrt{a}}\right]\left[erfc\left(-\sqrt{a\,t}\right) - erfc\left(\sqrt{a\,t}\right)\right] \\
&- \left[a_6\exp(a_5 t)\right]\left[\left(\sqrt{(a+a_5)}\right) erfc\left(\sqrt{(a+a_5)\,t}\right) - \left(\sqrt{(a+a_5)}\right) erfc\left(-\sqrt{(a+a_5)\,t}\right)\right] \\
&- \left(\frac{2}{\sqrt{\pi\,t}}\right)\exp[-(a+a_5)\,t]\Big] - \left[2\,a_6\sqrt{\frac{Sc}{\pi\,t}}\right] - \left[2\,a_5\,a_6\,t\right]2\left[\sqrt{\frac{Sc\,t}{\pi}}\right]
\end{aligned}
$$

$$+ [a_6 \exp(a_5 t)] \left[(\sqrt{S_c a_5}) \operatorname{erfc} (\sqrt{a_5 t}) - (\sqrt{Sc\, a_5}) \operatorname{erfc} (- \sqrt{a_5 t})] - \left(\frac{2\sqrt{Sc}}{\sqrt{\pi t}} \right) \exp[-(a_5 t)] \right] \quad (20)$$

v. Nusselt Number

The non dimensional form of Nusselt Number is given below is to find the rate of heat transfer coefficient of the temperature field.

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

$$Nu = 2\sqrt{\frac{Pr\, t}{\pi}} \quad (21)$$

VI. Sherwood Number

The rate of mass transfer coefficient can be obtained from the following non dimensional form of Sherwood Number to know the concentration field.

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

$$Sh = 2\sqrt{\frac{Sc\, t}{\pi}} \quad (22)$$

Where,

$$\eta = \left(\frac{Y}{2\sqrt{t}}\right), a = \left(\frac{1}{k}\right), \quad a_3 = \left(\frac{a}{Pr-1}\right), \quad a_4 = \left(\frac{Gr}{2\, a_3^2 (1-Pr)}\right) \quad a_5 = \left(\frac{a}{Sc-1}\right), \quad a_6 = \left(\frac{Gc}{2\, a_5^2 (1-Sc)}\right)$$

VII. Results and Discussions

In the Figure (2) and (3) the effects of heat transfer Grashof numbers (Gr) and mass transfer Grashof numbers (Gc) for velocity is plotted. At all the points of the flow the Grashof numbers Gr, Gc accelerate the velocity of the flow. The effect of the porous medium parameter k presented in the figure (4) for the velocity distribution. The increasing values of porous medium parameter the velocity is raising. When the value of k enlarges the effect of the porous medium k is very smaller. This is possible only the holes of the porous medium may be ignorable. The effect of time t = 0.2, 0.4, 0.6, 0.8 on the velocity is shown in Figure. (5). It is observes from the figure that the velocity increases with the increase of time t.

The velocity decreases near the plate and it increases away from the plate with an increase in Prandtl number Pr is shown in figure. (6). Prandtl number Pr encapsulates the ratio of momentum diffusivity to thermal diffusivity for a given fluid. It is also the product of dynamic viscosity and specific heat capacity divided by thermal conductivity. Higher Pr fluids will therefore posses higher viscosities and lower thermal conductivities implying that such fluids will flow slower than lower Pr fluids. Due to raise the Schmidt number (Sc) it is concluded that velocity reduced is examined in the Figure (7). The thickness of the concentration boundary layer raised for the lower values of Sc and farther away from the plate the flow region is extend.

The temperature profile with variation of time t and Pr are shows in figure (8) and (9). As time increases the temperature increases and as Pr increases the temperature decreases. For different values of time and the Schmidt number (Sc) the concentration profiles are plotted in Figures (10), (11). As time increase the concentration increases. The ratio between the momentum diffusivity and the mass diffusivity is defined as the Schmidt number Sc. It relates the concentration boundary layer and thickness of the hydrodynamic boundary layer.The concentration reduced when the Schmidt number raises.

Skin friction is a measure of shearing stress experienced at the solid surface. Figures (12)-(16) exhibit the effects of various parameters on skin friction. It is clearly shown through graphs that as Pr and Sc increase the skin-friction increases and it is reverse in other cases.

Nusselt number against time t for various values of parameter Pr = 0.71, 2, 5, 7 is presented in the figure. (17). The smaller values of Pr are equivalent to increasing thermal conductivities and therefore heat is able to diffuse away from the plate more rapidly than higher values of Prandtl number. Hence the rate of heat transfer is enhanced. For dissimilar values of the Schmidt number Sc the Sherwood number is plotted in the figure (18).when the Schmidt number raises the rate of mass transfer coefficient Sherwood number increase.

VIII. Conclusion

The precise investigation in closed form is to study the influence of variable temperature stream past a perpendicular accelerated plate in permeable medium. Solutions are obtained via Laplace transform procedure. The conclusions of the study are as presented below.

- The Velocity enhances with an increase in Grashof Number (Gr), Modified Grashof Number (Gc), Permeability of Porous medium (k) and time (t). It shows the reverse effect with an increase in Prandtl Number (Pr) and Schmidt number (Sc).
- The Temperature profile amplifies with an increase of time (t) but reduces with an increase of Prandtl number (Pr).
- The Concentration profile reduces with a raise of Schmidt number (Sc) but amplifies as time increases.
- As Thermal Grashof Number (Gr), Modified Grashof Number (Gc) and Permeability parameter (k) enlarges the coefficient Skin-friction decreases but the prandtil number and Schmidt number reduces the skin- friction.
- The local Nusselt Number and local Sherwood Number coefficient enhances with a raise of Prandtl Number (Pr) and Schmidt number (Sc).

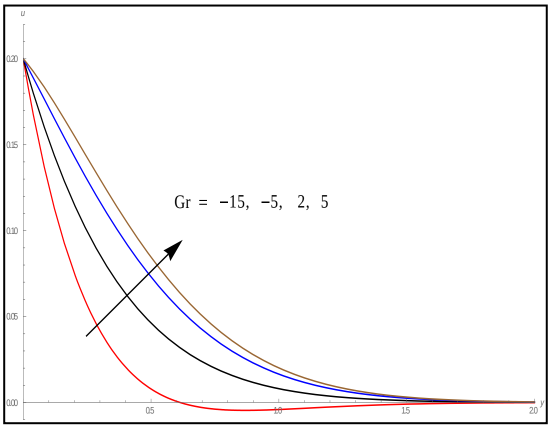

Fig. 2: Velocity profiles for different values of Gr
$\mathbf{Gc = 5, k = 1, t = 0.2, Pr = 0.71, Sc = 0.6}$

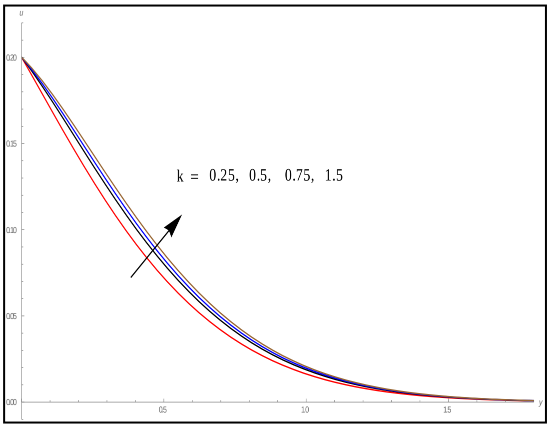

Fig. 4: Velocity profiles for different values of k
$\mathbf{Gr = 5, Gc = 5, t = 0.2, Pr = 0.71, Sc = 0.6}$

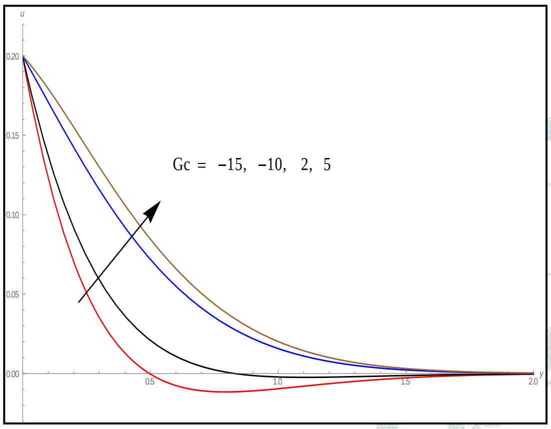

Fig. 3: Velocity profiles for different values of Gc
$\mathbf{Gr = 5, k = 1, t = 0.2, Pr = 0.71, Sc = 0.6}$

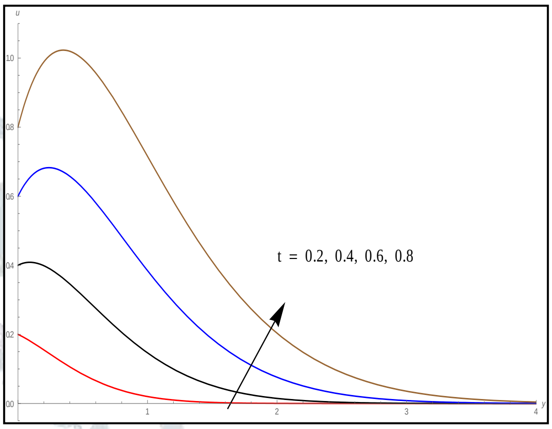

Fig. 5: Velocity profiles for different values of t
$\mathbf{Gr = 5, Gc = 5, k = 1, Pr = 0.71, Sc = 0.6}$

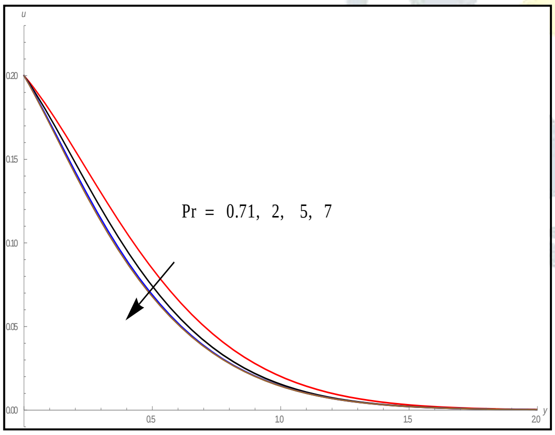

Fig. 6: Velocity profiles for different values of Pr
$\mathbf{Gr = 5, Gc = 5, k = 1, t = 0.2, Sc = 0.6}$

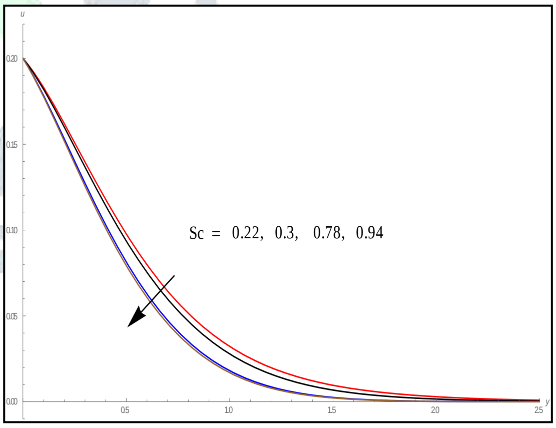

Fig. 7: Velocity profiles for different values of Sc
$\mathbf{Gr = 5, Gc = 5, k = 1, t = 0.2, Pr = 0.71}$

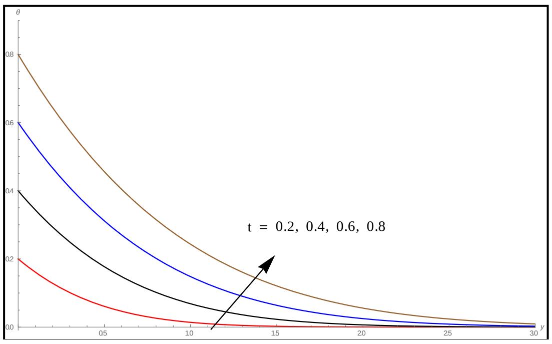

Fig. 8: Temperature profiles for different values of t
$\mathbf{Pr = 0.71}$

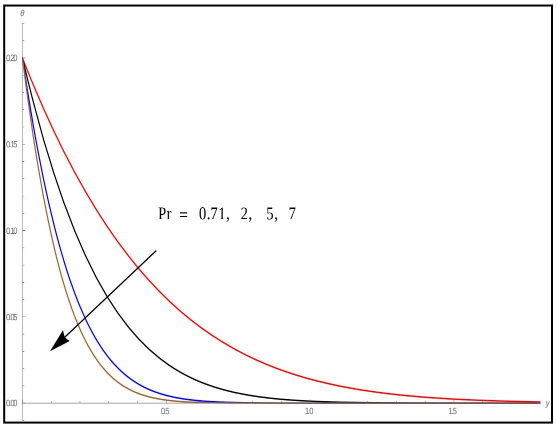

Fig. 9: Temperature profiles for different values of Pr
$t = 0.2$

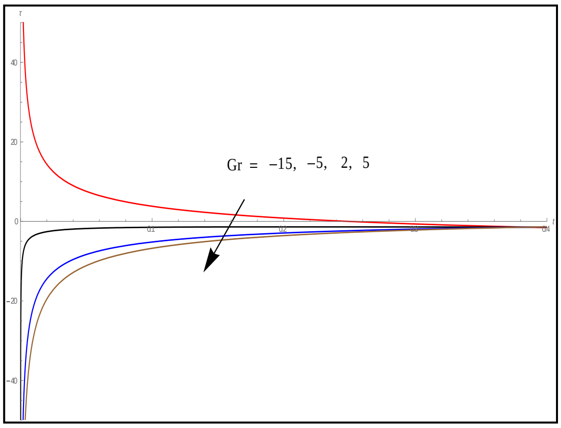

Fig. 12: Skin − friction for different values of Gr
$Gc = 5, k = 1, Pr = 0.71, Sc = 0.6$

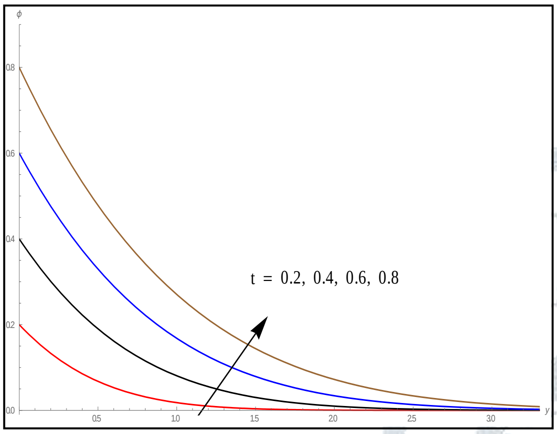

Fig. 10: Concentration profiles for different values of t
$Sc = 0.6$

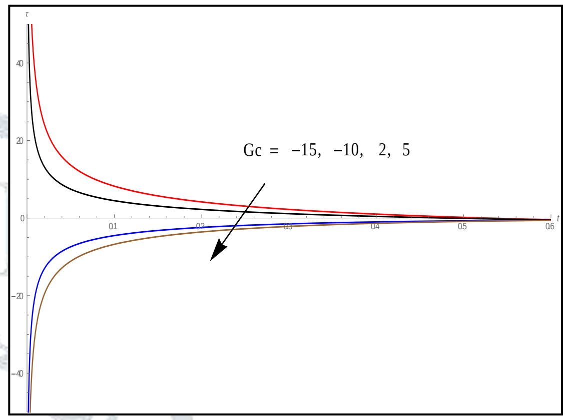

Fig. 13: Skin − friction for different values of Gc
$Gr = 5, k = 1, Pr = 0.71, Sc = 0.6$

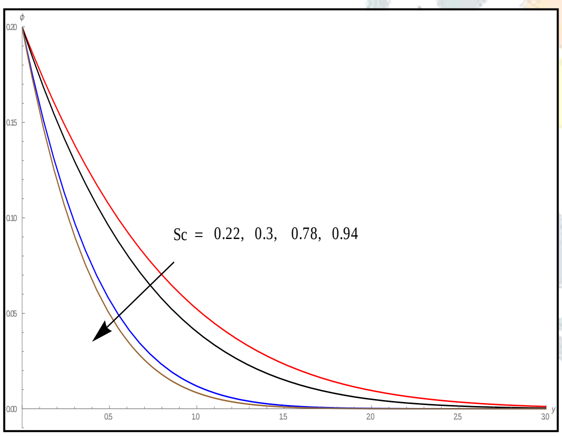

Fig. 11: Concentration profiles for different values of Sc
$t = 0.2$

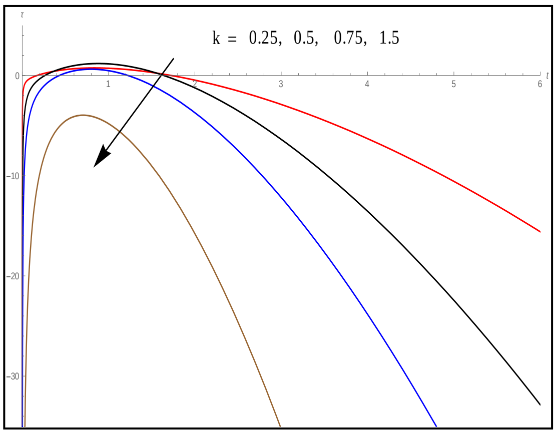

Fig. 14: Skin − friction for different values of k
$Gr = 5, Gc = 5, Pr = 0.71, Sc = 0.6$

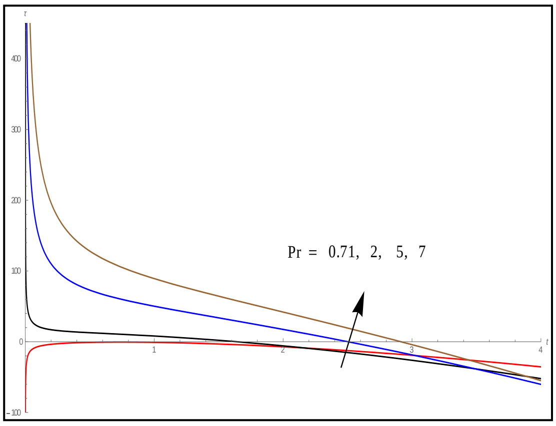

Fig. 15: Skin − friction for different values of Pr
$Gr = 5, Gc = 5, k = 1, Sc = 0.6$

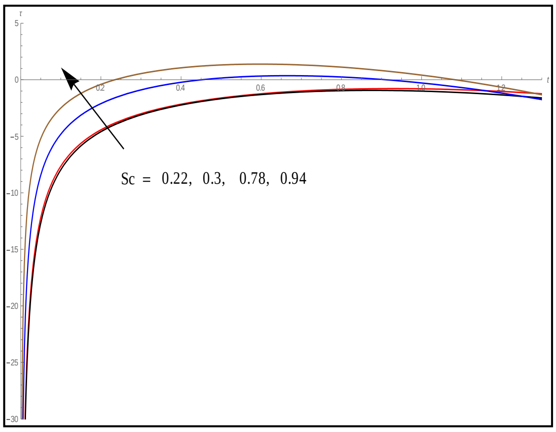

Fig. 16: Skin − friction for different values of Sc
$\mathrm{Gr} = 5, \mathrm{Gc} = 5, k = 1, Pr = 0.71$

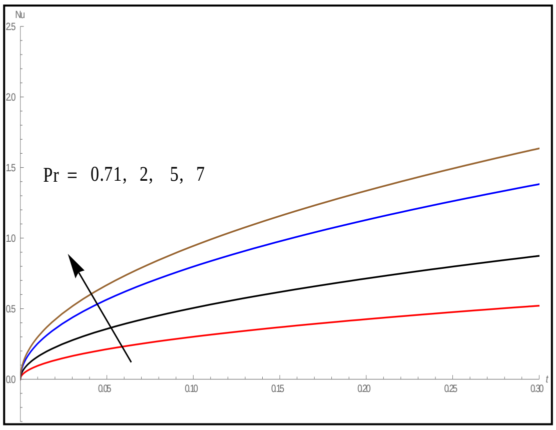

Fig. 17: Effect fo Prandtl number on Nusselt number

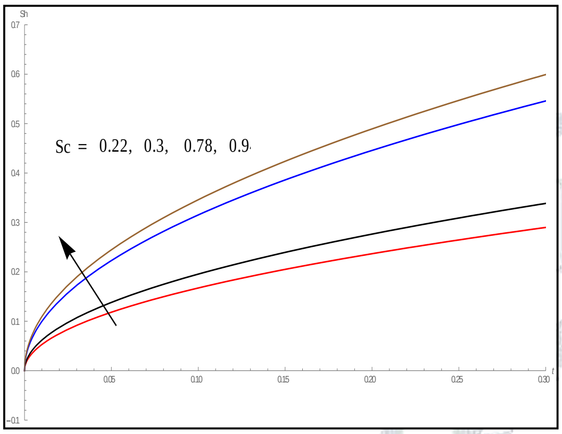

Fig. 18: Effect of schmidt number on Sherwood number

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