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# MHD and Diffusion Thermo Effects on Flow Accelerated Vertical Plate with Chemical reaction

KEYWORDS: Accelerated, Chemical reaction, Dufour effect, Vertical plate

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**ABSTRACT** *The work is focused to investigate heat and mass transfer in MHD over diffusion-thermo (Dufour effect) and chemical reaction on unsteady flow past an exponentially accelerated infinite vertical plate with variable temperature and uniform mass diffusion with heat source. The plate temperature is raised linearly with time and the concentration level near the plate is raised uniformly. The dimensionless governing equations are solved using the perturbation technique. The effect of flow parameters on velocity, temperature, concentration, the skin friction, the rate of heat transfer and the rate of mass transfer are shown through graphs for different physical parameters.*

## INTRODUCTION

The heat transfer caused by the concentration gradient is called Dufour effect. In addition, the double-diffusive convection is of importance in various fields such as high quality crystal production, oceanography, production of pure medication, solidification of molten alloys, geothermally-heated lakes and magmas. For example the quality of the single crystal produced from the melts is limited by chemical and structural in homogeneities. The defect generation depends on heat and mass transfer rates during solidification. The diffusion thermo effect was discovered, but not understood, by Dufour in 1872, and was then apparently forgotten for nearly 70. Diffusion thermo and radiation effects on MHD free convective heat and mass transfer flow past an infinite vertical plate in the presence of a chemical reaction of first order have been studied by Raveendra Babu et al. [7]. Rita choudhury1, Paban Dhar [8] Diffusion thermo effects of visco-elastic fluid past a porous surface in presence of magnetic field and radiation. Raveendra Babu et. al [9] Diffusion-thermo and radiation effects on MHD free convective heat and mass transfer flow past an infinite vertical plate in the presence of a chemical reaction of first order.

These fluxes are mainly governed by convective phenomena of the liquid phase during processing. Also the thermal-diffusion and the diffusion-thermo effects are an interesting macroscopically physical phenomenon in fluid mechanics. Chamkha and Ben-Nakhi [1] analyzed the MHD mixed convection flow under radiation interaction along a vertical permeable surface immersed in a porous medium in the presence of Soret and Dufour's effects. The effects of thermal diffusion and diffusion thermo on the transport of heat and mass has been developed from the kinetic theory of gases by Hirshfelder *et al*. [6] explained the phenomena and derived the necessary formulae to calculate the thermal diffusion coefficient and thermal-diffusion factor for monatomic gases or for polyatomic gas mixtures. Kfoussias and Williams [4] studied the effects of thermal-diffusion and diffusion thermo on steady mixed free-forced convective and mass transfer over a vertical flat plate, when the viscosity of the fluid is varies with temperature. Seddeek and Faiza [5] included the effects chemical reaction, variable viscosity, radiation, variable suction on hydromagnetic convection flow problems. Sparrow *et al*. [6] studied experimentally the effect of diffusion thermo in stagnation-point flow of air with injection of gases of various molecular weights into the boundary layer.

The study of magnetohydrodynamic viscous radiate flows has important industrial, technological and geothermal applications such as high-temperature plasmas, cooling of nuclear reactors, liquid-metal fluids, MHD accelerators, and power-generation systems. Duwairi and Damseh [2] studied the radiation–conduction interaction in free and mixed convection fluid flow for a vertical flat plate in the presence of a magnetic field effect.

It is here proposed to study the unsteady flow heat transfer in MHD over past an exponentially accelerated infinite vertical plate with uniform mass diffusion, in the presence of a first order chemical reaction, heat source and Diffusion thermo (Dufour effects) effects are presented. The dimensionless governing equations are solved using the perturbation technique.

## FORMULATION OF THE PROBLEM

The effects of a first order chemical reaction on the unsteady flow of a viscous incompressible fluid past an exponentially accelerated infinite vertical plate with variable temperature and uniform mass diffusion in the presence of Dufour effect is studied. It is assumed that the effect of viscous dissipation is negligible in the energy equation. Here the *x*- axis is taken along the plate in the vertically upward direction and the *y*-axis is taken normal to the plate. At time $t' < 0$ the plate and fluid are at the same temperature $T_\infty$. At time $t' > 0$, the plate is exponentially accelerated with a velocity $u = u_0 e^{at}$ in its own plane and the temperature of the plate is raised linearly with respect to time and the concentration level near the plate is raised to $C_w$ It is also assumed that there is a first order chemical reaction between the fluid and the species concentration. The reaction is assumed to take place entirely in the stream. Then under the usual Boussinesq approximation the unsteady flow is governed by the following equations:

$$\frac{\partial u}{\partial t'} = g\beta\left(T - T_\infty\right) + g\beta^*\left(C' - C_\infty'\right) + \nu\frac{\partial^2 u}{\partial y^2} - \frac{\sigma B_0^2}{\rho}u \qquad (1)$$

$$\rho C_p \frac{\partial T}{\partial t'} = \frac{\partial^2 T}{\partial y^2} - Q_0\left(T - T_\infty\right) + \frac{D_M k_T}{C_s C_p}\frac{\partial^2 C'}{\partial y^2} \qquad (2)$$

$$\frac{\partial C'}{\partial t'} = D_M \frac{\partial^2 C}{\partial y^2} - Kr^* C' \qquad (3)$$

with the following initial and boundary conditions:

$$\begin{aligned} &u = 0, T = T_\infty, C' = C_\infty \quad for \quad all\ y, t \le 0 \\ &t' \ge 0, u = u_0 \exp\left(a't'\right), T = T_\infty + \left(T_\infty - T_\infty\right)At' \\ &\qquad C' = C_w',\ at\ \ y = 0 \\ &u \to 0, T \to T_\infty C' \to C_\infty' \quad as \quad y \to \infty \end{aligned} \qquad (4)$$

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where $A = \frac{u_0^2}{\nu}$

On introducing the non-dimensional quantities

$$U = \frac{u}{u_0}, \quad t = \frac{t' u_0^2}{\nu}, \quad Y = \frac{y u_0}{\nu}, \quad \theta = \frac{T - T_\infty}{T_w - T_\infty} \quad (5)$$

$$C = \frac{C - C_\infty}{C_w' - C_\infty'}, M = \frac{\sigma B_0 \nu}{\rho u_0^2}, Q = \frac{Q_0 \nu}{\rho C_p u_0^2}, Sc = \frac{\nu}{D}$$

$$Gr = \frac{g\beta(T_w - T_\infty)}{u_0^3}, \quad Gc = \frac{\nu g \beta^* \left(C_w' - C_\infty'\right)}{u_0^3}$$

$$Du = \frac{D_M k_T \left(C_w' - C_\infty'\right)}{\nu c_s c_p \left(T_w - T_\infty\right)}, \ Kr = \frac{\nu Kr^*}{u_0^2}, \Pr = \frac{\mu C_p}{k}$$

in (1) to (3), we obtain

$$\frac{\partial U}{\partial t} = Gr\,\theta + Gm\,C + \frac{\partial^2 U}{\partial Y^2} - Mu \quad (6)$$

$$\frac{\partial \theta}{\partial t} = \frac{1}{\Pr}\frac{\partial^2 \theta}{\partial Y^2} - Q\,\theta + Du\frac{\partial^2 C}{\partial Y^2} \quad (7)$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial Y^2} - Kr\,C \quad (8)$$

The initial and boundary conditions in non-dimensional quantities are

$$\begin{aligned} &U = 0, \theta = 0, = 0 \quad for \ all \ Y, t \le 0 \\ &t > 0, U = u_0 \exp(at), \theta = t, C = 1 \ at \quad Y = 0 \\ &U \to 0, \theta \to 0, C \to 0 \qquad as \quad Y \to \infty \end{aligned} \quad (9)$$

**METHOD OF SOLUTION**

Equation (6) – (8) are coupled, non – linear partial differential equations and these cannot be solved in closed – form using the initial and boundary conditions (9). However, these equations can be reduced to a set of ordinary differential equations, which can be solved analytically. This can be done by representing the velocity, temperature and concentration of the fluid in the neighborhood of the fluid in the neighborhood of the plate as

$$\begin{aligned} U &= U_0(y) + \varepsilon e^{at} U_1(y) \\ \theta &= \theta_0(y) + \varepsilon e^{at} \theta_1(y) \\ C &= C_0(y) + \varepsilon e^{at} C_1(y) \end{aligned} \quad (10)$$

Substituting (10) in Equation (6) – (8) and equating the harmonic and non – harmonic terms, we obtain

$$U_0'' - MU_0 = -Gr\theta_0 - GmC_0 \quad (11)$$

$$\theta_0'' - Q\Pr\theta_0 = -Du\Pr C_0'' \quad (12)$$

$$C_0'' - KrSc = 0 \quad (13)$$

$$U_1'' - (M + a)U_1 = -Gr\theta_1 - GmC_1 \quad (14)$$

$$\theta_1'' - \beta_2\theta_1 = -Du\Pr C_1'' \quad (15)$$

$$C_1'' - \beta_1 C_1 = 0 \quad (16)$$

Where $\beta_1 = (Kr + a)Sc, \beta_2 = (Q + a)\Pr$

Corresponding boundary condition becomes

$$\left.\begin{aligned} U_0 = 0, \theta_0 = t, C_0 = 1 \\ U_1 = 1, \theta_0 = 0, C_1 = 0 \end{aligned}\right\} \quad at \quad y = 0 \quad (17)$$

$$\left.\begin{aligned} U_0 = 0, \theta_0 = 0, C_0 = 0 \\ U_1 = 0, \theta_0 = 0, C_1 = 0 \end{aligned}\right\} \quad at \quad y \to \infty$$

The solution of equation (11) - (16) under boundary condition (17) is

$$U(Y,t) = A_1 e^{m_2 y} + A_2 e^{m_6 y} + A_3 e^{m_2 y} + A_4 e^{m_{10} y} \quad (18)$$

$$\theta(Y,t) = Z_1 e^{m_2 y} + Z_2 e^{m_6 y} \quad (19)$$

$$C = e^{m_2 y} \quad (20)$$

The shear stress, Nusselt number and Sherwood number can now be obtained easily from equations (18), (19) and (20)

Skin friction coefficient $\tau$ is

$$\tau = \left(\frac{\partial U}{\partial y}\right)_{y=0} = m_2 A_1 + m_6 A_2 + m_2 A_3 + m_{10} A_4 \quad (21)$$

Heat transfer coefficient $Nu$ (Nusselt number) is:

$$Nu = \left(\frac{\partial \theta}{\partial Y}\right)_{y=0} = m_2 Z_1 + m_6 Z_2 \quad (22)$$

Mass transfer coefficient $Sh$ (Sherwood number) is:

$$Sh = \left(\frac{\partial C}{\partial y}\right)_{y=0} = m_2 \quad (23)$$

**APPENDIX**

The constants are not given due to save the space

**RESULTS AND DISCUSSION**

In this section, representative numerical results are displayed with the help of graphical illustrations. Computations were carried out for various values of physical parameters are presented in figures (1) – (21).

The effect of velocity for different times $(t)$ are shown in figure (1). In this case, the velocity increases gradually with respect to time $(t)$. The effects of Grashof number on the velocity field are shown in figure (2). It is seen from this figure that the velocity increases with the increase of Grashof number (or increase of free convection current). The effects of modified Grashof number on the velocity field are shown figure (3), shows that the velocity increases when the concentration difference between the mean and free stream values increases. Figure (4) show the effects of Dufour number $(Du)$ on the velocity profiles, respectively. Increasing the Dufour number, by virtue of the thermal buoyancy effect, this in turn, induces more flow along the plate represented by the increases in the fluid velocity. Figure (5) exhibits the effects of exponential index on velocity field. It is observed that the exponential index$(a)$ increases the velocity. Figure (6) shows the effects of chemical reaction parameter on the velocity field. It is seen that as chemical reaction parameter increases, the velocity field increases. Figures (7) present the effects of the magnetic field parameter $(M)$ on the velocity. Application of a magnetic field has the tendency to slow down the movement of the fluid causing its velocity to decrease as the magnetic field parameter increases. In addition, this decrease in the flow movement as the magnetic field parameter increases is accompanied by increases in both the temperature and concentration profiles. These behaviours are clearly displayed in Figure (7). Figure (8) shows the effect of Prandtl number on velocity field. It is noticed that as Prandtl number increases, the velocity field decreases. Figures (9) and (10) exhibits the

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effect of heat source parameter and Schmidt number $(Sc)$ on velocity field. The increase in $Q$ and $Sc$ decreases the velocity and consequently increases.

In figure (11) the temperature profiles for different values of Dufour number $(Du)$ are shown. It is observed from this figure that the Dufour number $(Du)$ has an increasing effect. Also, increasing the chemical reaction parameter leads to an increase in the temperature profiles shown in the figure (12). In addition, increasing the Schmidt number $(Sc)$ increases in the temperature profiles increase. In figure (13), the temperature profiles for different values of Prandtl number $(\mathrm{Pr})$ are shown. This figure revels that the Prandtl number $(\mathrm{Pr})$ has a large decreasing effect on temperature. Figure (14) exhibits the effects of heat source parameter $(Q)$ on the temperature field. It is observed that as the heat source parameter increases, the temperature decreases. Figures (15) and (16) exhibits the effects of Schmidt number $(Sc)$ and time $(t)$ parameter on temperature profiles. It is observed that the increase Schmidt number $(Sc)$ and time $(t)$ parameter, increases the temperature.

Figures (17) – (18) show the influence of the chemical reaction parameter $(Kr)$ and the Schmidt number $(Sc)$ on the concentration profiles in the boundary layer, respectively. Increasing the chemical reaction parameter produces a decrease in the species concentration. In turn, this causes the concentration buoyancy effects to decrease as $Kr$ increases. Consequently, less flow is induced along the plate resulting in decreases in the fluid velocity in the boundary layer. In addition, increasing the Schmidt number $(Sc)$ causes decreases in the concentration.

Figure (19) illustrate the effects of the Dufour number $(Du)$ distributions of the local skin-friction coefficient versus $Gr$. It is seen that the local skin-friction coefficient increases with the increases in the Dufour number. However, the local Nusselt number or local rate of heat transfer increases as the Dufour number increases as shown in figure (20). On the other hand, the local Sherwood number is predicted to decrease with increasing as Schmidt number shown in figure (21).

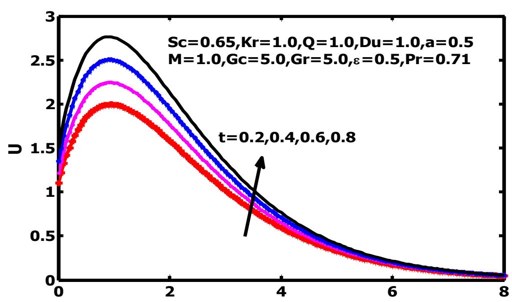

Figure (1): Velocity profiles for different values of t

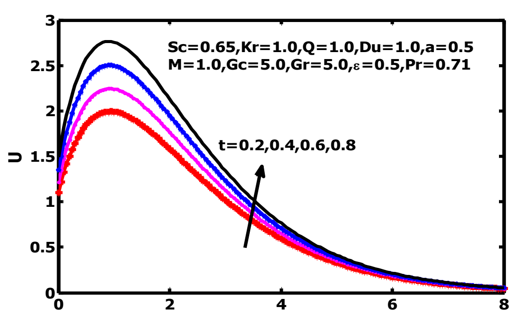

Figure (1): Velocity profiles for different values of t

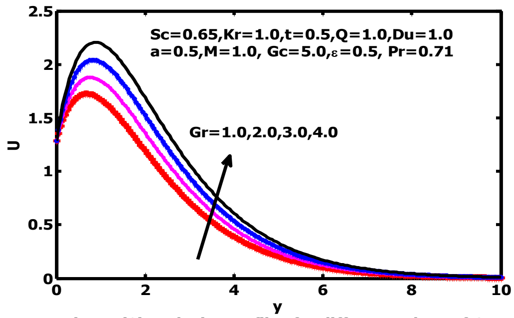

Figure (2): Velocity profiles for different values of Gr

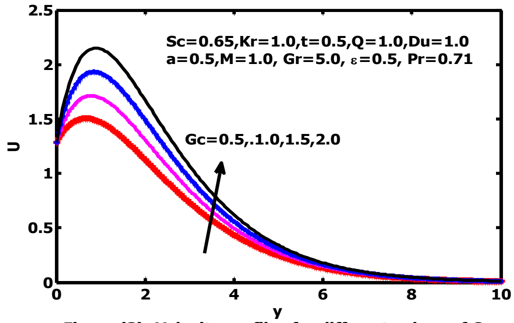

Figure (3): Velocity profiles for different values of Gc

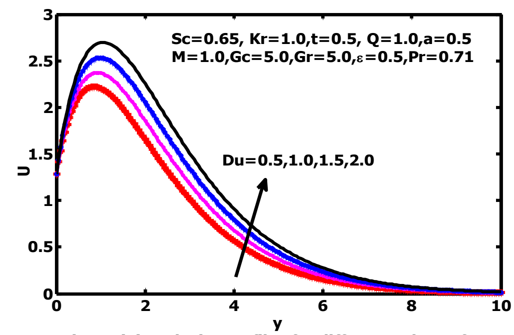

Figure (4): Velocity profiles for different values of Du

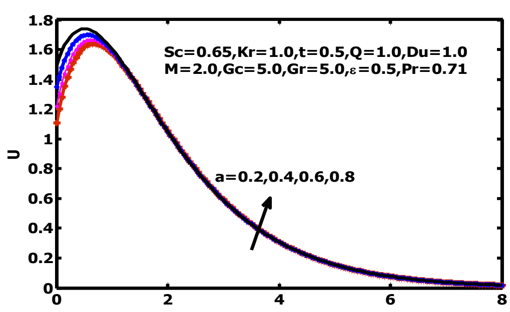

Figure (5):Velcoity profiles for diffeent values of a

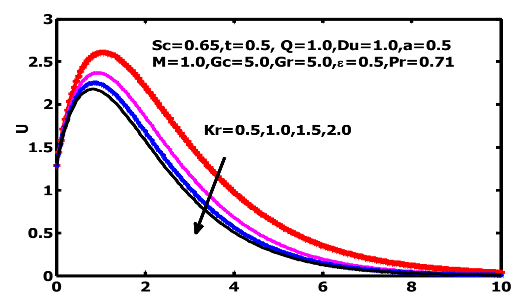

Figure (6): Velocity profiles for different values of Kr

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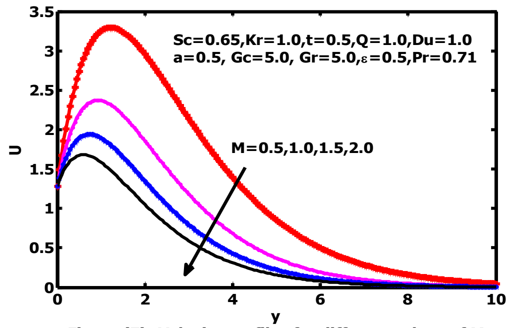

Figure (7): Velocity profiles for different values of M

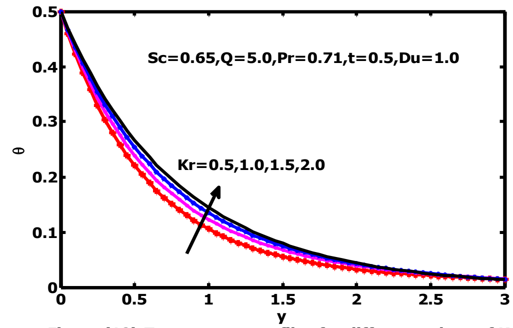

Figure (12):Temperature profiles for different values of Kr

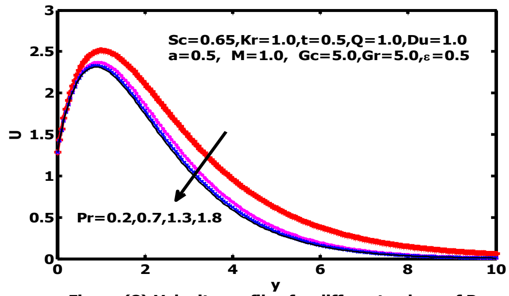

Figure (8):Velocity profiles for different values of Pr

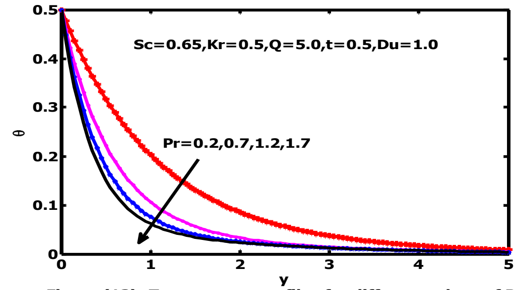

Figure (13): Temperature profiles for different values of Pr

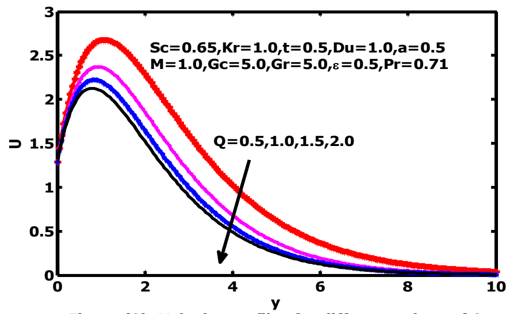

Figure (9): Velocity profiles for different values of Q

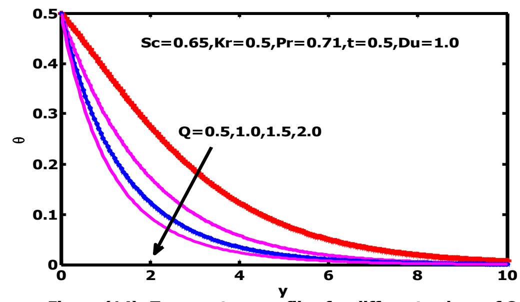

Figure (14): Temperature profiles for different values of Q

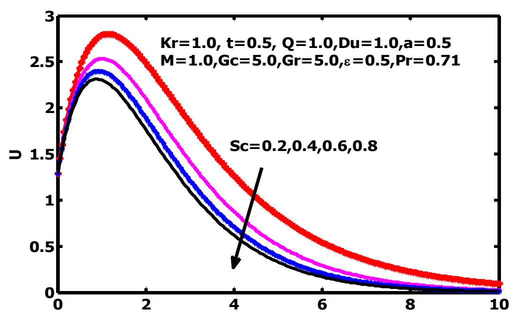

Figure (10): Velocity profiles for different values of Sc

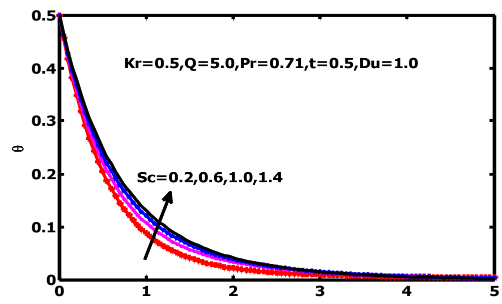

Figure (15): Temperature profiles for different values of Sc

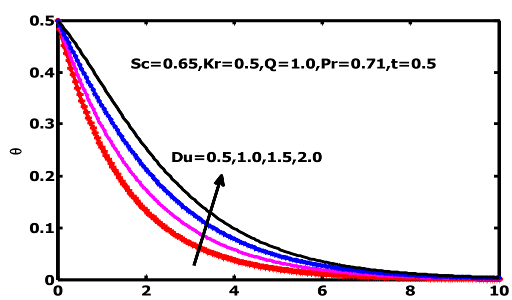

Figure (11): Temeprature profiles for different values of Du

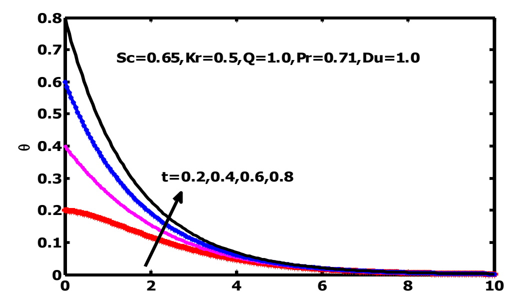

Figure (16): Temperature profiles for different values of t

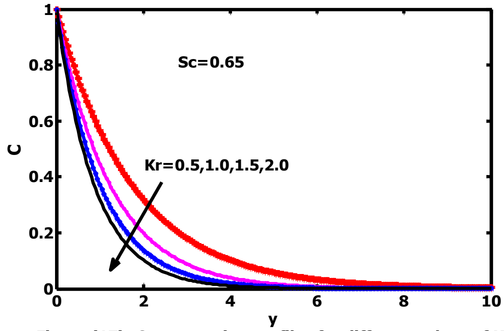

Figure (17): Concentration profiles for different values of Kr

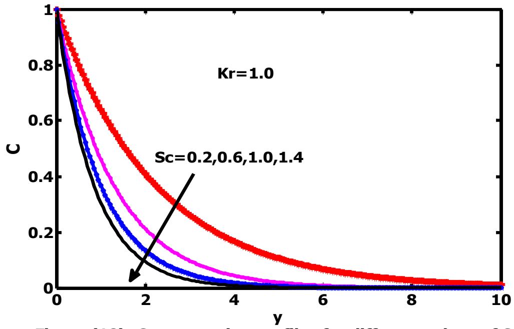

Figure (18): Concentration profiles for different values of Sc

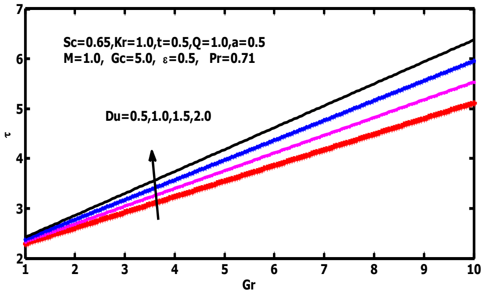

Figure (19): Skin friction for different values of Du versus Gr

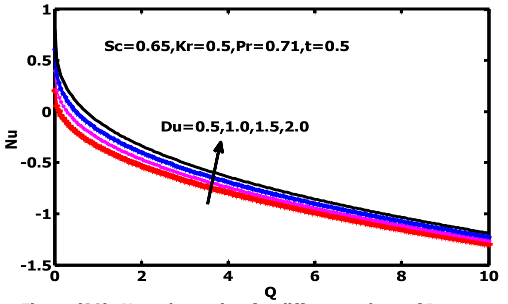

Figure (20): Nusselt number for different values of Du versus Q

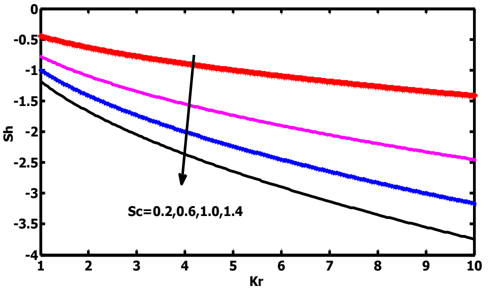

Figure (21): Sherwood number for different values of Sc

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