CHEMICAL REACTION AND MHD EFFECTS ON FREE CONVECTION FLOW OF A VISCOELASTIC DUSTY GAS THROUGH A SEMI INFINITE PLATE MOVING WITH RADIATIVE HEAT TRANSFER

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ABSTRACT

The present paper is concerned with the study of MHD free convective flow of a viscoelastic (Kuvshinski type) dusty gas through a porous medium induced by the motion of a semi-infinite flat plate under the influence of radiative heat transfer moving with velocity decreasing exponentially with time and chemical reaction taking into an account. The expressions for velocity distribution of a dusty gas and dust particles, concentration profile and temperature field are obtained. The effect of Schmidt number (Sc), Magnetic field parameter (M), Chemical reaction parameter (Kr) and Radiation parameter (N) on velocity distribution of dusty gas and dust particles, concentration and temperature distribution are discussed graphically.

Keywords: Chemical reaction, MHD, Free convection, Radiative heat transfer, Dusty Gas

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INTRODUCTION

The study of radiation in thermal engineering is of great interest for industry point of view. Many processes in thermal engineering areas occur at high temperature and radiative heat transfer becomes very important for the design of pertinent equipment. Nuclear power plants, gas turbines and the various propulsion devices for air craft, missiles, satellites and space vehicles are example of such engineering areas. In view of above some authors observed (Aboeldahab Emad 2000) has been studied radiation effect on heat transfer in an electrically conducting fluid at a stretching surface with uniform free stream, (Cortell 2006) shown a note on flow and heat transfer of a viscoelastic fluid over a stretching sheet, (Chenna Kesavaiah et. al. 2021) motivated study on radiative MHD Walter's Liquid-B flow past a semi-infinite vertical plate in the presence of viscous dissipation with a heat source, (Datti et. al. 2004) depicted MHD viscoelastic fluid flow over a non- isothermal stretching sheet, (Rami Reddy et.al. 2021) explained on hall effect on MHD flow of a viscoelastic fluid through porous medium over an infinite vertical porous plate with heat source, (Chenna Kesavaiah and B Venkateswarlu 2020) expressed in detailed on chemical reaction and radiation absorption effects on convective flows past a porous vertical wavy channel with travelling thermal waves, (Mallikarjuna Reddy et. al. 2019) has been considered the radiation and diffusion thermo effects of viscoelastic fluid past a porous surface in the presence of magnetic field and chemical reaction with heat source, (Srinathuni Lavanya and Chenna Kesavaiah 2017) observed that heat transfer to MHD free convection flow of a viscoelastic dusty gas through a porous medium with chemical reaction, (Mallikarjuna Reddy et. al. 2018) motivated study on effects of radiation and thermal diffusion on MHD heat transfer flow of a dusty viscoelastic fluid between two moving parallel plates, (Chenna Kesavaiah et. al. 2013) intended their plane in radiation and Thermo - Diffusion effects on mixed convective heat and mass transfer flow of a viscous dissipated fluid over a vertical surface in the presence of chemical reaction with heat source.

As for as dusty viscoelastic fluid is concerned, it is one of the multiphase flows. The particular importances in various engineering disciplines are heat transfer and flow attitude of viscoelastic fluid among parallel plates. In the aspects of these uses, the study of the perspective of boundary layers has been channeled to viscoelastic fluid. (Karunakar Reddy et.al. 2013) MHD heat and mass transfer flow of a viscoelastic fluid past an impulsively started infinite vertical plate with chemical reaction, (Ch Kesavaiah et. al. 2012) Radiation and mass transfer effects on moving vertical plate with variable temperature and viscous dissipation, (Satyanarayana et. al. 2011) Viscous dissipation and thermal radiation effects on an unsteady MHD convection flow past a semi-infinite vertical permeable moving porous plate, (Ch Kesavaiah et. al. 2011) Effects of the chemical reaction and radiation absorption on an unsteady MHD convective heat and mass transfer flow past a semi-infinite vertical permeable moving plate embedded in a porous medium with heat source and suction, (Edmundo et. al. 1998) Numerical model for radiative heat transfer analysis in arbitrary shaped axisymmetric enclosures with gases media, (Chenna Kesavaiah and Satyanarayana 2013) MHD and Diffusion Thermo effects on flow accelerated vertical plate with chemical reaction, (El-Hakiem 2000) MHD oscillatory flow on free convection-radiation through a porous medium with constant suction velocity, (Hossain et. al. 1999) The effect of radiation in free convection from a porous vertical plate, (Jae Hyun Park and Seung Wook Baek 2002): Non gray thermal radiation effects on the sound wave propagation in gasparticle two-phase medium, (Chenna Kesavaiah et. al. 2013) Natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Kee Soo Han et. al. 1991): Analysis of heat transfer in a pipe carrying two-phase gas-particle suspension, (Gretler and Regenfelder 2002) Similarity solution for laser-driven shock waves in a dust-laden gas with internal heat transfer effects.

The physical significance of Newtonian heating is discussed broadly in the literature. According to Newton's law of cooling, the rate of heat loss of a body varies directly to the distinction of temperature between the surrounding and the body. Newtonian heating performs a very decisive role in heat exchanger designing, associate heat transfer about fins, radiation of solar, heating and cooling processes of buildings, and in petroleum industries. The matter of the convection of heat in the cylinders invites a lot of researchers globally due to the enormous number of applications in wires coating and polymer fiber spinning. (Chenna Kesavaiah and Sudhakaraiah 2014) Effects of heat and mass flux to MHD flow in vertical surface with radiation absorption, (Makinde and Chinyoka 2010) Numerical investigation of transient heat transfer to hydromagnetic channel flow with radiative heat and convective cooling, (Mansour 1997) Forced convection-radiation interaction heat transfer in boundary layer over a flat plate submerged in a porous medium, (Ch Kesavaiah et. al. 2013) Effects of radiation and free convection currents on unsteady Couette flow between two vertical parallel plates with constant heat flux and heat source through porous medium, (Mbeledogu et. al. 2007) Unsteady MHD free convection flow of a compressible fluid past a moving vertical plate in the presence of radiative heat transfer, (Murthy et. al. 2004) Combined radiation and mixed convection from a vertical wall with suction/ injection in a non-darcy porous medium, (Muthukumarswamy and Kumar Senthil 2004) Heat and Mass transfer effect on moving vertical plate in the presence of thermal radiation, (Raptis et. al. 2004) Effect of thermal radiation on MHD flow,(Saffman 1962) On the stability of laminar flow of a dusty gas, (Seddeek and Abdelmeguid 2006) Effect of radiation and thermal diffusivity on heat transfer over a stretching surface with variable heat flux,

(Siddheshwar and Mahabaleswar 2005) Effects of radiation and heat source on MHD flow of a viscoelastic liquid and heat transfer over a stretching sheet, (Sujit Kumar Khan 2006): Heat transfer in a viscoelastic fluid flow over a stretching surface with heat Source/sink, suction/blowing and radiation, (Varshney Ram Prakash 2004) MHD free convection flow of a viscoelastic dusty gas through a porous medium induced by the motion of a semi- infinite flat plate moving with velocity decreasing exponentially with time, (Chenna Kesavaiah et. al. 2021) MHD effect on convective flow of dusty viscous fluid with fraction in a porous medium and heat generation.

In the present paper a proper sign for the normal stress modulus $\left(i.e.\alpha_1 \geq 0\right)$ is used and, as we will see the effects of viscous dissipation, uniform transverse magnetic field, internal heat generation/absorption and thermal radiation are included in the energy equation.

FORMULATION OF THE PROBLEM

Let the dusty gas to confine in the space $y > 0$ and the flow is produced by the motion of a semi – infinite flat plate moving with velocity $ve^{\lambda^2 t}$ in $x-$direction. The $x-$axis is taken along the plate and y is measured normal to it. Since the plate is semi infinite, all the physical quantities will be function of y and t only.

The gas is optically thin with a relatively low density and radiative heat flux is given by

$$\frac{\partial q}{\partial y} = 4\alpha^2\left(T_0 - T\right) \qquad (1)$$

Where *u* and *v* are the gas and the particle velocity, ν is the kinematic coefficient of viscosity of the gas, K_0 is the Stoke's resistance coefficient N_0 is the number density of the dust particles which is taken to be constant, *ρ* is the density of gas, *m* is the mass of a dust particle, K_T is the thermal conductivity and C_p is the specific heat at constant pressure.

According to Saffman,1 the equation of motion of dusty gas and dust particles along the $x-$axis with the body forces due to applied magnetic field, porous medium, concentration and radiation are given by:

$$\left(1+\eta\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t}=\nu\frac{\partial^2 u}{\partial y^2}+\frac{K_0 N_0}{\rho}\left(1+\eta\frac{\partial}{\partial t}\right)(v-u)-\left(\frac{\sigma B_0}{\rho}+\frac{\nu}{K}\right)\left(1+\eta\frac{\partial}{\partial t}\right)u+g\beta\left(T-T_0\right)+g\beta'\left(C-C_0\right) \qquad (2)$$

$$\frac{\partial v}{\partial t}=\frac{K_0}{m}(v-u) \qquad (3)$$

$$\frac{\partial T}{\partial t}=\frac{K_T}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-4\alpha^2\left(T_0-T\right) \qquad (4)$$

$$\frac{\partial C}{\partial t}=D\frac{\partial^2 C}{\partial y^2}-Kr'\left(C-C_0\right) \qquad (5)$$

Boundary conditions are:

$$\left.\begin{array}{l} u=\nu e^{\lambda^2 t}, T=\nu e^{\lambda^2 t} \\ C=\nu e^{\lambda^2 t}\end{array}\right\} \quad at \quad y=0 \qquad (6)$$
$$u\to 0, T\to 0, C\to 0 \;\; at \quad y\to\infty$$

Solution of the problem

Let us introduce the non- dimensional variables,

$$u^*=\frac{u}{\nu}, \qquad v^*=\frac{v}{\nu}, \;\; y^*=\frac{y}{(\nu\tau)^{\frac{1}{2}}}$$

$$t^*=\frac{t}{\nu}, T=\frac{T-T_0}{T_\infty-T_0}, C=\frac{C-C_0}{C_\infty-C_0}$$

The dimensionless forms of the equations (2)–(5) respectively are:

$$\left[1+\alpha_1\left(f+M+\frac{1}{K_1}\right)\right]\frac{\partial u}{\partial t}=\frac{\partial^2 u}{\partial y^2}+\alpha_1 f\frac{\partial v}{\partial t}+f\left(v-u\right)-Mu-\frac{1}{K_1}u+GrT+GmC \qquad (7)$$

$$\frac{\partial v}{\partial t}=\left(v-u\right) \qquad (8)$$

$$\frac{\partial T}{\partial t}=\frac{1}{Pe}\frac{\partial^2 T}{\partial y^2}-\frac{N^2}{\mathrm{P}e}T \qquad (9)$$

$$\frac{\partial^2 C}{\partial y^2}-Sc\frac{\partial C}{\partial t}-KrSc=0 \qquad (10)$$

where f is the mass-concentration of dust particles, M is the magnetic field parameter, N is radiation parameter, Gr is the thermal Grashof number, Gm is modified Grashof number α_1 is the visco-elastic parameter, Pe is the Peclet number, K_1 is the permeability parameter, N is radiation parameter , Kr is the Chemical reaction parameter and Sc is Schmidt number.

$$f=\frac{mN_0}{\rho}, \;\; \alpha_1=\frac{\eta}{\tau}, \;\; \frac{1}{K_1}=\frac{\nu\tau}{K}, \;\; M=\frac{m\sigma B_0{}^2}{K_0\rho}$$

$$Gm=\frac{\beta' g\tau\left(C-C_0\right)}{\nu}, \qquad Gr=\frac{\beta g\tau\left(T-T_0\right)}{\nu}$$

$$\mathrm{P}e=\frac{\nu\rho C_p}{K_T}, N^2=\frac{4\alpha^2\nu\tau}{K_T}, Kr=\frac{Kr'\nu}{U_0{}^2}, Sc=\frac{\nu}{D}$$

Boundary conditions (6) reduced to

$$\left.\begin{array}{l} u=\nu e^{\lambda^2 t}, T=\nu e^{\lambda^2 t} \\ C=\nu e^{\lambda^2 t}\end{array}\right\} \quad at \quad y=0 \qquad (11)$$
$$u\to 0, T\to 0, C\to 0 \quad at \quad y\to\infty$$

Let the solutions of various profiles are:

$$u=F\left(y\right)e^{-\lambda^2 t} \qquad (12)$$

$$v=G\left(y\right)e^{-\lambda^2 t} \qquad (13)$$

$$T=H\left(y\right)e^{-\lambda^2 t} \qquad (14)$$

$$C=W\left(y\right)e^{-\lambda^2 t} \qquad (15)$$

The boundary conditions (11) reduced to:

$$\begin{array}{ll} H=1, F=1, W=1 & at \quad y=0 \\ H\to 0, F\to 0, W\to 0 & at \;\; y\to\infty \end{array} \qquad (16)$$

The equations (7)–(10) becomes with (12)–(15):

$$F''+\left(\alpha_2\lambda^2-M-\frac{1}{K_1}-f\right)F+\left(1-\alpha_1\lambda^2\right)f\,G=-GrH-GmH \qquad (17)$$

$$\left(1-\lambda^2\right)G=F \qquad (18)$$

$$H'' + \left(N^2 + \lambda^2 Pe\right)H = 0 \qquad (19)$$

$$W'' + \lambda^2 ScW - KrSc = 0 \qquad (20)$$

Eliminating G from (17) and (18)

$$F'' + n^2 F = -GrH - GmW \qquad (21)$$

The equations (19) and (20) give:

$$W = e^{-izy}$$

$$H = e^{-isy}$$

Equation (21) with boundary conditions (16) gives:

$$F = e^{-iny} + \frac{Gr\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} - \frac{Gm\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \qquad (22)$$

Equation (18) with (22);

$$F = \frac{1}{\left(1-\lambda^2\right)}\left[\begin{array}{l} e^{-iny} + \dfrac{Gr\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \\ -\dfrac{Gm\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \end{array}\right] \qquad (23)$$

The velocity of dusty gas for equation (12) is:

$$u = \left[\begin{array}{l} e^{-iny} + \dfrac{Gr\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \\ -\dfrac{Gm\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \end{array}\right] e^{-\lambda^2 t} \qquad (24)$$

The velocity of dust particles with (13) is:

$$v = \frac{1}{\left(1-\lambda^2\right)}\left[\begin{array}{l} e^{-iny} \\ +\dfrac{Gr\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \\ -\dfrac{Gm\left(e^{-iny} - e^{-isy}\right)}{n^2 - s^2} \end{array}\right] e^{-\lambda^2 t} \qquad (25)$$

The concentration profile is:

$$C = e^{-izy}.e^{-\lambda^2 t}$$

The temperature field for dusty gas is:

$$\theta = e^{-isy}.e^{-\lambda^2 t}$$

Real part of *u* is:

$$u = \left[\begin{array}{l} \cos ny + \dfrac{Gr}{n^2 - s^2}\left(\cos ny - \cos sy\right) \\ -\dfrac{Gm}{n^2 - s^2}\left(\cos ny - \cos zy\right) \end{array}\right] e^{-\lambda^2 t}$$

Similarly, the real part of velocity of dust particle is:

$$v = \frac{1}{\left(1-\lambda^2\right)}\left[\begin{array}{l} \cos ny \\ +\dfrac{Gr}{n^2 - s^2}\left(\cos ny - \cos sy\right) \\ -\dfrac{Gm}{n^2 - s^2}\left(\cos ny - \cos zy\right) \end{array}\right] e^{-\lambda^2 t}$$

Real part of *C* is:

$$C = Cos\left(zy\right)e^{-\lambda^2 t}$$

Real part of ϑ is:

$$\theta = Cos\left(sy\right)e^{-\lambda^2 t}$$

RESULTS AND DISCUSSION

To examine the different behaviours of both the velocities, we need to inspect and understand the above-plotted graphs. These graphs give us the other physical conduct of different parameters like Schmidt number$\left(Sc\right)$, magnetic field parameter $\left(M\right)$ and radiation parameter$\left(N\right)$, chemical reaction parameter $\left(Kr\right)$ on velocity distribution of dusty gas and dust particles, concentration and temperature field is mainly emphasized. Analysis of each graphical representation is discussed separately. From figure (1) and (2) show that the concentration profiles for different values of Schmidt number and Chemical reaction parameter; it is observed that concentration decreases for increasing value of Schmidt number and Chemical reaction parameter; also time concentration is decreases for increasing value of y.

Temperature profile:

From figure (3) it is clear that the behaviour of radiation parameter N with temperature. This figure shows that there is a direct variation between radiation and temperature. It is the fact that by increasing the radiation parameter N, the kinetic energy is increasing and therefore decrease occurs in the temperature of the fluid.

Velocity profile for dusty gas:

Figures (4) – (6) represents that the velocity for dusty gas for various values of magnetic parameter, radiation parameter and Schmidt number for the fixed values of the $\lambda = 2.0,\ \alpha_1 = 1.0, \alpha_2 = 2.0,\ f = 1.0,$ $K^{-1} = 0.1, Gr = 10.0,\ Gm = 5.0,\ Sc = 0.6,$ $Pe = 0.71, t = 1.0$. Figures (4) show that the velocity for the dusty gas increases for increasing values of radiation number. The relation between magnetic parameter factor and fluid and dust particles velocities can be observed in figures (5), respectively. It is revealed from these graphs that the magnetic parameter is the decreasing function of the velocities of dust particles and fluid. Physically, greater magnetic parameter values enhance the drag forces called the Lorentz forces, which retards the flow. It is true that the fractional force is motivated to increase by increasing the magnetic parameter values, which contributes to confront the fluid flow and thus reduces its velocity; but the reverse effect observed from figure (6) for increasing values of Schmidt number.

Velocity profile for dust particles:

From figures (7) – (9) we observed that velocity of dust particles for fixed values of the $\lambda = 2.0,\ \alpha_1 = 1.0, \alpha_2 = 2.0,\ f = 1.0,$ $K^{-1} = 0.1, Gr = 10.0,\ Gm = 5.0,\ Sc = 0.6,$ $Pe = 0.71,\ t = 1.0$. From figure (7), we observed that the velocity of the dust particles increases for increasing value of magnetic parameter. Figure (8) corresponds to the behaviour of radiations parameter N on the velocity profiles of fluid and dust particles respectively. According to these graphs by increasing the radiation parameter the dust particles and fluid velocity are also increases. It is obvious that by increasing the radiation the temperature of the fluid increases which brings increase in kinetic energy and this why the dust particles and fluid velocity increases.

CONCLUSIONS

The results for temperature field, concentration profile and velocity distribution for both dusty gas and dust particles have been discussed graphically to clarify the impact of magnetic field parameter, radiation number etc. we conclude the following remarks:

- Concentration is decreasing for increasing values of Schmidt number and chemical reaction parameter.
- Temperature is decreasing for increasing values of radiation number.
- Velocity for both the dusty gas and dust particle is increasing for increasing values of radiation number and magnetic field parameter while decreasing for increasing values of Schmidt number.

APPENDIX

$$z = -\left(\frac{\lambda^2 Sc + \sqrt{\left(\lambda^4 Sc^2 + 4KrSc\right)}}{2} \right)$$

$$s = \sqrt{N^2 + \lambda^2 \mathrm{P}e}, \alpha_2 = \left\{ 1 + \alpha_1 \left(M + \frac{1}{K_1} + f \right) \right\}$$

$$n^2 = \left[\frac{\alpha_2 \lambda^2 - \lambda^2 \left(\alpha_2 - \alpha_1 f + M + f + K^{-1} \right) + M + K^{-1}}{\lambda^2 - 1} \right]$$

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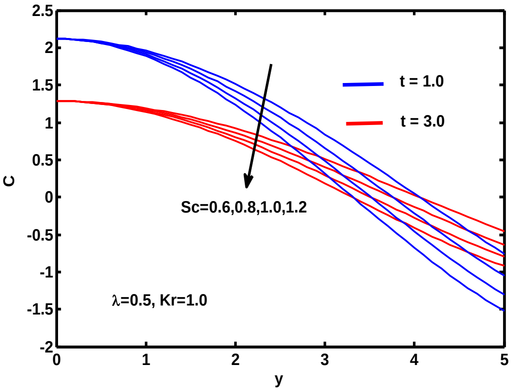

Figure 1. Concenentration profile for different values of Sc.

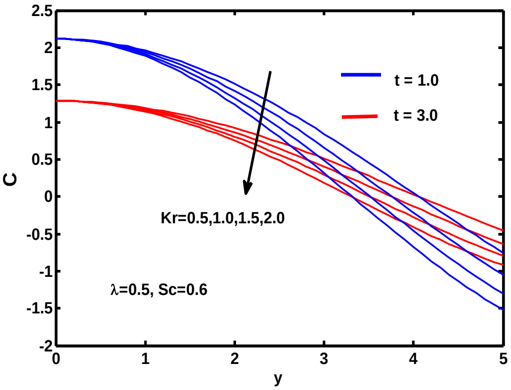

Figure 2. Concenentration profile for different values of Kr

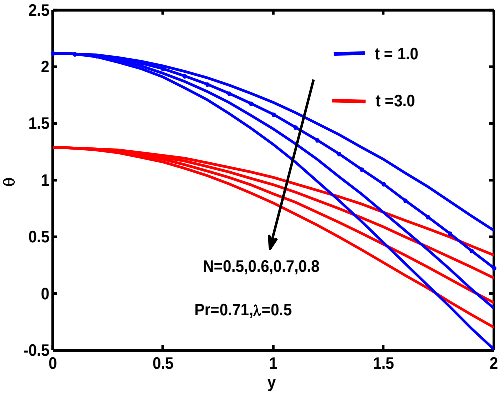

Figure 3. Temperature profile for diffrenet values of N

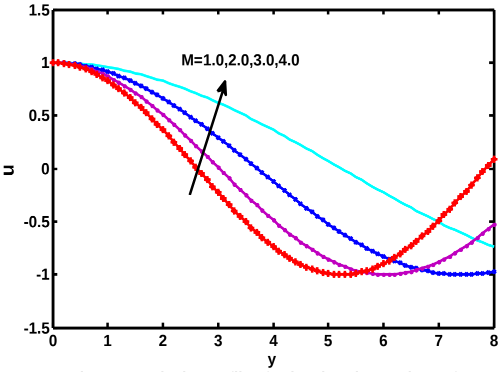

Figure 4: Velocity profiles for (Gas) various values of M

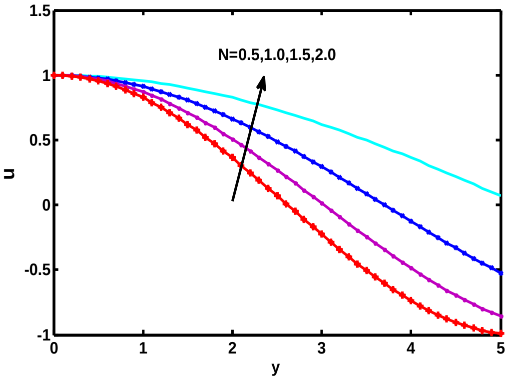

Figure 5: Velocity profiles for (Gas) various values of N

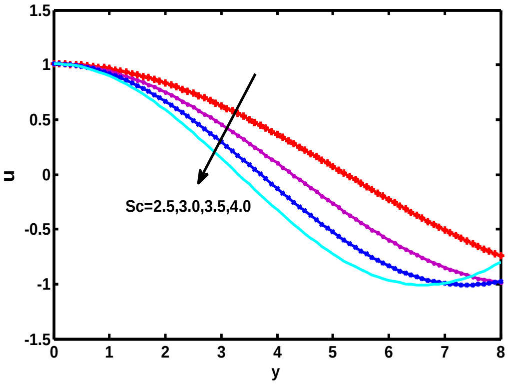

Figure 6: Velocity profiles for (Gas) various values of Sc

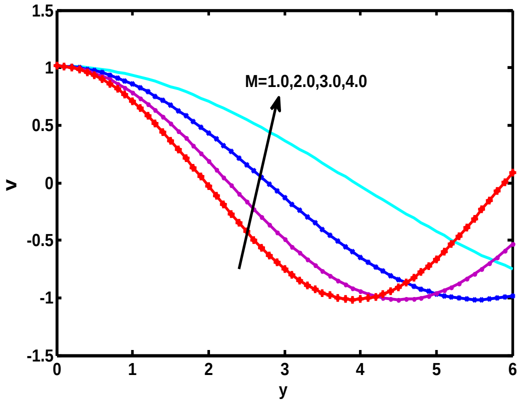

Figure 7: Velocity profiles for (dust) various values of M

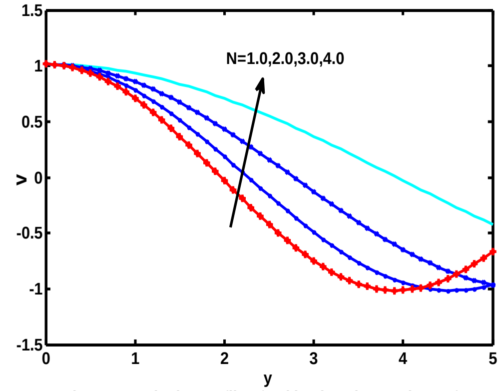

Figure 8: Velocity profiles for (dust) various values of N

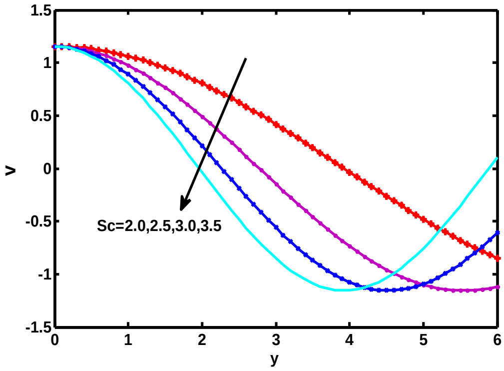

Figure 9: Velocity profiles for (dust) various values of Sc