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CHEMICAL REACTION AND MHD EFFECTS ON THE RADIATIVE CONVECTIVE FLOW OF A VISCOELASTIC DUSTY GAS OVER AN INCLINED PLATE

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Abstract

Incorporating the effects of magnetohydrodynamics, chemical reactions, and radiative heat transfer, we study in detail a semi-infinite flat plate inclined at an assumed angle (γ) to analyze a Kuvshinski-type viscoelastic dusty gas passing through a porous medium.We extracted the analytical expressions for the velocity and concentration and temperature profiles of viscoelastic gas and dust particles, after solving them analytically, the graphical results shows that the inclination angle(γ) was important for slowing down the flow of fluids. By graphical analysis we also conclude that Schmidt number(Sc) and Magnetic field parameter(M) is responsible for slowing down of fluid flow velocity in inclined plane however the radiation parameter (N) boosts the flow velocity by increasing the kinetic energy of the viscoelastic dusty gas and dust particles.

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1. Introduction

For the smooth functioning of industrial ecosystem which relies heavily on power plants and turbines, efficient propulsion mechanisms of aircrafts, space vehicles and missiles, also the methods for petroleum recovery and polymer science are of great importance. In all of these the thermal engineering plays a vital role as radiative heat transfer (represented by N) is crucial for designing of efficient equipment.Thus, the fluid dynamics which deals with flow of fluids (gas and liquids) with involvement of magnetic field and heat transfer is important for outcomes in industrial applications. The study of concerned dusty viscoelastic fluid is considered as one of the multiphase flows. Saffman has pioneered the study of dusty gases, his work on stability of laminar flow in fluids is treated as benchmark [23]; Han et al. [8] gave a study on heat transfer in pipes carrying gas-particle suspensions; Gretler and Regenfleder [6] studied similarity solutions for shock waves in dust-laden gases, from these works we

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now have an understanding about behavior of fluids flow due to its interaction with dust particles.

Viscoelastic fluids exhibit viscous and elastic properties. Cortell and Datti et al.[4, 5] investigated the flow rate and heat transfer of viscoelastic fluids over stretching sheets. Khan [11] advanced the same by assuming radiation and heat source/sink effects. Prakash et al. [18]examined Kuvshinski-type viscoelastic dusty gas on a moving plate, this study is linked to memory based fluid models.

MHD plays an important role in controlling the fluid flow through magnetic fields. Abo-Eldahab [1] and Raptis et al. [20] presented the impact of thermal radiation on electrically conducting fluids. Makinde and Chinyoka [12] numerically investigated the hydromagnetic channel flows. Mbeledogu et al. [13] and Damala et al. [3] studied the impact of viscous dissipation on radiative MHD flows past vertical plates.

To have essential understanding of underground filtration it is required to study effects of porous media and chemical reactions flowing through porous materials. Hady and Mohamed et al. [7] and Venkata Ramana et al. [6] investigated the hall effect on MHD flow of Visco-elastic fluid through porous media. Nookala and Rao et al. [16] examined dusty viscous fluids in porous environments. Kesavaiah et al [10], Venkatswarlu [24] and Reddy et al.[21] showed that chemical reactions effects the flow speed and impact concentration, they examined the significance of chemical reaction and absorption of radiation on convective flows. Mohd and Nookala [14] extended the concept of mass transfer effects in Newtonian fluids with chemical reaction.

Inclination angle is also an important factors that impacts flow velocity. Bang and Sagar [2] and Rani et al. [19] examined MHD free convection on plates with certain inclination. Heat and mass transfer through inclined plates with viscous dissipation was studied by Jimoh and Abdullahi et al.[9] and Omamoke et al. [17]. Flow of nanofluid over inclined vertical porous plates with heat and radiation was studied by Reddy et al. [24].

These cited literatures comprehensively cover the understanding of MHD, radiation and chemical reactions. Through these works we gain an understanding about Kuvshinski-type viscoelastic dusty gases over an inclined plane, it laid the basic path for advancement in specialized research work. Here we attempted to understand the collective influence of chemical reactions and radiation on the MHD free convection flow of a viscoelastic dusty gas over a semi-infinite inclined plate.

We used a proper sign for the stress modulus ($\alpha_1 \geq 0$) in this paper. The energy equation accounts for viscous dissipation, magnetic fields, heat generation and inclined angle γ. To get a realistic representation of heat transfer process we included thermal radiation here.

2. Mathematical Formulation

Here we have taken unsteady, laminar, MHD free convective flow of Kuvshinski-type incompressible viscoelastic dusty gas through a porous medium where the flow is restricted in a semi-infinite flat plate that is inclined at an angle γ with the vertical.

The y-axis is taken perpendicular to the x-axis that is taken along the plate. The plate is moving is with a velocity $u = e^{\lambda^2 t}$ along the x-axis. The given physical quantities are essentially the function of y and t. The gas optically thin with a relatively lower concentration and density. The radiative heat flux is given by:

$$\frac{\partial q_r}{\partial y} = 4\alpha^2(T_0 - T) \tag{2.1}$$

According the Saffman [23] the momentum equation gets modified due to inclusion of resolved buoyancy terms.
Momentum equation for viscoelastic dusty gas:

$$\left(1+\eta\frac{\partial}{\partial t}\right)\frac{\partial u}{\partial t} = \nu\frac{\partial^2 u}{\partial y^2} + \frac{K_0 N_0}{\rho}\left(1+\eta\frac{\partial}{\partial t}\right)(v-u) - \left(\frac{\sigma B_0}{\rho} + \frac{\nu}{K}\right)\left(1+\eta\frac{\partial}{\partial t}\right)u + g\beta(T-T_0)\cos\gamma + g\beta'(C-C_0)\cos\gamma \tag{2.2}$$

Momentum equation for dust particles:

$$\frac{\partial v}{\partial t} = \frac{K_0}{m}(u-v) \tag{2.3}$$

Energy equation (Radiative heat transfer):

$$\frac{\partial T}{\partial t} = \frac{K_T}{\rho C_p}\frac{\partial^2 T}{\partial y^2} - 4\alpha^2(T-T_0) \tag{2.4}$$

Concentration equation (Chemical reaction):

$$\frac{\partial C}{\partial t} = D\frac{\partial^2 C}{\partial y^2} - Kr'(C-C_0) \tag{2.5}$$

Boundary conditions are:

$$\left.\begin{array}{ll} u = Ve^{\lambda^2 t}, \quad T = Ve^{\lambda^2 t}, c = Ve^{\lambda^2 t} & \text{at } y = 0 \\ T \to 0, \quad c \to 0, \quad u \to 0 & \text{at } y \to \infty \end{array}\right\} \tag{2.6}$$

Where u is the gas velocity ,v is the dust velocity, V is the kinematic coefficient of viscosity of the gas, K_0 is the Stokes' resistance coefficient, N_0 is the number density of the dust particles, ρ is the density of the gas, m is the mass of a single dust particle, K_T is the thermal conductivity, C_p is the specific heat at constant pressure.
Introducing the dimensionless variables:

$$u^* = \frac{u}{V}, \quad v^* = \frac{v}{V}, \quad y^* = \frac{y}{\sqrt{V\tau}}, \quad t^* = \frac{t}{V}, \quad T^* = \frac{T-T_0}{T_\infty - T_0}, \quad C^* = \frac{C-C_0}{C_\infty - C_0}$$

The dimensionless equations are expressed as:

$$\left[1+\alpha_1\left(f+M+\frac{1}{K_1}\right)\right]\frac{\partial u}{\partial t} = \frac{\partial^2 u}{\partial y^2} + \alpha_1 f\frac{\partial v}{\partial t} + f(v-u) - Mu - \frac{1}{K_1}u + (GrT + GmC)\cos\gamma \tag{2.7}$$

$$\frac{\partial v}{\partial t} = (u - v) \tag{2.8}$$

$$\frac{\partial T}{\partial t} = \frac{1}{Pe}(\frac{\partial^2 T}{\partial y^2} - N^2 T) \tag{2.9}$$

$$\frac{\partial C}{\partial t} = \frac{1}{Sc}\frac{\partial^2 C}{\partial y^2} - Kr\, C \tag{2.10}$$

Where M is the magnetic field parameter, N is the radiation parameter, K_1 is the permeability parameter, Gr is the thermal Grashof number, Gm is the solutal Grashof number, α_1 is the viscoelastic parameter, Kr is the chemical reaction parameter, Pe is the Peclet number, Sc is the Schmidt number and f is the mass concentration of dust particles.

$$f = \frac{mN_0}{\rho}, \alpha_1 = \frac{\eta}{\tau}, \frac{1}{K_1} = \frac{V\tau}{K}, M = \frac{m\sigma B_0^2}{K_0\rho}, Gm = \frac{\beta' g\tau(C - C_0)}{V}, Gr = \frac{\beta g\tau(T - T_0)}{V}$$

$$Pe = \frac{V\rho C_p}{K_T}, N^2 = \frac{4\alpha^2 V\tau}{K_I}, K_r = \frac{K_r' V}{U_0^2}, Sc = \frac{V}{D}$$

The appropriate boundary conditions for the moving inclined plate are:

$$\left.\begin{aligned} &u = Ve^{\lambda^2 t}, \quad T = Ve^{\lambda^2 t}, c = Ve^{\lambda^2 t} \quad \text{at } y = 0 \\ &T \to 0, \quad c \to 0, \quad u \to 0 \quad \text{at } y \to \infty \end{aligned}\right\} \tag{2.11}$$

3. Solution of the Problem

To solve the coupled governing equations, we assume the solutions for the velocity of the gas, velocity of the particles, temperature, and concentration in the following form:

$$u = F(y)e^{-\lambda^2 t} \tag{3.1}$$

$$v = G(y)e^{-\lambda^2 t} \tag{3.2}$$

$$T = H(y)e^{-\lambda^2 t} \tag{3.3}$$

$$C = W(y)e^{-\lambda^2 t} \tag{3.4}$$

Boundary conditions equation (3.5) reduced to:

$$\left.\begin{aligned} &H = 1, \quad F = 1, \quad W = 1 \quad \text{at } y = 0 \\ &H \to 0, \quad F \to 0, \quad W \to 0 \quad \text{at } y \to \infty \end{aligned}\right\} \tag{3.5}$$

Substituting these into dimensionless equations (2.7)–(2.10) becomes with equations (3.1)–(3.4), we obtain the following ordinary differential equations:

$$F'' + [\alpha_2\lambda^2 - M - \frac{1}{K_1} - f]F + (1 - \alpha_1\lambda^2)fG = -[GrH + GmW]\cos\gamma \tag{3.6}$$

$$(1-\lambda^2)G = F \tag{3.7}$$

$$H'' + (N^2 + \lambda^2 Pe)H = 0 \tag{3.8}$$

$$W'' + Sc(\lambda^2 W - Kr) = 0 \tag{3.9}$$

The transformed momentum equation for gas phase after removing G from equations (3.6) and (3.7)

$$F'' + n^2 F = -(GrH + GmW)\cos\gamma \tag{3.10}$$

The solutions for concentration and temperature satisfying the boundary conditions, the equation (3.8) and (3.9) gives:

$$W = e^{-izy} \tag{3.11}$$

$$H = e^{-isy} \tag{3.12}$$

From equation (3.11) and (3.12), equation (3.10) becomes.

$$F'' + n^2 F = -Gr\cos\gamma e^{-isy} - Gm\cos\gamma e^{-izy} \tag{3.13}$$

The general solution for F is given by:

$$F = e^{-iny} + \frac{Gr\cos\gamma}{n^2 - s^2}(e^{-izy} - e^{-isy}) - \frac{Gm\cos\gamma}{n^2 - z^2}(e^{-iny} - e^{-izy}) \tag{3.14}$$

Velocity of viscoelastic dusty gas for equation (3.1) is:

$$u = \left[e^{-iny} + \frac{Gr\cos\gamma(e^{-iny} - e^{-isy})}{n^2 - s^2} - \frac{Gm\cos\gamma(e^{-iny} - e^{-izy})}{n^2 - z^2}\right]e^{-\lambda^2 t} \tag{3.15}$$

Velocity of dust particles with equation (3.2) is:

$$v = \frac{1}{(1-\lambda^2)}\left[e^{-iny} + \frac{Gr\cos\gamma(e^{-iny} - e^{-isy})}{n^2 - s^2} - \frac{Gm\cos\gamma(e^{-iny} - e^{-izy})}{n^2 - z^2}\right]e^{-\lambda^2 t} \tag{3.16}$$

The concentration profile with equation (3.3) is:

$$C = e^{-izy}.e^{-\lambda^2 t} \tag{3.17}$$

The temperature profile with equation (3.4) is:

$$T = e^{-isy}.e^{-\lambda^2 t} \tag{3.18}$$

Where:-

$$z = -\left(\frac{\lambda^2 Sc + \sqrt{\lambda^4 Sc^2 + 4K_r Sc}}{2}\right),\ s = \sqrt{N^2 + \lambda^2 Pe}, \qquad \alpha_2 = \left\{1 + \alpha_1\left(M + \frac{1}{K_1} + f\right)\right\},$$

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

Real part of gas velocity u is

$$u = \left[\cos ny + \frac{Gr\cos\gamma(\cos ny - \cos sy)}{n^2 - s^2} - \frac{Gm\cos\gamma(\cos ny - \cos zy)}{n^2 - z^2}\right] e^{-\lambda^2 t} \quad (3.19)$$

Real part of dust velocity v is:

$$v = \frac{1}{(1-\lambda^2)}\left[\cos ny + \frac{Gr\cos\gamma(\cos ny - \cos sy)}{n^2 - s^2} - \frac{Gm\cos\gamma(\cos ny - \cos zy)}{n^2 - z^2}\right] e^{-\lambda^2 t} \quad (3.20)$$

Real part of concentration profile C is:

$$C = \cos(zy)e^{-\lambda^2 t} \quad (3.21)$$

Real part of temperature profile T is:

$$T = \cos(sy)e^{-\lambda^2 t} \quad (3.22)$$

4. RESULTS AND DISCUSSION

The non-dimensional governing equations for gas velocity (u), dust particles velocity (v), concentration (C) and temperature (T). Resulting data is represented graphically to provide in detail the clear physical insights. The study specifically focused on how does the variation in γ (inclination angle), Sc (Schmidt number), M (magnetic parameter) and N (radiation parameter) impacts the flow dynamics. The proper analysis and discussion of graphs is given in following sections. The impact of M (magnetic parameter), N (radiation parameter), Sc (Schmidt number) and γ (inclination angle) on dusty gas velocity , dust velocity, concentration profile and temperature profile is presented in Figures (1-11), while other governing parameters were kept fixed. $\lambda = 0.5\alpha_1 = 1.0, \alpha_2 = 2.0, f = 1.0, K^{-1} = 0.1, Gr = 10.0, Gm = 5.0, Sc = 0.6, Pe = 0.71, t = 1.0$

Velocity profile:

Here figure (1-2) shows that on increasing M (= 1, 2, 3, 4) the gas velocity and dust velocity reduces near the plate, it is due to the fact that a resistive Lorentz force is acting on the fluid, which indirectly slows down the dust flow through fluid-particle interaction. At $\gamma = 60°$, both gas and dust velocity profiles shows characteristic oscillatory behavior before converging.

Figures (3-4) indicates that increasing of N (= 0.1,0.5,1.0,1.5) modifies both gas velocity (u) and dust velocity (v). Physically, Kinetic energy within the boundary increases with increase in radiation, accelerating the flow of the viscoelastic dusty gas along the inclination $\gamma = 60°$. Both gas and dust velocity profiles maintain the oscillatory nature before converging.

Figure (5-6) shows that on increasing Sc (= 2.0,2.5,3.0 3.5) both gas velocity (u) and dust velocity (v) decreases. The larger values of Sc reduces molecular diffusivity and increases effective viscosity, due to this the flow of viscoelastic dusty gas slows down as it advances along the inclined plate (inclination angle fixed at 60°). This retarding effect becomes prominent with increase in y distance.

Figure (7-8) shows that when γ changes from 0° to 60°, it is found that gas velocity and dust velocity is increasing. The reason behind this increment is that higher inclination angle makes the gas move faster due to reduction in resistance, dust particle also moves faster as they got mixed with the gas and gas pulling the dust along. The highest speed is found near the plate and as we move away it shows reduction in speed.

Concentration profile:

Figures (9-10) show the effect of the chemical reaction parameter (Kr) and the Schmidt number (Sc) on the concentration profile. Increasing both parameters results in a narrowing of the concentration distribution. Furthermore, as we move along the transverse coordinate, a steady decrease in concentration levels is observed.

Temperature profile:

Figure (11) shows the effect of changing the Radiation parameter (N) on thermal behavior. It shows that the temperature decreases as N increases. This is because the higher the radiation parameter, the lower the temperature.

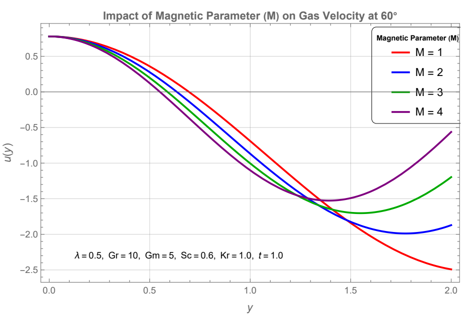

FIGURE 1. Gas velocity for different values of M

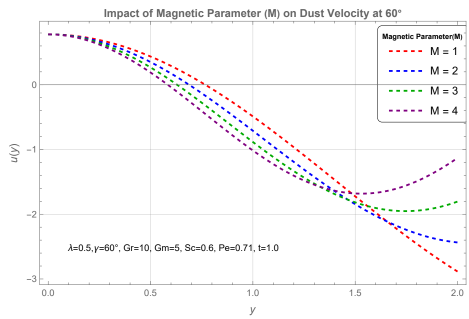

FIGURE 2. Dust velocity for different values of M

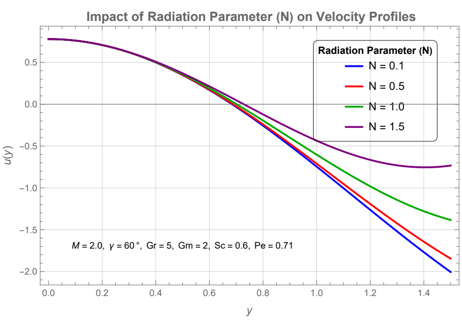

FIGURE 3. Gas velocity for different values of N

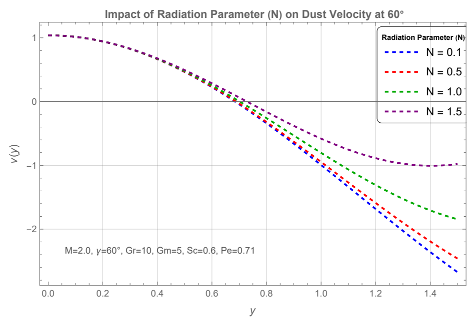

FIGURE 4. Dust velocity for different values of N

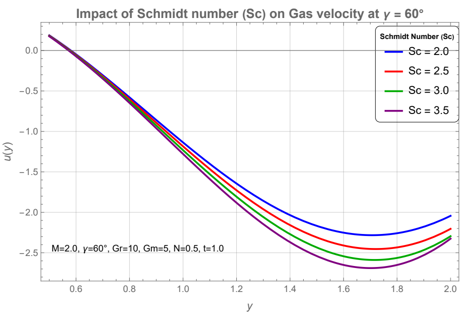

FIGURE 5. Gas velocity for different values of Sc

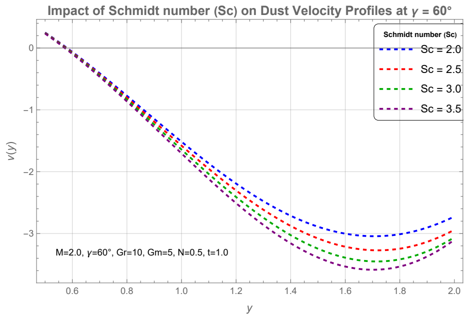

FIGURE 6. Dust velocity for different values of Sc

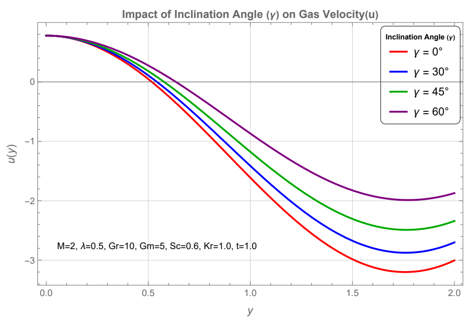

FIGURE 7. Gas Velocity for different values of γ

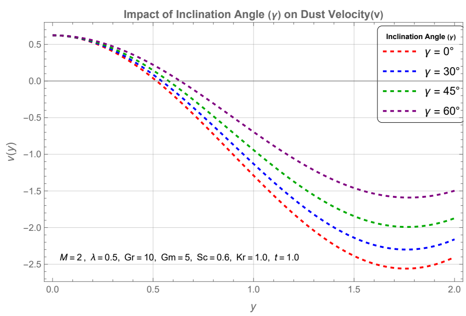

FIGURE 8. Dust Velocity for different values of γ

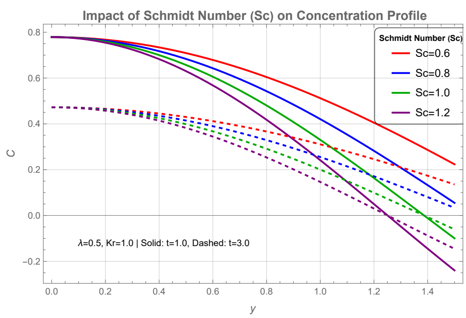

FIGURE 9. Concentration profile for Sc

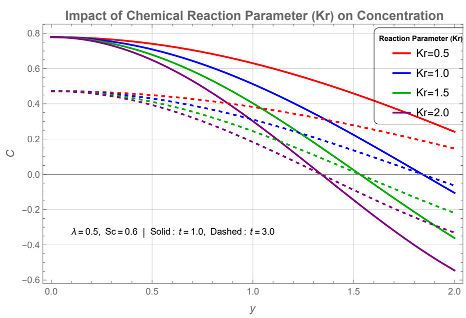

FIGURE 10. Concentration profile for Kr

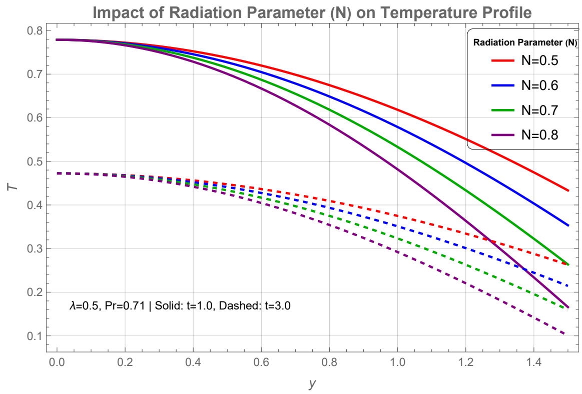

Figure 11. Temperature Profile

5. CONCLUSIONS

In this work the study of MHD free convective flow of Kuvshinski-type viscoelastic dusty gas passing through a porous media over an inclined plate (inclination angle $\gamma = 60°$) is done. From the analysis of graphs for velocity of gas (u) and dust phases (v), concentration (C) and temperature (T), it is evaluated how the factors like magnetic field (M), radiation (N) and inclination angle (γ) impacts the flow. On the basis this investigation we can give following conclusions:

(i) The gas and dust velocity were found to decrease with increase in M and Sc because of resistive Lorentz forces and higher effective viscosity. Gas and dust velocities found to increase with N due to enhanced kinetic energy. Increase in γ decreases the flow resistance, this leads to increase in both gas and dust velocities. The flow speed becomes highest at $\gamma = 60°$ and is maximum near the plate surface.

(ii) Concentration (C) is a decreasing function of Sc and Kr.

(iii) Temperature (T) decreases with radiation parameter N and Pe increases, due to high loss of heat and lower thermal conductivity.

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