ISSN(Online): 2319-8753
ISSN (Print): 2347-6710

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 6, Issue 11, November 2017

Multiple Slip Conditions on MHD Carreau Dusty Fluidover Sheet with Cattaneo-Christov Heat Flux and Thermal Radiation

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Abstract: Essence of the present study is to investigate the combined impact of thermal conductivity and non-Fourier heat flux model of the steady boundary layer flow of a Carreau Dusty Fluid past a stretching sheet in the presence of slip conditions. Similarity transformations are considered to transform the governing non-linear partial differential equations into nonlinear ordinary differential equations. The transformed ODEs are solved numerically by employing Runge-Kutta Fehlberg Scheme (RKFS). To interpret the influence of flow parameters on the fluid velocity, temperature and concentration profiles graphs and tables were developed and the results are discussed. The present results are validated by comparing with the published results and noticed favorable agreement. Our result implies that the rate of heat transfer significantly increases with the enhancement of thermal radiation parameters and an opposite influence is observed due to the thermal relaxation time in case of both fluid and dust phase. When we incorporate dust particles in the flow, dust particle opposes the flow, hence the momentum, thermal and concentration profiles are decreasing in dust phase. Thus we conclude that dust particles are helpful in cooling applications.

Keywords: Carreau Fluid, Cattaneo-Christov heat flux model, Stretching sheet, Thermal radiation, Diffusion, Thermal and momentum slip boundary conditions

I. INTRODUCTION

Many fluids of industrial significance, especially of the multi-phase nature (lubricants, emulsions, foams, slurries, dispersions and suspensions) and polymer melts and solutions (both natural and man-made), biological fluids (blood, saliva, synovial fluid) and liquids with special intermolecular forces (ionic liquids, magnetic liquids) exhibits complex flow behavior that diverge significantly from the classical Newtonian (Navier-Stokes) model. Accordingly, these fluids are classically known as non-Newtonian, non-linear or rheological complex fluids. Newtonian fluids have a constant viscosity and non-Newtonian fluids do not have constant viscosity, their viscosities strongly depend on the velocity gradients and they may display "elastic effects". Various mathematical expressions have been suggested in the literature to model the flow diversity of non-Newtonian fluids. Such as Ostwald-De Waele model or power-law model, Sisko model, The Ellis model, The Carreau model, The Cross model, The Bingham model, The Herschel-Bulkey model, The Casson model, etc. Amongst these Fluid models four-parameter Carreau inelastic model [1] which was introduced in 1972 by Pierre Carreau caught the attention of many researchers and engineers [2-12]. Carreau fluid behaves as Newtonian at low shear rate and power law fluid at high shear rate. The Carreau fluid model is generally used to describe the time independent, shear-thinning category of non-Newtonian fluids. In particular Carreau model is used to

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Consider a steady slip flow of an incompressible, 2D, magneto hydrodynamic Carreau dusty fluid over a stretching sheet. The *x*-axis is taken as the direction of fluid motion and *y*-axis is vertical to the sheet. The flow is confined to the region $y>0$. It is assumed that the sheet is stretched by two equal and opposite forces with the velocity $u_w(x) = ax$. Here a is positive constant. Along the *y*-axis a uniform magnetic field of strength B_0 is imposed which generates magnetic effect in the *x*-direction. Dust particles are supposed to be spherical in shape and homogeneously distributed all the way through the fluid. It is assumed that the number density to be constant and volume fraction of dust particles can be neglected. The fluid and dust particle motion are coupled only through drag, heat and mass transfer between them. Stokes linear drag theory is used to model the drag force. The fluid temperature $\theta(\xi)$ and concentration at the boundary and free stream are denoted by T_w, T_∞ and C_w, C_∞. The magnetic Reynolds number is supposed to be small hence forth the induced magnetic field is neglected. Cattaneo-Christov heat flux and radiation heat flux are considered in this study. The constitutive equation for a Carreau fluid is given by [10];

$$\tau = \eta_\infty + \left(\eta_0 - \eta_\infty\right)\left[1 + \left(\Gamma \dot{\gamma}\right)^2\right]^{\frac{n-1}{2}}$$

Where η_0 is the zero-shear rate viscosity, $\boldsymbol{\tau}$ is the extra stress tensor, η_∞ is the infinite –shear rate viscosity, Γ is a material time constant and n is the power law index .The shear rate is well-defined as

Where Π is the second invariant strain tensor. Based on the above expectations, the flow equations of continuity, momentum, energy and conservation of mass for both the fluid and dust phase takes the following for [19];

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$

(2)

(3)

(4)

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + \lambda\left(u^2\frac{\partial^2 T}{\partial x^2} + v^2\frac{\partial^2 T}{\partial y^2} + \left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right)\frac{\partial T}{\partial x} + 2uv\frac{\partial^2 T}{\partial x \partial y} + \left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right)\frac{\partial T}{\partial y}\right) =$$
$$\frac{1}{\rho c_p}\left(K\frac{\partial^2 T}{\partial y^2} - \frac{\partial q_r}{\partial y}\right) + \frac{\rho_p c_p}{\tau_T}\left(T_p - T\right) + \frac{\rho_p}{\tau_v}\left(u_p - u\right)^2 \qquad (5)$$

(6)

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$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_m\frac{\partial^2 C}{\partial y^2}+\frac{\rho_p}{\rho\tau_c}\left(C_p-C\right) \quad (7)$$

(8)

Corresponding boundary conditions for the physical problem are given by

$$as\ y\to\infty:\quad u\to 0,\ u_p\to 0, T\to T_\infty, v_p\to v, T_p\to T_\infty, C\to C_\infty, C_p\to C_\infty \quad (9)$$

Where (u,u_p) and (v,v_p) are the velocity mechanisms along the x and y direction of the fluid and dust particle phase , ρ and $\rho_p= mN$ are the density of the dust and fluid particle phase, m and N are the mass and number density of the dust particles per unit volume, μ is the dynamic viscosity of the fluid, σ is the electrical conductivity, B_0 is the uniform magnetic field, $k=6\pi\mu r$ is the stokes resistance (drag coefficient) and r is the radius of the dust phase. T and T_p are the temperature of the fluid and dust particle, c_p and c_m are the specific heat of fluid and dust particles, τ_T represents the thermal equilibrium time. τ_v represents the dust phase relaxation time k is the thermal conductivity of the fluid and q_r is the radioactive heat flux. σ^* is the Stefan –Boltzmann constant and K^* is the mean absorption coefficient. C and Cp are the concentration species of the fluid and dust particle phase; the dust particles gain mass concentration from the fluid by diffusion through their spherical surface. D_m is the Brownian mass diffusivity coefficient, τ_c is the time required by dust particles to adjust its concentration relative to the fluid. K_1, K_2 and K_3 are the hydrodynamic, thermal, and concentration slip factors.

The Roseland diffusion flux model is used for the thermal radiation heat transfer and is given by

From Taylor's series

Substituting this expression into equation (5) energy equation leads to the following form:

(10)

To transform the governing equations into a set of ordinary equations, we bring together the succeeding transformation as,

$$u=axf'(\zeta),\zeta=\left(\frac{a}{\upsilon}\right)^{0.5}y,\quad v=-\sqrt{\upsilon a}\,f(\zeta)$$

$$C=(C_w-C_\infty)\phi(\zeta)+C_\infty,\quad C_p=(C_w-C_\infty)\phi_p(\zeta)+C_\infty \quad (11)$$

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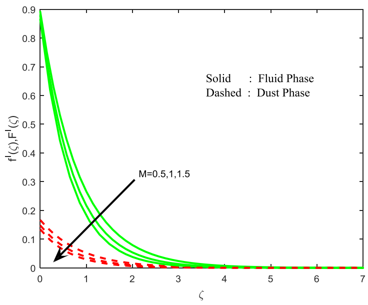

Fig. 3. Velocity distributions for various values of magnetic field *M.*

Fig. 4. Temperature distributions for various values of magnetic field *M.*

Fig. 5. Concentration profiles for different values of magnetic field *M.*

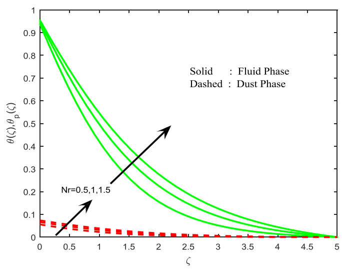

Fig. 6. Temperature profiles for different values of thermal radiation *Nr.*

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Fig. 11. Concentration fields for different values of concentration slip.

Fig. 12. Temperature fields for different values of thermal relaxation time.

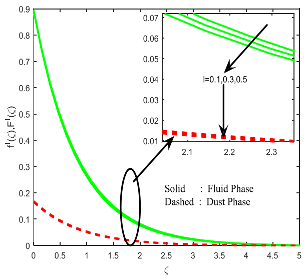

Fig. 13. Velocity profiles for various values of dust particles mass concentration parameter.

Fig. 14. Temperature profiles for various values of dust particles mass concentration parameter.