HEAT TRANSFER TO MHD FREE CONVECTION FLOW OF A VISCOELASTIC DUSTY GAS THROUGH A POROUS MEDIUM WITH CHEMICAL REACTION

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Abstract

In this paper we focused on combined effects of free convective an unsteady MHD dusty viscoelastic (Walters's liquid model- B) fluid 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 coupled partial differential equations are solved by analytically using perturbation technique and expressions for velocity distribution of a dusty gas and dust particles, temperature field and concentration profile have been studied for various combination of physical parameter are discussed graphically.

Keywords: Chemical reaction, MHD, Porous medium, Radiation, Viscoelastic fluid.

1. Introduction

Dusty fluid flows has its importance in many applications like wastewater treatment, power plant piping, combustion and petroleum transport. Fluid flow under the influence of magnetic field and heat transfer occurs in magneto-hydrodynamics accelerators, pumps and generators. This type of fluid has uses in nuclear reactors, plasma studies, geothermal energy extraction, and the boundary layer control in the field of aerodynamics. The flow of fluids through porous media has become an important topic, because of recovery of crude oil from pores of reservoir rocks. Several authors have examined this type of problem theoretically in various ways. (Chenna Kesavaiah et.al, 2013) Natural convection heat transfer oscillatory flow of an elastico-viscous fluid from vertical plate, (Om Prakash et.al, 2011) MHD free convection flow of a visco-elastic (Kuvshiniski type) dusty gas through a semi infinite plate moving with velocity decreasing exponentially with time and radiative heat transfer, (Omprakash et.al, 2015) studies heat transfer to MHD oscillatory dusty fluid flow in a channel filled with a porous medium.

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. The effect of variable viscosity on the combined radiation and forced convection on the flow over a flat plate submerged in a porous medium of variable viscosity, have studied by Harinath Reddy (Harinath Reddy et.al, 2016). Magneto convective flow of a non-Newtonian fluid through non-homogeneous porous medium passes a vertical porous plate with variable suction, (Gireesh & Mahanthesh, 2013). Perturbation solution for radiating viscoelastic fluid flow and heat transfer with convective boundary condition in non- uniform channel with hall current and chemical reaction has discussed by Pal & Talukdar (Pal & Talukdar, 2010). Perturbation analysis of unsteady magnetohydrodynamic convective heat and mass transfer in a boundary layer slip flow past a vertical permeable plate with thermal radiation and chemical reaction, (Gretler & Regenfelder, 2002) obtained similarity solution for laser-driven shock waves in a dust-laden gas with internal heat transfer effects studied by (Prakash, 2014) effects of chemical reaction and radiation absorption on MHD flow of

dusty viscoelastic fluid, (Madhura & Kalpana, 2013) studied Thermal effect on unsteady flow of a dusty visco-elastic fluid between two parallel plates under different pressure gradients.
MHD free convection fluid flows frequently occur in natural world. Fluid passes through porous medium are of great interest nowadays and many researcher attract towards the application in the field of science and technology namely such as MHD power generation, flow meters, pumps agriculture engineering to know about the ground water resources, in fuel technology to study the moment of natural gas, oil and water through the oil reservoirs. (Varshney and Prakash, 2004) have discussed 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. However we observed some of the authors results in the followings. (Cortell, 2006) studies a note on flow and heat transfer of a viscoelastic fluid over a stretching sheet. (Mishra, 2013) Free convective MHD flow of a visco-elastic (Walters model - B') dusty fluid through a porous medium and constant heat source, (Shivaraj & Rushi Kumar, 2013) Chemically reacting dusty viscoelastic fluid flow in an irregular channel with convective boundary.

The present investigation is the study of MHD free convection flow of a viscoelastic dusty gas through a semi infinite plate moving with velocity decreasing exponentially with time and radiative heat transfer with chemical reaction under the assumptions are taken in to account. The expressions for velocity distribution temperature field and concentration profile for both dusty fluid (gas) and dust particles are derived.

2. Formulation of Problem

We consider a two - dimensional, unsteady flow and free convection heat and mass transfer of an electrically conducting, incompressible viscoelastic (Walters liquid - B model) fluid between a vertical long wavy wall and a parallel flat wall saturated with porous medium placed in the plane $Y=0$ of a coordinate system as shown in figure (1). The $x-$axis is taken in the direction along the channel which is set in motion and the $y-$axis is taken perpendicular to it. The flow field is exposed to the influence of an external transversely applied uniform magnetic field of strength B_0, thermal and mass buoyancy effects, heat absorption, thermal radiation, radiation absorption and first order chemically reactive species. The wavy wall $Y=\in^* \cos\left(K_2 X\right)$ maintains a temperature T_{w1} which represents the convective boundary condition $-k\dfrac{\partial T}{\partial Y}=hf\left(T_1-T+\left(T_2-T_1\right)\in e^{-n^*t^*}\right)$ and $C_{w1}=C_2+\left(C_2-C_1\right)\in e^{-n^*t^*}$ concentration respectively. The flat wall $\left(Y=d\right)$ maintains a temperature T_{w2} which represents the convective boundary condition $-k\dfrac{\partial T}{\partial Y}=hf\left(T_1-T+\left(T_2-T_1\right)\in e^{-n^*t^*}\right)$ and concentration $C_{w1}=C_2+\left(C_2-C_1\right)\in e^{-n^*t^*}$ respectively.
It is assumed that the convective heat exchange with the wall temperatures at the channel surface follows Newton's law of cooling. Rest of properties of the fluid are assumed to be constant. Taking into consideration of these assumptions, the equations that describe the physical situation can be written in Cartesian frame of references, as follows:

$$\frac{\partial U}{\partial t^*}=\nu\left(1-K_0\frac{\partial}{\partial t^*}\right)\frac{\partial^2 U}{\partial Y^2}+\frac{K_1N_0}{\rho}\left(V-U\right)-\left(\frac{\sigma B_0}{\rho}+\frac{\nu}{K^*}\right)U+g\beta_T\left(T-T_1\right)+g\beta_C\left(C-C_1\right) \quad (1)$$

$$\frac{\partial v}{\partial t^*}=\frac{K_1}{m}\left(U-V\right) \quad (2)$$

$$\frac{\partial T}{\partial t^*}=\frac{k}{\rho C_p}\frac{\partial^2 T}{\partial Y^2}-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial Y}-\frac{Q_T}{\rho C_p}\left(T-T_1\right)+\frac{Q_C}{\rho C_p}\left(C-C_1\right)+\frac{D_M D_T}{C_s C_p}\frac{\partial^2 C}{\partial Y^2} \quad (3)$$

$$\frac{\partial C}{\partial t^*} = D\frac{\partial^2 C}{\partial Y^2} - K_R\left(C - C_1\right) \quad (4)$$

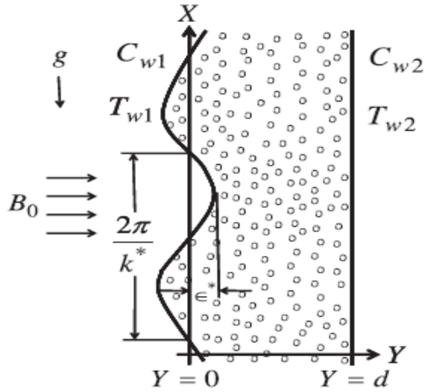

Figure (1): Flow geometry of the problem

Boundary conditions are:

$$t^* = 0 : U = V = 0, T = T_1, C = C_1 \quad for \quad Y\varepsilon\left(\in^* \cos\left(K_2 X\right), d\right)$$

$$t^* > 0 : U = V = 0, -k\frac{\partial T}{\partial Y} = hf\left(T_1 - T + \left(T_2 - T_1\right)\in e^{-n^* t^*}\right), \quad (5)$$

$$C_{w1} = C_2 + \left(C_2 - C_1\right)\in e^{-n^* t^*} \quad at\, Y \in \left(\in^* \cos\left(K_2 X\right), d\right)$$

The gas is optically thin with a relatively low density and radiative heat flux (Cogley et al, 1968) is given by

$$\frac{\partial q}{\partial y} = 4\alpha^2\left(T - T_1\right)I', I' = \int_0^\infty K_{\lambda i\omega}\frac{\partial e_{b\lambda i}}{\partial T}d\lambda i \quad (6)$$

Introduce the non- dimensional variables,

$$u = \frac{U}{U_0},\ v = \frac{V}{V_0},\ y = \frac{Y}{d},\ x = \frac{X}{d},\ t^* = \frac{\nu t}{d^2},\ \theta = \frac{T - T_1}{T_2 - T_1}, C = \frac{C - C_1}{C_2 - C_1}$$

$$n = \frac{n^* d^2}{\nu}, E = \frac{K_0 \nu}{d^2}, \delta = \frac{mN_0}{\rho}, w = \frac{m\nu}{K_1 d^2}, M^2 = \frac{\sigma_e B_0^2 d^2}{\mu}, \frac{1}{K} = \frac{d^2}{K^*}$$

$$Gr = \frac{g\beta_T\left(T_2 - T_1\right)}{\nu U_0},\ Gc = \frac{g\beta_C\left(C_2 - C_1\right)}{\nu U_0},\ Sc = \frac{\nu}{D_M},\quad \Pr = \frac{\mu C_p}{k} \quad (7)$$

$$F = \frac{4I' d^2}{k},\ \alpha_C = \frac{Q_C\left(C_2 - C_1\right)d^2}{k\left(T_2 - T_1\right)},\ Kr = \frac{K_R d^2}{\nu},\ \lambda = K_2 d,\ \in = \frac{\in^*}{d}$$

$$\alpha_T = \frac{Q_T d^2}{k},\qquad h = \in\cos\left(\lambda x\right),\qquad Du = \frac{D_M D_T\left(C_2 - C_1\right)d^2\rho}{kc_s\left(T_2 - T_1\right)}$$

Where M is the magnetic field parameter, F is radiation parameter, Gr is the thermal Grashof number, Gm is modified Grashof number α_1 is the visco-elastic parameter, $\Pr$ is the Prandtl number, K is the permeability parameter, Kr is the Chemical reaction parameter and Sc is Schmidt number.

In view of equation (7), the basic field of equations (1) – (4) can be expressed in non-dimensional form as

$$\frac{\partial u}{\partial t}=\left(1-E\frac{\partial}{\partial t}\right)\frac{\partial^2 u}{\partial y^2}+\frac{\delta}{\omega}(v-u)-\left(M^2+\frac{1}{K}\right)u+Gr\theta+Gm\phi \quad (8)$$

$$\omega\frac{\partial v}{\partial t}=v-u \quad (9)$$

$$\Pr\frac{\partial\theta}{\partial t}=\frac{\partial^2\theta}{\partial y^2}-(\alpha_T+F)\theta+\alpha_C\phi+D_M\frac{\partial^2\phi}{\partial y^2} \quad (10)$$

$$Sc\frac{\partial\phi}{\partial t}=\frac{\partial^2\phi}{\partial y^2}-KrSc\,\phi \quad (11)$$

The corresponding initial and boundary conditions (5) - (7) in dimensionless form are

$$\begin{aligned}&t=0; u=0, v=0, \theta=0, \phi=0 \quad for\ y\varepsilon(h,1)\\ &t>0; u=0=v, \theta'=B_i\left(\theta-\in e^{-nt}\right), \phi=\in e^{-nt} \quad at \quad y=h\\ &\quad u=0=v, \theta'=B_i\left(\theta-1-\in e^{-nt}\right), \phi=1+\in e^{-nt} \quad at \quad y\to 1\end{aligned} \quad (12)$$

3. Method of Solution

Equations (10) – (13) represent a set of partial differential equations that cannot be solved in closed-form. However, these equations can be solved analytically after reducing them according to (Prakash et al, 2010) as a set of ordinary differential equations in dimensionless form. Thus, we can represent the velocity (u), temperature (θ) and concentration (ϕ) in terms of power of $(\in<<1)$ as follows:

$$\begin{aligned}u(y,t)&=u_0+\in e^{-nt}u_1(y,t)+o\left(\in^2\right)\\ v(y,t)&=v_0+\in e^{-nt}v_1(y,t)+o\left(\in^2\right)\\ \theta(y,t)&=\theta_0+\in e^{-nt}\theta_1(y,t)+o\left(\in^2\right)\\ \phi(y,t)&=\phi_0+\in e^{-nt}\phi_1(y,t)+o\left(\in^2\right)\end{aligned} \quad (13)$$

Substituting the above expressions in Equations (17) – (20) into Equations (10) – (16), equating harmonic and non-harmonic terms and neglecting the higher-order terms of $0\left(\in^2\right)$, we get the following set of equations

$$u_0''-Nu_0=-Gr\,\theta_0-Gc\,\phi_0 \quad (14)$$

$$(1+nE)u_1''-(N-n)u_1=-Gr\theta_1-Gc\phi_1 \quad (15)$$

$$\theta_0''-(\alpha_T+F)\theta_0=-\alpha_C\phi_0+Du\phi_0'' \quad (16)$$

$$\theta_1''-(\alpha_T+F-n\Pr)\theta_1=-\alpha_C\phi_1-Du\phi_1'' \quad (17)$$

$$\phi_0''-KrSc\phi_0=0 \quad (18)$$

$$\phi_1''-(Kr-n)Sc\phi_1=0 \quad (19)$$

The appropriate boundary conditions become

$$\left.\begin{array}{l} u_0 = 0 = v_0, \theta_0' = B_i\theta_0, \phi_0 = 0 \\ u_1 = 0 = v_1, \theta_1' = B_i(\theta_1 - 1), \phi_1 = 1 \end{array}\right\} \quad at \quad y = h$$
$$\left.\begin{array}{l} u_0 = 0 = v_0, \theta_0' = B_i(\theta_0 - 1), \phi_0 = 1 \\ u_1 = 0 = v_1, \theta_1' = B_i(\theta_1 - 1), \phi_1 = 1 \end{array}\right\} \quad at \quad y \to 1 \qquad (20)$$

Equations (14) – (19) are solved and the solution for dusty fluid velocity, dust particles velocity, temperature and concentration are given as follows:

$$u(y,t) = A_{19}y + A_{18}e^{m_9 y} + A_{15}e^{m_{10} y} + A_9 e^{m_3 y} + + A_{10}e^{m_4 y} + A_{11}e^{m_7 y} + A_{12}e^{m_8 y} + \in e^{-nt}\{A_{31}e^{\beta_1 y} + A_{29}e^{-\beta_1 y} + A_{20}e^{\beta y} + A_{21}e^{-\beta y} + A_{22}e^{m_7 y} + A_{23}e^{m_8 y} + A_{24}e^{m_7 y} + A_{25}e^{m_8 y} + A_{26}e^{m_7 y} + A_{27}\, e^{m_8 y}\}$$

$$\theta(y,y) = B_1 e^{m_1 y} + B_2 e^{m_2 y} + B_3 e^{m_1 y} + B_4 e^{m_2 y} + B_{10}e^{m_6 y} + B_{13}e^{m_5 y} + \in e^{-nt}\{B_{14}e^{m_7 y} + B_{15}e^{m_8 y} + B_{16}e^{m_7 y} + B_{17}e^{m_8 y} + B_{22}e^{\beta y} + B_{25}\, e^{-\beta y}\}$$

$$\phi(y,t) = A_1 e^{m_2 y} + A_2 e^{m_1 y} + \in e^{-nt}\{A_7 e^{m_7 y} + A_8 e^{m_8 y}\}$$

The shear stress for dusty fluid and dust particles, coefficient of rate of heat and mass transfer at any point in the fluid can be characterized in order by

$$\tau_f^* = -\mu U', \tau_p^* = -\mu V', Nu^* = -kT', Sh^* = -DC'$$

In dimensionless form

$$\tau_f = \frac{\tau_f^* d}{\mu U_0,} = u', \tau_p = \frac{\tau_p^* d}{\mu U_0,} = -v', Nu = \frac{Nu^* d}{k(T_1 - T_0)} = -\theta', Sh = \frac{Sh^* d}{D(C_1 - C_0)} = -\phi'$$

The skin friction (τ), the Nusselt number (Nu) and the Sherwood number (Sh) at the wavy wall $y = h$ and the flat wall $y = 1$ are given by

$$\tau_{f_0} = -u'|_{y=h}, \tau_{f_1} = -u'|_{y=1}$$
$$\tau_{p_0} = -v'|_{y=h}, \tau_{p_1} = -v'|_{y=1}$$
$$Nu_0 = -\theta'|_{y=h}, Nu_1 = -\theta'|_{y=h}$$
$$Sh_0 = -\phi'|_{y=h}, Sh_1 = -\phi'|_{y=1}$$

4. Results and Discussion

In order to get the physical insight into the problem, the analytical solutions of this problem is performed and the results are shown graphically from figures (2) – (19). The interesting features of significant physical parameters on the velocity, temperature, concentration, skin friction, Nusselt number and Sherwood number distributions by using **MatLab**. For this computations we have used $\lambda = 2\pi, Gc = 1.0,\ \varepsilon = 0.02, t = 1.0,\ \omega = 10.0, K = 2.0, Gr = 2.0, M = 2.0, \Pr = 0.71,$ $F = 2.0, \alpha_T = 1.0,\ \alpha_C = 2.0, Bi = 0.1\ Sc = 0.96,\ Kr = 2.0$.

Velocity Profiles:

Figures (2) – (9) displays the effect of $M, K, Gr, Gc, F, Bi, Kr, Du$ on the velocity profiles of dusty fluid and dust particles. Figure (2) signifies the velocity decreases with increasing of the magnetic parameter the movement of the dusty fluid and dust particles in the channel because it gives rise to a resistive force. The consequences increase in porosity parameter leads to enhance the velocity profiles because it reduces the drag force shown in Figure (3). Figures (4) and (5) exposes the both thermal and solutal Grashof numbers enhances the velocity of the dusty fluid and dust particles which is taking place through the application of a pressure gradient and also which the inclusion of the buoyancy effects. The presence of the buoyancy effects complicates the problem, by coupling of the flow problem with thermal and mass problem. Figure (6) and (7) shows that the velocity profiles decrease for the higher values of thermal radiation and Biot number. Figure (8) represents the velocity profiles for different values of chemical reaction parameter; it is observed that the velocity decreases of both dusty fluid and dust particles with increasing values of the parameter. We can clearly see the effect of wavy wall on the velocity profile. Figure (9) illustrated the influence of Dufour number on the fluid velocity. We can observe that the diffusion thermal effect increases with increasing Dufour number. Which means the magnitude of the decrease in the velocity profiles near the wavy wall is proportional to the amplitude of the wavy wall and depends on frequency parameter and length of the wavy wall.

Temperature distribution:

Figures (10) – (14) are plotted to show the influence of $\alpha_T, F, \alpha_C, B_i$ and Du on temperature distribution respectively. Figure (10) shows that the heat absorption parameter has tendency to decrease the thermal buoyancy effects which decrease the heat transfer. Figure (11) represents that an increase in the radiation parameter decreases the temperature distribution, because large values of radiation parameter enhance the conduction over radiation, thereby which decreases the thickness of the thermal boundary layer. The fluid temperature of the channel decreases for increasing the Biot number shown in figure (13), since as B_i increases, the thermal resistance of the channel decreases and convective heat transfer to the fluid increases. It is expected that as the Biot number goes to infinity, the convective boundary conditions will become the prescribed wall temperature case (Yao et.al, 2011). As the values of Dufour number increase, the fluid temperature also increases shown in figure (14).

Concentration profiles:

It is observed from the figure (15) – (16) the concentration profiles of chemical reaction parameter and Schmidt number, it is observed an increasing both the parameter the concentration is decreases, because the which indicates that the diffusion rate can be changed by the chemical reaction parameter and mass transfer by Schmidt number.

Skin friction:

Figure (17) present the variations of skin friction co-efficient against the frequency of the wavy wall for various values of viscoelastic parameter with dusty fluid and dust particles at the wavy wall and flat wall, respectively. The magnitude of skin friction at the wavy wall increases with an increase of viscoelastic parameter for dusty fluid but this trend is reversed for the dust particles which are plotted in Figure (17).

Rate of heat transfer (Nusselt number):

The Nusselt number with respect to the heat absorption parameter for various values of F is graphically displayed in figure (18); it shows that an increase in the radiation parameter increases the rate of heat transfer at both the walls.

Rate of mass transfer (Sherwood number):

Figure (19) shows the influence of Sherwood number against the chemical reaction parameter for various values of Schmidt number. An increase in the Schmidt number increases the rate of mass transfer at $y = h$ but the opposite effect is observed at $y = 1$.

5. Conclusions

In the present investigation the following conclusion can be made;

- 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.
- Temperature is decreasing for increasing values of radiation number.
- Concentration is decreasing for increasing values of chemical reaction and Schmidt number

6. Appendix

$$N = \frac{1}{K} + M^2 \quad m_1 = \sqrt{KrSc}, m_2 = -\sqrt{KrSc} \quad m_5 = \sqrt{\alpha_T + F}, m_6 = -\sqrt{\alpha_T + F}$$

$$m_7 = \sqrt{(Kr+n)Sc}, m_8 = -\sqrt{(Kr+n)Sc}, \beta = \sqrt{\alpha_T + F + n\Pr}, \beta_1 = \sqrt{\frac{N-n}{1+nE}}$$

The other constants not given to brave the space

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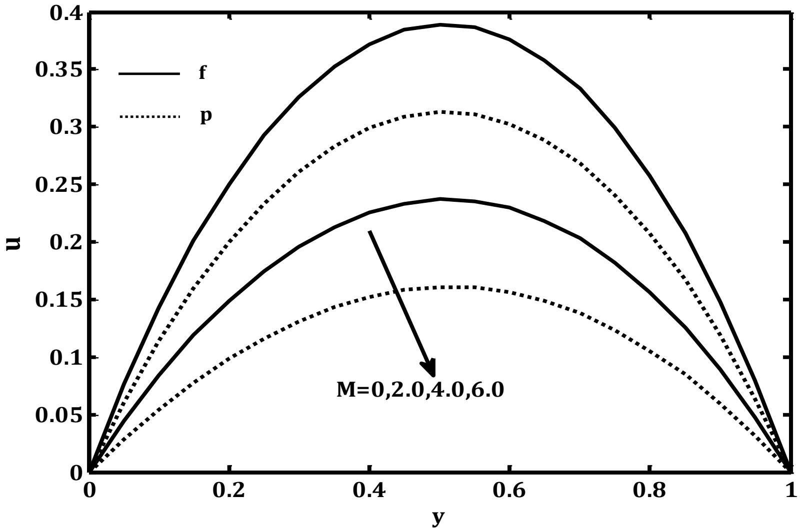

Figure (2): Velocity distribution for different values of M

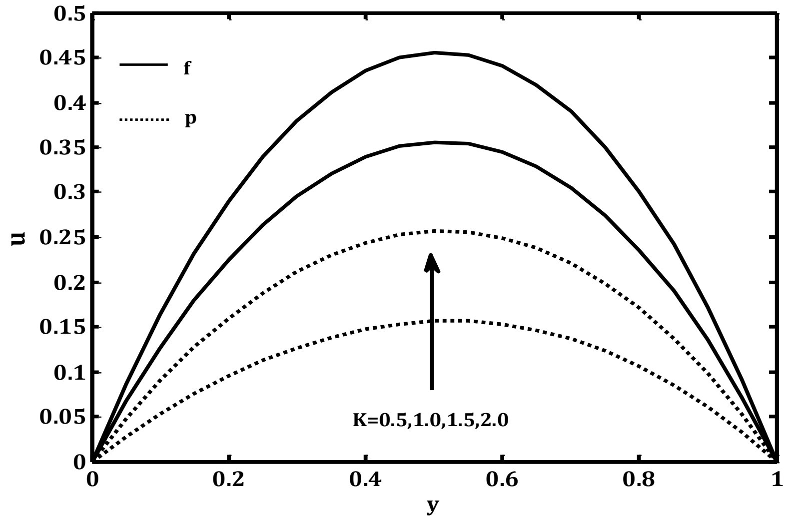

Figure (3): Velocity distribution for different values of Kr

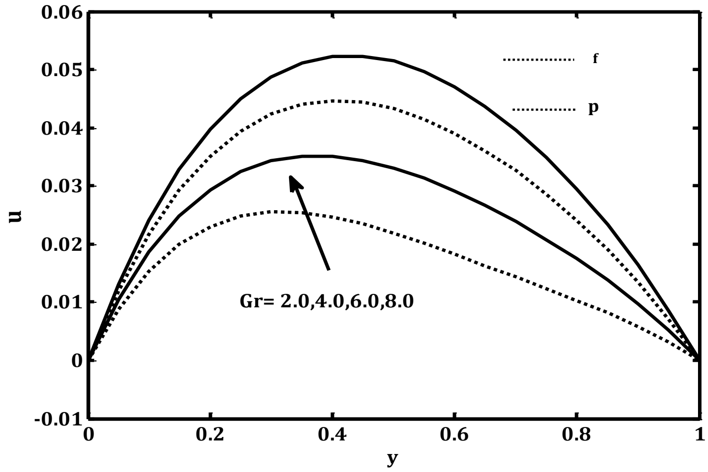

Figure (4): Velocity distribution for differnt values of Gr

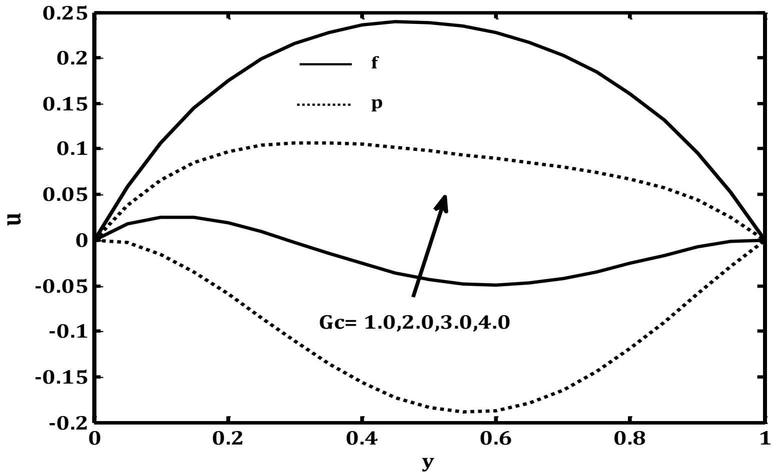

Figure (5): Velocity distribution for different values of Gc

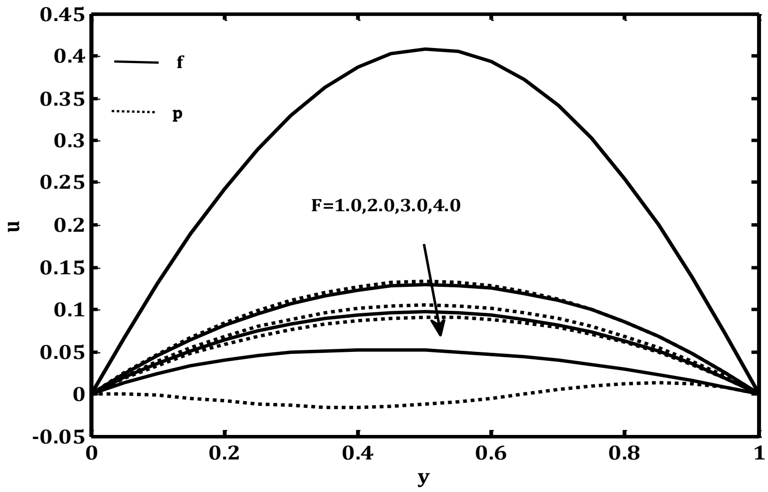

Figure (6): Velocity distribution for different values of F

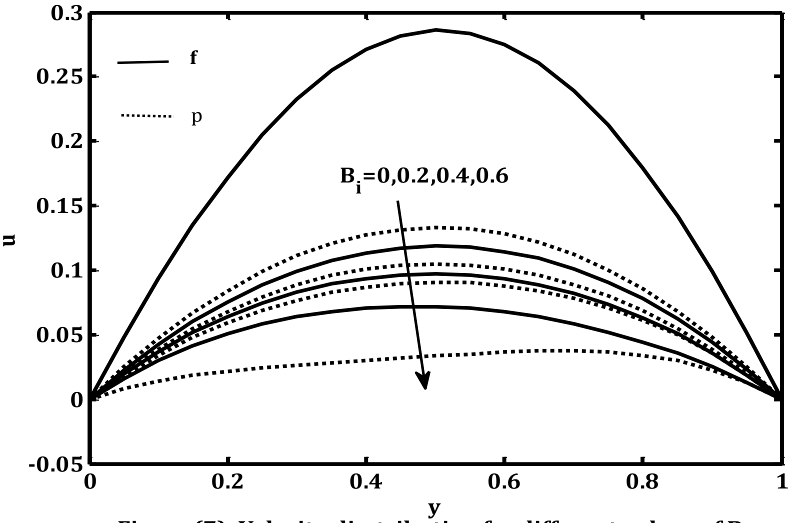

Figure (7): Velocity disstribution for different values of B_i

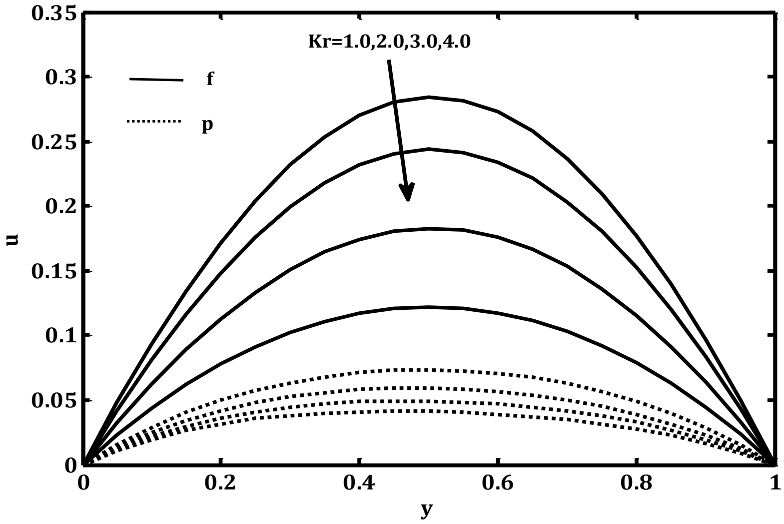

Figure (8): Velocity distribution for different values of Kr

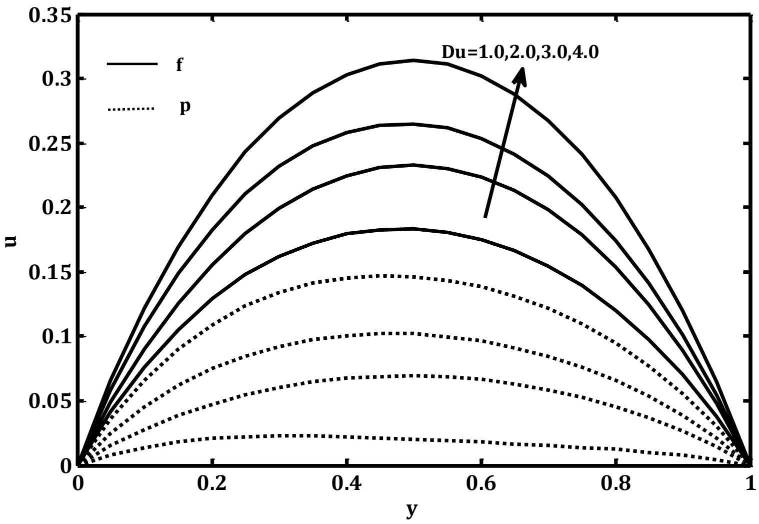

Figure (9): Velocity distribution for different values of Du

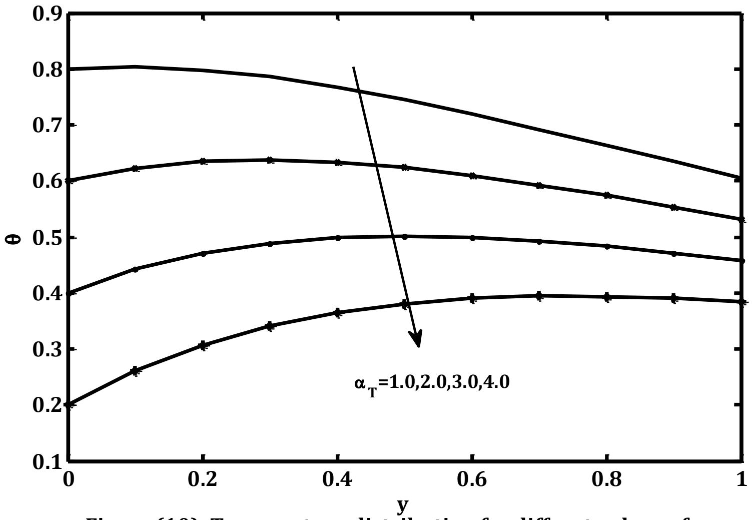

Figure (10): Temeprature distribution for differnt values of α_T

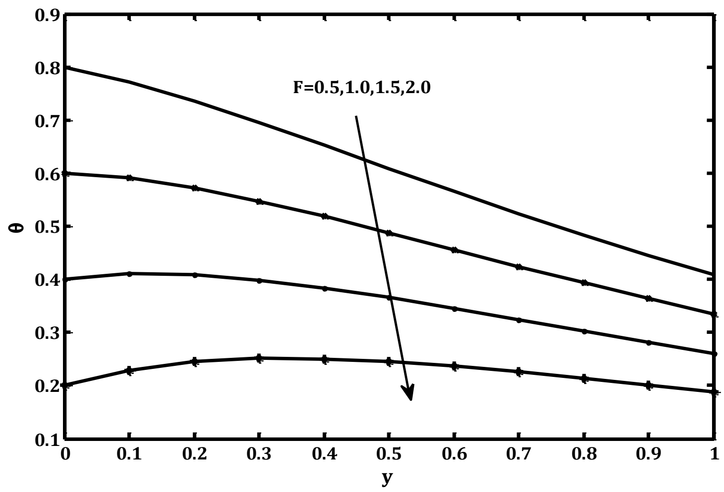

Figure (11): Temeparature distribution for differnt values of F

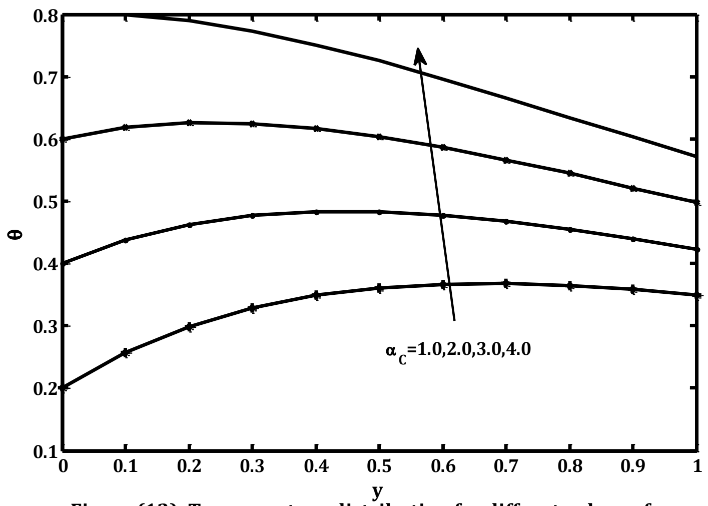

Figure (12): Temeparature distribution for differnt values of α_C

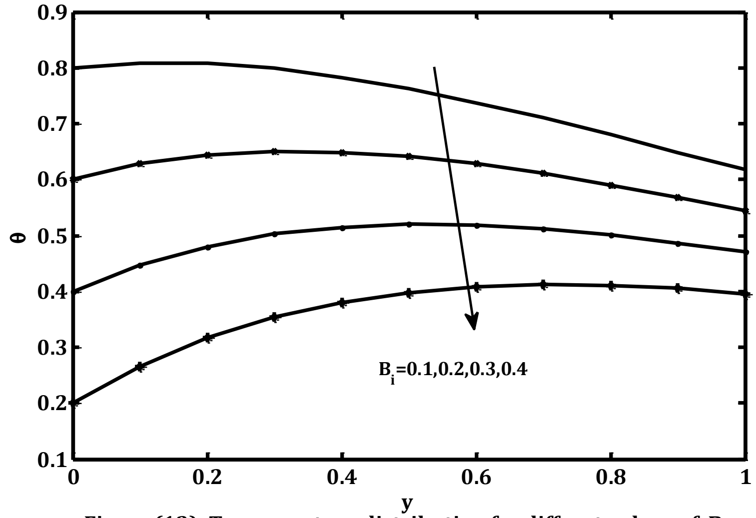

Figure (13): Temeparature distribution for differnt values of B_i

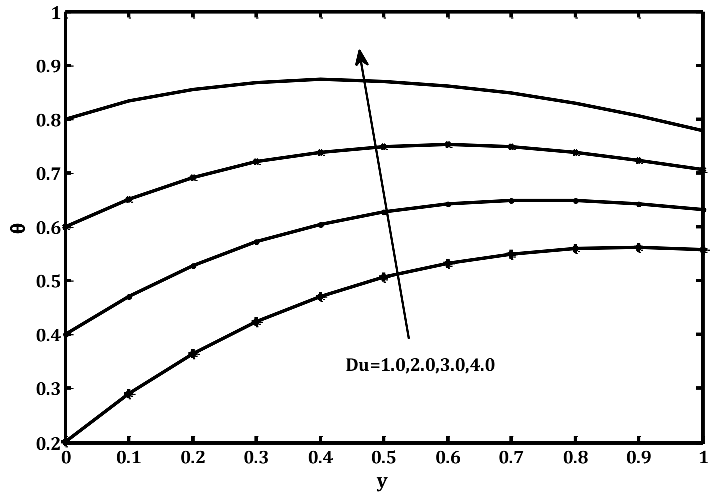

Figure (14): Temperature distribution for differnet values of Du

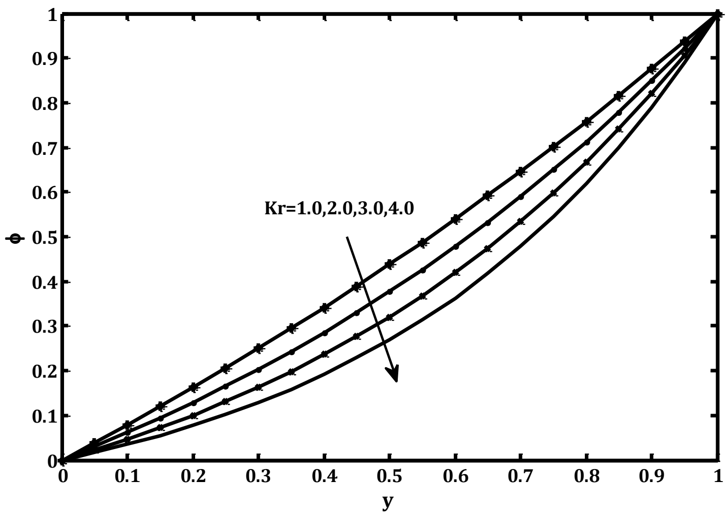

Figure (15): Concentration distribution for different values of Kr

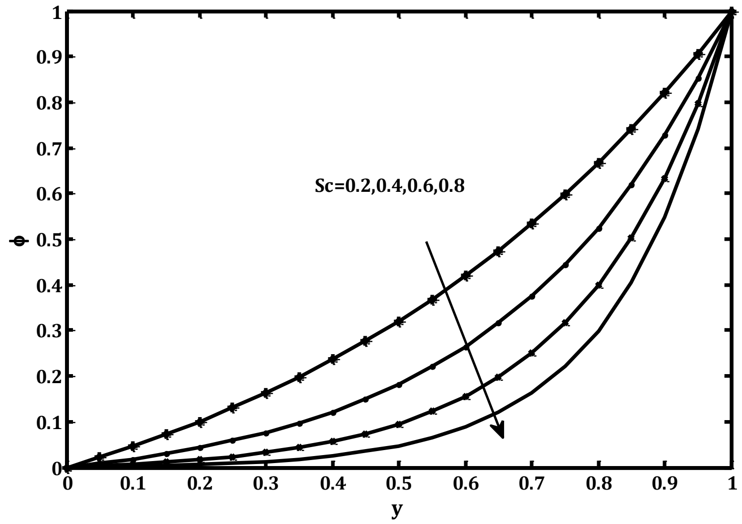

Figure (16): Concentration distribution for different values of Sc

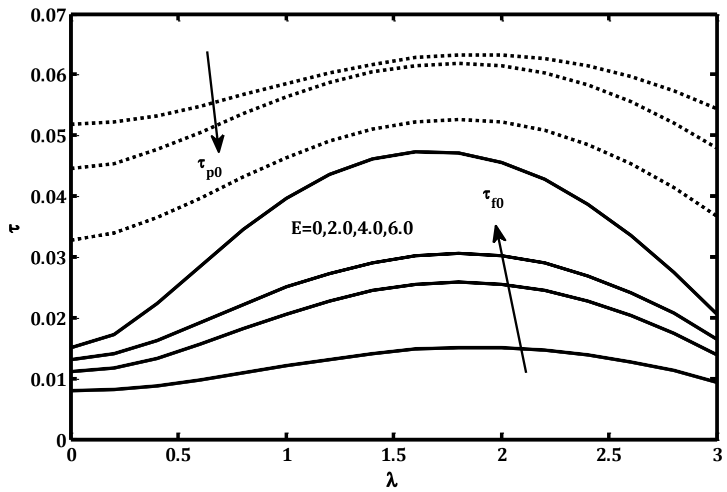

Figure (17):Skin friction profiles for differnt values of E at the wavy wall

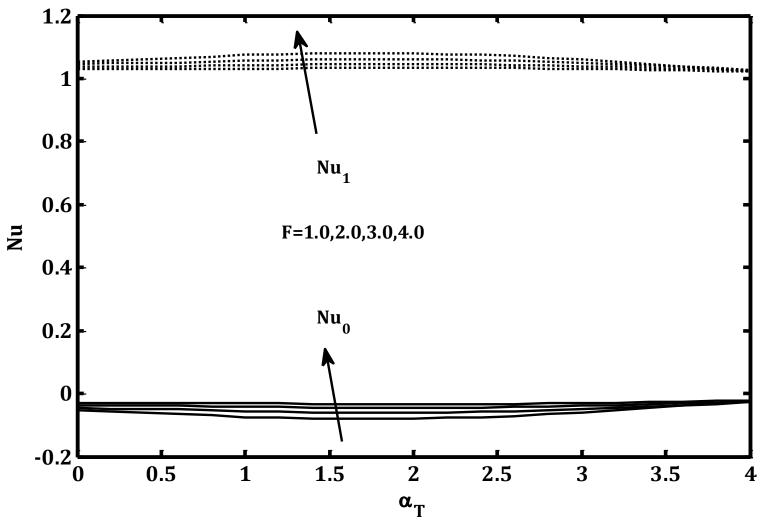

Figure (18): Nusselt number profiles different values of F

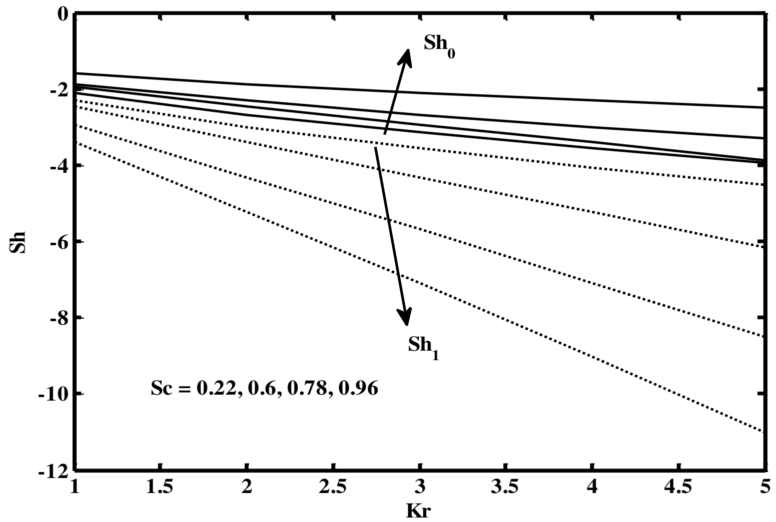

Figure (19):Sherwood number profiles for different values of Sc