CHAPTER -7

MHD COUETTE FLOW AND HEAT TRANSFER OF A DUSTY COUPLE STRESS FLUID WITH EXPONENTIAL DECAYING PRESSURE GRADIENT

7.1. Introduction

The importance and application of solid/fluid flows and heat transfer in petroleum transport, waste water treatment, combustion, power piping, corrosive particles in engine oil flow, and many other are well known in the literature Ref [89-92] and Particularly, the flow and heat transfer of electrically conducting fluid in channels and circular pipes under the effect of transverse magnetic field occurs in magnetohydrodynamics (MHD) generators, pumps, accelerators, and flow meters and has possible applications in nuclear reactors, filtration, geothermal systems, and others.

The possible presence of solid particles such as ash or soot in combustion MHD generator’s and plasma MHD accelerators and their effect on the performance of such device led to study of particular suspensions in conducting fluids in the presence of magnetic fields, in MHD generator, coal mixed with seed is fed into a combustor. The coal and seed mixture is burned in oxygen and the combustion gas expands
through a nozzle before it enters the generator section. The gas mixture flowing through the MHD canal consists of a condensable vapor (slag) and a non-condensable gas mixed with seeded coil combustion products. Both the slag and the non-condensable gas are electrically conducting Ref [89, 90]. The presence of the slag and the seeded particles significantly influences the flow and heat transfer characteristic in the MHD channel. Ignoring the effect of the slag and considering the MHD generator start up condition, the problem reduces to unsteady two-phase flow in MHD channel Ref [93-96]. Unsteady dusty couette flow with heat transfer of a couple stress fluids under exponential decaying pressure gradient was studied by Rathod and Rasheed [97].

In the present study, the transient couette flow with heat transfer of an electrically conducting, viscous, in-compressible, dusty couple stress fluid is considered. The upper plate is moving with a constant velocity while the lower plate is kept stationary. The fluid is acted upon by an exponentially decaying with time pressure gradient. The fluid is flowing between two infinite electrically insulating porous plates maintained at two constant but different temperatures while the particle
phase is assumed to be electrically non-conducting. The fluid is subjected to a uniform suction from above and a uniform injection from below and mass conservation is assumed. An external uniform magnetic field is applied perpendicular to the plates while no electric field is applied and the induced magnetic field is neglected by assuming a very small magnetic Reynolds number. The governing equation for both fluid and dust particles are solved by using transform technique. In the energy equations Joule and viscous dissipations are considered. The effect of magnetic field, couple stress parameter, Hall current, ion slip, and suction velocity on both the velocity and temperature field are reported.

7.2. Description of the problem

The couple stress dusty fluid is assumed to be flowing between two infinite horizontal porous plates located at the \( y = \pm h \) planes. The upper plate is moving with a constant velocity \( u_o \) while the lower plate is kept stationery. The plates are subjected to a uniform suction from above and a uniform injection from below. Thus velocity of the fluid is constant and denoted by \( v_o \). The dust particles are assumed to be
electrically non-conducting spherical in shape and uniformly distributed throughout the fluid, so that they are not pumped out through the porous plates and have no y-component of velocity. The two plates are assumed to be electrically non-conducting and kept at constant temperature $T_1$ for the lower plate and $T_2$ for the upper plate with $T_2>T_1$.

An uniform pressure gradient, which is taken to be exponentially decaying with time, is applied in the $x$-direction. A uniform magnetic field $B_0$ is applied in the positive $y$-direction. The induced magnetic field is neglected by assuming a very small magnetic Reynolds number. The fluid motion starts from rest at $t=0$, and no-slip condition at the plates implies that fluid and dust particle velocities have neither $z$ nor $x$-component at $y=\pm h$. The initial temperatures of the fluid and dust particles are assumed to be equal to $T_1$. It is required to obtain the time varying velocity and temperature distributions for both fluid and dust particles. Due to inclusion Hall current term, a $z$-component of velocities of fluid and dust particles is expected to arise. Since the plates are infinite in the $x$ and $z$ – direction, the physical quantities do not change in these direction that $\frac{\partial}{\partial x} = \frac{\partial}{\partial z} = 0$ and the problem is
essentially one–dimensional. The governing equations for this study are based on the conservation law of mass, linear momentum and energy of both phases. It is assumed that both phases are treated as two interacting continua, the interaction between the phases is restricted to the inter-phase drag force which is modeled by Ref[38] linear drag theory and inter phase heat transfer. The flow of fluid is governed by the momentum equation

\[ \rho \frac{Dv}{Dt} = \nabla p + \mu \nabla^2 v + J \times B_o - \eta \nabla^2 (\nabla^2 v) - kN(v - v_p) \]  \hspace{1cm} 7.2.1

Where \( \rho \) is density of clean fluid, \( \mu \) is the viscosity of clean fluid, velocity of fluid \( v = u(y, t)i + v_p j \), velocity of the dust particles \( v_p = u_p(y, t)i \), \( J \) is the current density. \( N \) is the number of dust particles per unit volume. \( k \) is the Stokes constant = \( 6\pi \mu a \), and \( a \) is the average radius of the dust particles. The first four terms in right hand side of equation (7.2.1) are pressure gradient, viscosity, Lorentz force terms and couple stress terms respectively. The last term represents force due to relative motion between fluid and dust particles. It is assumed that Reynolds number of relative velocity is small. In such a case the force between dust and fluid is proportional to the relative velocity Ref [1].

The current density \( J \) from the generalized ohm’s law is given by

\[ J = \sigma [E + v \times B_o] \]  \hspace{1cm} 7.2.2
Where $\sigma$ is the electric conductivity of the fluid simplifying equation (7.2.2) for $J$ and substituting the result in equation (7.2.1)

$$\rho \frac{\partial u}{\partial t} + \rho v_0 \frac{\partial u}{\partial y} = - \frac{dp}{dx} + \mu \frac{\partial^2 u}{\partial y^2} - \sigma B_0^2 u - \eta \nabla^2 (\nabla^2 u) - kN (u-u_p)$$

7.2.3

The motion of the dust particle is governed by Newton’s Second law applied in the $x$ and $z$-directions.

$$m_p \frac{\partial u_p}{\partial t} = kN (u-u_p)$$

7.2.4

Where $m_p$ is the average mass of dust particles. It is assumed that the pressure gradient is applied at $t=0$ and the fluid starts its motion from rest. Thus

$t \leq 0: u = u_p = 0$.

7.2.5

$$\frac{\partial^2 u}{\partial y^2} = 0, \text{ at } y = 0 \text{ and } y = \pm h$$

For $t > 0$, the no-slip condition at the plates implies that

$t > 0: y = -h, u = u_p = 0, y = h, u = u_o, u_p = 0$.

7.2.6

Heat transfer takes place from upper hot plate to lower cold plate by conduction through the fluid. Since the hot plate is above, there is no natural convection, however, there is a convection force due to the suction and injection. In addition to heat transfer, there is a heat generation due to both joule and viscous dissipations. The dust particle gain heat from the fluid by Conduction through their spherical surface. Since the problem deals with a two-phase flow, hence two energy equations describing the temperature distributions for both fluid and dust particles are
\[ \rho c \frac{\partial T}{\partial t} + \rho c v_0 \frac{\partial T}{\partial y} = k \frac{\partial^2 T}{\partial y^2} + \mu \left( \frac{\partial u}{\partial y} \right)^2 + \sigma B_0^2 u^2 + \frac{\rho_p c_s}{\gamma_T} (T_p - T) \]  

7.2.7

\[ \frac{\partial T_p}{\partial t} = -\frac{1}{\gamma_T} (T_p - T) \]  

7.2.8

The initial and boundary conditions \( T \) and \( T_p \) are.

\[ t \leq 0 : \ T = T_p = 0. \]  

7.2.9a

\[ t > 0 \quad y = -h : \ T = T_p = T_1 \]  

7.2.9 b

\[ t > 0 \quad y = h : \ T = T_p = T_2 \]  

7.2.9c

Where \( T \) is temperature of the fluid, \( T_p \) is temperature of the particles. \( c \) is specific heat capacity of fluid at constant volume, \( k \) is thermal conductivity of fluid, \( \rho_p \) is mass of dust particles per unit volume of the fluid, \( \gamma_T \) is the temperature relaxation time, and \( C_s \) is the specific heat capacity of the particles. The last three terms on the right hand side of equation (7.2.7) represent the viscous dissipation, Joule dissipation \((j^2/\sigma)\) and the heat conduction between the fluid and dust particles respectively. The temperature relaxation time depends, in general, on the geometry, and since the dust particles are assumed to be spherical in shape. The last term in equation (7.2.7) is the simplified form of \( 4\pi a N k(T_p - T) \) where

\[ \gamma_T = \left( \frac{3p_r y_p c}{2c} \right), \text{where} \quad y_p = \frac{2q_d^2}{\mu_s}, \quad \text{velocity relaxation time,} \quad p_r = \frac{\mu c}{k} \quad \text{Prandtl number} \]  

and \( \rho_s = \frac{3\rho_p}{4\pi a^3 N} \) material density of dust particles.

Using non-dimensional quantities of chapter 3.2.3d and \( \hat{x} = \frac{x}{u_0} \),

\[ \hat{y} = \frac{y}{u_0}, \hat{w} = \frac{w}{h}, P_r = \frac{P}{\rho h}, \hat{t} = \frac{t}{h}, \hat{u} = \frac{\hat{u}}{h}, \hat{T} = \frac{T - T_s}{T_2 - T_s}, \quad \hat{T}_p = \frac{T_p - T_1}{T_2 - T_s}, \quad G = \frac{m_p u}{\rho h^2 k} \]
The velocity and energy equations (7.2.3), (7.2.4), (7.2.7) and (7.2.8) becomes

\[ \frac{\partial u}{\partial t} + s \frac{\partial u}{\partial y} = -\frac{\partial p}{\partial x} + \frac{1}{\alpha^2} \frac{\partial^2 u}{\partial y^2} - \frac{1}{\alpha^2} \frac{\partial^4 u}{\partial y^4} - \frac{1}{\alpha^2} \frac{H_{\alpha}^2 u}{\alpha^2} - \frac{R}{\alpha^2} (u-u_p) \] 7.2.10

\[ G \frac{\partial u_p}{\partial t} = u - u_p \] 7.2.11

\[ \frac{\partial T}{\partial t} + s \frac{\partial T}{\partial y} = \frac{1}{\alpha^2} \frac{\partial^2 T}{\partial y^2} + \frac{E_c}{\alpha^2} \left( \frac{\partial u}{\partial y} \right)^2 + H_{\alpha}^2 E_c u^2 + \frac{2R}{\alpha^2} (T_p - T) \] 7.2.12

\[ \frac{\partial T_p}{\partial t} = -L_o (T_p - T) \] 7.2.13

The initial and boundary condition in non-dimensional form are

\( t \leq 0 : u = u_p = 0, \ \frac{\partial^2 u}{\partial y^2} = 0, \) at \( y = 0 \) and \( y = 1 \)

\( t > 0 : y = -1, u = u_p = 0, y = 1, u = 1, u_p = 0 \) 7.2.14

\( t \leq 0, \ T = T_p = 0, t > 0, T_p = 0, y = -1, \)

\( T = T_p = 0, y = 1, T = T_p = 1 \) 7.2.15

Pressure gradient is assumed in the form \( \frac{dp}{dx} = ce^{-at}. \)

Equations (7.2.10), (7.2.11), (7.2.12) and (7.2.13) represent a system of coupled and nonlinear partial differential equation and are solved by using transformation method.

\[ u = \frac{4}{\alpha} \sum_{m=0}^{\infty} \frac{\alpha}{\text{Re}} \left( 1 - \frac{1}{G} \right) \frac{(-1)^n}{\frac{(2m+1)}{2\alpha}} \left( \frac{1}{a^2 - ax_1 + x_2} \right) \]

\[ \left[ e^{-at} + \frac{1}{(x_1^2 - 4x_2)} \left( (\alpha_2 + a)e^{\alpha_1 t} - (\alpha_1 + a)e^{\alpha_2 t} \right) \right] \sum_{l=1}^{\infty} \frac{1}{\alpha_l} \frac{J_0(y\alpha_l)}{J_1(\alpha_l)} \]

\[ \cos \frac{(2m+1)\pi y}{2\alpha} \] 7.2.16
\[ u_p = \frac{4}{\alpha} \sum_{m=0}^{\infty} \frac{ca}{\text{Re} \left( 1 - \frac{1}{\sigma} \right)} \left( \frac{1}{2m+1} \right) \left( 1 - e^{-\frac{t}{\alpha}} \right) \frac{1}{a^2 - a x_1 + x_2} \]

\[
\left[ \frac{1}{1 - a \sigma} \left( e^{-at} - e^{-\frac{t}{\sigma}} \right) \frac{1}{(x_1^2 - 4x_2)} \left\{ \frac{(\alpha_2 + a) (e^{\alpha_2 t} - e^{-\frac{t}{\sigma}})}{(1 + \alpha_1 \sigma)} - \frac{(\alpha_1 + a) (e^{\alpha_1 t} - e^{-\frac{t}{\sigma}})}{(1 + \alpha_2 \sigma)} \right\} \right] \]

\[
\sum_{t=1}^{\infty} \frac{1}{\varepsilon_i} \frac{I_0(y \varepsilon_i)}{I_0(\varepsilon_i)} = \cos \left( \frac{(2m+1)\pi y}{2\alpha} \right) \quad 7.2.1
\]

\[
T = \frac{B}{(y_1^2 - 4y_2)} \left\{ \frac{(-2a + L_0) \left[ (2a - Z_2) e^{Z_1 t} - (a - Z_1) e^{Z_2 t} + e^{-Z_1 t} \right]}{4a^2 + ay_1 + y_2} \right\}
\]

\[
+ \frac{1}{(x_1^2 - 4x_2)} \left\{ \frac{(\alpha_2 + a) \left[ (2a - Z_2) e^{Z_1 t} - (a - Z_1) e^{Z_2 t} + e^{-2Z_1 t} \right]}{(4x_1^2 - 2x_1 y_1 + y_2) \left[ (2a - Z_2) e^{Z_1 t} - (a - Z_1) e^{Z_2 t} + e^{-2Z_1 t} \right]} \right\}
\]

\[
+ \frac{2(\alpha_1 + \alpha_2 + L_0) (\alpha_1 + a)}{(\alpha_1 + \alpha_2)^2 - (\alpha_1 + \alpha_2) y_1 + y_2} \left\{ \frac{(\alpha_1 + \alpha_2 - Z_1) e^{Z_1 t} - e^{(\alpha_1 + \alpha_2) t}}{(\alpha_1 + \alpha_2 - Z_1) e^{Z_1 t} + e^{(\alpha_1 + \alpha_2) t}} \right\}
\]

\[
+ \frac{2}{(x_1^2 - 4x_2)} \left\{ \frac{(\alpha_2 + a) \left[ (\alpha_1 + a - L_0) \left[ (\alpha_1 - a - Z_2) e^{Z_1 t} - (\alpha_1 - a - Z_1) e^{Z_2 t} + e^{(\alpha_1 - a) t} \right] \right]}{(\alpha_1 - a)^2 - (\alpha_1 - a) y_1 + y_2} \right\}
\]

\[
- \frac{(\alpha_2 - a + L_0) (\alpha_1 + a)}{(\alpha_2 - a)^2 - (\alpha_2 - a) y_1 + y_2} \left\{ \frac{(\alpha_1 + a - Z_2) e^{Z_1 t} - (\alpha_1 + a - Z_1) e^{Z_2 t} + e^{(\alpha_1 + a) t}}{(\alpha_1 + a - Z_2) e^{Z_1 t} - (\alpha_1 + a - Z_1) e^{Z_2 t} + e^{(\alpha_1 + a) t}} \right\}
\]

7.2.18
\[
T_p = \frac{B}{(y_1^2 - 4y_2)} \left\{ \frac{(-2a+L_0)}{4a^2 + 2ay_1 + y_1} \left[ \frac{(-2a+Z_2)}{(Z_1+L_0)} \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] + \frac{1}{(x_1^2 - 4x_2)} \left( \frac{(-2a+Z_2)}{(2x_1+L_0)} \right) \left[ \frac{(-2a-Z_1)}{(Z_1+L_0)} \frac{e^{Z_1 t} - e^{-L_0 t}}{(Z_2+L_0)} \right] \right\} + \frac{1}{(x_1^2 - 4x_2)} \frac{e^{-\alpha x_1 t} - e^{-L_0 t}}{(2x_1+L_0)} + \frac{1}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] + \frac{1}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] - \frac{2}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] + \frac{2}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] - \frac{2}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] + \frac{2}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] - \frac{2}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] + \frac{2}{(x_1^2 - 4x_2)} \left( \frac{(-2a-Z_1)}{(Z_2+L_0)} \right) \left[ \frac{(e^{Z_1 t} - e^{-L_0 t})}{(Z_2+L_0)} \right] \right\}
\]

Where \( B = (1+H_0^2) \left( \sum_{\alpha} \frac{ca}{\alpha} \Re \left( 1 - \frac{1}{\alpha} \frac{(-1)^m}{(2m+1)^2} \frac{1}{\alpha^2 - ax_1 + x_2} \right) \right)^2 \)

\[
\left( \sum_{\alpha} \frac{1}{\alpha} \frac{I_0(y_{\alpha})}{I_0(\alpha_{\alpha})} - \cos \left( \frac{(2m+1)\pi y}{2\alpha} \right) \right)^2 \]

\[
y_1 = SL_0 - \frac{R}{3R_0} \quad y_2 = L_0 - \frac{2}{3R_0} \quad x_1 = \frac{1}{R_0} + \frac{1}{\alpha^2 R_0^2} \quad x_2 = \frac{1}{R_0} \left[ H_0^2 - \frac{1}{G} + R + \frac{1}{R_0 G} + S - \frac{1}{\alpha^2 R_0} \right] \]

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\[
x_3 = \frac{c_0}{R_e} \left(1 - \frac{1}{G}\right) \frac{(-1)^m}{(2m+1)2\alpha}
\]

\[
\alpha_1 = \frac{1}{2} \left[-x_1 + \sqrt{x_1^2 - 4y_2}\right], \quad \alpha_2 = \frac{1}{2} \left[-x_1 - \sqrt{x_1^2 - 4y_2}\right],
\]

\[
Z_1 = \frac{y_1 + (y_1^2 - 4y_2)}{2}, \quad Z_2 = \frac{y_1 - \sqrt{y_1^2 - 4y_2}}{2}.
\]

Computations have been made for \(c = -5\), \(\alpha = 1\), \(R_e = 1\), \(P_r = 1\), \(R = 0.5\), \(L_o = 0.7\), \(G = 0.8\), and \(E_c = 0.2\), and plotted the graph for different values of couple stress parameter, suction parameter, Hartman, decaying parameter and time parameter.
**FIG 7.3.1a** Effect of $\tilde{\alpha}^2$ on time variation of $u$, [ $y=0$, $s=0$, $H_z=0$]
FIG 7.3.1c Effect of $\bar{a}^2$ on time variation of $T$ [$y=0, s=0, H_a=0$]

FIG 7.3.1d Effect of $\bar{a}^2$ on time variation of $T_p$ [$y=0, s=0, H_a=0$]
Fig 7.3.2a Effect of $H_a$ on time variation of $u$ [$y=0$, $\bar{\alpha}^2=0.1$, $s=1$]

Fig 7.3.2b Effect of $H_a$ on time variation of $u_p$ [$y=0$, $\bar{\alpha}^2=0.1$, $s=1$]
Fig. 7.3.2c Effect of \( H_a \) on time variation of \( T \) \([y=0, \bar{\alpha}^2=0.1, s=1]\)

Fig. 7.3.2d Effect of \( H_a \) on time variation of \( T_p \) \([y = 0, \bar{\alpha}^2 = 0.1, s=1]\)
FIG 7.3.3a Effect of s on time variation of $u$  \([y=0, \bar{\alpha}^2=0.1, H_a=1]\)

FIG 7.3.3b Effect of s on time variation of $u_p$\([y=0, \bar{\alpha}^2=0.1, H_a=1]\)
FIG 7.3.3c Effect of $s$ on time variation of $T_{y=0} \{ \alpha^2=0.1, H_a=1 \}$

FIG 7.3.3d Effect of $s$ on time variation of $u_p \{ y=0, \alpha^2=0.1, H_a=1 \}$
Fig 7.3.4a Time variation of the profile of $u$ \[ H_a = 1, s = 1, \alpha^2 = 0.1 \]

Fig 7.3.4b Time variation of the profile of $u_p$ \[ H_a = 1, s = \alpha^2 = 0.1 \]
Fig 7.3.4c Time variation of the profile of $T$, $[H_a = 1, s = 1, \alpha^2 = 0.1]$

Fig 7.3.4d Time variation of the profile of $T_p$, $H_a = 1, s = 1, \alpha^2 = 0.1$. 
7.3. Results and discussions:

Figure 7.3.1 presents, the profiles of the velocity and temperature of fluid \( u \) and \( T \) and particles \( u_p \) and \( T_p \) for various values of couple stress parameter \( \alpha^2 \). These figures are plotted for \( H_a = 0.5 \) and \( s=0.5 \). It is observed that from figures 7.3.1(a) (b) (c) and (d) as couple stress parameter increase \( u \), \( u_p \), \( T \) and \( T_p \) decreases for all values of \( t \).

Figure 7.3.2 shows the velocity and temperature at the centre of the channel \( y = 0 \), respectively, for the fluid and particle phases for various values of the Hartmann number \( H_a \) and \( s = 1, \alpha^2 = 0.1 \). In figures 7.3.2(a) and 7.3.2(b) indicate that as \( H_a \) increases \( u \) and \( u_p \) decreases for all \( t \), as a result of increasing the damping force on \( u \) which decreases \( u \) and \( u_p \). Figures 7.3.2(c) and 7.3.2(d) indicate that the variation of \( T \) and \( T_p \) with \( H_a \) depends on time. It is clear that for small \( t \) increasing \( H_a \) increases \( T \) and \( T_p \) due to increasing the Joule dissipation. But, for large \( t \) increasing \( H_a \) decreases \( T \) as a result the velocity \( u \) and \( u_p \) and consequently decreases the viscous and Joule dissipations.

Figure 7.3.3 presents the time of velocity components and temperature at centre of channel \( y = 0 \), respectively for fluid and particle phases for various values of suction parameter \( s \) and \( H_a=0 \). \( \alpha^2=0.1 \). It is shown in Figures 7.3.3(a) and 7.3.3(b) that increasing suction parameter decreases both \( u \) and \( u_p \) due to convection of fluid from regions in the lower half of centre which has higher fluid speed. Figures 7.3.3(c) and 7.3.3(d) shows that increasing \( s \) decreases the temperature at the centre of
the channel. This is due to the influence of convection in pumping the fluid from cold lower half towards centre of channel. It is observed from Figure 7.3.2 and 7.3.3 that suction has a more pronounced effect on the particles than that of the magnetic field.

Figure 7.3.4 presents, the profiles of velocity component and temperature of the fluid $u$ and $T$ and particles $u_p$ and $T_p$ for various values of time $t$, graphs are plotted for $H_s=1, s=1, \alpha^2=0.1$. It is observed that velocity and temperature of fluid reach steady state faster than that of particle phase. This is because the fluid velocity is the source for the dust particles velocity. It is shown that velocity and temperatures of fluid and dust particles do not reach steady state monotonically due to the effect of pressure gradient.
7.4 Conclusion:

The unsteady flow with heat transfer of a dusty couple stress conducting fluid under the influence of an applied uniform magnetic field has been studied in the presence of uniform suction and injection and an exponential decaying pressure gradient. Solutions for the equations of motion and energy have been obtained using transform technique. The effect of the magnetic field, couple stress parameter and suction and injection velocity on velocity and temperature distributions for both fluid and particles phases have been investigated. It is of interest to note that the effect of magnetic field on the temperature of fluid and particles depends on time. Also, it is observed that suction velocity has more apparent effect than the magnetic field and couple stress parameter on steady state time of the velocity and temperature of the dust particles.