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MHD EFFECT ON CONVECTIVE FLOW OF DUSTY VISCOUS FLUID WITH FRACTION IN A POROUS MEDIUM AND HEAT GENERATION

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Abstract. This paper deals with laminar convective flow of an incompressible, conducting, viscous fluid embedded with non – conducting dust particles through a porous medium in the presence of uniform magnetic field and constant pressure gradient taking volume fraction of a dust particles into account when one plate of the channel is fixed and the other is oscillating in time and magnitude about a constant non-zero mean. Solutions of the equations governing the flow are obtained for the velocity of fluid and dust particles. It is found that both the velocity of the liquid and dust particles decreases with the increase in the porous parameter ε_3 . The effects of the elasticity, porous parameter, heat generation, Magnetic parameter and magnetic interaction parameter with Prandtl number on the primary velocity, primary temperature and the transient velocity distributions have been discussed and illustrated graphically.

KEYWORDS: Magnetohydrodynamics, Heat generation, volume particle and dust particles

1. INTRODUCTION

Boundary layer behaviour over a moving continuous solid surface is an important type of flow occurring in a number of engineering processes. To be more specific, heat treated materials travelling between a feed roll and a wind-up roll, aerodynamic extrusion of plastic sheets, glass fibre and paper production, cooling of an infinite metallic plate in a cooling path, manufacturing of polymeric sheets are examples for practical applications of continuous moving flat surfaces.

These are related studies to the present investigation about second-grade fluids. The viscoelastic nature of a second grade fluid is found in some dilute polymer solutions or in polymer fluids. These fluids exhibit both the viscous and elastic characteristics. Same as Newtonian fluids, the viscous property is due to the transport phenomenon of the fluid molecules. The elastic property is due to the chemical structure and configuration of the polymer molecule. The term "elastic" means that the viscoelastic fluid "remembers" where it was. Macromolecules act as small rubber band and tend to snap back when the external forces have removed, and hence produce "elastic recoil" of the fluid.

The parallel plates are assumed to be porous and subjected to a uniform suction from above and injection from below while the fluid is acted upon by an external uniform magnetic field applied perpendicular to the plates. The governing equations are solved numerically using finite differences to yield the velocity and temperature distribution for both the fluid and dust particles. It is found that both the fluid and the solid particle phases have two components velocity. The main two components of velocity of the fluid and dust particles, u and up respectively, are found to increase with an increase in the Hall parameter m. However, the other two components of velocity j and jp, which result due to the Hall Effect, increase with the Hall parameter m for small *m* and decrease with *m* for large values of *m*. It is also found that the temperatures of both fluid and particles phases decrease with the Hall parameter. In these studies, the volume fraction of dust particles is neglected. However, the assumption of ignoring volume fraction of the particles is not justified for high fluid densities or high particle mass fraction where the volume fraction of the particles may become significantly large and cannot be neglected.

Convection in porous media has gained significant attention in recent years because of it importance in engineering applications such as geothermal systems, solid matrix heat exchangers, thermal insulations, oil extraction and store of nuclear waste materials. Convection in porous media can also be applied to underground coal gasification, ground water hydrology, iron blast furnaces, wall cooled catalytic reactors, solar power collectors, energy efficient drying processes, cooling of nuclear fuel in shipping flasks, cooling of electronic equipment and natural convection in earth's crust. Many studies, with applications, are gathered in comprehensive review of convective heat transfer mechanism through porous media.

2. MATHEMATICAL FORMULATION

In Cartesian co-ordinate system, we consider unsteady laminar flow of a dusty, incompressible, Newtonian, electrically conducting, viscous fluid through a porous medium with heat generation of uniform cross section h, when one wall of the channel is fixed and the other is oscillating in time about a constant non-zero mean Ibrahim et. al. [20]. Initially at $(t < 0)$ the channel wall as well as the fluid is assumed to be at the same temperature T_0. When $t > 0$, the temperature of the channel walls is instantaneously raised to T_w which oscillate with time and is thereafter maintained constant. Let x-axis be along the flow of liquid at the fixed wall and y-axis perpendicular to it. A uniform magnetic field of strength $B_0 \left(= \mu c H_0 \right)$ is applied perpendicular to the flow region.

Assumptions Ibrahim et. al. [20]**:**

The governing equations are written based on the following assumptions:

The dust particles are solid, spherical, non-conducting equal in size and uniformly distributed in the flow region. This means that the dust particles gain heat energy from the fluid by conduction through their spherical surface.

- The number density of dust particles is constant and the temperature between the particles is uniform throughout the motion. It is an incompressible fluid, therefore the density is constant and also to prevent energy loss between the particles.
- The interactions between the particles, chemical reaction and radiation between the particles and liquid have not been considered. This is necessary in order to avoid multiple equations.
- The buoyancy force, induced magnetic field and Hall effects have been neglected. This means that the flow region has uniform temperature, uniform applied magnetic field and a Cartesian coordinate.
- The volume occupied by the particles per unit volume of the mixture, (i.e., volume fraction of dust particles) and mass concentration have been taken into consideration.
- The magnetic Reynolds number is taken to be very small so that induced magnetic field is negligible. This means that a uniform magnetic field B0 is

applied in the positive y-direction and is the only magnetic field in the problem.

- The dust concentration is so small so that it is not disturbing the continuity and hydro magnetic effects. This means that the continuity equation is satisfied.

Governing Equations (Ibrahim et. al. [20])

The fluid flow is governed by the momentum and energy equation under the above assumptions:

$$(1-\phi)\frac{\partial u}{\partial t}=(1-\phi)\frac{1}{\rho}\left[\frac{\partial p}{\partial x}+\nu\frac{\partial^2 u}{\partial y^2}+g\beta^+(T-T_0)\right]+\frac{KN_0}{\rho}(v-u)$$
$$-\frac{KN\sigma\mu_c^{\,2}H_0^{\,2}}{\rho}u-\frac{\nu}{K_1}u \tag{2.1}$$

$$N_0 m\frac{\partial v}{\partial t}=\phi\left[\frac{\partial p}{\partial x}+\mu\frac{\partial^2 T}{\partial y^2}+\rho g^+(T-T_0)\right]+KN_0(u-v) \tag{2.2}$$

$$\frac{\partial T}{\partial t}=\frac{K}{\rho C_p}\frac{\partial^2 T}{\partial y^2}-\frac{Q_0}{\rho C_p}(T-T_0) \tag{2.3}$$

The boundary conditions to the problem are:

$$\begin{aligned}
&t\le 0; u(y,t)=v(y,t)=0; T(y,t)=0 && for\ 0\le y\le 1\\
&t>0; u(y,t)=v(y,t)=0; T(y,t)=0 && at\ y=0\\
&u(y,t)=v(y,t)=1+\varepsilon e^{\mathrm{int}}; T(y,t)=1+\varepsilon e^{\mathrm{int}} && at\ y=1
\end{aligned} \tag{2.4}$$

where $u(y,t)$ is the velocity of the fluid and $v(y,t)$ velocity of the dust particles, *m* is the mass of each dust particle, *No* is the number density of dust particles, *T* is the temperature. T_0 is the initial temperature, T_w is the raised temperature, β^+ is the volumetric coefficient of thermal expansion. C_p is the specific heat at constant pressure, f is the volume fraction of dust particles (i.e., the volume occupied by the particles per unit volume of the mixture), *K* is the Stoke's resistance coefficient $(=6\pi\mu r$ for spherical particles of radius r). H_0 is the magnetic field induction μ_c is magnetic permeability, σ is the electrical conductivity of the liquid, κ is thermal conductivity and K_1 is the porous parameter. The first term in the right hand side of equation (2.1) consists of pressure gradient while the second is the viscous flow and the third buoyancy force terms respectively. The last three terms represent the force term due to the relative motion between fluid and dust particles, magnetic and porous terms respectively .While the left hand side represent stream wise velocity unsteady term. From equation (2.2) the left hand side signifies unsteady normal velocity expressed in terms of pressure and viscous dissipation terms while equation (2.3) is the energy balance. The problem is simplified by writing the equations in the non-dimensional form. The characteristic length is taken to be h and the characteristic velocity is v. We introduce the following non-dimensional variables:

$$x^* = \frac{x}{h}, y^* = \frac{y}{h}, p^* = \frac{h^2 p}{\rho v^2}, t^* = \frac{tv}{h^2}, u^* = \frac{uh}{v}, v^* = \frac{vh}{v},$$
$$T^* = \frac{T - T_0}{T_w - T_0}, a^* = \frac{d^2 a}{v} \qquad (2.5)$$

Substituting equations (5) in equation (1-3), and then removing asterisks, we get

$$\frac{\partial u}{\partial t} = -\frac{\partial p}{\partial t} + \frac{\partial^2 u}{\partial y^2} GrT + \varepsilon_1 (v - u) - \varepsilon_2 Mu - \varepsilon_3 u \qquad (2.6)$$

$$f \frac{\partial v}{\partial t} = \phi \left[\frac{\partial p}{\partial t} + \frac{\partial^2 u}{\partial y^2} + GrT \right] + \beta (u - v) \qquad (2.7)$$

$$\frac{\partial T}{\partial t} = \frac{1}{\Pr} \frac{\partial^2 T}{\partial y^2} - \phi T = 0 \qquad (2.8)$$

where Gr is the Grashof number, M is the magnetic parameter, $\Pr$ is the Prandtl number, mass concentration dust particle, ϕ is the heat source parameter

$$Gr = \frac{g\beta^+ \left(T_w^* - T_0^*\right) h^3}{v^2}, \varepsilon_1 = \frac{f}{\sigma_1 (1-\phi)}, \sigma_1 = \frac{mv}{kh^2}, \varepsilon_2 = \frac{1}{(1-\phi)}$$

$$M^2 = \mu_c^2 h^2 H_0^2 \frac{\sigma}{\rho}, \quad \Pr = \frac{\mu C_p}{k}, \quad f = \frac{nm_0}{\rho}, \quad \phi = \frac{Q_0 h^2}{v \rho C_p}$$

The non-dimensional boundary conditions are:

$$t \le 0; u(y,t) = v(y,t) = 0; T(y,t) = 0 \qquad for\ 0 \le y \le 1$$
$$t > 0; u(y,t) = v(y,t) = 0; T(y,t) = 0 \qquad at\ y = 0$$
$$u(y,t) = v(y,t) = 1 + \varepsilon e^{\text{int}}; T(y,t) = 1 + \varepsilon e^{\text{int}} \qquad at\ y = 1$$
$$(2.9)$$

The solution to equations (2.6) - (2.9) are in the form of the following Soundalgekar and Bhat [21] equations.

$$u(y,t) = u_0(y) + \varepsilon e^{i\omega t} u_1(y)$$
$$v(y,t) = v_0(y) + \varepsilon e^{i\omega t} v_1(y)$$
$$T(y,t) = T_0(y) + \varepsilon e^{i\omega t} T_1(y) \qquad (2.10)$$
$$\frac{\partial p}{\partial x} = P = \text{Constant}$$

3. SOLUTION OF THE PROBLEM

We solve equations (2.6) – (2.8) under the boundary conditions (2.9) Substituting equation (2.2) in equations (6) – (8), we get

$$u_0''(y) - (\varepsilon_1 + M\varepsilon_2 + \varepsilon_3) u_0(y) + \varepsilon_1 v_0(y) = P - GrT_0(y) \qquad (3.1)$$

$$\beta v_0(y) = \beta u_0(y) + \phi \left[u_0''(y) - P + GrT_0(y) \right] \qquad (3.2)$$

$$T_0''(y) - N_1 T_0(y) = 0 \tag{3.3}$$

$$u_1''(y) - (\varepsilon_1 + M\varepsilon_2 + \varepsilon_3) u_1(y) + \varepsilon_1 v_1(y) = GrT_1(y) \tag{3.4}$$

$$(\beta + nif) v_1(y) = \beta u_1(y) + \phi\left[u_1''(y) + GrT_1(y)\right] \tag{3.5}$$

$$T_1''(y) - N_2 T_1(y) = 0 \tag{3.6}$$

where $N_1 = \phi \Pr, N_2 = \phi \Pr - in$

The corresponding boundary conditions are now

$$u_0(y) = u_1(y) = v_1(y) = 0, T_0(y) = T_1(y) = 0 \qquad at\ y = 0$$

$$u_0(y) = u_1(y) = v_1(y) = 1, T_0(y) = T_1(y) = 1 \qquad at\ y = 1$$

(3.7)

The solution to equations (3.1) – (3.6) subject to the boundary conditions (3.7) is
By solving equation (13), we obtain

$$T_0''(y) = D_1 e^{N_1 y} + D_2 e^{-N_1 y} \tag{3.8}$$

Substituting equation (3.8) in equation (3.1), and (3.2), we obtain

$$u_0''(y) - (\varepsilon_1 + M\varepsilon_2 + \varepsilon_3) u_0(y) + \varepsilon_1 v_0(y) = P - Gr\left(D_1 e^{N_1 y} + D_2 e^{-N_1 y}\right) \tag{3.9}$$

$$\beta v_0(y) = \beta u_0(y) + \phi\left[u_0''(y) - P + Gr\left(D_1 e^{N_1 y} + D_2 e^{-N_1 y}\right)\right] \tag{3.10}$$

$$u_0''(y) - A^2 u_0(y) + \varepsilon_1 v_0(y) = P - Gr\left(D_1 e^{N_1 y} + D_2 e^{-N_1 y}\right) \tag{3.11}$$

where $A^2 = \dfrac{\beta(\varepsilon_2 M + \varepsilon_3)}{(\beta + \phi\varepsilon_1)}$

By solving equation (3.11), we obtain

$$u_0(y) = J_6 e^{Ay} + J_4 e^{-Ay} + J_1 e^{N_1 y} + J_2 e^{-N_1 y}$$

$$v_0(y) = J_6 e^{Ay} + J_4 e^{-Ay} + J_1 e^{N_1 y} + J_2 e^{-N_1 y} +$$

$$\frac{\phi}{\beta}\Big[A^2 J_6 e^{Ay} + A^2 J_4 e^{-Ay} + N_1^2 J_1 e^{N_1 y} + N_1^2 J_2 e^{-N_1 y}$$

$$+P + Gr\left\{D_1 e^{N_1 y} + D_2 e^{-N_1 y}\right\}\Big]$$

$$T_0(y) = D_1 e^{N_1 y} + D_2 e^{-N_1 y}$$

$$u_1(y) = J_{10} e^{L_2 y} + J_9 e^{-L_2 y} + J_7 e^{N_2 y} + J_8 e^{-N_2 y}$$

$$v_1(y) = \left(\frac{\phi}{\beta + nif}\right)\left\{J_{10} e^{L_2 y} + J_9 e^{-L_2 y} + J_7 e^{N_2 y} + J_8 e^{-N_2 y}\right\}$$

$$+\left(\frac{\phi}{\beta + nif}\right)\Big[L_2^2 J_{10} e^{L_2 y} + L_2^2 J_9 e^{-L_2 y} + N_2^2 J_7 e^{N_2 y} + N_2^2 J_2 e^{-N_2 y}$$

$$+Gr\left(D_1 e^{N_3 y} + D_3 e^{-N_3 y}\right)\Big]$$

$$T_1(y) = D_4 e^{N_2 y} + D_5 e^{-N_2 y}$$

4. RESULTS AND DISCUSSIONS

Velocity and temperature of the liquid and dust particles $(Gr < 0)$

Figure (1), (6) and (7) depicts the primary velocity, Transient velocity for liquid as well as dust particles of M, we observe that an increases M results in a decreases in primary velocity $u_0(y)$ and the transient velocities $u\left(y, \frac{\pi}{2n}\right), v\left(y, \frac{\pi}{2n}\right)$ for both $\varepsilon_3 = 0$ and various values of ε_3. Figure (2), (5) and (10) shows that primary velocity, temperature and transient velocity for various of ϕ, we noticed that an increases ϕ leads to small changes in primary velocity, temperature $u_0(y), T_0(y)$ and the transient velocities $u\left(y, \frac{\pi}{2n}\right)$ decreases for both $\varepsilon_3 = 0$ and various values of ε_3. From figure (3), (8) and (9) we observed that an increases β leads to small changes in primary velocity, temperature $u_0(y), T_0(y)$ and the transient velocities $u\left(y, \frac{\pi}{2n}\right)$ decreases for both $\varepsilon_3 = 0$ and various values of ε_3. Figure (4) shows that the primary temperature of the various values of Pr. It is clear that the primary temperature decreases with increasing values of Pr.

5. CONCLUSIONS

In this paper the velocities of the fluid, velocities of the particles, skin friction and heat transfer are obtained. The effects of concentration resistance ratio (β), volume fraction of dust particles (ϕ), porous parameter (ε_3) frequency parameter (n) mass concentration of dust particles (f), Grashof number and (Gr) an external magnetic field on the unsteady laminar flow of a dusty, incompressible, Newtonian, electrically conducting viscous fluid through a porous medium are studied. It is found that both the velocity of the liquid and dust particles decreases with the increase in the porous parameter (ε_3)

APPENDIX

$$D_1 = \frac{1}{2\sinh N_1}, D_2 = -\frac{1}{2\sinh N_1}, D_3 = -\frac{1}{2\sinh N_1}, D_4 = \frac{1}{2\sinh N_1}$$

$$L_1 = \left(\varepsilon_1 + \varepsilon_2 + \varepsilon_3 - \frac{\varepsilon_1 \beta}{\beta + nif}\right), B = \frac{\varepsilon_1 \phi}{\beta + nif}, L_2{}^2 = \left(\frac{L_1}{1+B}\right)$$

$$J_1 = -\frac{P}{A^2}, J_2 = -\frac{Gr\, D_2}{N_1{}^2 - A^2},\ J_3 = J_1\left(e^{N_1} - e^A\right) + J_2\left(e^{-N_1} - e^A\right) - 1$$

$$J_4 = -\frac{J_3}{2\sinh A} \; J_6 = -\frac{J_5}{2\sinh A}$$
$$J_7 = -\frac{GrD_4}{N_2^{\,2} - L_2^{\,2}}, J_8 = -\frac{GrD_3}{N_2^{\,2} - L_2^{\,2}},$$
$$J_{10} = \left(\frac{1 - 2J_7 \sinh N_2}{2\sinh N_2}\right), J_9 = -\left(\frac{1 + 2J_8 \sinh N_2}{2\sinh N_2}\right)$$

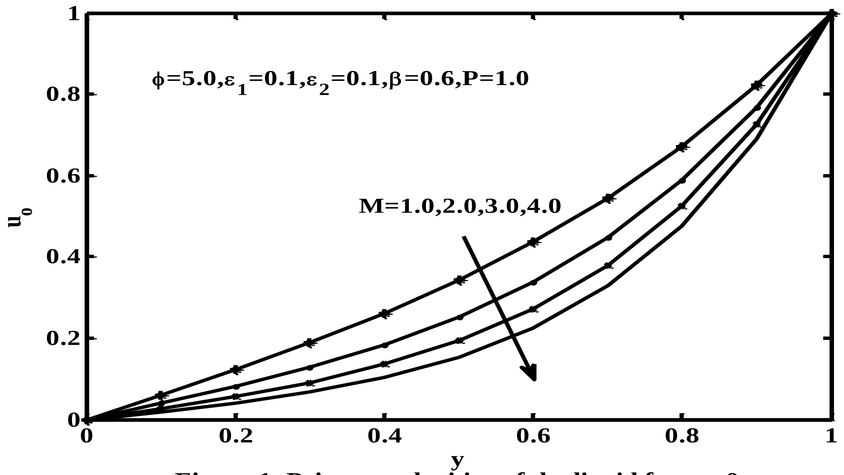

Figure 1. Primary velocities of the liquid for ε_3=0

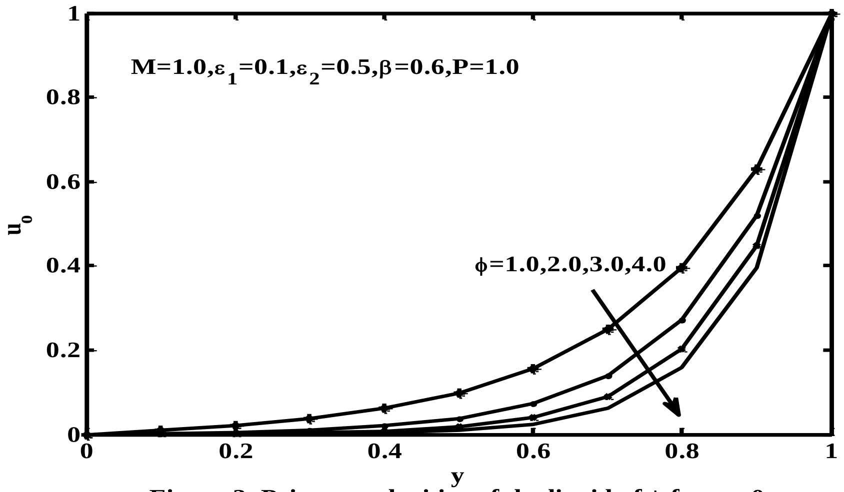

Figure 2. Primary velocities of the liquid of ϕ for ε_3=0

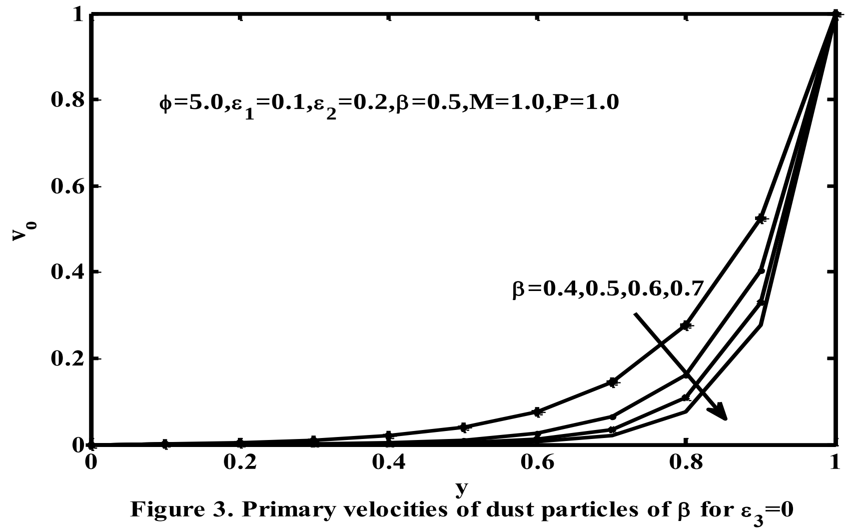

Figure 3. Primary velocities of dust particles of β for ε_3=0

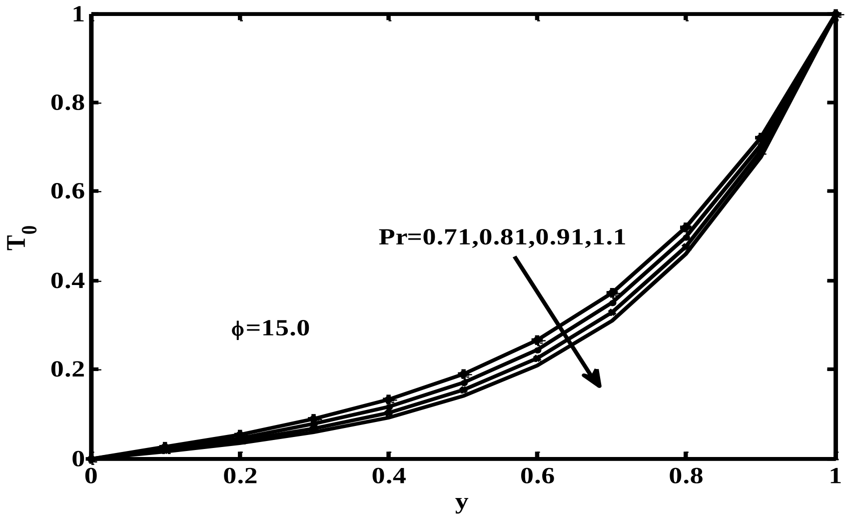

Figure 4. Primary Temperature distribution of Pr

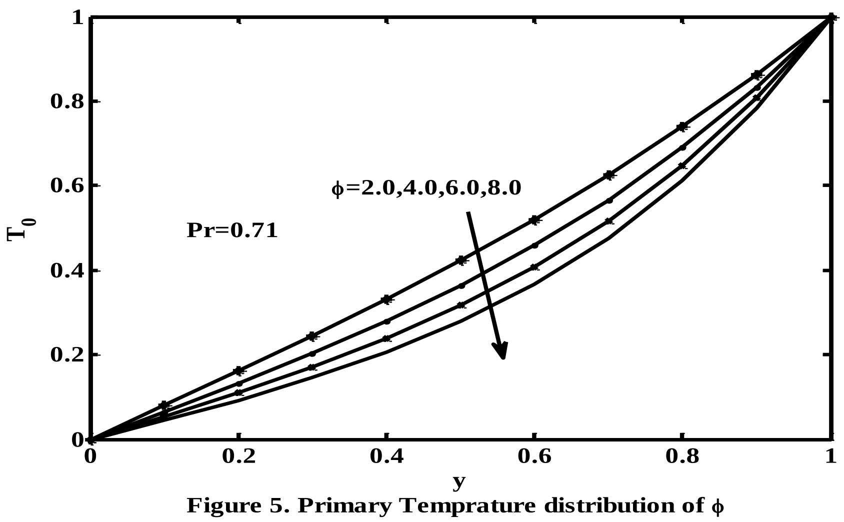

Figure 5. Primary Temprature distribution of ϕ

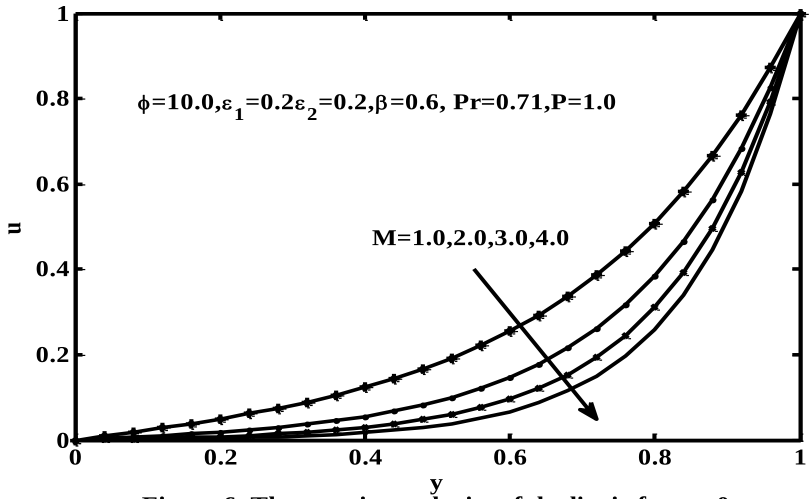

Figure 6. The transient velocity of the liquie for $\varepsilon_3=0$

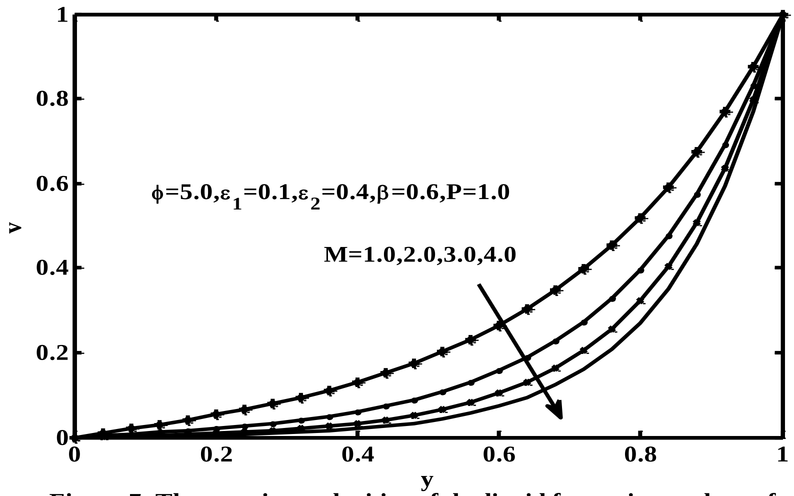

Figure 7. The transient velocities of the liquid for various values of ε_3

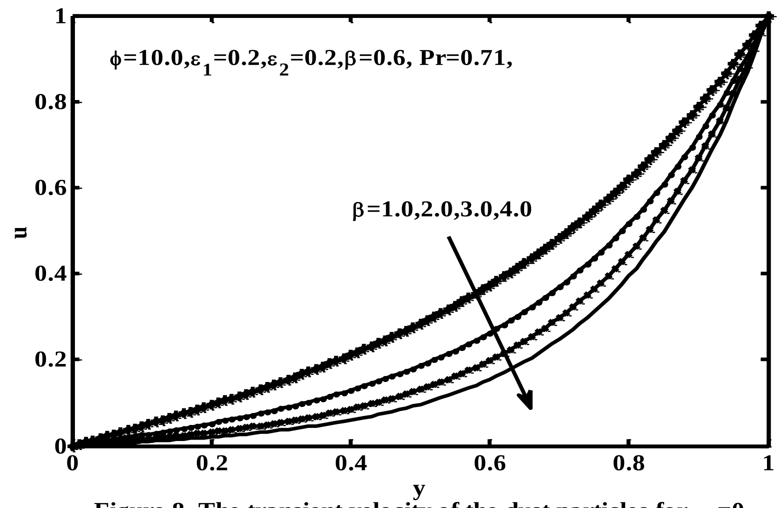

Figure 8. The transient velocity of the dust particles for $\varepsilon_3=0$

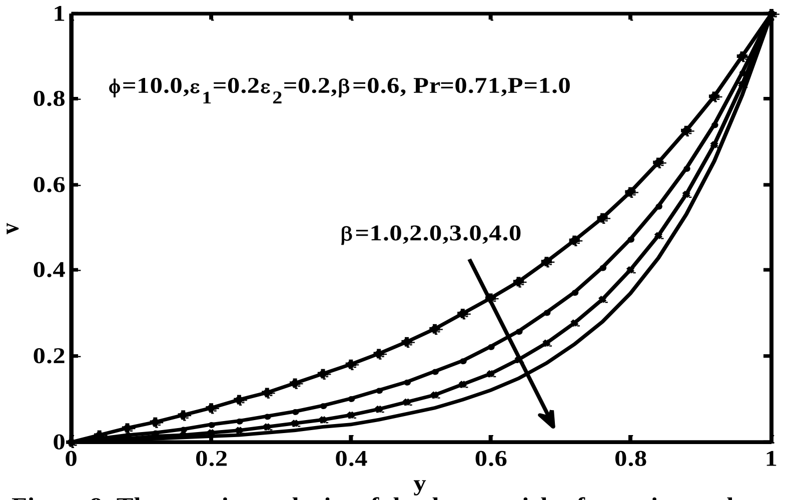

Figure 9. The transient velocity of the dust particles for various values of ε_3

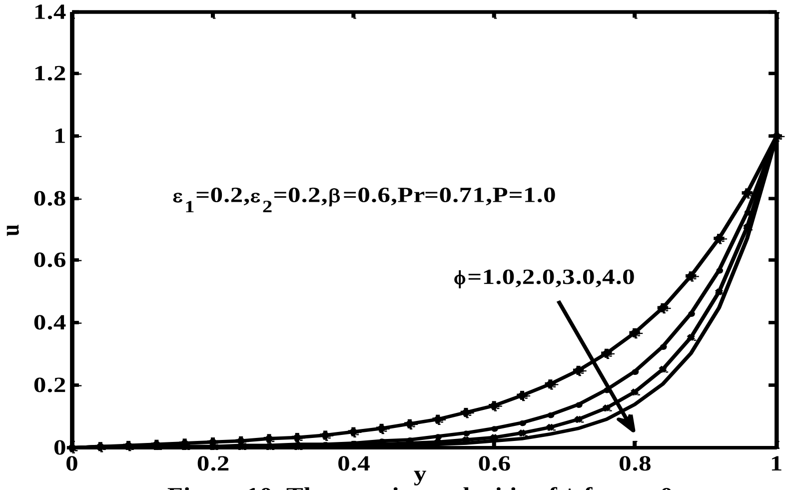

Figure 10. The transient velocitiy of ϕ for $\varepsilon_2=0$

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