Volume: 3 **Issue:** III **Month of publication:** March 2015

DOI:

www.ijraset.com Volume 3 Issue III, March 2015
IC Value: 13.98 ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

Hydro-Magnetic Oscillatory Dusty Fluid Flow with Volume Fraction and Periodic Pressure Gradient in a Rotating Channel

Debasish Dey
Department of Mathematics, Dibrugarh University, Dibrugarh- 786004

Abstract-Analytic solution of unsteady oscillatory hydro-magnetic flow of a dusty, electrically conducting fluid in a horizontal channel has been obtained under the influence of periodic pressure gradient. The system is rotating with a constant angular velocity Ω about an axis normal to the plates and |Ω| is so small that centripetal acceleration|Ω x (Ω x r)| can be neglected. Characteristics of volume fraction (volume occupied by the dust particles per unit volume of the mixture) is exhibited through the parameter ϕ. The dusty fluid flow model is governed by Saffman model. Channel is bounded by two porous electrically non-conducting plates and fluid is injected with constant velocity through the lower stationary plate and the upper plate is subjected to the same constant suction velocity. Also, the upper plate is oscillating in its own plane with a velocity U(t). A magnetic field of strength B_o is applied in the transverse direction to the plate. Governing equations of motion of fluid particles and dust particles are solved analytically. The effect of the various parameters on the governing motion of fluid, dust particles and skin-friction at both the plates have been discussed graphically.
Keywords: Dusty fluid, Volume fraction, Coriolis force, skin-friction.

I. INTRODUCTION

Saffman [1] has studied the stability of laminar flow of a dusty gas by neglecting the volume fraction of dust particles. Michael and Miller [2] have investigated the behaviour of plane parallel flow of a dusty gas. The errors in the governing gas particle mixtures by neglecting volume fraction have been shown by Rudinger [3]. Nayfeh [4] has formulated the equations of motion of the fluid particles in presence of volume fraction of dust particles. Gupta and Gupta [5] have analysed the flow of a dusty gas through a channel with time varying pressure gradient. Singh [6] has analysed the unsteady flow of a dusty fluid through a rectangular channel with time dependent pressure gradient. The unsteady two dimensional flow of an electrically conducting dusty viscous fluid through a channel in presence of transverse magnetic field has been investigated by Singh and Ram [7]. Prasad and Ramacharyulu [8] have discussed the unsteady flow of a dusty incompressible fluid between two parallel plates under an impulsive pressure gradient. Gupta and Gupta [9] have investigated the unsteady flow of a dusty visco-elastic fluid through channel with volume fraction. Ajadi [10] has analysed the isothermal flow of a dusty viscous electrically conducting fluid between oscillatory and non-oscillatory boundary motions. The unsteady Couette flow flow with heat transfer of a viscous incompressible electrically conducting fluid under the influence of an exponentially decreasing pressure gradient has been discussed by Attia et al. [11].
Unsteady Couette flow of a dusty gas between two infinite parallel plates, when one plate of channel is kept stationary and other plate moves uniformly in its own plane has been studied by Nag et al. [12]. Dalal [13] has discussed the nature of generalized Couette flow of dusty gas due to an impulsive pressure gradient as well as due to impulsive start of lower plate. Singh and Singh [14] have investigated the problem of free convective MHD flow of dusty viscous fluid in presence of volume fraction through vertical parallel plates, when one plate is fixed and the other is oscillating with time. Attia [15] and [16] has analysed MHD flow of dusty fluid with heat transfer under various physical considerations. The problem of has been studied by Ahmed et al. [17]. An unsteady flow of a dusty, viscous, electrically conducting fluid in a horizontal channel rotating with an angular velocity by neglecting the volume fraction has been studied by Singh et al. [18]. The aim of the paper is to study the effects of volume fraction of dust particles on the flow of an unsteady oscillatory electrically conducting viscous fluid through horizontal channel rotating with constant magnetic field in presence of transverse magnetic field. It is worth mentioning that the results obtained from $\phi = 0$ coincide with the results from Singh et al. [18].

II. FORMULATION OF THE PROBLEM

Let us consider an unsteady dusty viscous fluid is flowing between two horizontal parallel plates at $z = \pm\frac{d}{2}$. The lower plate is

International Journal for Research in Applied Science & Engineering Technology (IJRASET)

subjected with a constant injected velocity and the fluid is sucked with same velocity through the upper porous plate. In the present study, the following assumptions are made:

The dust particles are spherical in shape and uniformly distributed.

The temperature is uniform within the particle.

Plates are assumed to be electrically non-conducting. Upper plate is oscillating with a velocity U' (t).

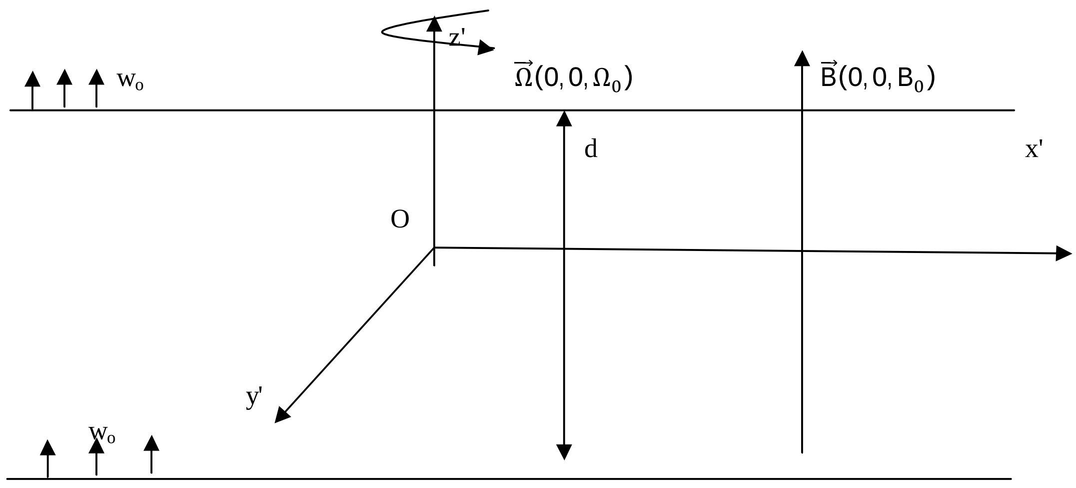

Figure 1: The physical configuration of the problem

A periodic pressure gradient varying with time is experienced in *x*'- direction.

A uniform magnetic field of uniform strength is applied in the direction *z*'- axis. Induced magnetic field is neglected by assuming very small values of magnetic Reynolds number (Cramer and Pai [19]).

The system is rotating with a constant angular velocity **Ω** about an axis normal to the plates and |**Ω**| is so small that the centripetal acceleration |**Ω x (Ω x r)**| can be neglected

The plates are of infinite in length in *x*′ and *y*' directions, so all physical quantities except *p*' depend on *z*' and *t*' (time) respectively.

III. GOVERNING EQUATIONS

The governing equations of motion of both fluid and dust particles based on conservation of mass and momentum are given as follows:

$$\frac{\partial w'}{\partial z'} = 0 \;=>\; w = w_0 \tag{3.1}$$

$$\nabla . u_p' = 0 \tag{3.2}$$

$$(1-\Phi)\left[\frac{\partial u'}{\partial t'} + w_0\frac{\partial u'}{\partial z'} - 2\Omega_0 v'\right] = (1-\Phi)\left[-\frac{1}{\rho}\frac{\partial p'}{\partial x'} + \nu\frac{\partial^2 u'}{\partial z'^2} - \frac{\sigma B_0^2 u'}{\rho}\right] + \frac{KN}{\rho}(u_p' - u') \tag{3.3}$$

$$(1-\Phi)\left[\frac{\partial v'}{\partial t'} + w_0\frac{\partial v'}{\partial z'} + 2\Omega_0 u'\right] = (1-\Phi)\left[-\frac{1}{\rho}\frac{\partial p'}{\partial y'} + \nu\frac{\partial^2 v'}{\partial z'^2} - \frac{\sigma B_0^2 v'}{\rho}\right] + \frac{KN}{\rho}(v_p' - v') \tag{3.4}$$

$$0 = -\frac{1}{\rho}\frac{\partial p'}{\partial z'} \tag{3.5}$$

$$m_p\left[\frac{\partial u_p'}{\partial t'} - 2\Omega_0 v_p'\right] = \Phi\left[-\frac{1}{\rho}\frac{\partial p'}{\partial x'} + \nu\frac{\partial^2 u'}{\partial z'^2}\right] - K(u_p' - u') \tag{3.6}$$

$$m_p\left[\frac{\partial v_p'}{\partial t'} + 2\Omega_0 u_p'\right] = \Phi\left[-\frac{1}{\rho}\frac{\partial p'}{\partial y'} + \nu\frac{\partial^2 v'}{\partial z'^2}\right] - K(v_p' - v') \tag{3.7}$$

Here x', *y*' and *z*' are the displacement variables and t be the time. $\vec{u}(u', v', w')$ and $\vec{u_p}(u_p', v_p', w_p')$ represent the fluid and particle velocities respectively, magnetic field and angular velocity for the present study are defined as $\vec{B}(0,0,B_0)$and $\vec{\Omega}(0,0,\Omega_0)$ respectively. Let *p*' be the pressure, ρ be the density of the clear fluid, ν be the viscosity of clear fluid, N the number of dust particle per unit volume, K= 6πμa (a= radius of dust particle) be the Stokes constant, σ be the electrical conductivity of the fluid, m_p be the

Volume 3 Issue III, March 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

average mass of dust particles.

The relevant boundary conditions of the problem are:

$$\left.\begin{aligned} z = -\frac{d}{2};\ u' = v' = u'_p = v'_p = 0 \\ z = \frac{d}{2};\ u' = u'_p = U_0 e^{i\omega' t'}, v' = v'_p = 0 \end{aligned}\right\} \tag{3.8}$$

where, U_0 be the amplitude of oscillation and at $t' = 0$, it coincides the velocity of fluid and dust particles, ω' be the frequency of oscillations and d be the distance between two two plates.

IV. METHOD OF SOLUTION

Introducing the following non-dimensional quantities,

$$x = \frac{x'}{d}, y = \frac{y'}{d}, z = \frac{z'}{d}, u = \frac{u'}{w_0}, v = \frac{v'}{w_0}, u = \frac{u'_p}{w_0}, v = \frac{v'_p}{w_0}, p = \frac{p'}{\rho\omega_0^2}, t = \frac{t'\omega_0}{d}, G = \frac{m_p \nu}{KNd^2},$$

$$\omega = \frac{\omega' d}{\omega_0}, \Omega = \frac{\Omega_0 d^2}{\nu}, R = \frac{KNd^2}{\mu}, M = \frac{\sigma B_0^2 d}{\mu}, \lambda = \frac{w_0 d}{\nu} \tag{4.1}$$

in the equations (3.3) – (3.7), the non-dimensional form of equations of motion become:

$$(1-\phi)\left(\frac{\partial u}{\partial t} + \frac{\partial u}{\partial z} - \frac{2\Omega v}{\lambda}\right) = (1-\Phi)\left(-\frac{\partial p}{\partial x} + \frac{1}{\lambda}\frac{\partial^2 u}{\partial z^2} - \frac{M}{\lambda}u\right) + \frac{R}{\lambda}(u_p - u) \tag{4.2}$$

$$(1-\phi)\left(\frac{\partial v}{\partial t} + \frac{\partial v}{\partial z} + \frac{2\Omega u}{\lambda}\right) = (1-\Phi)\left(-\frac{\partial p}{\partial x} + \frac{1}{\lambda}\frac{\partial^2 v}{\partial z^2} - \frac{M}{\lambda}v\right) + \frac{R}{\lambda}(v_p - v) \tag{4.3}$$

$$0 = -\frac{\partial p}{\partial z} \tag{4.4}$$

$$\frac{\partial u_p}{\partial t} - \frac{2\Omega v_p}{\lambda} = \frac{\Phi}{m_p}\left(-\frac{\partial p}{\partial x} + \frac{1}{\lambda}\frac{\partial^2 u}{\partial z^2}\right) - \frac{1}{G_\lambda}(u_p - u) \tag{4.5}$$

$$\frac{\partial v_p}{\partial t} + \frac{2\Omega u_p}{\lambda} = \frac{\Phi}{m_p}\left(-\frac{\partial p}{\partial x} + \frac{1}{\lambda}\frac{\partial^2 v}{\partial z^2}\right) - \frac{1}{G_\lambda}(v_p - v) \tag{4.6}$$

where, $\frac{1}{G_\lambda} = \frac{Kd}{w_0 m_p}$ is the dimensionless relaxation time of particles.

The non-dimensional forms of boundary conditions are as follows:

$$\left.\begin{aligned} z = -\frac{1}{2};\ u = u_p = v = v_p = 0 \\ z = +\frac{1}{2};\ u = u_p = Ue^{i\omega t}, v = v_p = 0 \end{aligned}\right\} \tag{4.7}$$

where, $U = \frac{U_0}{w_0}$

Equation (4.4) suggests that fluid pressure is constant along z-axis. We assume that the fluid flows only under the pressure gradient along x-axis.

$$-\frac{\partial p}{\partial x} = A\cos\omega t$$

In order to combine the velocity components for fluid particles and dust particles, let u consider

$$F = u + iv, F_p = u_p + iv_p \tag{4.8}$$

Using equations (4.8), equations (4.2) and (4.3) can be combined as

$$(1-\phi)\left(\frac{\partial F}{\partial t} + \frac{\partial F}{\partial z} + i\frac{2\Omega F}{\lambda}\right) = (1-\Phi)\left(-\frac{\partial p}{\partial x} + \frac{1}{\lambda}\frac{\partial^2 F}{\partial z^2} - \frac{M}{\lambda}F\right) + \frac{R}{\lambda}(F_p - F) \tag{4.9}$$

Similarly, (4.5) and (4.6) can be combined as

$$\frac{\partial F_p}{\partial t} + i\frac{2\Omega F_p}{\lambda} = \frac{\Phi}{m_p}\left(-\frac{\partial p}{\partial x} + \frac{1}{\lambda}\frac{\partial^2 F}{\partial z^2}\right) - \frac{1}{G_\lambda}(F_p - F) \tag{4.10}$$

Boundary conditions reduce to

Volume 3 Issue III, March 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

$$\left.\begin{array}{c} z = -\frac{1}{2};\ F = F_p = 0 \\ z = +\frac{1}{2};\ F = F_p = Ue^{i\omega t} \end{array}\right\} \quad (4.11)$$

To solve the equations, we assume the solutions of the problem in the complex form as follows:

$$F(z,t) = \bar{\phi}(z)e^{i\omega t}, -\frac{\partial p}{\partial x} = Ae^{i\omega t}, F_p(z,t) = \psi(z)e^{i\omega t} \quad (4.12)$$

Substituting (4.12) in the equations (4.9) and (4.10), we obtain the following equations for the fluid and dust particle velocities

$$\bar{\phi}'' - \lambda\bar{\phi}' - \bar{\phi}L_1 = -A\lambda - R(1-\phi)\psi \quad (4.13)$$

$$\psi' = \frac{1}{L_2 + iL_3}\left[\frac{\Phi}{m_p}A + \frac{\bar{\phi}''}{\lambda} + \frac{\bar{\phi}}{G_\lambda}\right] \quad (4.14)$$

These equations are solved under the following boundary conditions

$$\left.\begin{array}{c} z = -\frac{1}{2};\ \bar{\phi} = \psi = 0 \\ z = +\frac{1}{2};\ \bar{\phi} = \psi = Ue^{i\omega t} \end{array}\right\} \quad (4.15)$$

V. RESULTS AND DISCUSSION

Solving the equations (4.13) and (4.14) subject to the boundary conditions, we get the solutions as follows:

$$\bar{\phi} = e^{\alpha_1 z}(C_1 cos\beta_1 z + iC_1 sin\beta_1 z) + e^{\alpha_2 z}(C_2 cos\beta_2 z + iC_2 sin\beta_2 z) + L_{12} + iL_{13}$$

$$\psi = \frac{L_2 - iL_3}{L_2^2 + L_3^2}[L_{14} + iL_{13} + e^{\alpha_1 z}\, cos\beta_1 z(L_{15} + iL_{16}) + e^{\alpha_2 z}\, cos\beta_1 z(L_{17} + iL_{18}) + e^{\alpha_1 z}\, sin\beta_1 z(iL_{15} - L_{16}) + e^{\alpha_2 z}\, sin\beta_1 z(iL_{17} - L_{18})\,]$$

Then the velocity components can be derived as

$$u = \{e^{\alpha_1 z}(C_{1a}cos\beta_1 z - C_{1b}sin\beta_1 z) + e^{\alpha_2 z}(C_{2a}cos\beta_2 z - C_{2b}sin\beta_2 z)\}cos\omega t - \{e^{\alpha_1 z}(C_{1b}cos\beta_1 z + C_{1a}sin\beta_1 z) + e^{\alpha_2 z}(C_{2b}cos\beta_2 z + C_{2a}sin\beta_2 z)\}sin\omega t$$

$$v = \{e^{\alpha_1 z}(C_{1a}cos\beta_1 z - C_{1b}sin\beta_1 z) + e^{\alpha_2 z}(C_{2a}cos\beta_2 z - C_{2b}sin\beta_2 z)\}sin\omega t + \{e^{\alpha_1 z}(C_{1b}cos\beta_1 z + C_{1a}sin\beta_1 z) + e^{\alpha_2 z}(C_{2b}cos\beta_2 z + C_{2a}sin\beta_2 z)\}cos\omega t$$

$$u_p = \frac{1}{L_2^2 + L_3^2}[\{L_2A'(z) + L_3B'(z)\}cos\omega t - \{-L_3A'(z) + L_2B'(z)\}sin\omega t]$$

$$v_p = \frac{1}{L_2^2 + L_3^2}[\{L_2A'(z) + L_3B'(z)\}sin\omega t + \{-L_3A'(z) + L_2B'(z)\}cos\omega t]$$

The non-dimensional shearing stresses at the plates are given by

$$\sigma_{xz}(= Sh) + i\sigma_{yz}(= Sh') = \frac{\sigma'_{xz} + i\sigma'_{yz}}{\left(\frac{\rho\nu^2}{d^2}\right)} = \frac{1}{\lambda}\bar{\phi}'(z)e^{i\omega t}$$

The objective of the present paper is to investigate the effects of volume fraction in the governing motion of an oscillatory electrically conducting dusty fluid in a horizontal channel rotating with a constant angular velocity. The effect of volume fraction is exhibited through the parameter Φ. The velocity profiles of both fluid particles and dust particles and shearing stresses at both the plates are analyzed graphically for various values of flow parameters involved in the problem.

Figures 2 to 11, represent the velocity profiles of both fluid particles and dust particles against the displacement variable z in combination of Magnetic parameter (M), Suction parameter (λ), particle concentration parameter (R), the frequency of oscillation (ω), the amplitude of pressure gradient (A), particle mass parameter (G) and rotation parameter (Ω). Figure 2 notifies the effect of phase angle (wt) on the fluid flow against the displacement variable and it is seen that, the impact of phase angle is prominent in the neighborhood of the upper plate, where fluid flow is oscillating. Also, it can be concluded that the phase angle has a retarding effect on the speed of the fluid flow. During wt=pi, the fluid particles experience a back flow. During the cross flow of fluid particles, an oscillating trend is experienced and it is represented in figure 3. The difference in flow pattern due to the presence and absence of volume fraction ϕ is shown in figure 4. It is seen that, the presence of volume fraction subdues the speed of fluid particles and same retarding trend is also experienced in case of cross flow along with the increasing values of displacement variable 'z'. Application of transverse magnetic field generates the Lorentz force. As a consequence, a decelerating trend is seen in the motion of fluid (Figure 5). Effects of rotation parameter (Ω) on velocity profiles u and v, are seen in figures 6 and 7. In the both the figures, it is noticed that the magnitudes of u and v slow down during the enhancement of rotation parameter. Figures 8-11, signify the behavior of motion of dust particles against the displacement variable z and increasing values of phase angle $0 \le \omega t \le \frac{\pi}{2}$, the speed increases and in case of $\omega t = \pi$, a back flow is noticed (figure 8). An opposite phenomenon is noticed during cross flow of dust particles against the displacement variable 'z' (figure 9). Figure 10 and 11 explain the effects of rotation parameter on the motion dust particle and it can be concluded that the growth of rotation parameter decreases the magnitude of velocity components u and v.

After finding the velocity profile, the shearing stress at both the plates are calculated for different values of flow parameters involved in the solution and represented graphically against the suction parameter, λ (figures 12 to 16). It is revealed that as suction parameter increases, the shearing at both lower and upper plates decreases. Increasing values of rotation parameter diminishes the shearing stress at the lower plate (figure 12) but an opposite trend is noticed at the upper plate (figure 13). Figure 14 and 15 characterize that during the growth of volume fraction, the shearing stresses at both the plates decrease along with the increasing values of suction parameter. Figure 16, shows the difference in shearing stress generated by regular and cross flow at both the plates and it is concluded that at the upper plate, the shearing generated by cross flow has lesser order of magnitude than the shearing stress generated by regular flow but an opposite phenomenon is noticed at the lower plate.

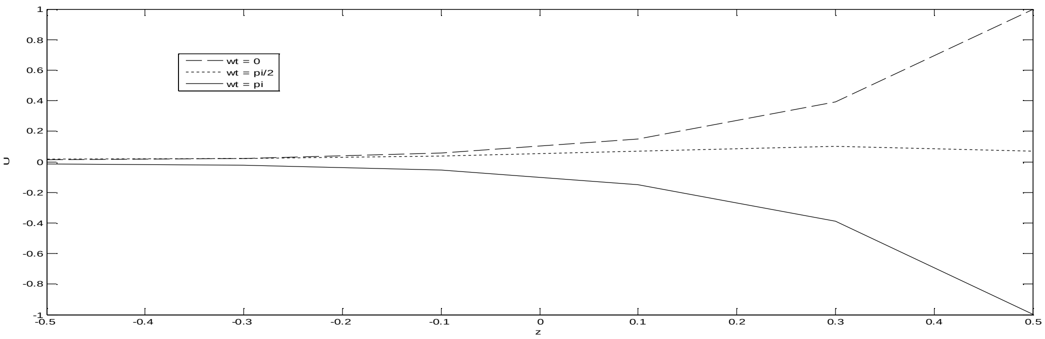

Figure 2: Velocity profile u against z for M = 2, R=2, λ = 3, ϕ = 0.01, ω = 2, G = 3, Ω =2, A = 0.01.

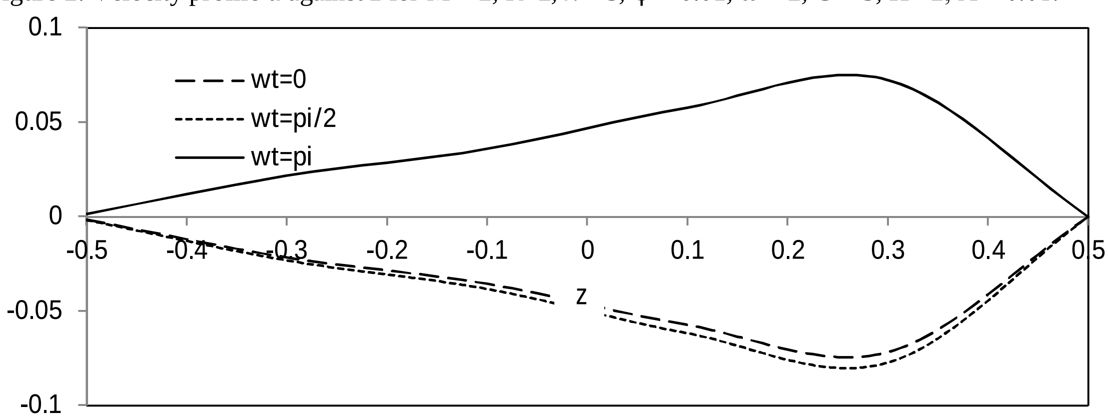

Figure 3: Transient Velocity profile v against z for M = 2, R=2, λ = 3, ϕ = 0.01, ω = 2, G =3, Ω =2, A = 0.01.

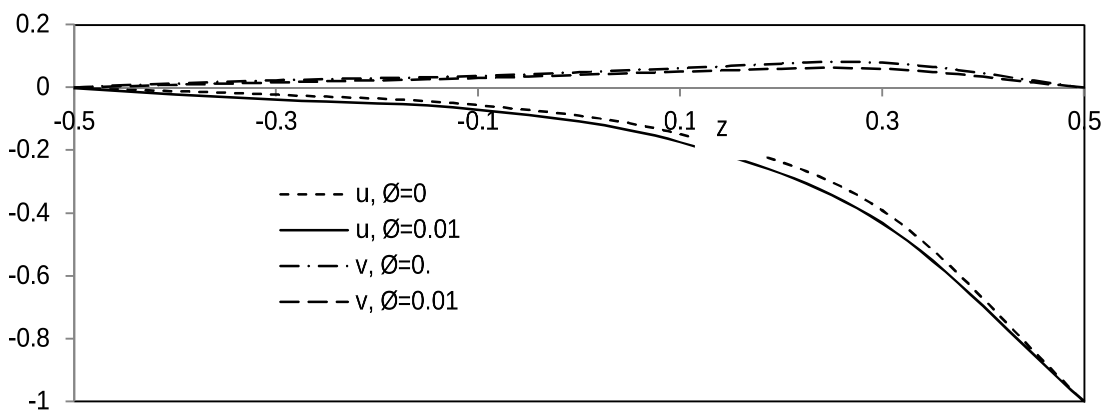

Figure 4: Velocity u and transient velocity v against z for M = 2, R=2, λ = 3, ω = 2, G = 3, Ω =2, A = 0.01, $\omega t = \pi$.

Volume 3 Issue III, March 2015
ISSN: 2321-9653
International Journal for Research in Applied Science & Engineering Technology (IJRASET)

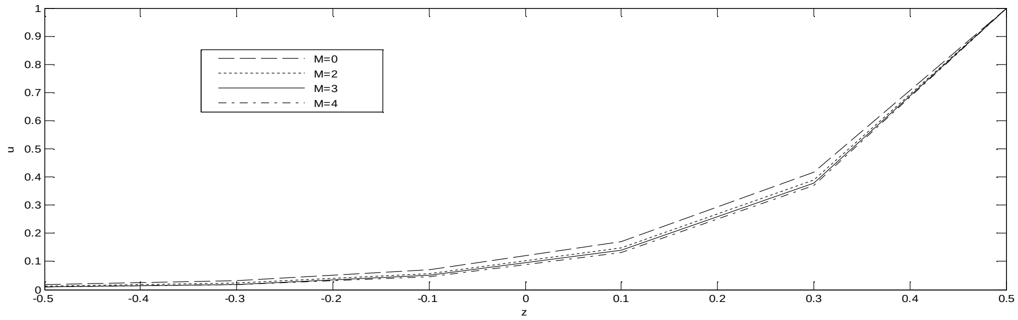

Figure 5: Absolute velocity profile, |u| against z for R=2, $\lambda = 3$, $\phi = 0.01$, $\omega = 2$, G = 3, Ω =2, A = 0.01, $\omega t = \pi$.

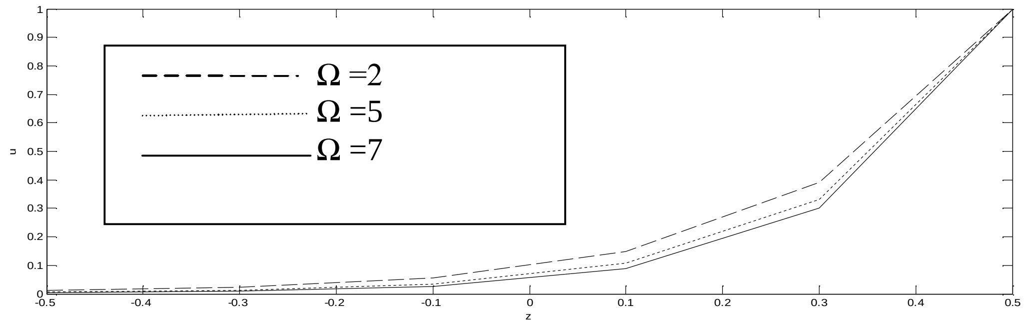

Figure 6: Absolute velocity profile, |u| against z for R=2, $\lambda = 3$, $\phi = 0.01$, $\omega = 2$, G = 3, M=2, A = 0.01, $\omega t = \pi$.

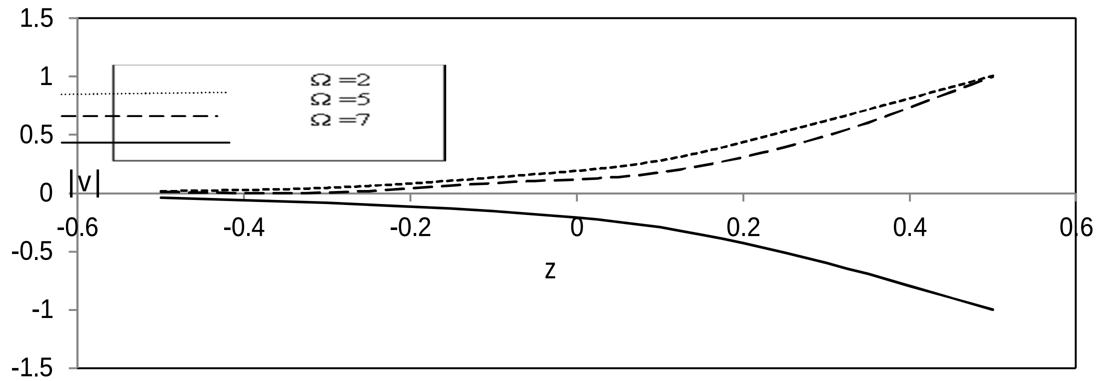

Figure 7: Transient velocity profile, |v| against z for R=2, $\lambda = 3$, $\phi = 0.01$, $\omega = 2$, G = 3, M=2, A = 0.01, $\omega t = \pi$.

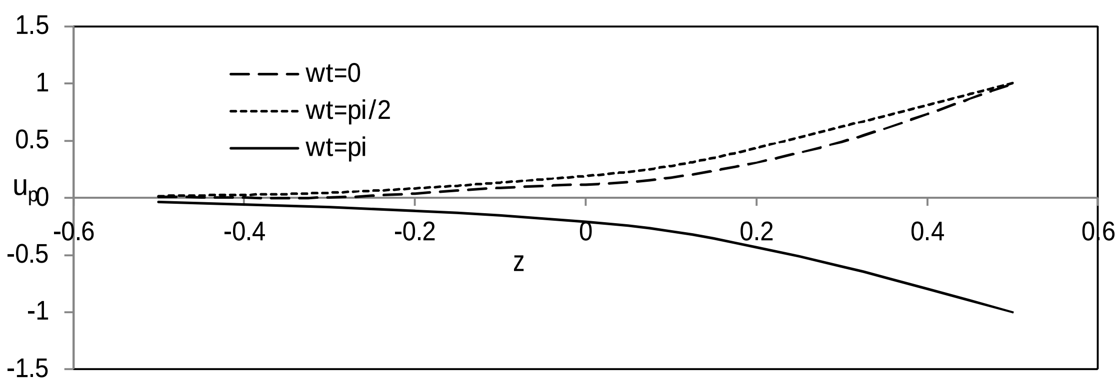

Figure 8: Dust particle velocity profile u_p against z for M = 2, R=2, $\lambda = 3$, $\phi = 0.01$, $\omega = 2$, G = 3, Ω =2, A = 0.01.

Volume 3 Issue III, March 2015
ISSN: 2321-9653

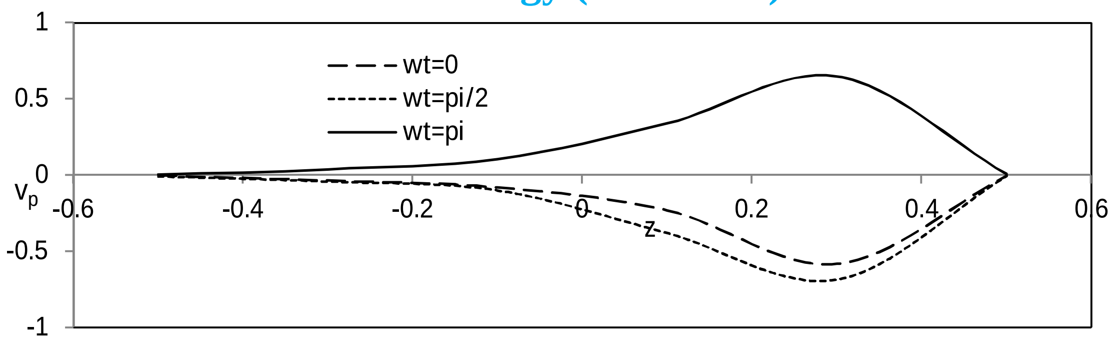

Figure 9: Transient dust particle velocity profile v_p against z for M = 2, R=2, λ = 3, ϕ = 0.01, ω = 2, G = 3, Ω =2, A = 0.01.

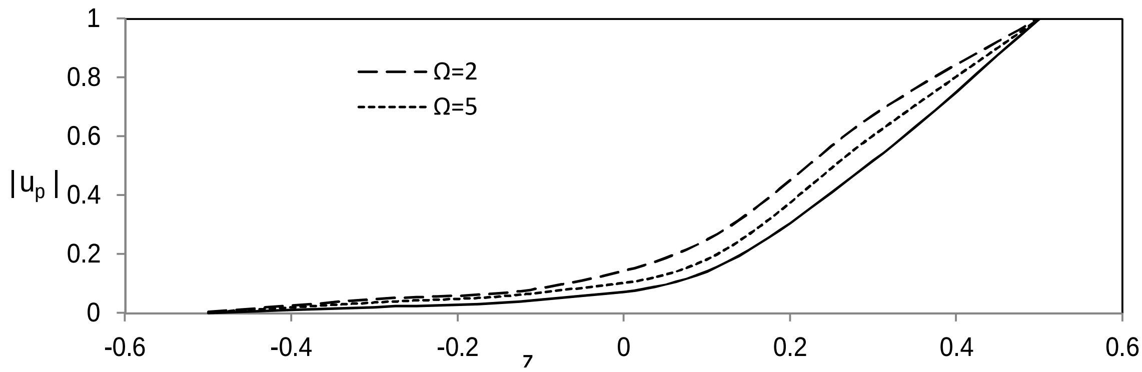

Figure 10: Absolute velocity profile of dust particle, $|u_p|$ against z for R=2, λ = 3, ϕ = 0.01, ω = 2, G = 3, M=2, A = 0.01, $\omega t = \pi$.

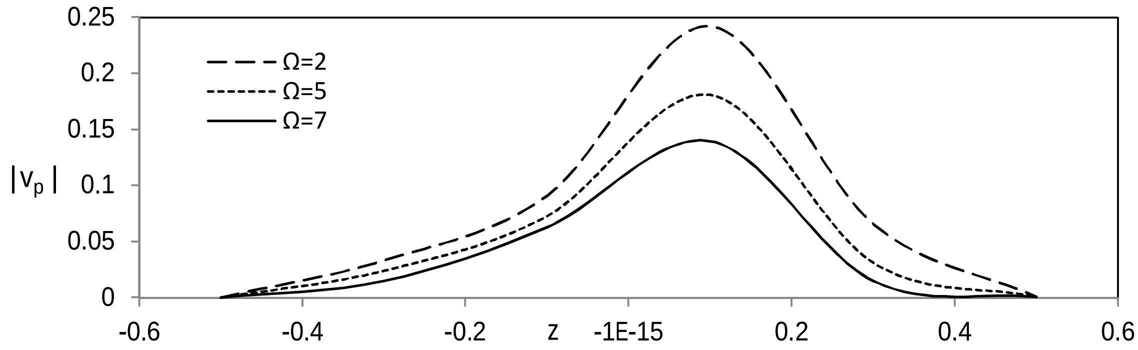

Figure 11: Transient velocity profile of dust particle, |' 0 for R=2, λ = 3, ϕ = 0.01, ω = 2, G = 3, M=2, A = 0.01, $\omega t = \pi$.

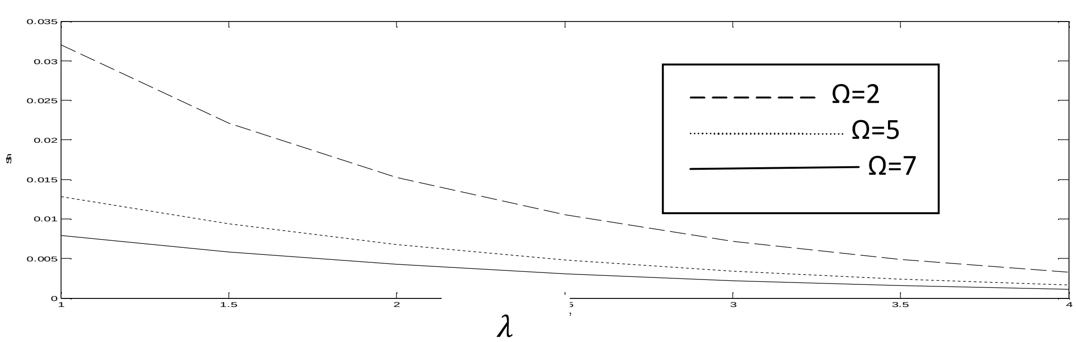

Figure 12: Shearing stress at the lower plate, Sh against λ for R=2, ϕ = 0.01, ω = 2, G = 3, M=2, A = 0.01, $\omega t = \pi$.

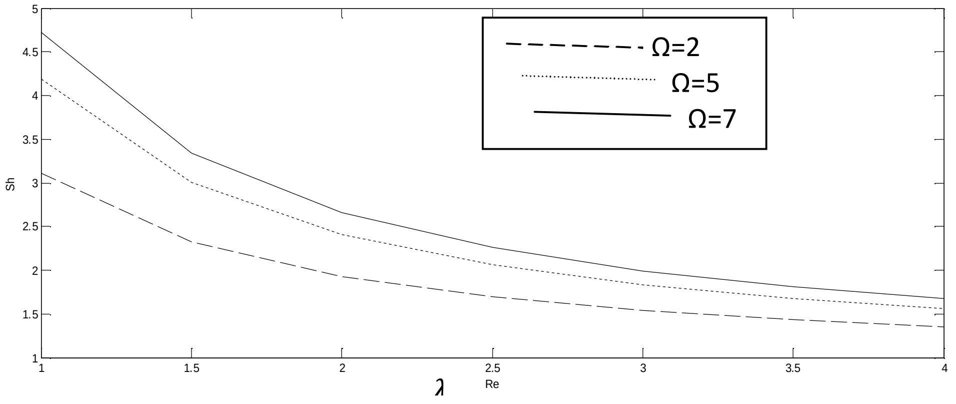

Figure 13: Shearing stress at the upper plate, Sh against λ for R=2, ϕ = 0.01, ω = 2, G = 3, M=2, A = 0.01, ωt = π.

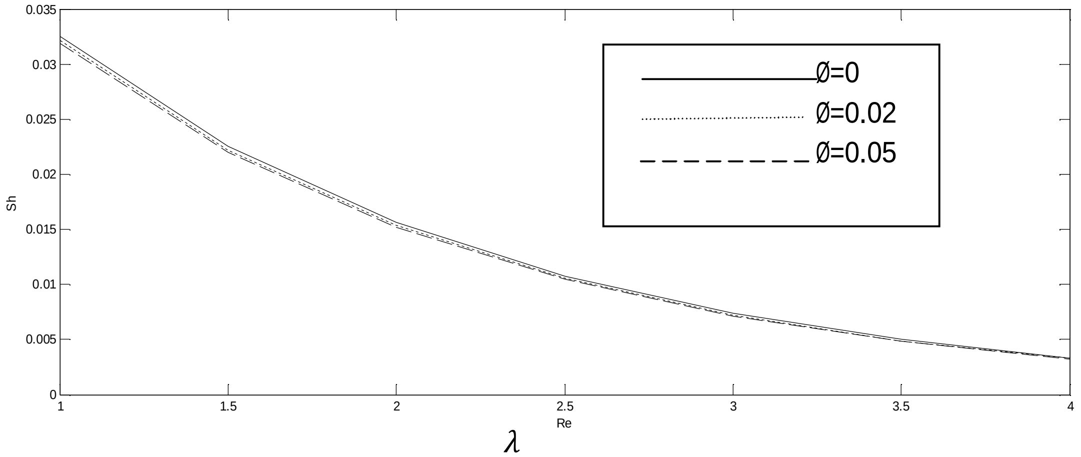

Figure 14: Shearing stress at the lower plate, Sh against λ for R=2, Ω=2, ω = 2, G = 3, M=2, A = 0.01, ωt = π.

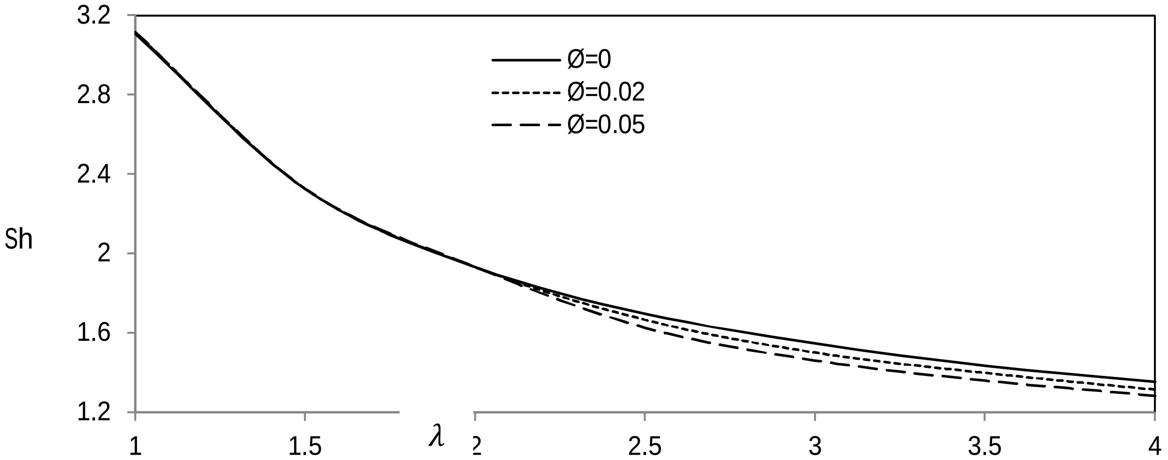

Figure 15: Shearing stress at the upper plate, Sh against λ for R=2, Ω=2, ω = 2, G = 3, M=2, A = 0.01, ωt = π.

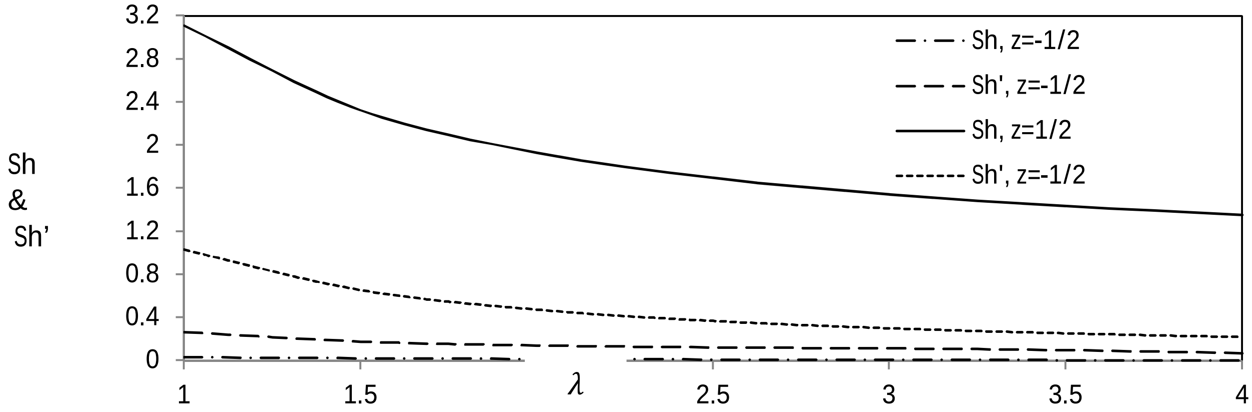

Figure 16: Component of shearing stress along and in the transverse direction, against λ for R=2, Ω=2, ω = 2, G = 3, M=2, A = 0.01, ϕ = 0.01.

REFERENCES

[1] Saffman P. G. (1962), On the stability of laminar flow of a dusty gas, J. Fluid Mech., 13, 120-128.
[2] Michael, D. H. and Miller, D. A. (1966), Plane parallel flow of a dusty gas, Mathematika, 13, 97-109.
[3] Rudinger, G. (1965), Some effects of finite particle volume on the dynamics of gas-particle mixtures, AIAA Journal, 3, 1217-1222.
[4] Nayfeh A. H., (1966), Oscillating two-phase flow through a rigid pipe, AIAAJ, 4(10), 1868-1870.
[5] Gupta, P. K. And Gupta, S. C. (1976), Flow of a dusty gas through a channel with arbitrary time varying pressure gradient, Journal of Appl. Math. and Phys., 27, 119.
[6] Singh K. K. (1976), Unsteady flow of a conducting dusty fluid through a rectangular channel with time dependent pressure gradient, Indian J. Pure and Appl. Math., 8, 1124.
[7] Singh, C. B. and Ram, P. C. (1977), Unsteady flow of an electrically conducting dusty viscous liquid through a channel, Indian J. Pure and Appl. Math., 8 (9), 1022-1028.
[8] Prasad, V. R. and Ramacharyulu, N. C. P. (1979), Unsteady flow of a dusty incompressible fluid between two parallel plates under an impulsive pressure gradient, Def. Sci, Journal, 38, 125-130.
[9] Gupta, R. K. And Gupta K., (1990), Unsteady flow of a dusty visco-elastic fluid through channel with volume fraction, Indian J. Pure and Appl. Math. 21(7), 677-690.
[10] Ajadi, S. O., (2005), A note on the unsteady flow of dusty viscous fluid between two parallel plates, J. Appl. Math. and Computing, 18(1-2), 393-403.
[11] Attia, H. A., Al-Kaisy, A. M. A. and Ewis, K. M., (2011), MHD Couette flow and heat transfer of a dusty fluid with exponential decaying pressure gradient, Tamkang J. Sci. and Engg., 14(2), 91-96.
[12] Nag S. K., Jana R. N. and Datta, N., (1979), Couette flow of a dusty gas. Acta Mechanica, Springer Verlag. Vol. 33(3), 179-187.
[13] Dalal, D., (1992), Generalized Couette flow of a dusty gas. Indian Journal of Technology, Vol. 30, 260-264.
[14] Singh, N. P. And Singh, A. K., (2002), MHD effects on convective flow of a dusty viscous fluid with volume fraction, Bulletin of the Institute of Academia Sinica. Vol. 30, 141-151.
[15] Attia, H. A, (2001), Influence of temperature dependent viscosity on the MHD channel flow of dusty fluid with heat transfer, Acta Mechanica, Vol. 151 (1-2), 89-101.
[16] Attia, H. A., (2006), Time varying hydromagnetic Couette flow with heat transfer of a dusty fluid in presence of uniform suction and injection considering hall effect. Turkish Journal of Engg. Vol. 30, 285-297.
[17] Ahmed, N., Goswami, J. K. and Barua, D. P., (2013), MHD Transient Flow with Hall Current Past an Accelerated Horizontal Porous Plate in a Rotating System,Open Journal of Fluid Dynamics Vol.3 (4), 278-285
[18] Singh, K. D., Chand, K. And Sharma, K. D., (2012), Hydromagnetic oscillatory flow of a dusty fluid in a rotating porous channel, International Journal of Mathematical Archive. Vol. 3 (6), 2331- 2339.
[19] Crammer, K. R. And Pai, S., (1973), Magneto-fluid dynamics for engineers and applied physicist. McGraw- Hill, New York.