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Effects of Transverse Magnetic Field on Oscillating Plate of Second Grade Fluid

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Abstract: The analysis in this research article is to establish some exact solutions for transverse magnetic field second grade fluid for oscillating plate. The transformations techniques are introduced on governing partial differential equations to have exact solutions under the impacts of magnetic field. The exact solutions are found out for the velocity field and shear stress along with interested limiting cases in which existence and nonexistence of magnetic field are particularized. Thegeneral solutions are written in the formof simple integral form and product of convolution theorem. All the general solutions have motivating impacts regarding presence and absence of transverse magnetic field.The solutions are considered in the absence of magnetic field, presence of magnetic field for Newtonian fluid. Finally several parameters related to fluid flow are considered for graphical descriptions and figures are plotted for the motion of fluid under the impacts of transverse magnetic field.

Keywords*:* Transverse Magnetic Field, Second grade fluid, Transformations techniques, Graphical descriptions.

1. INTRODUCTION

Electromagnetic phenomenon belongs to the study of interaction of electrically conducting fluids. The impacts transverse magnetic field has received much attention and interest of mathematicians, engineers and numerical analysts due to uncountable applications and usage in engineering and physical phenomenon. For instance, underground control of pollutants and chemical wastes, solidification process of metal alloys for certain optimizations. The metallurgical processes and control of boundary layer flow depend upon the significance of impacts transverse magnetic field. Many scientists and researchers have diverted their attention towards impacts of transverse magnetic fieldin industrial and engineering applications including plasma studies, MHD power generation, MHD pumps, MHD generators, geothermal energy extractions, nuclear reactors and various others.Even MHD effects for flow problems have been investigated with great interest. For instance, MHD effects for flow over stretching surface (Turkyilmazoglu 2011). A permeable and vertical stretching surface for MHD boundary layer flow of neon fluid is discussed in (Kandasamy *et al.,* 2011)Flow of second grade fluid is investigated for MHD mixed convection in (Hsiao 2011). The MHD flow of generalized Oldroyd-B fluid over an accelerating surface with slip effects is examined in (Zheng 2016). Under the study of heat transfer three-dimensional flow of viscoelastic fluid over a stretching surface is presented in (Ahmad 2011). Maxwell fluid for upper convected flow under the effects of transverse magnetic field is studied in (Mamaloukas 2010). The flow over a stretching surface is discussed for MHD elastic-viscous in (Aiboud 2010). The main aim of thispaper is to established exact solutions for MHD second grade fluid in which the motion of fluid has the impacts of absence and presence of impacts transverse magnetic field. These exact solutions are investigatedfor velocity field and shear stress by using the integral transforms methodsby researchers in literature(Fetecau 2009),(Hayat 2007),(Khan,and Hayat 2008), (Khan 2010), (Fetecau 2010) (Fetecau 2003), (Fetecau 2011), (Jamil 2010), Jamil 2011), (Jamil 2013), (Jamil 2011),(Jamil 2012).Graphs are plotted to show the impacts of emerging rheological parameters for electrically conducting fluid flows.

Modeling of Governing Equations

The constitutive equations for incompressible homogenous fluid of second grade or second-order fluid given by $\boldsymbol{T} = \boldsymbol{S} - \boldsymbol{p}\mathbf{I}$, $\boldsymbol{S} = \alpha_2 \boldsymbol{A}_1^2 + \mu \boldsymbol{A_1} + \alpha_1 \boldsymbol{A_2}$, (1)

where

$$\boldsymbol{A_1} = (\nabla \boldsymbol{V})^{\boldsymbol{T}} + (\nabla \boldsymbol{V}), \qquad \boldsymbol{A_2} = \frac{d\boldsymbol{A_1}}{dt} + \boldsymbol{A_1}(\nabla \boldsymbol{V})^{\boldsymbol{T}} + \boldsymbol{A_1}(\nabla \boldsymbol{V}) \tag{2}$$

$$\nabla \boldsymbol{V} = tr\boldsymbol{A_1} = \mathbf{0}, \ \nabla \boldsymbol{T} = \rho \frac{d\boldsymbol{V}}{dt} - \rho \boldsymbol{b}, \tag{3}$$

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Where, ρ is constant density of fluid and $\boldsymbol{b}$is body force. For the under consideration

$$\boldsymbol{V} = u(t,y)\boldsymbol{i} = \boldsymbol{V}(t,y), \qquad \boldsymbol{S}(t,y) = \boldsymbol{S}, \tag{4}$$

At the moment $t = 0$, the fluid is at rest thenthe constraint of incompressibility is automatically satisfied. If the fluid is at rest up to the moment $t = 0$, then

$$\boldsymbol{S} = (y,0) = 0, \quad \boldsymbol{V} = (y,0) = 0\,, \tag{5}$$

The expression for the velocity and pressure drop for magnetic field in a second grade fluid is

$$\frac{\partial p}{\partial y} = \frac{\partial p}{\partial z} = \sigma B_0^2 u(y,t), \qquad \frac{\partial \tau(y,t)}{\partial x} - \frac{\partial p}{\partial x} = p\left(\frac{\partial u}{\partial t}\right) + \sigma B_0^2 u(y,t) \tag{6}$$

Solving forτ equations (5) and (6), we get governing differential equations for second grade fluid in magnetic fieldfor which$M = \frac{\sigma B_0}{\rho}$.

$$\frac{\partial u(y,t)}{\partial t} - \left(\nu + \alpha\frac{\partial}{\partial t}\right)\frac{\partial^2 u(y,t)}{\partial t^2} + M\left(u(y,t) + \lambda\frac{\partial u(y,t)}{\partial t}\right) = 0, \tag{7}$$

$$\tau(y,t) - \left(\mu\frac{\partial u(y,t)}{\partial y} + \alpha_1\frac{\partial^2 u(y,t)}{\partial y \partial t}\right) = 0. \tag{8}$$

Under consideration of electrically conducting fluid that is infused by the transverse magnetic field M which acts in the positive y-direction for themotion of second grade fluid which is at rest over an infinitely extended plate. The plate is moving with constant velocity within the boundaries$u(0,t) = UH(t)\,cos\omega t \;\; or \;\; UH(t)\,sin\omega t$,Due to the fact of time$t = 0$ the plate is at rest, $H(t)$Heaviside function is used. The fluid above the plane is moved gradually under the effects of shear stress obtained by the fluid due to the motion of the plane.For the relevant problem the initial and boundary conditions are mentioned as under

$$\frac{\partial u(y,0)}{\partial t} = 0, \quad u(y,0) = 0, \qquad \tau(y,0) = 0, \qquad y > 0, \tag{9}$$

$$u(0,t) = UH(t)cos\omega t \quad or \quad UH(t)sin\omega t \qquad t \geq 0. \tag{10}$$

Where the conditions described below are satisfied,

$$u(y,t), \qquad \frac{\partial u(y,t)}{\partial t} \to 0 \qquad as \qquad y \to \infty \qquad and \quad t > 0, \tag{11}$$

2. VELOCITY FIELD FOR CASE-I:$\boldsymbol{u(0,t) = UH(t)sin\omega t}$

Applying Fourier Sine transform on governing equation (7) having in mind theboundaryand initial conditions (11) and (10),we have,

$$\frac{\partial u_s(\xi,t)}{\partial t} + \xi^2\left(\nu + \alpha\frac{\partial}{\partial t}\right)u_s(\xi,t) - U\xi\sqrt{\frac{2}{\pi}}\{\alpha\delta(t)sin\omega t + \alpha\omega H(t)cos\omega t + \nu H(t)sin\omega t\}$$
$$+M\left(u_s + \lambda\frac{\partial u_s(\xi,t)}{\partial t}\right) = 0, \tag{12}$$

Where$\delta'(t)$and $\delta(t)$is derivative of delta function and delta function respectively. And the initial conditions have to full fill and satisfy,

$$u_s(\xi,0) = 0, \qquad \frac{\partial u_s(\xi,0)}{\partial t} = 0, \qquad \xi > 0\,, \tag{13}$$

Using the Laplace transforms to (12) and keeping in concentration for the initial conditions (10), for more efficient representation of equation(13),

$$\overline{u_s}(\xi,s) = \frac{U\,\omega}{\xi}\sqrt{2/\pi}\left[\frac{1}{(s^2+\omega^2)} - \frac{s(1+M\lambda) - M}{(s^2+\omega^2)\{\{(1+M\lambda-\alpha\xi^2)s + \nu\xi^2 + M\}\}}\right], \tag{14}$$

Employing inverse Fourier sine transform on equation (14), we get

$$\bar{u}(\xi,s) = \frac{U\omega}{(s^2+\omega^2)} - \frac{2U\omega(1+M\lambda)}{\pi}\int_0^\infty \frac{sin(y\xi)}{\xi(1+M\lambda-\alpha\xi^2)}\frac{s}{(s^2+\omega^2)\left(s + \frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)}d\xi$$
$$+\frac{2UM}{\pi}\int_0^\infty \frac{sin(y\xi)}{\xi(1+M\lambda-\alpha\xi^2)}\frac{\omega}{(s^2+\omega^2)\left(s + \frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)}\,d\xi, \tag{15}$$

In order to achieve the final form of velocity field, we apply inverse Laplace transform to (15), having the usage of convolution theorem, we have

$$u_S(y,t) = UH(t)\,sin\omega t - \frac{2U\omega(1+M\lambda)}{\pi}\int_0^\infty\int_0^t \frac{sin(y\xi)}{\xi(1+M\lambda-\alpha\xi^2)}cos\omega(t-w) \times exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2UM}{\pi}\int_0^\infty\int_0^t \frac{sin(y\xi)}{\xi(1+M\lambda-\alpha\xi^2)}\,sin\omega(t-w) \times exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi, \quad (16)$$

3. CALCULATION OF THE SHEAR STRESS

Performing partial differentiation of equation (16) with respect to "y"

$$\frac{\partial u_s}{\partial y} = -\frac{2U\omega(1+M\lambda)}{\pi}\int_0^\infty \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}cos\omega t * exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)t\,d\xi + \frac{2UM}{\pi}\int_0^\infty \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}sin\omega t * exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)t\,d\xi, \quad (17)$$

Yet again performing partial differentiation of equation (16) with respect to "t"

$$\frac{\partial}{\partial t}\left(\frac{\partial u_s}{\partial y}\right) = \frac{2U\omega(1+M\lambda)}{\pi}\int_0^\infty \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}sin\omega t * exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)t\,d\xi + \frac{2UM}{\pi}\int_0^\infty \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}cos\omega t * exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)t\,d\xi, \quad (18)$$

Substituting equations (17) and (18) in governing equation (11), we get

$$\tau_S(y,t) = -\frac{2U\omega\mu(1+M\lambda)}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}cos\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2U\mu M}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}sin\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2U\omega\alpha_1(1+M\lambda)}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}sin\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2U\alpha_1 M}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}cos\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi, \quad (19)$$

expression for shear stress.

4. VELOCITY FIELD FOR CASE-II: $u(0,t) = UH(t)cos\omega t$

Following analogous process, we have found out velocity field and correspondingshear stress for the second case cosine oscillation.

$$u_C(y,t) = UH(t)\,cos\omega t - \frac{2U\omega(1+M\lambda)}{\pi}\int_0^\infty\int_0^t \frac{sin(y\xi)}{\xi(1+M\lambda-\alpha\xi^2)}sin\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi - \frac{2UM}{\pi}\int_0^\infty\int_0^t \frac{sin(y\xi)}{\xi(1+M\lambda-\alpha\xi^2)}cos\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi\,, \quad (20)$$

$$\tau_C = -\frac{2U\mu(1+M\lambda)}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}cos\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2U\mu M}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}sin\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2U\omega\alpha_1(1+M\lambda)}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}sin\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi + \frac{2U\alpha_1 M}{\pi}\int_0^\infty\int_0^t \frac{cos(y\xi)}{(1+M\lambda-\alpha\xi^2)}cos\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda-\alpha\xi^2}\right)w\,dw\,d\xi, \quad (21)$$

5. SOLUTIONS UNDER LIMITING CASES

5.1. Second Grade Fluidwithoutmagnetic field $M \to 0$

Letting $M \to 0$ in equations (16), (19), (20) and (21), we get

$$u_S(y,t) = UH(t)\,sin\omega t - \frac{2U\omega}{\pi}\int_0^{\infty}\int_0^{t}\frac{sin(y\xi)}{\xi(1-\alpha\xi^2)}cos\omega(t-w)exp\left(-\frac{\nu\xi^2}{1-\alpha\xi^2}\right)u\,dw\,d\xi, \quad (22)$$

$$\tau_S = -\frac{2U\omega\mu}{\pi}\int_0^{\infty}\int_0^{t}\frac{cos(y\xi)}{(1-\alpha\xi^2)}cos\omega(t-w)\,exp\left(\frac{-\nu\xi^2}{1-\alpha\xi^2}\right)wdw\,d\xi + \frac{2U\omega\alpha_1}{\pi}\int_0^{\infty}\int_0^{t}\frac{cos(y\xi)}{(1-\alpha\xi^2)} \times sin\omega(t-w)exp\left(-\frac{\nu\xi^2}{1-\alpha\xi^2}\right)w\,dw\,d\xi, \quad (23)$$

5.2. Newtonian Fluidwith magnetic field$\alpha_1 \to 0$and$\alpha \to 0$

Substituting $\alpha = \alpha_1 \to 0$ in equations (16), (19), (20) and (21), we get

$$u_S(y,t) = UH(t)sin\omega t - \frac{2U\omega(1+M\lambda)}{\pi}\int_0^{\infty}\int_0^{t}\frac{sin(y\xi)}{\xi(1+M\lambda)}cos\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda}\right)w\,dw\,d\xi + \frac{2UM}{\pi}\int_0^{\infty}\int_0^{t}\frac{sin(y\xi)}{\xi(1+M\lambda)}sin\omega(t-w)exp\left(-\frac{\nu\xi^2+M}{1+M\lambda}\right)w\,dw, \quad (24)$$

$$\tau_S = -\frac{2U\omega\mu(1+M\lambda)}{\pi}\int_0^{\infty}\int_0^{t}\frac{cos(y\xi)}{(1+M\lambda)}cos\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda}\right)w\,dw\,d\xi + \frac{2U\mu M}{\pi}\int_0^{\infty}\int_0^{t}\frac{cos(y\xi)}{(1+M\lambda)} \times sin\omega(t-w)\,exp\left(-\frac{\nu\xi^2+M}{1+M\lambda}\right)w\,dw, \quad (25)$$

5.3. Newtonian Fluidwithout magnetic field$M \to 0$, $\alpha \to 0$ and $\alpha_1 \to 0$

Taking the$M \to 0$,$\alpha \to 0$and $\alpha_1 \to 0$into equations (16), (19), (22), (23), (24) and (25)the solutions for velocity field and the shear stressunder the form of Newtonian fluid are familiar.

6. CONCLUDING REMARKS

This portion is analyzed for the graphical profiles of velocity field and shear stress for the motion of second grade fluid. Due to physical parameters such as viscosity, time, amplitude, kinematic viscosity and magnetic field have been plotted for showing the variations and effects. Here we have used above parameters under numerical increasing values to know the physical aspects of motion of fluid.The comparisons are focused and emphasized over the existence and non-existence condition of magnetic field for the solution of velocity field and shear stress. The exact solutions are obtained under the mathematical transformation techniques. The general solutions satisfy the required conditions i-e initial and boundary conditions under the presence and absence of magnetic field. However the major consequences and results are listed below:

(i). Equation (21) and (24) and equation (25) and (26) are the general solutions of velocity field and shear stress for sine and cosine oscillations under an influence of magnetic field respectively.

- (ii). The figures 1-3 are depicted in which the behavior of fluid motion decreases over the boundary when the time(t) increases, on the contrary, as material parameter (α) and viscosity (ν) increase the profiles of velocity field and shear stress decreases in the whole domain.
- (iii). The variation in amplitude (ω) and (y) leads the motion of fluid in oscillating phenomenon from figures 4 and 5.
- (iv). Figures 6 and 7 have been depicted for the impacts of magnetic field over the velocity field and shear stress in which profile of velocity field slow down the behavior of fluid and profile of shear stress has reciprocal impact.
- (v). It is pointed out that in figures 6 and 7, four models have been shown as MHD second grade, second grade, MHD Newtonian and Newtonian fluids. Sometimes Newtonian and others fluids move faster and slower near the plane.

7. ACKNOWLEDGEMENT

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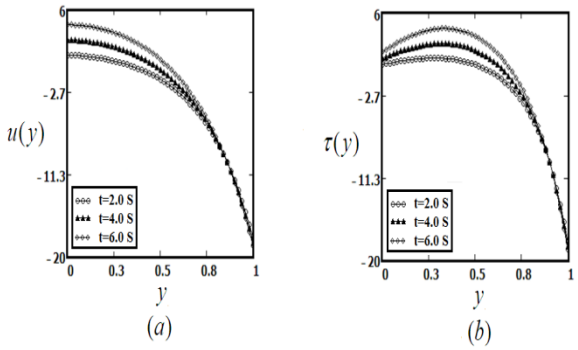


Fig. 1:Velocity profile and shear stress form equations (16) and (19) with respect to t.

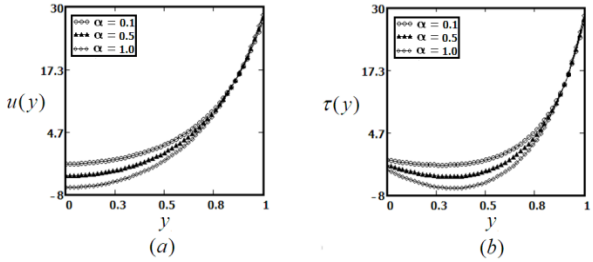


Fig. 2:Velocity profile and shear stress form equations(16) and (19) with respect to α.

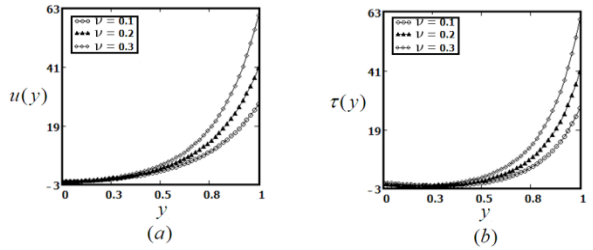
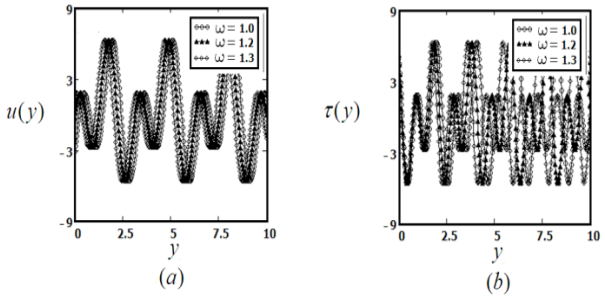


Fig. 3:Velocity profile and shear stress form equations(16) and (19) with respect toν.

Fig. 4:Velocity profile and shear s



tress form equations(16) and (19) with respect toω.

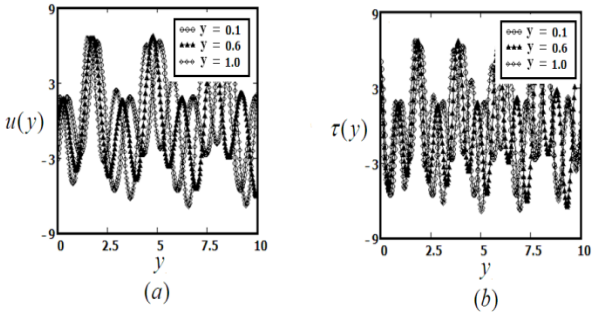


Fig. 5:Velocity profile and shear stress form equations(16) and (19) with respect to y.

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