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***Research paper***

# Unsteady Rotatory Oscillations of a Vertical Cylinder In Jeffery Fluid With Ion Slip Currents and Porous Medium

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## Abstract

The generated flow of a Jeffery fluid due to an infinite circular cylinder's rotatory oscillations is examined. Consideration is given to the effects of Magnetic field, Hall and Ion currents with porous medium. The governing partial differential equations ensuing from the linear momentum equations are determined analytically by the theory of Bessel's functions. The velocity field, tangential drag force, torque and axial force acting on the cylinder are enumerated. The impacts different fluid parameters on transverse and axial velocities are investigated and presented in graph form. It is found that the longitudinal and polar velocity decreases with increasing Reynold number at a distance from the wall. The θ-component and z-component a velocity increase with a raise in Deborah number, also it increases with rising in Ion-slip parameter.

## Nomenclature

*P:*Fluid Density
$\mu$:Viscosity
*Σ:*Electrical Conductivity
$k_0$:Permeability of the Porous Medium
*T:*Cauchy Stress Tensor
*I:*Identity Tensor
*S:*Extra Stress Tensor
*E:*Rate of Strain
$\lambda_1, \lambda_2$:Jeffery Parameters
$Q_0$:Magnitude of Oscillations
$B_0$:Angle between the Directions of Transverse Oscillation with Base Vector $e_\theta$
*J:*Current Density
*B:*Magnetic Field
*M:*Magnetic Parameter
*Re:*Reynolds Number
*Da:*Darcy Number
*De:*Debroah Number
$\beta_i$:Ion Slip Parameter
$\beta_h$:Hall Factor,
$\alpha_e = 1 + \beta_h \beta_i$

***Keywords***: *Circular Cylinder; Ion-Slip;Jeffery Fluid; Magneto Hydrodynamic; Porous Medium.*

## 1. Introduction

The primary author to handle the matter of rotatory oscillations of a rod was Stoke[1]. The problem of flow due to axial and rotational oscillations were first initiated by Casarella and Laura[2] by finding an analytical solution to a viscous flow developed due to a cylinder performing rotary oscillations. The practicable problems connected to stimulation of long rods and cables require the expression force performing on the rods. This will have a prominent cause on tension in the rods and subsequently on the reaction of fluids. Few applications of this type flows include:

i) Purification of a hole
ii) Refrigerate and lubricate the bit and drill string
iii) Suspending drill seedling once drilling has blocked (i.e., to alter the drill bit)
iv) Transport of cuttings during drilling to the surface.

Since these flows are very important in oil industry and in design and development of drilling machinery, many papers have ap-

peared within the literature addressing the issues of transverse and longitudinal oscillations of the cylinder [3-15]. Several researchers have projected the varied models of non-Newtonian fluids so as to investigate completely different rheologic properties, one amongst the models is that the Jeffrey fluid model that uses time derivatives rather than connected derivatives. Many researchers have examined the Jeffrey fluid model underneath completely different geometries. The latest literature on Jeffrey fluid can be seen in [16-18].
The Hall and ion currents in Ohm's law are unheeded in most of the MHD flow issues thought-about to this point. However, within the occurrence of a powerful magnetic flux, the influence of Hall current and particle slip is very significant. Ellahi et al [19] examined the consequences of the hall with particle slip for the flow through Jeffrey fluid in an exceedingly non-uniform rectangular channal. Nagaraju et al [20] studied hall and ion-slip, and cross diffusion effects of micropolar flow through the two vertical cylinders. Sara et al [21] examined the peristaltic motion of a hyperbolic tangent fluid with the effects of Hall and ion slip through a non-uniform channel taking the chemical reaction into consideration. Imran Haider Qureshi et al. [22] investigated the heat transfer in Erying-Powell liquid with thermal radiation and Hall and Ion currents. They observed that the width of thermal boundary layer is decelerates as Ion slip parameter increases.
Flow through porous medium may be a subject of general interest and has developed a separate area of study. Numerous usual substances like aquifers, fossil fuel reservoirs, biological tissues (i.e., bones and cork), and manmade equipment like blocks of cement and ceramics will be thought-about as porous media. Various vital properties will solely be rationalized by considering them to be porous media. The thought of porous media is employed in several applications of industries such as Soil mechanics, engineering, geosciences, biology and physical science, material science. Nallapusantosh and Radhakrishnamacharya[23] examined two-fluid representation for Jeffrey fluid through tube with a magnetic field and porous medium. They found that the mean hematocrit decrease with Darcy's parameter. Mohd Zin et al[24] found the exact solution to the unsteady flow through Jeffrey's rotating model with the magnetic field, porous medium and rampedness of a temperature. They identified that the velocity decreases with an raise in Jeffery parameter. A Comprehensive list of latest references with porous media in Jeffery fluid can be found in [25-26].
Motivated and inspiration of the above studies, we have studied the unsteady incompressible electrically conducting Jeffery fluid flow generated by transversely and longitudinally rotating vertical circular cylinder is investigated by considering porous media and Hall and Ion current impacts. The explanations for polar and axial velocity elements, shear stress, drag force, torque, and axial physical phenomenon area unit obtained and their variation with regard to numerous parameters is studied.

## 2. Mathematical formulation

The conservation mass associated momentum equation that govern the unsteady MHD flow of an incompressible Jeffrey fluid during a vertical cylinder with porous media and Hall currents may be written as [23]

$$\nabla . Q = 0 \quad (1)$$

$$\rho \frac{dQ}{d\tau} = -\nabla P + divT + J \times B - \frac{\mu}{k_0} Q \quad (2)$$

Where

$$T = -PI + S \quad (3)$$

$$S = \frac{\mu}{1+\lambda_1}\left(1 + \lambda_2 \frac{d}{d\tau}\right) E \quad (4)$$

Since we shall investigate the flow generated by circular cylinder is of infinite length, we shall use cylindrical polar coordinates $(R, \theta, Z)$ with axis of cylinder along Z-axis and assume the velocity Q is given by

$$Q = \left[0, V(R,\tau), W(R,\tau)\right] \quad (5)$$

The cylinder oscillates with velocity as given by the expression

$$Q_r = Q_{R=a} = q_0\left(Cos\,\beta_0 e^{i\omega_1\tau} e_\theta + Sin\,\beta_0 e^{i\omega_2\tau} e_z\right) \quad (6)$$

Where the cylinder is taking longitudinal oscillations and transverse oscillations with magnitude $q_0 Sin\beta_0$, $q_0 Cos\beta_0$ in conjunction with the individual directions with $\omega_1$as the frequency of the longitudinal oscillations, $\omega_2$ because the frequency of the transverse oscillations. In the lightweight off on top of assumptions and because of tiny magnetic Reynolds's variety the magneto hydrodynamic force in equivalent. (2) is given by

$$J \times B = -\frac{\sigma B_0^2 (1+\beta_h \beta_i) Q}{(1+\beta_h \beta_i)^2 + \beta_h^2} = -\frac{\sigma B_0^2 \alpha_e Q}{\alpha_e^2 + \beta_h^2} \quad (7)$$

The subsequent non-dimensional variables are accustomed build the quantities dimensionless

$$q = \frac{Q}{q_0},\ p = \frac{P}{\rho q_0^2},\ t = \frac{q_0}{a}\tau,\ r = \frac{R}{a} \text{ and } z = \frac{Z}{a} \quad (8)$$

In sight of (7) and (8), the equations within (1)-(2), for the flow take the subsequent non-dimensional type

$$\nabla \cdot q = 0 \quad (9)$$

$$Re\left(\frac{dq}{dt}\right) = -Re\ \nabla p + \frac{1}{1+\lambda_1}\left[1 + De\frac{d}{dt}\right]\left(\nabla q + (\nabla q)^T\right) - \left(\frac{M^2\alpha_e}{\alpha_e^2 + \beta_h^2} + \frac{1}{Da}\right) q \quad (10)$$

Where

$$\frac{d}{dt} = \frac{\partial}{\partial t} + q \bullet \nabla$$

If we put $\lambda_1 \to 0$, we get the equations for classical viscous fluids.

Where

$$Re = \frac{aq_0}{\upsilon},\ De = \frac{q_0\lambda_2}{a},\ Da = \frac{k_0}{a^2} \text{ and } M^2 = \frac{\sigma a^2 B_0^2}{\mu} \quad (11)$$

Let's select the vector q and pressure in the shape

$$q = v(r) e^{i\sigma_1 t}\, e_\theta + w(r)\, e^{i\sigma_2 t}\, e_z \quad (12)$$

$$p = p_1(r) e^{2i\sigma_1 t} \quad (13)$$

Where

$$\sigma_1 = \frac{\omega_1 a}{q_0} \text{ And } \sigma_2 = \frac{\omega_2 a}{q_0}$$

Substituting (12), (13) in (10) and comparing the coefficients of $e_r$, $e_\theta$, $e_z$ we get

$$\frac{dp_1}{dr} = \frac{v^2}{r} \quad (14)$$

$$iRe\sigma_1 v = \frac{(1+i\sigma_1 De)}{1+\lambda_1}\left(\frac{d^2u}{dr^2}+\frac{1}{r}\frac{du}{dr}-\frac{u}{r^2}\right)-\frac{M^2\alpha_e}{\alpha_e{}^2+\beta_h^2}v-\frac{1}{Da}v \quad (15)$$

$$iRe\sigma_2 w = \frac{(1+i\sigma_2 De)}{1+\lambda_1}\left(\frac{d^2w}{dr^2}+\frac{1}{r}\frac{dw}{dr}\right)-\frac{M^2\alpha_e}{\alpha_e{}^2+\beta_h^2}w-\frac{1}{Da}w \quad (16)$$

The problem's boundary conditions are:

$v = Cos\beta_0$ and $w = Sin\beta_0$ at r = 1 (17)

$v, w \to 0$ as $r \to \infty$ (18)

Condition (17) is the classical no-slip boundary condition for the velocity, (18) is the regularity condition far away from the body.

### 3.1. Solution of the problem

Equation (15) can be rewritten as

$$\frac{d^2v}{dr^2}+\frac{1}{r}\frac{dv}{dr}-\left(\frac{1}{r^2}+S_1^2\right)v = 0 \quad (19)$$

Where

$$S_1 = \left\{\frac{(1+\lambda_1)\left[\frac{M^2(1+\beta_h\beta_i)}{(1+\beta_h\beta_i)^2+\beta_h^2}+\frac{1}{Da}+iRe\sigma_1\right]}{1+iDe\sigma_1}\right\}^{\frac{1}{2}}$$

Since $v$ =0 as $r \to \infty$ , the solution of (19) can be taken as

$$v = a_1 K_1(S_1 r) \quad (20)$$

Using (17), $a_1 = \cos\beta_0/K_1(S_1)$ (21)
Similarly from equation (16),

$w = a_2 K_0(S_2 r)$ Where $a_2 = \sin\beta_0/K_0(S_2)$ (22)

Where

$$S_2 = \left\{\frac{(1+\lambda_1)\left[\frac{M^2(1+\beta_h\beta_i)}{(1+\beta_h\beta_i)^2+\beta_h^2}+\frac{1}{Da}+iRe\sigma_2\right]}{1+iDe\sigma_2}\right\}^{\frac{1}{2}}$$

Now the constants $a_1$ and $a_2$ can be found out numerically for different values of Jeffery fluid parameters by calculating $S_1$ and $S_2$ and by specifying $\beta_0$. Then velocity components v and w are found analytically.

### 3.2. Drag calculation

The drag $D$ acting on a cylinder of length $L$ is given by

$$D = aL\int_0^{2\pi}(T_{\theta r}Cos\beta_0 + T_{zr}Sin\beta_0)d\theta \quad (23)$$

Now the stress components $T_{zr}$ and $T_{\theta r}$ on the cylinder (at r = 1) can be calculated as

$$T_{zr} = \frac{\mu q_0}{a(1+\lambda_1)}(1+i\sigma_2 De)a_2[(K_0(S_2)-S_2K_1(S_2)]e^{i\sigma_2 t} \quad (24)$$

$$T_{\theta r} = \frac{\mu q_0}{a(1+\lambda_1)}(1+i\sigma_1 De)a_1[2K_1(S_1)-S_1K_2(S_1)]e^{i\sigma_1 t} \quad (25)$$

Now finally the non–dimensional drag $D'$is given by

$D' = T_{\theta r}Cos\beta_0 + T_{zr}Sin\beta_0$ on $r = 1$ (26)

Where $D' = \frac{D}{2\pi L\mu q_0}$

The torque and axial force per unit length are given respectively by

$$M = 2\pi a^2 T_{\theta r} = \frac{2\pi a\mu q_0}{(1+\lambda_1)}(1+i\sigma_1 De)a_1[2K_1(S_1)-S_1K_2(S_1)]e^{i\sigma_1 t} \quad (27)$$

$$F = 2\pi a T_{zr} = \frac{2\pi\mu q_0}{(1+\lambda_1)}(1+i\sigma_2 De)a_2[(K_0(S_2)-S_2K_1(S_2)]e^{i\sigma_2 t} \quad 28)$$

The dimensionless torque and axial force are given by

$$\bar{M} = \frac{1}{(1+\lambda_1)}(1+i\sigma_1 De)a_1[2K_1(S_1)-S_1K_2(S_1)]e^{i\sigma_1 t} \quad (29)$$

$$\bar{F} = \frac{1}{(1+\lambda_1)}(1+i\sigma_2 De)a_2[(K_0(S_2)-S_2K_1(S_2)]e^{i\sigma_2 t} \quad (30)$$

Where

$\bar{M} = \frac{M}{2a\pi\mu q_0}$ and $\bar{F} = \frac{F}{2\pi\mu q_0}$, the over bar denotes dimensionless quantities

## 3. Results and discussions

The mathematical results are calculated in the form of graphs at $M$ =1, $\beta_i$ =0.4, $\beta_h$ = 5, $Re$=0.25, $De$ = 4, $\lambda_1 = 0.4, \sigma_1 = 1.25$, $\sigma_1 = 1.5, \beta_0 = 0.7$, $Da$ = 5 and $t = \pi$. It can be observed from figure 1 that as Reynolds number increases, the velocity $v$ and $w$ decrease at a distance six times the radius of the cylinder. Figure 2 illustrates that when the Jeffrey parameter $\lambda_1$ increases, the velocity $v$ decreases at a cylinder far away from cylinder and the same trend is observed for $w$. Figure 3 shows the effect of Debroah number $De$ on velocity components. It is examined that as $De$ increases the profiles of both velocity components. It is because of the fact that $\lambda_1$ being the viscoelastic parameter exhibit both viscous and elastic characteristics. Thus, the fluid will always retard whenever viscosity or elasticity decrease. Figure 4 depicts the variation of $M$ on velocity components. It can be identified that $M$ decreases the profiles of velocity components. This is because of an increasing in the magnetic field parameter develops the opposite force of the flow is called Lorentz force. This force has a tendency to reduce the velocity. It reveals from Figure 5 that for large values of Ion-slip parameter $\beta$i the velocity increases when $\beta_i$ increases. The impacts of Darcy's number $Da$ on $v$ and $w$ are shown in figure 6. The Darcy number ($Da$) represents the relative effect of the permeability of the medium versus its cross-sectional area. The both the components of velocity enchances with the rise in $Da$. We get the case of viscous fluids from the Jeffery fluid by applying the limit $\lambda_1 \to 0$. These results are shown in Figure 7 for velocities $v$ and $w$ and our results are in good agreement with the observations of Rao et al. [3] in the case of Newtonian fluids. The dimensionless drag is computed for different values of time and this result is shown in the Fig. 8. It can be seen from this figure that as $De$ increases the amplitude of drag decreases. Table 1 shows a comparison of results. The results are in good agreement with the results of Akyildiz [4].

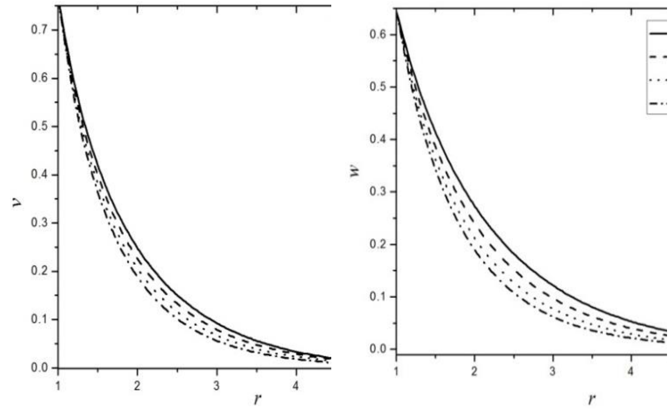


**Fig. 1:**Response of *Re* on Velocity Components.

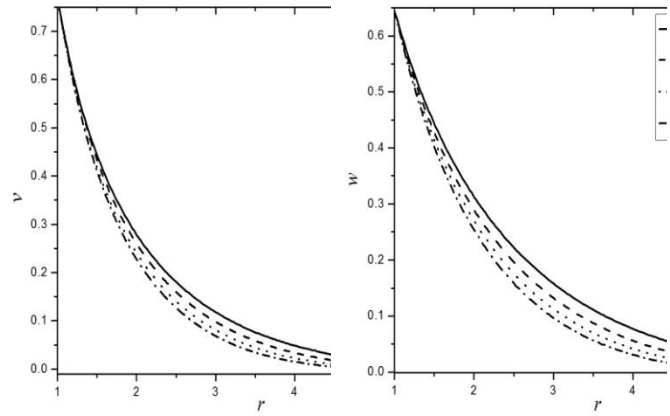


**Fig. 2:**Response of $\lambda_1$on Velocity Components.

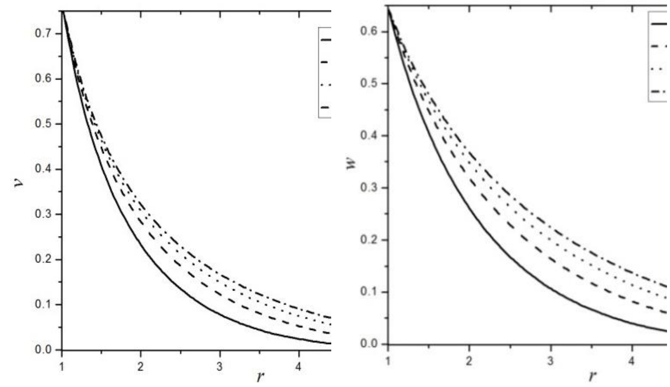


**Fig. 3:**Response of *De* on Velocity Components.

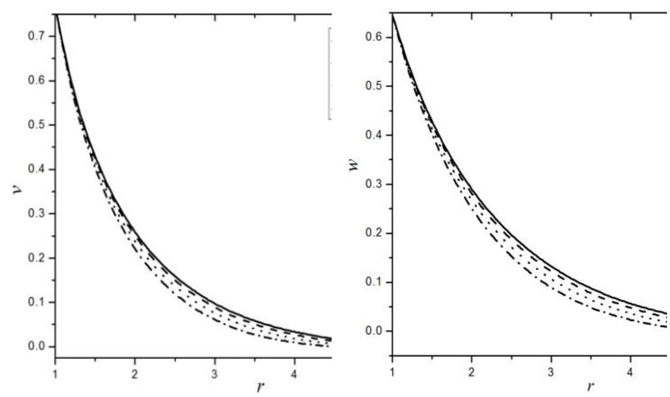


**Fig. 4:**Response of *M* on Velocity Components.

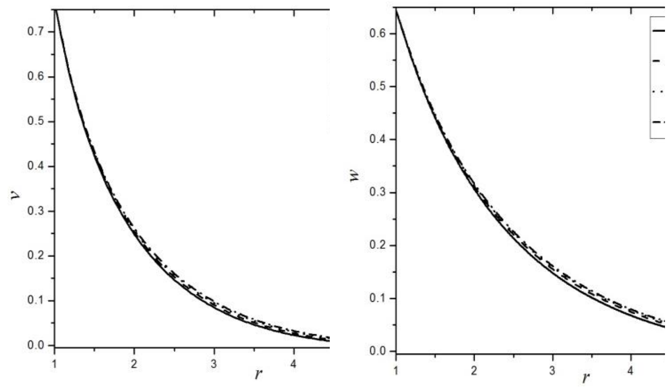


**Fig. 5:**Response of $\beta_i$ on Velocity Components.

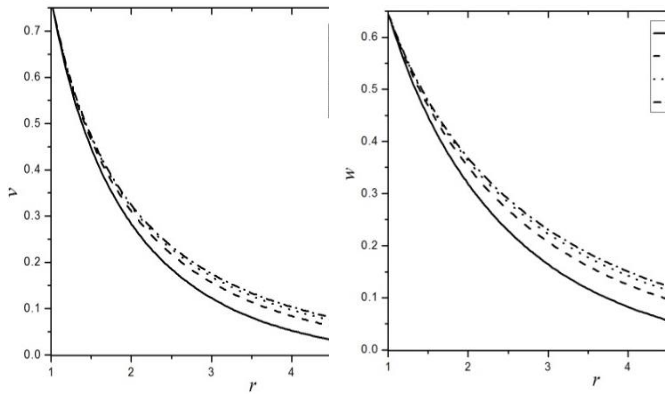


**Fig. 6:**Response of *Da* on Velocity Components.

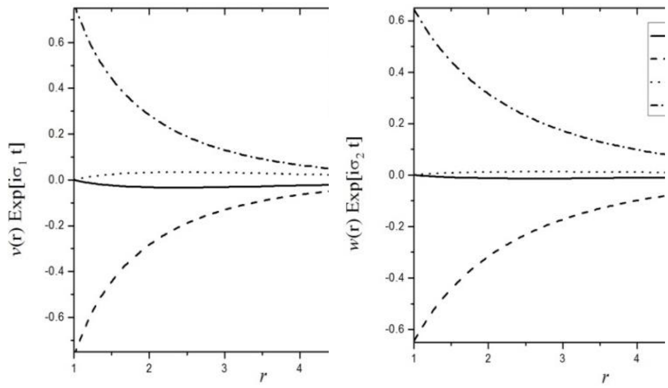


**Fig. 7:**Response of time(*t*) on Velocity Components.

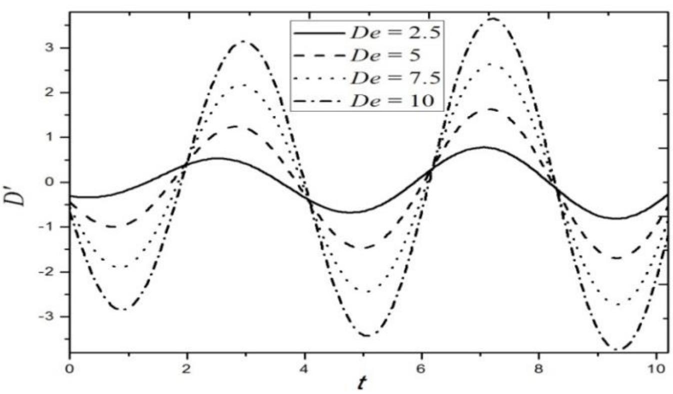


**Fig.8:** Response of *De* on Drag.

**Table 1:**Comparison of Results for Axial Force

| *De* | Previous work of Akyildiz [4] | Present work at $\lambda_1 \to 0$. |
|---|---|---|
| 0.1 | 0.37434 | 0.37524 |
| 0.3 | 1.12427 | 1.12536 |
| 0.5 | 1.87446 | 1.87548 |
| 0.7 | 2.60987 | 2.62560 |
| 0.9 | 3.36988 | 3.37572 |

## 4. Conclusion

In this article, we discussed MHD flow generated by performing oscillations about its axis and transversely of a Jeffrey fluid through a porous medium in a vertical cylinder under the influence of a magnetic field and Ion current taking into account. Analytical solutions are presented for the coupled linear ordinary differential equations. The impact of all the pertinent parameters is taken into account with the help of graphs. The major points for the present study are summarized below.

1) The velocity markedly enhances with increasing Ion parameter and decelerates with the magnetic parameter.
2) Both the velocity profiles increase with increasing Darcy parameter and Debroah number.
3) As *De* increasesthe amplitude of dimensionless drag decreases.


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