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# Pulsatile flow through a circular pipe with porous medium under the influence of time varying pressure gradient: Effects of with and without visco-elastic fluid

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**Abstract**

In this paper, the effects of with and without viscous elastic pulsatile flow of an incompressible Newtonian conducting fluid in porous medium through a circular pipe under the influence of time varying pressure gradient are investigated analytically by using Bessel function. The effect of different parameters on fluid velocity, flow rate and shear stress are discussed in case (i): with the effect of visco-elastic and case (ii): without visco-elastic fluid and comparing results through graphically.

**Keywords**

Pulsatile flow, Porous medium, Elastic-Viscous fluid, Slip parameter.

**AMS Subject Classification**

00A79, 00A71, 00A69, 00A05.

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## Contents



## 1. Introduction

The phenomenon of the fluid flow through a porous medium is a crucial factor of studying the scientific and technological processes such as purification of drinking water, petroleum industry, combustion, chemical spills and fluidization, etc. In current years the flow of fluids through a porous medium in a circular pipe has become the field of concentration for many authors as the study of varying pressure gradient, flow of axial velocity numerically and analytically with condition of slip boundary.

Particularly, the unsteady pulsatile flow with the effect of visco-elastic fluid in porous medium through a circular pipe occur in filtration, oil reservoir engineering, geothermal and have feasible function in neutron factory and others. Interest in the study of flow viscous incompressible Newtonian fluids has increased due to the applications in polymer and food processing, science and engineering including food and slurry transportation, etc. It is also useful in the study of lunar ash flow which explains many aspect of lunar soil. In addition studies, the flow in porous medium have found out the law of Darcy that linearly relates the flow velocity to the pressure gradient across the porous medium. An essential feature of the fluid and porous medium sequence is the tortuous which defines the impediment to flow diffusion imposed by near boundaries or local viscosity. The slip condition plays an essential role in spurt, shear skin and hysteresis effects. The boundary conditions applicable to flowing fluids are very interesting and important in predicting fluid flows in many applications.

Ahmadi and Manvi (1971) derived a general equation of motion through a porous medium for the flow of a viscous fluid. Wang (2003) presented an exact solution of the Navier- Stokes stagnation flow equations with slip. Dube et al., (1975) and Ritler et al., (1997) examined the solution for unsteady dusty gas flow in a circular pipe in the absence of magnetic field. El-Shehawey et al., (1999,2000) studied the impact of MHD flow of blood under body acceleration and the problem of Womersley on pulsatile flow of blood in porous medium. By assuming the flow of MHD of an elastic-viscous fluid under periodic body acceleration, using Laplace and finite Hankel transforms the analytical solutions of above cases are solved. Malekzadeh (2011) studied the influence of a magnetic field on the skin friction factor of a steady, fully developed laminar flow through a pipe and the Finite Difference scheme solves a numerical solution of the governing equations. M. Chitra and V. Kavitha (2019) studied the influence of time varying pressure gradient on unsteady visco-elastic pulsatile flow through a circular pipe in porous medium. Khem Chand (2013) discussed the hydromagnetic flow through a porous medium in a circular pipe with slip conditions. Eldesoky (2014) discussed the numerical analysis the slip effect of MHD pulsatile unsteady flow through porous in an artery.

Theory of incompressible Newtonian fluids has received a major interest during the recent years, because the traditional viscous fluid cannot accurately describe many physiological fluids characteristics. S.A.Gilligan and R.S.Jones (1970) discussed the unsteady flow of an elastico-viscous fluid past a circular cylinder. M. Chitra and V. Kavitha (2017) discussed the pulsatile unsteady flow under the impact of slip condition through porous medium in a circular pipe. Girish Kumar et al., (1990) discussed the unsteady flow by a channel of conducting dusty visco-elastic liquid. N.C.Ghosh et al., (2000) discussed the results for the hydromagnetic flow of a dusty fluid visco-elastic between two infinite parallel plates. Song and Li (2007) discussed the flow of blood in capillaries under the model of porous medium. Kumar.A et al., (2012) studied the mathematical model of blood flow in fluid of visco-elastic under periodic body acceleration with porous effect. Varun Mohan et al., (2013) studied the effect of magnetic field on blood flow (elastic- viscous) under periodic body acceleration in porous medium. R.N. Barik et al., (2017) worked on the steady MHD laminar flow of visco-elastic fluid through a porous pipe embedded in a porous medium. M.Chitra and R. Bhaskaran (2018) have been discussed the impact of permeable wall under the effects of elastic-viscous fluid on blood flow.

In this paper, compromise the study of pulsatile unsteady flow with porous medium in a circular pipe with and without the effect of visco-elastic fluid. Consider, the fluid medium is porous in nature. Using Bessel Function, the governing equation for fully developed incompressible laminar and Newtonian fluid is solved by assuming time varying pressure gradient subject to the boundary conditions. The analytical expressions for fluid velocity profile ($u$), volumetric rate of flow ($Q$), and fluid shear stress ($\tau$) have been obtained. The effect of Knudsen number ($k_n$), Womersley parameter ($\alpha$) and porosity parameter ($k$) on velocity, flow rate and shear stress are discussed in case(i): with the effect of visco-elastic fluid and case(ii): without the effect of visco-elastic fluid and comparing results through graphically.

## 2. Mathematical Formulation

We take into account the unsteady pulsatile viscous flow of incompressible and Newtonian fluid in a circular pipe of radius R with a time varying pressure gradient. Consideration is also taken of the slip boundary. The study of flow as axially symmetric pulsatile and absolutely developed. Above prescribed flow is as shown in Figure 1.

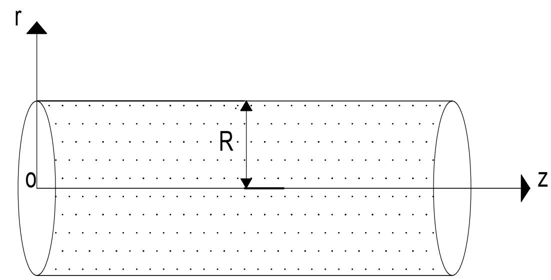


**Figure 1.** Geometry flow through porous medium.

Assume to be periodic with time varying pressure gradient as

$$-\frac{\partial p}{\partial z} = A_0 + A_1 \cos(\omega t) \tag{2.1}$$

Where $A_0$ and $A_1$ are steady flow of pressure gradient and $\omega = 2\pi f$, where $f$ is the flow of frequency and $t$ is time.

The boundary conditions that must be satisfied by the fluid on the wall of cylindrical pipe are the slip conditions. The Navier-stokes equation obeys for slip flow, but the no slip condition is changed by slip condition $u_t = A_p(\frac{\partial u_t}{\partial n})$, Where $n$ is normal to the surface, $u_t$ is tangential velocity and $A_p$ is a coefficient close to the fluid mean free path. The boundary conditions of the cylindrical pipe are:

$$u(r,t) = A_p \frac{\partial u(r,t)}{\partial r} \quad at \quad r = R \quad (Slip\ condition) \tag{2.2}$$

$$\frac{\partial u}{\partial r} = 0 \qquad at \qquad r = 0 \qquad (Symmetry\ condition) \tag{2.3}$$

Let us introducing the dimensionless parameters are:

$$\left.\begin{array}{llll} u^* = \frac{u}{\omega R}, & r^* = \frac{r}{R}, & t^* = t\omega, & A_0^* = \frac{R}{\mu\omega}A_0 \\ A_1^* = \frac{R}{\mu\omega}A_1, & z^* = \frac{z}{R}, & k^* = \frac{k}{R^2}, & \omega^* = \frac{\mu\omega}{R^2} \end{array}\right\} \tag{2.4}$$

The parameter of Womersley $(\alpha)$ and number of Knudsen $(k_n)$ are defined by:

$$\alpha = R\sqrt{\frac{\rho\omega}{\mu}}, \qquad k_n = \frac{A_p}{R} \tag{2.5}$$

**Case(i): with the effect of visco-elastic fluid**
The governing equation of the motion through a circular pipe is given by

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\rho\left(\frac{\partial u}{\partial t}\right)=-\frac{\partial p}{\partial z}+\mu\nabla^2 u-\left(\frac{\mu}{k}\right)\left(1+\lambda\frac{\partial}{\partial t}\right)u \tag{2.6}$$

Where $u(r,t)$ represents the fluid axial velocity, $\lambda$ is the visco-elastic coefficient, $k$ is the porosity, $\rho$ is the fluid density, $\mu$ is the kinematic viscosity and $p$ is the fluid pressure.

The required equation can be written in cylindrical form as

$$\left(1+\lambda\frac{\partial}{\partial t}\right)\rho\left(\frac{\partial u}{\partial t}\right)=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)-\left(\frac{\mu}{k}\right)\left(1+\lambda\frac{\partial}{\partial t}\right)u \tag{2.7}$$

where $\nabla^2=\frac{1}{r}\left(\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right)\right)$

Using equations (2.4) and (2.5) in equation (2.7) and dropping starts, we get

$$\alpha^2\left(\frac{\partial u}{\partial t}\right)+\alpha^2\lambda\left(\frac{\partial^2 u}{\partial t^2}\right)=A_0+A_1\cos(t)+\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)-\frac{1}{k}R^2u-\frac{1}{k}R^2\lambda\left(\frac{\partial u}{\partial t}\right) \tag{2.8}$$

**Case(ii): without the effect of visco-elastic fluid**
The governing equation of the motion through a circular pipe is given by

$$\rho\frac{\partial u}{\partial t}=-\left(\frac{\partial p}{\partial z}\right)+\mu\nabla^2 u-\left(\frac{\mu}{k}\right)u \tag{2.9}$$

Where $u(r,t)$ represents the fluid axial velocity, $p$ is the fluid pressure, $\rho$ is the density, $\mu$ is the kinematic viscosity and $k$ is the porosity.
The required equation can be written in cylindrical form as

$$\rho\frac{\partial u}{\partial t}=-\frac{\partial p}{\partial z}+\mu\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)-\left(\frac{\mu}{k}\right)u \tag{2.10}$$

where $\nabla^2=\frac{1}{r}\left(\frac{\partial}{\partial r}\left(r\frac{\partial}{\partial r}\right)\right)$
Using equations (2.4) and (2.5) in equation (2.10) and dropping the stars, we get

$$\alpha^2\frac{\partial u}{\partial t}=A_0+A_1e^{it}+\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}\right)-\left(\frac{1}{k}\right)u \tag{2.11}$$

After using dimensionless parameters, we get the boundary conditions are:

$$u(r,t)=k_n\frac{\partial u(r,t)}{\partial r}\quad at\quad r=1\quad (Slip\ condition) \tag{2.12}$$

$$\frac{\partial u}{\partial r}=0\quad at\quad r=0\qquad (Symmetry\ condition) \tag{2.13}$$

The linearity of differential equation to be solved, complex notation advocated itself, hence the real part of $e^{int}=\cos nt+i\sin nt$, has the physical importance.

## 3. Method of Solution

**Case(i): with the effect of visco-elastic fluid**
We assume the solution of equation (2.8) under the boundary conditions (2.12) and (2.13).

$$u(r,t)=f(r)e^{int} \tag{3.1}$$

We get the differential form as

$$f''(r)+\frac{1}{r}f'(r)+C^2f(r)=-A \tag{3.2}$$

Where $C^2=\left(\alpha^2n^2\lambda-\alpha^2in-\frac{R^2}{k}-\frac{R^2\lambda in}{k}\right)$
and $A=(A_0+A_1e^{it})e^{-int}$

After solving the above equation, we get the solution is

$$u(r,t)=\left(\frac{-A}{C^2}+BJ_0(Cr)\right)e^{int} \tag{3.3}$$

Where $J_0$ is the Bessel function of zeroth order. Substituting the boundary conditions, we have the resulting expression for the axial velocity $u$ in a circular pipe is

$$u(r,t)=\left(\frac{J_0(Cr)}{(J_0(C)-k_nJ_0'(C)C)}-1\right)\left(\frac{A_0+A_1e^{it}}{C^2}\right) \tag{3.4}$$

The rate of fluid flow $Q$ is

$$Q=2\pi\int_0^R urdr \tag{3.5}$$

Hence, the volumetric flow rate $Q$ of the circular pipe with the effect of visco-elastic fluid is

$$Q=\frac{\pi}{C^2}\left(\frac{2J_1(C)}{C(J_0(C)-k_nJ_0'(C)C)}-1\right)(A_0+A_1e^{it}) \tag{3.6}$$

The fluid shear stress expression $\tau$ is defined by

$$\tau = \mu \left( \frac{\partial u}{\partial r} \right)_{r=1} \tag{3.7}$$

Hence, the shear stress $\tau$ of the circular pipe with the effect of visco-elastic fluid is

$$\tau = -\left( \frac{J_1(C)C}{(J_0(C) - k_n J_0'(C)C)} \right) \left( \frac{A_0 + A_1 e^{it}}{C^2} \right) \tag{3.8}$$

**Case(ii): without the effect of visco-elastic fluid**

We assume the solution equation (2.11) under the boundary conditions (2.12) and (2.13).

$$u(r,t) = h(r)e^{int} \tag{3.9}$$

We get the differential form as

$$h''(r) + \frac{1}{r}h'(r) + M^2 h(r) = -A \tag{3.10}$$

Where $\quad M^2 = -\left( \alpha^2 in + \frac{1}{k} \right)$

and $\quad A = (A_0 + A_1 e^{it})e^{-}int$

After solving the above equation, we get the solution is

$$u(r,t) = \left( \frac{-A}{M^2} + EJ_0(Mr) \right) e^{int} \tag{3.11}$$

Where $J_0$ is the Bessel function of order zero.
Substituting the boundary conditions, we have the resulting expression for the axial velocity $u$ in a circular pipe is

$$u(r,t) = \left( \frac{J_0(Mr)}{(J_0(M) - k_n J_0'(M)M)} - 1 \right) \left( \frac{A_0 + A_1 e^{it}}{M^2} \right) \tag{3.12}$$

The rate of fluid flow $Q$ is

$$Q = 2\pi \int_0^R urdr \tag{3.13}$$

Hence, the volumetric flow rate $Q$ of the circular pipe without the effect of visco-elastic fluid is

$$Q = \frac{\pi}{M^2} \left( \frac{2J_1(M)}{M(J_0(M) - k_n J_0'(M)M)} - 1 \right) (A_0 + A_1 e^{it}) \tag{3.14}$$

The fluid shear stress expression $\tau$ is defined by

$$\tau = \mu \left( \frac{\partial u}{\partial r} \right)_{r=1} \tag{3.15}$$

Hence, the shear stress $\tau$ of the circular pipe without the effect of visco-elastic fluid is

$$\tau = -\left( \frac{J_1(M)M}{(J_0(M) - k_n J_0'(M)M)} \right) \left( \frac{A_0 + A_1 e^{it}}{M^2} \right) \tag{3.16}$$

## 4. Results and Discussion

The existing model has been developed to study the slip velocity on unsteady pulsatile flow with and without the effect of visco-elastic fluid flow of a circular pipe in porous medium as to behave like the Newtonian incompressible fluid. The governing equations of the problems are solved analytically by using Bessel function; it gives the solution of fluid velocity, fluid shear stress and fluid rate flow. In order to have an estimate of the quantitative impact of the various parameters involved in the flow analysis, MATLAB 2013a is used to depicted the graphs. The analytical results obtained for fluid velocity, rate of fluid flow and fluid shear stress profiles in a circular pipe through a porous medium are computed for various parameters like Knudsen number ($k_n$), Womersley parameter ($\alpha$) and Porosity parameter ($k$). The fixed numerical values are : $A_0 = 1, A_1 = 1, n = 5, t = 1$.

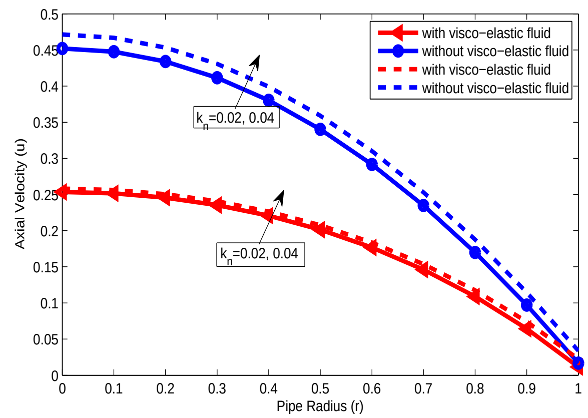


**Figure 2.** Variation of with and without the effect of visco-elastic fluid, the profile of axial velocity for various values of Knudsen number ($k_n$).

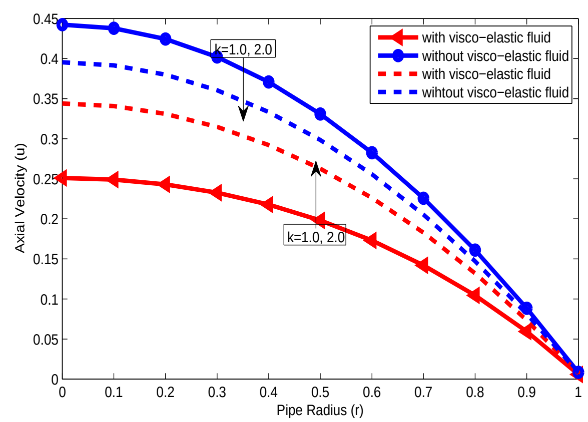


**Figure 3.** Variation of with and without the effect of visco-elastic fluid, the profile of axial velocity for various values of porosity parameter ($k$).

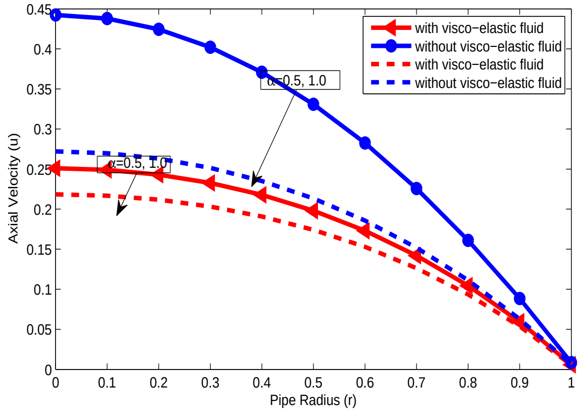


**Figure 4.** Variation of with and without the effect of visco-elastic fluid, the profile of axial velocity for various values of Womersley parameter ($\alpha$).

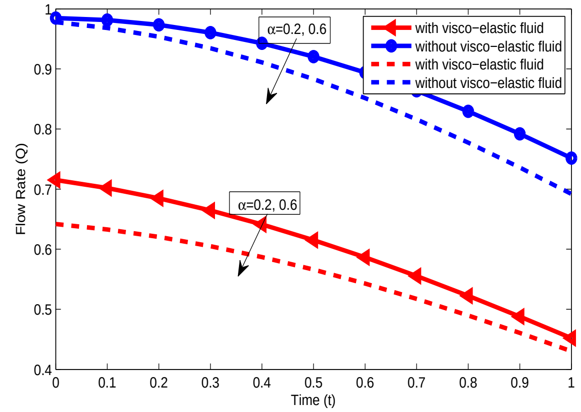


**Figure 7.** Variation of with and without the effect of visco-elastic fluid, the profile of flow rate for various values of Womersley parameter ($\alpha$).

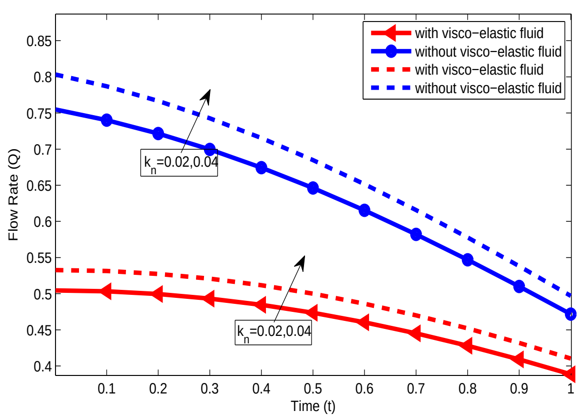


**Figure 5.** Variation of with and without the effect of visco-elastic fluid, the profile of flow rate for various values of Knudsen parameter ($k_n$).

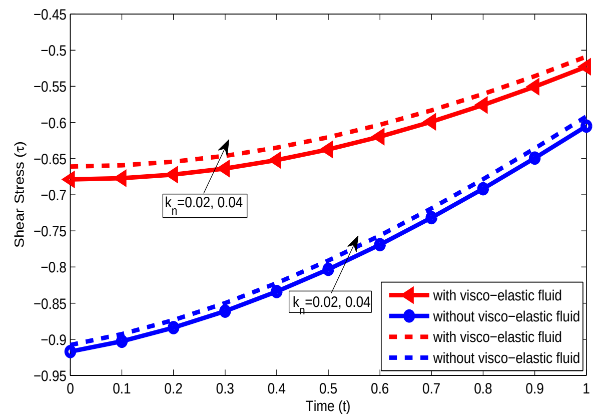


**Figure 8.** Variation of with and without the effect of visco-elastic fluid, the profile of shear stress for various values of Knudsen parameter ($k_n$).

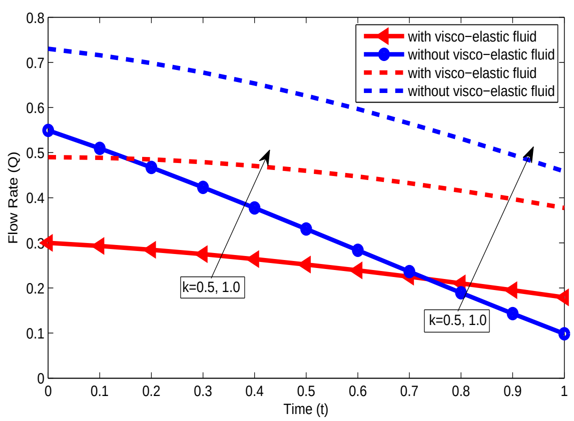


**Figure 6.** Variation of with and without the effect of visco-elastic fluid, the profile of flow rate for various values of porosity parameter ($k$).

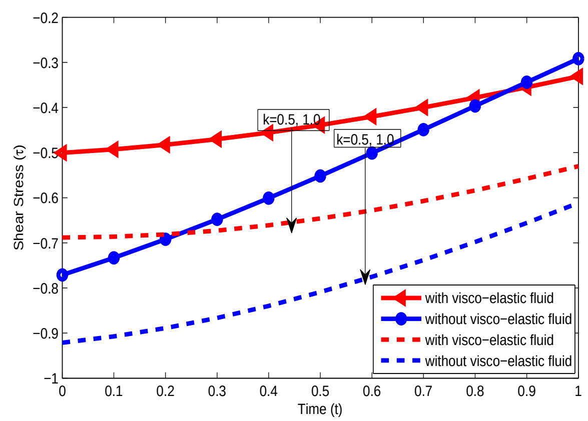


**Figure 9.** Variation of with and without the effect of visco-elastic fluid, the profile of shear stress for various values of porosity parameter ($k$).

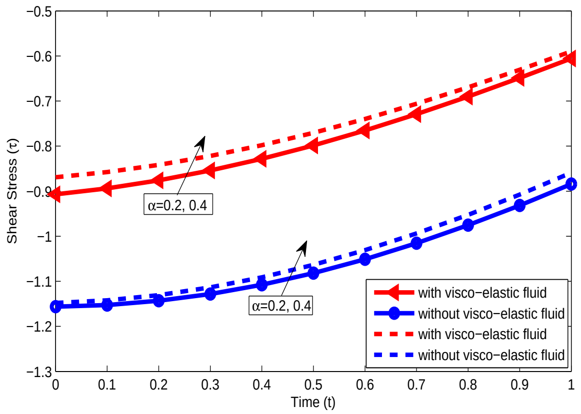


**Figure 10.** Variation of with and without the effect of visco-elastic fluid, the profile of shear stress for various values of Womersley parameter ($\alpha$).

$*$ The variation of with and without the effect of visco-elastic fluid for axial velocity have been discussed and examined in Figures (2) to (4).

$*$ In Figure (2) seems that the Knudsen number $(k_n)$ increase, the axial velocity also increase in case of with and without the effect of visco-elastic fluid and it is also shows that without the effect of visco-elastic fluid of axial velocity is higher than with the effect of visco-elastic fluid axial velocity.

$*$ In Figure (3) observed that the porosity parameter $(k)$ increase, the fluid flow velocity increase in case of with the effect of visco-elastic fluid and decreasing of without the effect of visco-elastic fluid. It is also shows that without the effect of visco-elastic fluid of axial velocity is higher than with the effect of visco-elastic fluid axial velocity.

$*$ In Figure (4) found out that the axial velocity profile decreases with increasing of womersley parameter $(\alpha)$ in case of with and without the effect of visco-elastic fluid. It is also appears that without the effect of visco-elastic fluid of axial velocity is higher than with the effect of visco-elastic fluid axial velocity.

$*$ The flow rate profiles with and without the effect of visco-elastic flow have been studied and presented in Figures (5) to (7).

$*$ In Figure (5)and (6) shows that the flow rate profile in case of with and without the effect of visco-elastic fluid increase with increasing of Knudsen number$(k_n)$ and Porosity parameter$(k)$. It is also indicates that without the effect of visco-elastic fluid of flow rate is higher than with the effect of visco-elastic fluid.

$*$ In Figure(7) indicates the rate of fluid flow profile decreases with increasing of Womersley parameter $(\alpha)$ in case of with and without the effect of visco-elastic fluid and also shows that without the effect of visco-elastic fluid flow rate is higher than with the effect of visco-elastic fluid flow rate.

$*$ The shear stress profiles with and without the effect of visco-elastic flow have been examined and indicated in Figures (8) to (10).

$*$ In Figure (8) and (10) illustrate that the shear stress profiles increases with increasing of Knudsen number $(k_n)$ and Womersley parameter $(\alpha)$ in case of with and without the effect of visco-elastic fluid ad also show that with the effect of visco-elastic fluid shear stress is higher than without the effect of visco-elastic fluid shear stress. .

$*$ In Figure (9) indicates the shear stress profiles decreases with increasing of porosity parameter $(k)$ in case of with and without the effect of visco-elastic fluid. It is show that with the effect of visco-elastic fluid of shear stress is higher than without the effect of visco-elastic fluid of shear stress.

## 5. Conclusion

In summary, the effect of with and without elastic viscous fluid on pulsatile unsteady flow in a porous medium under the impact of time varying pressure gradient has been studied. Analytically, the modelled equations are solved using the Bessel function. The impact of axial velocity, shear stress and flow rate on various parameters are discussed in case(i): with visco-elastic fluid and case(ii): without visco-elastic fluid. Further, for a clearer picture, the physical parameters specifically, Knudsen number, Porosity and Womersley parameter are analysed and studied in detail and correct agreement among with and without the effect of visco-elastic fluids and results are compared through graphically. The conclusion of the study are as follows

$*$ Profile of axial velocity increases with increasing of Knudsen number and decreases with increasing of Womersley parameter in case of with and without the effect of visco-elastic fluid.

$*$ Profile of axial velocity increase, the porosity parameter increases in case of with the effect of visco-elastic fluid. Also, the axial velocity profile decreases with increasing of porosity parameter in case of without the effect of visco-elastic fluid.

$*$ Profile of flow rate increase, the Knudsen number and porosity parameter increases and the flow rate profile decreases with increasing of Womersely parameter in case of with and without the effect of visco-elastic fluid.

$*$ Shear stress profile increases with increasing of Knudsen number and Womeersley parameter and also shear stress profile decreases with increasing of porosity parameter in case of with and without the effect of visco-elastic fluid.

In addition, we indicates that without the effect of axial velocity visco-elastic fluid is higher than with the effect of axial velocity and flow rate visco-elastic fluid. Finally, we seems that with the effect of shear stress visco-elastic fluid is higher than without the effect of shear stress profile of visco-elastic fluid.

The effect of with and without visco-elastic fluid on unsteady pulsatile flow is to suppress the axial velocity, shear stress and flow rate field which in turn cause the enhancement of the porous medium. The analytical solutions are accurate and self-contained, it's far predicted that those solutions can deliver as a favourable benchmark to increase and justifying different types of solutions in the concept and framework of visco-elastic flow of dynamic fluid in porous area.

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