International Journal of Mathematical Archive-10(1), 2019, 13-20
Available online through www.ijma.info ISSN 2229 – 5046

PERISTALTIC TRANSPORT OF A COUPLE STRESS FLUID THROUGH A POROUS MEDIUM IN AN INCLINED CHANNEL

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(Received On: 30-11-18; Revised & Accepted On: 04-01-19)

ABSTRACT

The present paper investigates the peristaltic transport of a couple stress fluid in a two dimensional inclined channel through a porous medium. The effects of various physical parameters on velocity, pressure gradient and friction force have been discussed & computed numerically. The effects of various key parameters are discussed with the help of graphs.

Keywords: *Peristaltic transport, Couple stress fluid, Porous media and inclined channel.*

1. INTRODUCTION

The aim of this paper is to study a physiological situation with the presence of an endoscope placed concentrically. Srivastava *et al.* [9] investigated peristaltic transport of a physiological fluid: part I flow in non- uniform geometry. Latham [18] investigated the fluid mechanics of peristaltic pump and science. Ramchandra and Usha [16] studied the influence of an eccentrically inserted catheter on the peristaltic pumping in a tube under long wavelength and low Reynolds numbers approximations. Gupta and Sheshadri [4] studied peristaltic transport of a Newtonian fluid in non-uniform geometries. Cotton and Williams [15] investigated practical gastrointestinal endoscopy. Mekhemier [7] studied non linear peristaltic transport a porous medium in an inclined planar channel. Srivastava and Srivastava [10] have investigated peristaltic transport of a non-newtonian fluid: applications to the vas deferens and small intestine. Rathod and Asha [30] have investigated peristaltic transport of a couple stress fluid In a uniform and non-uniform annulus. Raptis and Peridikis [17] are investigated flow of a viscous fluid through a porous medium bounded by a vertical surface. El-dabe and El-Mohandis [5] have studied magneto hydrodynamic flow of second order fluid through a porous medium on an inclined porous plane. Ayman and Sobh [2] investigated peristaltic transport of a magneto-newtonian fluid through a porous medium. Habtu and Radhakrishnamacharya (6) studied dispersion of a solute in peristaltic motion of a couple stress fluid through a porous medium with slip condition. Rathod and Mahadev [31] investigated effect of thickness of the porous material on the peristaltic pumping of a Jeffry fluid with non - erodible porous lining wall. Rathod, *et al.* [22] have investigated peristaltic pumping of couple stress fluid through non - erodible porous lining tube wall with thickness of porous material. Mekhemier and Abd elmaboud [8] studied peristaltic flow of a couple stress fluid in an annulus: application of an endoscope. Alsaedi *et al.* [1] studied peristaltic flow of couple stress fluid through uniform porous medium. Rathod and Sridhar [19] investigated peristaltic transport of couple stress fluid in uniform and non-uniform annulus through porous medium. Rathod and Asha [30] studied effect of couple stress fluid and an endoscope in peristaltic motion. Abd elmaboud and Mekheimer [40] study non-linear peristaltic transport of a second-order fluid through a porous medium. Rathod and Asha [21] studied effects of magnetic field and an endoscope on peristaltic motion. Rathod and Mahadev [29] studied effect of magnetic field on ureteral peristalsis in cylindrical tube. Rathod and Mahadev [26] Studied of ureteral peristalsis in cylindrical tube through porous medium. Rathod and Pallavi [36] studed the influence of wall properties on MHD Peristaltic transport of dusty fluid. Rathod and Pallavi [37] investigated the influence of wall properties on Peristaltic transport of dusty fluid through porous medium. Rathod and Mahadev [27] studied of ureteral peristalsis with Jeffrey fluid flow. Rathod and Mahadev [28] studied Slip effects and heat transfer on MHD peristaltic flow of Jeffrey fluid in an inclined channel. Rathod and Laxmi [25] investigated slip effect on peristaltic transport of a conducting fluid through a porous medium in an asymmetric vertical channel by Adomian decomposition method. Rathod and Laxmi [24] studied peristaltic transport of a conducting fluid in an asymmetric vertical channel with heat and mass transfer. Rathod and Laxmi [23] studied effects of heat transfer on the peristaltic MHD flow of a Bingham fluid through a porous medium in a channel. Rathod and Sridhar [35] studied effects of couple stress fluid and an endoscope on peristaltic transport through a porous medium, Jayarami Reddy *et al.*, [3] have studied the peristaltic flow of a Williamson fluid in an inclined planar channel under the effect of a magnetic field. Rathod and Sridhar [33] studied peristaltic flow of a couple stress fluid in an inclined channel. Rathod *et al.*, [38] studied peristaltic flow of a couple stress fluid in an inclined channel under the effect of magnetic field.

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Rathod *et al.*, [39] studied peristaltic transport of a conducting couple stress fluid through a porous medium in a channel. Rathod *et al.*, [32] studied effect of magnetic field on peristaltic transport of a couple stress fluid in a channel. Sridhar [11] studied effect of thickness of the porous material using porous media on the peristaltic pumping of couple stress fluid through non - erodible porous lining tube. Sridhar [12] studied effects of magnetic field with variable viscosity and an endoscope on peristaltic transport of couple stress fluids through a porous medium. Sridhar [13] studied peristaltic pumping of couple stress fluid through non - erodible porous lining tube wall with thickness of porous material using magnetic field. Rathod and Sridhar [34] studied peristaltic flow of a couple stress fluids through a porous medium in an inclined channel. Sridhar [14] studied peristaltic flow of a couple stress fluid in an inclined channel under the effect of magnetic field with slip condition

The present research aim is to investigate the peristalsis for the flow of a couple stress fluid in a two dimensional inclined channel through a porous medium. The computational analysis has been carried out for drawing velocity profiles, pressure gradient and frictional force.

2. FORMULATION OF THE PROBLEM

We consider a peristaltic flow of a Couple stress fluids through two-dimensional channel of width 2a and inclined at an angle α to the horizontal symmetric with respect to its axis. The walls of the channel are assumed to be flexible.

The wall deformation is

$$H(x,t) = a + bCos\left(\frac{2\pi}{\lambda}(X - ct)\right) \tag{1}$$

Where 'b' is the amplitude of the peristaltic wave, 'c' is the wave velocity, 'λ' is the wave length, t is the time and X is the direction of wave propagation.

Neglecting the body force and the body couples, the continuity equation and equations of motion (Mekheimer 2002) through a porous medium are

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{2}$$

Navier Stokes equations are:

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \mu\nabla^2 u - \eta^*\nabla^4 u + \rho g\sin\alpha - \frac{\mu}{K}u \tag{3}$$

$$\rho\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \mu\nabla^2 v - \eta^*\nabla^4 v - \rho g\cos\alpha - \frac{\mu}{K}v \tag{4}$$

Where, $\nabla^2 = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}, \nabla^4 = \nabla^2\nabla^2$

u and v are velocity components, 'p' is the fluid pressure, 'ρ' is the density of the fluid, 'μ' is the coefficient of viscosity, 'η^*' is the coefficient of couple stress, 'g' is the gravity due to acceleration, 'α' angle of inclination and 'K' is porous media.

Introducing a wave frame (x, y) moving with velocity c away from the fixed frame (X, Y) by the transformation

$$x = X - ct, y = Y, u = U, v = V, p = P(X,t) \tag{5}$$

We introduce the non-dimensional variables:

$$x^* = \frac{x}{\lambda}, \; y^* = \frac{y}{a}, u^* = \frac{u}{c}, \; v^* = \frac{v}{c\delta}, \; t^* = \frac{tc}{\lambda}, \; (\eta^*)^* = \frac{\eta^*}{a}, p^* = \frac{pa^2}{\mu c\lambda}, G = \frac{\rho g a^2}{\mu c},$$
$$p = \frac{a^2}{\lambda\mu c}p^*(z^*), K = \frac{K^*}{\lambda}, \phi = \frac{b}{a}, h = \frac{H}{a} \tag{6}$$

Equation of motion and boundary conditions in dimensionless form becomes

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{7}$$

$$\operatorname{Re}\delta\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\left(\delta^2\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\frac{1}{\gamma^2}(\delta^2\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2})(\delta^2\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2})$$
$$-G\sin\alpha-k^2u \tag{8}$$

$$\operatorname{Re}\delta^3\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right)=-\frac{\partial p}{\partial y}+\delta^2\left(\delta^2\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-\frac{1}{\gamma^2}\delta^2\left(\delta^2\frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}\right)\left(\delta^2\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)$$
$$-\rho g\delta\cos\alpha-\delta^2k^2v \tag{9}$$

Where, $\gamma^2=\dfrac{\eta^*}{\mu a^2}$ couple-stress parameter and $k^2=\dfrac{a}{K}$ porous media.

The dimensionless boundary conditions are:

$$\frac{\partial u}{\partial y}=0;\quad \frac{\partial^2 u}{\partial y^2}=0\qquad at\quad y=0$$
$$u=-1;\frac{\partial^2 u}{\partial y^2}\quad finite\quad at\quad y=\pm h=1+\phi Cos[2\pi x] \tag{10}$$

Using long wavelength approximation and neglecting the wave number δ, one can reduce

Navier Stokes equations:

$$\frac{\partial p}{\partial y}=0 \tag{11}$$

$$\frac{\partial p}{\partial x}=\frac{\partial^2 u}{\partial y^2}-\frac{1}{\gamma^2}\frac{\partial^4 u}{\partial y^4}-G\sin\alpha-k^2u \tag{12}$$

Solving the Eq. (12) with the boundary conditions (10), we get

$$u=\frac{\partial p}{\partial x}\left(\left(1+\frac{h^2}{\gamma^2}\right)\frac{y^2}{2}-\frac{h^2}{2}-\frac{1}{\gamma^2}\left(\frac{y^4}{4}+\frac{h^4}{4}\right)-\frac{1}{k^2}\right)+\frac{G\sin\alpha}{2}(h^2-y^2)+\frac{(y^2-h^2)}{2\gamma^2}+\frac{1}{\gamma^2}-1 \tag{13}$$

The volumetric flow rate in the wave frame is defined by

$$q=\int_0^h u\,dy=\frac{h^3}{3}\left(G\sin\alpha-\frac{1}{\gamma^2}\right)+h\left(\frac{1}{\gamma^2}-1\right)-\frac{\partial p}{\partial x}\left(\frac{h^3}{3}+\frac{2h^5}{15\gamma^2}+\frac{h}{k^2}\right) \tag{14}$$

The expression for pressure gradient from Eq.(14) is given by

$$\frac{\partial p}{\partial x}=\frac{\left(\frac{h^3}{3}\left(G\sin\alpha-\frac{1}{\gamma^2}\right)+h\left(\frac{1}{\gamma^2}-1\right)-q\right)}{\left(\frac{h^3}{3}+\frac{2h^5}{15\gamma^2}+\frac{h}{k^2}\right)} \tag{15}$$

The instantaneous flux Q (x, t) in the laboratory frame is

$$Q(x,t)=\int_0^h (u+1)dy=q+h \tag{16}$$

The average flux over one period of peristaltic wane is $\overline{Q}$

$$\overline{Q}=\frac{1}{T}\int_0^T Q\,dt=q+1 \tag{17}$$

From equations (15) and (17), the pressure gradient is obtained as

$$\frac{\partial p}{\partial x}=\frac{\left(\frac{h^3}{3}\left(G\sin\alpha-\frac{1}{\gamma^2}\right)+h\left(\frac{1}{\gamma^2}-1\right)-(\overline{Q}-1)\right)}{\left(\frac{h^3}{3}+\frac{2h^5}{15\gamma^2}+\frac{h}{k^2}\right)} \tag{18}$$

The pressure rise (drop) over one cycle of the wave can be obtained as

$$\Delta P=\int_0^1\left(\frac{dp}{dx}\right)dx \tag{19}$$

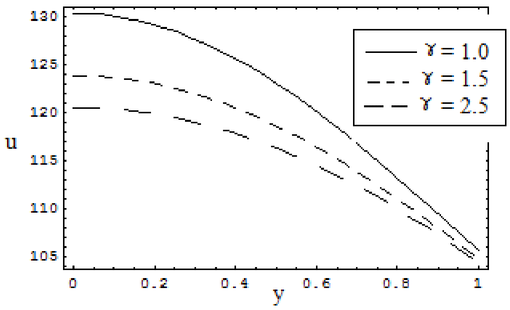
The dimensionless frictional force F at the wall across one wavelength is given by

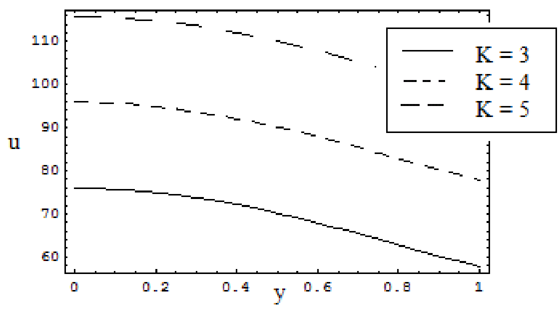
$$F=\int_0^1 h\left(-\frac{dp}{dx}\right)dx \tag{20}$$

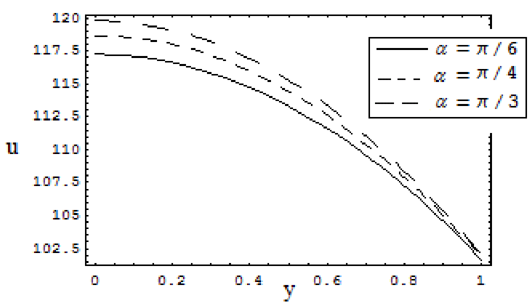
3. RESULTS AND DISCUSSIONS

In this section we have presented the graphical results of the solutions axial velocity u, pressure rise ΔP , friction force F for the different values of couple stress (γ), porous medium (K), angle of inclination (α) and gravitational parameter (G). The axial velocity is shown in **Figs. (1 to 4)**.

The Variation of u with γ, we find that u depreciates with increase in γ (**Fig. 1**). The Variation of u with porous medium K shows that for u increases with increasing in K (**fig. 2**). The Variation of u with angle of inclination α shows that for u increases with increasing in α (**Fig 3**). The Variation of u with gravitational parameter G shows that for u increases with increasing in G (**Fig 4**).







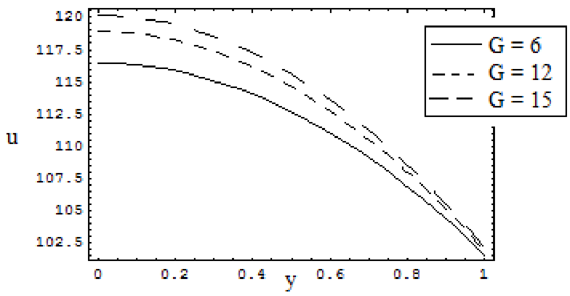


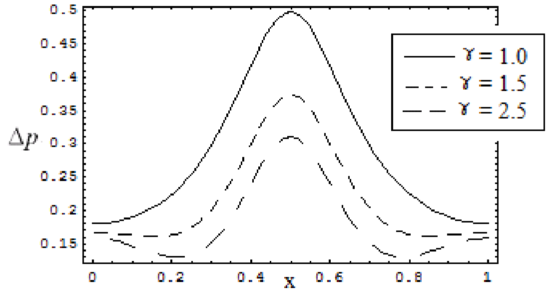
Fig. 1: Effect of γ on u, when ϕ = 0.2,x= 0.1, p=-25, a=1.25, G= 6, K=5 & α = π/4.

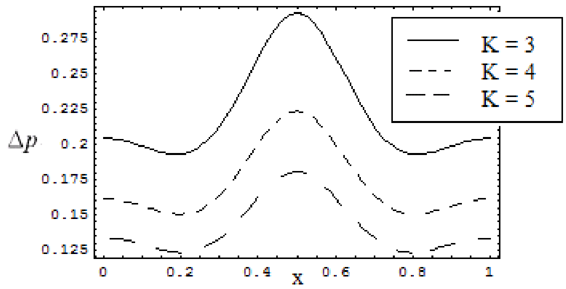
Fig. 2: Effect of **K** on u,when γ =1,ϕ=0.3, x=0.3, p=-25, a=1.25, G=6 & α = π/4.

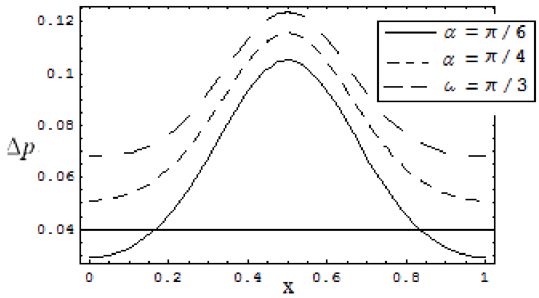
Fig. 3: Effect of α on u,when γ =8,ϕ=0.1,x= 0.1,p =-25, a=1.25, K = 5&G = 12.

Fig. 4: Effect of G on u, when γ =5, ϕ=.1, x=0.1, p=-25, a=1.25, K = 5 & α = π/4.

The variation of pressure rise ΔP is shown in **Figs (5 to 8**) for a different values of γ, K, α & G. We find that ΔP depreciates with increase in γ (**Fig. 5**). The Variation of ΔP with porous medium K shows that for ΔP decreases with increasing in K (**Fig 6**).The Variation of ΔP with angle of inclination α shows that for ΔP increases with increasing in α (**Fig 7**). The Variation of ΔP with gravitational parameter G shows that for ΔP increases with increasing in G (**Fig 8**).







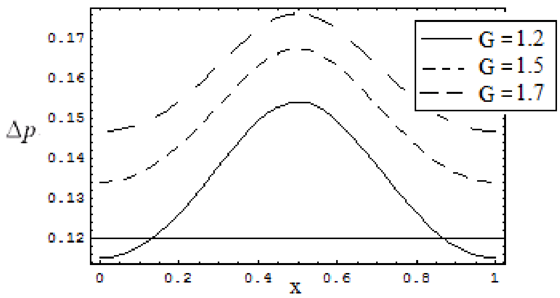


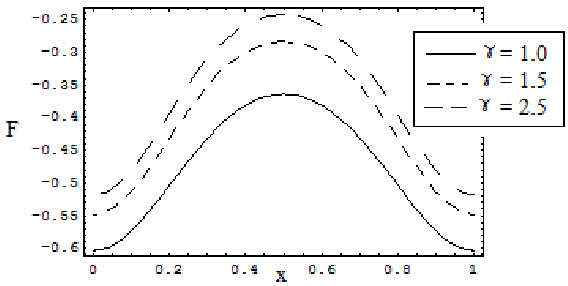
Fig. 5: Effect of γ on Δp ,when ϕ=0.5, G = 2, α = π/4, Q = 0 & a=1.25, K = 5.

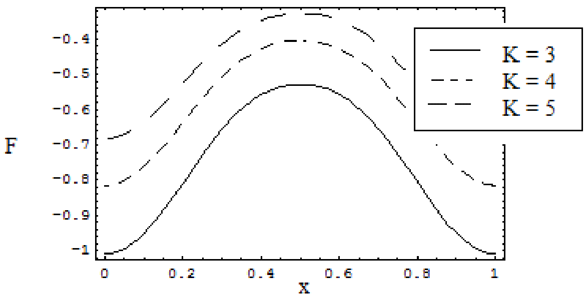
Fig. 6: Effect of **K** on Δp ,when γ =3, ϕ=0.3, G=2, a=1.25, α = π/4 & Q = 0.

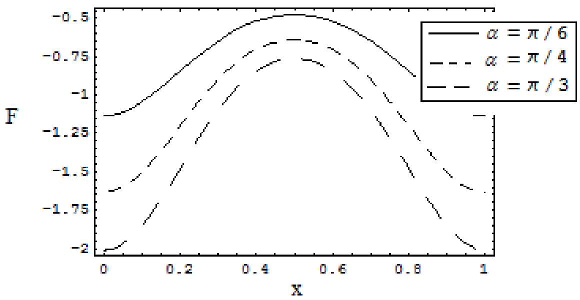
Fig. 7: Effect of α on Δp ,when γ =3, ϕ=0.2, a=1.25, K = 5, Q=0 & G = 1.

Fig. 8: Effect of G on Δp ,when γ =1.5, ϕ=0.1,a=1.25, K = 5, Q=0 & α =π/4.

The variation of friction force F is shown in **Figs.(9 to 12**) for a different values of γ, K, α & G. Here, it is observed that the effect of all the parameters on friction force are opposite behavior as to the effects on pressure with time average mean flow rate is observed.







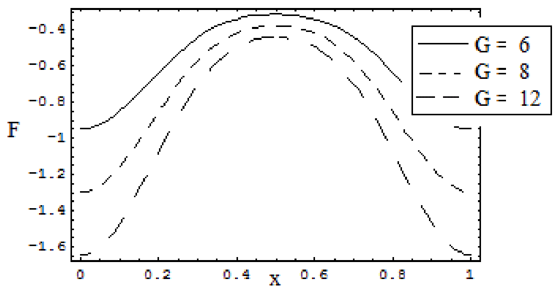


Fig. 9: Effect of γ on F,when G = 6, ϕ=0.2,α = π/4, Q = 0 & a=1.25, K = 5.

Fig. 10: Effect of K on F, when γ =1, ϕ=0.3,α = π/4, Q = 0, a=1.25 & G=6.

Fig. 11: Effect of α on F, when γ =5, ϕ=0.2, G = 12, Q=0, a=1.25 & K = 3.

Fig. 12: Effect of G on F, when γ =5, ϕ=.2, α = π/4, Q=0, a=1.25 & K = 3.

4. CONCLUSION

In this paper we presented a theoretical approach to study the peristaltic flow of a couple stress fluid in an inclined channel through a porous medium. The effect of various values of parameters on Velocity, Pressure rise and Friction force have been computed numerically and explained graphically.
We conclude the following observations:

1. The velocity u increases with increasing in gravitational parameter G, angle of inclination α & porous medium K but, decreases with increasing in couple stress parameter γ .
2. The pressure ΔP increases with increasing in gravitational parameter G & angle of inclination α but, decreases with increasing in couple stress parameter γ & porous medium K.
3. The friction force F increases with decreasing in gravitational parameter G & angle of inclination α but, increases with increasing in couple stress parameter γ & porous medium K.

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Source of support: Nil, Conflict of interest: None Declared.