

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

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**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.

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**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 Jeffery 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  $\alpha$  to the horizontal symmetric with respect to its axis. The walls of the channel are assumed to be flexible.

The wall deformation is

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

Where 'b' is the amplitude of the peristaltic wave, 'c' is the wave velocity, ' $\lambda$ ' 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

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (2)$$

Navier Stokes equations are:

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

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

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, ' $\rho$ ' is the density of the fluid, ' $\mu$ ' is the coefficient of viscosity, ' $\eta^*$ ' is the coefficient of couple stress, 'g' is the gravity due to acceleration, ' $\alpha$ ' 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

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

We introduce the non-dimensional variables:

$$x^* = \frac{x}{\lambda}, y^* = \frac{y}{a}, u^* = \frac{u}{c}, v^* = \frac{v}{c\delta}, t^* = \frac{tc}{\lambda}, (\eta^*)^* = \frac{\eta^*}{a}, p^* = \frac{pa^2}{\mu c \lambda}, G = \frac{\rho g a^2}{\mu c}, \quad (6)$$

$$p = \frac{a^2}{\lambda \mu c} p^*(z^*), K = \frac{K^*}{\lambda}, \phi = \frac{b}{a}, h = \frac{H}{a}$$

Equation of motion and boundary conditions in dimensionless form becomes

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (7)$$

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

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

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

The dimensionless boundary conditions are:

$$\frac{\partial u}{\partial y} = 0; \quad \frac{\partial^2 u}{\partial y^2} = 0 \quad \text{at } y = 0$$

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

Using long wavelength approximation and neglecting the wave number  $\delta$ , one can reduce

Navier Stokes equations:

$$\frac{\partial p}{\partial y} = 0 \quad (11)$$

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

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

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

The volumetric flow rate in the wave frame is defined by

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

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

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

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

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

The average flux over one period of peristaltic wave is  $\bar{Q}$

$$\bar{Q} = \frac{1}{T} \int_0^T Q dt = q + 1 \quad (17)$$

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

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

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

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

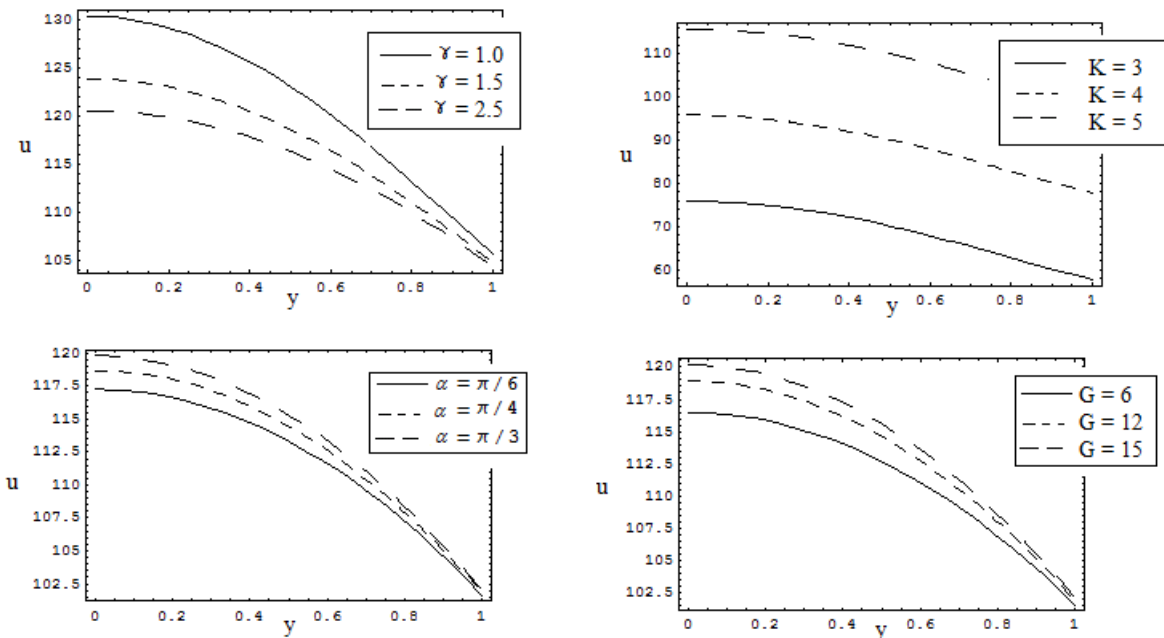
The dimensionless frictional force F at the wall across one wavelength is given by

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

### 3. RESULTS AND DISCUSSIONS

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

The Variation of  $u$  with  $\gamma$ , we find that  $u$  depreciates with increase in  $\gamma$  (**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  $\alpha$  shows that for  $u$  increases with increasing in  $\alpha$  (**Fig 3**). The Variation of  $u$  with gravitational parameter  $G$  shows that for  $u$  increases with increasing in  $G$  (**Fig 4**).



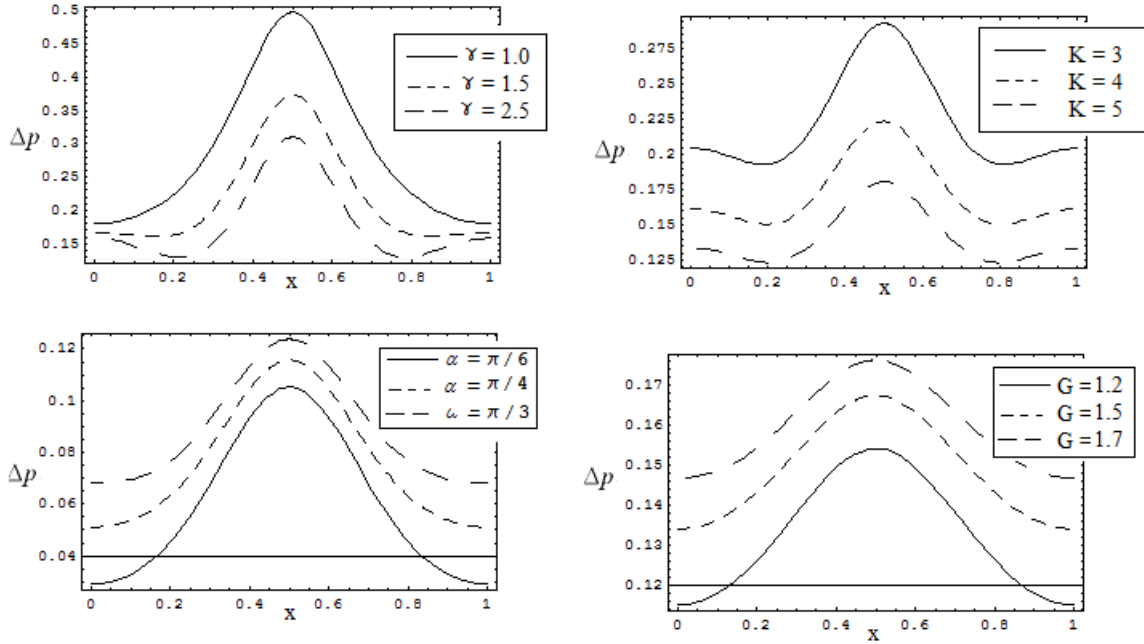
**Fig. 1:** Effect of  $\gamma$  on  $u$ , when  $\phi = 0.2, x = 0.1, p = -25, a = 1.25, G = 6, K = 5$  &  $\alpha = \pi/4$ .

**Fig. 2:** Effect of  $K$  on  $u$ , when  $\gamma = 1, \phi = 0.3, x = 0.3, p = -25, a = 1.25, G = 6$  &  $\alpha = \pi/4$ .

**Fig. 3:** Effect of  $\alpha$  on  $u$ , when  $\gamma = 8, \phi = 0.1, x = 0.1, p = -25, a = 1.25, K = 5$  &  $G = 12$ .

**Fig. 4:** Effect of  $G$  on  $u$ , when  $\gamma = 5, \phi = 0.1, x = 0.1, p = -25, a = 1.25, K = 5$  &  $\alpha = \pi/4$ .

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



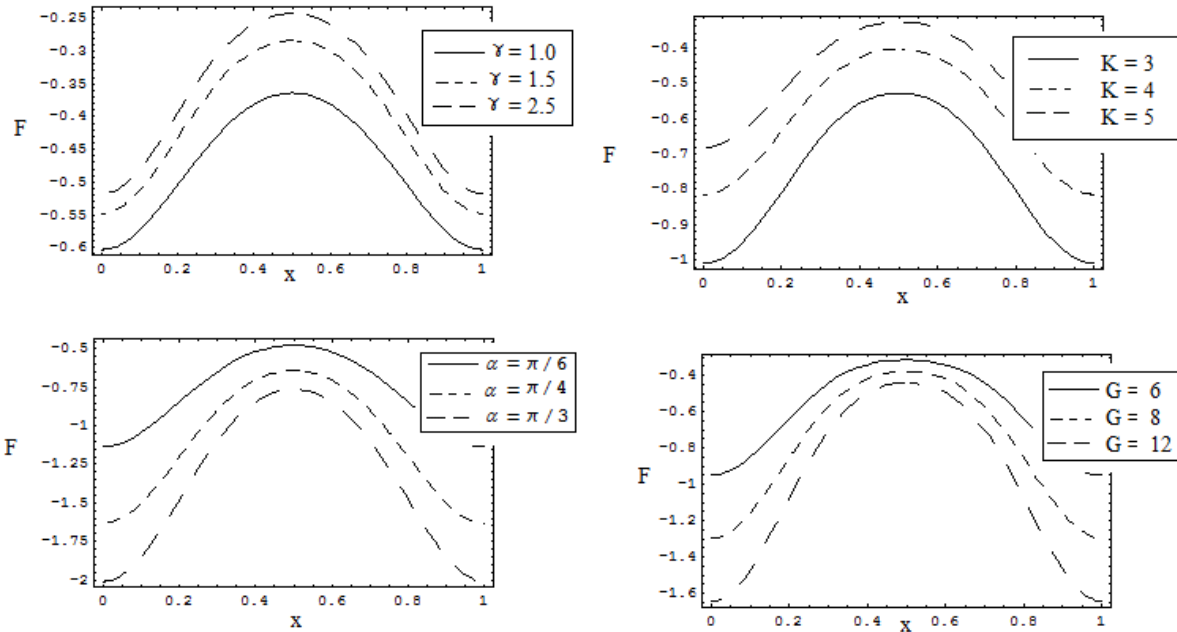
**Fig. 5:** Effect of  $\gamma$  on  $\Delta p$ , when  $\phi=0.5$ ,  $G = 2$ ,  $\alpha = \pi/4$ ,  $Q = 0$  &  $a=1.25$ ,  $K = 5$ .

**Fig. 6:** Effect of  $K$  on  $\Delta p$ , when  $\gamma=3$ ,  $\phi=0.3$ ,  $G=2$ ,  $a=1.25$ ,  $\alpha = \pi/4$  &  $Q = 0$ .

**Fig. 7:** Effect of  $\alpha$  on  $\Delta p$ , when  $\gamma=3$ ,  $\phi=0.2$ ,  $a=1.25$ ,  $K = 5$ ,  $Q=0$  &  $G = 1$ .

**Fig. 8:** Effect of  $G$  on  $\Delta p$ , when  $\gamma=1.5$ ,  $\phi=0.1$ ,  $a=1.25$ ,  $K = 5$ ,  $Q=0$  &  $\alpha = \pi/4$ .

The variation of friction force  $F$  is shown in **Figs.(9 to 12)** for a different values of  $\gamma$ ,  $K$ ,  $\alpha$  &  $G$ . 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  $\gamma$  on F, when  $G = 6, \phi = 0.2, \alpha = \pi/4, Q = 0$  &  $a = 1.25, K = 5$ .

**Fig. 10:** Effect of K on F, when  $\gamma = 1, \phi = 0.3, \alpha = \pi/4, Q = 0, a = 1.25$  &  $G = 6$ .

**Fig. 11:** Effect of  $\alpha$  on F, when  $\gamma = 5, \phi = 0.2, G = 12, Q = 0, a = 1.25$  &  $K = 3$ .

**Fig. 12:** Effect of G on F, when  $\gamma = 5, \phi = 0.2, \alpha = \pi/4, Q = 0, a = 1.25$  &  $K = 3$ .

#### 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  $\alpha$  & porous medium  $K$  but, decreases with increasing in couple stress parameter  $\gamma$ .
2. The pressure  $\Delta P$  increases with increasing in gravitational parameter  $G$  & angle of inclination  $\alpha$  but, decreases with increasing in couple stress parameter  $\gamma$  & porous medium  $K$ .
3. The friction force  $F$  increases with decreasing in gravitational parameter  $G$  & angle of inclination  $\alpha$  but, increases with increasing in couple stress parameter  $\gamma$  & porous medium  $K$ .

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