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INFLUENCE OF AN INCLINED MAGNETIC FIELD ON PERISTALTIC FLOW THROUGH A POROUS MEDIUM WITH PARTIAL SLIP IN AN INCLINED TAPERED CHANNEL

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ABSTRACT

The present study concerned with the impact of velocity slip on peristaltic flow of non-Newtonian fluid through a porous medium in a symmetric inclined channel with heat transfer and inclined magnetic field is investigated. The relevant equations of flow with heat transfer have been developed. Analytic solution is carried out under long-wavelength and small Reynolds number approximations. The expressions for the stream function, temperature and the heat transfer coefficient are obtained. Numerical results are graphically discussed for various values of physical parameters of interest.

***Keywords**: Peristalsis, porous medium, slip flow, heat transfer, inclined magnetic field, compliant walls*

I. INTRODUCTION

The study of Peristaltic mechanism has become popular among the researchers during the last four decades because of its vital and extensive applications in physiology and industry. Some of these applications incorporate chyme movement in gastrointestinal tract, swallowing food through esophagus, chyme movement in the gastrointestinal tract, urine transport from kidney to bladder through the ureter, vasomotion of blood vessels in capillaries and arterioles. Since the seminal work of Latham [1] several theoretical and experimental investigations have been carried out in order to understand the peristaltic flows of hydrodynamic fluids under varied assumptions of long wave length, low Reynolds number, small wave amplitude etc. Although the literature on the topic is extensive but few recent investigations can be mentioned by the studies [2-8].

Influence of magnetohydrodynamic (MHD) on peristaltic flow problems have gained significance on the basis of engineering and biomedical applications. Bio magnetic fluid dynamics in medical science has wide range of applications such as stoppage of bleeding during surgeries, cancer tumor treatment, cell separation, targeted transport of drug using magnetic particles as drug carriers etc. Agarwal and Anwaruddin [9] has studied the peristaltic flow of a blood under long wave length and low Reynolds number assumption. Mekheimer [10] reported peristaltic flow of blood under effect of magnetic field in anon-uniform channel. Eldabe et al. [11] analyzed the induced magnetic field effect on peristaltic transport of biviscosity fluid in a non-uniform tube. Mekheimer and Elmaboud [12] had reported the influence of heat and magnetic field on peristaltic transport of Newtonian fluid in a vertical annulus. Vajravelu et al. [13] discussed the combined influence of velocity slip, temperature and concentration jump conditions on MHD peristaltic transport of a Carreau fluid in a non-uniform channel. The simultaneous effects of an inclined magnetic field and heat transfer with connective boundary conditions [14-16]. the purpose of present paper is to discuss the effect of inclined magnetic field on the peristaltic flow of non-Newtonian fluid through a porous medium with partial slip in an inclined tapered channel.

The continuity, momentum and temperature equations have been linearized under long wavelength and low Reynolds number assumption and exact solutions for the flow fluid dynamical variables have been derived. The contribution of several interesting parameters embedded in the flow system is examined by graphical representations.

The paper is arranged as follows, Sections two provides the mathematical formulation of the problem. Section three contain the dimension less. Solution of the problem obtain in section four. Graphical discussion is presented in section five while the concluding remarks are given in section six.

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II. THE MATHEMATICAL FORMULATION OF THE PROBLEM:

Peristaltic motion of an incompressible viscous fluid in an inclined symmetric channel of mean half width d (as shown in figure (1)) is investigated. A sinusoidal wave with speed c is propagating on the channel walls. The fluid is electrically conducting and an inclined magnetic field is taken into consideration. The channel walls are non-conducting. We choose rectangular coordinates $(\bar{X},\bar{Y})$ with $\bar{X}$ in the direction of wave propagation and $\bar{Y}$ transverse to it. The geometry of the wall surfaces are

$$\bar{y} = \pm\bar{\eta}(\bar{x},\bar{t}) = \pm\left[d + \bar{m}\bar{x} + a\,sin\frac{2\pi}{\lambda}(\bar{x} - c\bar{t})\right] \quad (1)$$

Where d is the mean half width of the channel, a is the amplitude, λ is the wave length, $\bar{t}$ is the time, $\bar{m}$ is the non-uniform parameter and c is the phase speed of the wave respectively.
The magnetic Reynolds number and induced magnetic field are assumed to be small and neglected. Under these assumptions the governing equation of continuity, momentum and heat transfer are as follow:

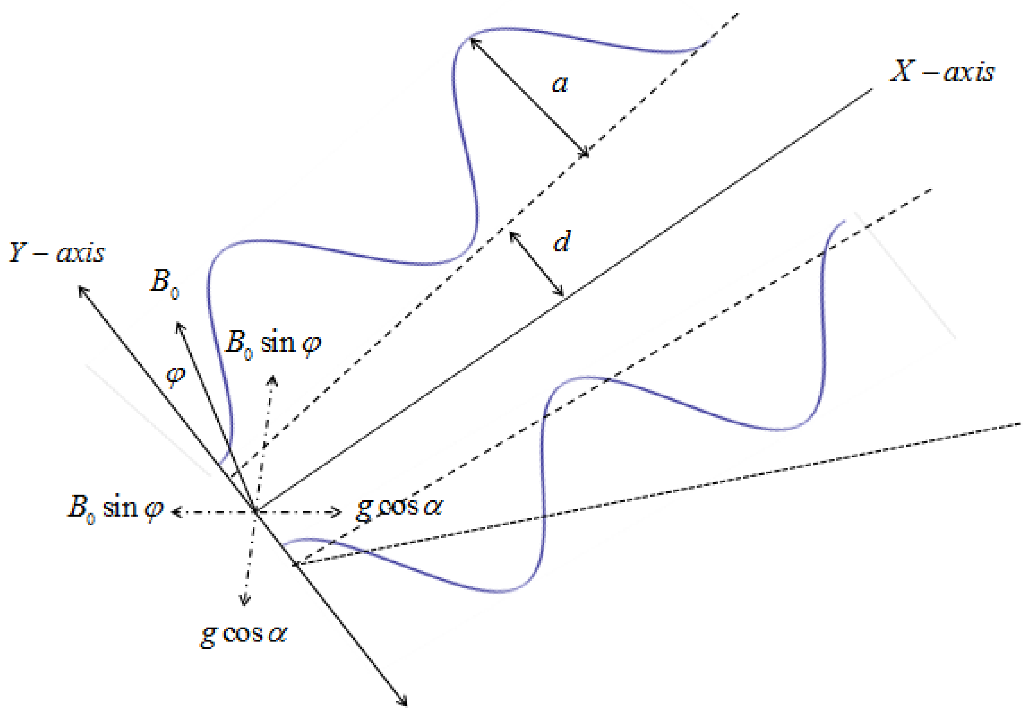

Figure (1) schematic diagram of the problem

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

$$\rho\left(\frac{\partial\bar{u}}{\partial\bar{t}} + \bar{u}\frac{\partial\bar{u}}{\partial\bar{x}} + \bar{v}\frac{\partial\bar{u}}{\partial\bar{y}}\right) = -\frac{\partial\bar{p}}{\partial\bar{x}} + \mu\left[\frac{\partial^2\bar{u}}{\partial\bar{x}^2} + \frac{\partial^2\bar{u}}{\partial\bar{y}^2}\right] - \frac{\mu}{k}\bar{u}$$
$$-\sigma B_0^2\cos\emptyset\,(\bar{u}\cos\emptyset - \bar{v}\sin\emptyset) + \rho g\sin\alpha \quad (3)$$

$$\rho\left(\frac{\partial\bar{v}}{\partial\bar{t}} + \bar{u}\frac{\partial\bar{v}}{\partial\bar{x}} + \bar{v}\frac{\partial\bar{v}}{\partial\bar{y}}\right) = -\frac{\partial\bar{p}}{\partial\bar{y}} + \mu\left[\frac{\partial^2\bar{v}}{\partial\bar{x}^2} + \frac{\partial^2\bar{v}}{\partial\bar{y}^2}\right] - \frac{\mu}{k}\bar{u}$$

$$+\sigma B_0^2 \sin\emptyset\,(\bar{u}\cos\emptyset - \bar{v}\sin\emptyset) - \rho g\cos\alpha \qquad (4)$$

$$\zeta\left(\frac{\partial T}{\partial \bar{t}} + \bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}}\right) = \frac{\kappa}{\rho}\left[\frac{\partial^2 T}{\partial \bar{x}^2} + \frac{\partial^2 T}{\partial \bar{y}^2}\right] + v_1\left[\left(\frac{\partial \bar{u}}{\partial \bar{y}} + \frac{\partial \bar{v}}{\partial \bar{x}}\right)^2 + 2\left(\left(\frac{\partial \bar{u}}{\partial \bar{y}}\right)^2 + \left(\frac{\partial \bar{v}}{\partial \bar{x}}\right)^2\right)\right] + \frac{\sigma B_0^2}{\rho}(\bar{u}\cos\emptyset - \bar{v}\sin\emptyset)^2 \qquad (5)$$

Where $\bar{u}, \bar{v}$ are the components of velocity along x and y direction ,$\bar{p}$ is the pressure, μ is the coefficient of viscosity of the fluid, β is the coefficient of thermal expansion, σ is the electrical conductivity of the fluid, k is the permeability parameter, B_0 is the applied magnetic field, α is the thermal diffusivity, v_1 is the kinematic viscosity, ρ is the density of the fluid, ζ is the specific heat at constant pressure, κ is the chemical reaction of rate constant, g is gravitational acceleration, $\emptyset$ is inclination angle of magnetic field, α is inclination angle of channel and T is the temperature.

The governing equation of motion of the flexible wall is expressed as

$$L^*(\bar{\eta}) = \bar{p} - \bar{p}_0 \qquad (6)$$

Where L^* is an operator, which is used to represent the motion of stretching membrane with viscosity damping forces such that

$$L^* = -\tau\frac{\partial^2}{\partial \bar{x}^2} + m\frac{\partial^2}{\partial \bar{t}^2} + C\frac{\partial}{\partial \bar{t}} + B\frac{\partial^4}{\partial \bar{x}^4} + H. \qquad (7)$$

Here τ is the elastic tension in the membrane, m is the mass per unit area, C is the coefficient of viscous damping forces, B is the flexural rigidity of the plate, H is the spring stiffness and p_0 is the pressure on the outside surface of the wall due to the tension in the muscles and assume that $\bar{p}_0 = 0$.

The associated boundary condition for the velocity slip and temperature at the wall interface are given by

$$\bar{u} = \mp\beta^*\frac{\partial \bar{u}}{\partial \bar{y}}, \qquad T = T_0 \qquad at\ \bar{y} = \pm\bar{\eta} = \pm\left[d + a\,sin\frac{2\pi}{\lambda}(\bar{x} - c\bar{t}) + \bar{m}\bar{x}\right] \qquad (8)$$

And the boundary conditions due to wall flexibility are

$$\frac{\partial}{\partial \bar{x}}L^*(\bar{\eta}) = \frac{\partial \bar{p}}{\partial \bar{x}} = \mu\left[\frac{\partial^2 \bar{u}}{\partial \bar{x}^2} + \frac{\partial^2 \bar{u}}{\partial \bar{y}^2}\right] - \rho\left[\frac{\partial \bar{u}}{\partial \bar{t}} + \bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}}\right] - \frac{\mu}{k}\bar{u} - \sigma B_0^2\cos\emptyset\,(\bar{u}\cos\emptyset - \bar{v}\sin\emptyset) + \rho g\sin\alpha \qquad at\ \ \bar{y} = \pm\bar{\eta} \qquad (9)$$

III. DIMENSIONLESS ANALYSIS

To make the Equations (2)-(9) non-dimensional, it is convenient to introduce the following non-dimensional variables and parameters:

$$x = \frac{\bar{x}}{\lambda},\ \ y = \frac{\bar{y}}{\lambda},\ \ t = \frac{c\bar{t}}{\lambda},\ \ \eta = \frac{\bar{\eta}}{d},\ \ p = \frac{d^2\bar{p}}{c\lambda\mu},\ \ \theta = \frac{T - T_0}{T_0},\ \ \epsilon = \frac{a}{d},\ \ \delta = \frac{d}{\lambda},\ \ R = \frac{\rho c d}{\mu},\ \ M = \sqrt{\frac{\sigma}{\mu}}B_0 d,\ \ K = \frac{k}{d^2},$$
$$Pr = \frac{\rho v_1 \zeta}{k},\ \ Ec = \frac{c^2}{\zeta T_0},\ \ \beta = \frac{\beta^*}{d},\ \ E_1 = \frac{-\tau d^3}{\lambda^3 \mu c},\ \ E_2 = \frac{m c d^3}{\lambda^3 \mu},\ \ E_3 = \frac{C d^3}{\lambda^2 \mu},\ \ E_4 = \frac{B d^3}{c\mu\lambda^5},\ \ E_5 = \frac{H d^3}{\lambda c \mu}, m = \frac{\bar{m}\lambda}{d},$$
$$v_1 = \frac{\mu}{\rho},\ \ Fr = \frac{c^2}{gd} \qquad (10)$$

Where $R, \delta, M, K, Pr, Ec, \beta, Fr$ and E_1, E_2, E_3, E_4, E_5 are the Reynolds number, wave number, Hartmann number, permeability parameter, Prandtl number, Eckert number, Velocity slip parameter, Froude number and wall compliant parameters.

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Introducing the stream function ψ ($u = \frac{\partial\psi}{\partial y}$, $v = -\frac{\partial\psi}{\partial x}$), equations (2)-(9) can be written as:

$\frac{\partial^2\psi}{\partial x\partial y} - \frac{\partial^2\psi}{\partial x\partial y} = 0$ (mean continuity equation automatically satisfied) (11)

$$\delta R\left[\frac{\partial^2\psi}{\partial t\partial y} + \frac{\partial\psi}{\partial y}\frac{\partial^2\psi}{\partial x\partial y} - \frac{\partial\psi}{\partial x}\frac{\partial^2\psi}{\partial y^2}\right] = -\frac{\partial p}{\partial x} + \delta^2\frac{\partial^3\psi}{\partial x^2\partial y} + \frac{\partial^3\psi}{\partial y^3} - \frac{1}{K}\frac{\partial\psi}{\partial y} - M^2\cos\emptyset\,(\frac{\partial\psi}{\partial y}\cos\emptyset + \delta\frac{\partial\psi}{\partial x}\sin\emptyset) + \frac{R}{Fr}\sin\alpha \quad (12)$$

$$\delta^3 R\left(-\frac{\partial\psi}{\partial t\partial x} - \frac{\partial\psi}{\partial y}\frac{\partial^2\psi}{\partial x^2} + \frac{\partial\psi}{\partial x}\frac{\partial^2\psi}{\partial y\partial x}\right) = -\frac{\partial p}{\partial y} + \delta^2\left[-\delta^2\frac{\partial^3\psi}{\partial x^3} - \frac{\partial^3\psi}{\partial y^2\partial x}\right] - \frac{\delta}{K}\frac{\partial\psi}{\partial y} + \delta M^2\sin\emptyset\,(\frac{\partial\psi}{\partial y}\cos\emptyset + \delta\frac{\partial\psi}{\partial x}\sin\emptyset) - \frac{\delta R}{Fr}\cos\alpha \quad (13)$$

$$\delta R\left(\frac{\partial\theta}{\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial\theta}{\partial x} - \frac{\partial\psi}{\partial x}\frac{\partial\theta}{\partial y}\right) = \frac{1}{Pr}\left[\delta^2\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right] + Ec\left[\left(\frac{\partial^2\psi}{\partial y^2} - \delta^2\frac{\partial^2\psi}{\partial x^2}\right)^2 + 4\delta^2\left(\frac{\partial^2\psi}{\partial xy}\right)^2\right] + Ec\,M^2\left(\frac{\partial\psi}{\partial y}\cos\emptyset + \delta\frac{\partial\psi}{\partial x}\sin\emptyset\right)^2 \quad (14)$$

$$\frac{\partial\psi}{\partial y} = \mp\beta\frac{\partial^2\psi}{\partial y^2}, \quad \theta = 0 \quad at\ y = \pm\eta = \pm[1 + \epsilon\sin 2\pi(x - t) + mx] \quad (15)$$

$$\left[E_1\frac{\partial^3}{\partial x^3} + E_2\frac{\partial^3}{\partial t^2\partial x} + E_3\frac{\partial^2}{\partial t\partial x} + E_4\frac{\partial^5}{\partial x^5} + E_5\frac{\partial}{\partial x}\right](\eta) = \left[\delta^2\frac{\partial^3\psi}{\partial x^2\partial y} + \frac{\partial^3\psi}{\partial y^3}\right] - \delta R\left[\frac{\partial^2\psi}{\partial y\partial t} + \frac{\partial\psi}{\partial y}\frac{\partial^2\psi}{\partial x\partial y} - \frac{\partial\psi}{\partial x}\frac{\partial^2\psi}{\partial y^2}\right] - \frac{1}{K}\frac{\partial\psi}{\partial y} - M^2\cos\emptyset\left(\frac{\partial\psi}{\partial y}\cos\emptyset + \delta\frac{\partial\psi}{\partial x}\sin\emptyset\right) + \frac{R}{Fr}\sin\alpha \quad \text{at} \quad y = \pm\eta \quad (16)$$

With the assumption of long wavelength approximation and neglecting the wave number ($\delta \ll 1$) and small Reynolds number in equation (12)-(14) along with the boundary condition (15) and (16), we get

$$-\frac{\partial p}{\partial x} + \frac{\partial^3\psi}{\partial y^3} - A^2\frac{\partial\psi}{\partial y} + \frac{R}{Fr}\sin\alpha = 0 \quad (17)$$

$$-\frac{\partial p}{\partial y} = 0 \quad (18)$$

$$\frac{\partial^2\theta}{\partial y^2} + Br\left(\frac{\partial^2\psi}{\partial y^2}\right)^2 + H^2\left(\frac{\partial\psi}{\partial y}\right)^2 \quad (19)$$

The corresponding dimensionless boundary conditions are

$$\frac{\partial\psi}{\partial y} = \mp\beta\frac{\partial^2\psi}{\partial y^2}, \quad \theta = 0 \quad at\ y = \pm\eta = \pm[1 + \epsilon\sin 2\pi(x - t) + mx] \quad (20)$$

$$\left[E_1\frac{\partial^3}{\partial x^3} + E_2\frac{\partial^3}{\partial t^2\partial x} + E_3\frac{\partial^2}{\partial t\partial x} + E_4\frac{\partial^5}{\partial x^5} + E_5\frac{\partial}{\partial x}\right](\eta) = \frac{\partial^3\psi}{\partial y^3} - A^2\frac{\partial\psi}{\partial y} + \frac{R}{Fr}\sin\alpha \quad \text{at}\ y = \pm\eta \quad (21)$$

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Here $Br = \Pr Ec$ is the Brinkman number, $A^2 = M^2 \cos^2 \emptyset + \frac{1}{K}$ and $H^2 = M^2\, Br \cos \emptyset$.

IV. SOLUTION OF THE PROBLEM

The set of equations (17)-(19) are solved exactly for expression ψ and θ and it's found that:

$$\psi = \frac{e^{Ay} c1}{A^2} + \frac{e^{-Ay} c2}{A^2} + c3 + yc4 \qquad (22)$$

$$\theta = \frac{2c4 e^{-Ay}(c2 - c1 e^{2Ay})H^2}{A^3} - \frac{e^{-2Ay}(c2^2 + c1^2 e^{4Ay})H^2}{4A^4} - \mathrm{Br\,c1\,c2}\, y^2 - \frac{1}{2}\mathrm{c4}^2 H^2 y^2 + \frac{-\frac{1}{4}\mathrm{Br} e^{-2Ay}(\mathrm{c2}^2 + \mathrm{c1}^2 e^{4Ay}) + \mathrm{c1c2}\, H^2 y^2}{A^2} + \mathrm{b1} + y * \mathrm{b2} \qquad (23)$$

The velocity can be written as:

$$u = \frac{\partial \psi}{\partial y} = c4 - \frac{c2\, e^{-Ay}}{A} + \frac{c1\, e^{Ay}}{A} \qquad (24)$$

By the boundary conditions (20) and (21), we can find the constant value c1, c2, c3, c4, b1, b2 which are:

$$c1 = (e^{A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}\ (\mathrm{E5Fr}m + 2\mathrm{Fr}\pi(\mathrm{E5} - 4\pi^2\ (\mathrm{E1} + \mathrm{E2} - 4\mathrm{E4}\pi\text{^}2\ )\ )\epsilon \mathrm{Cos}[2\pi(-t+x)\ ] + 4\mathrm{E3Fr}\pi^2\ \epsilon \mathrm{Sin}[2\pi(-t+x)\ ] - R\mathrm{Sin}[\alpha]\ ))/a\mathrm{Fr}(1 - A\beta + e^{2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}\ (1 + A\beta)\ )$$

$$c2 = -((\mathrm{e}^{\mathrm{A}\ (1+\mathrm{m}\ \mathrm{x}+\epsilon\ \mathrm{Sin}\ [2\ \pi\ (-\mathrm{t}+\mathrm{x})])}\ (\mathrm{E5\ Fr\ m} + 2\ \mathrm{Fr}\ \pi\ (\mathrm{E5} - 4\ \pi^2\ (\mathrm{E1} + \mathrm{E2} - 4\ \mathrm{E4}\ \pi^2))\ \epsilon\ \mathrm{Cos}[2\ \pi\ (-\mathrm{t} + \mathrm{x})] + 4\ \mathrm{E3\ Fr}\ \pi^2\ \epsilon\ \mathrm{Sin}[2\ \pi\ (-\mathrm{t}+\mathrm{x})] - \mathrm{R\ Sin}[\alpha]))/(\mathrm{A\ Fr}\ (1 - \mathrm{A}\ \beta + \mathrm{e}^{2\ \mathrm{A}\ (1+\mathrm{m}\ \mathrm{x}+\epsilon\ \mathrm{Sin}\ [2\ \pi\ (-\mathrm{t}+\mathrm{x})])}\ (1 + \mathrm{a}\ \beta))))$$

$$c3 = 0$$

$$c4 = \frac{-\mathrm{E5Fr}m - 2\mathrm{Fr}\pi(\mathrm{E5} - 4\pi^2(\mathrm{E1} + \mathrm{E2} - 4\mathrm{E4}\pi^2))\epsilon \mathrm{Cos}[2\pi(-t+x)] - 4\mathrm{E3Fr}\pi^2 \epsilon \mathrm{Sin}[2\pi(-t+x)] + R\mathrm{Sin}[\alpha]}{A^2 \mathrm{Fr}}$$

$$\mathrm{b1} = \frac{1}{8A^4} e^{-2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}(8A(\mathrm{c1} - \mathrm{c2})\mathrm{c4} e^{A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}(1 + e^{2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])})H^2 + (\mathrm{c1}^2 + \mathrm{c2}^2)(1 + e^{4A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])})H^2 + 4A^4 e^{2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}(2\mathrm{Brc1c2} + \mathrm{c4}^2 H^2)(1+mx)^2 + A^2(\mathrm{Br}(\mathrm{c1}^2 + \mathrm{c2}^2)(1 + e^{4A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}) - 8\mathrm{c1c2} e^{2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}(H + Hmx)^2) + 8A^2 e^{2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}(-2\mathrm{c1c2}H^2 + A^2(2\mathrm{Brc1c2} + \mathrm{c4}^2 H^2))(1+mx)\epsilon \mathrm{Sin}[2\pi(-t+x)] + 4A^2 e^{2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)])}(-2\mathrm{c1c2}H^2 + A^2(2\mathrm{Brc1c2} + \mathrm{c4}^2 H^2))\epsilon^2 \mathrm{Sin}[2\pi(-t+x)]^2)$$

$$\mathrm{b2} = ((\mathrm{c1} + \mathrm{c2}) e^{(-2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)]))}\ (-1 + e^{(2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)]))})(A^2\ \mathrm{Br}(\mathrm{c1} - \mathrm{c2})(1 + e^{(2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)]))}) + 8A\mathrm{c4} e^{(A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)]))}\ H^2 + (\mathrm{c1} - \mathrm{c2})(1 + e^{(2A(1+mx+\epsilon \mathrm{Sin}[2\pi(-t+x)]))})H^2))/(8A^4\ (1 + mx + \epsilon \mathrm{Sin}[2\pi(-t+x)]))$$

All the solution in this section are made by using MATHEMATICA package.

V. RESULT AND DISCUSSION

The purpose of this section is to study the influences of various parameters on the velocity, temperature and stream line (see figures (2)-(45)).

In the present study following default parameters value are adopted for computations: $E_1 = 1$, $E_2 = 0.5$, $E_3 = 0.5$, $E_4 = 0.2$, $E_5 = 0.1$, $K = 0.1$, $Br = 0.7$, $\beta = 0.1$, $M = 1$, $m = 0.1$, $t = 0.1$, $\epsilon = 0.1$, $R =$

0.2, $Fr = 1.2$, $\emptyset = \frac{\pi}{3}$, $\alpha = \frac{\pi}{3}$ and $x = 0.4$. All graphs therefore correspond to these values unless specifically indicated on the appropriate graph.

All the results in this section are made through plotting by using MATHEMATICA package.

stream line

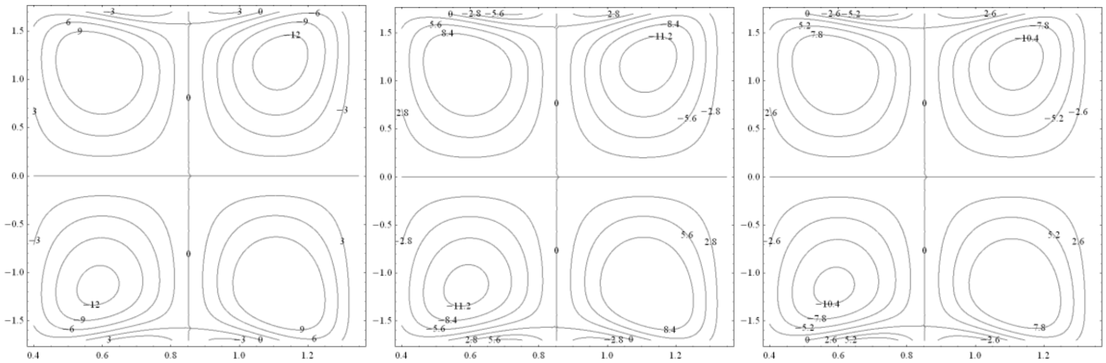
The formation of internally circulating bolus of fluid through closed stream line is called trapping and this trapped bolus is pushed ahead along with the peristaltic wave. The effect of $M, K, \beta, E_1, E_2, E_3, E_4, E_5, m, t, \epsilon, R, Fr, \emptyset, \alpha$ can be seen through figures (2)-(12) respectively. It reveals that the volume of the trapped bolus deceases with increase Hartmann number M. Notice that the stream line closed loops creating a cellular flow pattern in the channel and trapped bolus increases in size as permeability parameter K increases. The size of the trapping bolus increase with increasing slip parameter β. The effect of wall complaint parameters obtain as the size of trapped bolus increases by increasing E_4 while it decrease with increasing E_1, E_2, E_3 and not change with increase E_5. Also the size of the trapping bolus increases with increasing non-uniform parameter m, time t inclination angle of magnetic field $\emptyset$ and ϵ. While the size of the trapping bolus don't effect with change Reynolds number$R$, Froude number Fr and inclination angle of channel α.

Variation of temperature

The temperature profiles for various values of $M, \beta, x, K, m, Br, \epsilon, t, E_1, E_2, E_3, E_4, E_5, R, Fr, \emptyset, \alpha$ can be seen through figures (13)-(29) respectively. We observe that the temperature decreases with increasing velocity slip parameter β, and inclination angle of magnetic field $\emptyset$. While the opposite behavior for the permeability parameter K, Hartmann number M, non-uniform parameter m, Brinkman number Br, Reynolds number R, time t, x and ϵ.. The effect of wall complaint parameters obtain as the temperature increases by increasing E_4 while it decrease with increasing E_1, E_2, E_3, and it's not change with change E_5. But the temperature don't effect with change Froude number Fr and the inclination angle of channel α.

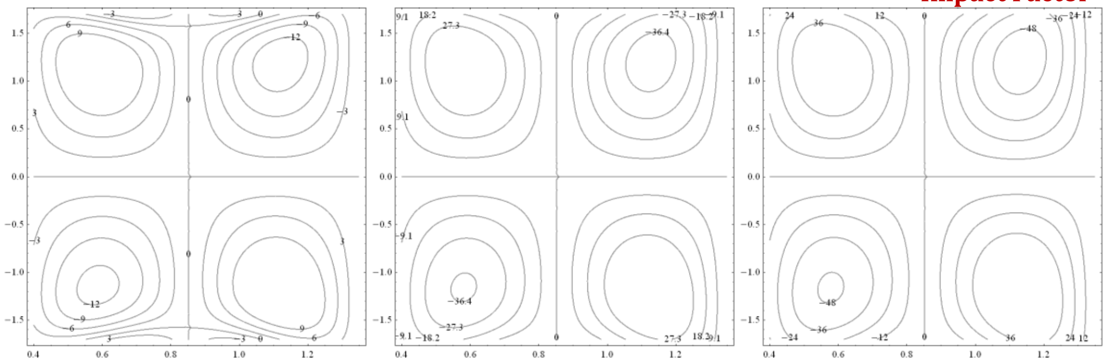
Variation of velocity

The influence of $M, K, t, \beta, m, x, \epsilon, E_1, E_2, E_3, E_4, E_5, R, Fr, \emptyset, \alpha$ on the velocity distribution can see graphically in figures (30)-(45) respectively. It reveals that increasing Hartmann number M, leads to fall in the velocity because the effect of increasing in magnetic field strength dampens the velocity. The effect of permeability parameter K that when it increasing the velocity leads to enhance. An increasing K means reduce the drag force and hence cause the flow velocity to increase. Also the velocity decreases with increasing time t. The velocity increases with increasing velocity slip parameter β, non-uniform parameter m, Reynolds number M, inclination angle of magnetic field $\emptyset$, x and ϵ. The effect of wall compliant parameters that obtain as the velocity increases with increasing E_4 and decreases with increasing E_1, E_2, E_3 But the velocity not change by change E_5. While the velocity don't effect when changing Froude number Fr and the inclination angle of channel α.



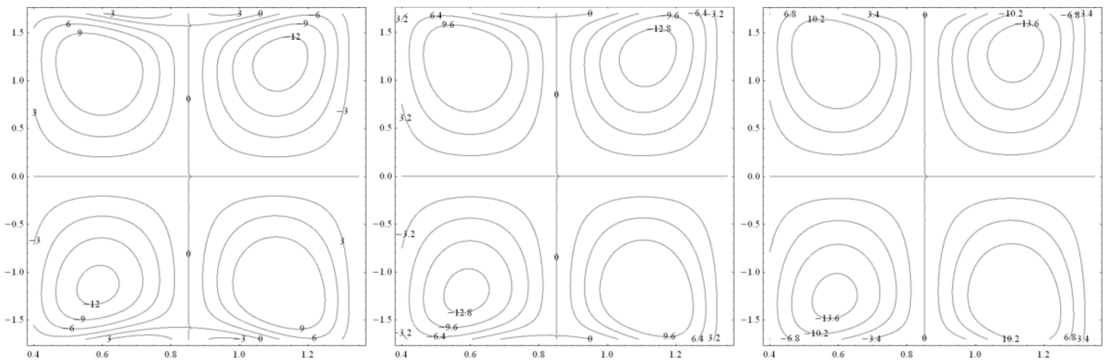
(a) (b) (c)

Fig (2) Stream line for (a) $M = 1$, (b) $M = 2$, (c) $M = 3$



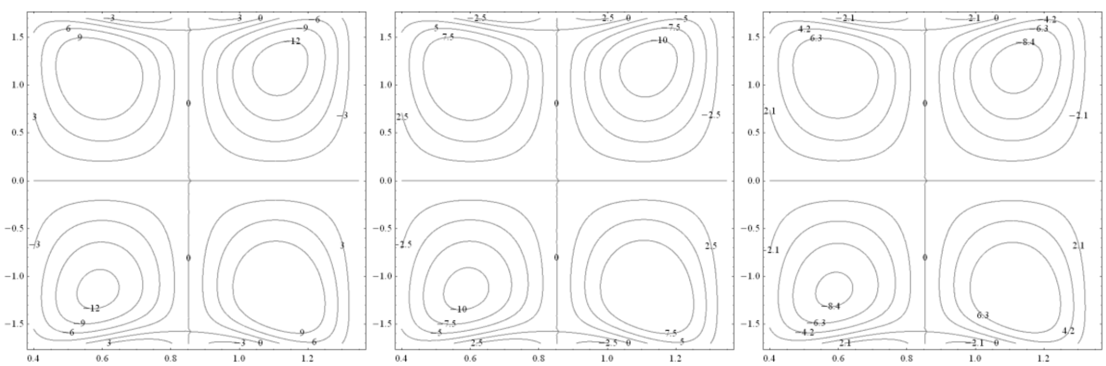
$(\boldsymbol{a})$ $(\boldsymbol{b})$ $(\boldsymbol{c})$

Fig (3) Stream line for (a) $\boldsymbol{K = 0.1}$, ***(b)*** $\boldsymbol{K = 0.5}$, ***(c)*** $\boldsymbol{K = 1}$



$(\boldsymbol{a})$ $(\boldsymbol{b})$ $(\boldsymbol{c})$

Fig (4) Stream line for (a) $\boldsymbol{\beta = 0.1}$, ***(b)*** $\boldsymbol{\beta = 0.2}$, ***(c)*** $\boldsymbol{\beta = 0.3}$



$(\boldsymbol{a})$ $(\boldsymbol{b})$ $(\boldsymbol{c})$

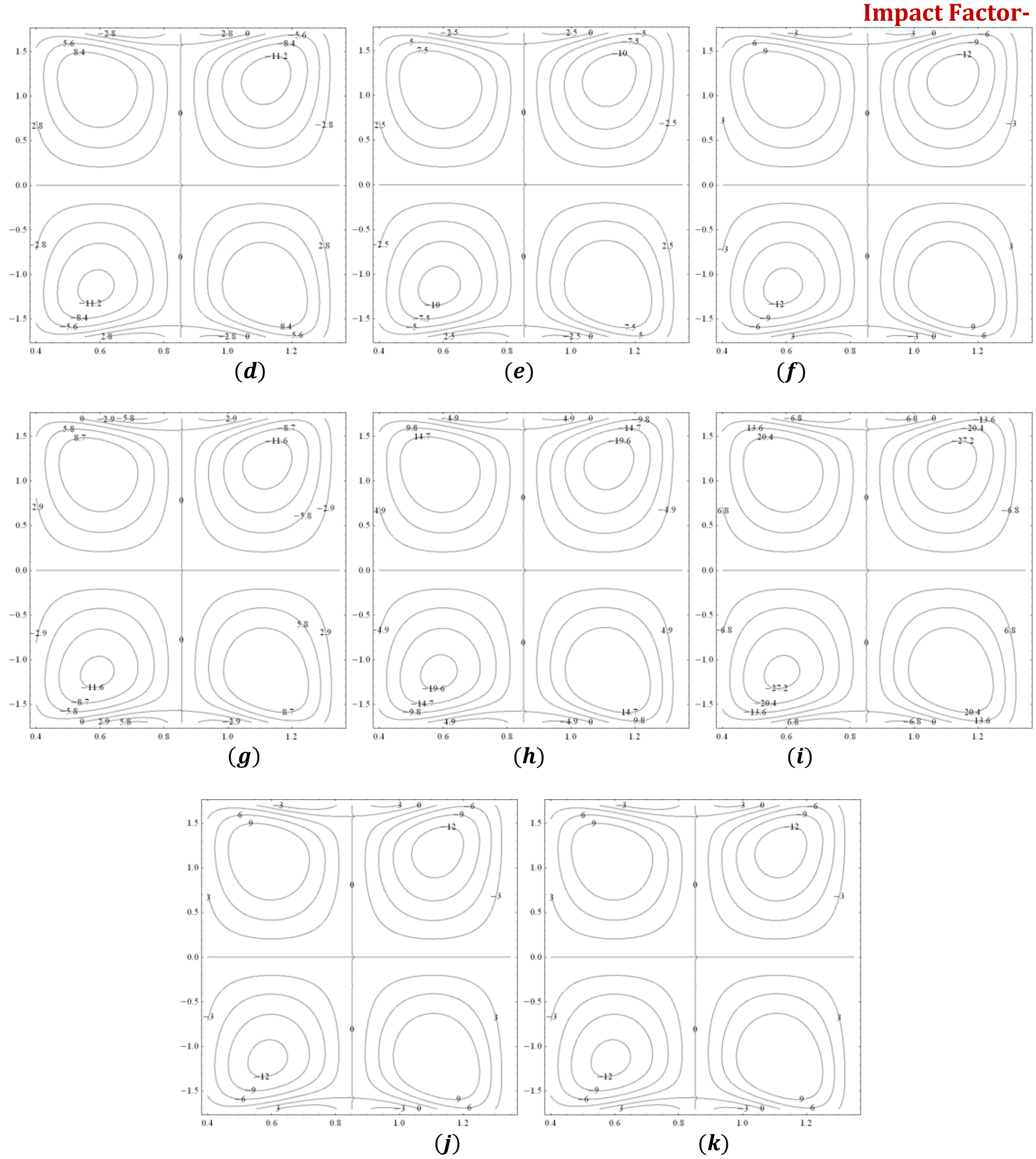


Fig (5) Stream line for (a) $E_1 = 1$, $(b) E_1 = 2$, $(c) E_1 = 3$, $(d) E_2 = 1$, $(e) E_2 = 1.5$, $(f) E_3 = 1$, $(g) E_3 = 1.5$, $(h) E_4 = 0.3$, $(i) E_4 = 0.4$, $(j) E_5 = 0.5$, $(k) E_5 = 1$

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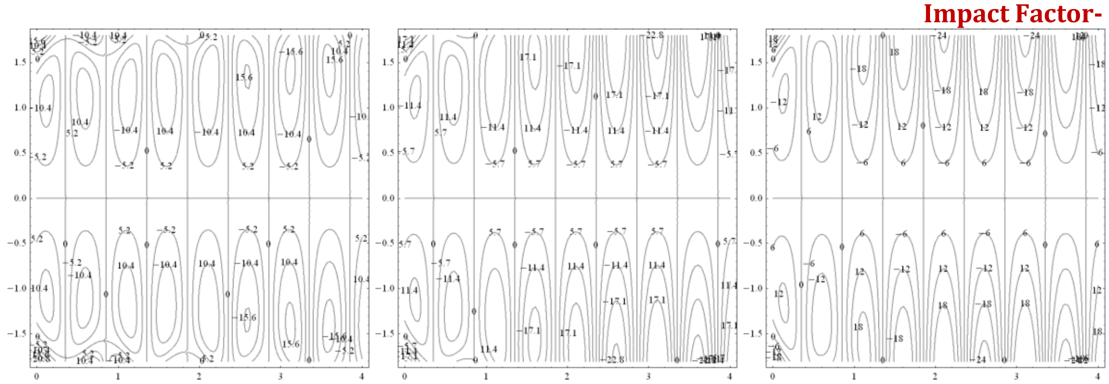
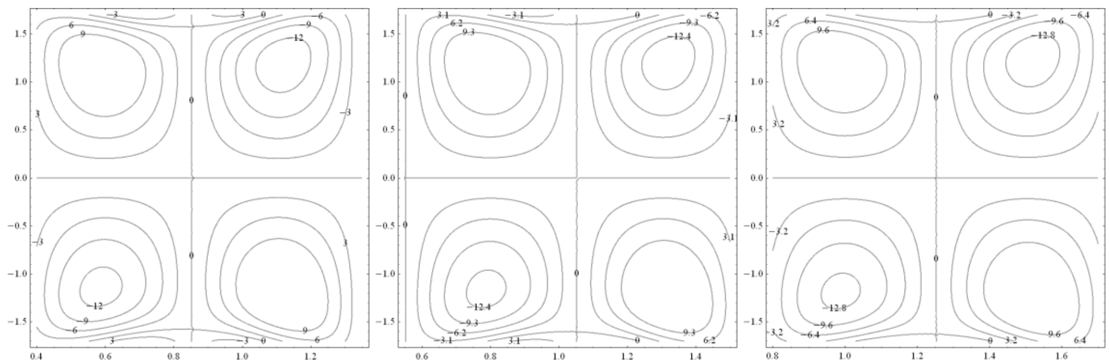


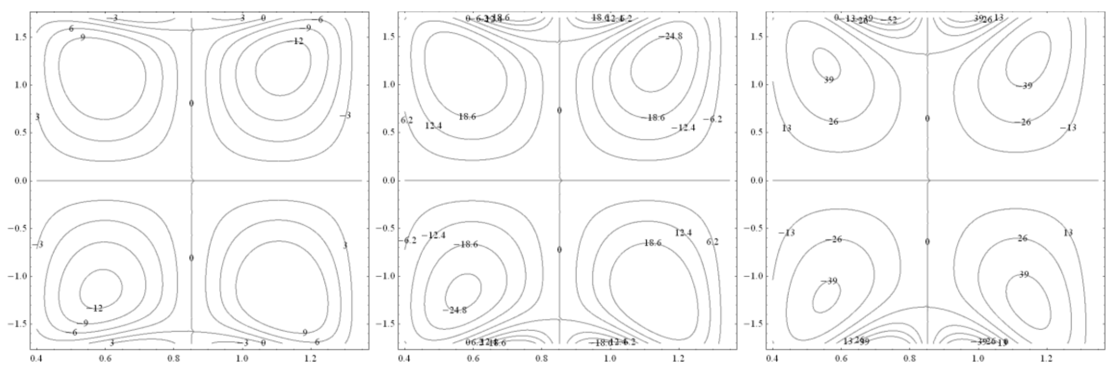
(a) (b) (c)

Fig (6) Stream line for $(a)\ m = 0.1,\ (b)\ m = 0.3,\ (c)\ m = 0.5$



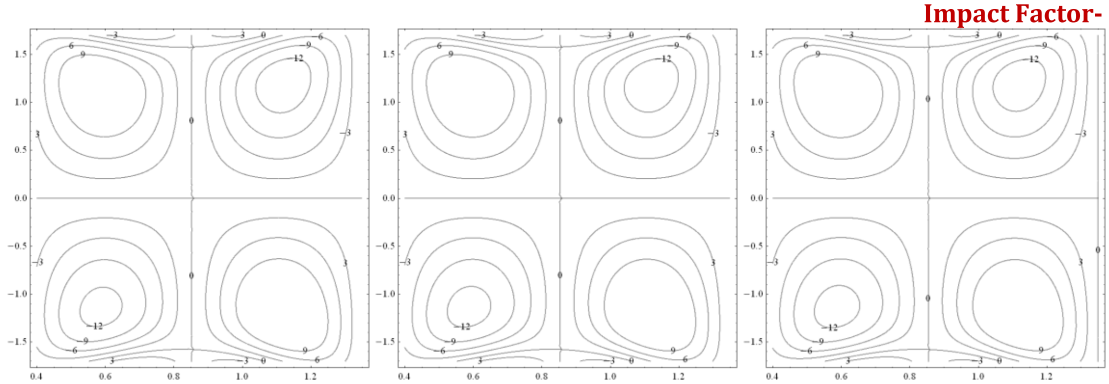
(a) (b) (c)

Fig (7) Stream line for $(a)\ t = 0.1,\ (b)\ t = 0.3,\ (c)\ t = 0.5$



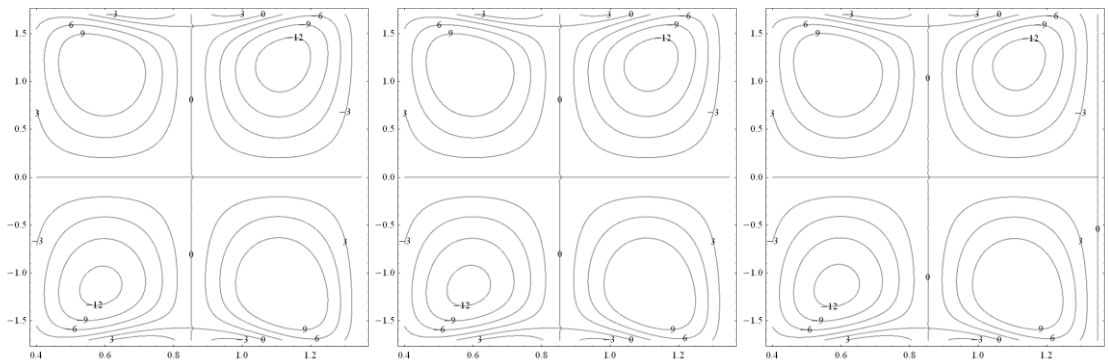
(a) (b) (c)

Fig (8) Stream line for $(a)\ \epsilon = 0.1,\ (b)\ \epsilon = 0.2,\ (c)\ \epsilon = 0.3$



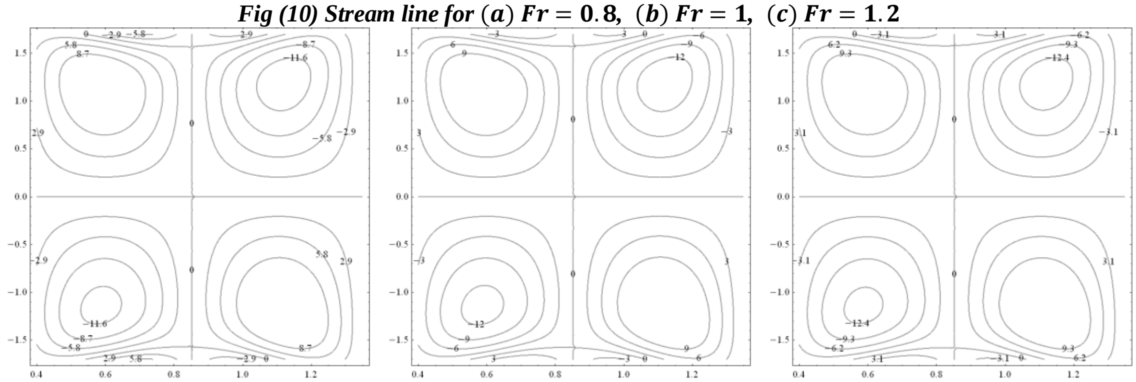
(a) (b) (c)

Fig (9) Stream line for $(a)\ R = 0.2,\ (b)\ R = 1,\ (c)\ R = 2$



(a) (b) (c)

Fig (10) Stream line for $(a)\ Fr = 0.8,\ (b)\ Fr = 1,\ (c)\ Fr = 1.2$



(a) (b) (c)

Fig (11) Stream line for $(a)\ \emptyset = \frac{\pi}{6},\ (b)\ \emptyset = \frac{\pi}{3},\ (c)\ \emptyset = \frac{\pi}{2}$

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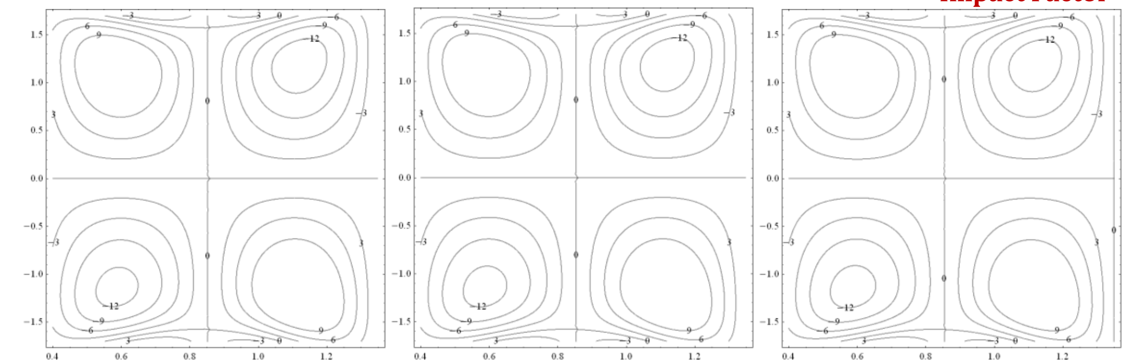
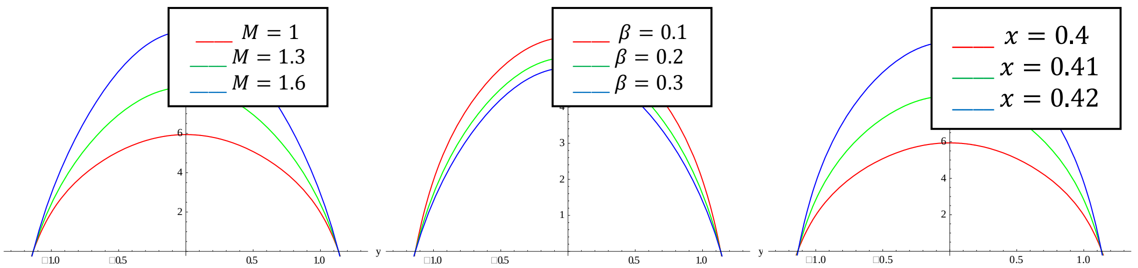
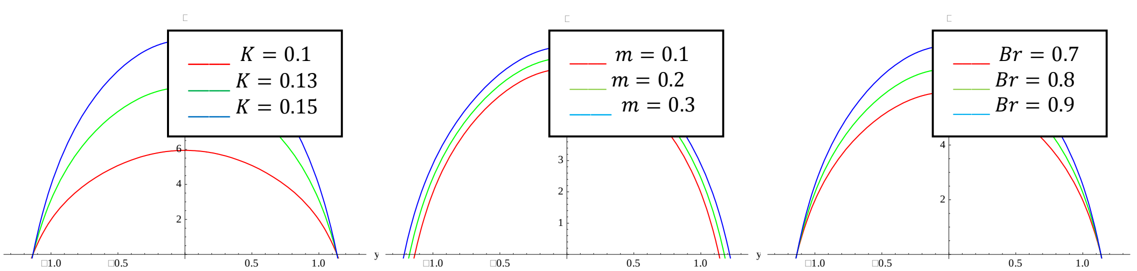


$(\boldsymbol{a})$ $(\boldsymbol{b})$ $(\boldsymbol{c})$

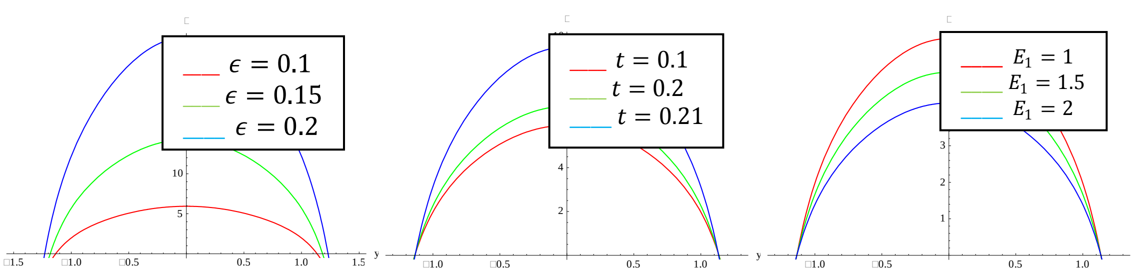
Fig (12) Stream line for $(\boldsymbol{a})\ \boldsymbol{\alpha}=\frac{\pi}{6}$, $(\boldsymbol{b})\ \boldsymbol{\alpha}=\frac{\pi}{3}$, $(\boldsymbol{c})\ \boldsymbol{\alpha}=\frac{\pi}{2}$



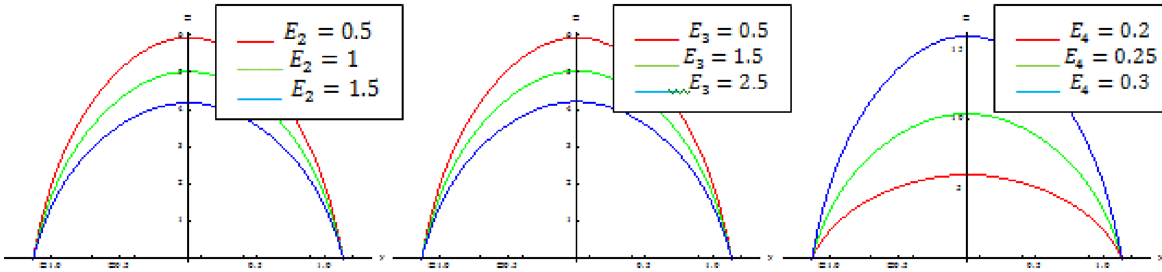
Figs. (13)-(15) variation of temperature θ for different value of $\boldsymbol{M}, \boldsymbol{\beta}, \boldsymbol{x}$ ***respectively***



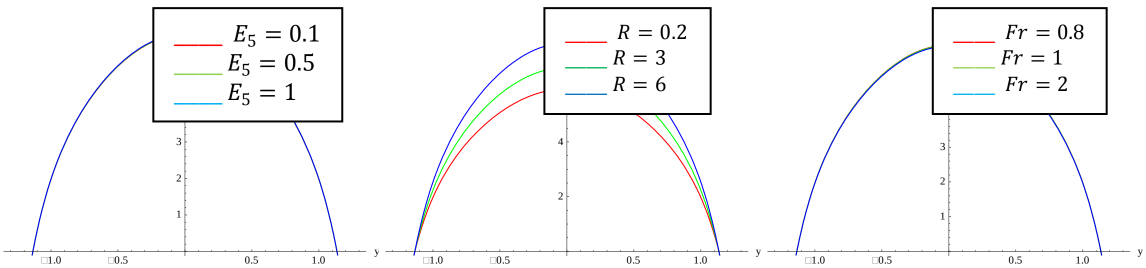
Figs. (16)-(18) variation of temperature θ for different value of $\boldsymbol{K}, \boldsymbol{m}, \boldsymbol{Br}$ ***respectively***



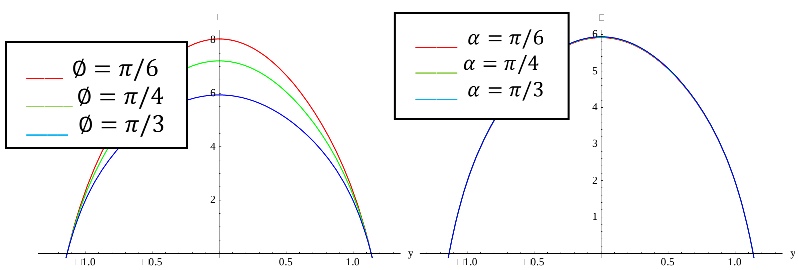
Figs. (19)-(21) variation of temperature θ for different value of $\boldsymbol{\epsilon}, \boldsymbol{t}, \boldsymbol{E_1}$ ***respectively***



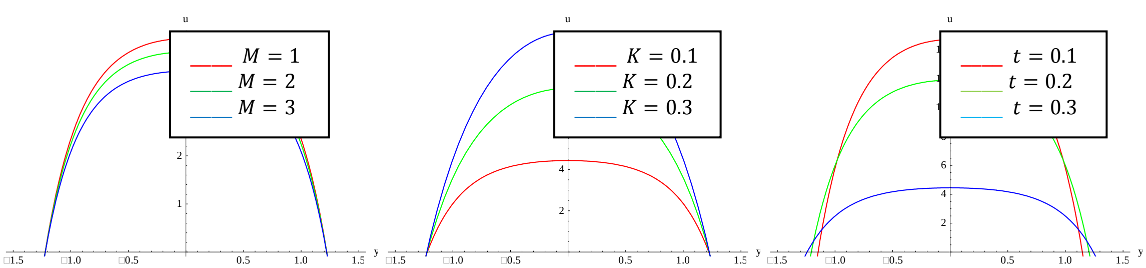
Figs. (22)-(24) variation of temperature θ for different value of E_2, E_3, E_4 respectively



Figs. (25)-(27) variation of temperature θ for different value of E_5, R, Fr respectively



Figs. (28), (29) variation of temperature θ for different value of $\emptyset$, α respectively



Figs. (30)-(32) variation of velocity u for different value of M, K, t respectively

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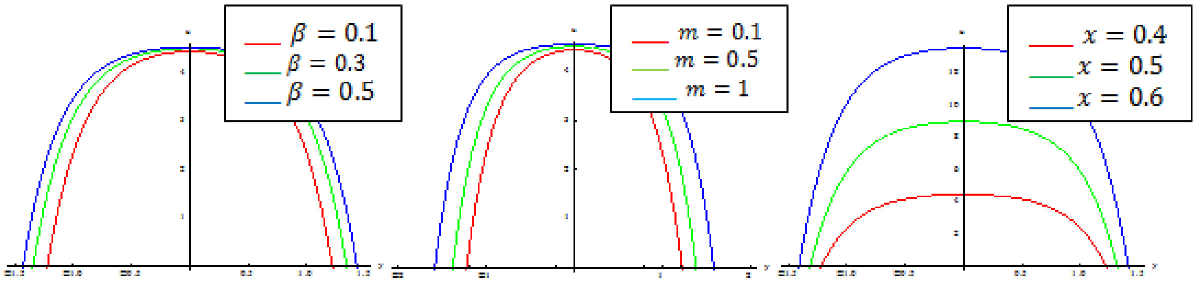
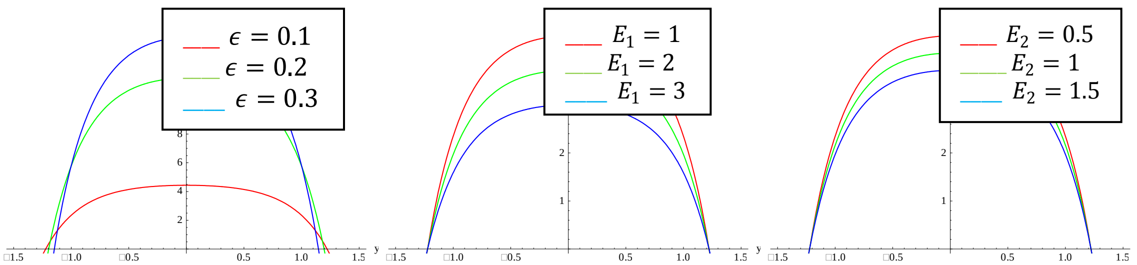
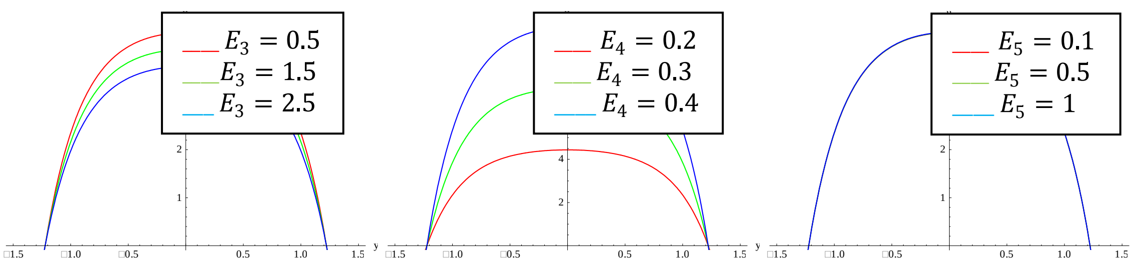


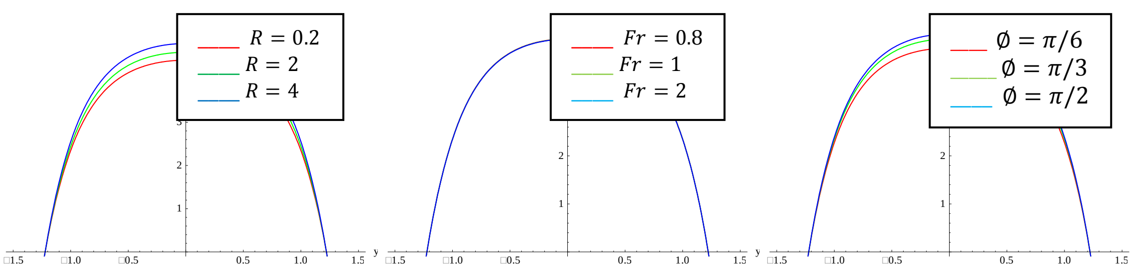
Figs. (33)-(35) variation of velocity u for different value of β, m, x respectively



Figs. (36)-(38) variation of velocity u for different value of ϵ, E_1, E_2 respectively



Figs. (39)-(41) variation of velocity u for different value of E_3, E_4, E_5 respectively



Figs. (42)-(44) variation of velocity u for different value of $R, Fr, \emptyset$ respectively

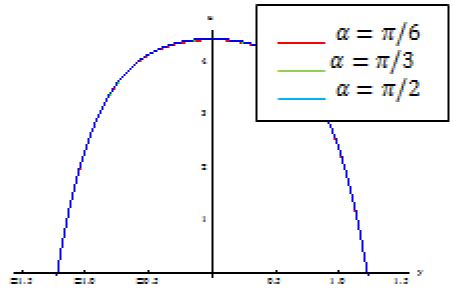


Fig. (45) variation of velocity u *for different value of* α *respectively*

VI. CONCLUSION

The influence of velocity slip on MHD peristaltic flow through a porous medium with heat transfer, inclined channel and inclined magnetic field is investigated. The exact solutions for stream function and temperature have been developed. The features of the flow characteristics are analyzed by plotting graphs and discussed in detail. The important findings of the present study are as follows:

1- The size of trapped bolus increases with increasing slip parameter β, permeability parameter K, non-uniform parameter m, time t wall compliant parameters E_4 , inclination angle of magnetic field $\emptyset$ and ϵ.
2- The size of trapped bolus decreases with increasing Hartmann number M and wall compliant parameters E_1 , E_2 , E_4
3- The size of the trapped bolus don't effect with change Reynolds number R, Froude number Fr and inclination angle of channel α.
4- The temperature field increases with an increase in permeability parameter K, non-uniform parameter m, Brinkman number Br, wall compliant parameters E_4 , Hartmann number M, time t, Reynolds number R, x and ϵ.
5- The temperature field decreases with an increase in velocity slip parameter β, wall compliant parameters E_1 , E_2 , E_3 and inclination angle of magnetic field $\emptyset$
6- The velocity field increases by increasing permeability parameter K, velocity slip parameter β, non-uniform parameter m, wall compliant parameter E_4, Reynolds number R, inclination angle of magnetic field $\emptyset$, x and ϵ.
7- The velocity field decreases by increasing Hartmann number M, wall compliant parameters E_1, E_2, E_3 and time t.
8- The temperature and velocity field does not effected via changing Froude number Fr, inclination angle of channel α, wall compliant parameter E_5.

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