Effect of Thickness of Porous Lining on the Peristaltic Transport of a Conducting Fluid in an Inclined Channel Bounded By Flexible Walls Coated With Porous Material

N.Naga Jyothi, P.Devaki, S.Sreenadh

Abstract— **Peristaltic pumping of a conducting fluid in a channel lined with porous material is investigated under long wavelength and low Reynolds number assumptions. The expressions for velocity distribution, the volume flow rate, the pressure rise and the frictional force are obtained and are discussed through graphs for various values of physical parameters of interest. The effect of thickness of porous lining on the peristaltic pumping is discussed graphically. Besides the phenomena of trapping is analyzed for the thickness of porous lining, Darcy number and the magnetic parameter.**

Index Terms— **Peristaltic Pumping, Porous lining, Conducting fluid, Flexible walls, Porous material.**

I. INTRODUCTION

Peristalsis is now well known to the physiologists as one of the major mechanisms for fluid transport in many biological systems. When a tract is filled with the fluid e.g. water, blood, secretions etc, because of distension of tract, the waves of contraction and expansion make crust and trough that occur along the walls of the tract. These waves are known as the peristaltic waves which push ahead the fluid contents in the tract. Peristalsis is used by a living body to propel or to mix the contents of the tube such as, in transport of urine from the kidney through the ureter to the bladder, food through the digestive tract, bile from the gall-bladder into the duodenum, movement of ovum in the fallopian tube, movement of chyme in the gastrointestinal tract and in the vasomotion of small blood vessels as well as blood flow in arteries. Now a day's scientists and engineers are trying to advance their models where the fluid flow is governed by the peristalsis.The first attempt to study the aspects of peristaltic transport with an experimental investigation was done by Latham [1]. A complete review of peristaltic transport is given by Jaffrin and Shapiro [2]. Rath [3] made studies on peristalsis for different cross sectional shapes and Bohme and Friedrich [4] investigated the peristaltic flow of viscoelastic liquids. Peristaltic transport of a Bingham fluid in contact with a Newtonian fluid was studied by Narahari and Sreenadh [5]. Rami Reddy and Venkataramana [6] have studied the peristaltic motion of viscous conducting fluid through a porous medium in an asymmetric vertical channel by using lubrication approach. Nadeem and Akbar [7] have studied the effects of mixed convection heat and mass transfer on peristaltic flow of Williamson fluid model in a vertical annulus. The dispersion of a solute in the peristaltic flow of a Jeffrey fluid in the presence of both homogeneous and heterogeneous chemical reaction has been discussed by Ravi Kiran and Radhakrishnamacharya [8]. The peristaltic flow of a Jeffrey fluid in an asymmetric channel has been investigated by Abd-Alla et al. [9]. The influence of hall, heat and mass transfer on the peristaltic flow of MHD third order fluid is investigated by Eldabe et al. [10]

MHD which studies the dynamics of electrically conducting fluids include planner liquid metals and saltwater or electrolytes. The idea of MHD is that magnetic fields can induce currents in a moving conducting field, which create forces on the fluid and also change the magnetic field itself. This MHD is applied to study several aspects in Geophysics (earth's core), Astrophysics (solar wind which is governed by MHD). MHD relates to engineering problems such as plasma confinement, liquid- metal cooling of nuclear reactors and electromagnetic casting (among others).It has been established that the biological systems, in general are greatly addicted by the application of the external magnetic field. More over the MHD flow of a fluid in a channel with elastic rhythmically contracting walls (Peristaltic Flow) is of interest in connection with certain problems of the movement of conductive physiological fluids e.g. the blood and blood pump machines and with the need for theoretical resource on the operation of a peristaltic MHD compressor, also the principle of magnetic fluid may be used in clinical application MRI (magnetic resonance imaging).

The study of peristaltic flow of a fluid in the presence of magnetic field is of enormous importance with regard to certain problems involving the movement of conductive physiological fluids, e.g., blood and saline water. Sud et al. [11] have first investigated the effect of moving magnetic field on the blood flow. They found that a suitable moving magnetic field accelerates the speed of blood. Srivastava and Agrawal [12] considered the blood as an electrically conducting fluid and that it constitutes a suspension of red cells in plasma. Hayat et al. [13] have discussed the peristaltic transport of a third order fluid under the effect of a magnetic field. The wall properties on the MHD peristaltic flow of a Maxwell fluid with heat and mass transfer are studied by Hayat and Hina [14]. Singh and Rathee [15] studied the non-Newtonian effects on the blood flow through stenosed vessel in the presence of magnetic field and porous space. Peristaltic transport of conducting fluid in a composite region between two flexible walls is investigated under the assumptions of long wavelength and low Reynolds number by

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Sreenadh et al. [16]. The effect of heat generation and radiation on the peristaltic motion of micropolar fluid with heat and mass transfer through porous medium in a symmetric channel was investigated by Eldabe et al. [17]. A theoretical study on the effects of magnetohydrodynamics on the peristaltic flow of Jeffrey fluid in a rectangular duct by Ellahi et al. [18], under low Reynold number and long wavelength assumptions. The effect of magnetic field with heat and mass transfer for the flow of peristaltic pumping of a conducting non-Newtonian fluid obeying Sisko model through porous medium is analyzed by El-Dabe et al. [19].

Viscous fluid flows through or past porous media is of fundamental importance in many areas of applied science and engineering. In recent years considerable interest has been developed in the study of the flow through porous media because of its important application to ground water hydrology and petroleum industry. The concept of porous media is used by petroleum engineers in seepage problems arising in extraction of petroleum from oil wells. Using this knowledge of flow through porous media, biologists study the water movement through plants. Abnormal flow of blood in the arteries occurs due to formation of stenosis. The artery will get narrow because of stenosis.The blood in the artery will be bounded by a thin layer of tissue. The situation can be idealized to the flow through a channel of varying gap bounded by permeable walls (where the thin layer can be thought of as a porous medium). Thus the study of flows involving porous media acquires biomedical significances. Recently so many works are done on the MHD flows in a porous medium.

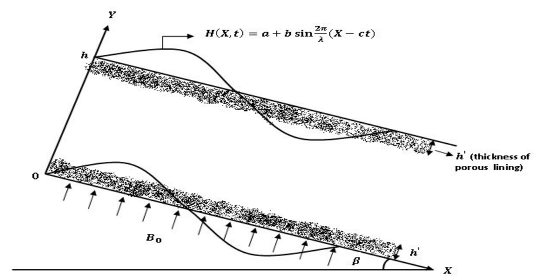
Some studies about this point have been made by Varshney [20], Raptis and Perdikis [21] and El-Dabe and El-Mohendis [22]. Srinivas and Kothandapani [23] analyzed the peristaltic transport in an asymmetric channel with heat transfer. Srinivas and Gayathri [24] have studied peristaltic transport of a Newtonian fluid in a vertical symmetrical channel with heat transfer and porous medium. Vajravelu et al. [25] studied the influence of heat transfer on the peristaltic transport of Jeffrey fluid in a vertical porous stratum. Effect of thickness of the porous material on the peristaltic pumping when the tube wall is provided with non-erodible porous lining has been studied by Hemadri et al. [26]. Rathod et al. [27] discussed the effect of thickness of porous material on the peristaltic pumping of couple stress fluid when the tube wall is provided with non-erodible porous lining. Devaki et al. [28] have considered the pulsatile flow of a Jeffrey fluid in a circular tube lined internally with porous material. Eldabe et al. [29] studied the peristaltic motion of non-Newtonian fluid with heat and mass transfer through a porous medium in channel under uniform magnetic field. Santhosh et al.. [30] studied the effects of porous medium on a two fluid model for the flow of Jeffrey fluid in tubes of small diameters.

In practical problems involving flow past a porous lining it is necessary to involve directly the thickness of the porous lining to have an increase in the mass flow rate. Motivated by this the peristaltic pumping of a conducting fluid in a channel lined with porous material is investigated under long wavelength and low Reynolds number assumptions. The velocity distribution, the volume flow rate, the pressure rise and the frictional force are obtained. The effect of thickness of porous lining on the peristaltic pumping is discussed through graphs.

II. MATHEMATICAL FORMULATION AND SOLUTION

Consider the peristaltic pumping of a viscous incompressible fluid in an inclined channel of angle β and half-width a. The fluid is conducting in the presence of applied magnetic field B_0. The channel is bounded by flexible walls which are lined with non-erodible porous material of thickness $h^{'}$. A longitudinal train of progressive waves takes place on the upper and lower walls of the channel. For simplicity we restrict our discussion to the half width of the channel.

Fig 1: Schematic diagram of the inclined channel



The wall deformation is given by

$$H(X,t) = a + b\sin\frac{2\pi}{\lambda}(X - ct) \qquad (1)$$

where b the amplitude, the wavelength and c is the wave speed.

Under the assumption that the channel length is an integral multiple of the wavelength and the difference across the ends of the channel is a constant, the flow becomes steady in the wave frame (x, y) moving with velocity c away from the fixed (laboratory) frame (X,Y) .The transformation between these two frames is given by

$$x = X - ct; y = Y; u(x,y) = U(X - ct, Y) - c;$$
$$v(x,y) = V(X - ct, Y); p'(x) = P'(X,t) \qquad (2)$$

where U and V are velocity components in the laboratory frame u and v are velocity components in the wave frame and p' , P' are pressures in wave and fixed frame of references respectively.

In many physiological situations it is proved that the Reynolds number of the flow is very small. So we assume that the flow is inertia-free. Further, we assume that the wavelength is infinite.

Using the non-dimensional quantities

$$\bar{u}=\frac{u}{c};\bar{x}=\frac{x}{c};\bar{y}=\frac{y}{c};\bar{h}=\frac{h}{a};\varepsilon=\frac{h'}{a};\bar{p}=\frac{pa^2}{\lambda\mu c};$$
$$\bar{q}=\frac{q}{c};\bar{t}=\frac{ct}{\lambda};Da=\frac{k}{a^2};\phi=\frac{b}{a};\psi=\frac{\psi}{ac} \quad (3)$$

The non dimensional form of equations governing the motion becomes (dropping the bars).

$$0=\frac{\partial p'}{\partial x}+\frac{\partial^2 u}{\partial y^2}+M^2u+\eta\sin\beta \quad (4)$$

$$0=\frac{\partial p'}{\partial y}+\eta_1\cos\beta \quad (5)$$

where $\eta=\frac{a^2 g}{\nu c},\eta_1=\frac{a^2 g}{\nu c\lambda},M^2=\frac{\sigma^2 B_0{}^2 a_1{}^2}{\nu}$ and g is the acceleration due to gravity, β is the angle of inclination B_0 is the applied magnetic field and M is the magnetic parameter.

Let

$$p'=p(x)-\eta_1\cos\beta \quad (6)$$

Substituting (6) in (4) we get

$$\frac{dp}{dx}=\frac{\partial^2 u}{\partial y^2}-M^2u+\eta\sin\beta \quad (7)$$

Now the non - dimensional boundary conditions are

$$\frac{\partial u}{\partial y}=0 \quad \text{at} \quad y=0 \quad (8)$$

$$u=\frac{\sqrt{Da}}{\alpha}\frac{\partial u}{\partial y}-1 \text{ at } \quad y=h-\varepsilon \quad (9)$$

(Saffman slip condition, 1971)

where ε is the thickness of the porous lining.

Solving equation (7) using (8) and (9), we get

$$u=\left[\frac{-1+\frac{1}{M^2}(P-\eta\sin\beta)}{M\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+\cosh M(h-\varepsilon)}\right](\cosh My)-\frac{1}{M^2}(P-\eta\sin\beta)$$
(10)

Integrating the above equation and using the condition $\psi=0$ at y = 0 we get the stream function as

$$\psi=\left[\frac{-1+\frac{1}{M^2}(P-\eta\sin\beta)}{M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)}\right](\sinh My)-\frac{1}{M^2}(P-\eta\sin\beta) \quad (11)$$

The volume flux q through each cross section in the wave frame is given by

$$q=\int_0^{h-\varepsilon}u\,dy$$
$$=(P-\eta\sin\beta)\left[\frac{\frac{1}{M^2}\sinh M(h-\varepsilon)}{M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)}-\frac{1}{M^2}(h-\varepsilon)\right]-\frac{1}{M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)} \quad (12)$$

The instantaneous volume flow rate $Q(X,t)$ in the laboratory frame between the central line and the wall is

$$Q(X,t)=\int_0^{H-\varepsilon}U(X,Y,t)dY \quad (13)$$

From equation (13) we can write the pressure gradient in the form

$$\frac{dp}{dx}=\frac{qM^2\left(\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)\right]+M^2\right)}{\sinh M(h-\varepsilon)-\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)\right](h-\varepsilon)} \quad (14)$$

Averaging the equation (1.13) over one period yields the time mean flow rate $\bar{Q}$ as

$$\bar{Q}=\frac{1}{T}\int_0^T Q\,dt$$
$$=q+1 \quad (15)$$

Integrating the equation (14), we get the pressure drop (rise) over one cycle of the wave as

$$\Delta p=\frac{(\bar{Q}-1)M^2\left(\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)\right]+M^2\right)}{\sinh M(h-\varepsilon)-\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)\right](h-\varepsilon)} \quad (16)$$

The pressure rise required to produce zero average flow rate is denoted by Δp_0 and is given by

$$\Delta p_0 = \int_0^1 \left(\frac{-M^2\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)\right]+M^2}{\sinh M(h-\varepsilon)-\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)\right](h-\varepsilon)} dx + \eta\sin\beta \right) dx \quad (17)$$

The dimensionless frictional force F at the wall across one wave length in an inclined tube is given by

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

$$=-\int_0^1 \left(\frac{hqM^2\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)\right]+M^2}{\sinh M(h-\varepsilon)-\left[M^2\frac{\sqrt{Da}}{\alpha}\sinh M(h-\varepsilon)+M\cosh M(h-\varepsilon)\right](h-\varepsilon)} dx + \eta\sin\beta \right) dx \quad (18)$$

III. Results and Discussions

The main goal of this section lies in the analysis of significant parameters on u and $\frac{dp}{dx}$. Further the pressure rise per wave length and the frictional force at the channel walls are carefully analyzed through numerical integration.

To study the behavior of axial velocity u numerical calculations for several values of Darcy number Da, thickness of the porous lining ε and magnetic parameter M are carried out. Fig (2) shows that the increase in Darcy number results in increase of velocity distribution. Fig (3) depicts that velocity decreases with increase in thickness of porous lining ε.The effect of the magnetic parameter M on the velocity distribution can be seen through Fig (4). We reveals that the axial velocity decreases with the increase in M.

The variation of pressure rise verses average flow rate is plotted in Figures (5), (6) and (7) and observed that all the curves are linear. The variation of Δp with $\bar{Q}$ for different Darcy numbers Da is shown in Fig (5). It is interesting to note that all the curves are intersecting in the free pumping region $(\Delta p = 0)$ at $\bar{Q}=1.0$. For $0 \le \bar{Q} \le 1.0$, we observe that Δp increases with increase in Da. Fig (6) shows the variation of Δp with ϕ. It is seen that Δp increases with the increase in amplitude ratio ϕ. The variation of Δp with $\bar{Q}$ for different values of magnetic parameter M is shown in Fig (7). We observed that Δp decreases with the increase in M.

An interesting phenomenon of peristalsis is trapping in which stream lines split to trap a bolus in the wave frame. The effect of magnetic parameter M on trapping is analyzed through Fig (8). We concluded that the size of the trapped bolus decreases with increase in M and disappears for $M=1.5$. Fig (9) shows the outcome of Da on trapping. We observe that the size of trapped bolus increases with increase in Da. From Fig (10) it is noticed that for increasing ε, the size of the bolus decreases and finally disappears for $\varepsilon \ge 0.2$.

Conclusion

In this article, the effect of thickness of porous lining on the channel walls in the peristaltic transport of a conducting viscous fluid has been studied. Analytical solutions have been developed for velocity distribution, stream function and pressure rise are analyzed through graphs and we find some interesting observations as given below:

1. The fluid velocity increases as Darcy number increases and decreases as the thickness of porous lining and magnetic parameter increases.
2. The pumping phenomenon increases with increase in Darcy number and amplitude ratio.
3. The pumping phenomenon decreases with increase in magnetic parameter.
4. The size of the trapped bolus decreases with increase in magnetic parameter and the thickness of porous lining and size increases as Darcy number increases.

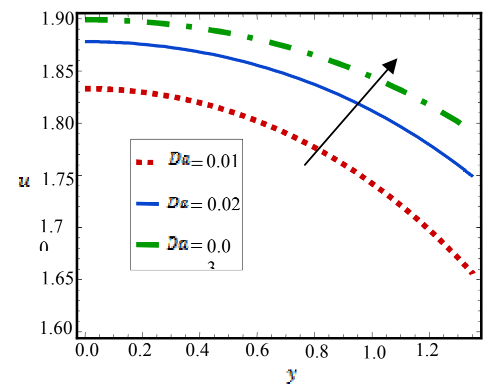


Fig 2: The velocity profiles for different Da with $\varphi=0.6,\beta=\frac{\pi}{6},M=1,\varepsilon=0.1,\alpha=0.01,P=-1$

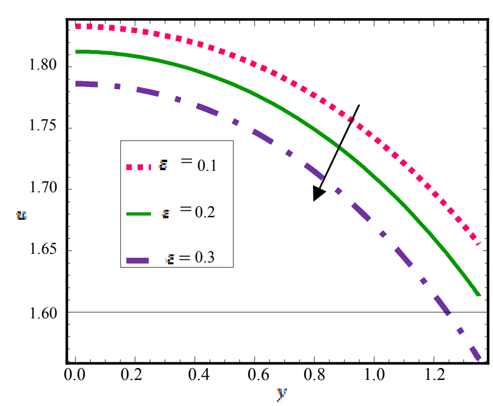


Fig 3: The velocity profiles for different ε with $\varphi=0.6,\beta=\frac{\pi}{6},M=1,\alpha=0.1,Da=0.01,P=-1$

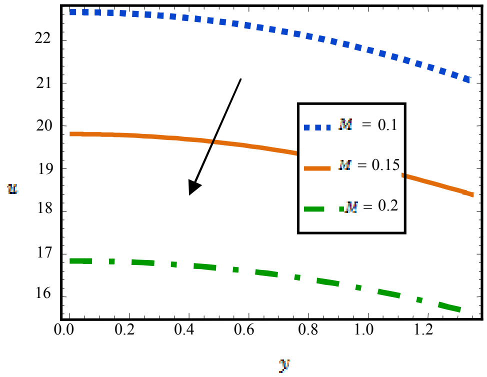


Fig 4: The velocity profiles for different M with $\varphi = 0.6, \beta = \frac{\pi}{6}, \varepsilon = 0.1, \alpha = 0.1, Da = 0.01, P = -1$

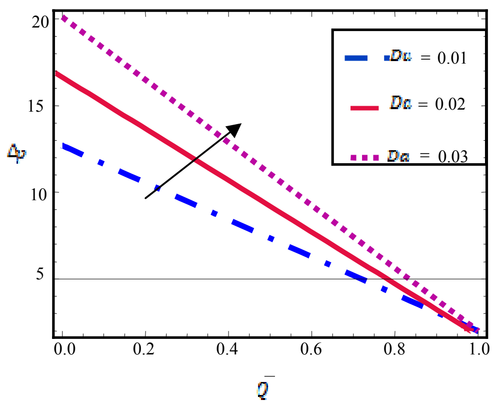


Fig 5: The variation Δp with $\overline{Q}$ for different Da with $\varphi = 0.6, \beta = \frac{\pi}{2}, M = 1, \varepsilon = 0.1, \alpha = 0.01$

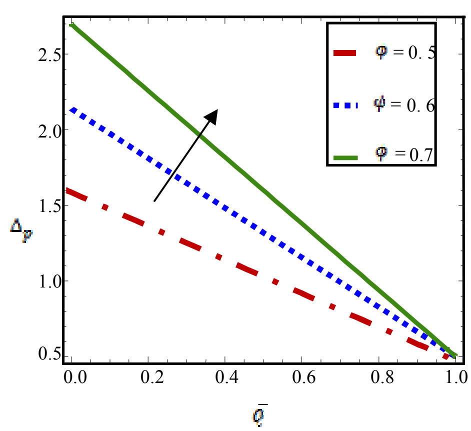


Fig 6: The variation of Δp with $\overline{Q}$ for different ϕ with $Da = 0.1, \beta = \frac{\pi}{6}, M = 1, \varepsilon = 0.1, \alpha = 0.3$

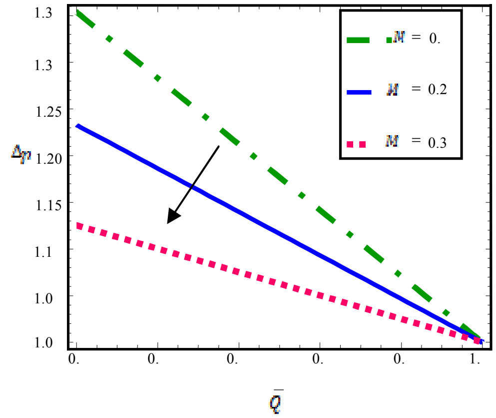


Fig 7: The variation of Δp with $\overline{Q}$ for different M with $\varphi = 0.6, \beta = \frac{\pi}{6}, \varepsilon = 0.1, \alpha = 0.1, Da = 0.01$

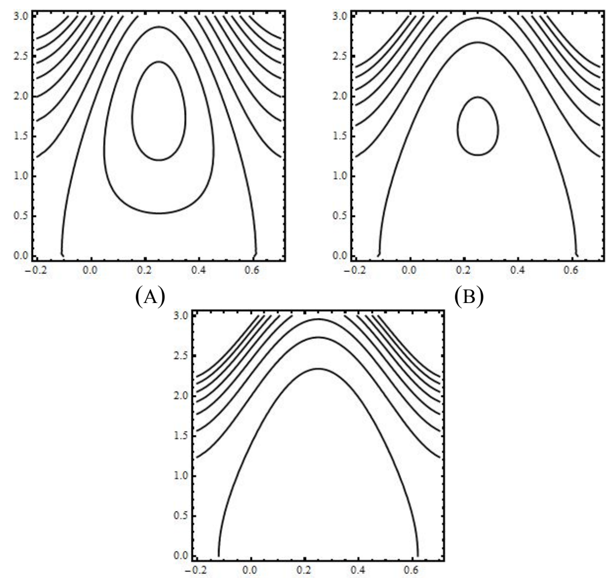
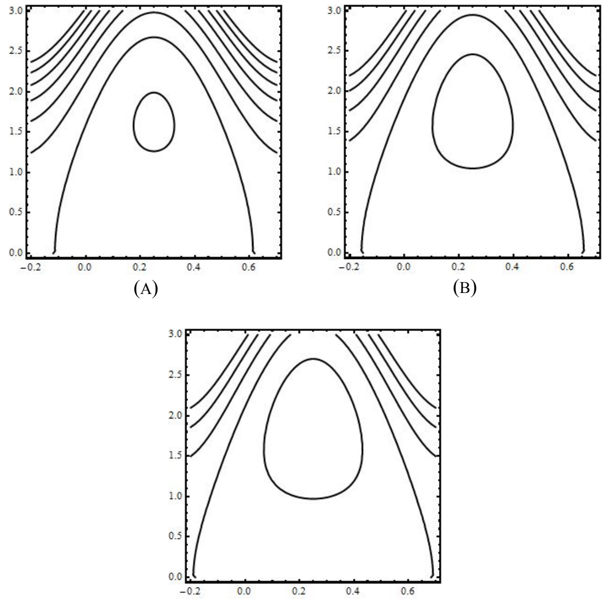


Fig.8: Streamline profile when

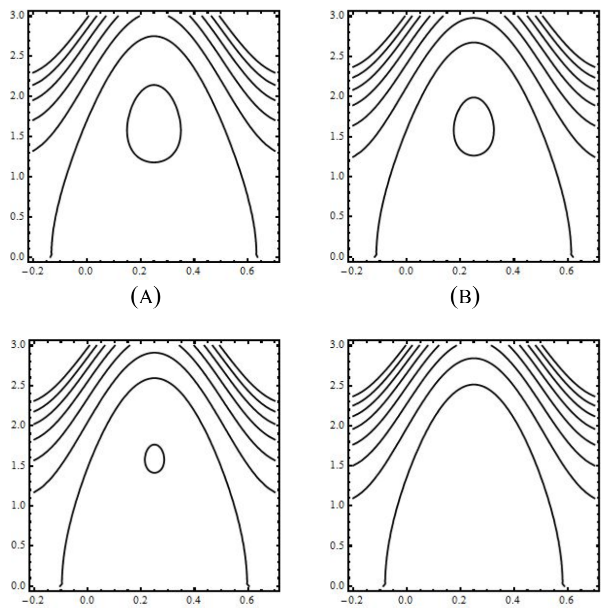
$$\varphi = 0.6, \beta = \frac{\pi}{4}, \varepsilon = 0.1, \alpha = 0.1, Da = 0.01,$$
$$P = -0.1, (A) M = 0.5 (B) M = 1 (C) M = 1.5$$



(A) (B) (C)

Fig 9: Streamline profile when

$$\varphi = 0.6, \beta = \frac{\pi}{4}, \varepsilon = 0.1, \alpha = 0.1, M = 1, P = -0.1,$$
$$(A)\,\mathrm{Da} = 0.01 (B)\,\mathrm{Da} = 0.02 (C)\,\mathrm{Da} = 0.03$$



(A) (B) (C) (D)

Fig 10: Streamline profile when

$$\varphi = 0.6, \beta = \frac{\pi}{4}, \mathrm{Da} = 0.01, \alpha = 0.1, M = 1, P = -0.1,$$
$$(A)\varepsilon = 0.05 (B)\varepsilon = 0.1 (C)\varepsilon = 0.15 (\mathrm{D})\varepsilon = 0.2$$

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