THINK INDIA JOURNAL

ISSN:0971-1260
Vol-22- Issue-14-December-2019

Slip Effects on Peristaltic Flow of a Williamson Fluid in a Channel Under the Effect of a Magnetic Field

a. **Dr.Gangavathi P**, b. **Prof. Yogeswara Reddy P**
a. Associate Professor, Sri Sairam College of Engineering, Anekal, Bangalore,
b. Assistant Professor, Vemana Institute of Technology, Bangalore.

INTRODUCTION

The study of peristaltic pumping has grabed the notice of many researchers ever since the primary and foremost analysis of Latham [50]. A theoretical investigation truly for the peristaltic motion was carried out by Burns and Parkes [18] have modeled the pipe and a channeled flow of a Newtonian Fluid with peristalsis. A contemporary investigation was reported by Shapiro [64] for two - dimensional peristaltic pumping under conditions that the low Reynolds number that the flow may be considered as inertia free and the length of the have analysed the Williamson fluid flow with peristssis in an asymmetric channel.

In recent years, the MHD motion of a liquid in a channel by way of resilient, regularly contracting walls is of significance in association with some troubles of the activity of physiological fluids. Subba Reddy and Gangadhar [80] have deliberated the symmetric channeled, Carreau fluid flow in an inclined in occurrence of a magnetic field with peristalsis. Recently, Subba Reddy et al. [81] have investigated the MHD effects on peristaltic pumping of Williamson fluid in a horizontal channel.

In many applications, the flow pattern corresponds to a slip flow the fluid shows a slaughter of sticking together at the wetted wall building the fluid slip along the wall. When the molecular average free path length of the fluid is comparable to the distance between the plates as in nano channels or micro channels, the fluid shows non-continuum effects such as slip-flow was verified practically by Derek et al. [20]. Newtonian fluid flow through a 2D micro channel with slip effects and peristalsis has been represented by Kwang [49]. Effect of slip on Maxwell fluid in a channel with peristalsis was considered by El sehaway et al. [31].Slip Effects on the movement of pseudoplastic fluid with peristalsis and induced magnetic field in a channel were analyzed by Noreen et al [57].

Keeping all this in the view, we analyed the effects of slip and magnetic field on the Williamson fluid flow in a symmetric channel with peristalsis and lubrication approch. The flow is formulated in a wave frame of reference which also moves with swiftness of the wave. The expressions for the

The flow is unsteady in the laboratory frame (X, Y). However, in a co-ordinate system moving peristaltic wave is very long when compare with the width of a tube. An asymptotic solution for the peristaltic transport in a tube in terms of small wave number was presented by Yin and Fung [92] for a finite range of Reynolds number and wavelength. The small amplitude assumption has been relaxed under infinite wavelength approximation by Shapiro et al. [65]. Complete review on peristaltic pumping has been given by Jaffrin and Shapiro [47]. The lubrication-theory model is applicable globally in the limit of totally occluding peristaltic waves and is found velocity field and pressure gradient are obtained explicitly by applying perturbation series in terms of small Weissenberg number ($We < 1$). The effects of Weissenberg number We, slip parameter β, Hartmann number M and amplitude ratio ϕ on the pressure gradient and pumping characteristics are discussed with the aid of 2D plots.

MATHEMATICAL OUTLINE OF THE PROBLEM

Let us think of the movement of Williamson fluid with peristalsis in a two-dimensional channel of width $2a$ which is symmetric. The flow is caused by sinusoidal wave chain transmit with constant speed c along the channel walls. A consistent magnetic field B_0 is taken in the direction perpendicular to the fluid flow. Small electrical conducting fluid is taken, so to facilitate the Reynolds number is small and the induced magnetic field can be ignored in assessment with the input magnetic field. Fig. 6.1 shows the graphical representation of channel.

The wall expression is as follows

$$Y = \pm H(X,t) = \pm a \pm b\cos\frac{2\pi}{\lambda}(X - ct) \quad (6.2.1)$$

Where b is the amplitude of the wave, λ - the wave length and X and Y - the rectangular co-ordinates with X measured along the axis of the channel and Y perpendicular to X. Let (U,V) be the velocity components in fixed frame of reference (X,Y).

ISSN:0971-1260
Vol-22- Issue-14-December-2019

with the propagation velocity c (wave frame (*x, y*)), the boundary shape is stationary. The relations which are usefull in converting
fixed frame to wave frame are as follows
$x = X - ct, y = Y, u = U - c, v = V$ (6.2.2)
Where (u,v) and (U,V) are velocity components in the wave and laboratory frames respectively.

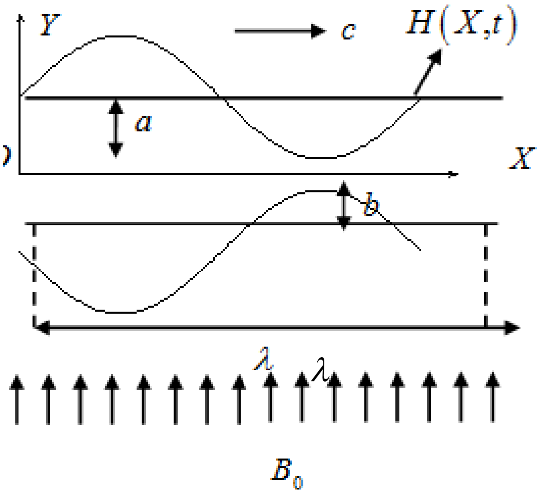

Fig. 6.1. The Physical Model

The Williamson fluid and its constitutive equation is

$$\tau = -\left[\eta_\infty + (\eta_0 + \eta_\infty)(1 - \Gamma\dot{\gamma})^{-1}\right]\dot{\gamma} \quad (6.2.3)$$

Where
τ -The extra stress tensor

$$\tau_{xx} = -2\left[1 + We\,\dot{\gamma}\right]\frac{\partial u}{\partial x},$$

$$\tau_{xy} = -\left[1 + We\,\dot{\gamma}\right]\left(\frac{\partial u}{\partial y} + \delta^2\frac{\partial v}{\partial x}\right),$$

$$\tau_{yy} = -2\delta\left[1 + We\,\dot{\gamma}\right]\frac{\partial v}{\partial y},$$

$$\dot{\gamma} = \left[2\delta^2\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial y} + \delta^2\frac{\partial v}{\partial x}\right)^2 + 2\delta^2\left(\frac{\partial v}{\partial y}\right)^2\right]^{\frac{1}{2}}$$

and
$M^2 = aB_0\sqrt{\frac{\sigma}{\eta_0}}$ is the Hartmann number.

With the lubrication approach and neglecting the terms of order δ and Re, we get

fixed frame to wave frame are as follows
$x = X - ct, y = Y, u = U - c, v = V$ (6.2.2)
Where (u,v) and (U,V) are velocity components in the wave and laboratory frames respectively.

η_∞ - The infinite shear rate viscosity
ρ - The density
B_0 - The magnetic field strength and
σ - The electrical conductivity.
Introducing the non-dimensional variables define

$$\bar{x} = \frac{x}{\lambda},\ \bar{y} = \frac{y}{a},\ \bar{u} = \frac{u}{c},\ \bar{v} = \frac{v}{c\delta},\ \delta = \frac{a}{\lambda},\ \bar{p} = \frac{pa^2}{\eta_0 c\lambda}, \phi = \frac{b}{a}$$

$$h = \frac{H}{a},\ \bar{t} = \frac{ct}{\lambda},\ \tau_{xx} = \frac{\lambda}{\eta_0 c}\tau_{xx},\ \bar{\tau}_{xy} = \frac{a}{\eta_0 c}\tau_{xy},\ \tau_{yy} = \frac{\lambda}{\eta_0 c}\tau_{yy},$$

$$\mathrm{R}_e = \frac{\rho ac}{\eta_0},\ We = \frac{\Gamma c}{a},\ \bar{\dot{\gamma}} = \frac{\dot{\gamma}a}{c},\ \bar{q} = \frac{q}{ac} \quad (6.2.9)$$

into the Equations (6.2.5) - (6.2.8), reduce to (on ignoring the bars)

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (6.2.10)$$

$$\mathrm{Re}\,\delta\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} - \delta^2\frac{\partial \tau_{xx}}{\partial x} - \frac{\partial \tau_{xy}}{\partial y} - M^2(u+1) \quad (6.2.11)$$

$$\mathrm{Re}\,\delta^3\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} - \delta^2\frac{\partial \tau_{xy}}{\partial y} - \delta\frac{\partial \tau_{yy}}{\partial y} \quad (6.2.12)$$

Where

$$\frac{\partial p}{\partial x} = \frac{\partial}{\partial y}\left\{\left[1 + We\frac{\partial u}{\partial y}\right]\frac{\partial u}{\partial y}\right\} - M^2(u+1) \quad (6.2.13)$$

$$\frac{\partial p}{\partial y} = 0 \quad (6.2.14)$$

From Eq. (6.2.13) and (6.2.14), we get

$$\frac{dp}{dx} = \frac{\partial^2 u}{\partial y^2} + We\frac{\partial}{\partial y}\left[\left(\frac{\partial u}{\partial y}\right)^2\right] - M^2(u+1) \quad (6.2.15)$$

The corresponding non-dimensional slip boundary conditions in the wave frame are given by

$$u + \beta\left[\frac{\partial u}{\partial y} + We\left(\frac{\partial u}{\partial y}\right)^2\right] = -1 \text{ at } y = h = 1 + \phi\cos 2\pi x \quad (6.2.16)$$

$$\frac{\partial u}{\partial y} = 0 \text{ at } y = 0 \quad (6.2.17)$$

The volume flow rate q in a wave frame of reference is given by

ISSN:0971-1260
Vol-22- Issue-14-December-2019

$$q = \int_0^h u dy \quad . \qquad (6.2.18)$$

The immediate flow Q (X,t) in the laboratory frame is

$$Q(X,t) = \int_0^h U dY = \int_0^h (u+1) dy = q + h \quad (6.2.19)$$

The time averaged flux $\overline{Q}$ over one period $T\left(= \frac{\lambda}{c} \right)$ of the peristaltic wave is given by

$$\overline{Q} = \frac{1}{T}\int_0^T Q dt = q + 1 \qquad (6.2.20)$$

Observe that, as $M \to 0$ and $\beta \to 0$ our results coincide with the results of Shapiro et al [65].

6.3 SOLUTION

Since Equation (6.2.15) is a non-liner differential equation, it is not possible to obtain closed form solution. Therefore we employ regular perturbation to find the solution.

For perturbation solution, we consider u, p and q as follows

$$u = u_0 + We u_1 + O\left(We^2\right) \qquad (6.3.1)$$

$$\frac{dp}{dx} = \frac{dp_0}{dx} + We\frac{dp_1}{dx} + O\left(We^2\right) \qquad (6.3.2)$$

$$q = q_0 + We q_1 + O\left(We^2\right) \quad (6.3.3)$$

Making use of these in Equations. (6.2.15) - (6.2.17), we attain

6.3.1. System of order We^0

$$\frac{dp_0}{dx} = \frac{\partial^2 u_0}{\partial y^2} - M^2\left(u_0 + 1\right) \qquad (6.3.4)$$

and the respective boundary conditions are

$$u_0 + \beta\frac{\partial u_0}{\partial y} = -1 \text{ at } y = h \qquad (6.3.5)$$

$$\frac{\partial u_0}{\partial y} = 0 \text{ at } \quad y = 0 \qquad (6.3.6)$$

6.3.2. System of order We^1

$$\frac{dp_1}{dx} = \frac{\partial^2 u_1}{\partial y^2} + \frac{\partial}{\partial y}\left[\left(\frac{\partial u_o}{\partial y}\right)^2\right] - M^2 u_1 \qquad (6.3.7)$$

and the respective boundary conditions are

$$u_1 + \beta\frac{\partial u_1}{\partial y} + \beta\left(\frac{\partial u_0}{\partial y}\right)^2 = 0 \quad \text{at } y = h \, (6.3.8)$$

$$\frac{\partial u_1}{\partial y} = 0 \text{ at } y = 0 \qquad (6.3.9)$$

6.3.3. Solution for system of order We^0

Solving Eq. (6.3.4) via the border line (boundary) conditions (6.3.5) and (6.3.6), we attain

$$u_0 = \frac{1}{M^2}\frac{dp_0}{dx}\left[\frac{\cosh My}{A_1} - 1\right] - 1 \, (6.3.10)$$

Where $A_1 = \cosh Mh + \beta M \sinh Mh$.

The volume flow rate q_0 is given by

$$q_0 = \frac{dp_0}{dx}\frac{\left[\sinh Mh - MhA_1\right]}{A_1 M^3} - h \qquad (6.3.11)$$

From Eq. (6.3.11), we have

$$\frac{dp_0}{dx} = \frac{\left(q_0 + h\right)M^3 A_1}{\left(\sinh Mh - MhA_1\right)} \qquad (6.3.12)$$

6.3.4. Solution for system of order We^1

Substituting Equation (6.3.10) in the Eq. (6.3.7) and solving the Eq. (6.3.7), by means of the border line conditions (6.3.8) and (6.3.9), we attain

$$u_1 = \frac{1}{M^2}\frac{dp_1}{dx}\left[\frac{\cosh My}{A_1} - 1\right] + \frac{2}{3}\frac{\left(\frac{dp_0}{dx}\right)^2}{A_1^3 M^3}\left[A_2 \cosh My + A_1 \sinh My - \frac{A_1}{2}\sinh 2My\right]$$

(6.3.13)

Where

$$A_2 = -\sinh Mh + \frac{1}{2}\sinh 2Mh - \beta M \cosh Mh + \beta M \cosh 2Mh - \frac{3}{2}\beta M \sinh^2 Mh$$

The volume flow rate q_1 is given by

$$q_1 = \frac{1}{A_1 M^3}\frac{dp_1}{dx}\left[\sinh Mh - MhA_1\right] + \frac{2}{3}\frac{A_3}{A_1^3 M^4}\left(\frac{dp_0}{dx}\right)^2$$

(6.3.14)

Where

$$A_3 = A_2 \sinh Mh + A_1 \cosh Mh - \frac{A}{4}\cosh 2Mh - \frac{3}{4}A_1 .$$

From Eq. (6.3.14) and (6.3.12),weave

$$\frac{dp_1}{dx} = \left[q_1 - \frac{2}{3}\frac{A_3}{A_1^3 M^4}\left(\frac{dp_0}{dx}\right)^2\right] A_1 M^3 / \left(\sinh Mh - MhA_1\right)$$

(6.3.15)

Making use of Equations (6.3.12) and (6.3.15) in the Eq. (6.3.2) and also the relation $\frac{dp_0}{dx} = \frac{dp}{dx} - We\frac{dp_1}{dx}$ by neglecting terms larger than $O\left(We\right)$, we acquire

$$\frac{dp}{dx} = \left[\frac{(q+h)A_1 M^3}{\left(\sinh Mh - MhA_1\right)} - We\frac{2A_3\left(q+h\right)^2 M^5}{3\left(\sinh Mh - MhA_1\right)^3}\right]$$

(6.3.16)

The non-dimensionl hike (rise) in pressure for unique wavelength in the wave frame is defined as

$$\Delta p = \int_0^1 \frac{dp}{dx} dx \qquad (6.3.17)$$

6.4. RESULTS AND DISCUSSIONS

Fig. 6.2illustrates the fluid flow pattern for a preference of values of the Weissenberg number

ISSN:0971-1260
Vol-22- Issue-14-December-2019

We. The graph is ploted by considering pressure gradient $\frac{dp}{dx}$ along Y direction and Noted the variations in the pressure gradient along the X axis for the fixed values of $\phi = 0.6$, $M = 1$ and $\beta = 0.1$.We can make out from the graph that the $\frac{dp}{dx}$ increases when there is a rise in We.

Fig. 6.3illustrates the fluid flow pattern for a preference of values of the slip parameter β. The graph is ploted by considering pressure gradient $\frac{dp}{dx}$ along Y direction and Noted the deviations in the pressure gradient along the X axis for the fixed values of $\phi = 0.6$, $M = 1$ and $We = 0.02$. We can make out from the graph that the $\frac{dp}{dx}$ decreases when there is a rise in β.

Fig. 6.4illustrates the fluid flow pattern for a preference of values of the Hartmann number M. The graph is ploted by considering pressure gradient $\frac{dp}{dx}$ along Y direction and Noted the deviations in the pressure gradient along the X axis for the fixed values of $\phi = 0.6$, $We = 0.02$ and $\beta = 0.1$ We can make out from the graph that the $\frac{dp}{dx}$ increases when there is a rise in M.

Fig. 6.5illustrates the fluid flow pattern for a preferred of values of the Amplitude Ratio ϕ. The graph is ploted by considering pressure gradient $\frac{dp}{dx}$ along Y direction and Noted the deviations in the pressure gradient along the X axis for the fixed values of $We = 0.02$, $M = 1$ and $\beta = 0.1$ We can make out from the graph that the $\frac{dp}{dx}$ increases when there is a rise in ϕ.

Fig. 6.6 illustrates the deviation in the pressure rise Δp against time averaged volume flow rate $\overline{Q}$. Δp Has been taken along Y aixs and $\overline{Q}$ is taken along X-axis. Graph is obtained for distinct values of the Weissenberg number We. When $\phi = 0.6$, $\beta = 0.1$ and $M = 1$. Where and when the flow takes place is noted. In pumping $(\Delta p > 0)$, free pumping $(\Delta p = 0)$ and in the co pumping $(\Delta p < 0)$ regions the volume flow rate $\overline{Q}$ rises up when there is a rise in We.

Fig. 6.7 illustrates the deviation in the pressure rise Δp against time averaged volume flow rate $\overline{Q}$. Δp Has been taken along Y aixs and $\overline{Q}$ is taken along X-axis. Graph is plotted for distinct values of the Slip parameter β. When $\phi = 0.6$, $We = 0.02$ and $M = 1$. Where and when the flow takes place is noted. In pumping $(\Delta p > 0)$ and free pumping $(\Delta p = 0)$ regions the volume flow rate $\overline{Q}$ decreases when there is a hike in β. even if, in the co pumping $(\Delta p < 0)$ region the volume flow rate $\overline{Q}$ rises up when there is a rise in β.

Fig. 6.8 Reveals the deviation in the pressure rise Δp against time averaged volume flow rate $\overline{Q}$. Δp Has been taken along Y aixs and $\overline{Q}$ is taken along X-axis. Graph is plotted for distinct values of the Hartmann number M. When $\phi = 0.6$, $We = 0.02$ and $\beta = 0.1$. Where and when the flow takes place is noted. In pumping $(\Delta p > 0)$ region the volume flow rate $\overline{Q}$ increases when there is a hike in M. Even if, in both the co pumping $(\Delta p < 0)$ region and free pumping $(\Delta p = 0)$ region, the volume flow rate $\overline{Q}$ goes down when there is a rise in M.

Fig. 6.9 Reveals the deviation in the pressure rise Δp against time averaged volume flow rate $\overline{Q}$. Δp Has been taken along Y aixs and $\overline{Q}$ is taken along X-axis. Graph is plotted for distinct values of the Amplitude ratio ϕ. When $M = 1$, $We = 0.02$ and $\beta = 0.1$. Where and when the flow takes place is noted. In both pumping $(\Delta p > 0)$ region and free pumping $(\Delta p = 0)$ region, the volume flow rate $\overline{Q}$ increases when there is a hike in ϕ. Even if, in co pumping

ISSN:0971-1260
Vol-22- Issue-14-December-2019

$\left(\Delta p < 0\right)$ region, the volume flow rate $\overline{Q}$ goes down when there is a rise in ϕ.

CONCLUSION

In this chapter, we did an experiment on the influence of slip and magnetic field on Williamson fluid flow in a planar channel with peristalsis, with aid of low Reynolds number and long wavelength consideration. We found the velocity of the wave in a wave frame of reference. The perturbation solution is found for velocity field and pressure gradient per one wavelength. It is also found that the axial pressure gradient and time-averaged volume flow rate, in the pumping region rises up if there is hike in Weissenberg number We, Hartmann number M and amplitude ratio ϕ although they moves down with hike in slip parameter β. Further, it is found that the "pumping is more for Williamson fluid than that of Newtonian fluid".

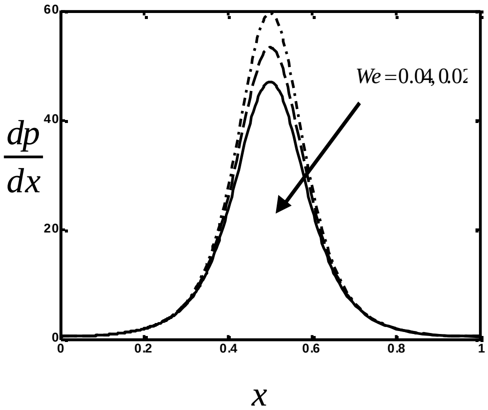

Fig. 6.2. Pressure gradient $\frac{dp}{dx}$ with the axis of the flow is ploted for We with $\phi = 0.6$, $\beta = 0.1$ and $M = 1$.

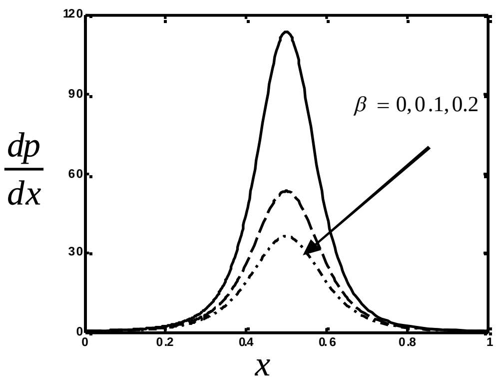

Fig. 6.3. Pressure gradient $\frac{dp}{dx}$ with the axis of the flow is ploted for β with $\phi = 0.6$, $We = 0.02$ and $M = 1$.

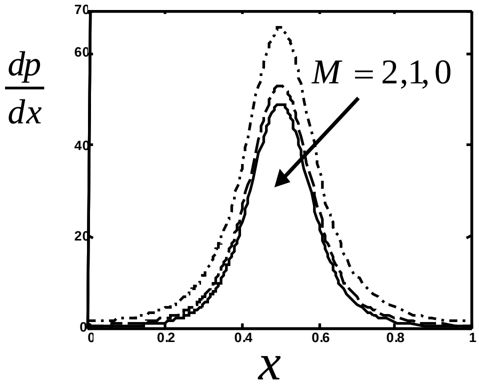

Fig. 6.4. Pressure gradient $\frac{dp}{dx}$ with the axis of the flow is ploted for M with $\phi = 0.6$, $\beta = 0.1$ and $We = 0.02$. For $M = 2, 1, 0$

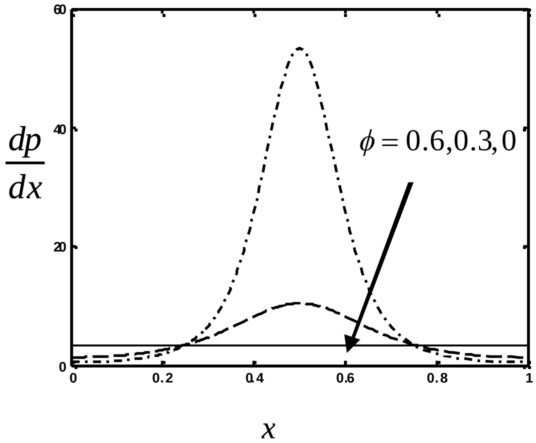

Fig. 6.5. Pressure gradient $\frac{dp}{dx}$ with the axis of the flow is ploted for ϕ with $M = 1$, $\beta = 0.1$ and $We = 0.02$.

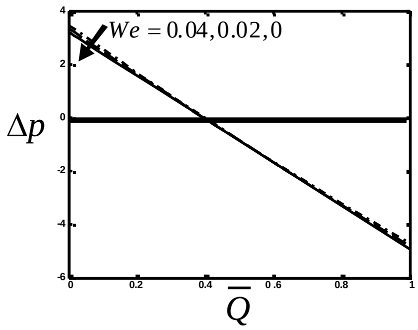

Fig. 6.6. The dissimilarity in pressure rise Δp with flux $\overline{Q}$ for unlike Values of We with $\phi = 0.6$, $\beta = 0.1$ and $M = 1$

ISSN:0971-1260
Vol-22- Issue-14-December-2019

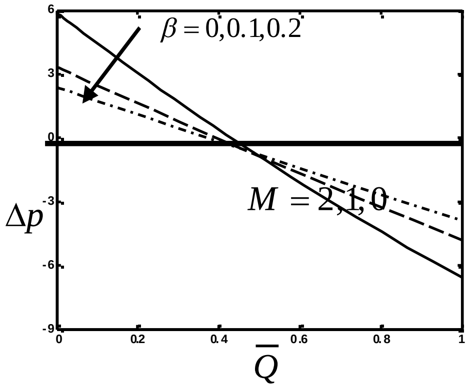

Fig. 6.7. The dissimilarity in pressure rise Δp with flux $\overline{Q}$ for like Values of β with $\phi = 0.6$, $We = 0.02$ and $M = 1$.

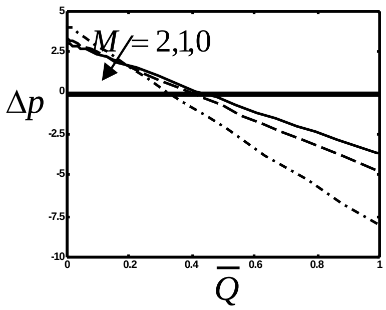

Fig. 6.8. The dissimilarity in pressure rise Δp with flux $\overline{Q}$ for unlike

Values of M with $\phi = 0.6$, $\beta = 0.1$ and $We = 0.02$.

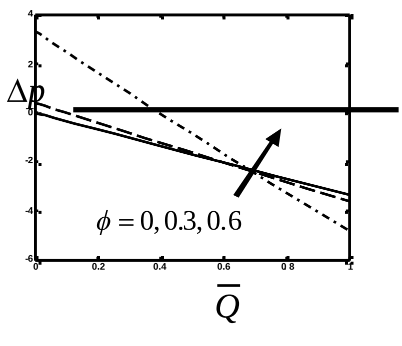

Fig. 6.9. The dissimilarity in pressure rise Δp with flux $\overline{Q}$ for Unlike Values of ϕ with $We = 0.02$, $\beta = 0.1$ and $M = 1$.

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