Heat Transfer and Slip Effects on the Mhd Peristaltic Flow of Viscous Fluid in A Tapered Microvessels: Application of Blood Flow Research

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ABSTRACT--- This research work is proposed at reporting heat transfer on the peristaltic flow of an electrically conducting fluid in a tapered microvessels under the lubrication theory. The proposed geometry analyzes the blood flow in the heart vessels and maintain the pressure level in the human body. The solutions for the distribution of axial velocity, temperature distribution, pressure gradient and stream function have been obtained analytically. The influences of many evolving parameters on the flow characteristics are revealed and deliberated with the assist of figures. The mathematical outcomes show that the trapped bolus enhances in size with increasing slip parameter but decreases with the increase of Grashof number.

Keywords: Peristaltic transport, Slip effect, Heat transfer, Tapered microvessels.

I. INTRODUCTION

Recent development of scientific technology is to play crucial role in the field of fluid dynamics and fluid flow. The concept of peristalsis transport is to play a crucial role in many areas such as blood flow pumping, blood vessels, heart machine and many living system. This model is first coined by Latham [1] and many theoretical and experimental studies have been discussed by [2-10] for the various type of fluid flow channel in peristalsis motion. Some recent studies [11-17] have deliberated the peristaltic transport of magnetohydrodynamics (MHD), non-Newtonian fluids and Newtonian fluid in microvessels. The channel flow under the MHD field is playing a vital role in biological system and medical industrial areas. The impact of wall properties, heat transfer and MHD peristaltic motion was investigated by Kothandapani and Srinivas [18] in the presence of porous channel. The MHD Newtonian fluid has been reported by Akyildiz and Vajravelu [19]. This concept has been extended by Abbas and Hayat [20] in the presence of porous space and thermal radiation. Peristaltic transport of Non-Newtonian fluid has been analyzed by Srivastava and Srivastava [21]. Peristaltic transport of a Williamson fluid in a microvessels was discussed by Prakash et al. [22] under the impact of magnetic field. The influence of heat transfer on peristaltic motion have been investigated by many researchers with various channels like non-uniform channel [23], symmetric channel [24], porous annulus [25], asymmetric channel [26-28].

Some investigators [29] have considered peristalsis motion with point of reference to water transport in trees. The presently existing mechanism for the transport of water molecular movement from the ground to upper branches of high in stature tree is not considerably realized, it is to believe especially on uncertain that peristalsis motion with free convection contribution. The water movement of tree is based on diameters of the tree size and vary with time, which was clearly discussed by Aikman and Anderson [30]. The combined effect of forced and free convection motion in a vertical channel have been discussed by Barletta [31]. The rotational influence of micropolar fluid in a vertical channel have been observed by Chamkah *et al.* [32] which was the fully developed free convection of a micropolar fluid. The effect of surface wavy wall on the MHD peristalsis flow has been analyzed by Mekheimer *et al.* [33] in the presence of slip flow in a porous medium. The impact of heat transfer on peristaltic motion of a Jeffrey fluid have been analyzed by Vajravelu *et al.* [34].

The above review literatures has been observed that no study is discussed about the heat transfer of peristaltic transport of electrically conducting fluid in a vertical tapered microvessels. This concept is very useful in biomedical research areas with clearly realizing heat transfer process in human body. So that, we have proposed the most generalized mathematical channel i.e. tapered asymmetric microvessel model with presence of heat transfer and magnetic field. The concept of lubrication theory is utilized in the governing equations and diluted the governing equations are solved analytically. The vital parameters are clearly expressed with the assist of figures.

II. MATHEMATICAL FORMULATION

Consider the MHD peristaltic transport of Newtonian fluid through a tapered microvessels under the action of a slip parameter. Let $Y = H_1$ and $Y = H_2$ be left wall and right wall respectively with a constant speed c along the tapered microvessels [see Fig.1], such that [35-37]

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$$H_2(x,t) = m'x + d + b_1 \sin^2\left[\frac{\pi}{\lambda} X_1\right],$$

$$H_1(x,t) = -m'x - d - a_1 \sin^2\left[\frac{\pi}{\lambda} X_1 + \phi\right], \qquad (1)$$

in which $X_1 = x - ct$.

where d, a_1, b_1, λ, m' and ϕ are the half-width channel, the wave amplitudes of the left microvessel, the wave amplitudes of the right microvessel, wave length, non-uniform parameter $(m' << 1)$ and the phase difference.

The governing motion equations are

(i) Continuity equation

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

(ii) *x*-Momentum equation

$$\rho\left[\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right] = -\frac{\partial p}{\partial x} + \mu\left[\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right] - \sigma B_0^2 u + \rho g \alpha (T - T_0), \qquad (3)$$

(iii) y – momentum equation

$$\rho\left[\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right] = -\frac{\partial p}{\partial y} + \mu\left[\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right], \qquad (4)$$

(iv) temperature equation

$$\rho\zeta\left[\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right] = \kappa\left[\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right] + Q_0, \qquad (5)$$

where u, v, μ, ρ, p, σ, κ, Q_0, T and α are the axial velocity, transverse velocity, viscosity, density, pressure, electric field, fluid character in thermal conductivity, constant heat addition. Heat absorption, fluid temperature and linear thermal expansion of the fluid.

The non-dimensional parameters are as follows,

$$\theta = \frac{T - T_0}{T_1 - T_0}, h_2 = \frac{H_2}{d}, h_1 = \frac{H_1}{d}, \; p' = \frac{d^2 p}{c\lambda\mu}, \; \nu = \frac{\mu}{\rho}, \; y' = \frac{y}{d}, x' = \frac{x}{\lambda}, \; t' = \frac{ct}{\lambda}, \qquad (6)$$

$$v' = \frac{v}{c\delta}, u' = \frac{u}{c}, \; m = \frac{m'}{d}, \; b = \frac{b_1}{d}, a = \frac{a_1}{d}.$$

Under the assumptions of lubrication theory and after omitting the primes the above eqs (1 – 5) becomes and we get

$$\frac{\partial^2 u}{\partial y^2} - M^2 u + Gr\;\theta = \frac{\partial p}{\partial x}, \qquad (7)$$

$$\frac{\partial p}{\partial y} = 0, \qquad (8)$$

$$\frac{\partial^2 \theta}{\partial y^2} = -\gamma\;. \qquad (9)$$

In which $M^2 = \frac{\sigma B_0^{\,2} d^2}{\mu}$ is the Hartmann number, $\delta = \frac{d}{\lambda}$ is the wave number, $Gr = \frac{\rho g \alpha (T_1 - T_0) d^2}{c\mu}$ is heat transfer Grashof number, $R = \frac{\rho c d}{\mu}$ is the Reynolds number, $\Pr = \frac{\mu\varsigma}{\kappa}$ is the Prandtl number and $\gamma = \frac{d^2 Q_0}{\kappa(T_1 - T_0)}$ is heat source/heat sink parameter.

The suitable boundary conditions of the governing equations are

$u = -\beta\frac{\partial u}{\partial y}$, $\theta = 0$ at

$$y = h_1 = -1 - mx - a\sin\left[\pi(x-t) + \phi\right]\sin\left[\pi(x-t) + \phi\right],$$

and $u = \beta\frac{\partial u}{\partial y}$, $\theta = 1$ at

$$y = h_2 = 1 + mx + b\sin\left[\pi(x-t)\right]\sin\left[\pi(x-t)\right]. \qquad (10)$$

III. ANALYTICAL SOLUTION OF THE PROPOSED PROBLEM

The exact solutions for the axial velocity and temperature distributions are

$$u(y,t) = \left(\left(\partial p/\partial x\right)\frac{1}{M^2}\left(\frac{1}{a_1} - \frac{a_2(a_4 - a_1)}{a_1(a_4 a_2 - a_5 a_1)}\right) - \frac{a_3}{a_1} - \frac{a_2(a_6 a_1 - a_3 a_4)}{a_1(a_4 a_2 - a_5 a_1)}\right)\cosh My$$
$$+ \frac{Gr}{M^2}\left(\frac{1}{(h_1 - h_2)}\left(\frac{\gamma}{2}\left(h_1^{\,2} - h_2^{\,2}\right) - 1\right)\right) y + \frac{Gr}{M^2}\left(\frac{\gamma}{2}h_1^{\,2} - Bh_1\right) - \frac{Gr\;\gamma}{M^4}$$
$$+ \left(\left(\partial p/\partial x\right)\frac{(a_4 - a_1)}{M^2(a_4 a_2 - a_5 a_1)} + \frac{(a_6 a_1 - a_3 a_4)}{a_4 a_2 - a_5 a_1}\right)\sinh My - \left(\partial p/\partial x\right)\frac{1}{M^2} - \frac{Gr\;\gamma}{2M^2}y^2, \qquad (11)$$

$$\theta(y,t) = \left(\frac{\gamma}{2}h_1^{\,2} - Bh_1\right)y + \left(\frac{\gamma}{2}(h_1 + h_2) - \frac{1}{(h_1 - h_2)}\right) - \frac{\gamma}{2}y^2\;. \qquad (12)$$

The flow rate $F(x,t)$ is specified by

$$F(x,t) = \int_{h_2}^{h_1} u\, dy, \qquad (13)$$

It provides

$$\frac{\partial p}{\partial x} = M^2\left(F + \frac{a_3 a_9}{a_1} + \frac{a_2 a_9 (a_1 a_6 - a_3 a_4)}{a_1(a_2 a_4 - a_1 a_5)} - \frac{a_{10}(a_1 a_6 - a_3 a_4)}{a_2 a_4 - a_1 a_5} - a_1 + a_2\right)$$
$$\left(\frac{a_9}{a_1} - \frac{a_2(a_4 - a_1)a_9}{a_1(a_4 a_2 - a_5 a_1)} + \frac{a_{10}(a_4 - a_1)}{a_4 a_2 - a_5 a_1} - h_2 + h\right)^{-1}{}_{1}, \qquad (14)$$

The corresponding stream function is given by

$$\psi(y,t) = \frac{1}{M}\left(\left(\partial p/\partial x\right)\frac{1}{M^2}\left(\frac{1}{a_1} - \frac{a_2(a_4 - a_1)}{a_1(a_4 a_2 - a_5 a_1)}\right) - \frac{a_3}{a_1} - \frac{a_2(a_6 a_1 - a_3 a_4)}{a_1(a_4 a_2 - a_5 a_1)}\right)\sinh My$$
$$+ \frac{1}{M}\left(\left(\partial p/\partial x\right)\frac{(a_4 - a_1)}{M^2(a_4 a_2 - a_5 a_1)} + \frac{(a_6 a_1 - a_3 a_4)}{a_4 a_2 - L_5 a_1}\right)\cosh My - \frac{y}{M^2}\left(\partial p/\partial x\right) - \frac{B_1}{M}$$
$$+ Gr\left(\frac{1}{(h_1 - h_2)}\left(\frac{\gamma}{2}\left(h_1^{\,2} - h_2^{\,2}\right) - 1\right)\left(\frac{y^2}{2M^2} - \frac{h_1 y}{M^2}\right) + \gamma\left(\frac{h_1^{\,2} y}{2M^2} - \frac{y^3}{6M^2} - \frac{y}{M^4}\right)\right). \qquad (15)$$

The time-average rise in pressure $\Delta p_\lambda(t)$, on the right hand side wall as follows:

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$$\Delta p_{\lambda}(t) = \int_0^1 \frac{\partial p}{\partial x}\, dx, \quad (16)$$

IV. RESULTS AND DISCUSSION

In this study to discuss the model of blood flow volume rate [36-38] in the form of

$$F(x,t) = Qe^{-At}. \quad (17)$$

where Q is the average flow rate and A is the constant rate of Blood flow.

The performance of parameters necessitated in the formulation of axial velocity and temperature distributions, time-average pressure rise and streamline characteristics are shown in figures 2-6. Figure 2 depicts that the mixed influences of wave amplitude of the left hand side wall (a), (β) slip parameter, (M) Hartmann number and mean flow rate (Q) on axial velocity profiles. u. Figure 2(a) has been portrayed to examine the influence of wave amplitude of the right hand side wall on u. It shows that enhancement in a upturns in the axial velocity distribution. Figure 2(b) describes that the distribution of axial velocity rises with enhancing the slip parameter. Figure 2(c) illustrates that the growth of Hartmann number with decrease of distribution of axial velocity field u. In real things, the influences of magnetic field strength gains with dampens of axial velocity and it is very useful in the treatment of cardio heart disease. The influence of mean flow rate on distribution of axial velocity u is shown in figure 2(d). It is observed that increasing Q lead to increase in the fluid velocity.

The impacts of heat sink/heat source parameter (γ), wave amplitude of the right hand side wall (b), phase difference (ϕ) and uniform/non-uniform parameter (m) on the heat transfer distribution (θ) are illustrated in figure 3. In figure 3(a), we have discussed the impacts of heat sink/heat source parameter on the distribution of heat transfer. It is seen that the distribution of heat transfer enhances as γ increases. The growing impacts of the left hand side microvessel on θ is plotted in figure 3(b). It reveals that the enhancing in b increases the amplitude of the temperature distribution. The effects of increasing ϕ on the temperature distribution are plotted in figure 3(c). It is evident that heat transfer rate θ falls with rise in the phase difference. The reversed character performance is noticed in Figure 3(d) for different values of uniform/non-uniform parameter (m). It can be perceived that distribution of heat transfer enhances with increase in m. Also, the rate of heat transfer is higher in non-uniform microvessel compared with uniform microvessel.

The distribution of pressure rise $\Delta\bar{p}$ calculated by averaging $\Delta p_{\lambda}(t)$ over one oscillating period of wave. The visual representation of the relations between the time-average rise in pressure distribution $\Delta\bar{p}$ and average flow rate Q in figure 4. In figure 4(a), the impact of heat transfer Grashof number (Gr) on the time-average rise in pressure distribution is captured. It is focused that the time-average rise in pressure distribution and peristaltic pumping $(Q > 0 \,\&\, \Delta\bar{p} > 0)$ increase by enhancing the heat transfer Grashof number. Figure 4(b) is provided the impact of Hartmann number (M) on the time-average rise in pressure distribution. It is noticed that the rate of peristaltic pumping increases when the Hartmann number enhances. The impact of slip parameter (β) on the time-average rise in pressure distribution versus average flow rate Q is represented in figure 4(c). It is found that with gain in β, results in increasing retrograde pumping $(Q < 0 \,\&\, \Delta\bar{p} > 0)$. Further, figure 4(d) reveals that peristaltic pumping decreases with increasing phase difference ϕ.

Another important physical phenomena of streamlines is discussed in figures 5-6. The effects of slip parameter (β) on trapping of bolus are plotted in figure 5. It is noted that the number and trapped size of bolus increases on the left hand side of micovessel with increasing the slip parameter. Figure 7 shows that the impact of heat transfer Grashof number (Gr) on the trapped bolus. When increasing Gr, trapped bolus size of the streamline reduces near the microvessel left wall.

V. CONCLUSION

The proposed mathematical mode isl to study the impact of slip on the MHD peristaltic motion of an electrically conducting fluid in a vertical tapered microvessels with heat transfer is presented. The core outcomes can be shortened as follows:

- The velocity of the fluid gains with the enhances of a, β, M and Q.
- One can see that while increasing of γ, b, ϕ and m the temperature distribution increases.
- The time-averaged rise in pressure declines with the enhancing of Gr and ϕ. When M and β increases, $\Delta\bar{p}$ also increases.
- Size of the trapped circular bolus enhances with enhancing of β, while reduces in size with the increase of M.

The discussed model is may be very good sample analysis of blood flow in the heart pumping mechanics and calculate the average rise pressure in the tapered micro vessels.

Appendix

$$a_1 = \cosh Mh_1 + \beta M \sinh Mh_1 \ ,$$

$$a_2 = \sinh Mh_1 + \beta M \cosh Mh_1 \ ,$$

$$a_3 = \frac{Gr}{M^2}\left[\frac{\beta}{(h_1 - h_2)}\left[\frac{\gamma}{2}\left(h_1^2 - h_2^2\right) - 1\right] - \gamma\left(\frac{1}{M^2} + h_1\beta\right)\right],$$

$$a_4 = \cosh Mh_2 - \beta M \sinh Mh_2 \ ,$$

$$a_5 = \sinh Mh_2 - \beta M \cosh Mh_2 \ ,$$

$$a_6 = \frac{(h_2 - \beta - h_1)Gr}{(h_1 - h_2)M^2}\left(\frac{\gamma}{2}\left(h_1^2 - h_2^2\right) - 1\right) + \frac{\gamma Gr}{M^2}\left(\frac{h_1^2 - h_2^2}{2} + \beta h_2 - \frac{1}{M^2}\right),$$

$$a_7 = \frac{\left(h_2^2 - 2h_1h_2\right)Gr}{2(h_1 - h_2)M^2}\left(\frac{\gamma}{2}\left(h_1^2 - h_2^2\right) - 1\right) + \frac{\gamma Gr}{M^2}\left(\frac{h_1^2 h_2}{2} - \frac{h_2}{M^2} - \frac{h_2^3}{6}\right),$$

$$a_8 = \frac{\gamma Gr}{M^2}\left(\frac{h_1^3}{3} - \frac{h_1}{M^2}\right) - \frac{h_1^2 Gr}{2(h_1 - h_2)M^2}\left(\frac{\gamma}{2}\left(h_1^2 - h_2^2\right) - 1\right),$$

$$a_9 = -\left(\sinh(Mh_1) - \sinh(Mh_2)\right) \text{ and}$$

$$a_{10} = -\left(\cosh(Mh_1) - \cosh(Mh_2)\right) \ .$$

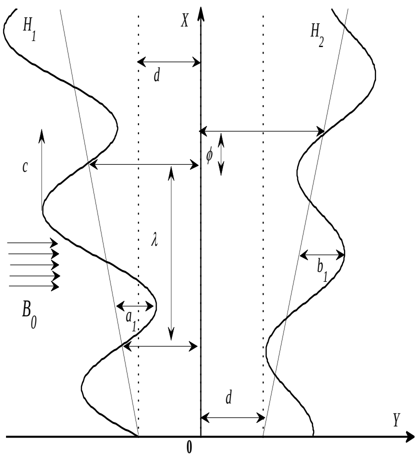
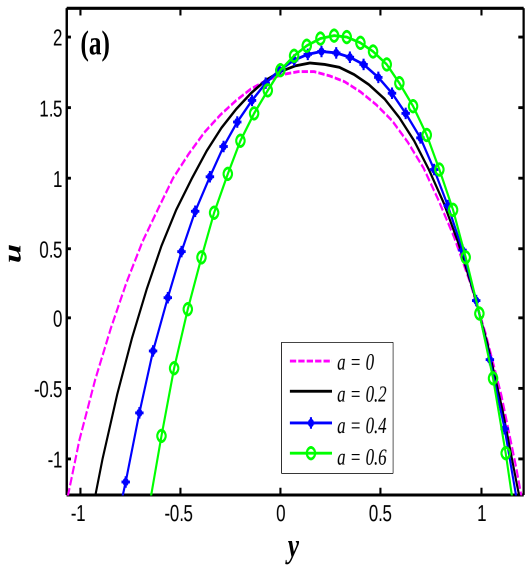
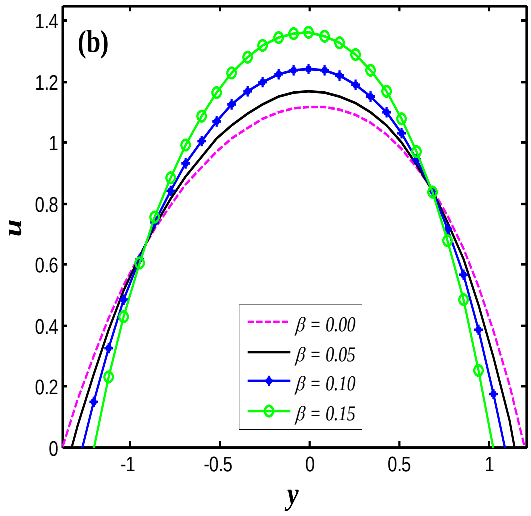
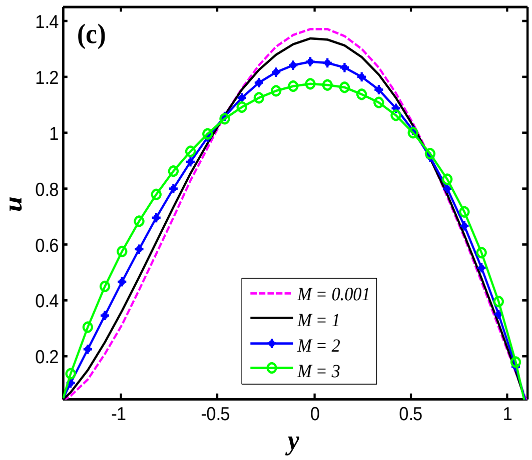


Fig. 1 Schematic plot of the problem







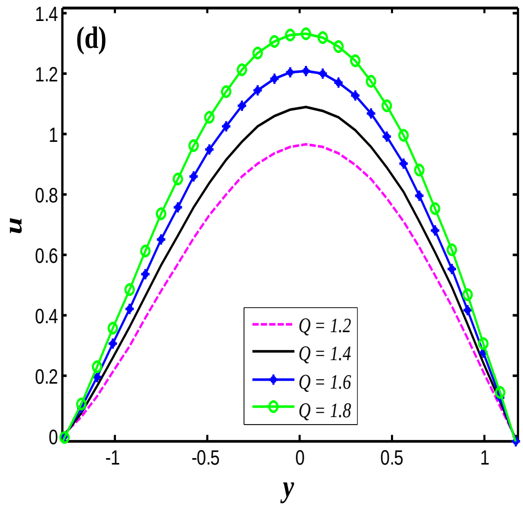


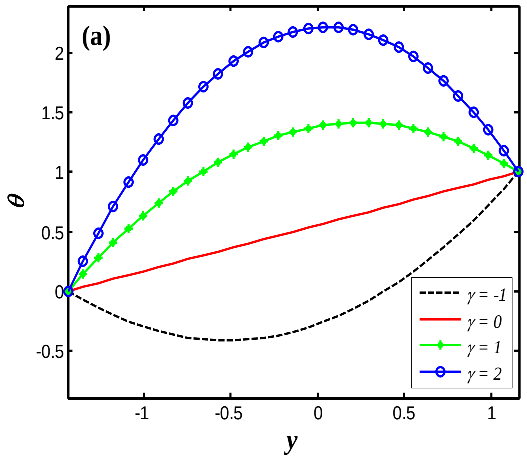
Fig. 2 Vertical Velocity Distribution

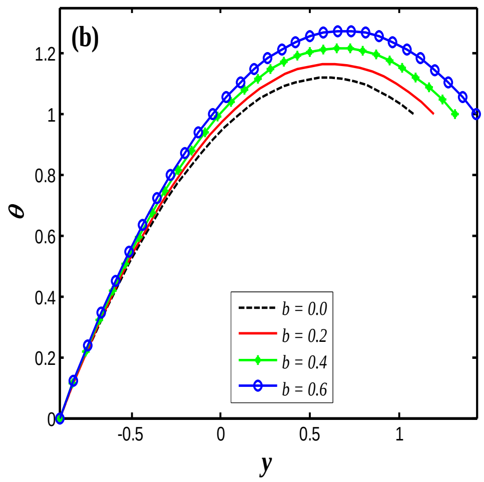
(a) $\phi = \pi, b = 0.3, \beta = 0.2, Q = 1.7, \gamma = 1, m = 0.2, M = 2, x = 0.4, Gr = 3, t = 0.3.$

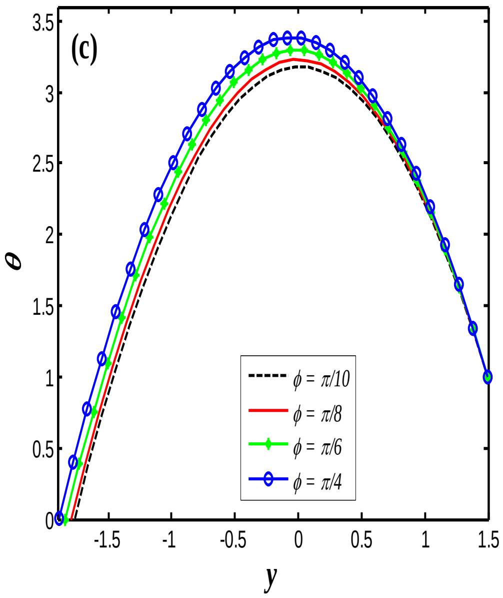
(b) $a = 0.3, x = 0.4, b = 0.2, Q = 1, \gamma = 1, m = 0.2, \phi = \pi/4, Gr = 2, M = 2, t = 0.3.$

(c) $Q = 1.4, \beta = 0.1, a = 0.4, b = 0.3, \phi = \pi/4, \gamma = 2, Gr = 4, m = 0.1, x = 0.4, t = 0.3.$

(d) $a = 0.2, x = 0.2, b = 0.1, \phi = \pi/2, M = 1, m = 0.5, \beta = 0.1, \gamma = 3, Gr = 1, t = 0.4.$







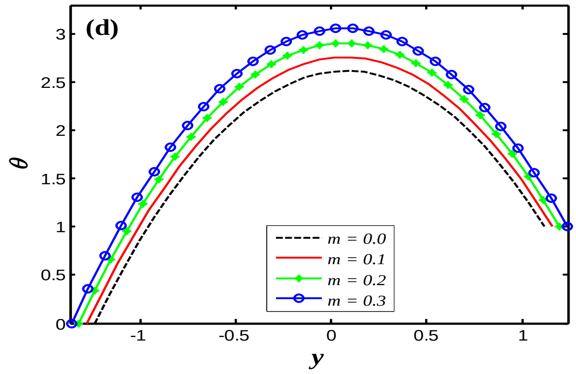


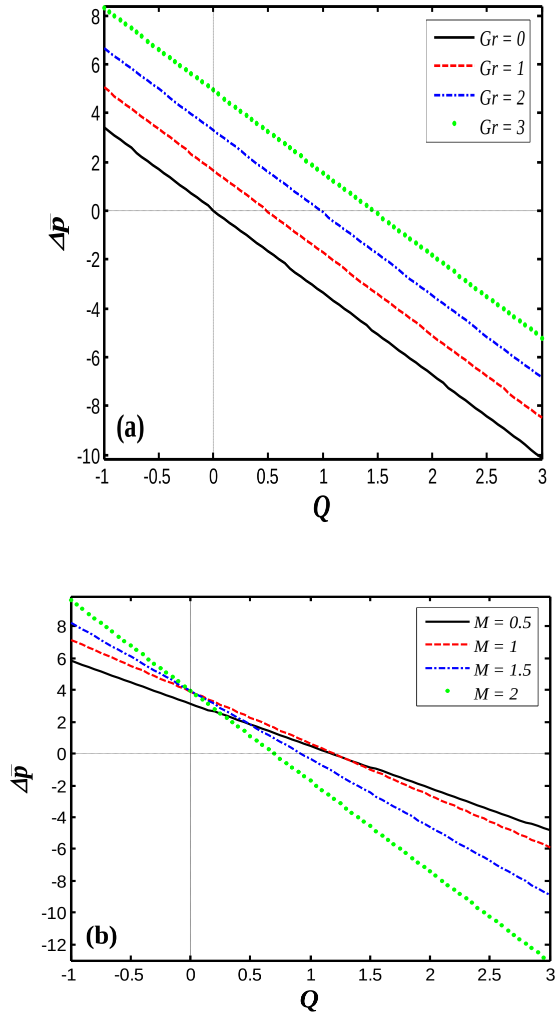
Fig. 3 Vertical Temperature Distribution

(a) $x = 0.4, m = 0.1, a = 0.4, \phi = \pi/3, b = 0.2, t = 0.3.$

(b) $\phi = \pi, a = 0.3, x = 0.4, \gamma = 1, m = 0.2, t = 0.3.$

(c) $x = 0.5, b = 0.5, \gamma = 2, m = 0.4, a = 0.7, t = 0.4.$

(d) $x = 0.4, a = 0.3, \phi = \pi/2, \gamma = 3, b = 0.2, t = 0.3.$



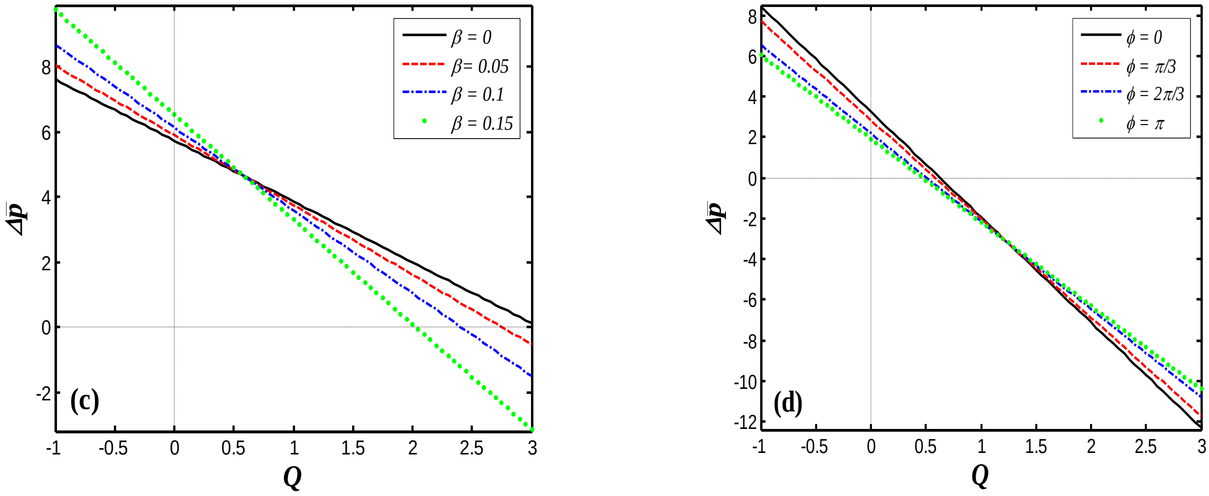


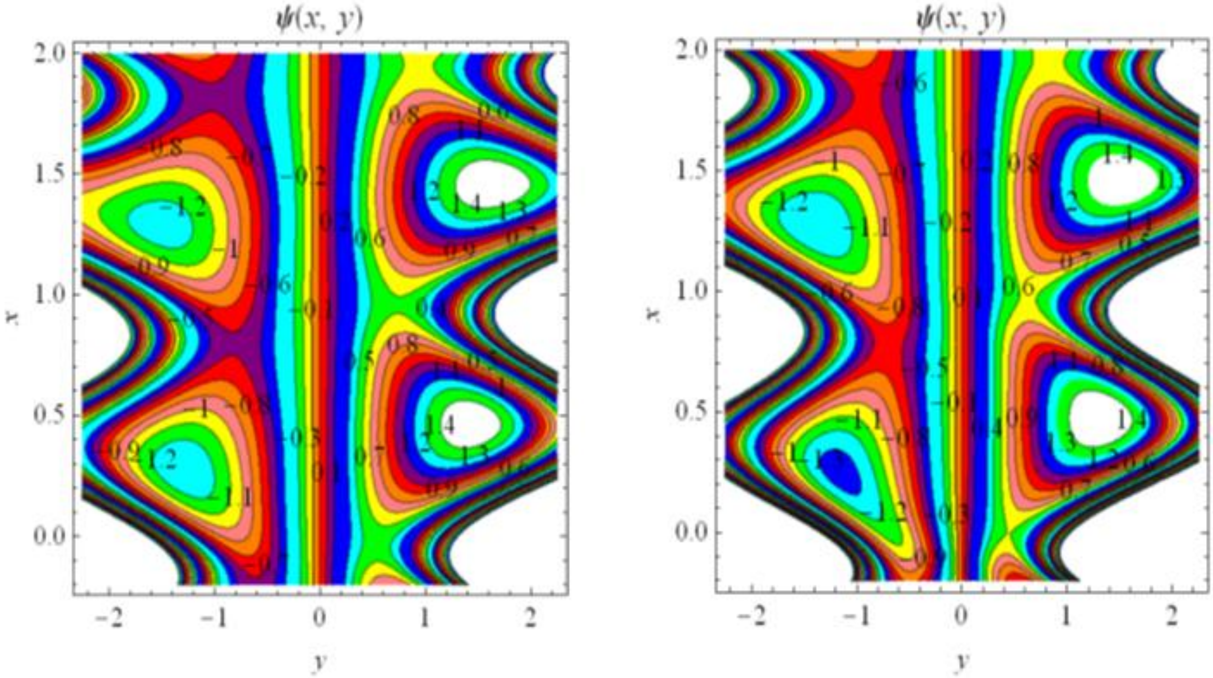
Fig. 4 Pressure rise $\Delta\bar{p}$ versus mean flow rate Q

(a) $\phi = \pi, a = b = 0.4, \beta = 0.2, m = 0.15, M = 0.75, \gamma = 2.$

(b) $a = 0.2, m = 0.1, \beta = 0.15, \gamma = 2, b = 0.1, \phi = \pi/3, Gr = 2.$

(c) $a = 0.3, \phi = \pi/4, M = 1, m = 0.2, \gamma = 3, b = 0.2, Gr = 3.$

(d) $\beta = 0.1, a = 0.3, \gamma = 2, m = 0.2, b = 0.4, M = 2, Gr = 1.$

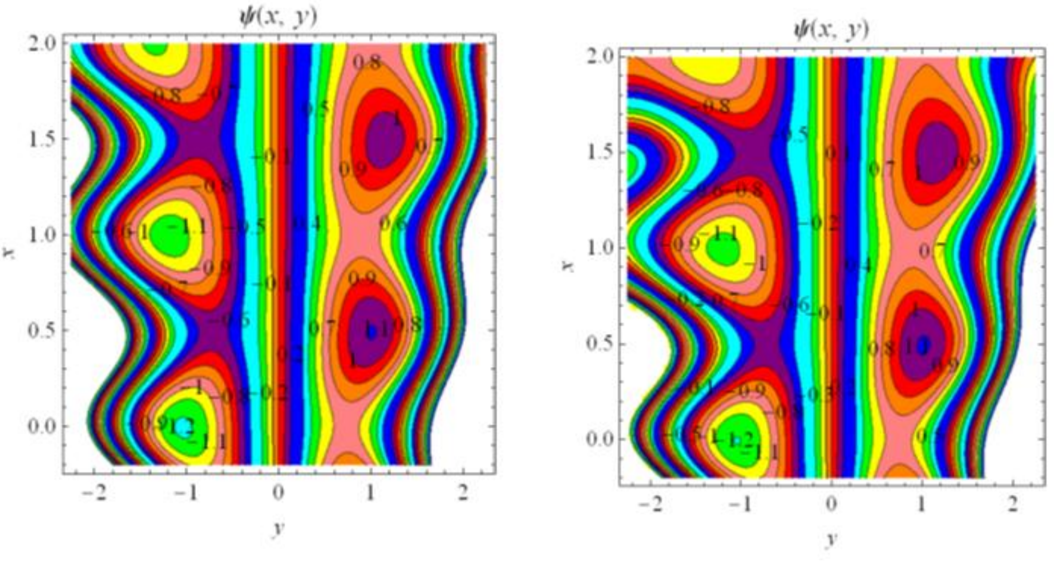


(a) **(b)**

Fig. 5 Streamlines

(for unlike in nature values of β : (a): $\beta = 0.05$, (b). $\beta = .15$,)

$a = 0.3, \phi = \pi/4, Q = 2, b = 0.4, m = 0.2, M = 1, \gamma = 1, Gr = 1, t = 0.2.$



(a) **(b)**

Fig. 6 Streamlines

(for unlike in nature values of Gr: (a): $Gr = 0$, (b). $Gr = 1.5$,)

$a = 0.2, M = 0.5, \gamma = 1, b = 0.1, m = 0.15, \phi = \pi, \beta = 0.15, Q = 0.75, t = 0.25.$

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