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Peristaltic Movement of a Dusty Fluid in a Curved Configuration with Mass Transfer

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Abstract.: This paper discusses the impact of mass transfer on the peristaltic flow of a dusty fluid in a curved configuration with elastic properties of the walls. A perturbation solution is being obtained which resolves the governing equations in which wave number is taken small. The expressions for concentration and stream function of fluid and particle phases are being obtained. The salient features of trapping phenomena are being discussed explicitly. It has been shown that the size of bolus expands by increasing curvature effects. The trapped bolus expands for fluid particles as δ increases and has opposite effect for dust particles.

AMS (MOS) Subject Classification Codes: 76B99; 76Z99; 70K60
Key Words: Dusty fluid, Curved channel, Peristalsis.

1. Introduction

A great number of two phase flows occur and they can be categorized into three main classes such as dispersed flow, separated flow and mixed flow. In this article, the dispersed flow is being discussed. The effect of the particulate substances on the fluid is denoted by the source term added in the right side of the momentum equation. The two phase fluid contained of two continuity and two momentum equations. A fluid, which contains solid particles, is termed as dusty fluid. The investigation of two phase flow has many applications in different branches of physical science and engineering. Some of the biological phenomena, involve the flow of diseased urine in the ureter are based on the flow of a particle fluid mixture in spite of uncontaminated fluid. Industrial examples of such flows are suspensions in paper making, the flow of dissolved micro molecules of fiber, blood through arteries, propulsion and combustion in rockets etc. Saffman [1] observed the streamline motion of a dusty gas. Wang et al. [2] examined the viscous flow having spherical particles in a cylindrical tube. Chakrabarti [3] discussed the boundary layer in a dusty gas. Zhang et al. [4] discussed the particles motion in the air with wall decomposition. Turkyilmazogla [5] discussed the effect of the MHD on two phase fluid. Tariq et al. [6] debated the influence

of inclined magnetic field on dusty Walters B fluid by considering peristaltic waves.
Peristalsis is the mechanism in which fluid is transported through the successive wave of contraction and relaxation of an extensible channel/ tube. The flow produced by this process has a vital role in the physiology, biology and engineering. Peristaltic pumps are used in oil refineries and many other industries. Mittra and Prasad [7] studied the elastic behavior of walls on the peristaltic waves. Davies et al. [8] debated the instabilities of flow in a channel between complaint walls. Vafai et al. [9] illustrated the wall properties effect on the third grade fluid with hall current. Parthasarathy et al. [10] explored the impact of peristaltic dusty fluid transport past a porous passage with the wall properties. When the flow through glandular ducts and physiological conducts are being considered. The flow configuration in these conditions are curved in nature. Micro wrinkles model on human skin has a curved configuration. The effect of curvature is meaningful in such situations. Having such in mind, Jaffrin [11] observed the curvature effect on the peristaltic waves. Sato [12] analyzed peristaltic flow in two dimensional curved channels. Few studies on the peristaltic flow with curved configuration are given in Refs $[13-17]$.
Mass transfer denotes that transfer of mass from one place to another. Mass transfer occurs in the field of chemical engineering such as distillation system, separation of petroleum components many biological processes in the body of living things. The peristaltic movement with mass and heat transfer was reported by Bhatti et al. [18]. Reddy [19] explored the mass and heat transfer influence on peristaltic wavy motion. Khan et al. [20] observed peristaltic movement in a curved configuration with mass transfer.
The literature survey indicates that many studies have been report for peristaltic flow in curved channel without the contribution of dust particles. Therefore in above mentioned attempts the peristaltic transport of a dusty fluid in a curved passage with mass transport is not being considered. Therefore the problem is first modeled and then explained analytically. The expression for velocity, stream function and concentration for both solid particles and fluid particles were being obtained.

2. Mathematical Formulation

Consider two dimensional curved passage of constant thickness $2a$ filled with a mixture of small solid particles in a viscous fluid. C_0 and C_1 are the concentration fields at the lower and upper walls respectively. The velocity components in the axial (x) and radial (r) directions be u' and v' for fluid particles and $u_s^{'}$ and $v_s^{'}$ for solid particles respectively. The walls are explained as

$$N'(x',t) = [a + \frac{2\pi}{\lambda}(x' - ct')], \tag{2. 1}$$

here b be the wave amplitude,λ be the wave length and c be the wave speed respectively.

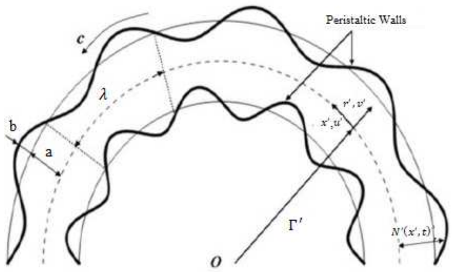

FIGURE 1. shows the geometry of the channel.

The equations governing the fluid flow with uniformly distributed solid particles through a curve channel are given as [12].
For fluid phase

$$\frac{\partial}{\partial r'}[(r'+\Gamma')v']+\Gamma'\frac{\partial u'}{\partial x'}=0, \tag{2. 2}$$

$$\begin{aligned}\frac{\partial u'}{\partial t}+(v'.\nabla)u'+\frac{u'v'}{r'+\Gamma'}=-\frac{\Gamma'}{\rho(r'+\Gamma')}\frac{\partial P}{\partial x'}+\\ \vartheta\left[\nabla^2u'-\frac{u'}{(r'+\Gamma')^2}+\frac{2\Gamma'}{(r'+\Gamma')^2}\frac{\partial v'}{\partial x'}\right]+\frac{k_0N_0}{\rho}({u'}_s-u'),\end{aligned} \tag{2. 3}$$

$$\begin{aligned}\frac{\partial v'}{\partial t}+(v'.\nabla)v'+\frac{{u'}^2}{r'+\Gamma'}=-\frac{1}{\rho}\frac{\partial P}{\partial r'}+\\ \vartheta\left[\nabla^2v'-\frac{v'}{(r'+\Gamma')^2}+\frac{2\Gamma'}{(r'+\Gamma')^2}\frac{\partial u'}{\partial x'}\right]+\frac{k_0N_0}{\rho}(v'_s-v'),\end{aligned} \tag{2. 4}$$

$$\left(\frac{\partial C'}{\partial t}+v'\frac{\partial C'}{\partial r'}+\frac{\Gamma'u'}{r'+\Gamma'}\frac{\partial C'}{\partial x'}\right)=D(\nabla^2C'). \tag{2. 5}$$

For dust phase

$$R'\frac{\partial {u'}_s}{\partial x'}+\frac{\partial}{\partial r'}[(r'+\Gamma')v'_s]=0, \tag{2. 6}$$

$$\frac{\partial {u'}_s}{\partial t'}+\frac{{u'}_s v'_s}{r'+\Gamma'}+(v'_s.\nabla){u'}_s=\frac{k_0}{m}(u'-{u'}_s), \tag{2. 7}$$

$$\frac{\partial v'_s}{\partial t'}-\frac{{{u'}_s}^2}{r'+\Gamma'}+(v'_s.\nabla)v'_s=\frac{k_0}{m}(v'-{v'}_s), \tag{2. 8}$$

$$\left(\frac{\partial C'_s}{\partial t}+v'\frac{\partial C'_s}{\partial r'}+\frac{R'u'}{r'+\Gamma'}\frac{\partial C'_s}{\partial x'}\right)=D_s(\nabla^2C'_s), \tag{2. 9}$$

where

$$(v'.\nabla)=\frac{\Gamma'u'}{r'+\Gamma'}\frac{\partial}{\partial x'}+v'\frac{\partial}{\partial r'}, \tag{2. 10}$$

$$(v'_s.\nabla)=\frac{\Gamma'{u'}_s}{r'+\Gamma'}\frac{\partial}{\partial x'}+v'_s\frac{\partial}{\partial r'}, \tag{2. 11}$$

$$\nabla^2 = \left(\frac{\Gamma'}{r'+\Gamma'}\right)^2 \frac{\partial^2}{\partial x'^2} + \frac{\partial^2}{\partial r'^2} + \frac{1}{r'+\Gamma'}\frac{\partial}{\partial r'}, \tag{2. 12}$$

where P represents pressure of the fluid, k_0 represents resistance coefficient, m represents mass of the dust particles, represents kinematic viscosity, C' represents concentration of the fluid, N_0 represents number density of dust particles and it is considered as a constant, D_s represents mass diffusivity coefficient of dust particles, D represents mass diffusivity coefficient of the fluid, C'_s represents concentration of the dust particles and ρ the density of the fluid.

The boundary conditions for curved configuration with compliant walls are described as below

$$u' = 0, \quad u'_s = 0 \quad at \quad r' = \pm N',$$
$$C' = C_1, \quad at \quad r' = N', \quad C' = C_0 \quad , \quad at \quad r' = -N',$$
$$\left(\frac{\Gamma'}{r'+\Gamma'}\right)\left[-\tau\frac{\partial^3}{\partial x'^3} + m_1'\frac{\partial^3}{\partial t^2 \partial x'} + d'\frac{\partial^2}{\partial t \partial x'}\right]N' = -\rho\left[\frac{\partial u'}{\partial t} + (v'.\nabla)u' + \frac{u'v'}{r'+\Gamma'}\right]$$
$$+\mu\left[\nabla^2 u' - \frac{u'}{(r'+\Gamma')^2} + \frac{2\Gamma'}{(r'+\Gamma')^2}\frac{\partial v'}{\partial x'}\right] + k_0 N_0(u'_s - u') \quad at \quad r' = \pm N', \tag{2. 13}$$

here m_1' represents mass per unit area, d' represents viscous damping coefficient and τ represents elastic tension in the membrane.
The stream functions and dimensionless quantities can be defined as

$$x = \frac{x'}{\lambda}, \quad r = \frac{r'}{a}, \quad \psi = \frac{\psi'}{\vartheta}, \quad \phi = \frac{\phi'}{\vartheta}, \quad P = \frac{a^3}{\lambda\vartheta^2}P', \quad h = \frac{h'}{a},$$
$$\delta = \frac{a}{\lambda}, \quad \sigma = \frac{C' - C_0}{C_1 - C_0}, \quad \sigma_s = \frac{C'_s - C_0}{C_1 - C_0},$$
$$u = -\frac{\partial\psi}{\partial r}, \quad v = \frac{l\delta}{(l+r)}\frac{\partial\psi}{\partial x}, \quad u_s = -\frac{\partial\phi}{\partial r}, \quad v_s = \frac{l\delta}{(l+r)}\frac{\partial\phi}{\partial x}, \tag{2. 14}$$

Using (2. 14) into (2. 2)-(2. 9). The equation of continuity for fluid as well as dust particles are automatically satisfied. Solving (2. 3) and (2. 4) for fluid particles and (2. 7) and (2. 8) for solid particles give

$$\delta\left[\frac{\partial}{\partial t}(\nabla^2\psi) + \frac{\partial\psi}{\partial r}\left(\frac{l}{l+r}\right)\frac{\partial}{\partial x}(\nabla^2\psi) - \frac{\partial\psi}{\partial x}\left(\frac{l}{l+r}\right)\frac{\partial}{\partial r}(\nabla^2\psi)\right] = \nabla^4\psi + A(\nabla^2\phi - \nabla^2\psi), \tag{2. 15}$$

$$\delta\left[\frac{\partial}{\partial t}(\nabla^2\phi) + \frac{\partial\phi}{\partial r}\left(\frac{l}{l+r}\right)\frac{\partial}{\partial x}(\nabla^2\phi) - \frac{\partial\phi}{\partial x}\left(\frac{l}{l+r}\right)\frac{\partial}{\partial r}(\nabla^2\phi)\right] = B(\nabla^2\psi - \nabla^2\phi), \tag{2. 16}$$

$$\delta\left(\frac{\partial\sigma}{\partial t} - \left(\frac{l}{l+r}\right)\frac{\partial\sigma}{\partial r}\frac{\partial\psi}{\partial x} - \frac{\partial\phi}{\partial r}\left(\frac{l}{l+r}\right)\frac{\partial\sigma}{\partial x}\right) = \frac{1}{Sc}(\nabla^2\sigma), \tag{2. 17}$$

$$\delta\left(\frac{\partial\sigma_s}{\partial t} - \left(\frac{l}{l+r}\right)\frac{\partial\sigma_s}{\partial r}\frac{\partial\psi}{\partial x} - \frac{\partial\phi}{\partial r}\left(\frac{l}{l+r}\right)\frac{\partial\sigma_s}{\partial x}\right) = \frac{1}{Sc}(\nabla^2\sigma_s), \tag{2. 18}$$

where

$$\nabla^2 = \delta^2\left(\frac{l}{r+l}\right)^2\frac{\partial^2}{\partial x} + \frac{l}{r+l}\frac{\partial}{\partial r} + \frac{\partial^2}{\partial r^2}, \tag{2. 19}$$

$A = \frac{(k_0 N_0 a^2)}{\rho v}$ and $B = \frac{ka^2}{\vartheta m}$ are dimensionless parameters and $Sc = \frac{\mu}{\rho D}$ and $Sc_s = \frac{\mu}{\rho D_s}$ are Schmidt number for fluid and dust particles,
with boundary conditions

$$\frac{\partial \psi}{\partial r} = 0, \quad \frac{\partial \phi}{\partial r} = 0, \quad at \quad r = \pm N,$$
$$\sigma = 1, \quad at \quad r = N, \quad \sigma = 0, \quad at \quad r = -N, \tag{2. 20}$$

$$k\left[E_1 \frac{\partial^3}{\partial x^3} + E_2 \frac{\partial^3}{\partial x^2 \partial t} + E_3 \frac{\partial^2}{\partial x \partial t}\right] N = -\left[\left(\frac{l}{r+l}\right) \frac{\partial \psi}{\partial x} \frac{\partial^2 \psi}{\partial r^2} + \left(\frac{l}{r+l}\right) \frac{\partial \psi}{\partial x} \frac{\partial^2 \psi}{\partial r \partial x} - \left(\frac{l}{r+l}\right) \frac{\partial \psi}{\partial x} \frac{\partial \psi}{\partial r}\right] - (r+l)\delta \frac{\partial^2 \psi}{\partial t^2} + \frac{\partial}{\partial r}\left[(r+l) \frac{\partial^2 \psi}{\partial r^2}\right] + \frac{\delta^2 l^2}{(r+l)^2} \frac{\partial^3 \psi}{\partial x^3} - \frac{1}{r+l} \frac{\partial \psi}{\partial r} - 2\delta^2 \frac{l^2}{(r+l)^2} \frac{\partial^2 \psi}{\partial x^2} + A\left[\frac{\partial \phi}{\partial r} - \frac{\partial \psi}{\partial r}\right] \quad at \quad r = \pm N, \tag{2. 21}$$

where $E_1 = \frac{\tau a^4}{\nu \rho}$ the tension parameter, $E_2 = \frac{m' a^2}{\lambda^3 \rho}$ the characterizing parameter and $E_3 = \frac{d' a^3}{\lambda^2 \nu \rho}$ the damping parameter.

3. Perturbation Solution

Due to non-linear system of equations, perturbation technique has been employed to get the solution. Consider small wave number as perturbation parameter and expands ψ,ϕ, σ and σ_s as below

$$\psi = \psi_0 + \delta \psi_1 + O(\delta^2),$$
$$\phi = \phi_0 + \delta \phi_1 + O(\delta^2),$$
$$\sigma = \sigma_0 + \delta \sigma_1 + O(\delta^2),$$
$$\sigma_s = \sigma_{s_0} + \delta \sigma_{s_1} + O(\delta^2). \tag{3. 22}$$

3.1. **Zeroth Order System.**

$$\frac{\partial^4 \psi_0}{\partial r^4} + \frac{2}{(r+l)} \frac{\partial^3 \psi_0}{\partial r^3} - \frac{1}{(r+l)^2} \frac{\partial^2 \psi_0}{\partial r^2} + + \frac{1}{(r+l)^3} \frac{\partial \psi_0}{\partial r} = A[\nabla^2 \psi_0 - \nabla^2 \phi_0], \tag{3. 23}$$
$$B[\nabla^2 \phi_0 - \nabla^2 \psi_0] = 0, \tag{3. 24}$$
$$\nabla^2 \sigma_0 = 0, \tag{3. 25}$$
$$\nabla^2 \sigma_{s_0} = 0, \tag{3. 26}$$

where

$$\nabla^2 = \frac{1}{(r+l)} \frac{\partial}{\partial r} + \frac{\partial^2}{\partial r^2},$$
$$\frac{\partial \psi_0}{\partial r} = 0, \quad \frac{\partial \phi_0}{\partial r} = 0, \quad at \quad r = \pm N,$$
$$\sigma_0 = 1 = \sigma_{s_0}, \quad at \quad r = N, \quad \sigma_0 = 0 = \sigma_{s_0}, \quad at \quad r = -N,$$

$$k\left[E_1\frac{\partial^3}{\partial x^3}+E_2\frac{\partial^3}{\partial x^2\partial t}+E_3\frac{\partial^2}{\partial x\partial t}\right]N=\frac{\partial}{\partial r}\left[(r+l)\frac{\partial^2\psi_0}{\partial r^2}\right]$$
$$-\frac{1}{r+l}\frac{\partial\psi_0}{\partial r}+A\left[\frac{\partial\phi_0}{\partial r}-\frac{\partial\psi_0}{\partial r}\right](r+l)\quad at\quad r=\pm N. \tag{3. 27}$$

3.2. **First Order System.**

$$\frac{\partial^4\psi_1}{\partial r^4}+\frac{2}{(r+l)}\frac{\partial^3\psi_1}{\partial r^3}-\frac{1}{(r+l)^2}\frac{\partial^2\psi_1}{\partial r^2}+\frac{1}{(r+l)^3}\frac{\partial\psi_1}{\partial r}=A[\nabla^2\psi_1-\nabla^2\phi_1]$$
$$+\frac{\partial}{\partial t}\nabla^2\psi_0+\frac{\partial\psi_0}{\partial r}+\frac{l}{r+l}\frac{\partial}{\partial r}\nabla^2\psi_0, \tag{3. 28}$$

$$B(\nabla^2\psi_1-\nabla^2\phi_1)=\frac{\partial}{\partial t}\nabla^2\phi_0+\frac{\partial\phi_0}{\partial r}\frac{l}{r+l}\frac{\partial}{\partial x}\nabla^2\phi_0-\frac{\partial\phi_0}{\partial x}\frac{l}{r+l}\frac{\partial}{\partial r}\nabla^2\phi_0, \tag{3. 29}$$

$$\frac{1}{Sc}(\nabla^2\sigma_1)=\left(\frac{\partial\sigma_0}{\partial t}-\left(\frac{l}{r+l}\right)\frac{\partial\phi_0}{\partial x}\frac{\partial\sigma_0}{\partial r}-\left(\frac{l}{r+l}\right)\frac{\partial\phi_0}{\partial r}\frac{\partial\sigma_0}{\partial x}\right), \tag{3. 30}$$

$$\frac{1}{Sc}(\nabla^2\sigma_{s_1})=\left(\frac{\partial\sigma_{s_0}}{\partial t}-\left(\frac{l}{r+l}\right)\frac{\partial\phi_0}{\partial x}\frac{\partial\sigma_{s_0}}{\partial r}-\left(\frac{l}{r+l}\right)\frac{\partial\phi_0}{\partial r}\frac{\partial\sigma_{s_0}}{\partial x}\right), \tag{3. 31}$$

$$\frac{\partial\psi_1}{\partial r}=0,\quad \frac{\partial\phi_1}{\partial r}=0,\quad at\quad r=\pm N,$$
$$\sigma_1=0=\sigma_{s_1},\quad at\quad r=N,\quad \sigma_1=0=\sigma_{s_1},\quad at\quad r=-N,$$
$$k\left[E_1\frac{\partial^3}{\partial x^3}+E_2\frac{\partial^3}{\partial t^2\partial x}+E_3\frac{\partial^2}{\partial x\partial t}\right]N=\frac{\partial}{\partial r}\left[(r+l)\frac{\partial^2\psi_1}{\partial r^2}\right]-\frac{1}{r+l}\frac{\partial\psi_1}{\partial r}-(r+l)\left[\frac{\partial^2\psi_0}{\partial r\partial t}\right.$$
$$\left.-\left(\frac{l}{r+l}\right)\frac{\partial\psi_0}{\partial x}\frac{\partial^2\psi_0}{\partial r^2}+\left(\frac{l}{r+l}\right)\frac{\partial\psi_0}{\partial x}\frac{\partial^2\psi_0}{\partial r\partial x}-\left(\frac{l}{r+l}\right)\frac{\partial\psi_0}{\partial x}\frac{\partial\psi_0}{\partial r}\right]\quad at\quad r=\pm N. \tag{3. 32}$$

The solution of above system of equations are solved by DSolver command in Mathematica.

4. Results and Discussion

This section includes the physical interpretation of velocity, concentration and stream line pattern of the fluid and solid particles for pertinent quantities. Figures 2 to 15 represent the profile of velocity and concentration of fluid and dust particles for various values of emerging parameters respectively. Figure 2 shows the influence of δ on velocity of fluid. The velocity of fluid rises by increasing δ. Figures 3 and 4 are being plotted for tension and mass parameters. The velocity of the fluid rises as the value of these parameters are increased. Tension parameter can be related by lessening of viscosity thus resulting increase in the velocity. Figure 5 displays the effect of damping parameter on fluids velocity. It is found that the velocity of fluid declines by rising the value of E_3. Increase in damping parameter can be related with the resistive forces thus as resistive forces are enhanced, velocity declines. Figure 6 explains the effect of l on the velocity of fluid. The fluids velocity rises as l increases. Figures 7 to 11 exhibit the behavior of δ, E_1, E_2, E_3 and l on the velocity of the dust particles respectively. It is being explained that the velocity of dust particles rises by increasing the values of wave number, tension parameter, the mass parameter, curvature parameter and damping parameter. Figures 12 to 15 represent the concentration distribution

for fluid along with solid particles. From these figures, it is noticed that the concentration field rises by increasing δ both fluid and dust particles, whereas the concentration field declines as Schmidt number increases for both fluid and dust particles. The mass diffusion declines for increasing Schmidt number therefore concentration decreases.
The trapping is a main phenomenon in peristaltic flow and this confined bolus is moved forward by the peristaltic wave. The influence of δ on the streamline pattern of fluid particles is examined through Figure 16. It can be said that the trapped bolus size increased as δ is increased. The influence of l on the streamline pattern of fluid particles has been showed in Figure 17. This figure displays that the trapped bolus increases in size and it moves towards right as l increases. The stream line patterns of solid particle have been shown in Figures 18 and 19. It is viewed that the bolus size reduces by rising δ and the bolus expand as l rises.

5. Conclusion

This paper presented the impact of mass transfer on peristaltic motion of a viscous dusty fluid in a curved passage is being analyzed under small wave number approximation. The vital elements of the existing study are as under
1. The volume of the bolus for the fluid particles increases by increasing δ and l, whereas the volume of the bolus for the solid particles decreases by enhancing δ.
2. The velocity of the fluid rises by enhancing the stiffness and rigidity of the wall and decreases as damping parameter increases.
3. The velocity of the solid particles rises by enhancing the damping parameter, stiffness and rigidity of the wall.
4. The concentration field declines for both fluid and dust particles as Schmidt number increases.

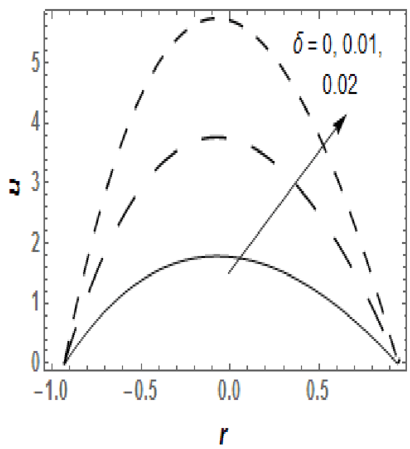

FIGURE 2. Consequence of δ on the fluids velocity with $E_1 = 0.01$,$\epsilon = 0.08$,$t = 0.5$,$E_2 = 0.03$,$E_3 = 0.02$,$l = 3.6$,$A = 0.5$ and $B = 0.2$.

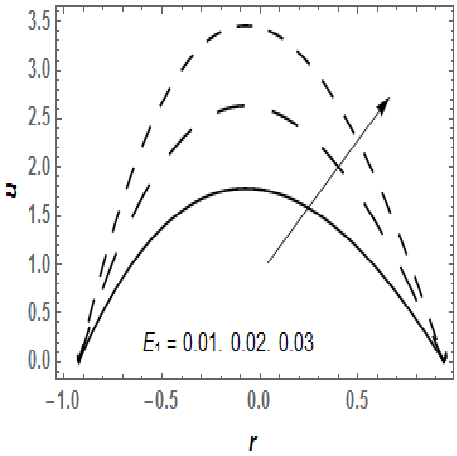

FIGURE 3. Consequence of E_1 on the fluids velocity with $\delta = 0.01$,$E_3 = 0.02$,$\epsilon = 0.08$,$t = 0.5$,$E_2 = 0.03$,$l = 3.6, A = 0.5$ and $B = 0.2$.

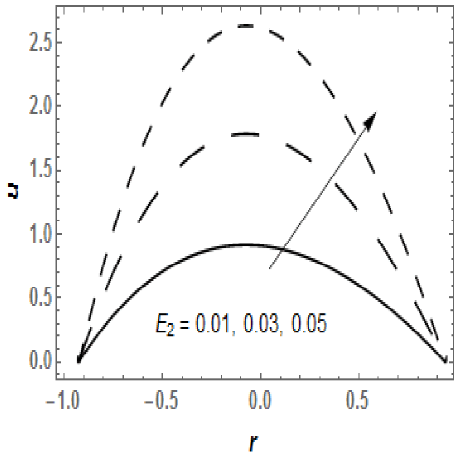

FIGURE 4. Consequence of E_2 on the fluids velocity with $\delta = 0.01$,$E_1 = 0.03$,$E_3 = 0.01$,$\epsilon = 0.08$,$t = 0.5$,$l = 3.6, A = 0.5$ and $B = 0.2$.

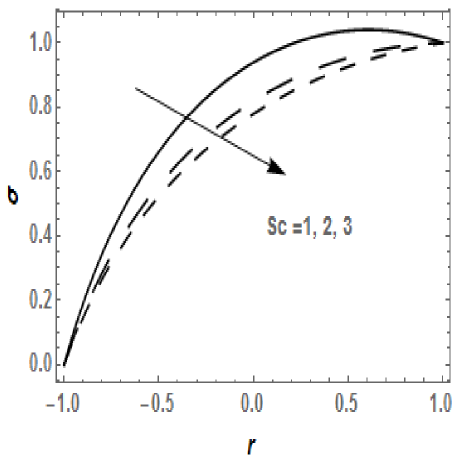

FIGURE 13. Concentration of fluid for Sc with $E_3 = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.1, x = 0.08, \delta = 0.01, l = 3.6, A = 0.5$ and $B = 0.2$.

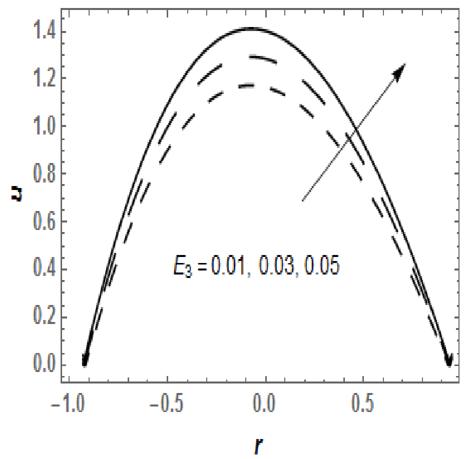

FIGURE 5. Consequence of E_3 on the fluids velocity with $\delta = 0.01$,$E_2 = 0.03$,$E_1 = 0.02$,$\epsilon = 0.08$,$t = 0.5, l = 3.6, A = 0.5$ and $B = 0.2$.

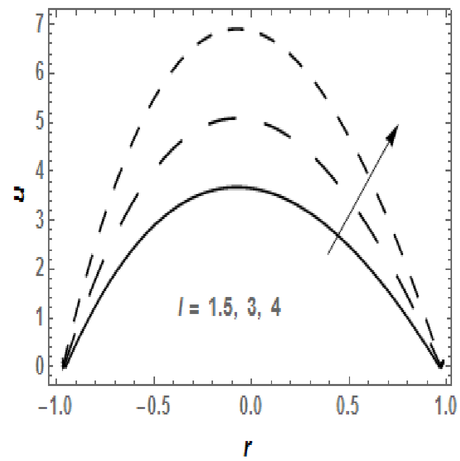

FIGURE 6. Consequence of l on the fluids velocity with $\delta = 0.01$,$E_2 = 0.03$,$E_1 = 0.01$,$\epsilon = 0.1, x = 1, t = 0.5, E_3 = 0.02, A = 0.5$and $B = 0.2$.

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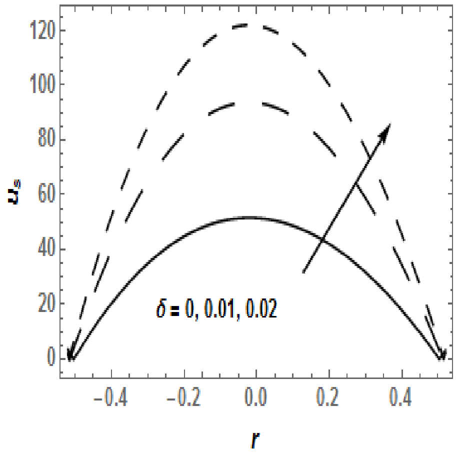

FIGURE 7. Consequence of δ on the solid particles velocity with $E_3 = 0.01, E_2 = 0.03, E_1 = 0.02$,$\epsilon = 0.08, t = 0.5, k = 3.6, A = 0.5$ and $B = 0.2$.

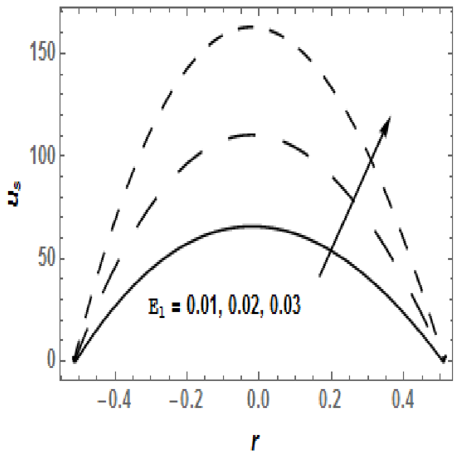

FIGURE 8. Consequence of E_1 on the solid particles velocity with $\delta = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, l = 3.6, A = 0.5$ and $B = 0.2$.

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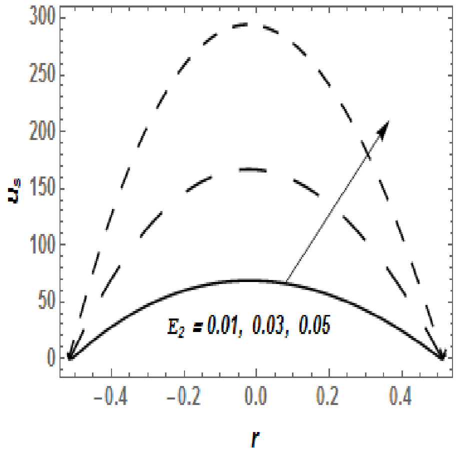

FIGURE 9. Consequence of E_2 on the solid particles velocity with $\delta = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, l = 3.6, A = 0.5$ and $B = 0.2$.

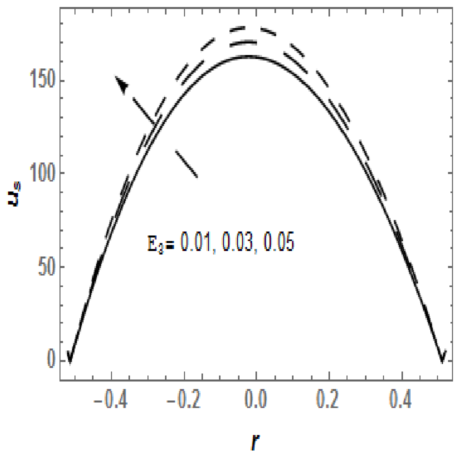

FIGURE 10. Consequence of E_3 on the solid particles velocity with $\delta = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, l = 3.6, A = 0.5andB = 0.2$.

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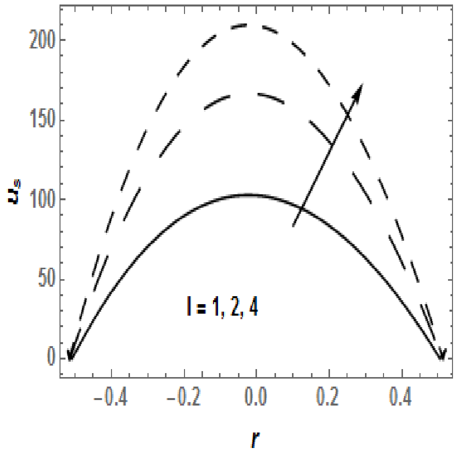

FIGURE 11. Fig 10: Consequence of l on the solid particles velocity with $\delta = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, l = 3.6, A = 0.5$ and $B = 0.2$.

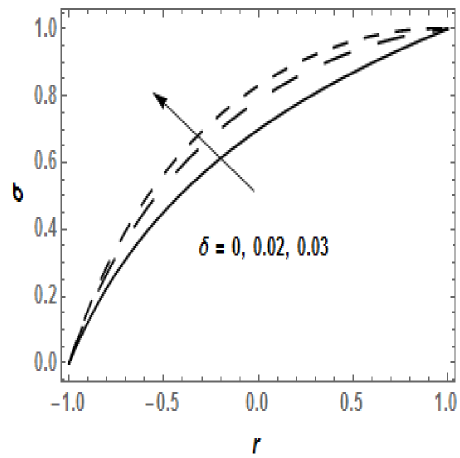

FIGURE 12. Concentration of fluid for δ with $E_3 = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, l = 3.6, Sc = 0.3, A = 0.5$ and $B = 0.2$.

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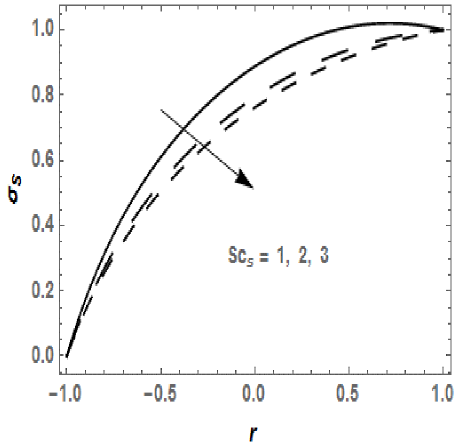

FIGURE 14. Concentration of solid particles for Sc_s with $E_3 = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, \delta = 0.01, l = 3.6, A = 0.5$ and $B = 0.2$.

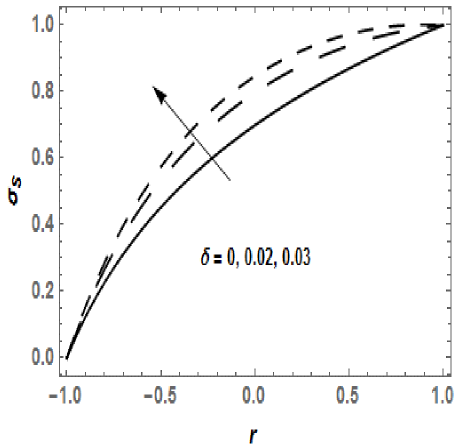

FIGURE 15. Concentration of solid particles for δ on with $E_3 = 0.01, E_2 = 0.03, E_1 = 0.02, \epsilon = 0.08, t = 0.5, l = 3.6, Sc = 3, A = 0.5$ and $B = 0.2$.

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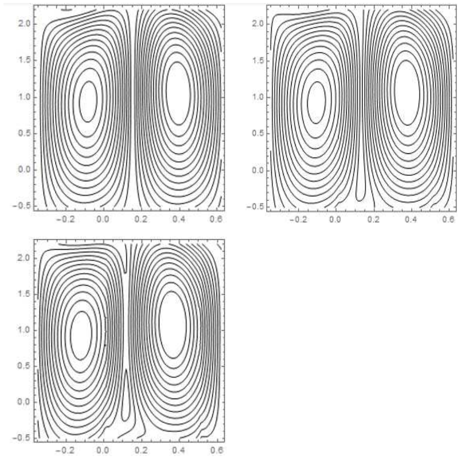

FIGURE 16. Streamline for fluid (a) $\delta = 0$, (b) $\delta = 0.01$, (c) $\delta = 0.02$, with $E_3 = 0.08, E_2 = 0.02, E_1 = 0.01, \ = 0.1, t = 0.5, l = 3.6, A = 0.5$ and $B = 0.2$.

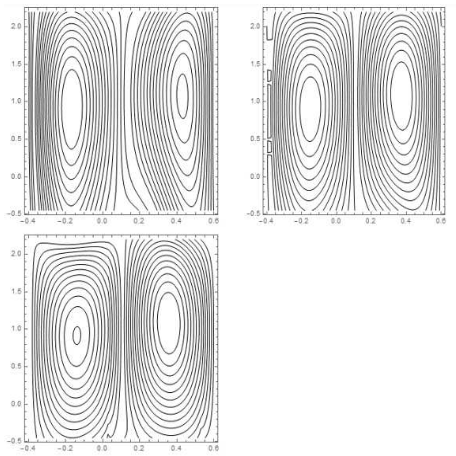

FIGURE 17. Streamline for fluid (a) $l = 2$, (b) $l = 3$, (c)$l = 4$, with $E_3 = 0.02, E_2 = 0.03, E_1 = 0.01, \epsilon = 0.1, t = 0.5, \delta = 0.01, A = 0.5$ and $B = 0.2$.

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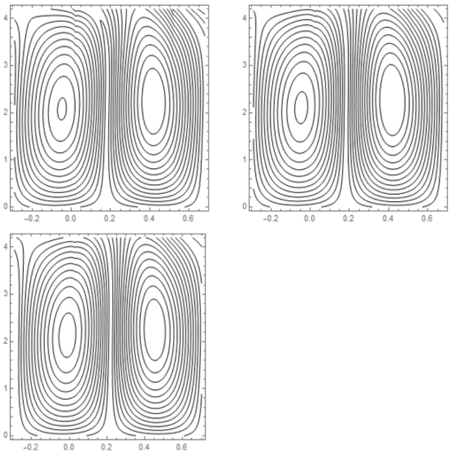

FIGURE 18. Streamline for dust particle (a) $\delta = 0$, (b) $\delta = 0.01$, (c) $\delta = 0.02$, with $E_3 = 0.07, E_2 = 0.03, E_1 = 0.01, \epsilon = 0.1, t = 0.5, l = 3.6, A = 0.5$ and $B = 0.2$

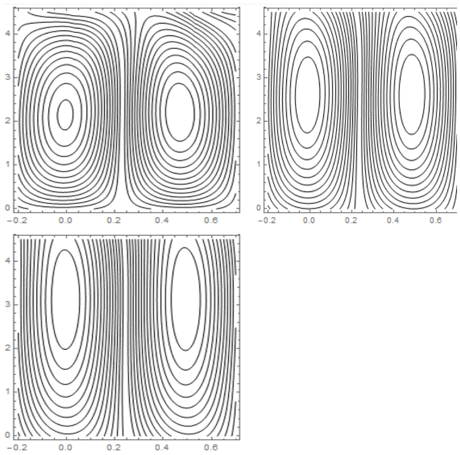

FIGURE 19. Streamline for dust particle (a) $l = 2$, (b) $l = 3$, (c) $l = 4$, with $E_3 = 0.03, E_2 = 0.02, E_1 = 0.01, \epsilon = 0.1, t = 0.5, \delta = 0.01, A = 0.5$ and $B = 0.2$.

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