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Impact of Variable Liquid Properties on Peristaltic Transport of Non-Newtonian Fluid Through a Complaint Non-Uniform Channel

Manjunatha Gudekote[1], Rajashekhar Choudhari[2], Prathiksha Sanil[1], Hanumesh Vaidya[3], Balachandra Hadimani[1,*], Kerehalli Vinayaka Prasad[3], Jyoti Shetty[2]

[1] Department of Mathematics, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, India
[2] Department of Mathematics, Manipal Institute of Technology Bengaluru, Manipal Academy of Higher Education, Manipal, India
[3] Department of Mathematics, Vijayanagara Sri Krishnadevaraya University, Ballari, India

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ABSTRACT

The present investigation emphasises a new attempt at the peristaltic mechanism of Eyring Powell fluid through a non-uniform channel. The analysis is performed in the presence of wall properties under the influence of variable liquid properties, and the flow problem is mathematically developed. The channel walls are subjected to no-slip conditions with long-wavelength and low Reynolds-number approximations employed in the study. The nonlinear governing equations are normalised using relevant non-dimensional parameters, and the solutions are obtained with the help of a regular perturbation technique. The influence of pertinent physical parameters of interest, such as velocity, temperature, concentration and streamlines, are represented graphically. The investigation reveals that the material parameters and elastic parameters of the Eyring Powell fluid model strongly affect the velocity and temperature profiles and that the opposite behaviour has been observed in the material parameters.

1. Introduction

Peristalsis has been a significant focus of scientific study over the last several decades. Because of its applications in medical research and engineering, it has recently attracted widespread attention. Biological fluids may be carried through the natural contraction and expansion of distensible vessels. Regarding biological fluid, peristalsis may be seen in eating food down the throat, urinating into a ureter, and moving chyme along the digestive system. Due to peristaltic mechanisms, the nuclear industry hygienic fluids may be transported, such as corrosive, toxic, and noxious fluids. Numerous studies have

[*] *Corresponding author.*
E-mail address: bs.hadimani@manipal.edu

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been conducted to better understand peristalsis in various geometric and waveform configurations. Circulatory pumps in the heart-lung machine and roller-finger are examples of industrial applications that use the peristaltic mechanism.

Latham [1] first explored the peristalsis of a viscous, incompressible fluid through the ureter. Another example is the mathematical model for peristaltic pumping created by Shapiro *et al.,* [2]. They examined the peristaltic pumping, refluxing, and trapping effects on viscous, incompressible fluid flow in a two-dimensional channel. Furthermore, Srivastava and Srivastava [3] attempted a beneficial study on the Peristaltic mechanism of a non-Newtonian fluid. Second-order fluid peristalsis in a porous region was studied by Mekheimer and Abd Elmaboud [4] as an application of an endoscope. Series solutions of the non-linear governing equations were constructed for velocity and pressure gradient.

Due to its widespread application in the medical profession, heat transfer in biological systems is critical in peristaltic flow studies. Heat transmission in biological systems may be accomplished via the employment of any one of three basic types of heat transfer mechanisms: convection, conduction, or radiation. As one of the three heat transport mechanisms, the convective approach plays a vital role in understanding blood oxygenation and hemodialysis. In addition, human lungs, small-radius blood arteries, and gallbladder stones are all examples of this. In addition, liquids with varying thermal conductivity are the most accurate representations of blood flowing through arteries. Vajravelu *et al.,* [5] examined the impact of heat transmission on the peristaltic process through the permeable annulus. An investigation into the influence of heat transfer on peristaltic transport through an arcing channel was carried out by Ali *et al.,* [6]. Peristaltic flow of Rabinowitsch liquid through an inclined non-uniform slippery tube was explored by Manjunatha *et al.,* [7]. MHD Carreau fluid was studied by Tanveer *et al.,* [8] using a modified Darcy law for peristaltic transport in a circular channel. Viscose scattering and gravitational influence cause temperature and velocity profiles to vary. Ellahi *et al.,* [9] studied peristaltic transport in an irregular channel for the impact of heat and mass transfer on the process of peristaltic pumping. Under Low-Reynolds number and long-wavelength assumptions, Srinivas and Gayathri [10] looked into the problem of Newtonian fluid peristaltic flow with heat exchange in a porous vertical asymmetric channel. The study of how heat transmission affects the peristaltic mechanism is also developing. Continue reading Peristalsis heat transfer study for MHD Carreau fluid was carried out by Faraq *et al.,* [11] using a modified Darcy law. Mass and heat transfer have recently been shown to influence the peristaltic flow of a Ree-Eyring liquid using variable characteristics for hemodynamic flow analysis by Rajashekhar *et al.,* [12]. In biomedical engineering, the diverse types of biological fluid reflect slip effects. Analytical solutions for MHD peristaltic flow using the Eyring-Powell model in a planar channel with wall characteristics and viscous dissipation were investigated by Hina [13].

Several natural systems may be used to study the evolution of slip. The slide occurs on the surface when the shear flow is introduced to a biological liquid. Slip effects may influence spring and hysteresis behaviour. For non-Newtonian fluids with varied geometries, slip effects on peristaltic transport have been explored [14–15]. The Eyring-Powell model was established by Powell and Eyring [16] in 1944 and is a complex mathematical model. The kinetic theory of gases was used for this model to construct the constitutive equations, rather than experimental connections, as in the other non-Newtonian models. This model can reduce Newtonian flow behaviour at low and high shear rates. The peristalsis of Eyring Powell fluid model has piqued the researchers' interest in recent years. An investigation of heat and mass transport on Eyring-Powell fluid peristaltic flow was initiated by Akbar and Nadeem [17]. Hayat *et al.,* [18] investigated the slip effects on the Eyring-Powell fluid model's peristaltic transport. It was shown by Abbasi *et al.,* [19] that the Eyring-Powell fluid model may be transported using the peristaltic method given the conditions of a small Reynolds number and a long wavelength.

Experts have studied the peristaltic transport's wall characteristics to understand blood flow better. Considering this, Radhakrishnamacharya and Srinivasulu [20] examined the impact of heat transmission in Newtonian fluid flow with wall characteristics in peristaltic flow. The MHD peristaltic flows of Jeffery fluid in a conduit with compliant walls and a porous medium have also been studied by Hayat *et al.,* [21]. Srinivas and Kothandapani [22] studied the effects of heat and mass transport on MHD peristaltic flow in a porous channel. Peristaltic transport of Casson fluid in an axisymmetric porous tube has been explored recently by Vaidya *et al.,* [23]. Nooren *et al.,* [24] examined the electroosmotic modulated peristaltic flow of an Eyring Powell fluid in a straight microchannel with heat transfer effects. The results show that shear stress strongly relies on the Helmholtz-Smoluchowski velocity, Eyring-Powell fluid parameter, and electroosmotic parameter. The joule heating and radiation effects on the electroosmotic modulated peristaltic transport in a tapered channel were examined by Abbasi *et al.,* [25]. Using a porous micro tube, Noreen and Waheed [26] studied the heat transfer characteristics of electroosmotic-modulated peristalsis flow. Various scholars have examined the influence of MHD peristaltic flow via diverse genetic considerations of wall features in peristalsis, motivated by the applications of MHD flows in the study of blood and vein flow, urine flow, and lung airflow. There are studies on wall characteristics [27-30].

In light of the previous research, we may conclude that no studies have been conducted on the peristaltic mechanism of Eyring-Powell fluid in non-uniform channels with varying liquid characteristics and wall qualities. The governing nonlinear equations are made simpler using approximations with low Reynolds numbers and long wavelength as assumptions. Perturbation is used to solve these problems as well. To fill this gap, the current research is being conducted to address the Eyring Powell fluid's changing liquid characteristics and heat transport. Modelling parameters have been shown in a graphical form to illustrate their impact on the model.

2. Formulation of the Problem

Consider an incompressible viscous fluid flowing through an inclined non-uniform channel. Non-Newtonian Eyring-Powell fluid governs the flow. The equations that govern the flow [15] are written as follows

$$\frac{\partial u'}{\partial x'}+\frac{\partial w'}{\partial y'}=0 \tag{1}$$

$$\rho\left[\frac{\partial u'}{\partial t'}+u'\,\frac{\partial u'}{\partial x'}+w'\frac{\partial u'}{\partial y'}\right]=-\frac{\partial p'}{\partial x'}+\frac{\partial {\tau'}_{x'x'}}{\partial x'}+\frac{\partial {\tau'}_{x'y'}}{\partial y'}+\rho g\sin\alpha \tag{2}$$

$$\rho\left[\frac{\partial w'}{\partial t'}+u'\frac{\partial w'}{\partial x'}+w'\,\frac{\partial w'}{\partial y\prime}\right]=-\frac{\partial p'}{\partial y'}+\frac{\partial {\tau'}_{x'y'}}{\partial x'}+\frac{\partial {\tau'}_{y'y'}}{\partial y'}+\rho g\,\cos\alpha \tag{3}$$

$$\rho C_P\left[\frac{\partial T'}{\partial t'}+u'\frac{\partial T'}{\partial x'}+w'\frac{\partial T'}{\partial y'}\right]=k_1\left[\frac{\partial}{\partial x'}\left(k(T')\frac{\partial T'}{\partial x'}\right)+\frac{\partial}{\partial y'}\left(k(T')\frac{\partial T'}{\partial y'}\right)\right]+{\tau'}_{x'x'}\,\frac{\partial u\prime}{\partial x\prime}+ {\tau'}_{x'y'}\,\frac{\partial w\prime}{\partial y}+{\tau'}_{x'y'}\left(\frac{\partial u'}{\partial x'}+\frac{\partial w'}{\partial y'}\right) \tag{4}$$

$$\left[\frac{\partial C'}{\partial t'} + u'\frac{\partial C'}{\partial x'} + w'\frac{\partial C'}{\partial y'}\right] = D\left[\frac{\partial^2 C'}{\partial x^2} + \frac{\partial^2 C'}{\partial y^2}\right] + \frac{DK_T}{T_m}\left[\frac{\partial^2 T'}{\partial x^2} + \frac{\partial^2 T'}{\partial y^2}\right] \tag{5}$$

where u', w' are velocity components in radial and axial directions, respectively. ${\tau'}_{x'x'}$, ${\tau'}_{x'y'}$, ${\tau'}_{y'y'}$ are the stress components, p' is the pressure, ρ is the fluid density and k_1, T', C_P denotes mass diffusivity coefficient, temperature, and the specific heat at constant volume, respectively. Flow problem has the following boundary conditions

$$\psi' = \frac{F}{2}, \quad \frac{\partial^2 \psi'}{\partial {y'}^2} = 0,\ \frac{\partial T'}{\partial y'} = 0,\ \frac{\partial C'}{\partial y'} = 0 \quad at \quad y' = 0 \tag{6}$$

$$\frac{\partial \psi'}{\partial y'} = -c\ , T' = {T'}_1\ , C' = {C'}_1\ \ at\ \ y' = H' = l(x') + b'\ \sin\left(\frac{2\pi}{\lambda}\ (x' - ct')\right) \tag{7}$$

where H' is the length of non-uniform wave in which b' is the wave amplitude, $l(x')$ is the non-uniform radius, c is the wave propagation speed, λ is the wavelength, and t' is the time. We now introduce the dimensionless quantities

$$x = \frac{x'}{\lambda}, y = \frac{y'}{a'}, w = \frac{w'}{c}, u = \frac{\lambda u'}{ca}, \tau_{xx} = \frac{a'{\tau'}_{x'x'}}{c\,\mu}, \tau_{xy} = \frac{a'{\tau'}_{x'y'}}{c\,\mu}, \tau_{yy} = \frac{a'{\tau'}_{y'y'}}{c\,\mu}, \vartheta = \frac{\mu_0}{\rho},$$
$$t = \frac{c\,t'}{\lambda},\ \psi = \frac{\psi'}{ac}, Re = \frac{a\,c\,\rho}{\mu}, p = \frac{{a'}^2 p'}{c\,\lambda\,\mu}, \epsilon = \frac{b'}{a'}, \theta = \frac{T' - {T'}_0}{{T'}_0}, Sr = \frac{\rho D K_T (T' - {T'}_0)}{T_m {C'}_0}, Sc = \frac{\mu}{\rho D},\ Pr =$$
$$\frac{\mu\, C_P}{k_1}, \delta = \frac{a'}{\lambda},\ \mu_0' = \frac{\mu_0}{\mu}, F = \frac{\vartheta c}{g a'^2},\ Ec = \frac{c^2}{\delta T_0},\ Br = Ec.Pr,\ \sigma = \frac{C' - {C'}_0}{{C'}_0},\ E_1 = -\frac{\tau {a'}^3}{\lambda \mu_0^3 c},$$
$$E_2 = \frac{m_1\, {a'}^3 c}{\lambda^3 \mu_0}, E_3 = \frac{m_2 {a'}^3}{\lambda^3 \mu}, h = \frac{H'}{a'} = 1 + m\,x + \epsilon \sin\big(2\pi(x - t)\big) \tag{8}$$

Using Eq. (8) in Eq. (1)-(7) and using the longer wavelength and low Reynolds number approximations, we obtain the non-dimensional governing equations of the form as below

$$\frac{\partial p}{\partial x} = \frac{\partial\, \tau_{xy}}{\partial y} + \frac{\sin\gamma}{F} \tag{9}$$

$$\frac{\partial p}{\partial y} = 0 \tag{10}$$

$$\frac{\partial}{\partial y}\left(k(\theta)\ \frac{\partial \theta}{\partial y}\right) +\ Br\ \tau_{xy}\frac{\partial^2 \psi}{\partial y^2}\ =\ 0 \tag{11}$$

$$\frac{\partial^2 \phi}{\partial y^2} + ScSr\frac{\partial^2 \theta}{\partial y^2} = 0 \tag{12}$$

where Br is the Brinkman number and τ_{xy} is the Constitutive Equation of Eyring-Powell fluid [13] which is given by

$$\tau_{xy} = \ \{\mu(y) + B\}\ \frac{\partial^2 \psi}{\partial y^2} - \frac{A}{3}\left(\frac{\partial^2 \psi}{\partial y^2}\right)^3 \tag{13}$$

where A and B are material parameters of Eyring Powell fluid.

The corresponding non-dimensional boundary conditions for Eq. (6) and Eq. (7) are

$$\psi = \frac{F}{2}, \quad \frac{\partial^2 \psi}{\partial y^2} = 0, \quad \frac{\partial \theta}{\partial y} = 0, \quad \frac{\partial \phi}{\partial y} = 0 \quad at \quad y = 0 \tag{14}$$

$$\frac{\partial \psi}{\partial y} = -1, \ \theta = 1, \ \phi = 1, \ at \quad y = h \tag{15}$$

The varying viscosity across the channel walls is given by

$\mu(y) = 1 - \alpha y$, for α << 1, (16)

where α is the coefficient of variable viscosity.
The varying thermal conductivity is given by

$k(\theta) = 1 + \beta\theta$, for β << 1. (17)

where β is the coefficient of varying thermal conductivity.

3. Solution Methodology

The above Eq. (9) and Eq. (11) are non-linear in nature and hence analytical solution for these are unobtainable. Hence, we introduce the series solution using perturbation technique to obtain the solutions. The solution for velocity(u) and concentration (σ) is obtained in closed form. Consider equation (9). Let $\mathrm{P} = \frac{\partial \mathrm{p}}{\partial \mathrm{x}}$ and $\mathrm{f} = \frac{\sin \alpha}{F}$. On integrating Eq. (9), we get

$$\tau = (P - f)y \tag{18}$$

Similarly, consider Eq. (11). On integrating Eq. (11), we get

$$K(\theta)\frac{\partial \theta}{\partial y} + \int Br\, \tau\, \frac{\partial^2 \psi}{\partial y^2} = 0 \tag{19}$$

3.1 Perturbation Technique

We use series perturbation approach to obtain the solution of streamline function and temperature expression using the equation given below.

$$\psi = \Sigma A^n \psi_n \tag{20a}$$

$$\theta = \Sigma A^n \theta_n \tag{20b}$$

We consider zeroth and first order terms by ignoring the terms of order A^2 and above. Hence, we obtain streamline function from Eq. (20a) as
$\psi = \psi_0 + A\,\psi_1$

The zeroth order streamline equation is given by

$$(P-f)\,y = \{1-\alpha y+B\}\,\frac{\partial^2\psi_0}{\partial y^2}$$

with the boundary conditions,

$$\psi_0 = \frac{F}{2},\quad \frac{\partial^2\psi_0}{\partial y^2} = 0 \quad at \quad y=0 \;\; and \quad \frac{\partial\psi_0}{\partial y} = -1 \quad at \quad y=h \tag{21}$$

The first order streamline equation is given by

$$\{1-\alpha y+B\}\,\frac{\partial^2\psi_1}{\partial y^2} - \frac{1}{3}\left(\frac{\partial^2\psi_0}{\partial y^2}\right)^3 = 0$$

with the boundary condition as

$$\psi_1 = 0,\;\; \frac{\partial^2\psi_1}{\partial y^2} = 0 \;\; at \;\; y=0 \;\; and \;\; \frac{\partial\psi_1}{\partial y} = 0 \quad at \;\; y=h \tag{22}$$

Similarly, we obtain temperature solution by Eq. (20b) as

$\theta = \theta_0 + \beta\theta_1$

where,

Zeroth order temperature expression is given by,

$$\frac{\partial\theta_0}{\partial y} + \beta\theta_0\frac{\partial\theta_0}{\partial y} + C_1 = 0$$

with boundary conditions as

$$\frac{\partial\theta_0}{\partial y} = 0 \quad at \quad y=0 \qquad \text{and} \quad \theta_0 = 1 \quad \text{at} \quad y=h \tag{23}$$

First order temperature expression is given by,

$$\frac{\partial\theta_1}{\partial y} + \beta\theta_0\frac{\partial\theta_1}{\partial y} + \beta\theta_1\frac{\partial\theta_0}{\partial y} + C_2 = 0$$

with the boundary conditions as

$$\frac{\partial\theta_1}{\partial y} = 0 \quad at \quad y = 0 \qquad \text{and} \quad \theta_1 = 0 \quad \text{at} \quad y = h \tag{24}$$

The above equations are nonlinear, and hence the double perturbation technique is employed to obtain the expressions for stream functions and temperature.

$$\psi_i = \Sigma\alpha^j\psi_{ij} \; where \quad 0 \le j \le n \tag{25a}$$

$$\theta_i = \Sigma\, \beta^j\, \theta_{ij} \; where \quad 0 \le j \le n \tag{25b}$$

Ignoring $O(\alpha^2)\; and\; O(\beta^2)$, the simpler solution for streamlines and temperature are obtained. The solution for streamlines through double perturbation technique is given by

$$\psi_0 = \psi_{00} + \alpha\psi_{01} \tag{26a}$$

$$\psi_1 = \psi_{10} + \alpha\psi_{11} \tag{26b}$$

Substituting Eq. (26a) in Eq. (21) and Eq. (26b) in Eq. (22) and simplifying the expression, we obtain streamline solution as

$$\psi = (\psi_{00} + \alpha\psi_{01}) + A(\psi_{10} + \alpha\psi_{11})\,,$$
$$\psi = \frac{(P-f)y^3}{6(1+B)} + y\left(-1 - \frac{(P-f)h^2}{2(1+B)}\right) + \frac{F}{2} + \alpha\left(\frac{(P-f)y^4}{12(1+B)^2} - \frac{(P-f)h^3}{3(1+B)^2}y\right) + A\left(\frac{(P-f)^3y^5}{60(1+B)^4} - \frac{(P-f)^3h^4}{12(1+B)^4}y\right)$$
$$+A\alpha\left(\frac{4(P-f)^3y^6}{90(1+B)^5} + \frac{4(P-f)^3h^5}{15(1+B)^5}y\right) \tag{27}$$

The analytical solution for the velocity can be obtained using the formula, $u = \frac{\partial\psi}{\partial y}$. Therefore, velocity

$$u = \frac{(P-f)y^2}{2(1+B)} - \frac{(P-f)h^2}{2(1+B)} + \alpha\left(\frac{(P-f)y^3}{3(1+B)^2} - \frac{(P-f)h^3}{3(1+B)^2}\right) + A\left(\frac{(P-f)^3y^4}{12(1+B)^4} - \frac{(P-f)^3h^4}{12(1+B)^4}\right) + A\,\alpha\left(\frac{4(P-f)^3y^5}{15(1+B)^5} + \frac{4(P-f)^3h^5}{15(1+B)^5}\right) \tag{28}$$

Similarly, the solution for temperature Eq. (11) is obtained by solving Eq. (23) and Eq. (24) through double perturbation technique.

$$\theta = \theta_{00} + \beta\theta_{01} + A(\theta_{10} + \beta\theta_{11}) \tag{29}$$

where,

$$\theta_{00} = Q_1 - Q_2 + 1$$

$$\theta_{01} = Q_3 + Q_5 + Q_7 + Q_9 - (Q_4 + Q_6 + Q_8 + Q_{10}) - Q_1(1 - Q_2) + Q_2(1 - Q_2)$$
$$\theta_{10} = Q_{11} - Q_{12}$$

$$\theta_{11} = -(Q_1 + 1 - Q_2)(Q_{11} - Q_{12})$$

The analytic solution for concentration is obtained by solving the Eq. (12) with boundary conditions (14) and (15).

$$\sigma = 1 - ScSr[R_1 + AR_2 + \beta\{(1 - Q_2)R_1 + R_3\} + A\beta\{-AQ_{12}R_1 + (1 - Q_2)R_2 + R_4\}] + ScSr[R_5 + AR_6 + \beta\{(1 - Q_2)R_5 + R_7\} + A\beta\{-Q_{12}R_5 + (1 - Q_2)R_6 + R_8\}] \quad (30)$$

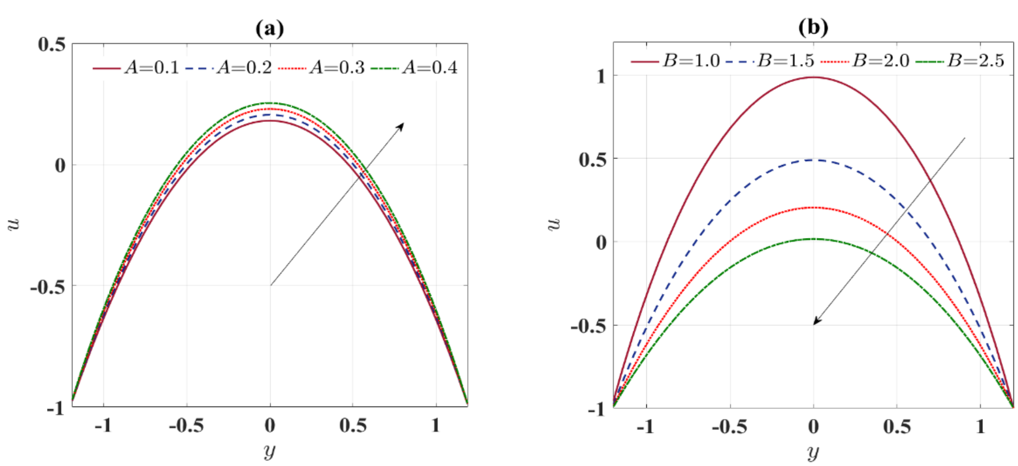
Values of Q_i , $1 \leq i \leq 12$ and $R_j, 1 \leq j \leq 8$ are given in appendix.

4. Results and Discussions

In the current section, parameters that influence the velocity, stream functions, temperature, and concentration are discussed. The influence of variable liquid properties, wall properties and inclination angles are discussed. MATLAB programming has been utilised to represent the relevant parameter of interest graphically. The impact of these parameters on physiological quantities is discussed below.

4.1 Velocity Profiles

The graphical representation of the variation of different physiological parameters on velocity is shown in Figure 1(a)-(g). The fluid parameters of the Eyring-Powell fluid on velocity are depicted in Figure 1(a) and (b). As the fluid parameter A increases, velocity profile also increase. In the case of fluid parameter B, the opposite trend has been observed. Figure 1(c) has been sketched to analyse the impact of inclination angle on velocity. The graph reveals that the rise in the velocity profiles is due to an increase in the inclination angle. A similar effect has been observed in the non-uniform parameter (see Figure 1 (d)). Figure 1(e) depicts the velocity variation for amplitude ratio. It shows that velocity profiles improve as the amplitude ratio increases. It has been observed that larger value of variable viscosity causes a rise in velocity profiles (See Figure 1(f)). Figure 1(g) has been drawn to analyse the effect of wall properties on velocity. The figure reveals that velocity profiles increase for higher values of rigidity and stiffness parameters. The velocity profiles show an inverse effect as the wall-damping parameter is increased.



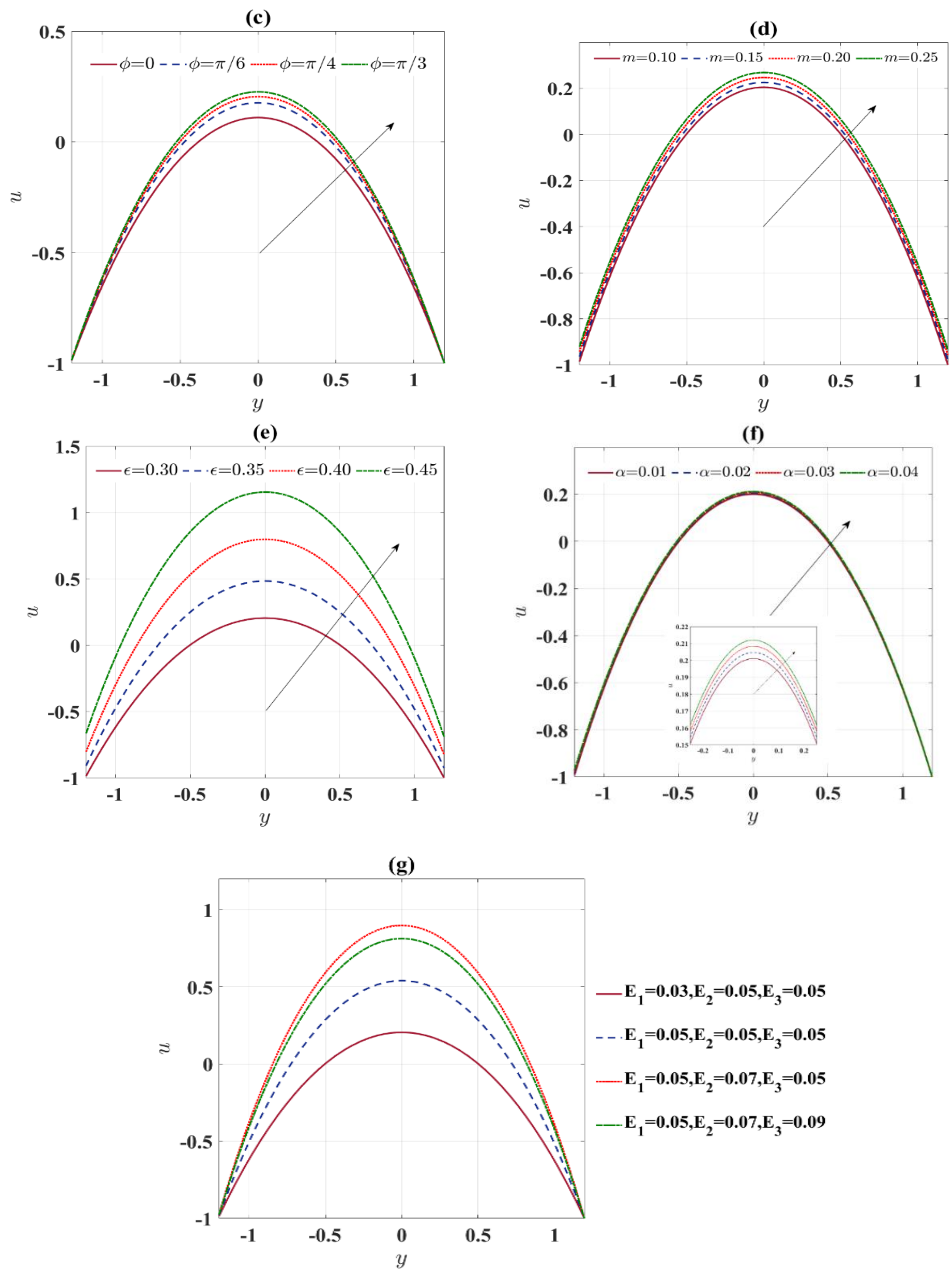


Fig. 1. Variation of velocity profiles when E_1= 0.03, E_2= 0.05, E_3= 0.05, A= 0.2, B =2, x = 0.2, F= 2, φ = $\frac{\pi}{4}$, α = 0.02, t =0.1, $\epsilon = 0.3$, m=0.1

4.2 Temperature Profiles

Figure 2(a)-(i) shows the variation of temperature profiles for varying physical parameters. Figure 2(a) and (b) has been sketched to analyse the variation in temperature on material parameters. It has been noticed that a rise in the fluid parameter A increases the temperature profiles, while an increase

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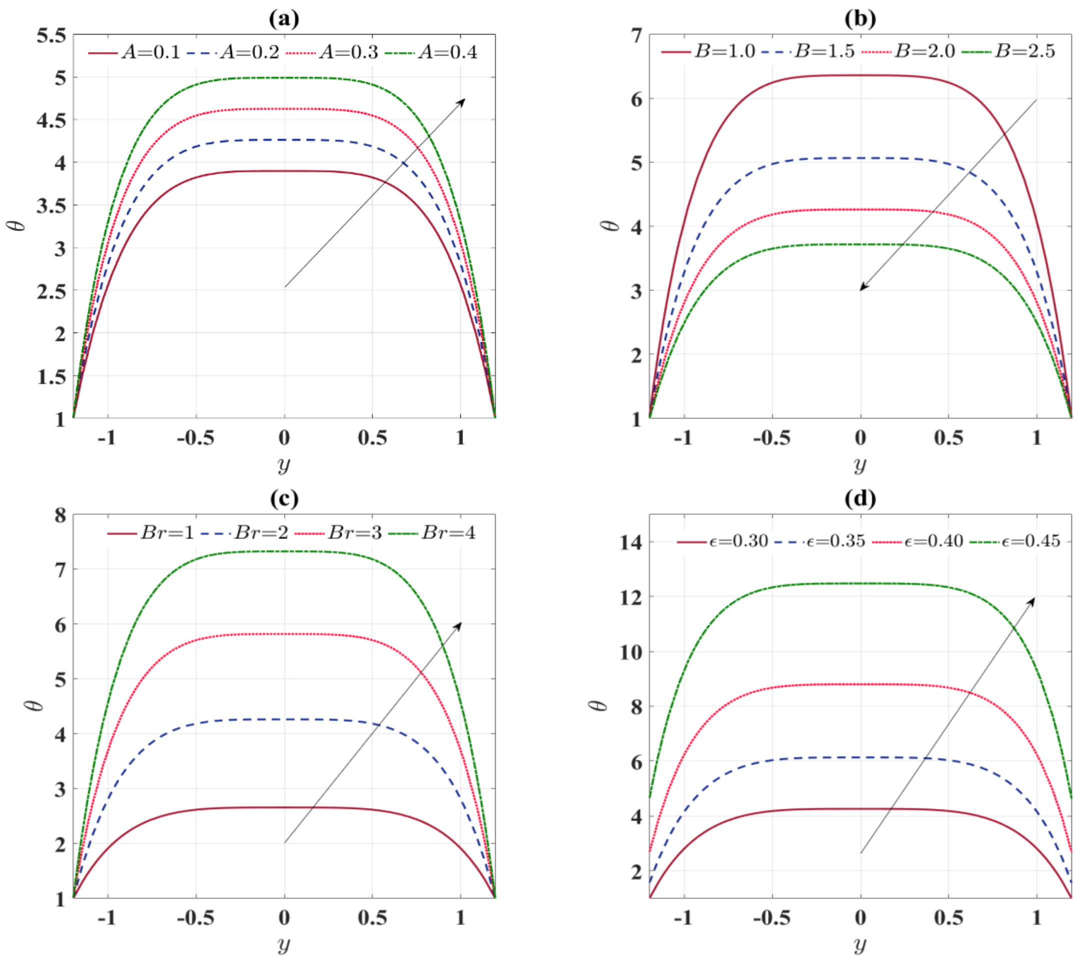
in the liquid parameter B decrease the temperature. Figure 2(c) shows that the temperature profile improves due to increased Brinkman numbers. Figures 2(d)-(f) show the temperature variation for the amplitude ratio, angle of inclination, and non-uniform parameter on temperature. All these parameters exhibit similar temperature behaviour for increasing these parameters. Figure 2(g)-(h) has sketched the effect of variable thermal conductivity on temperature. From the figure, it has been noticed that the temperature is an increasing function for variable viscosity. The opposite trend has been seen for variable thermal conductivity. Figure 2(i) shows that increasing the rigidity and stiffness parameters raises the temperature in the axial direction. As the wall damping value increase, the temperature profile shifts in the opposite direction.



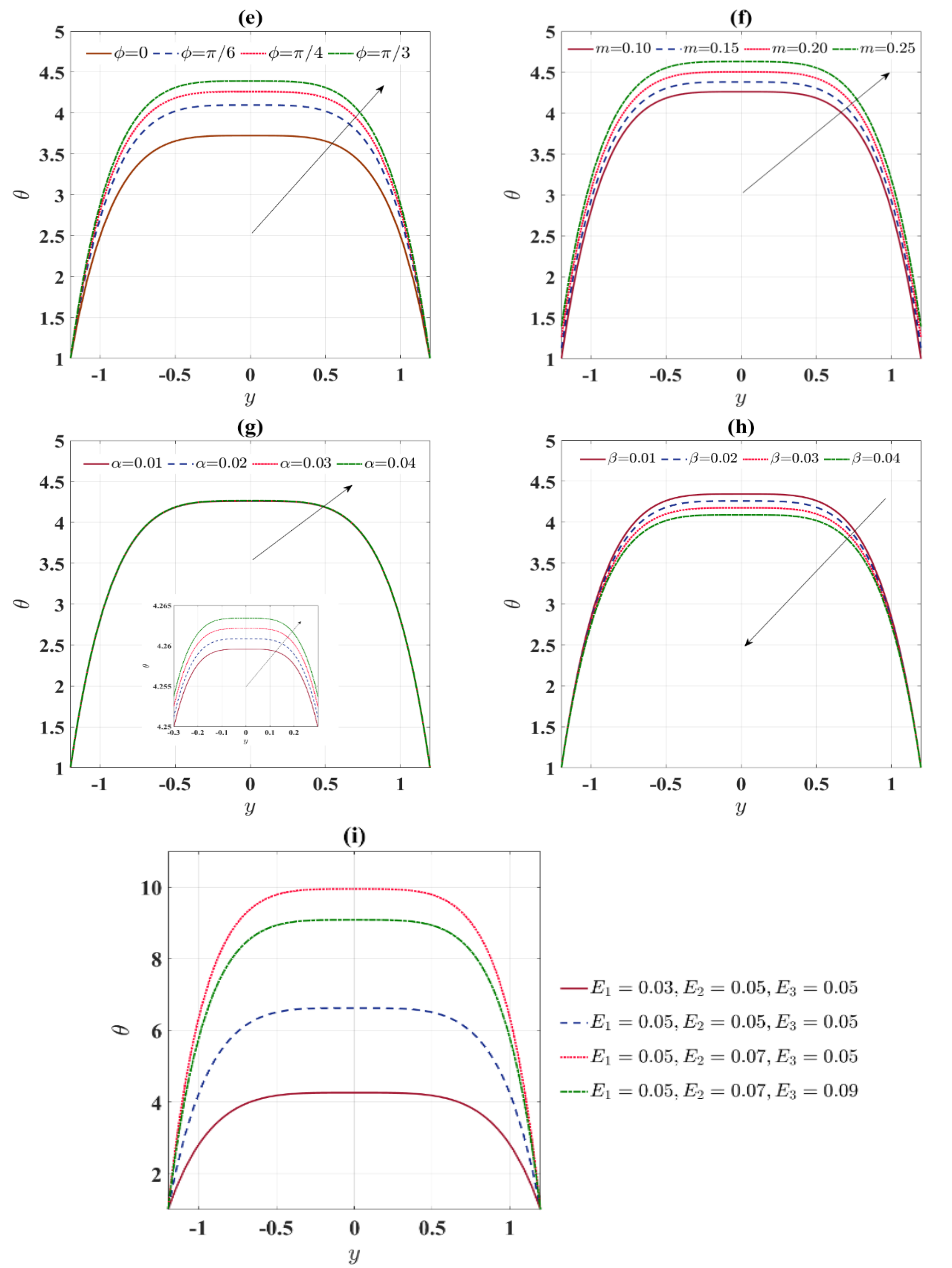
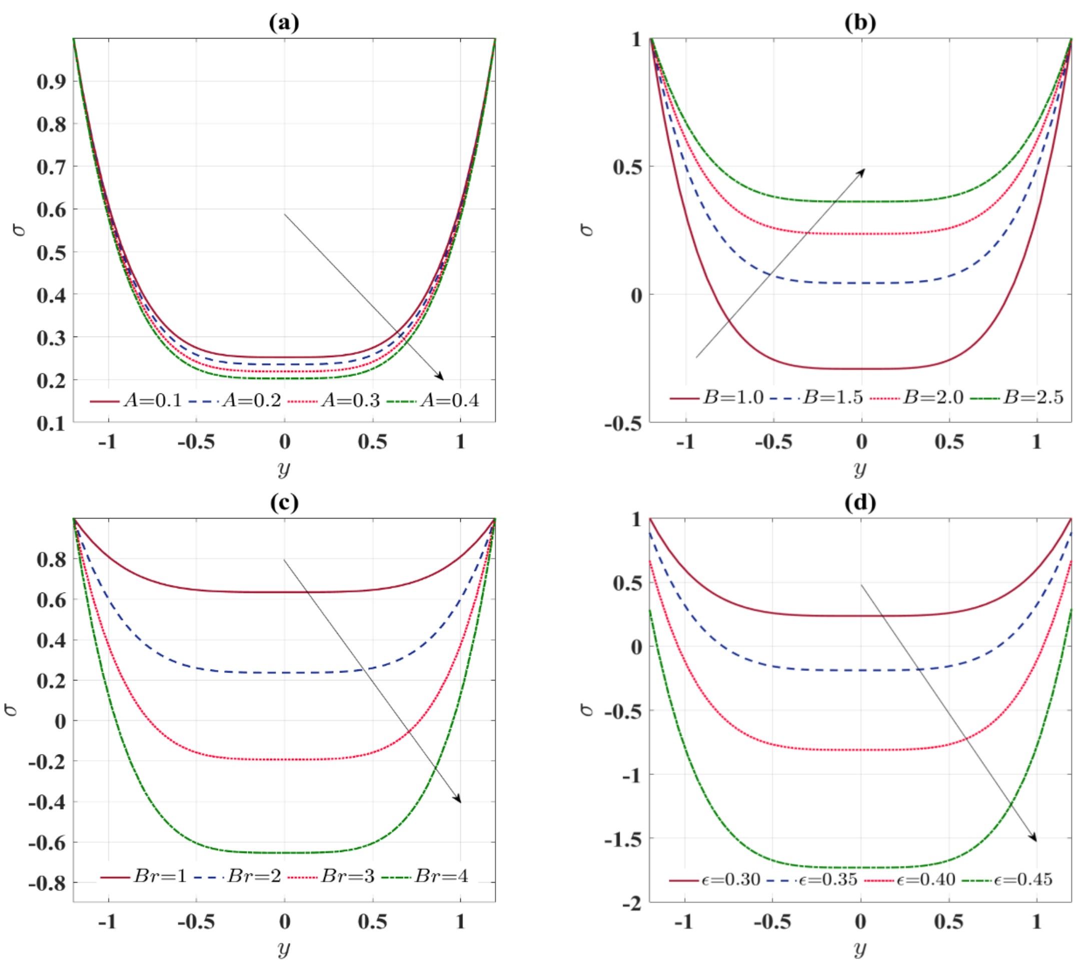
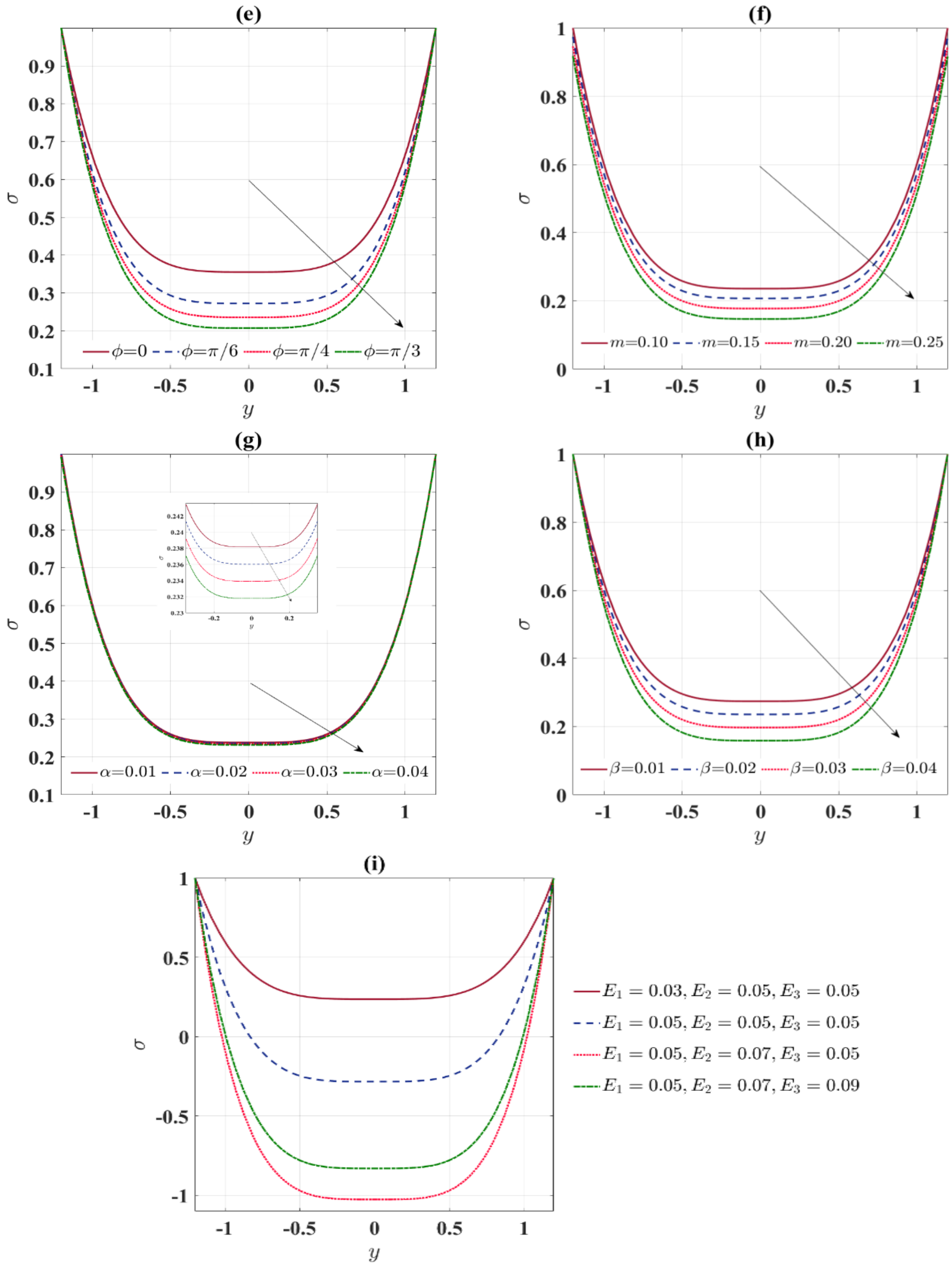


Fig. 2. Variation of Temperature profiles when $E_1 = 0.3, E_2 = 0.2, E_3 = 0.3, A = 0.2, B = 2, x = 0.2, F = 2, \phi = \frac{\pi}{4}, \alpha = 0.02, \beta = 0.02, t = 0.1, \epsilon = 0.3, Br = 2, m = 0.1$

4.3 Concentration Profiles

The present section examines the impact of the pertinent variable parameters on concentration, as depicted in Figure 3(a)-(k). Figure 3(a) and (b) are sketched to analyse the variation of material parameters on concentration. The figure shows that the fluid parameter A is increased, the concentration profile decreases, and an opposite behaviour has been noticed in the case of liquid parameter B. Figure 3(c) depicts the decrease in concentration profiles as we enhance the Brinkman number. The concentration profiles decrease as the amplitude ratio, inclination angle, and non-uniform parameter are increased (See Figure 3(d)-(f)). Figure 3(g) has been drawn to analyse the effect of variable viscosity on concentration. It has been noticed that concentration decreases due to an increasing variable viscosity. A similar pattern has been observed in the case of variable thermal conductivity (See Figure 3(h)). Figure 3(i) depicts how changing the rigidity and stiffness parameters reduces fluid particle concentration in the axial direction. As the wall damping value increases, the concentration profile shifts in the opposite direction. Soret number and Schmidt number have a similar impact on the concentration profiles (See Figure 3(j)-(k)).




(e)
ϕ=0 ϕ=$\pi/6$ ϕ=$\pi/4$ ϕ=$\pi/3$
(f)
m=0.10 m=0.15 m=0.20 m=0.25
(g)
α=0.01 α=0.02 α=0.03 α=0.04
(h)
β=0.01 β=0.02 β=0.03 β=0.04
(i)
$E_1 = 0.03, E_2 = 0.05, E_3 = 0.05$
$E_1 = 0.05, E_2 = 0.05, E_3 = 0.05$
$E_1 = 0.05, E_2 = 0.07, E_3 = 0.05$
$E_1 = 0.05, E_2 = 0.07, E_3 = 0.09$
σ
y

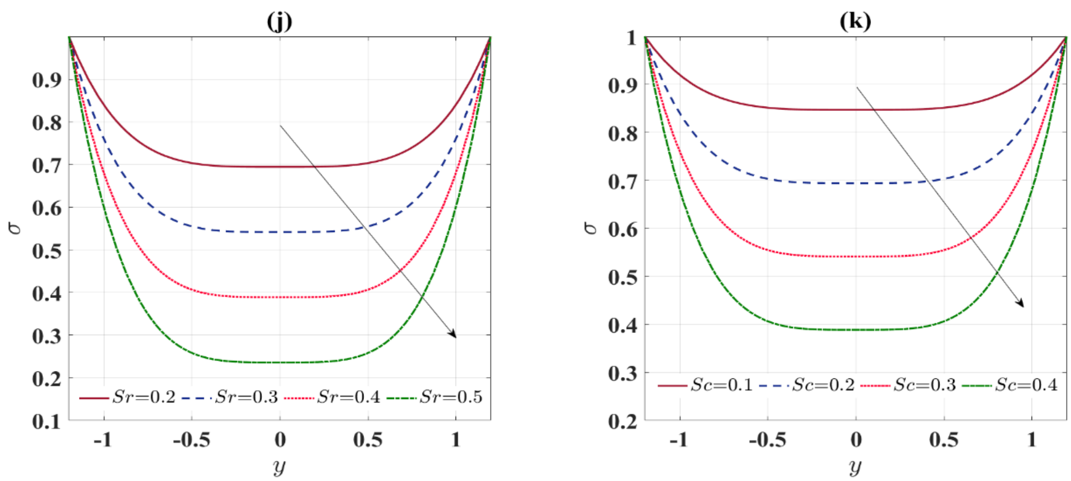


Fig. 3. Variation of concentration profiles when $\mathrm{E_1} = 0.03, \mathrm{E_2} = 0.05, \mathrm{E_3} = 0.05, \mathrm{A} = 0.2$, $\mathrm{B} = 2$, $\mathrm{x} = 0.2, \mathrm{F} = 2, \phi = \frac{\pi}{4}, \alpha = 0.02, \beta = 0.02, \mathrm{t} = 0.1, \epsilon = 0.3, \mathrm{Br} = 2, \mathrm{Sc} = 0.9$, $\mathrm{Sr} = 0.7, \mathrm{m} = 0.1$

4.4 Trapping Phenomenon

The trapping phenomenon occurs during peristaltic transport when the streamlines get closed, resulting in boluses that circulate internally and move forward with the speed of peristaltic waves. This section attempts to study this exciting phenomenon through plots of stream functions represented in Figure 4-9. Figure 4 and 5 give the influence of Eyring Powell parameters A and B on streamlines. Figure 4 shows that an enhancing the Eyring Powell parameter A results in the increase of the bolus size while increasing parameter B reduces the number of boluses formed during trapping, as noticed in Figure 5. Figure 6 is drawn the effect of variable viscosity on stream. It can be seen that as variable viscosity increases, the size of the boluses also increases. Figure 7 depicts that a higher inclination angle enhances the size of the bolus at the centre, but the size of the bolus near the walls reduces. The higher value of the non-uniform parameter decreases the bolus size and number of boluses (See Figure 8). Figure 9(a)-(b) shows an increase in the number of boluses due to the increase in the rigidity parameter. A similar effect is seen in Figure 9(c) for increasing stiffness parameters. A decrease in the number of boluses can be noticed in Figure 9(d). An increase in wall damping parameter reduces the number of boluses during peristalsis.

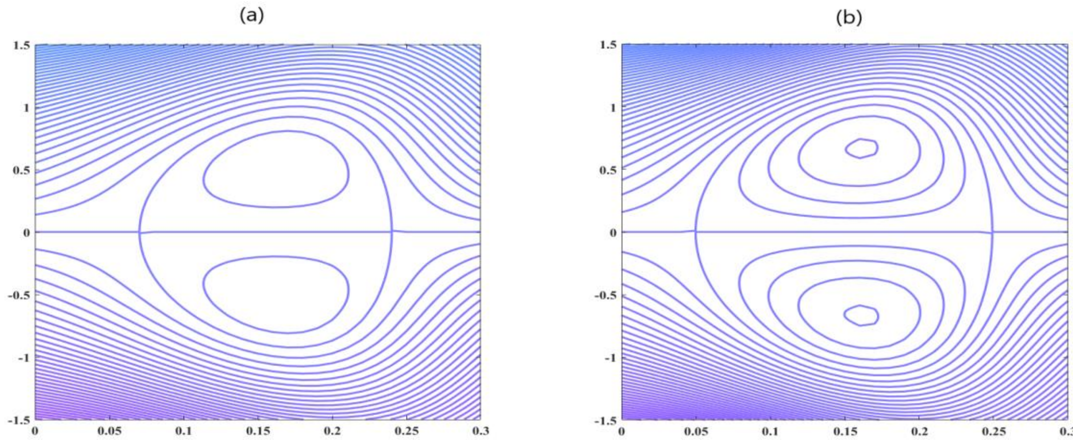


Fig. 4. Variation of streamlines for (a) A= 0.1 (b) A= 0.5

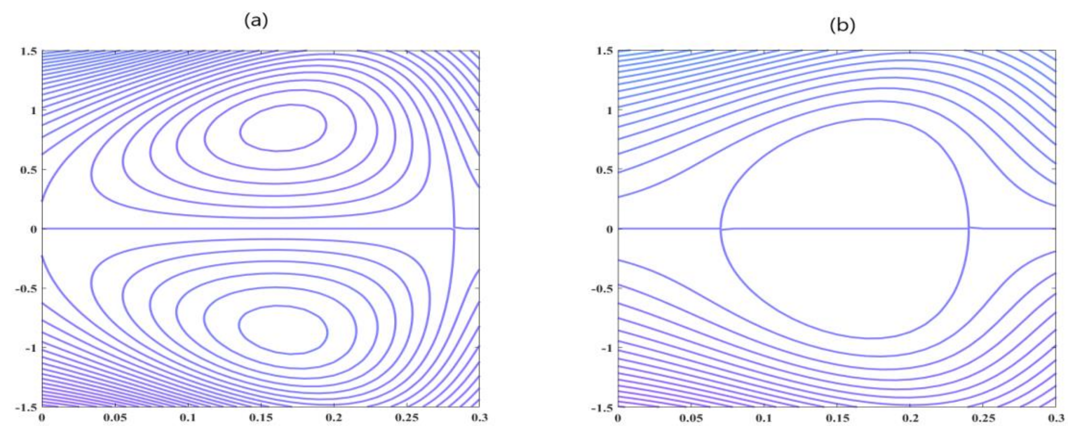


Fig. 5. Variation of streamlines for (a) B=1.5 (b) B= 2.5

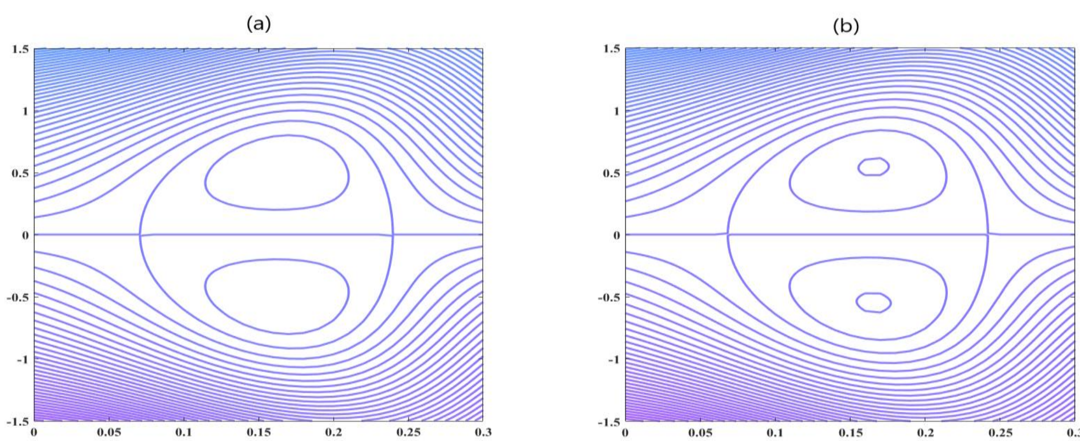


Fig. 6. Variation of streamlines for (a) α_1=0.01 (b) α_1= 0.06

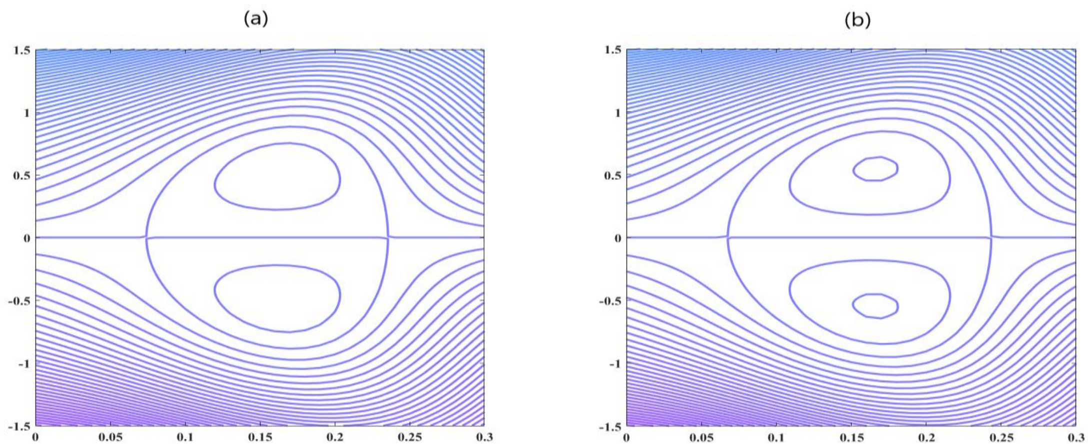


Fig. 7. Variation of streamlines for (a) $\phi = \frac{\pi}{6}$ (b) $\phi = \frac{\pi}{3}$

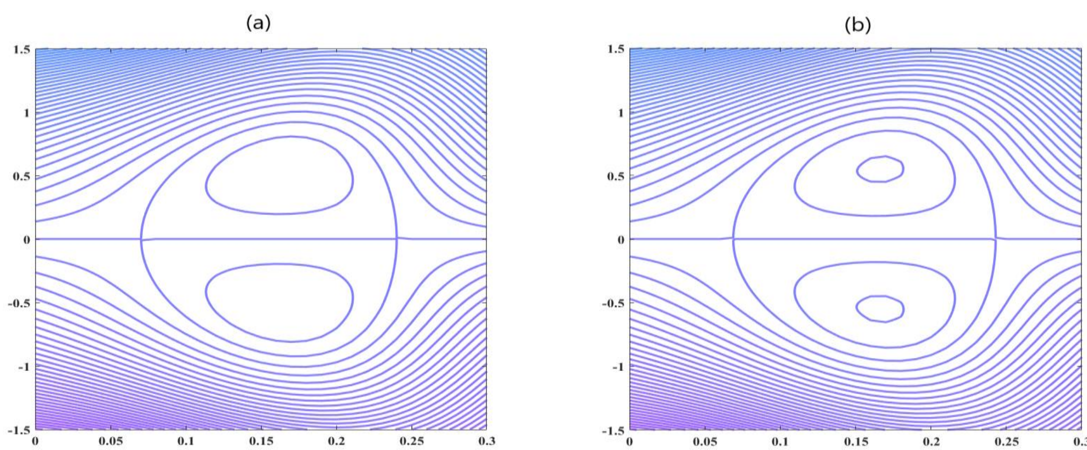


Fig. 8. Variation of streamlines for (a) m = 0.1 (b) m = 0.2

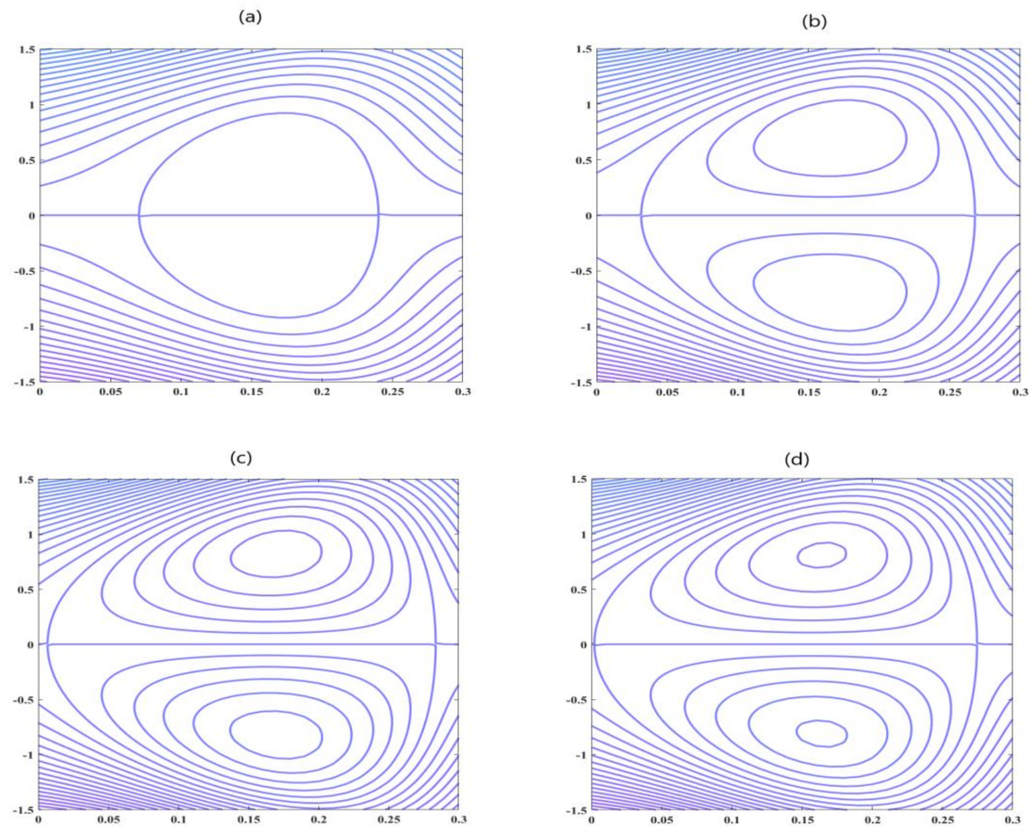


Fig. 9. Variation of streamlines for (a) $E_1 = 0.03, E_2 = 0.05, E_3 = 0.05$; (b) $E_1 = 0.05, E_2 = 0.05, E_3 = 0.05,$; (c) $E_1 = 0.05, E_2 = 0.07, E_3 = 0.05,$;(d)$E_1 = 0.05, E_2 = 0.07, E_3 = 0.09$

4.5 Validation of the Results

The obtained solutions satisfy both the required boundary conditions and the dimensionless governing equations perfectly. The streamline, temperature, and concentration solutions obtained by Eq. (27), Eq. (29) and Eq. (30) respectively, are in accordance with the boundary conditions given in Eq. (15), and we obtain ψ = - 1 , ϑ = 1, and σ = 1 as specified in boundary conditions (15). Also, if these solutions provided by Eq. (27), Eq. (29) and Eq. (30) are inserted in Eq. (9-12) then these equations are also satisfied. As a result, all governing equations and conditions are satisfied by the presented solutions. Additionally, the graphical results provide suitable representations of the flow profile in accordance with the simulated problem, which serves to validate the boundary conditions for this flow that were taken into consideration. The results are furthur validated with the study conducted by Hina [13] in the absence of MHD and slip conditions as well as non-uniform parameter. The results agree with the same in the absence of Variable Liquid Properties as well.

5. Conclusions

The non-Newtonian Eyring-Powell fluid is considered in the analysis of peristaltic transport in the human system. Various fluid properties like varying viscosity, varying thermal conductivity and wall properties are considered. The main findings are listed below.

i. Eyring Powell fluid parameters exhibit opposite behaviour for velocity, temperature and concentration profiles.
ii. Wall rigidity and stiffness parameters improve the velocity and temperature profiles, while wall damping parameters behave oppositely.
iii. Variable viscosity parameter improves the velocity and temperature profile while reducing fluid concentration during peristalsis.
iv. Parameters such as variable thermal conductivity and angle of inclination improve the temperature profiles.
v. Higher values of non-uniform parameters reduce the number of boluses.

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