CHEMICAL ENGINEERING TRANSACTIONS
VOL. 71, 2018

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Xiantang Zhang, Songrong Qian, Jianmin Xu

ISBN 978-88-95608-68-6; **ISSN** 2283-9216
DOI: 10.3303/CET1871167

Impact of Hall Current, Joule Heating and Mass Transfer on MHD Peristaltic Hemodynamic Jeffery Fluid with Porous Medium under the Influence of Chemical Reaction

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The purpose of the present investigation is to examine the impact of Hall current, joule heating and mass transfer on MHD peristaltic hemodynamic Jeffery fluid with the porous medium under an influence of chemical reaction through an inclined tapered vertical channel. Thermal radiation is also taken into the account. An analytical solution is carried out under a small Reynolds number and large wavelength approximations. Numerical results were presented for axial velocity, pressure rise, frictional force, temperature and concentration. Variations of the said quantities with dissimilar parameters are computed by using MATHEMATICA software. It is worth mentioning that the pumping rate enhances in free pumping ($\Delta p = 0$) and augmented ($\Delta p < 0, \bar{Q} > 0$) zones whereas the trend is reserve in retrograde pumping region ($\Delta p > 0, \bar{Q} > 0$) and peristaltic pumping region ($\Delta p > 0, \bar{Q} > 0$) with an increase in hall current parameter .We notice that the frictional force exactly has an opposite behaviour when compared to the pressure rise. It is clear that the temperature of the fluid reduces by an increase in thermal radiation parameter. We notice that the concentration distribution reduces by increase in chemical reaction parameter.

1. Introduction

To the satisfactory of our expertise, no research has been made yet to hall current, joule heating and mass transfer on MHD peristaltic hemodynamic Jeffery fluid with the porous medium under an influence of thermal radiation through an inclined tapered vertical channel. Interest in peristaltic go with the flow has been aroused by its relevance to biological approaches, and its potential for industrial and medical applications. The behaviour of most of the physiological fluids, oil, hydrocarbons and polymer are known to be non-Newtonian. One of the major chemical mechanisms for fluid transport in many biological systems is well known to physiologists to be peristalsis. Peristalsis is an important mechanism for mixing and transporting fluids, which is generated by a progressive wave of contraction or expansion moving along a tube. This travelling wave phenomenon is referred to as peristalsis. Peristalsis has its immense applications in medical physiology as well as in industry. In medical physiology, it is involved in the motion of food material in the GIT. (Latham 1966) was probably the first to study the mechanism of peristaltic pumping in his M. S. Thesis. Later on, this mechanism has become an important topic of research owing to the above-mentioned applications in biomechanical engineering and biomedical technology. Peristaltic transports of fluids in tubes for better and clear understanding of peristaltic mechanism have studied by (Barton a et al., 1968; Yin et al., 1969; Chow 1970; Colgan et al., 1987; Weinberg et al., 1971; Misra et al., 2002).
The energy transfer by heat flow cannot be measured directly. But the concept has a physical meaning because it is related to the measurable quantity called temperature. In another paper, (Vajravelu et al., 2014) investigated the peristaltic transport of a conducting Jeffrey fluid in an inclined asymmetric channel. Influence of heat transfer on magnetohydrodynamic peristaltic blood flow with porous medium through a coaxial vertical asymmetric tapered channel - an analysis of blood flow study by (Abzal et al., 2016). Ravikumar and Ameer

Please cite this article as: Rajesh R., Gowd Y.R., 2018, Impact of hall current, joule heating and mass transfer on mhd peristaltic hemodynamic jeffery fluid with porous medium under the influence of chemical reaction, Chemical Engineering Transactions, 71, 997-1002 DOI:10.3303/CET1871167

Ahmad (2016) examine the peristaltic hemodynamic Jeffery fluid through a tapered channel with heat and mass transfer under the Influence of radiation - Blood flow model. The mathematical model on peristaltic flow in a non-uniform channel with heat and mass transfer discussed by (Noreen 2017). Furthermore, (Selvi et al., 2017) discussed the effect of heat transfer on peristaltic flow of Jeffrey fluid in an inclined porous stratum. Peristaltic transportation with the porous medium through vertical tapered channel discussed by (Ravikumar et al., 2015, 2016, 2017 and 2018). (Rajakumar et al., 2018) discussed by radiation, dissipation and dufour effects on MHD free convection casson fluid flow through a vertical oscillatory porous plate with ion-slip current. Hall and convective boundary conditions effects on peristaltic flow of a couple stress fluid with porous medium through a tapered channel under Influence of chemical reaction examined by (Ravikumar et al., 2018).

2. Formulation of the problem

Let us consider the MHD peristaltic hemodynamic transport of an incompressible viscous fluid in a two-dimensional uneven inclined vertical tapered channel under the influence of the porous medium. The gravity field, thermal radiation, chemical reaction and joule heating are taken into the account. The left wall of the channel is maintained at temperature T_0, whereas the right wall has temperature T_1. We tend to assume that the fluid is subject to a relentless transverse magnetic field B_0. The fluid is induced by sinusoidal wave trains propagating with constant speed c along the channel walls.
The geometry of the wall deformations is drawn by the subsequent expressions

$$Y = \overline{H_2} = b + m^I\bar{X} + d\ \sin\left[\frac{2\pi}{\lambda}(\bar{X} - c\ \bar{t})\right] \tag{1}$$

$$Y = \overline{H_1} = -b - m^I\bar{X} - d\ \sin\left[\frac{2\pi}{\lambda}(\bar{X} - c\ \bar{t}) + \phi\right] \tag{2}$$

In the above equations, d is the wave amplitude of the peristaltic wave, c is the wave velocity, b is the mean half-width of the channel, m^I is dimensional the non-uniform parameter, λ is the wavelength, t is the time, X is the direction of wave propagation and ϕ is the phase variance.

The constitutive equations for an incompressible Jeffrey fluid are

$$\bar{T} = -\bar{p}\ \bar{I} + \bar{S} \tag{3}$$

$$\bar{S} = \frac{\mu}{1+\lambda_1(\dot{\bar{r}}+\lambda_2\ \ddot{\bar{r}})} \tag{4}$$

where $\bar{T}$ and $\bar{S}$ are Cauchy stress tensor and further stress tensor, respectively, $\bar{p}$ is that the pressure, $\bar{I}$ is the identity tensor, λ_1 is the quantitative relation of relaxation to retardation times, λ_2 is the retardation time $\dot{r}$ is the shear rate and dots over the quantities indicate differentiation with relevance time.
In laboratory frame, the equations governing the flow of an incompressible hydromagnetic hemodynamic peristaltic transportation through a porous medium in the vertical uneven tapered channel in cartesian form for the present problem are given by

$$\frac{\partial\bar{U}}{\partial\bar{X}} + \frac{\partial\bar{V}}{\partial\bar{Y}} = 0 \tag{5}$$

$$\rho\left(\bar{U}\ \frac{\partial\bar{U}}{\partial\bar{X}} + \bar{V}\frac{\partial\bar{U}}{\partial\bar{Y}}\right) = -\frac{\partial p}{\partial x} + \frac{\partial\bar{S}_{\overline{XX}}}{\partial\bar{X}} + \frac{\partial\bar{S}_{\overline{XY}}}{\partial\bar{Y}} + \left[\frac{\sigma\ B_0^2}{1+m^2}\right]\left(m\bar{V} - (\bar{U}+c)\right) - \frac{\mu}{k_1}(\bar{U}+c) + \rho g\sin\alpha \tag{6}$$

$$\rho\left(\bar{U}\ \frac{\partial\bar{V}}{\partial\bar{X}} + \bar{V}\frac{\partial\bar{V}}{\partial\bar{Y}}\right) = -\frac{\partial p}{\partial y} + \frac{\partial\bar{S}_{\overline{XY}}}{\partial\bar{X}} + \frac{\partial\bar{S}_{\overline{YY}}}{\partial\bar{Y}} - \left[\frac{\sigma\ B_0^2}{1+m^2}\right]\left(\bar{V} + m(\bar{U}+c)\right) - \frac{\mu}{k_1}(\bar{U}+c) - \rho g\cos\alpha \tag{7}$$

The energy equation is

$$\rho\ C_p\left(\bar{U}\ \frac{\partial}{\partial\bar{X}} + \bar{V}\frac{\partial}{\partial\bar{Y}}\right)\bar{T} = k\left(\frac{\partial^2}{\partial\bar{X}^2} + \frac{\partial^2}{\partial\bar{Y}^2}\right)\bar{T} + Q_0 + \sigma\ {B_0}^2\bar{U}^2 - \frac{\partial q_r}{\partial\bar{Y}} \tag{8}$$

The concentration equation is

$$\left(\bar{U}\ \frac{\partial\bar{C}}{\partial\bar{X}} + \bar{V}\frac{\partial\bar{C}}{\partial\bar{Y}}\right) = D_m\left(\frac{\partial^2\bar{C}}{\partial\bar{X}^2} + \frac{\partial^2\bar{C}}{\partial\bar{Y}^2}\right) + \frac{D_m K_T}{T_m}\left(\frac{\partial^2\bar{T}}{\partial\bar{X}^2} + \frac{\partial^2\bar{T}}{\partial\bar{Y}^2}\right) - k_2(\bar{C} - C_0) \tag{9}$$

Where $\bar{U}$ and $\bar{V}$ are the velocity components in the laboratory frame $(\bar{X}, \bar{Y})$, k_1 is that the permeability of the porous medium, ρ is the density of the fluid, p is the fluid pressure, k is the thermal conduction, μ is the coefficient of the viscosity, Q_0 is the constant heat addition/absorption, C_p is the specific heat at constant pressure, $\boldsymbol{\sigma}$ is the electrical conductivity, g is the acceleration attributable to gravity, m is the hall parameter, $\bar{T}$

is the temperature of the fluid, $\bar{C}$ is the concentration of the fluid, D_m is the coefficient of mass diffusivity, T_m is the mean temperature, K_T is the thermal diffusion ratio and q_r is the radioactive heat flux.
We introduce the following non-dimensional variables and parameters for the flow:

$$x = \frac{\bar{x}}{\lambda}, y = \frac{\bar{y}}{b}, \bar{t} = \frac{c\,t}{\lambda}, u = \frac{\bar{u}}{c}, \varepsilon = \frac{d}{b}, \delta = \frac{b}{\lambda}, v = \frac{\bar{v}}{c\delta}, S = \frac{b\bar{S}}{\mu\,c}, h_1 = \frac{\overline{H_1}}{b}, h_2 = \frac{\overline{H_2}}{b}, p = \frac{b^2\bar{p}}{c\,\lambda\,\mu}, M = B_0 b\sqrt{\frac{\sigma}{\mu}},$$
$$Re = \frac{\rho\,c\,b}{\mu}, \eta = \frac{\rho\,b^2 g}{\mu c}\,\eta_1 = \frac{\rho\,b^3 g}{\lambda\mu c}, \theta = \frac{\bar{T}-T_0}{T_1-T_0}, \Phi = \frac{\bar{C}-C_0}{C_1-C_0}, P_r = \frac{\mu\,C_p}{k}, \quad E_c = \frac{c^2}{C_p(T_1-T_0)}\,R_n = \frac{16\,\sigma^*\,{T_0}^3 b^2}{3k^*\mu\,C_p}, \beta = \frac{Q_0 b^2}{\mu\,C_p(T_1-T_0)},$$
$$S_c = \frac{\mu}{D_m\rho}, S_r = \frac{D_m\rho\,k_T(T_1-T_0)}{\mu T_m(C_1-C_0)}, S = \frac{K_2\rho\,d^2}{\mu} \tag{10}$$

where ε is the non-dimensional amplitude of channel, δ is the wave number, k_1 is the non - uniform parameter, Re is the reynolds number, M is the hartmann number, η andη_1 are gravitational parameters, Pr is the prandtl number, E_c is the eckert number, Rn is the thermal radiation parameter, β is the heat source/sink parameter, B_r is the brinkman number, S is the chemical reaction parameter, S_c schmidt number and S_r soret number.

3. Solution of the problem

By using the equation (10), the system of equations (5 -9) can be written in dimensionless form after dropping the bars

$$\delta\left(u\frac{\partial u}{\partial x} + v\frac{\partial v}{\partial y}\right) = 0 \tag{11}$$

$$Re\,\delta\,\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = -\frac{\partial p}{\partial x} + \delta\,\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y} + \frac{M^2}{1+m^2}\big(m\delta v - (u+1)\big) - \frac{1}{D}u - \frac{1}{D} + \eta\,\sin\alpha \tag{12}$$

$$Re\,\delta^3\,\left(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}\right) = -\frac{\partial p}{\partial y} + \delta^2\,\frac{\partial S_{xy}}{\partial x} + \delta\frac{\partial S_{yy}}{\partial y} - \frac{\delta M^2}{1+m^2}(m(u+1) + \delta v) - \delta^2\frac{1}{D}v - \delta^2\frac{1}{D} - \eta_1\cos\alpha \tag{13}$$

$$Re\left[\delta u\frac{\partial\theta}{\partial x} + v\frac{\partial\theta}{\partial y}\right] = \frac{1}{P_r}\left[\delta^2\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right] + \beta + M^2 E_c u^2 + R_n\frac{\partial^2\theta}{\partial y^2} \tag{14}$$

$$Re\delta\left[u\frac{\partial\Phi}{\partial x} + v\frac{\partial\Phi}{\partial y}\right] = \frac{1}{S_c}\left[\delta^2\frac{\partial^2\Phi}{\partial x^2} + \frac{\partial^2\Phi}{\partial y^2}\right] + S_r\left[\delta^2\frac{\partial^2\theta}{\partial x^2} + \frac{\partial^2\theta}{\partial y^2}\right] - S\Phi \tag{15}$$

Equations (11-15) under the assumptions of long wavelength and low-Reynolds number approximation take the form

$$\frac{\partial^2 u}{\partial y^2} - \left(\frac{M^2}{1+m^2} + \frac{1}{Da}\right)(1+\lambda_1)u = (1+\lambda_1)\frac{\partial p}{\partial x} + \left(\frac{M^2}{1+m^2} + \frac{1}{Da}\right)(1+\lambda_1) - \eta\sin\alpha\,(1+\lambda_1) \tag{16}$$

$$\frac{\partial p}{\partial y} + \eta_1\cos\alpha = 0 \tag{17}$$

$$(1 + R_n P_r)\frac{\partial^2\theta}{\partial y^2} = -\beta P_r - M^2 B_r u^2 \tag{18}$$

$$\frac{1}{S_c}\frac{\partial^2\Phi}{\partial y^2} + S_r\frac{\partial^2\theta}{\partial y^2} - S\phi = 0 \tag{19}$$

The relative boundary conditions in dimensionless form are given by

u = -1, θ = 0, Φ = 0 at $y = h_1 = -1 - k_1 x - \epsilon\,\sin[2\pi\,(x-t) + \phi]$ (20)

u = -1, θ = 1, Φ =1 at $y = h_1 = 1 + k_1 x + \epsilon\,\sin[2\pi\,(x-t)]$ (21)

The solutions of velocity and temperature with subject to boundary conditions (20) and (21) are given by

$$u = G\sinh[\alpha_1 y] + F\cosh[\alpha_1 y] + H \tag{22}$$

$$\theta = E_1 + E_2 y - a_{11}y^2 - a_{12}(e^{2\alpha_1 y}) - a_{13}(e^{-2\alpha_1 y}) - a_{14}(e^{\alpha_1 y}) - a_{15}(e^{-\alpha_1 y}) \tag{23}$$

$$\Phi = E_3\sinh[fy] + E_4\cosh[fy] + a_{21} + a_{22}(e^{2\alpha_1 y}) + a_{23}(e^{-2\alpha_1 y}) + a_{24}(e^{\alpha_1 y}) + a_{25}(e^{-\alpha_1 y}) \tag{24}$$

3.1 Volumetric flow rate

The volumetric flow rate in the wave frame is defined by

$$q = \int_{h_1}^{h_2} u\,dy = H\big(b_1 b_2 b_3 + b_1 b_4 + (h_1 - h_2)\big) + (b_1 b_2 b_3 + b_1 b_4) \tag{25}$$

The pressure gradient obtained from equation (25) can be expressed as

$$\frac{dp}{dx} = \eta \sin\alpha - \left(\frac{q-(b_1b_2b_3+b_1b_4)}{(b_1b_2b_3+b_1b_4+(h_1-h_2))}\right)\left(\frac{M^2}{1+m^2}+\frac{1}{Da}\right) - \left(\frac{M^2}{1+m^2}+\frac{1}{Da}\right) \tag{26}$$

The instantaneous flux Q (x, t) in the laboratory frame is

$$Q = \int_{h_2}^{h_1}(u+1)\,dy = q - h \tag{27}$$

The average volume flow rate over one wave period (T = λ/c) of the peristaltic wave is defined as

$$\bar{Q} = \frac{1}{T}\int_0^T Q\,dt = q + 1 + d \tag{28}$$

From the equations (26) and (28), the pressure gradient can be expressed as

$$\frac{dp}{dx} = \eta \sin\alpha - \left(\frac{(\overline{Q}-1-d)-(b_1b_2b_3+b_1b_4)}{(b_1b_2b_3+b_1b_4+(h_1-h_2))}\right)\left(\frac{M^2}{1+m^2}+\frac{1}{Da}\right) - \left(\frac{M^2}{1+m^2}+\frac{1}{Da}\right) \tag{29}$$

The dimensionless pressure rise per one wavelength in the wave frame is defined as

$$\Delta p = \int_0^1 \frac{dp}{dx}\,dx \tag{30}$$

The dimensionless friction force F at the wall (right wall) across one wavelength is given by

$$F = \int_0^1 {h_1}^2\left(-\frac{dp}{dx}\right)dx \tag{31}$$

4. Results and discussion

In order to gain physical perception into the axial velocity, pressure rise, frictional force, temperature and concentration have been discussed by assigning the numerical values to the parameter encountered in the problem in which the numerical results are displayed with the graphic illustrations (see figures 1-6). Mathematics software Mathematica is used to evaluate the numerical results. In the present study following default parameter values are adopted for computations: t=0.4, x=0.6, ε=0.2, p=-0.5, k_1=0.1, ϕ=$\frac{\pi}{6}$, α=π/2, d=2, Da=0.1, λ_1=0.1, M=3, η=0.5, m=1.5, β=0.2, Pr=3, Br=0.2, Rn=0.5, S=0.5, Sr=2, Sc=0.2. All graphs therefore correspond to these values unless specifically indicated on the appropriate graph.

4.1 Pressure rises

To examine the pumping characteristics, figures 1 to 4 are outlined for pressure rise and frictional force against hall current parameter (m) and Jeffery fluid parameter (λ_1). Moreover, these figures are divided into four regions: Retrograde pumping region ($\Delta p > 0, \overline{Q} < 0$), peristaltic pumping region ($\Delta p > 0, \overline{Q} > 0$), free pumping region ($\Delta p = 0$) and augmented region ($\Delta p < 0, \overline{Q} > 0$). Figure 1 reveals that when the hall current parameter increases (m = 0.5, 1.5, 2.5), then the pumping rate enhances in free pumping ($\Delta p = 0$) and augmented ($\Delta p < 0, \overline{Q} > 0$) zones. However, it shows opposite behaviour in retrograde pumping region ($\Delta p > 0, \overline{Q} < 0$) and peristaltic pumping region ($\Delta p > 0, \overline{Q} > 0$). Effect of Jeffery fluid on pressure rise is depicted in figure 2 with fixed other parameters. Impact of Jeffery fluid on pressure rise is not significant. It can be seen from this figure that an increase in Jeffery fluid, the pumping rate enhances in augmented ($\Delta p < 0, \overline{Q} > 0$) region whereas its behaviour is opposite in retrograde pumping ($\Delta p > 0, \overline{Q} < 0$) and peristaltic pumping ($\Delta p > 0, \overline{Q} > 0$) regions. Furthermore, the pumping curves coincide in the free pumping region ($\Delta p = 0$).

4.2 Friction force

Figures (3) and (4) divulges the variation of frictional force F against the flow rate for different parameters of interest like hall current parameter (m) and Jeffery fluid parameter (λ_1). We notice from these figures that the frictional force exactly has an opposite behavior when compared to the pressure rise.

4.3 Temperature and mass transfer characteristics

Figure (5) reveals that the effect of thermal radiation parameter on temperature distribution with fixed other parameters. It is clear from this figure that the results in the temperature of the fluid reduce by an increase in thermal radiation parameter. Figure (6) demonstrates the effect of chemical reaction parameter on concentration distribution. It can be observed that the concentration distribution reduces as we increase in chemical reaction parameter (S = 0.5, 3.5, 6.5).

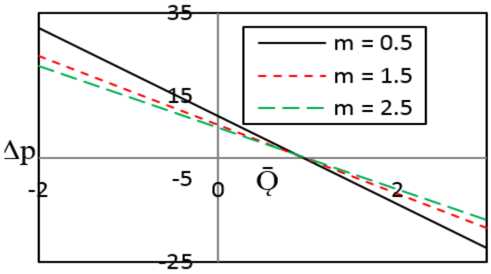

Figure 1: Impact of m on pressure rise (Δp)

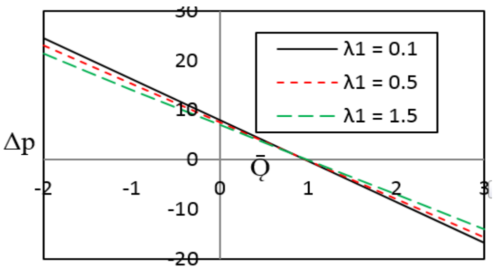

Figure 2: Impact of λ_1 on pressure rise (Δp)

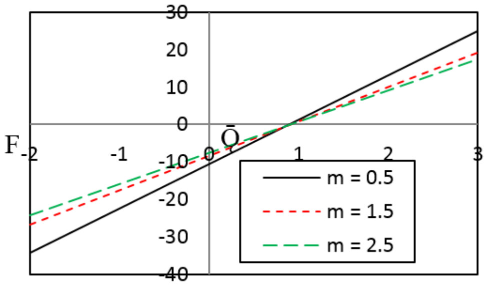

Figure 3: Impact of m on frictional force (F)

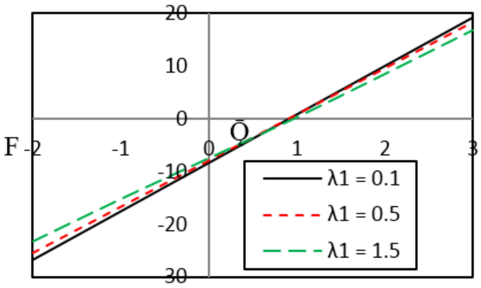

Figure 4: Impact of λ_1 on frictional force (F)

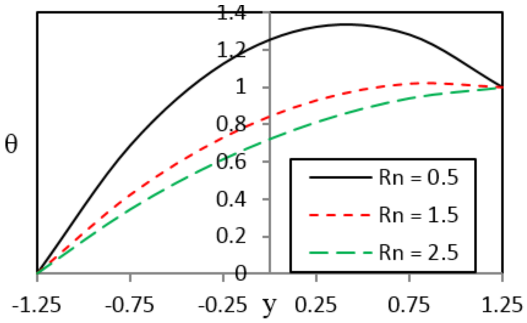

Figure 5: Impact of Rn on temperature distribution

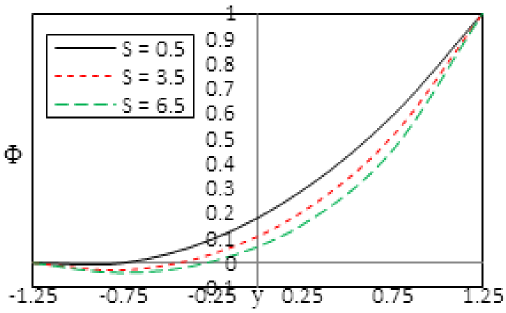

Figure 6: Impact of S on concentration distribution

5. Conclusions

In this paper, we study an impact of Hall current, joule heating and mass transfer on MHD peristaltic hemodynamic Jeffery fluid with the porous medium under an influence of chemical reaction through an inclined tapered vertical channel. The most findings are summarised below:

Pumping rate enhances in free pumping ($\Delta p = 0$) and augmented ($\Delta p < 0, \bar{Q} > 0$) zones whereas the trend is reserve in retrograde pumping region ($\Delta p > 0, \bar{Q} < 0$) and peristaltic pumping region ($\Delta p > 0, \bar{Q} > 0$) with increase in hall current parameter.

Pumping rate enhances in augmented ($\Delta p < 0, \bar{Q} > 0$) region whereas its behaviour is opposite in retrograde pumping ($\Delta p > 0, \bar{Q} < 0$) and peristaltic pumping ($\Delta p > 0, \bar{Q} > 0$) regions. Furthermore, the pumping curves coincide in the free pumping region ($\Delta p = 0$) by an increase in Jeffery fluid parameter.

Frictional force exactly has an opposite behavior when compared to the pressure rise.

Temperature of the fluid reduces by an increase in thermal radiation parameter.

The results in concentration distribution reduce by an increase in chemical reaction parameter.

Acknowledgments

We would like to thank the editor and anonymous reviewers for the encouraging comments and constructive suggestions in improving the manuscript of the present study.

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