Mathematical modeling and simulation of electromagnetohydrodynamic bio-nanomaterial flow through physiological vessels

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Abstract
Gold-based metal nanoparticles serve a key role in diagnosing and treating important illnesses such as cancer and infectious diseases. In consideration of this, the current work develops a mathematical model for viscoelastic nanofluid flow in the peristaltic microchannel. Nanofluid is considered as blood-based fluid suspended with gold nanoparticles. In the investigated geometry, various parametric effects such as Joule heating, magnetohydrodynamics, electroosmosis, and thermal radiation have been imposed. The governing equations of the model are analytically solved by using the lubrication theory where the wavelength of the channel is considered large and viscous force is considered more dominant as compared to the inertia force relating the applications in biological transport phenomena. The graphical findings for relevant parameters of interest are given. In the current analysis, the ranges of the parameters have been considered as: 0 < κ < 6, 0 < λ1 < 0.6, 2 < M < 8, 0 < ζ1 < 3, 0 < ζ2 < 3, 0.1 < φ1 < 0.4, 0 < Br < 3, 0 < β < 3, 0 < Rn < 0.3 and 0 < φ < π / 2. The current results reveal that, a stronger magnetic field leads the enhancement in nanoparticle temperature and shear stress, and it reduces the velocity and trapping bolus. The nanoparticle temperature rises with the increasing parameters such as Brinkman number and Joule heating parameter.

Keywords
Gold nanoparticles, electroosmosis, shape effects, joule heating, magnetohydrodynamics, peristalsis

Introduction
Nowadays nanofluids are well-known conventional fluids and being are used for enhancement of various thermal properties particularly thermal conductivity of the base fluids. Varieties of base fluids, including water, methanol, oil, and ethylene glycol are utilized to prepare the nanofluids and hybrid nanofluids. The numerous types of nanofluids and their distinctions are adequately explained by the types of nanoparticles and their shapes. The dispersed nanoparticles in base fluids have higher thermal conductivities, hence nanofluids give better thermal performance than traditional fluids. Chemical processes, cooling of electronic equipment, heat exchanger, machine cooling, heat transfer efficiency, improving diesel generator efficiency, solar water heating, and engine cooling are just a few of the industrial and engineering applications of nanofluids.1 In
view of these applications, many investigators have started working on nanofluid flows in various geometries. Homotopy analysis approach was employed for squeezing water-gold (along with various nanoparticle shapes such as lamina, tetrahedron, hexahedron, sphere, and column) based nanofluid flow between horizontal channels. Further, fourth and fifth order Runge-Kutta-Fehlberg technique was considered to analyze the gold nanoparticles effects on Sisko fluid (considering Sisko fluid as blood) flow over a stretching surface. The mobility of nanofluid in an inclined diverging or converging channel is analyzed using the perturbation method. The Matlab bvp4c simulation was used for the hybrid (copper and alumina treated as hybrid nanoparticles) nanoliquids flow along a widening/shrinking cylinder. The ANSYS Fluent 19.3 simulations for the Poiseuille flow of alumina nanofluid in parallel plates. The numerically approach was carried for the nanofluid flow in a pillow plate to discuss the applications for heat exchanger. The flow of nanofluid in a rotating system with the single and multi-carbon nanotubes is studied by using the HAM BVPH 2.0 program. Green’s function-based approach was used to squeeze nanofluid flow in parallel plates. The boundary layer flow of blood-gold nanofluid across a paraboloid of revolution using the Runge–Kutta method and the MATLAB bvp4c methodology. The nanofluid flow in a 3D tilted prismatic solar enclosure was studied using the ANSYS FLUENT program (version 19.1). The micropolar gold blood nanofluid flow in a permeable channel was studied using HAM. The Casson nanofluid flow is analytical solved to get the closed-form solution of the model.

In the gastrointestinal tract (GI), peristalsis is the movement of a food bolus across the entire length of the tract. The movement begins in the pharynx and concludes in the anus (windpipe). Peristalsis can be found in both smooth and skeletal muscles. In the field of physiology, it is well-known because it is a critical component of many biological systems, including spermatozoa transport, small blood vessel vasomotion, ovum movement, and urine flow from the kidney to the bladder. Nanofluids have the potential to benefit a wide range of gastrointestinal illnesses, including inflammatory bowel disease, drug administration, and the management of chronic intestinal inflammation. In light of these considerations, researchers have recently begun investigating nanofluid flows in the direction of biological applications in a variety of flow scenarios, including channel, endoscope, curved shape, and so on, in order to better understand how they work. The computational solutions demonstrated the heat and mass transfer characteristics on the motion of cilia for Newtonian, Pseudo-plastic, and Dilatant fluids in an inclined peristaltic channel using *Mathematica* software. The nature of third grade nanofluid flow in peristaltic vertical annulus was addressed by taking the gold nanoparticles in base fluid blood into account. Further several studies have been reported by using various technique to comprehend the thermal characteristic of the nanoparticle in the Newtonian and non-Newtonian fluid. The peristaltic flow of nanofluids in a vertically asymmetric channel (Ag-water and Cu-water nanofluids) is discussed and observed that the Cu has much better efficiency rather than Ag. The flow of nanofluid driven by peristalsis were discovered in an asymmetric channel. The heat transfer rate in a multiphase flow induced by metachronal propulsion is discussed through porous media.

Biological fluids can be found in living things when they are exposed to a strong magnetic field. Scientists have paid a great deal of attention to the behavior of physiological fluids with magnetohydrodynamics mechanisms over the course of the last few decades. Many applications in bioengineering and medical sciences, such as magnetic resonance imaging (MRI), cancer treatment, drug transport, reducing bleeding during surgeries, and the invention of magnetic devices for cell separation and wound healing, have made significant contributions to this field. On the basis of these findings, the current researchers have investigated the effect of MHD on nanofluid flows in biological geometries in the laboratory. The computational solutions for the of Eyring–Powell nanofluid flow under convective conditions are presented with applications of MHD and peristalsis mechanisms. The HPM was utilized to explore the motion of nanofluids generated by the peristalsis mechanism in their experiments. In the context of magneto-hydrodynamics, the magnetic nano particles are considered in the viscoelastic fluid and observed that the gold particle enhanced the thermal conductivity of the fluid. By employing the Runge-Kutta-Fehlberg approach, the flow of blood nanofluid in three distinct geometries is observed. Jeffrey nanofluid MHD peristaltic flow via peristaltic compliant barriers was studied theoretically, who presented their findings. The MHD peristalsis of Jeffrey nanofluid flow through a conduit was investigated while the MHD peristalsis motion of Carreau nanofluid with copper and silver nanoparticles is discussed. Further investigations on heat transfer analysis and nanofluid can be found in the given Refs. and several therein. The electro-osmotic flow (EOF) of various fluids is investigated in diverse microchannels, such as circular, elliptic, rectangular and slit microchannels. Nowadays the attention of researchers on electro-osmotic flow has shifted to the EOF heat transfer characteristics. In chemical and biological industries, the biofluids transport noticed in microfluidic devices, and shows the nonlinear rheological behavior. In view of these, many investigations have been done in various situations, such as EOF in diverging channels. EOF in parallel plates and EOF in converging channels.

Aforementioned works discuss the fluid flows in various directions such as nanofluids, peristalsis, electroosmosis and magnetic field, but no study is seen in the direction of blood-gold-based nanofluid flow through peristalsis with
electrohydrodynamics, magnetohydrodynamics, Joule heating and radiation. Therefore, the current research focuses on the electroosmotic blood-based nanofluids with gold nanoparticles suspension in presence of nanoparticles. Here, blood is modeled as non-Newtonian viscoelastic fluids model that is, Jeffrey fluid model to investigate the rheological importance of blood. The effects of Joule heating, electric field, thermal radiation, and magnetic fields have also been discussed. The mathematical formulation was carried out using the lubrication strategy to examine the creeping nature of the blood flow. Exact solutions are obtained and graphically explained the influence of emerging parameters. The findings of the present model may be applicable in targeting the drugs in circulatory systems and developments of the bio microfluidics pumps for health care.

**Problem description**

The flow of a viscoelastic nanofluid (blood as the base fluid with suspended gold nanoparticles) through a microchannel is studied under various factors such as MHD, radiation, Joule heating, and electroosmosis. Electric field and peristalsis in the positive $X$-axis direction are responsible for the flow. At both the walls (lower $\zeta_1$ and upper $\zeta_2$), it is believed that the various zeta potentials have been evaluated. The nanoparticle temperature at the lower wall and upper wall are kept at $T_0$ and $T_1$ respectively. Figure 1 represents the flow situation of the present problem.

The following are the wall shapes that relate to flow configurations:

$$H_1(X,t) = d_1 + a_1 \cos^\frac{\pi X}{\lambda} (X - ct)$$

$$H_2(X,t) = -d_2 + a_2 \cos^\frac{\pi X}{\lambda} (X - ct) + \phi,$$

where $H_1$ represents the upper peristaltic wall, $H_2$ represents the lower peristaltic wall, $X$ represents the wave direction, $t$ represents the time, $d^2 = (d_1 + d_2)$ represents the channel width, $a_1, a_2$ represent the wave amplitudes of upper and lower walls, $\lambda$ represents the wavelength, $c$ represents the wave speed and $\phi$ is the phase difference, respectively.

An incompressible Jeffrey fluid has the constitutive equations as follows:

$$\tau = -P \dot{I} + S,$$

$$S = \frac{\mu_{\text{eff}}}{1 + \lambda_1} (\dot{\gamma} + \lambda_2 \ddot{\gamma}),$$

where $\tau$ represents the Cauchy stress tensor, $S$ represents the extra stress tensor, $P$ represents the pressure, $I$ represents the identity tensor, $\mu_{\text{eff}}$ represents the effective viscosity coefficient of nanofluid, $\lambda_1$ represents the ratio of relaxation to retardation times, $\lambda_2$ represents the retardation time, $\dot{\gamma}$ represents the shear rate and dots over the quantities indicate differentiation with respect to time, and these are given as

$$\dot{\gamma} = \nabla \ddot{q} + (\nabla \ddot{q})^T$$

It is possible to write the two-dimensional governing equations for the viscoelastic nanofluid with electroosmosis, radiation, Joule heating and magnetic field as follows:

$$\frac{\partial V}{\partial Y} + \frac{\partial U}{\partial X} = 0,$$

$$\rho_{\text{eff}} \left( \frac{\partial U}{\partial t} + V \frac{\partial U}{\partial X} + U \frac{\partial U}{\partial X} \right) = -\frac{\partial P}{\partial X} + \frac{\partial S_{YX}}{\partial X} + \frac{\partial S_{XY}}{\partial Y} - \sigma_{\text{eff}} B^2_0 U + \rho_{\text{e}} E_x,$$

$$\rho_{\text{eff}} \left( \frac{\partial V}{\partial t} + V \frac{\partial V}{\partial Y} + U \frac{\partial V}{\partial X} \right) = -\frac{\partial P}{\partial Y} + \frac{\partial S_{YX}}{\partial Y} + \frac{\partial S_{XY}}{\partial X},$$

$$\left( \rho c_{\text{eff}} \right) \left( \frac{\partial T}{\partial t} + U \frac{\partial T}{\partial X} + V \frac{\partial T}{\partial Y} \right) = \kappa_{\text{eff}} \left( \frac{\partial^2 T}{\partial X^2} + \frac{\partial^2 T}{\partial Y^2} \right) + \sigma_{\text{eff}} B^2_0 \left( U^2 + V^2 \right) + \sigma_{\text{eff}} E_x^2 \left( \frac{\partial q_x}{\partial X} + \frac{\partial q_y}{\partial Y} \right),$$

where $U$ represents the axial velocity, $V$ is transverse velocity, $\rho_{\text{eff}}$ represents the effective density of nanofluid, $\rho_{\text{e}}$ represents the electric charge density, $E_x$ represents the applied electric field, $(pc)_{\text{eff}}$ represents the heat capacity of nanofluid, $T$ represents the specific temperature, $\kappa_{\text{eff}}$ represents the effective thermal conductivity, $\mu_{\text{eff}}$ represents the effective viscosity coefficient of nanofluid, $\lambda_1$ represents the ratio of relaxation to retardation times, $\lambda_2$ represents the retardation time, $\dot{\gamma}$ represents the shear rate and dots over the quantities indicate differentiation with respect to time, and these are given as

$$\dot{\gamma} = \nabla \ddot{q} + (\nabla \ddot{q})^T$$

Figure 1. Schematic representation of the peristaltic transport.
represents the effective thermal conductivity of nanofluid, $\sigma_{\text{eff}}$ represents the effective electrical conductivity and $q_r$ represents the thermal radiation, respectively.

In equation (9), the radiation $q_r$ is assumed under the Rosseland approximation and it is given by $q_r = -\frac{16\alpha_1 T_0^4}{3\alpha_1} \frac{\partial T}{\partial Y}$, in which $\sigma_1$ represents the Stefan-Boltzmann and $\alpha_1$ represents the mean absorption coefficients.

The following are the thermophysical properties:

\[
\begin{align*}
(\rho)_{\text{eff}} &= (\rho)_f (1-\phi) + (\rho)_s \phi_i, \\
(\rho c)_{\text{eff}} &= (\rho c)_f (1-\phi) + (\rho c)_s \phi_i, \\
\mu_{\text{eff}} &= \frac{1}{(1-\phi)^{2.5}}, \\
\kappa_{\text{eff}} &= \kappa_s + (m-1)\kappa_f - (m-1)(\kappa_f - \kappa_s)\phi_i, \\
\sigma_{\text{eff}} &= 1 + \frac{3\left(\frac{\sigma_s}{\sigma_f} - 1\right)}{\left(\frac{\sigma_s}{\sigma_f} + 2\right) - \left(\frac{\sigma_s}{\sigma_f} - 1\right)} \phi_i,
\end{align*}
\]

where $\kappa_s$ represents the thermal conductivity of nanoparticles, $\kappa_f$ represents the thermal conductivity of the base fluid, $m$ represents the electrical conductivity of nanoparticles, $\sigma_s$ represents the electrical conductivity of the base fluid, $\sigma_f$ represents the nanoparticle shape factor and $\phi_i$ represents the nanoparticle volume fraction, respectively.

**Potential distribution**

The Poisson equation is represented by

\[
\nabla^2 \Phi = -\frac{\rho_e}{\epsilon_{\text{ef}}},
\]

where $\rho_e$ denotes the electric charge density and $\epsilon_{\text{ef}}$ represents the dielectric constant.

As per Boltzmann distribution, the electric charge density is given by

\[
\rho_e = -2n_0e\sinh\left(\frac{e\varphi}{k_B T_n}\right),
\]

where $n_0$ represents the bulk concentration, $e$ represents the elementary charge valence, $z$ represents the valence of ions, $k_B$ represents the Boltzmann constant and $T_n$ represents the mean temperature, respectively.

Under Debye–Hückel linearization, the equations (15) and (16) will take the form as:

\[
\nabla^2 \Phi = \frac{2n_0e^2z^2}{\epsilon_{\text{ef}}k_B T_n} \Phi.
\]

**Scaling and transformations of mathematical model**

The transformations among both wave and fixed frames are as follows:

\[
x = X - ct, y = Y, u = U - c, p = P, v = V, \bar{T} = T,
\]

and the scaling parameters are defined as follows:

\[
\bar{x} = \frac{x}{\lambda}, \bar{y} = \frac{y}{\delta}, \bar{u} = \frac{u}{c}, \bar{V} = \frac{v}{c\delta}, \bar{\delta} = \frac{d_1}{\lambda}, \bar{h}_1 = \frac{H_1}{d_1},
\]

\[
a = \frac{a_1}{d_1}, b = \frac{a_2}{d_1}, \bar{\rho} = \frac{d_1^2 \rho}{c \lambda \mu_f}, \bar{\theta} = \frac{T - T_0}{T_1 - T_0},
\]

\[
Re = \frac{\rho_f c d_1}{\mu_f}, Pr = \frac{\mu_f c_f}{k_f}, Br = \frac{\mu_f c^2}{k_f (T_1 - T_0)},
\]

\[
\bar{\Phi} = \frac{\Phi}{\zeta}, \bar{\beta} = \frac{\sigma_f d_1^2 E_z^2}{k_f (T_1 - T_0)} - \frac{E_{\text{ef}} \xi}{c \mu_f},
\]

\[
Rn = \frac{16\sigma_1 T_0^3}{3\alpha_1 \mu_c c_f} \kappa = d_1 e \sqrt{\frac{2n_0}{\epsilon_{\text{ef}} k_B T_n}},
\]

where $\delta$ is the wave number, $h_1$ is the wall deformation of the lower wall, $h_2$ is the wall deformation of the upper wall, $d$ is the channel width ratio, $a$ is the amplitude ratio of the upper wall, $b$ is the amplitude ratio of the lower wall, $p$ is the dimensionless pressure, $\theta$ is the dimensionless nanoparticle temperature, $Re$ is the Reynolds number, $Pr$ is the Prandtl number, $Br$ is the Brinkmann number, $\Phi$ is the electric potential, $\beta$ is the ratio of joule heating to surface heat flux, $U_{\text{HS}}$ is the Helmholtz–Smoluchowski velocity, $Rn$ is the radiation parameter, $\kappa$ is the electroosmosis parameter, and $\psi$ is the stream function respectively. The equations (6)–(9) and (17) (after removing the bars) were reduced to their...
simplest form under the incorporation of transformations and scaling parameters with the assumption of long wave-length and lubrication. We get

$$\frac{1}{(1-\phi_0)^{2.5}(1+\lambda_0)} \frac{\partial^2 \theta}{\partial y^2} = \frac{\theta_{\text{eff}}}{\theta_{\text{f}}} M^2 \frac{\partial^2 \psi}{\partial y^2} + \frac{\sigma_{\text{eff}}}{\sigma_f} \left( \kappa f + \frac{Rn Pr}{\kappa f} \right) \frac{\partial^2 \theta}{\partial y^2} + \frac{\sigma_{\text{eff}}}{\sigma_f} \beta \Phi \kappa^2 U H S$$

(20)

$$\frac{\partial \Phi}{\partial y} = 0,$$

(21)

$$\nabla^2 \Phi = \kappa^2 \Phi,$$

(22)

in conjunction with the associated boundary conditions

$$\psi = \frac{F}{2} \frac{\partial \psi}{\partial y} = -1, \theta = 1, \Phi = \zeta_1$$

(23)

at $$y = h_1 = 1 + a \cos^2 (\pi x),$$

$$\psi = \frac{F}{2} \frac{\partial \psi}{\partial y} = -1, \theta = 0, \Phi = \zeta_2$$

(24)

at $$y = h_2 = -d - b \cos^2 (\pi x + \phi).$$

The flow rate is described this way in both the fixed and moving frames of reference:

$$Q = F + 1 + d + \left( \frac{a + b}{2} \right),$$

(25)

here $$F = \int h_1 u dy$$, $$F$$ and $$Q$$ denote the averaged flow rate in the wave frame and the fixed frame of reference respectively.

The dimensionless shear stress ($$\tau_s$$) and Nusselt number ($$Nu$$) at the peristaltic wall $$y = h_1$$ are given by

$$\tau_s = \frac{1}{(1-\phi_0)^{2.5}(1+\lambda_0)} \frac{\partial^2 \psi}{\partial y^2}$$

(26)

$$Nu = \frac{\partial \theta}{\partial x} \frac{\partial \theta}{\partial y}.$$  

(27)

Solution of the problem

Equations (20)–(22) are solved under the boundary conditions (23)–(24), and the solutions for various physical quantities are as follows:

$$\Phi = \left( \frac{\zeta_1 \sinh (\kappa h_1) - \zeta_1 \sinh (\kappa h_2)}{\sinh (\kappa (h_1 - h_2))} \right) \cosh (\kappa y)$$

(28)

$$- \left( \frac{\zeta_1 \cosh (\kappa h_1) - \zeta_1 \cosh (\kappa h_2)}{\sinh (\kappa (h_1 - h_2))} \right) \sinh (\kappa y),$$

$$\psi = k_1 + k_2 y + k_3 \cosh (\kappa y) + k_4 \sinh (\kappa y)$$

(29)

$$+ k_5 \sinh (\kappa y) + k_6 \cosh (\kappa y),$$

$$u = k_2 + k_3 r \sinh (\kappa y) + k_4 r \cosh (\kappa y)$$

(30)

$$+ k_5 \kappa \cosh (\kappa y) + k_6 \kappa \sinh (\kappa y),$$

$$\theta = m_1 + m_2 y + m_3 y^2 + m_4 \cosh (2\kappa y)$$

$$+ m_5 \sinh (2\kappa y) + m_6 \cosh (2\kappa y)$$

(31)

$$+ m_7 \sinh (2\kappa y) + m_8 \cosh (2\kappa y) + m_9 \sinh (\kappa y)$$

$$+ m_{10} \cosh (\kappa y) + m_{11} \sinh (\kappa y)$$

$$+ m_{12} \sinh (\kappa y) \cosh (\kappa y) + m_{13} \sinh (\kappa y) \cosh (\kappa y)$$

$$+ m_{14} \sinh (\kappa y) \sinh (\kappa y)$$

$$+ m_{15} \cosh (\kappa y) \cosh (\kappa y),$$

in which $$r, k_s$$, $$s (i = 1-6)$$ and $$m_j$$, $$s (j = 1-15)$$ are simple algebraic calculations.

Discussion of the findings

This section displays graphical representations of numerous fluid flow variables, including as velocity $$u$$, nanoparticle temperature $$\theta$$, shear stress $$\tau_s$$, heat transfer coefficient and streamlines with respect to electroosmosis parameter $$\kappa$$, viscoelastic fluid parameter $$\lambda$$, Hartmann number $$M$$, zeta potential $$\zeta$$, Brinkman number $$Br$$, normalized generation $$\beta$$, radiation parameter $$Rn$$, and Helmholtz-Smoluchowski velocity $$U_{HS}$$. Table 1 lists the thermophysical parameters of base fluid and nanoparticles, whereas Table 2 lists the shape factor of various types of particles. Table 3 represents the comparison of velocity profile with the existing literature in limiting cases. It is

| Material | $$\rho (kg/m^3)$$ | $$C_p (J/kgK)$$ | $$k(W/mK)$$ | $$\sigma (S/m)$$ | $$\beta \times 10^{-4}$$ | $$Pr$$ |
|----------|----------------|----------------|-------------|----------------|-------------------------|--------|
| Blood    | 1053           | 3594           | 0.492       | 0.8            | 1.8                     | 22.95  |
| Gold     | 19,300         | 129.1          | 318         | 4.52           | 4.52 \times 10^{-7}     | 14     |
noticed from the table that; the presented results are in good agreement with the existing literature.

Figure 2 represents the velocity profiles for various fluid parameters such as electroosmosis parameter $\kappa$, viscoelastic fluid parameter $\lambda$, Hartmann number $M$, zeta potentials $\zeta_1$ and $\zeta_2$, and nanoparticle volume fraction $\phi$, respectively. According to Figure 2(a), a higher electroosmosis parameter causes a drop in velocity in the center of the peristaltic channel, whereas the tendency reverses at the borders. It is also depicted that; the higher velocities are noticed in the absence of electroosmosis effects. Figure 2(b) displays the velocity with respect to viscoelastic fluid parameter. The velocity enhances near the middle portion of the channel walls and the decrement is observed near the boundaries (see Figure 2(b)). It is also noticed that the larger velocities are obtained for the Newtonian fluid model as compared with viscoelastic fluid model near the boundaries. A stronger magnetic field leads to a decrement in velocity in the middle of the channel (see Figure 2(c)), it is due to the generation of Lorentz forces. Figure 2(d) shows that when the zeta potential increases, the velocity increases near the lower wall and decreases near the higher wall of the peristalsis; the reverse tendency is seen for the other zeta potential at a distinct wall (see Figure 2(e)). Figure 2(f) shows that when the nanoparticle volume percentage increases, the velocity increases in the middle of the channel and drops toward the walls of the channel.

Figure 3 is plotted to see the variations of nanoparticle temperature with respect to Brinkman number, Joule heating parameter, Hartmann number and Radiation parameter. It is clear from these plots that; all the graphs are parabolic in nature. The nanoparticle temperature reduces with rising values of Brinkman number (see Figure 3(a)). It is also mentioned that the highest temperature is noticed for the stronger Brinkman number and the lowest temperature is recorded in the case of absence of Brinkman number. It is clear from Figure 3(b) that, with increase of the Joule heating parameter, the temperature increases and noticed that the lower temperatures have been recorded in the absence of the Joule heating parameter. A stronger magnetic field yields the decrement in nanoparticle temperature (see Figure 3(c)). It is depicted from Figure 3(d) that; the nanoparticle temperature decrement is noticed with rising values of radiation parameter. Figure 3(e) shows that when the viscoelastic fluid parameter is increased, the temperature rises; moreover, larger temperatures are engaged in

The viscoelastic nanofluid model in comparison to the viscous nanofluid model. The Figure 3(f) is sketched to see the temperature profile for various shapes of nanoparticles (sphere ($m = 3$), cylinder ($m = 4.9$), platelet ($m = 5.7$), and blade ($m = 8.6$)). The higher temperatures are noticed in the presence of sphere-shaped nanoparticles present in the nanofluid and the lowest temperatures are observed in case of blade-shaped nanoparticles suspended in the base fluid.

To see the behavior of shear stress distribution (at the wall $y = h/t$) for various values such as electroosmosis parameter, viscoelastic fluid parameter, Hartmann number and zeta potential, the Figure 4 is plotted. The shear stress increases at the upper peristaltic wall with enhancing values of electroosmosis parameter (see Figure 4(a)). Figure 4(b) provides the shear stress with respect to viscoelastic fluid parameter and noticed that shear stress decreases with rising values of viscoelastic fluid. It is also discovered that in the absence of the viscoelastic fluid characteristic, the largest shear stress is recorded (in case of Newtonian fluid model). Shear stress rises as the Hartmann number grows (see Figure 4(c)). The shear stress pattern at the peristaltic top wall increases as zeta potential increases (see Figure 4(d)), with the lowest shear stress reported in the utter lack of zeta potential. Moreover, it is also observed from Figure 4 that, all the figures are in wave type in nature, which is due to the peristaltic wave shapes. The shear stress decreases with the increase in nanoparticle volume fraction (see Figure 4(e)). The phase difference zero gives the symmetric model and the non-zero phase difference leads to an asymmetric channel. It is noted from Figure 4(f) that, it shows the mixed behavior.

Figure 5 is plotted to observe the mechanism of heat transfer coefficient at the wall $y = h/t$ for various values of interest such as radiation parameter, Hartmann number, viscoelastic parameter, Brinkman number, normalized generation parameter and various nanoparticle shapes. Figure 5(a) and (b) demonstrate that the heat transfer rate reduces in magnitude as the radiation parameter and Hartmann number rise. Heat transfer rate grows when the viscoelastic parameter, Brinkman number, and normalized

### Table 2. Shape factor of different shaped nanoparticles.45

| Geometry   | Shape factor ($m$) |
|------------|--------------------|
| Sphere     | 3.0                |
| Platelet   | 4.9                |
| Cylinder   | 5.7                |
| Blade      | 8.6                |

### Table 3. The comparison of velocity profile with the existing literature.49

| $y$        | Present study | Sridhar and Ramesh |
|------------|---------------|---------------------|
| -1         | -1.0000       | -1.0000             |
| -0.75      | 0.0805        | 0.0863              |
| -0.5       | 0.8069        | 0.8136              |
| -0.25      | 1.2253        | 1.2296              |
| 0          | 1.3618        | 1.3620              |
| 0.25       | 1.2253        | 1.2296              |
| 0.5        | 0.8069        | 0.8136              |
| 0.75       | 0.0805        | 0.0863              |
| 1          | -1.0000       | -1.0000             |
Figure 2. Influence of (a) electroosmosis parameter $\kappa$, (b) viscoelastic fluid parameter $\lambda_1$, (c) Hartmann number $M$, (d) zeta potential $\zeta_1$, (e) zeta potential $\zeta_2$, and (f) nanoparticle volume fraction $\phi_1$ on velocity profiles.
Figure 3. Influence of (a) Brinkman number $Br$, (b) normalized generation $\beta$, (c) Hartmann number $M$ (d) radiation parameter $Rn$, (e) viscoelastic parameter $\lambda_1$, and (f) shape factors of nanoparticles on nanoparticle temperature profiles.
Figure 4. Influence of (a) electroosmosis parameter $\kappa$, (b) viscoelastic fluid parameter $\lambda_1$, (c) Hartmann number $M$, (d) zeta potential $\zeta_1$, (e) nanoparticle volume fraction $\phi_1$, and (f) phase difference $\phi$ on shear stress profiles.
Figure 5. Influence of (a) radiation parameter $R_n$, (b) Hartmann number $M$, (c) viscoelastic parameter $\lambda_1$, (d) Brinkman number $Br$, (e) normalized generation $\beta$, and (f) shape factors of nanoparticles on heat transfer coefficient profiles.
generation parameter (Figure 5(c)–(e)) increase. It is clear from Figure 5(f) that, the highest heat transfer (in magnitude) is observed in sphere-shaped nanoparticles suspended in a fluid medium and the lowest heat transfer rate is noticed in blade-shaped nanoparticles merged in base fluid. Another interesting phenomenon is trapping. To see the trapping effect for various values like Hartmann number and Helmholtz-Smoluchowski velocity, the Figures 6 and 7 have been sketched. From both the figures, it is noticed that the size of trapped bolus decreases with increasing values of Hartmann number and Helmholtz-Smoluchowski velocity.

**Conclusions**

The proposed model takes into account the gold-blood-based nanofluid flow in an asymmetric peristaltic geometry. All of the different impacts, such as Joule heating, EMHD, and radiation, have been taken into consideration. The governing equations that resulted have been solved analytically for the electric potential, stream function, velocity, and temperature of nanoparticles, among other things. There have been graphical representations for a variety of flow quantities provided. The investigation is carried out in relation to the platelet nanoparticles that are engaged in the nanofluid model. The following are the key findings of the current investigation, summarized as follows:

- Stronger magnetic field leads the reduction in the velocity and trapping bolus.
- The shear stress distribution increases with higher Hartmann number.
- Electroosmosis parameter reduces the velocity and enhances the shear stress.
- Stronger viscoelastic fluid parameter increases the velocity and decreases the shear stress.
Higher values of Brinkman number and Joule heating parameter leads an increment in nanoparticle temperature.

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