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Comparative study of silver and copper water magneto nanoparticles with homogeneous-heterogeneous reactions in a tapered channel

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ABSTRACT

The core purpose is here to analyze the peristaltic motion of an electrically conducting silver and copper-water nanofluid in a tapered channel. Maxwell methodology is used to model the problem. Analysis is carried out in the presence of mixed convection, viscous dissipation and heat generation/absorption. Addition of homogeneous/heterogeneous effects has made this study more motivating. Galilean transformations are used to relate the two frames of reference. Simplified form of the governing equations is obtained via large wavelength and small Reynolds number approach. Results for stream function, velocity, temperature, heat transfer rate and homogeneous/heterogeneous reactants are studied and discussed precisely. Graphical results indicate that axial velocity of nanofluid enhances for larger Grashof number while decrease in the temperature of the nanoparticle is observed when porosity parameter is enhanced.

1. Introduction

The peristaltic transport of fluid has achieved special attention in the recent years due to its wide applications in engineering and biomechanics. This process is highly important in many physiological systems and industry such as swallowing food through esophagus, in the vasomotion of small blood vessels such as venules, capillaries and arterioles, in sanitary fluid transport, and toxic liquid transport in the nuclear industry. The peristaltic flows are due to the waves travelling along the walls having elastic properties. Latham [1] and Shapiro et al. [2] initially dealt the peristaltic flow of viscous fluid. Afterwards extensive research has been conducted for the peristaltic flows. We mention here few recent studies [3–12]. Moreover, the peristaltic transport of fluid in a channel with heat transfer is significant in the hemodialysis and oxygenation processes. The heat transfer analysis in the existing attempts on peristalsis has been mostly addressed through prescribed surface temperature or heat flux. Recently the idea of convective boundary condition has been used for the heat transfer analysis [13–15]. At present, the mechanics of nanofluids has motivated the recent researchers for the enhancement of thermal conductivity of base fluid. Choi [16] introduced the word "nanofluid". The term nanofluid refers to a liquid suspension containing ultrafine particles having diameter less than 50 nm. These particles can be found in the metals such as (Ai, Cu), oxides (Al_2O_3), carbides (SiC), nitrides (SiN) or nonmetals (Graphite, carbon nanotubes, nanofibers, nanosheets, droplets). Choi verified that the suspension of solid nanoparticles with typical length scales of 1–50 nm with high thermal conductivity enhances the effective thermal conductivity and the convective heat transfer of the base fluid. Buongiorno [17] proposed the nonhomogeneous equilibrium model and revealed that this massive increase in the thermal conductivity occurs due to the presence of two main effects namely the Brownian diffusion and the thermophoretic diffusion of the nanoparticles. Some representative studies on nanofluids have been carried in the investigations [11,18–39].

To our knowledge, there is yet scant information on the peristalsis of nanofluids. Even a single attempt is not available for peristaltic transport of nanofluid in a tapered asymmetric channel with slip effects. The object of present communication is to present model taking into account such considerations. Here analysis has been made by considering silver and copper nanoparticles. Impact of various physical parameters on velocity, temperature, homogeneous-heterogeneous concentration and heat transfer rate has been analyzed. Trapping phenomena is also discussed (see Fig. 1).

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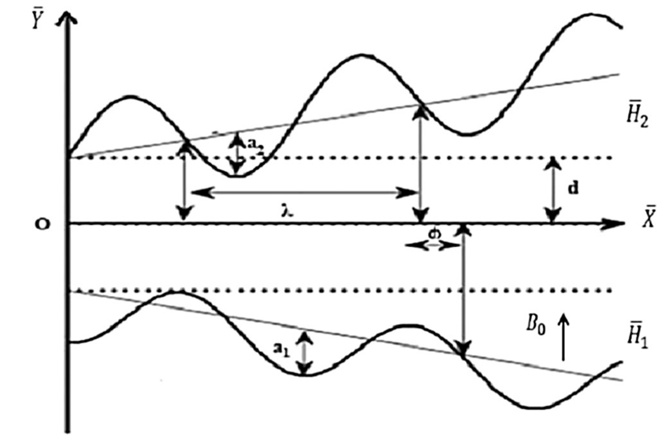

Fig. 1. Physical model.

2. Problem formulation

Let us consider the peristaltic flow of silver water (Ag-H_2O) and copper-water (Cu-H_2O) nanofluid flowing through a two dimensional vertical asymmetric tapered channel. Asymmetry in the channel is due to the propagation of waves with different amplitude and phases. Waves propagate along the channel of width $(d + d)$ due to peristaltic phenomena with wavelength λ and speed c. Geometry of the given problem is taken in such a way that $\overline{X}$-axis is along the length of the channel and $\overline{Y}$ -axis is taken in transverse direction to the flow in which magnetic field of strength B_0 is applied. As a result of applied magnetic field induced magnetic field also produced which is neglected using small magnetic Reynolds number.

The shape of waves is

$$\overline{H_1} = -d - m\overline{X} - a_1 \sin\left(\frac{2\pi}{\lambda}(\overline{X} - c\bar{t}) + \gamma\right), \tag{1}$$

$$\overline{H_2} = d + m\overline{X} + a_2 \sin\left(\frac{2\pi}{\lambda}(\overline{X} - c\bar{t})\right). \tag{2}$$

Here $\overline{H}_1(\overline{X},\bar{t})$ and $\overline{H}_2(\overline{X},\bar{t})$ are two walls of channel at $\overline{Y} > 0$ and $\overline{Y} < 0$ respectively with phase difference $\lambda \in [0,\pi]$ and a_1, b_1 are amplitudes of right and left channel walls. Moreover we used the isothermal effects of homogeneous and heterogeneous reactions using two phase model for effective conductivity. κ_{eff} is effective thermal conductivity of silver water (Ag-H_2O) and copper-water (Cu-H_2O) and κ_f is thermal conductivity of water taken as base fluid. We can represent ration of thermal conductivities as given below:

$$\frac{\kappa_{eff}}{\kappa_f} = \frac{\kappa_P + 2\kappa_f - 2\phi(\kappa_f - \kappa_p)}{\kappa_P + 2\kappa_f + 2\phi(\kappa_f - \kappa_p)}, \tag{3}$$

Homogeneous porous medium is investigated in this problem with porosity k_1. $\overline{U}(\overline{X},\overline{Y},\bar{t}), \overline{V}(\overline{X},\overline{Y},\bar{t})$ are velocity components along $\overline{X} - axis$ and $\overline{Y} - axis$ respectively. Derived equation from law of conservation of mass, momentum, energy and homogeneous/heterogeneous reactions related to this problem are given as follow:

$$\frac{\partial\overline{U}}{\partial\overline{X}} + \frac{\partial\overline{V}}{\partial\overline{Y}} = 0, \tag{4}$$

$$\begin{aligned}&\rho_{eff}\left(\frac{\partial}{\partial \bar{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)\overline{U} = -\frac{\partial\overline{P}}{\partial\overline{X}} + \mu_{eff}\left(\frac{\partial^2\overline{U}}{\partial\overline{Y}^2} + \frac{\partial^2\overline{V}}{\partial\overline{X}^2}\right) - \mu_{eff}\frac{\overline{U}}{k_1}\\ &-\sigma_{eff}B_0^2\overline{U} + g(\rho\beta)_{eff}(T - T_m),\end{aligned} \tag{5}$$

$$\begin{aligned}\rho_{eff}\left(\frac{\partial}{\partial \bar{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)\overline{V} &= -\frac{\partial\overline{P}}{\partial\overline{Y}} + \mu_{eff}\left(\frac{\partial^2\overline{V}}{\partial\overline{Y}^2} + \frac{\partial^2\overline{U}}{\partial\overline{X}^2}\right)\\ &- \mu_{eff}\frac{\overline{V}}{k_1} - \sigma_{eff}B_0^2\overline{V},\end{aligned} \tag{6}$$

$$\begin{aligned}&(\rho C)_{eff}\left(\frac{\partial}{\partial \bar{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)T = K_{eff}\left(\frac{\partial^2 T}{\partial\overline{X}^2} + \frac{\partial^2 T}{\partial\overline{Y}^2}\right) + \Phi\\ &+\mu_{eff}\left[2\left(\left(\frac{\partial\overline{U}}{\partial\overline{X}}\right)^2 + \left(\frac{\partial\overline{V}}{\partial\overline{Y}}\right)^2\right) + \left(\frac{\partial\overline{U}}{\partial\overline{X}} + \frac{\partial\overline{V}}{\partial\overline{Y}}\right)^2 + \frac{\overline{U}^2}{k_1}\right] + \sigma_{eff}B_0^2\overline{U}^2,\end{aligned} \tag{7}$$

$$\left(\frac{\partial}{\partial \bar{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)\overline{\alpha} = D_A\left(\frac{\partial^2}{\partial\overline{X}^2} + \frac{\partial^2}{\partial\overline{Y}^2}\right)\overline{\alpha} - k_c\overline{\alpha}\overline{\beta}^2, \tag{8}$$

$$\left(\frac{\partial}{\partial \bar{t}} + \overline{U}\frac{\partial}{\partial\overline{X}} + \overline{V}\frac{\partial}{\partial\overline{Y}}\right)\overline{\beta} = D_B\left(\frac{\partial^2}{\partial\overline{X}^2} + \frac{\partial^2}{\partial\overline{Y}^2}\right)\overline{\beta} + k_c\overline{\alpha}\overline{\beta}^2, \tag{9}$$

$$\begin{aligned}&\rho_{eff} = \rho_f(1-\phi) + \rho_p\phi, (\rho C)_{eff} = (1-\phi)(\rho C)_f\\ &\quad+\phi(\rho C)_p, \mu_{eff} = \frac{\mu_f}{(1-\phi)^{2.5}},\\ &(\rho\beta)_{eff} = (1-\phi)\beta_f\rho_f + \phi\beta_p\rho_p, \frac{\sigma_{eff}}{\sigma_f} = 1 + \frac{3\left(\frac{\sigma_p}{\sigma_f} - 1\right)\phi}{\left(\frac{\sigma_p}{\sigma_f} + 2\right) - \left(\frac{\sigma_p}{\sigma_f} - 1\right)\phi},\end{aligned} \tag{10}$$

where ρ, C, μ, β, σ and ϕ are the density, specific heat, dynamic viscosity, thermal expansion coefficient, electrical conductivity, and nanoparticle volume fraction respectively. The subscripts p and f are used to differentiate the nanoparticle and fluid phase quantities respectively. The numerical values of these quantities are given in Table 1.

Defining

$$\begin{aligned}&x = \frac{\overline{X}}{\lambda}, t = \frac{c\bar{t}}{\lambda}, a = \frac{a_1}{d}, b = \frac{a_2}{d}, y = \frac{\overline{Y}}{d}, u = \frac{\overline{U}}{c}, v = \frac{\overline{V}}{c\delta}, h_1 = \frac{\overline{H}_1}{d}, h_2 = \frac{\overline{H}_2}{d},\\ &\delta = \frac{d}{\lambda}, p = \frac{d^2\bar{p}}{c\mu_f\lambda}, v = \frac{\mu_f}{\rho_f}, Re = \frac{\rho_f cd}{\mu_f}, k = \frac{k_1}{d^2}, M = \sqrt{\left(\frac{\sigma_f}{\mu_f}\right)}B_0 d, Pr = \frac{\mu_f C_f}{\kappa_f},\\ &Br = Pr\,Ec, \varepsilon = \frac{d^2\Phi}{\kappa_f(T_1 - T_0)}, Ec = \frac{c^2}{C_f(T_1 - T_0)}, \theta = \frac{T - T_m}{T_1 - T_0}, Gr = \frac{\rho_f g\beta_f(T_1 - T_0)d^2}{\mu_f C},\\ &K = \frac{k_c\alpha_0^2 d^2}{\upsilon}, K_s = \frac{k_s d}{D_A},\end{aligned} \tag{11}$$

where θ depicts the dimensionless temperature, δ the wave number, p the pressure, v the kinematic viscosity, Re the Reynolds number, k the porosity parameter, M the Hartman number, Pr the Prandtl number, Br the Brinkman number, ε the source/sink parameter, Ec the Eckert number, Gr the Grashof number, K and K_s the strength measuring parameters for homogeneous and heterogeneous reactions respectively. The velocity component in terms of stream function and the concentrations $\overline{\alpha}$ and $\overline{\beta}$ for the species A and B in dimensionless form respectively are

$$u = \frac{\partial\psi}{\partial y}, v = -\frac{\partial\psi}{\partial x}, f = \frac{\overline{\alpha}}{\alpha_0}, g = \frac{\overline{\beta}}{\alpha_0}. \tag{12}$$

Eq. (4) is satisfied identically and other expressions after long wavelength and small Reynolds number yield [39–42]:

$$\begin{aligned}\frac{\partial p}{\partial x} &= \frac{1}{(1-\phi)^{2.5}}\frac{\partial^3\psi}{\partial y^3} - \left(\frac{1}{(1-\phi)^{2.5}k} + \frac{\sigma_{eff}}{\sigma_f}M^2\right)\left(\frac{\partial\psi}{\partial y}\right)\\ &+ Gr\left(1 - \phi + \phi\left(\frac{(\rho\beta)_p}{(\rho\beta)_f}\right)\right)\theta,\end{aligned} \tag{13}$$

$$\frac{\partial p}{\partial y} = 0, \tag{14}$$