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Combined effects of magnetohydrodynamic and temperature dependent viscosity on peristaltic flow of Jeffrey nanofluid through a porous medium: Applications to oil refinement

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ABSTRACT

Viscosity is an essential parameter of fluid physical properties for assaying the heat transfer when designing a nanofluid system. For this purpose, this article investigates the effect of temperature dependent viscosity on the peristaltic flow of Jeffrey nanofluid in an asymmetric channel. For peristaltic literature, this model is progressed for the first time. This model of nonlinear partial differential equation is reformulated under the assumption of long wavelength and low Renolds number, and solved semi-analytically with the aid of multi-step differential transform method (Ms-DTM). Semi-analytical solutions have been evaluated for the pressure gradient as well as the distributions of velocity, temperature and nanoparticles concentration. Moreover, numerical integration is also operated to assess the expressions for pressure rise. Two cases of temperature dependent viscosity are deliberated. Case (I), all non-dimensional parameters that are functions of viscosity, have been regarded as constant within the flow. Case (II), these acknowledged parameters are then supposed to vary with temperature. We have made a detailed comparison between the two cases, and unrealistic results have been found, although case (II) accepts the experimental results. Excellent agreements are found between the semi-analytical results of the present paper and the existing published results, by taking $(\beta = 0)$ and $Da = \infty$. In case (II), decrement in variable viscosity parameter β cause to enlarge the temperature of fluid. As the molecules of oil, the increase in temperature acquire it more energy and make them moves more freely, which is the main idea of crude oil refinement, where crude oil is converted and refined into more desirable products such as petroleum naphtha, gasoline, kerosene and heating oil.

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Nomenclature

B_0	applied magnetic field $(\mathrm{kg\,s^{-2}\,A^{-1}})$
Cp	specific heat at constant pressure $(\mathrm{J\,kg^{-1}\,K^{-1}})$
g	acceleration due to gravity $(\mathrm{ms^{-1}})$
Dm	molecular diffusivity $(\mathrm{m^{-2}\,s^{-1}})$
u, v	dimensional fluid velocities in the x- and y-direction respectively $(\mathrm{ms^{-1}})$
k_1	permeability of the porous medium
p	pressure of the fluid
c_p	specific heat
D_B	Brownian motion coefficient
D_T	thermophoretic diffusion coefficient
T	temperature (K)
T_m	mean temperature (K)
T_1, T_0	temperature at walls (K)
C	concentration
C_1, C_0	concentration at walls
S	extra stress tensor
D_a	Darcy number
E_c	Eckert number

Greek symbols

α	thermal diffusivity $(\mathrm{m^2\,s^{-1}})$
γ	volume expansion coefficient
σ	electrical conductivity of the fluid $(\mathrm{m^{-3}\,kg^{-1}\,s^3\,A^2})$
τ	ratio of effective heat capacity of the nanoparticle material to heat capacity of the fluid respectively
δ	dimensionless wave number
μ_0	dynamic viscosity
β	viscosity variation parameter
λ_1	ratio of relaxation to retardation times
λ_2	retardation time
$\dot{\gamma}$	shear rate and dots over the quantities indicate differentiation with regard to time
ψ	stream function $(\mathrm{m^2\,s^{-1}})$
θ	dimensionless temperature
φ	dimensionless concentration
ρ_f	density of the fluid $(\mathrm{kg\,m^{-1}})$
ϕ	phase difference

1. Introduction

Petroleum purification or oil refinement is an industrial process plant where crude oil is converted and refined into more desirable products such as gasoline, petroleum naphtha, asphalt base, diesel fuel, heating oil, kerosene, liquefied petroleum gas and fuel oils. Refineries of petroleum should have vacuum distillation units to get more products that are useful. In addition to thermal fracturing units such as viscosity breakers, units to lower the viscosity of the oil, which is named by visa breakers, see Refs. [1,2] (see Fig. 1).

Nanofluids are innovatively engineered materials having incalculable applications in medical science, biology, engineering, etc. These fluids are actually suspensions of nanometer sized metallic particles in orthodox liquids. Suspension of such particles enhances the thermo-physical properties (e.g. **viscosity**, density and specific heat) of base fluids. Due to unique chemical and mechanical properties, such fluids are easily being adopted in various industries to facilitate heat transfer process. Nanofluids have applications in biomedical engineering, nuclear reactors, domestic cooling, automobile, etc. [3,4]. Subject to such wide use of nanofluids, different researchers have analyzed such flows under various aspects [5–8] (see Table 1).

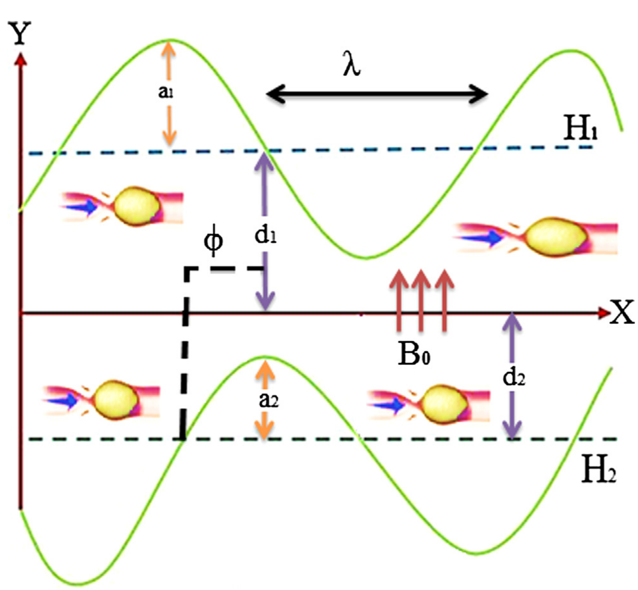

Fig. 1. Geometry of the physical model.

Peristaltic pumping is a form of material transport induced by the propagation of waves along the flexible walls of channel/tube. This mechanism has attracted the interest of many researchers as it models, many fluid transport processes encountered in physiological and bioengineering sciences. In the human body, peristalsis could be visualized in moving of bile from gall bladder, transporting urine through the urethras, chyme transport via gastrointestinal tract (GIT), into the transportation of spermatozoa from the epididymis to the urethra through the vast differences. In Industry, this transportation could be generated by the aid of a peristaltic pump, which consists of a flexible tube and a rotor with a number of rollers that compress on the liquid through the pump and directing it to the final destination. Hayat et al. [9] studied the influence of slip on the peristaltic motion of a third order fluid in an asymmetric channel. They found that the maximum pressure against which the peristalsis work as a pump decreases by increasing the slip parameter. Elshehawey et al. [10] constructed the peristaltic transport in an asymmetric channel through a porous medium. They found that the axial velocity component increases with the increase of the permeability parameter. Different researchers analyzed the peristaltic flow with various biological fluid models in disparate conditions and media [11–22].

Ellahi et al. [23] studied the effects of magneto- hydrodynamics on peristaltic flow of Jeffrey fluid in a rectangular duct through a porous medium. Bhatti et al. [24] constructed the Simultaneous effects of coagulation and variable magnetic field on peristaltically induced motion of Jeffrey nanofluid containing gyrotactic microorganism. They found that that velocity of a fluid diminishes near the walls due to the increment in the height of clot. Some relevant studies on the topic can be seen from the list of Refs. [25–27].

Fluid flows under the influence of applied magnetic field are apparent in certain engineering processes like crude oil refinement, glass manufacturing and in some geophysical studies. MHD peristaltic flow through a porous space with compliant walls was discussed by Srinivas et al. [28]. The influence magnetic field on peristaltic transport of a Newtonian fluid in a vertical annulus with application of an endoscope is debated by Mekheimer et al. [29]. Ellahi et al. [30] have studied the Analytical solution for MHD flow in a third grade fluid with variable viscosity. In another paper, the influence of Magnetohydrodynamic on peristaltic trans-