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Effects of thermal radiation parameter and magnetic field on the peristaltic motion of Williamson nanofluids in a tapered asymmetric channel

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ABSTRACT

This paper deals with a theoretical investigation of the peristaltic transport of a Williamson nanofluid in a tapered asymmetric channel under the action of a thermal radiation parameter. In general, the nanofluids are electrically conducting nature. A model of wall-induced fluid flow within an infinite tapered channel has been developed to simulate the transport phenomena due to asymmetric wall displacements. This problem has plentiful applications. Moreover, it may serve as a model for the intrauterine fluid motion in a sagittal cross-section of the uterus under cancer therapy and drug analysis. The analytical solution has been obtained for the temperature and concentration of the nanofluid. The expressions for the axial velocity, stream function and pressure gradient were also obtained by a regular perturbation technique. Numerical computations have been performed for the pressure rise and the effect of various emerging parameters on the flow characteristics are shown and discussed with the help of graphs. The numerical results shown that the trapped bolus was increased in size and more trapped bolus were also occurred near the right wall with increasing Weissenberg number and thermophoresis parameter but that got decreased for large values of local temperature Grashof number.

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1. Introduction

Numerous applications of nanofluids in engineering and industry have led to renewed interest among the researchers. Such applications include biological organisms on their primary cellular level, snapping shrimps and super-hydrophobic beetle wings, photodynamic therapy, use of charged polymers for lubrication, the lotus effect for self-cleaning surfaces, molecular motors, neuro electronic interfaces, membranes for filtering on size or charge (e.g. for desalination), nanoporous materials for size exclusion chromatography, cancer diagnosis and therapy, drug delivery, neuro electronic interfaces, cell repair machines, protein engineering, shedding new light on cells molecular motors like kinesis and charge based filtration in the kidney basal membrane etc., [1]. The term nanofluid was first developed by Choi [2] which refers to a conventional heat transfer fluid holding a distribution of nanosize particle. Further, it represents a liquid suspension containing ultrafine particles having diameters less than 50 nm and these particles could be discovered in the metals such as (Al, Cu), oxides (Al_2O_2), carbides (SiC), nitrides (SiN) or nonmetals (Graphite, carbon nanotubes, nanofiers, nanosheets, droplets). Masuda et al. [3] have investigated a characteristic feature of thermal conductivity enhancement, which indicates the possibility of using nanofluids in advanced nuclear systems. Keeping in view of a study on nanofluids flow, an analytical model for convective transport in nanofluids considering the Brownian diffusion and thermophoresis was carried out by Buongiorno [4,5]. Finally, he showed that Brownian diffusion and thermophoresis were the most important nanoparticle/base-fluid slip mechanisms and an explanation for abnormal convective heat transfer enhancement has also been studied in nanofluids.

In the recent times, the peristaltic flow analysis of nanofluids has been the topic of extensive research due to increase in thermal conductivity for heat transfer process. Owing to many applications in real life, such as the embryo transfer within the uterine cavity, where physiologists discovered that the intrauterine nanofluid flow as a result of myometrial contractions is peristaltic type motion. Akram et al. [6] viewed the peristaltic flow of a nanofluid in an asymmetric channel. Akbar and Nadeem [7] considered the peristaltic flow of a nanofluid in an endoscope. Also, the influence

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Nomenclature

a_1, a_2	dimensional amplitudes of right and left of the walls respectively
B_0	uniform applied magnetic field strength
Br	local nanoparticle Grashof number
c'	volumetric volume expansion coefficient
c	wave speed
C	dimensional nanoparticle volume fraction
C_0, C_1	nanoparticle volume fractions at the right and left walls respectively
D_B	Brownian diffusion coefficient
D_T	themophoretic diffusion coefficient
g	acceleration due to gravity
Gr	local temperature Grashof number
k^*	mean absorption coefficient
M	Hartmann number
m, m'	non-uniform parameters
Nb	Brownian motion parameter
Nt	thermophoresis parameter
P, p	dimensionless and dimensional pressure of the fluid respectively
Pr	Prandtl number
q_r	theradiative heat flux
R	Reynolds number
Rn	thermal radiation parameter
S	Cauchy stress tensor
t', t	dimensional and dimensionless time respectively
T	dimensional nanoparticle temperature
T_0, T_1	temperature at the right and left walls respectively
T_m	fluid mean temperature
U, V	dimensional velocity components in X, Y-directions respectively
u, v	dimensionless velocity components along the transformed coordinates system x, y respectively
We	Weissenberg number

Greek Symbol

θ	dimensionless temperature
κ	permeable parameter
σ'	electrical conductivity of the fluid
σ	dimensionless rescaled nanoparticle volume fraction
δ	wave number
τ	nanofluid kinematic viscosity
λ	wavelength
ϕ	phase difference
$(\rho c')_f$	heat capacity of base fluid
$(\rho c')_p$	effective heat capacity of the nanoparticles material
μ_∞	infinite shear rate viscosity
μ_0	zero shear rate viscosity
σ^*	Stefan–Boltzmann constant and
τ_{xy}	non-dimensional shear stress
Θ	dimensionless time average flux

of nanofluid characteristics on peristaltic heat transfer in a two dimensional axisymmetric channel investigated by Tripathi and Beg [8]. Mustafa et al. [9] concerned with the peristaltic transport of nanofluid in a channel with complaint walls.

The revision of the interaction of the pressure rise with the Magnetohydrodynamics (MHD) is one of the most significant factors. MHD is the science which deals with the motion of a highly conducting fluid in the presence of a magnetic field. The MHD flow of nanofluids in a channel with peristalsis is of interest in connection with certain problems of the movement of conductive physiological nanofluids, e.g., the study of geothermal sources, the treatment of nuclear fuel debris, the control of underground spreading of chemical wastes and pollution, design of MHD power generators, cancer tumor treatment causing hyperthermia, bleeding reduction during surgeries and targeted transport of drug using magnetic particles as drug carriers, blood pump machines and with the need for theoretical research on the operation of a peristaltic MHD compressor. In particular, Magnetic nanoparticles were injected into the tumor and then heated in an alternating magnetic field are discussed by Landeghem et al. [10]. The components of human tissue are most diamagnetic (very low magnetic susceptibility) and so magnetic influences are generally insignificant. Nevertheless, application of an electromagnetic induction field will cause eddy currents in any conducting medium, including biological tissue [11,12]. The MHD peristaltic flow of a Carreau nanofluid in an asymmetric channel was studied by Akbar et al. [13]. It is observed that the pressure rise increases with increase in Hartmann number and thermophoresis parameter. The drug absorption due to high concentration of the magnetic particles increases and magnetic force prevents uniform drug distribution in the circulatory system are discussed by Habibi et al. [14]. The cancer's tissues are destroyed if the temperature reaches 42–45 °C is discovered by Pankhurst et al. [15]. In general, the cancerous cells have a higher chance to die when the temperature is above 43 °C, on the other hand healthy cells will be safe and sound at this temperature [16,17].

Heat transfer and flow field in a wavy channel with nanofluid is numerically studied by Heidary and Kermani [18]. The boundary flow and heat transfer over a permeable stretching street due to a nanofluid with the effects of magnetic field, slip boundary condition and thermal radiation were investigated by Ibrahim and Shankar [19]. The total entropy generation minimization of nanofluid MHD flow through a two parallel isothermal plate's channel with thermal radiation flux included is considered by Matin et al. [20]. The peristaltic flow of an incompressible viscous fluid containing metallic nanoparticles in an irregular conduit is analyzed by Akbar [21]. The significance of nanofluid and partial slip on the peristaltic transport of a Jeffrey fluid model in an asymmetric channel with different wave forms was discussed by Safia Akram and Nadeem [22]. More recently, double-diffusive natural convective peristaltic flow of a Jeffrey nanofluid in a two-dimensional porous asymmetric channel has been carried out by Akbar [23]. A comprehensive review of the literature about nanofluids is given by references [24–33].

The Williamson nanofluids model is an example of a viscoelastic shear-thinning fluid and has been shown to accurately represent the behavior of a diverse variety of pseudoplastic liquids. Williamson fluids exhibit a decrease in viscosity with increasing rate of shear stress. Many biophysical and physiological fluids exhibit shear-thinning characteristics e.g. gastro-intestinal fluids and blood suspension [34,35]. During the cancer treatment, one of the successful methods is to inject the blood vessels which closest to the tumor with magnetic nanoparticles along with placing a magnet nearer to the tumor. This will be allowed doctors to suggest high local doses of drugs without damaging nearby healthy tissue, which may be a significant side consequence of traditional cancer treatment methods [36,37]. Owing to mathematical study, the peristaltic flow of a Williamson nanofluid in an asymmetric channel has been presented by Akbar et al. [38].

Recently, Physiologists considered that the intrauterine fluid flow due to myometrial contractions is peristaltic- type motion and the myometrial contractions may arise in both symmetric

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