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On effects of thermal radiation and radial magnetic field for peristalsis of sutterby liquid in a curved channel with wall properties

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ABSTRACT

A study is carried out to examine the peristaltic flow of Sutterby fluid in curved channel. The magnetic field is applied in radial direction. Magnetic Reynolds number is taken small. Viscous dissipation and thermal radiation effects are used to model energy equation. Lubrication approach is applied for the problem simplification. Solutions for stream function (ψ), velocity (u) and temperature (θ) for fluid parameter β have been derived. The results of velocity are analyzed graphically. The impacts of physical parameters on pumping and trapping are also explained in detail. The study discusses that velocity becomes symmetric about the central line for larger values of curvature parameter k.

1. Introduction

Rhythmic muscular contraction and relaxing movement that helps in the transportation of fluid in most physiological systems is termed as peristalsis. Such mechanism is seen in the movement of ingested food bolus along esophagus towards stomach, transportation of urine from kidney to bladder, blood circulation in small vessels, chyme transport in the gastrointestinal tract, locomotion of worms, bile in the duct, vasomotion of small blood vessels, spermatozoa movement in the ducts efferentes, ovum movement in the female fallopian tube, lymph transport in lymphatic vessels etc. Biomedical and industrial applications of peristalsis include the functioning of heart lung machine during bypass surgeries, cell separators, safe drainage of hazardous liquids in nuclear industry, roller and finger pumps etc. Thus extensive theoretical and experimental attempts have been done to understand the peristaltic action under various conditions after the initial attempts of Latham [1] and Shapiro et al. [2]. These studies are made in particular for different cases of Newtonian/non-Newtonian fluids subjected to different aspects (see refs. [3–17]).

Magnetic field has gained considerable importance due to its widespread applications in industry and bioengineering. An externally applied magnetic field introduces the electromagnetic force on the flowing fluid. These electromagnetic forces have considerable effect on the flow configuration. These situations are important in bleeding reduction in the case of severe injuries, hyperthermia, cancer therapy etc. The principle of magnetic field is successfully applied to magnetic resonance

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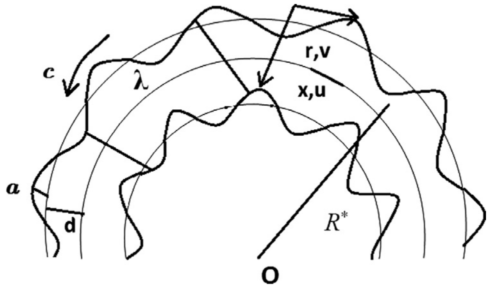

Fig. 1. Problem geometry.

imaging (MRI) when a patient goes in a high static magnetic field. In connection to peristalsis, MHD flows in a channel is of great interest when dealing with the problems involving the movement of conductive physiological fluids like blood, blood pump machines and experimental as well as theoretical investigations on the operation of peristaltic MHD compressor. Moreover when the shear rate of blood flow is below $100S^{-1}$ then it represents a mathematical model of peristaltic magnetohydrodynamic flows in the coronary arteries. Giant Magneto Resistive (GMR) technology is a device that applies magnetic field using very sensitive sensor to detect small movements of object within the magnetic field. Other applications of MHD include electrostatic precipitation, MHD generators, polymer technology, drug injection and MHD pumps etc. Considering such aspects of MHD Abbasi et al. [18] developed a mathematical model for peristaltic transport of MHD fluid by considering a variable viscosity. Ellahi and Hussain [19] discussed the combined effects of MHD and partial slip on peristalsis of Jeffery liquid in a rectangular duct. Sinha et al. [20] made a theoretical study describing MHD peristaltic flow in an asymmetric channel with slip conditions. Few other relevant attempts in this direction can be seen by the studies [21–27].

Heat transfer play a vital role in cooling processes of industries and medical applications. It usually takes place between bodies of varying temperature. Several processes rely on heat transfer and corresponding thermal coefficients. These include distillation, crystallization and other boiling operations. Hyperthermia, laser therapy and cryosurgery are most advance means to destroy undesirable tissues like cancer. Bolus transport in gastrointestinal tract is greatly effected by heat transfer. Hyperthermia, blood pump in heart lung machine and laser therapy are some more applications of heat transfer. It also helps in getting information about the properties of tissues inside human body. Viscous dissipation resulting from the internal friction caused by shear in the flow produces heat in the flow and hence cannot be ignored. Recent developments in analytical and computational tools have directed the attention towards thermal convection flows with significant radiative flux. The rate of energy transfer between two points in numerous conductive and convective processes strongly depend on temperature difference at the location. However, the transfer rate of energy due to thermal radiation between two bodies is dependent upon the absolute temperature difference. It is well established fact that the importance of radiation is intensified when the absolute temperature is very high. One cannot ignore importance of radiative heat transfer as it plays vital role in industries for designing reliable equipment, nuclear plants, gas turbines and various propulsion devices for aircraft, missiles, satellites and space vehicles. Also thermal radiation effects in forced and free convective flows cannot be neglected while dealing with space technology and high temperature processes. In addition, thermal radiation therapy gained special attention in the treatment of diseases like tissue coagulation, liver cancer, lung cancer and stomach acid reflux. Some studies on peristalsis involving thermal radiation/magnetic field effects can be seen through refs. [28–39]. Modern concepts of heat transfer can be highlighted via studies [40–45].

In all of the above mentioned studies, no attention is given to the peristaltic transport of Sutterby fluid in a curved geometry. Flows in curved geometry are encountered in many domestic and industrial piping system, human and animal physiology and in heating and cooling systems. Also the presence of radial magnetic field with thermal radiation is not given proper attention. Thus our intention here is to model and analyze the peristaltic transport of Sutterby fluid in a curved channel with flexible walls. Fluid is electrically conducting in presence of radial applied magnetic field. Radiative heat flux is used to model the problem. Resulting system is then simplified using lubrication approach. Perturbation technique is implemented for the solution. Results are displayed and discussed graphically.

2. Formulation

Let us consider an incompressible flow of Sutterby fluid in a curved channel of width $2d$. The walls of the channel are flexible in nature. The channel is coiled in a circle with radius of curvature R^* and centre O. The schematic diagram of the problem is illustrated in Fig. 1. A radial magnetic field $\mathbf{B} = (\frac{Bo}{r+R^*}, 0, 0)$ is applied while induced magnetic field is neglected due to small magnetic Reynolds number. Furthermore the electric field effect is not considered. A curvilinear coordinate system (r, x) is used for analyzing the flow in which r is taken along radial direction and x is along the axial direction.

The sinusoidal wave shapes along the walls are defined in the form

$$r = \pm\eta(x, t) = \pm\left[d + a\sin\frac{2\pi}{\lambda}(x - ct)\right], \tag{1}$$