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Effects of slip and convective conditions on the peristaltic flow of couple stress fluid in an asymmetric channel through porous medium

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A R T I C L E I N F O

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A B S T R A C T

Background: Assessment of the fluid flow pattern in a non-pregnant uterus is important for understanding embryo transport in the uterus. Fertilization occurs in the fallopian tube and the embryo enters the uterine cavity within three days of ovulation. In the uterus, the embryo is conveyed by the uterine fluid for another three to four days to a successful implantation site at the upper part of the uterus. The movements of fluid within the uterus may be induced by several mechanisms, but they seem to be dominated by myometrial contractions. The intrauterine fluid flow due to these myometrial contractions is peristaltic type motion in nature and the myometrial contractions may occur in both symmetric and asymmetric directions.

Objective: The aim of the present article is to investigate the peristaltic transport of couple stress fluid in an asymmetric channel. The channel asymmetry is produced by choosing the peristaltic wave train on the walls to have different wave amplitudes and phase differences. The fluid is filled with a homogeneous porous medium. The effects of slip and convective boundary conditions are also taken into consideration.

Method: The flow is investigated in the wave frame of reference moving with constant velocity with the wave. Long wavelength and low Reynolds number approximations are utilized in problem formulation. Exact solutions are presented for the stream function, pressure gradient and temperature.

Results: The graphical analysis is carried out to examine the effects of sundry parameters on flow quantities of interest. Comparative study is also made for couple stress fluid with Newtonian fluid.

Conclusions: The results revealed that the trapping fluid can be increased and the central line axial velocity can be raised to a considerable extent by increasing Darcy number. Increasing of slip parameter increases the velocity near the boundary of the walls and Brinkman number increases the temperature of the fluid.

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1. Introduction

Peristalsis is a natural mechanism of pumping that is observed in the case of most physiological fluids. This behavior is usually associated with a progressive wave of area contraction and expansion along the length of the boundary of a fluid filled distensible tube/channel. The need for peristaltic pumping may arise in circumstances where it is desirable to avoid using any internal moving parts such as pistons in a pumping process. Such pumping generally takes place from a region of lower pressure to higher pressure. In physiology, it is an inherent property of many of the smooth muscle tubes occurring in the gastrointestinal tract, in the vasomotion of small blood vessels, spermatozoa transport in the ductus efferents of the male reproductive tracts and ovum movement in the female fallopian tube. This mechanism is also involved in plant physiology which is useful in phloem translocation by driving a sucrose solution along tubules by peristaltic contractions. This phenomenon is also applied in the propulsion of some industrial fluids. This mechanism is also used in many biomedical appliances, such as finger pumps, heart-lung machine, blood pump machine, dialysis machine. This analysis was first introduced by Latham [1]. He performed several theoretical and experimental investigations to understand the phenomenon of peristalsis in the ureteral functions. After Latham's pioneering works, Shapiro [2] and Fung and Yih [3] have described biologically and medically important phenomenon of reflux. Vesicoureteral reflux (VUR) is the backward flow of urine from the bladder into the kidneys. The muscles of the bladder and ureters along with the pressure of urine in the bladder prevent urine from flowing backward through the ureters. Due to this reason, urine normally flows from the kidneys to the bladder. VUR allows bacteria, which may be present in the urine inside the bladder, to reach the kidneys. This can lead to kidney infection, scarring and damage. In the context of in vitro fertilization (IVF), Eytan et al. [4] have suggested that the fluid mechanical phenomenon of reflux is the cause of unsuccessful embryo implantation in women who suffer from hydrosalpinx, a tubal pathology that causes accumulation of fluid in the oviduct. Later on a number of analytical, numerical and experimental studies on the peristaltic flows with different fluids have been reported under different conditions with reference to physiological and mechanical situations. It is noted that much attention is given to the study of peristaltic motion of Newtonian fluid in channels and tubes though these studies are further narrowed down when non-Newtonian fluids are considered. The importance of the peristaltic motion in an asymmetric channel was firstly pointed out by Eytan and Elad [5]. Such consideration is of great value regarding an application in the intra uterine fluid flow in a non-pregnant uterus. Afterwards, many attempts have been made for the peristaltic transport in an asymmetric channel. One may look at the relevant investigations in this direction in the references [6–10] and many relevant studies therein.

Consideration of porosity is very much necessary to properly explain the fluid dynamical process that occurs in different parts of the body, such as vascular beds, lungs, kidneys and tumorous vessels. In many bio-mechanical studies, porosity of the media has significant influence on the transport of fluids. This applies more particularly to vessels impeded by clots, highly perfused skeletal tissues, tumors and soft connecting tissues. Porous medium is also applicable to the peristaltic transport of blood in coronary arteries of smaller dimensions in the pathological state, when the lumen of the segment of a small blood vessel turns into a porous medium due to the presence of numerous blood clots, or when arterial clogging takes place by deposition of fatty plaques of cholesterol in the arterial lumen, and also in cases where numerous tumors are grown inside the lumen due to excessive cell division. In the realm of physiological fluid dynamics, in many situations it is required to have an estimate of a variety of fluid mechanical variables when some physiological fluid has to pass through porous structures. The study of porous medium also has an important bearing in examining the flow in a vessel when the luminal surface of endothelial layer is attached with glycocalyx, which contains a series of micro-molecules and adsorbed plasma proteins [11]. In view of these applications in mind, many authors have studied the peristaltic flows through porous medium. For instance, Abd elmaboud and Mekheimer [12] have investigated the peristaltic motion of a second-order fluid through a porous medium in the case of a planar channel using the perturbation method. Tripathi and Beg [13] have studied numerically on oscillating peristaltic flow of generalized Maxwell fluid through a porous medium in a planar channel using homotopy perturbation method. Alsaedi et al. [14] have presented the exact solution for the peristaltic motion of couple stress fluid through a uniform porous medium in a symmetric channel under the large wavelength and low Reynolds number approximations.

Recently, the researchers have shown their considerable interest in the channel flows with heat transfer because of widespread applications in the biomedical sciences and industries. This is because of the significance that cooling is one of the technical challenges faced in many industries. It is now known that many conventional fluids like water, ethylene glycol and engine oil have limited capabilities in terms of thermal properties, which, in turn, may impose restrictions in several thermal processes. Most solids, in particular metals, have one to three times higher thermal conductivities in comparison to the conventional fluids. The fluids consisting of solid particles are very effective to enhance their thermal conductivities [15]. The applications including destruction of undesirable tissues, laser therapy, cryosurgery, cancer tumor treatment and hyperthermia through bio-heat transfer are crucial in this direction [16]. In particular, the thermodynamic aspects of blood are useful in oxygenation and hemodialysis processes. Moreover, the interaction of peristalsis is important in the metabolic processes involved in food digestion, heat conduction in tissues, and heat transfer due to the perfusion of arteriovenous blood [17]. The industrial applications include sanitary fluid transport and transport of corrosive materials. The blood flow rate can also be approximated by a technique in which heat is produced locally or injected and the thermal clearance is monitored. While blood flows through the arterial tree, blood carries a large quantity of heat to different parts of the body. On the skin surface, the transfer of heat can take place by any of the four processes: radiation, evaporation, conduction and convection. It may further be mentioned that blood flow is enhanced when a man performs hard physical work and also when the body is exposed