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Effect of magnetic field on peristaltic flow of a fourth grade fluid in a tapered asymmetric channel

M. Kothandapani [a,*], **V. Pushparaj** [b], **J. Prakash** [c]

[a] *Department of Mathematics, University College of Engineering Arni (A Constituent College of Anna University Chennai), Arni 632 326, Tamil Nadu, India*
[b] *Department of Mathematics, C. Abdul Hakeem College of Engineering and Technology, Melvisharam 632 509, Tamil Nadu, India*
[c] *Department of Mathematics, Arulmigu Meenakshi Amman College of Engineering, Vadamavandal 604 410, Tamil Nadu, India*

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Abstract The problem of peristaltic transport of an incompressible non-Newtonian fluid in a tapered asymmetric channel is debated under long-wavelength and low-Reynolds number assumptions. The fluid is considered to be fourth order and electrically conducting by a transverse magnetic field. The tapered asymmetry in the flow is induced by taking peristaltic wave imposed on the non uniform boundary walls to possess different amplitudes and phase. Series solutions for stream function, axial velocity and pressure gradient are given using regular perturbation technique, when Deborah number is small. Numerical computations have been performed for the pressure rise per wavelength. Influences of different physical parameters entering into the problem have also been discussed in detail.

1. Introduction

Peristaltic transport is a form of material transport induced by a progressive wave of contraction or expansion along the length of a distensible tube, mixing and transporting the fluid in the direction of the wave propagation. This kind of phenomenon is termed as peristalsis. It plays an indispensable role in transporting many physiological fluids in the body under various situations as urine transport form kidney to bladder, the movement of chyme in the gastrointestinal tracts, transport of spermatozoa in the ductus efferentes of the male reproductive tract, movement of ovum in the fallopian tubes, swallowing of food through esophagus and the vasomotion of small blood vessels. Many modern mechanical devices have been designed on the principle of peristaltic pumping to transport the fluids without internal moving parts. For example, the blood pump in the heart- lung machine and peristaltic transport of noxious fluid in nuclear industry. The mechanism of peristaltic transport has attracted the attention of many investigators since its investigation by Latham (1966), a number of analytical, numerical and experimental studies (Burns and Pareks, 1967; Shapiro et al., 1969; Fung and Yih, 1968; Shapiro et al., 1969; Takabatake and Ayukawa, 1982; Akram and Nadeem, 2013; Mekheimer and El Kot, 2008;

* Corresponding author. Tel./fax: +91 4173 244400.
E-mail address: mkothandapani@gmail.com (M. Kothandapani).
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Mekheimer and Al-Arabi, 2003; Mekheimer, 2003; Nadeem and Akbar, 2010; Kothandapani et al., 2015a) of peristaltic flow for different fluids have been reported under various conditions with reference to physiological and mechanical situations. Most of these investigations are confined to the peristaltic flow only in a symmetric channel or tube.

Recently, physiologists observed that the intra-uterine fluid flow due to myometrial contractions is peristaltic type motion and the myometrial contractions may occur in both symmetric and asymmetric directions. Eytan and Elad (1999) have established a mathematical model of wall induced peristaltic fluid flow in a two-dimensional channel with wave strains having a phase difference, moving independently on the upper and lower walls to stimulate intra-uterine fluid motion in a sagittal cross-section of the uterus. In another work, Eytan et al. (1999) pointed out that the width of the sagittal cross-section of the uterine cavity increases toward the fundus and the cavity is not fully occluded during the contractions. Pozrikidis (1987) has extensively studied the streamline pattern and mean flow rate due to different amplitudes and phases of the wall deformation. Mishra and Ramachandra Rao (2003) have discussed the peristaltic motion of viscous fluid in a two-dimensional asymmetric channel under assumptions of long-wavelength and low-Reynolds number in a wave frame of reference. Followed by the above works exhaustive studies have been made by many authors in the domain (Kothandapani and Srinivas, 2008a,b; Siddiqui and Schwarz, 1993; Hayat et al., 2003; El Hakeem et al., 2006; Hayat and Ali, 2006;Srinivas and Kothandapani, 2008). Moreover, Srinivas and Pushparaj (2007) have investigated the peristaltic pumping of MHD gravity flow of a viscous incompressible fluid in a two-dimensional asymmetric channel having electrically insulated walls.

It is well-known that the flow phenomena of non-Newtonian fluids arise in various Engineering, industrial and technological applications. In view of different physical structure and behavior of non-Newtonian fluids, there is no single mathematical expression which describes all the characteristics of non-Newtonian fluids. Hence, several mathematical models of non-Newtonian fluids such as micropolar fluid, power-law fluids, viscoelastic fluids etc. were developed by researchers. Moreover, the formulation of a constitutive equation of non-Newtonian fluids is greatly higher-order nonlinear and complex in nature. Among the differential-type non-Newtonian fluid models, the most generalized model is fourth grade fluid model which represents most of the non-Newtonian flow properties at one time. One of the important features of fourth grade fluid is capable to exhibit normal stress differences in simple shear flows, leading to characteristic phenomena such as rod-climbing or die-swell. The main aim of this work is to analyze a tapered asymmetric wall-induced peristaltic motion of a fourth grade fluid with the presence of a uniform magnetic field. Mention in this contest to some recent interesting analytical, experimental and review studies pertaining to non-Newtonian fluids which may give valuable insights into their behaviour (Haynes, 1960; Joseph, 1980; Srivastava et al., 1983; Renardy, 1988; Vajravelu et al., 2013; Akram et al., 2013;Nadeem et al., 2014a,b; Riaz et al., 2014a,b; Umavathi and Mohite, 2014; Oahimire and Olajuwon, 2014; Kothandapani and Prakash, 2015b). Further, Haroun (2007) has also analyzed the problem of non-linear peristaltic flow of a fourth-grade fluid in an inclined channel. Moreover, Ali and Hayat (2007) have developed a mathematical model for the flow of an incompressible Carreau fluid in an asymmetric channel using a perturbation technique for a small Weissenberg number. Radhakrishnamacharya and Radhakrishna Murty (1993) discussed the problem of Heat transfer to peristaltic transport in a Non-uniform channel. Vajravelu et al. (2012) have developed a peristaltic transport of a Williamson fluid in asymmetric channels with permeable walls. They have reported a perturbation analysis with a Weissenberg number and elucidated that the pressure gradient decreases with increasing Weissenberg number.

More recently, Akram (2014) has scrutinized the effects of nanofluid on peristaltic flow of a Carreau fluid model in the presence of an inclined channel and magnetic field. The effects of permeable walls and magnetic field on the peristaltic flow of a Carreau fluid in a tapered asymmetric channel have been studied by Kothandapani et al. (2015b). The mathematical observations for the peristaltic flow of a Williamson fluid model in a cross-section of a rectangular duct having compliant walls was reported by Ellahi et al. (2013). The effects of magnetohydrodynamics on the peristaltic flow of Jeffrey fluid in a rectangular duct under the constraints of low Reynold number and long wavelength have been discussed by Bhatti et al. (2014). Khan et al. (2014) have analyzed the peristaltic motion of Oldroyd fluid in an inclined asymmetric channel by regular perturbation method. Akram et al. (2014) studied the peristaltic flow of a couple stress fluid in a non-uniform rectangular duct. Akbar et al. (2015) considered the peristaltic flow in asymmetric channel with permeable wall. In their study, the influences of induced magnetic field, heat generation, heat flux water and CNTs nanofluid have been taken into account. The influence of walls attributes on the peristaltic transport in a three dimensional rectangular channel has been analyzed by Riaz et al. (2014). Kothandapani and Prakash (2015a) have studied the influences of inclined magnetic field, heat source, thermal radiation, and chemical reactions on peristaltic flow of a Newtonian nanofluid in a vertical generalized channel. They have also noted that the temperature profile increases with an increase of the non-uniform parameter, while it decreases when the thermal radiation parameter is increased. Akram and Nadeem (2014) have discussed the influence of nanofluid on peristaltic transport of a hyperbolic tangent fluid model under the effects of inclined magnetic field.

Further, it is worthwhile to mention here that the intrauterine fluid flow in a sagittal cross - section of the uterus discloses a narrow channel enclosed by two fairly parallel walls with wave trains having different amplitudes and phase difference (Eytan et al., 2001). With the aid of sufficient literature support, a theoretical investigation on the peristaltic motion of a fourth-grade fluid in a tapered channel or non-uniform asymmetric channel is carried out. To the best of our familiarity, so far no attempt has been made to examine the MHD Peristaltic transport of the fourth-grade in the tapered asymmetric channel which may help to imitate intra-uterine fluid motion in a sagittal cross-section of the uterus. The governing equations are solved under the long-wavelength and low-Reynolds number approximations. The stream function and the pressure gradient could be expanded in perturbation series in a small material parameter. The effects of emerging parameters on the axial velocity and pressure drop could be studied and the phenomenon of trapping is also discussable.

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