Chapter-1

Introduction

1.1. Peristalsis

Peristalsis is the phenomenon in which a circumferential progressive wave of contraction or expansion (or both) propagates along a tube. If the tube is long enough, one might see several identical waves moving along the tube simultaneously. Peristalsis appears in many organisms and a variety of organs. Peristaltic mechanisms may be involved in urine transport from the kidney to the bladder through the ureter, the movement of chyme in the gastrointestinal tract, the transport of spermatozoa in the ductus efferentus of the male reproductive tract and in the cervical canal, the movement of ova in the Fallopian tubes, the transport of lymph in the lymphatic vessels, and in the vasomotion in small blood vessels. These flows also provide efficient means for sanitary fluid transport and are thus exploited in industrial peristaltic pumping and medical devices, for example, industrial applications of mechanical roller pumps using viscous fluids in the printing industry and the peristaltic transport of noxious fluid in the nuclear industry. In addition, peristaltic pumping occurs in many practical applications involving biomedical systems. Many modern medical devices have been designed on the principle of peristaltic pumping to transport fluids without internal moving parts, for example, the blood in the heart-lung machine.

1.2. Physiological Systems Associated With Peristalsis

1.2.1 Gastrointestinal Tract

Two types of movements occur in the gastrointestinal tract: (1) Propulsive movements, which cause food to move forward along the tract at an appropriate rate to accommodate digestion and absorption and (2) mixing movements, which keep the intestinal contents thoroughly mixed at all times.

Propulsive Movements:

The basic propulsive movement of the gastrointestinal tract is peristalsis, which is illustrated in Fig. 1. A contractile ring appears around the gut and then moves forward;

this is analogous to putting one's fingers around a thin distended tube, then constricting the fingers and sliding them forward along the tube. Any material in front of the contractile ring is moved forward.

Mixing Movements:

The mixing movements are quite different in different parts of the alimentary tract. In some areas, the peristaltic contractions themselves cause most of the mixing. This is especially true when forward progression of the intestinal contents is blocked by a sphincter, so that a peristaltic wave can then only churn the intestinal contents, rather than propelling them forward.

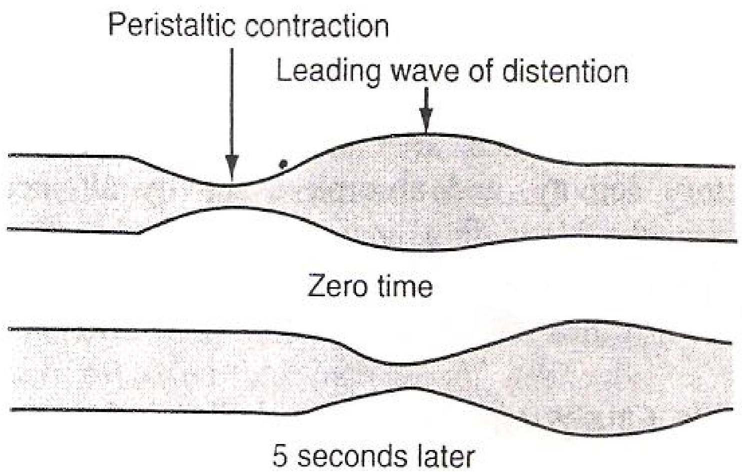

Fig. 1 Peristalsis

1.2.2 Esophagus

The esophagus normally exhibits two types of peristaltic movements: primary peristalsis and secondary peristalsis. Primary peristalsis is simply a continuation of the peristaltic wave that begins in the pharynx and spreads into the esophagus during the pharyngeal stage of swallowing. This wave passes all the way from the pharynx to the stomach in about 8 to 10 seconds. Food swallowed by a person who is in the upright position is usually transmitted to the lower end of the esophagus even more rapidly than the peristaltic wave itself, in about 5 to 8 seconds, because of the additional effect of gravity pulling the food downward. If the primary peristaltic wave fails to move into the stomach all the food that has entered the esophagus, secondary peristaltic waves result from the distention of the esophagus by the retained food, and these waves continue until all the food has emptied into the stomach. These secondary waves are initiated partly by intrinsic neural circuits in the myenteric nervous system and partly by reflexes that begin in the pharynx, then are transmitted upward through vagal afferent fibers to the medulla and then back again to the esophagus through glossopharyngeal and vagal efferent nerve fibers.

1.2.3 Small Intestine

Chyme is propelled through the small intestine by peristaltic waves. These can occur in any part of the small intestine, and they move analward at a velocity of 0.5 to 2.0 cm/sec, much faster in the proximal intestine and much slower in the terminal intestine. They normally are very weak and usually die out after travelling only 3 to 5 centimeters, very rarely farther than 10 centimeters, so that forward movement of the chyme is very slow, so slow in fact that net movement along the small intestine normally averages only 1 cm/min.

The function of the peristaltic waves in the small intestine is not only to cause progression of the chyme toward the ileocecal value but also to spread out the chyme along the intestinal mucosa. As the chyme enters the intestine from the stomach and causes initial distention of the proximal intestine, the elicited peristaltic waves begin immediately to spread the chyme along the intestine; this process intensifies as additional chyme enters the duodenum.

Peristaltic Rush

Although peristalsis in the small intestine is normally very weak, intense irritation of the intestinal mucosa, as occurs in some severe cases of infectious diarrhea, can cause both powerful and rapid peristalsis, called the peristaltic rush. This is initiated partly by nervous reflexes that involve the autonomic nervous system and the brain stem and partly by intrinsic enhancement of the myenteric plexus reflexes within the gut wall itself. The powerful peristaltic contractions travel long distances in the small intestine within minutes, sweeping the contents of the intestine into the colon and thereby relieving the small intestine of irritative chyme and excessive distention.

1.2.4 Large Intestine

Large intestines normally exhibit four types of motions: 1. Rhythmic variations of tone, 2. Peristalsis, 3. Mass peristalsis and 4. Anti-peristalsis.

Rhythmic variations of tone:

This take places throughout the large intestine but not always and is not at all concerned with propulsion; it rather maintains adequate circulation through the wall and helps in the absorption of water.

Peristalsis:

Peristalsis is not equivalent as rush peristalsis seen in the small intestine. It is a weak peristalsis alternately shortening and elongating in the transverse colon.

Mass peristalsis:

A movement is a modified type of peristalsis characterized by the following sequence of events: First, a constrictive ring occurs in response to a distended or irritated point in the colon, usually in the transverse colon. Then, rapidly thereafter the 20 or more centimeters colon distal to the constrictive ring lose their haustrations and instead contract as a unit, propelling the fecal material in this segment en masse further down the colon. The contraction develops progressively more force for about 30 seconds, and relaxation and then occurs during the next 2-3 minutes. Then, another mass movement occurs, this time perhaps farther along the colon.

Anti-peristalsis:

In the early stages of excessive gastrointestinal irritation, anti-peristalsis begins to occur often many minutes before vomiting appears. The anti-peristalsis may begin as far down in the intestinal tract as the ileum, and the anti-peristaltic wave travels backward up the intestine at a rate of 2-3 cm/sec; this process can actually push a large share of the intestinal contents all the way back to the duodenum and stomach within 3-5 minutes. Then, as these upper portions of the gastrointestinal tract, especially the duodenum, become overly distended, this destination becomes the exiting factor that initiates the actual vomiting act. In man it is rarely seen but is well marked in animals such as cat.

1.2.5 Renal System

Ureters:

The ureters propel the urine from the kidneys into the bladder by peristaltic contraction of smooth muscle layer. This is an intrinsic property of the smooth muscle and is not under autonomic nerve control. The waves of contraction originate in a pacemaker in the minor calyces. Peristaltic waves occur several times per minute, increasing in frequencies with the volume of urine produced, and send little spurts of urine into the bladder.

1.2.6 Reproductive System

Fallopian tubes:

The uterine tubes are about 10cm long and extend from the sides of the uterus between the body and the fundus. They lie in the upper free border of the broad ligament and their trumpet-shaped lateral ends penetrate the posterior wall, opening into the peritoneal cavity close to the ovaries. The end of each tube has finger like projections called fimbriae. The longest of these is the ovarian fimbriae, which is in close association with ovary. The uterine tubes (fallopian tubes) convey the ovum from the ovary to the uterus by peristalsis and ciliary movements.

1.3 CLASSIFICATION OF FLUIDS

1.3.1 Newtonian Fluid

If shear stress is linearly proportional to the rate of strain, the fluid is called as a Newtonian fluid. Newtonian behaviour has been observed in all gases in liquids or solutions of materials of low molecular weight.

The constitute equation for Newtonian fluid is

$$\tau = \mu\dot{\gamma}$$

wherer, τ is the stress, $\dot{\gamma}$ is the shear rate and μ is the viscosity of the fluid.

1.3.2 Non-Newtonian Fluid

Non-Newtonian fluids generally exhibit a nonlinear relationship between and shear rate. Foodstuffs (like banana juice, apple juice, chyme), blood, slurries, sperm, intra uterine fluid, etc. are behaves like a non-Newtonian fluids.

In this thesis an attempt is made to study the following non-Newtonian fluids:

(a) Jeffrey Fluid

The Jeffrey model is relatively simpler linear model using time derivatives instead of convected derivatives, for example Oldroyd-B model does; it represents a rheology different from the Newtonian.

The constitute equation for the Jeffrey fluid is

$$\tau = \frac{\mu}{1+\lambda_1}\left(\dot{\gamma} + \lambda_2 \ddot{\gamma}\right)$$

where μ is the dynamic viscosity of the fluid, $\dot{\gamma}$ is the shear rate, λ_1 is the ratio of relaxation time to retardation time and λ_2 is the retardation time and dots over the quantities denote differentiation with respect to time.

(b) Williamson fluid

Williamson fluid is a viscoelastic fluid.

The constitutive equation for a Williamson fluid (given in Bird et al.,1977) is

$$\tau = -\left[\eta_\infty + \left(\eta_0 + \eta_\infty\right)\left(1 - \Gamma\dot{\gamma}\right)^{-1}\right]\dot{\gamma}$$

Where τ is the extra stress tensor, η_∞ is the infinite shear rate, viscosity η_o is the zero shear rate viscosity, Γ is the time constant and $\dot{\gamma}$ is defined as

$$\dot{\gamma} = \sqrt{\frac{1}{2}\sum_i \sum_j \dot{\gamma}_{ij}\dot{\gamma}_{ji}} = \sqrt{\frac{1}{2}\pi}$$

where π is the second invariant stress tensor.

The above model reduces to Newtonian for $\eta_\infty = 0$ and $\Gamma = 0$.

(c) Hyperbolic Tangent Fluid

Hyperbolic tangent fluid is a shear thinning fluid.

The constitutive equation for a Hyperbolic Tangent fluid is

$$\tau = -\left[\eta_\infty + \left(\eta_0 + \eta_\infty\right)\tanh\left(\Gamma\dot{\gamma}\right)^n\right]\dot{\gamma}$$

where τ is the extra stress tensor, η_∞ is the infinite shear rate viscosity, η_o is the zero shear rate viscosity, Γ is the time constant, n is the power-law index and $\dot{\gamma}$ is defined as

$$\dot{\gamma} = \sqrt{\frac{1}{2}\sum_i \sum_j \dot{\gamma}_{ij}\dot{\gamma}_{ji}} = \sqrt{\frac{1}{2}\pi}$$

where π is the second invariant stress tensor.

(d) Prandtl Fluid

The Constitute equation for Prandtl fluid is given by

$$\tau = \frac{A\sin^{-1}\left(\frac{1}{C}\left[\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2\right]^{\frac{1}{2}}\right)}{\left[\left(\frac{\partial u}{\partial y}\right)^2 + \left(\frac{\partial v}{\partial x}\right)^2\right]^{\frac{1}{2}}} \frac{\partial u}{\partial y}$$

in which A and C are material constants of Prandtl fluid model.

(e) Carreau fluid

The constitute equation for a Carreau fluid (given in Bird et al., 1977[10]) is

$$\tau = -\left[\eta_\infty + (\eta_0 - \eta_\infty)\left(1 + (\Gamma\dot{\gamma})^2\right)^{\frac{n-1}{2}}\right]\dot{\gamma}$$

where τ is the extra stress tensor, η_∞ is the infinite shear rate viscosity, η_0 is the zero shear rate viscosity, Γ is the time constant, *n* is the dimensionless power-law index and $\dot{\gamma}$ is defined as

$$\dot{\gamma} = \sqrt{\frac{1}{2}\sum_i \sum_j \dot{\gamma}_{ij}\dot{\gamma}_{ji}} = \sqrt{\frac{1}{2}\pi}$$

here π is the second invariant of strain-rate tensor.

1.4. Literature Survey

Several theoretical and experimental studies have been undertaken to understand peristalsis through abrupt changes in geometry and realistic assumptions. Peristaltic transport of Newtonian fluids has been studied by Fung and Yih (1968)[23], Shapiro et al. (1969)[50] and Subba Reddy et al. (2005)[62] under different conditions.

It is well known that most physiological fluids including blood behave as non-Newtonian fluids. Hence, the study of peristaltic transport of non-Newtonian fluids may help to get better understanding of the working biological systems. Peristaltic transport of blood in small vessels was investigated using the viscoelastic fluid by Bohme and

Fredrich (1983)[11], power-law fluid by Radhakrishnamacharya [47], micropolar fluid by Srinivasacharya et al. (2003)[56], casson fluid by Srivastava and Srivastava (1984)[58]. Peristaltic flow of a second –order fluid in a planar channel and in an axisymmetric tube has been studied by Siddiqui et al. (1991)[52], Siddiqui and Schwarz (1994)[54] under long- wave length assumption. The power-law model was used to study the fluid transport in the male reproductive tract by Srivastava and Srivastava (1988[60]), oesophagus by Srivastava and Srivastava (1985)[59]. Peristaltic flow of third order fluid has been investigated by Siddiqui and Schwarz [93] for planar channel and by Hayat et al (2002)[24]. El Shehawey et al.[17] have investigated the peristaltic transport of Carreau fluid through a non uniform channel, under zero Reynolds number and long wavelength approximations. Abd El Hakeem and El-Misiery (2002)[1] have investigated the peristaltic pumping of Carreau fluid in the presence of an endoscope. Hayat et al. (2006)[28] have discussed the effect of endoscope on the peristaltic motion of a Jeffrey fluid in a tube. The peristaltic transport of a hyperbolic tangent fluid in an asymmetric channel was discussed by Nadeem and Akram (2009)[42]. The peristaltic transport of a Tangent hyperbolic fluid in an endoscope numerically was investigated by Nadeem and Akbar (2011)[45]. Akbar et al.[5] have studied the peristaltic flow of a Prandtl fluid in an asymmetric channel.

The study of MHD flows is quite attractive and useful because it is used in magnetic wound or cancer tumor treatment causing hypothermia, bleeding reduction during surgeries, targeted transport of drugs using magnetic particles as drug carries and MRI (magnetic resonance imaging) to diagnose the disease. Some significant studies involving MHD flows were discussed by Srivastava and Agrawal (1980)[57] and Agrwal and Anwaruddin (1984)[3]. The effects of the magnetic field on the peristalsis are also significant in connection with certain problems of the movement of the conductive physiological fluids, e.g., the blood and blood pump machines. Peristaltic transport of a MHD third order fluid in a circular cylindrical tube was investigated by Hayat and Ali (2006)[28]. Hayat et al. (2007)[29] studied peristaltic transport of a third order fluid in a uniform channel under the effect of a magnetic field. Hayat et al. (2007)[27] developed the peristaltic flow of a fourth grade fluid under the effect of a magnetic field in a planar channel. The influence of an endoscope on the peristaltic flow of a Jeffrey fluid under the effective of magnetic filed in a tube was studied by Hayat et al. (2008)[32]. Peristaltic flow of a Jeffrey fluid under the effect of a magnetic field in a tube was discussed by Hayat and Ali (2008)[28]. Subba Reddy and Gangadhar (2010)[64] have studied the peristaltic motion of a Carreau fluid under the effect of a magnetic field in an inclined planar channel. Subba Reddy et al. (2011)[66] have investigated the peristaltic pumping of Williamson fluid in a planar channel under the effect of magnetic field. Nadeem and Akram (2011)[44] have studied the effect of magnetic field on the peristaltic motion of a hyperbolic tangent fluid in a vertical asymmetric channel with heat transfer.

Flow through a porous medium has been of significant interest in recent years particularly among geophysical fluid dynamicists. Examples of natural porous media are beach sand, sandstone, limestone, rye bread, wood, the human lung, bile duct, gall bladder with stones and in small blood vessels. Flow through porous medium has been studied by a number workers employing Darcy's law (Sceidgger, 1974[49]; Raptis and Perdikis, 1983[48]; Varshney, (1979)[71]. El Shehawey and Husseny (2000)[19] have studied the peristaltic motion of a Newtonian fluid through a porous medium in a channel. The interaction of peristaltic flow with pulsatile fluid under the effect of a transverse magnetic field through a porous medium bounded by a two-dimensional channel is studied by Afifi and Gad (2001)[2]. Mekheimer and Arabi (2003)[40] studied the non-linear peristaltic transport of MHD flow through a porous medium. Non-linear peristaltic transport through a porous medium in an inclined planar channel has studied by Mekheimer (2003)[39] taking the gravity effect on pumping characteristics. Vajravelu et al. (2007)[72] have investigated the peristaltic flow of a Newtonian fluid through a porous medium in a vertical annulus with heat transfer. Hall effects on peristaltic transport of a Maxwell fluid in a porous medium have been studied by Hayat et al. (2007)[31]. El-Dabe et al. (2010)[14] have discussed the effect of magnetic field on the peristaltic motion of a Carreau fluid through a porous medium with heat transfer. Peristaltic motion of a couple stress fluid through a porous medium in a channel with slip condition was studied by Alemayehu and Radhakrishnamacharya (2010)[7]. Subba Reddy et al. (2011)[67] have investigated the non-linear peristaltic flow of a fourth grade fluid through a porous medium in an inclined asymmetric channel.

On the other hand it is observed that limited attention is paid to the peristaltic flows of non-Newtonian fluids when no-slip condition is not adequate. El Sehaway et al. (2006)[21] have studied the effect of slip on the peristaltic flow of a Maxwell fluid in a channel. The effects of slip and non- Newtonian parameters on the peristaltic flow of a third grade fluid in a circular cylindrical tube were investigated by Ali et al. (2009)[9]. Chaube et al. (2010)[12] have discussed the slip effects on the peristaltic flow of a micropolar fluid in a channel. Hayat et al. (2010)[35] have studied the simultaneous effects of partial slip and heat transfer on the peristaltic flow of viscous fluid in a two-dimensional channel are reported. Effect of slip and induced magnetic field on the peristaltic flow of pseudoplastic fluid was studied by Noreen et al. (2011)[46]. Subba Reddy et al. (2012)[68] have investigated the slip effects on the peristaltic motion of a Jeffrey fluid through a porous medium in an asymmetric channel under the effect of magnetic field. Akbar et al. (2012)[6] have studied the effects of slip and heat transfer on the peristaltic transport of a hyperbolic tangent fluid in an inclined asymmetric channel.

In view of several physiological applications, we are studying the effects of MHD on peristaltic flow of non-Newtonian fluids in different geometries.