CHAPTER 8
SUMMARY AND FUTURE SCOPE

8.1 SUMMARY

In this thesis, we have analyzed the six mathematical models (Chapter-2 to Chapter-7) on peristaltic transport of Newtonian fluids, couple stress fluids and nanofluids through various physiological flow regimes. Electroosmosis phenomenon has been considered in first four models (Chapter-2 to Chapter 5). This thesis has started with Chapter-1 in which a brief discussion of peristaltic transport, electrokinesitics, magnetohydrodynamics, couple stress fluids and nanofluids followed by a deep literature survey on peristaltic transport and electokinetic transport and identification of gaps in literature. The governing equations for the presented models are coupled non-linear partial differential equations and they are difficult to solve. We have simplified the governing equations using lubrication theory (low Reynolds number and large wavelength) and also used Debye-Hückel linearization (i.e. wall zeta potential ≤ 25mV). A closed-form solutions have been derived for axial velocity, electrical potential, local wall shear stress, axial pressure gradient and pressure difference. The effects of pertinent parameters, (Debye length, Helmholtz-Smoluchowski velocity, Hartmann number, permeability parameter, nanoparticle fraction, Grashof number, Brownian motion parameter and thermophoresis parameter) on flow characteristics, pumping characteristics and shear stress have been discussed through the computations. Trapping phenomenon has also been studied both with and without electrokinetic effects.

In Chapter-2 and Chapter-3, we have investigated the electroosmosis modulated peristaltic transport of Newtonian fluids through microchannel and capillary respectively. The study has been motivated by exploring the combined use of peristalsis and electroosmosis in biomimetic micro-pumps for possible hemodynamics applications. Some key findings are summarized as:

- Hydrodynamic pressure is increased with EDL thickness whereas it is suppressed with electric field.
- Stronger electric field also decelerates the flow and decreases local wall shear stress.
Streamline visualization reveals that the quantity of trapped bolus is decreased with increasing EDL thickness and also with higher external electric field.

Periodic distributions in wall shear stress are strongly evident indicating the wavy nature of peristaltic propulsion.

Local wall shear stress distribution is maximized at the initial stage of propulsion and is depressed with wall contraction and constant for wall relaxation, for both train wave propagation also single wave propagation cases.

A linear decay relation is computed between pressure difference and flow rate.

Pressure is boosted with stronger axial electric field and it is a minimum without external electric field.

Bolus magnitude is reduced with increasing axial external electric field and also with greater electroosmotic parameter (smaller Debye length).

The pressure distributions in the absence of electric field resemble those computed by (Shapiro et al. 1969).

An absence of electrical field accelerates the blood flow indicating that with electrical field hemodynamic control is achieved.

In Chapter 4, we have studied the influence of transverse magnetic field on time-dependent peristaltic transport of electrically-conducting fluids through a microchannel in presence of electroosmosis mechanism. The study has been motivated by exploring the combined use of magnetohydrodynamics and electrokinetics in biomimetic micro-pumps for possible medical applications. Some interesting outcomes are summarized as:

- With increasing Hartmann number, the formation of bolus in the regime is inhibited up to a critical value of magnetic field.
- Flow rate is however reduced with greater Hartmann number as is the local wall shear stress and the magnitude of axial velocity.
- Pressure difference is also found to be increased with greater Hartmann number at low time values whereas it is reduced with greater elapse in time.
- Furthermore increasing Hartmann number decreases local wall shear stress values.
SUMMARY

In chapter 5, we have studied the peristaltic transport of Newtonian fluids through finite length complex wavy microchannel filled with porous medium which is representative of complex peristaltic propulsion. Three wave functions of different amplitudes but the same wavelength has been used to simulate a complex wavy surface for the microchannel walls, corresponding to a more realistic peristaltic propulsion scenario. The Darcy model has been employed for linear porous media drag simulation. The study has been motivated by exploring the combined use of Darcy’s law and electrokinetics in biomimetic micro-pumps for possible intra-uterine fluid motion induced by uterine contractions. Some important results are summarized as:

- An increase in matrix permeability is observed to suppress pressure difference magnitudes for all three peristaltic waves.
- With progress in time, peak pressure differences are displaced along the microchannel axis.
- The peaks are spaced differently along the channel length for the three different waves considered.
- Axial flow acceleration is also observed with increasing permeability parameter.
- Permeability is observed to have a strong influence on circulation and bolus structure.

In Chapter-6, we have studied the transient peristaltic transport of nanofluids with diffusive effects through a finite non-uniform channel, this geometry being more representative of real micro-pumps. The study has been motivated by exploring the heat transfer analysis in cell responses, blood analysis, biomimetic capillary designs, and blood vessel tissue culture systems. Some significant findings are summarized as:

- Increasing thermophoresis effect accelerates transverse flow whereas it depresses pressure differences.
- Increasing thermal and mass Grashof number both serve to suppress pressure differences, whereas the latter achieves a greater effect for small increments.
- Pressure difference is also enhanced with greater Brownian motion effects.
• Axial velocity, nanoparticle volume fraction (species concentration) and temperatures are all decreased with greater divergence of the channel geometry i.e. non-uniformity parameter.

In Chapter-7, we have examined the endoscopic and magnetic field effects on peristaltic transport of couple stress fluids in the annular gap between flexible and rigid channels. The study has been motivated by exploring the combined use of magnetohydrodynamics and peristalsis in simulating magnetohydrodynamic (biomagnetic) control of chyme movement through the small intestine in gastrointestinal magneto-endoscopy and also magnetic blood pumps in heart lung machines. Some considerable remarks are summarized as:

• Velocity profile is elevated with increasing the magnitude of couple stress parameter.
• Velocity profile is suppressed with increasing the magnitude of Hartmann number (due to the Lorentzian hydromagnetic retarding effect) and width ratio of channels.
• Maximum pressure, against which peristalsis can work, diminishes with couple-stress parameter, whereas it increases with increasing the Hartmann number and the magnitude of the width ratio of the channels.
• The influence of emerging parameters on frictional forces (on rigid and flexible channels) is found to be similar in a magnitude sense and opposite in direction to that of pressure.
• Mechanical efficiency reduces with increasing magnitude of couple-stress parameter and Hartmann number, whereas, it increases with elevation in the magnitude of width ratio of the channels.

8.2 FUTURE SCOPE

An important pathway for extending the current linearized two-dimensional simulations is to deploy computational fluid dynamics (CFD) software for transient 3-D simulations. An excellent suite available for modelling such flows is the ANSYS FLUENT code. This has been implemented by (Laskowski & Bart 2015) in conjunction with open FOAM algorithms to analyse electrokinetic flow dynamics in chromatographic devices. Other softwares which have been utilized to simulate electrokinetic dynamics include the SIMION code and the finite element code,
COMSOL Multi-physics (Wissdorf et al. 2012). These simulations have explored ion motion at elevated pressure calibrated against experimentally derived ion current data. Peristaltic computational fluid dynamics studies include (Tharakan et al. 2010) with applications in gastric transport; however electrokinetics has not been considered. Therefore to the authors knowledge composite electrokinetic peristaltic hemodynamics has thus far not been analyzed with general purpose CFD softwares. However recently El Gendy has explored peristaltic flows in smart pumps using ANSYS FLUENT and also considered both Newtonian and non-Newtonian models. These studies may be further extended to consider combined models using the Navier–Stokes equations, energy equations for stationary temperature fields and mass transfer equations for the electrokinetic flow. Another aspect of significance which has been ignored in the present simulation is heat transfer. The heat-conducting properties of blood makes this an important feature to analyse in capillary electroosmotic flows. Furthermore this provides other key aspects of interest including entropy generation minimization via second law thermodynamic simulation. Important studies in this regard have been presented by Gorla (2014) for micro-channels and Goswami et al. (2016b) for conjugate electroosmotic heat transfer. These models have however only considered Newtonian flows. A non-Newtonian characteristics may feature strongly in micro-capillary transport. Important constitutive models which could be considered therefore include power-law models (Chen 2011), micropolar models (Murthy & Srinivas 2013) and couple stress models (Srinivas et al. 2015). These would provide more comprehensive insight into non-Newtonian biological entropy simulation in electroosmotic peristalsis and indeed both couple stress (Tripathi et al. 2017a) and viscoelastic models (Tripathi et al. 2017b).

The EDL overlap effect is significant at small nanochannel height, low salt concentration, and medium low pH. Neglecting the EDL overlap effect could result in a wrong estimation of the zeta potential and conductance of the nanochannel in a single measurement (Ma et al. 2015). So these models can be extended for overlapped double layers. Recently it was proposed by Das et al. (2013) that Electroviscous effect is independent of streaming potential for overlapped EDL. It was observed that in case of Graphite Oxide Single Layers due to size-mismatched, face-to-face interaction caused irreversible stacking, leading to double layers (Cote et al. 2009).
Apart from above, simulations presented in the thesis are equally applicable to the magnetic field control of the mechanisms of certain peristaltic pumps transporting electrically-conducting sanitary wastes and magnetized corrosive fluids, where wavy flow effects are significant (Kim et al. 2006; Al-Halhouli et al. 2010; Neto et al. 2011). Future work may explore non-Newtonian nanofluids (e.g. power-law) and microstructural Eringen models (Prasad et al. 2014; Latiff et al. 2015), which are more representative of certain linctus solutions, medical creams and ophthalmic agents and work in this direction is in progress.