INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
SHORT ABSTRACT OF THESIS

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Thesis Title: Migration of Liquid Drops through Narrow Passages and Flow Dynamics of Cancer Cells through Constricted Microchannels

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SHORT ABSTRACT

The aims of the present dissertation is to understand the ow dynamics of deformable drops as well as cancer cells in microchannels. In this regard, we study the motion and deformation of a neutrally buoyant drop in a microchannel both in the absence and presence of electric fields, tuning the various hydrodynamic and electrical properties in the first part of the thesis. The problems in the first part have been extensively investigated using numerical analysis. In the other part, we extend our understanding of motion of deformable drops in microchannels to investigate the flow behavior of cancer cells through constricted microchannels. Different biological assays are performed to analyze the metastatic potency of the cells after passing through the constriction. The study on this latter part opens up a horizon for further investigations; this class of flows is becoming increasingly relevant with advances in medical engineering and nanofluidics. The prime focus of the first problem of interest is to investigate the migration and break up of a neutrally buoyant droplet in a tube containing another immiscible liquid in the creeping ow. The interface between the two immiscible fluids has been captured using a coupled level-set and volume-of-fluid (CLSVOF) approach. The deformation and breakup dynamics of the droplet have been investigated in terms of three dimensionless parameters, namely, the ratio between the radius of the undeformed droplet and the radius of the capillary tube, the viscosity ratio between the dispersed and the continuous phases, and the capillary number that measures the relative importance of the viscous force over the surface tension force. A thorough computational study has been conducted to find the critical capillary number for a range of droplets of varied sizes suspended in flows having different viscosity ratios. Next, the cross-stream migration phenomenon exhibited by a two-dimensional drop is studied. The multiphase modeling is done adopting the volume-of-fluid(VOF) interface capturing method. In the absence of electric field, the important non-dimensional parameters pertaining to such two-phase flows are viscosity ratio between the drop fluid and the surrounding medium, the ratio of drop diameter to channel height and the capillary number. The influence of all these parameters in drop migration has been studied by varying the parameters in a wide range along with varied initial off-center positions. The presence of electric field introduces additional stresses at the drop interface and its effect on drop migration has been investigated by solving the electro-hydrodynamic Navier-Stokes equations. Extensive computations have been performed to analyze the combined effect of electric field and shear ow in the cross stream migration of the drop. The results obtained for perfect dielectric fluids indicate that the droplet migration enhances in the presence of electric field. The permittivity ratio and the electric field strength play a major role in drop migration and deformation. Computations using the leaky dielectric model also show that for certain combination of electrical properties, the drop undergoes immense elongation along the direction of electric field. The conductivity ratio is a vital parameter in such system of fluids. It has been observed that the leaky dielectric drops (subjected to certain set of conditions) along with translation also exhibit rotational behavior. Next, the dynamics of a droplet in shear ow under the influence of an external electric field has been investigated by performing extensive numerical simulations. The study has been again carried out by solving two-dimensional electro-hydrodynamic equations and the interface has been captured using a VOF approach. For the case of dielectric fluids, the deformation of the drops can be either enhanced or reduced by varying the permittivity ratio and electric field strength. The nature of the polarization forces acting at the interface can be either compressive or tensile depending on the magnitude of the permittivity ratio. The local electric field intensity inside the drop is significantly altered by varying the permittivity contrast between the fluids. The computations for leaky dielectric fluids reveal that the deformation of the drop can be effectively tuned by altering the permittivity as well as the conductivity ratios. The electric forces acting at the interface are critically dependent on the relative contrast between the electric properties of both the phases. The conductivity ratio decides the magnitude and nature of charge at the upper and lower portions of the droplet interface thereby fundamentally maneuvering the droplet dynamics under the applied electric field. Finally, to understand the burgeoning challenges of metastasis, a 3 mm long microchannel constricted to 7 µm width is designed and fabricated to mimic *in-vivo* capillaries of a human body. The motion of single or aggregated malignant HeLa cells (size 17 – 30 µm) have been observed microscopically through the constricted microchannel at a constant ow rate of 30 _l/h. Quantitative deconvolution of high-speed videographs of a single cell of 30 µm reveals cellular deformation while passing through constriction, having elongation index, average transit velocity and entry time of 2.67, 18 mm/s and 5.1 ms, respectively. Morphological analysis of live and apoptotic cells by dual staining with Acridine Orange/Ethidium Bromide demonstrated retention of a significant viable cell population after exit through the constriction and a viability index of 50% is quantified by dye exclusion assay. The cumulative data for microfluidic parameters, morphology and relevant metastatic MMP2 gene expression efficiency measured by real-time polymerase chain reaction reveal retention of virulence potency that could possibly cause metastasis. These findings related to motion and viability of HeLa cells would be beneficial in developing futuristic MEMS device for cancer theranostics.