ME – MTech (Res) Thesis Colloquium

Motion of Active Droplets in Serpentine Microchannels

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ABSTRACT

An active droplet is a synthetic active matter system in which a liquid droplet exhibits autonomous motion in the absence of externally imposed flows or fields. The self-propulsion is achieved through the generation of Marangoni stress at the droplet interface owing to a gradient in surfactant concentration, which is in turn sustained by droplet solubilization and the advective transport of surfactants. Towards realizing technological goals at the intersection of microfluidics and active matter, the major challenge is the control and manipulation of active droplets in complex microfluidic environments. Although the motion of active droplets in unbounded domains and straight microchannels has been studied quite extensively, their motion in channels with curved boundaries, and in particular the controlled navigation of active droplets in serpentine microchannels, remains poorly understood.

This dissertation presents a combined computational and experimental study of the motion of active droplets in serpentine microchannels. In particular, serpentine microchannels with curved lateral walls are considered in order to unravel the interaction between the droplet and the channel walls. Finite-element-based, arbitrary Lagrangian–Eulerian simulations are performed to obtain the droplet motion, the flow field, and the surfactant concentration field. In the microfluidic experiments, solubilizing droplets of CB15 oil ((S)-4-cyano-4-(2-methylbutyl)biphenyl) suspended in an aqueous solution of the surfactant tetradecyltrimethylammonium bromide (TTAB) are employed, and fluorescence microscopy and micro-particle image velocimetry are used to observe the droplet trajectory and the flow field. Three distinct swimming modes are identified: centreline motion, wall-shifting motion, and off-centred motion. In the centreline motion, the droplet follows the centreline of the serpentine microchannel; in the wall-shifting motion, the droplet migrates periodically from one wall to the other; and in the off-centred motion, the droplet approaches one of the walls and follows it in an off-centred position for the remainder of the trajectory. To explore the control capabilities, computations and experiments are carried out over a wide parameter range, which reveals that the mode of motion is governed by three dimensionless numbers: the confinement ratio (droplet size relative to channel width), the curvature ratio (radius of curvature of the channel centreline relative to channel width), and the Péclet number (strength of advective transport of surfactant relative to diffusion). For a given confinement ratio and curvature ratio, the droplet exhibits centreline motion at low Péclet number, wall-shifting motion at intermediate Péclet number, and off-centred motion at higher Péclet number. This combined experimental and computational approach not only enhances the understanding of active droplet motion but also paves the way towards the development of active droplet-based microfluidic devices that can be employed for a variety of applications, including point-of-care disease diagnostics, high-throughput drug screening, and single-cell analysis.

ABOUT THE SPEAKER

Sourav Chatterjee is currently pursuing an MTech (Research) in the Department of Mechanical Engineering at the Indian Institute of Science (IISc), Bengaluru, under the supervision of Dr. Shubhadeep Mandal. His research focuses on active droplets, integrating computational modelling and experimental techniques to investigate their dynamics and transport behaviour in microfluidic devices.