ME PhD Thesis Colloquium

MECHANICAL ENGINEERING
INDIAN INSTITUTE OF SCIENCE

Vapor Mediated Interactions in Droplets

Mr. Omkar Hegde, PhD Student, Department of Mechanical Engineering, IISc Bangalore

April 15, 2021 at 11:00 AM
Meeting link: Click here to join meeting **(Microsoft Teams)**

ABSTRACT

The advent of industrial applications such as surface patterning, bio-chemical assays, crystal arrays, inkjet printing, nanofabrication, self-assembly of complex DNA patterns has ignited widespread research interest in bottom-up techniques involving evaporating functional sessile droplets. In most of these applications, the sessile droplets undergo natural or forced evaporation, which is not as simple as contact-free droplets. Evaporation flux varies significantly across the droplet surface, which leads to internal flow within the droplets. The complexity is increased by manifolds when multiple droplets are placed adjacent to each other with different species involved. The effect of vapor-mediated interactions between droplets of contrasting volatilities placed in the vicinity is not well understood.

The principal methodology used in the thesis is as follows: we strategically position a highly volatile ethanol droplet asymmetrically in the vicinity of a target droplet of low volatility (there is no direct physical contact between the two droplets). The ethanol vapor molecules are consequently adsorbed asymmetrically on the target droplet interface, creating a gradient in surface tension. This results in a change of flow within the target droplet. The sessile droplets of contrasting volatilities communicate via long-range (~O (1) mm) vapor-mediated interactions, which allow the remote control of the flow within droplets, creating strong Marangoni convection of ~O (103-102) higher than the convection induced due to natural evaporation. Interestingly, the vaporization modes and droplet lifetime are unaffected due to the small amount of ethanol adsorbed on the target droplet interface. The strength of Marangoni convection can be controlled by controlling the distance of the vapor source. Experimental flow visualization and Micro-Particle Image Velocimetry (μ-PIV) reveals the complex flow fields within the droplet. Simple scaling arguments alongside is used to quantify the physical mechanism at play.

The modulation of internal convection in droplets is leveraged in several applications. In situ methods of mixing in microliter droplets depend on diffusion or evaporation-driven capillary flow, are typically slow and inefficient, while thermal or electro-capillary methods are either complicated to implement or may cause sample denaturing. A non-intrusive methodology is proposed to enhance flow inside the droplets using vapor-mediated interactions to overcome this limitation. It is conclusively shown that the mixing time reduces by ~10 hours due to the vapor-mediated Marangoni convection for the given volume of the droplet, even for a highly viscous droplet like glycerol.

Further vapor mediation is used as a simple template for hierarchical self-assembly and buckling in nano-fluid droplets. The inter-droplet distance is varied to demonstrate the effect on the precipitate shape (flatter to dome-shaped) and the buckling location (top to side). Particle aggregation occurs preferentially on one side of the droplet, leaving the other side to develop a relatively weaker shell which buckles under the effect of evaporation-driven capillary pressure. The vigorous Marangoni flow can also dis-assemble micro aggregates for applications that require inhibition of aggregate formation.

It is shown that our proposed approach of vapor mediation can spatio-topologically manipulate crystal precipitation in saline droplets. The universal character of such a phenomenon is verified for a variety of salt solutions on the glass substrate. This is extended to regulate multiscale dendritic patterns in sessile respiratory droplets that can form fomites, paving a secondary route to transmit infection. Controlling bacteria/virus emulating particles fomites can helpful in biomedical diagnostics.

ABOUT THE SPEAKER

Omkar Hegde is a Ph.D. student enrolled in the Dept. of Mechanical Engineering, IISc Bangalore. He has a Bachelor's degree in Mechanical Engineering from Basaveshwar Engineering College, Bagalkot (Autonomous). He has done his master's degree (M.Tech) in Thermal and Fluids Engineering from NIT Jamshedpur. His research interests include droplet fluid dynamics, microscale fluidics, colloids, and interfaces (soft matter research).