ME – PhD Thesis Defense

Vapor Mediated Interactions in Droplets

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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 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 ($\sim O$ (1) *mm*) vapor-mediated interactions, which allow the remote control of the flow within droplets, creating strong Marangoni convection of $\sim O$ (10^3-10^2) 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) reveal the complex flow fields within the droplet. Simple scaling arguments alongside are used to quantify the physical mechanism at play.

The modulation of internal convection in droplets is leveraged in a gamut of applications. *In situ* mixing methods in microliter droplets depend on diffusion or evaporation-driven capillary flow, which are typically slow and inefficient, while thermal or electro-capillary methods are complicated to implement or may cause sample denaturing. Vapor mediation (VM) is thus used to enhance mixing. Further, VM is used as a simple template for hierarchical self-assembly and buckling in nano-fluid droplets. It is shown that our proposed approach of VM 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 form fomites, paving a secondary route to transmit infection. Controlling bacteria/virus emulating particles in fomites can be helpful in biomedical diagnostics.

In essence, the thesis covers a broad spectrum of research ranging from inert droplets to biologically active matter encapsulated therein. We hope the work will serve as a beacon for further research in fluid dynamics-driven self-assembly in droplets with a wide range of applications such as inkjet printing, fabrication of functional coatings, development of miniaturized electronic devices, and disease diagnosis, to name a few.

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).