ME – PhD Thesis Colloquium

Evaporation of Liquid Bridges: Influence of Dissolved Salts, Surfactants and Polymers

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ABSTRACT

Evaporating liquid bridges are fundamental building blocks in a wide range of natural and engineering processes, including drying, transport, adhesion, and mechanical stability in partially saturated porous and granular materials. This thesis experimentally investigates the influence of dissolved salts, surfactants, and polymers on the evaporation of water bridges under controlled ambient conditions and establishes their effect on the evolution of bridge geometry, evaporation characteristics, and bridge force.

Pure water bridges provide the baseline behaviour governed by the coupled effects of contact-line dynamics, bridge geometry, and interfacial energetics. The results demonstrate that pendular bridges at lower substrate separations exhibit enhanced evaporative fluxes owing to geometric effects. An equivalent cylindrical bridge is established as a representative model for pendular bridge evaporation.

Aqueous salt solution bridges exhibit fundamentally different behaviour due to evaporation-driven crystallization. Prior to crystallization, the evaporative flux exhibits a monotonic dependence on equilibrium relative humidity (ERH), establishing ERH as the principal thermodynamic parameter governing evolution. Following crystallization, two distinct evolution pathways are identified, namely crystal creeping and the newly identified crystal shell formation. Crystal creeping promotes substrate-directed crystal growth and enhances evaporation, whereas crystal shell formation encloses the liquid, substantially suppressing evaporation. An intermediate bottom-supplied creeping pathway is further identified for ammonium chloride solution where creeping and shell formation exist together. Bridge-force evolution depends strongly on the evolution pathway and crystal morphology, with cubic morphologies developing repulsive forces associated with cracking-inducing crystallization pressure. The interplay between the bare surface energies of the substrate and the salt crystal is established to govern the transition between creeping and shell formation pathways, leading to a physically grounded energetic criterion for predicting the favoured pathway.

Unlike salt solutions, surfactants predominantly modify bridge mechanics through significant reductions in bridge force and modest changes in evaporative flux. Furthermore, the measured evolution of bridge force and geometry together reveals that the dynamic rather than equilibrium surface tension of the solution governs the initial stages of evolution. Polymer additives (polyacrylamide), in contrast, predominantly influence the final stages approaching pinch-off. The bridge evolution is governed by the interplay of viscous, capillary, and elastic stresses, with viscoelastic effects dominating at highly concentrated conditions with pronounced retardation of neck thinning and force evolution.

Overall, this thesis establishes experimentally grounded mechanistic frameworks for the evaporation-driven evolution of pure water and multicomponent liquid bridges, identifying salt crystallization, dynamic interfacial transport, and rheological effects as the dominant governing mechanisms for salt, surfactant, and polymer solution bridges, respectively.

ABOUT THE SPEAKER

Chetan Teki is a Ph.D. student in the Department of Mechanical Engineering at the Indian Institute of Science (IISc), Bengaluru, working under the supervision of Prof. M. S. Bobji and Prof. Jaywant Arakeri. He was a Prime Minister's Research Fellow (PMRF) during a part of his Ph.D. tenure. He received his B.Tech. degree from MVGR College of Engineering, Vizianagaram, Andhra Pradesh, and his M.Tech. degree from the Indian Institute of Engineering Science and Technology (IIEST) Shibpur, West Bengal. His research interests include microscale fluid mechanics, heat and mass transfer, and interfacial phenomena.