# ME – PhD Thesis Defense

## Bubble Coalescence in Electrolyte Solutions

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### ABSTRACT

Electrolyte thin films form when gas bubbles or liquid drops interact with solid or liquid interfaces in aqueous media containing dissolved ions. These films arise during bubble approach, attachment, coalescence, and rebound, and play a critical role in processes such as flotation, desalination, boiling heat transfer, foam stability, pulmonary airway reopening, and gas exchange in natural waters. The drainage dynamics of these nanometric films determine whether interfaces coalesce or remain separated. Despite their importance, the combined effects of hydrodynamics, ion-specific interfacial phenomena, and intermolecular forces remain incompletely understood. This thesis addresses these challenges through a combined experimental and theoretical investigation of electrolyte-mediated bubble–wall interactions.

To examine whether dissolved electrolytes modify the macroscopic hydrodynamic boundary condition, the terminal rise velocity of single bubbles was measured in deionized water and concentrated salt solutions. The measured velocities in DI water, 100 mM NaCl, and 100 mM $Na_2SO_4$ were indistinguishable and agreed with the classical prediction for a mobile interface. These results demonstrate that even at high ionic strengths, electrolytes do not immobilize the air–water interface during bulk bubble motion.

The spatiotemporal evolution of thin films between a bubble and a glass substrate was then resolved using high-speed colour interferometry. The experiments revealed that thin-film morphology exerts a stronger influence on drainage than interfacial boundary conditions. Thin-film drainage proceeds through three distinct regimes: an initial visco-capillary stage characterized by power-law thinning, an intermediate stage exhibiting exponential thinning due to rim stabilization, and a final disjoining-pressure-dominated regime in which the film relaxes exponentially toward its equilibrium thickness. Remarkably, film evolution for all electrolyte types and concentrations collapses onto a universal curve when scaled by characteristic thickness and time scales, indicating that electrolytes primarily renormalize drainage times without altering the underlying dynamics.

To provide a mechanistic interpretation of these observations, a thin-film model incorporating Marangoni stresses and electrolyte-dependent surface tension was developed. The model captures the wide variation in drainage times, ranging from O(10) s for 0.01 mM NaCl to O(1000) s for 10 mM NaCl, and reproduces the thinner equilibrium films observed at higher ionic strengths. It distinguishes electrolytes such as NaCl, NaI, and $Na_2SO_4$, which strongly retard drainage, from acids such as HCl and $HNO_3$, which behave similarly to pure water due to weaker interfacial exclusion. The simulations further show that rapidly evolving films generate small dimples quickly, whereas slowly evolving films form larger dimples over longer times.

Finally, a coupled boundary-integral–lubrication framework was developed to simultaneously resolve global Stokes flow and local thin-film hydrodynamics. By coupling the outer flow field with the lubrication dynamics within the thin film, the model captures the evolution of the entrapped liquid film during bubble–wall interaction. The simulations accurately reproduce the complete radial film structure, including dimple formation, hydraulic choke, and late-stage relaxation, and show excellent agreement with interferometric measurements for DI water and NaCl and $Na_2SO_4$ solutions at 1, 10, and 100 mM without case-specific parameter tuning.
Together, these results provide a unified and experimentally validated multi-scale framework for understanding electrolyte-mediated thin-film dynamics and bubble coalescence.

### ABOUT THE SPEAKER

Afsal C P is a PhD student in the Department of Mechanical Engineering working with Prof. Gaurav Tomar and Prof. Susmita Dash, joined in January 2019. He holds a B.Tech degree in Mechanical Engineering from Government Engineering College, Thrissur (Kerala) and M.Tech degree in Thermal Science from National Institute of Technology, Calicut. His research focuses on Interfacial fluid dynamics.