ME – PhD Thesis Defense

Passive Interfacial Evaporation-based Thermal Desalination Systems

Nabajit Deka, PhD student, Department of Mechanical Engineering, IISc Bengaluru

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ABSTRACT

Desalination offers a promising solution to the global water shortage by utilizing the vast resource of seawater. With 26% of the world's population lacking access to potable water currently, there is a growing need to develop sustainable freshwater generation solutions. Among various desalination technologies, solar thermal desalination has received growing attention for its low cost, modularity, and suitability in regions with limited energy infrastructure. The thesis advances passive thermal desalination systems by investigating and designing components associated with phase change processes: evaporation, condensation, and salt crystallization.

In the first part of the thesis, we investigate the transport processes involved in an evaporating binary mixture droplet, which is widely encountered in microfluidic devices, brine crystallizers, and evaporator-condenser assembly of thermal membrane desalination systems. Particle image velocimetry is used to visualize the convective flow driven by evaporation and crystallization in a saline liquid bridge, spanning both pre- and post-nucleation stages of crystallization. The crystal growth is modelled as a point sink to evaluate the flow fields in the post-nucleation stage. The results show that buoyancy-driven convection predominantly governs the recirculating flow in both pre- and post-nucleation phases.

In the second part, we focus on wicking-based multistage thermal desalination systems build on the concept of interfacial evaporation and latent heat recovery. Metallic textured substrates are proposed as efficient wicking materials, eliminating the usage of insulating hydrophilic materials for interfacial evaporation. The impact of condenser wettability on evaporation and collection flux is examined, with a ~21% enhancement in water collection demonstrated using a patterned condenser with wettability contrast regions in a single-stage system. Integrating the metallic textured evaporator and patterned condenser into a five-stage setup yields a water collection flux of ~2.1 $Lm^{-2}hr^{-1}$ under 1000 Wm^{-2}. A theoretical framework is further formed to study the phenomena of wicking in a porous wicking structure in the presence of evaporation, specifically in rectangular microchannels. Interestingly, the wicking length exhibits a non-monotonic behavior upon increasing the width of the microchannel, which is verified experimentally using infrared imaging. A set of geometric parameters of a microchannel is achieved at which evaporation rate is maximum at an applied heat flux.

In the final part of the thesis, we mitigate the problem of salt accumulation in evaporators of passive thermal desalination systems. A siphonage technique is introduced to enable effective drainage of concentrated brine, thereby preventing crystallization-induced fouling in the evaporators. A composite siphon structure, combining a wicking fabric with a metallic grooved substrate is proposed to enhance scalability beyond conventional wicking based desalination systems. The siphon desalination system is operated with a very low air gap of 2 mm between the evaporator and condenser, which resulted in high water productivity fluxes (~5.7 $Lm^{-2}hr^{-1}$ using 10-stage and ~6.2 $Lm^{-2}hr^{-1}$ using 15-stage) under 1000 Wm^{-2}.

ABOUT THE SPEAKER

Nabajit Deka is a PhD student in the Department of Mechanical Engineering, IISc. After completing his BTech from NIT Silchar in 2018, he joined IISc as a Prime Minister Research Fellow in 2019. His current research focuses on desalination, with emphasis on phase change processes of evaporation, condensation and crystallization.