IOWA STATE UNIVERSITY
Department of Mechanical Engineering

Tailoring Surface Chemistry and Surface Roughness to enable the Long-Term Stable Dropwise Condensation of Steam and Refrigerant Working Fluids

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Abstract

Almost a century ago, dropwise condensation of steam on a hydrophobic surface was shown to have a 10X higher condensation heat transfer coefficient when compared to filmwise condensation on hydrophilic surface. The resulting overall heat transfer enhancement has the potential to result in a 2% overall energy efficiency increase for steam-based power plants, which are responsible for the overwhelming majority of global electricity production. The potential of dropwise condensation has driven researchers to design thin (≈100 nm-thick) hydrophobic coating materials. However, the lack of long-term (> 3 year) durability has been the main hindrance to coating utilization over the past century. In this talk, I will present our recent progress in designing thin and durable hydrophobic coating materials that enable stable dropwise condensation. First, I will discuss our fundamental studies probing the origin of hydrophobic coating degradation. We show that nanoscale pinhole defects in the coating are the source of steam penetration during condensation, where the condensate forms water blisters that pressurize and delaminate the coating. The understanding of the mechanics of water blister formation and growth enables us to develop quantitative guidelines for rational coating design and selection. Next, I will present the design of self-healing vitrimer thin film (dyn-PDMS) that actively eliminate coating defects to prevent the initiation of blisters. The dyn-PDMS thin film maintains excellent hydrophobicity after scratching, cutting, and indenting due to the dynamic exchange of its network strands. In addition to dyn-PDMS, I will show how alternate coating solutions such as fluorinated-diamond like carbon (F-DLC) with polymer-like low surface energy and metal-like exceptional mechanical properties can enhance dropwise condensation durability. We show experimentally that the high bending stiffness and coating adhesion makes F-DLC durable to 5,000 cycles of mechanical abrasion and enables more than 3 years of continual stable dropwise condensation. I end my talk by discussing ongoing work focusing on integrating and evaluating our coatings into the Abbott Power Plant steam cycle and evaluating their durability and performance when applied to a stainless-steel shell-and-tube heat exchanger. Furthermore, I will discuss our recent exciting demonstration of the stable dropwise condensation of two commercial low surface tension refrigerants (HFO-1336mzz(E) and HFO-1233zd(E)), which are novel, non-flammable, low global warming potential (GWP) Hydrofluoroolefins (HFO).

Prof. Nenad Miljkovic is the Founder Professor of Mechanical Science and Engineering at the University of Illinois at Urbana-Champaign (UIUC). He has courtesy appointments in Electrical and Computer Engineering, and the Materials Research Laboratory. He is the Director of the Air Conditioning and Refrigeration Center (ACRC), which is supported by 25 industrial partners. His group's research intersects the multidisciplinary fields of thermo-fluid science, interfacial phenomena, scalable nanomanufacturing, and renewable energy. He is a recipient of the NSF CAREER Award, the ACS PRF DNI Award, the ONR YIP Award, the ASME ICNMM Young Faculty Award, the ASME Pi Tau Sigma Gold Medal, the CERL R&D Technical Achievement Award, the US Army Corps of Engineers ERDC R&D Achievement Award, the SME Young Faculty Award, the Bergles-Rohsenow Young Investigator Award in Heat Transfer, the ASME EPPD Early Career Award, and is an ASME Fellow.

This seminar counts towards the ME 600 seminar requirement for Mechanical Engineering graduate students.