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# Functional and Scalable Surfaces for Phase-Change Phenomena and Their Applications

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## Abstract

Surface modification provides a powerful tool in manipulating phase-change phenomena for applications ranging from thermal management and energy systems to water and wastewater treatment. Although a wide variety of surface modification techniques have been developed, many require access to cleanroom facilities, involve complex fabrication procedures, or rely on environmentally hazardous materials, limiting their scalability and practical implementation. In this talk, the role of functional surfaces designed with scalability, cost and sustainability will be discussed in the context of three important phase change phenomena: boiling, freezing/icing, and hydrodynamic cavitation.

The first part of the talk will focus on flow boiling heat transfer of HFE-7000 in minichannels modified using environmentally friendly and cost-effective microbial bio-coatings. The bio-coated surfaces, fabricated using a scalable dip-coating approach, were systematically optimized in terms of coating morphology, surface characteristics, thermal performance, and durability. The results demonstrate the impact of biologically derived surface structures on bubble nucleation and dynamics and consequently phase-change heat transfer without relying on conventional cleanroom-based micro/nanofabrication techniques.

The second part will address the development of passive anti-icing surfaces. Although numerous engineered surfaces can delay ice formation, their widespread industrial implementation remains constrained by limited mechanical robustness, poor scalability, and in some cases, dependence on environmentally hazardous or fluorinated materials. In this context, recombinant antifreeze protein (AFP) coatings will be introduced as fluorine-free interfacial regulators of ice nucleation and growth on aluminium surfaces. Their influence on ice formation and interfacial freezing behavior, together with their potential for developing sustainable and scalable anti-icing technologies, will be discussed.

The final part of the talk will explore microscale hydrodynamic cavitation for wastewater treatment, with particular emphasis on the removal of persistent per- and polyfluoroalkyl substances (PFAS). The proposed Hydrodynamic Cavitation-on-a-Chip (HCOC) concept employs microfluidic cavitation reactors incorporating engineered surface-roughness elements to manipulate cavitation inception, intensity, and bubble dynamics. The experimental results on PFAS degradation using these surface-engineered microreactors will be presented. The potential of HCOC as a compact and resource-efficient alternative for the treatment of persistent contaminants will also be highlighted.