I^{2}CNER Seminar Series

International Institute for Carbon-Neutral Energy Research (WPI-I^{2}CNER)
Kyushu University

Title **Phase Change Dynamics of Supercooled Water Droplets**

Speaker ***Professor Shuhuai Yao***
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The Hong Kong University of Science and Technology, Hong Kong, China

Time & Date 3:00 PM (JST), Wednesday, March 4th, 2026

Venue Hybrid format (I^{2}CNER Hall C, I^{2}CNER Bldg. 1, Ito Campus, Zoom)

Abstract

The phase change of water under extreme conditions is pivotal in energy-related and aerospace processes. The vaporization of sensible water droplets under vacuum involves a complex interplay of states that challenges conventional understanding. Unlike direct cooling, in a low-pressure environment, droplet temperatures rapidly decrease to supercooled levels due to intense evaporative cooling at the liquid-gas interface. In our study, we investigate the intriguing phase change dynamics and transport phenomena of supercooled freezing droplets on various surfaces at low pressures (~ 100 Pa). First, we reveal a significant counteractive momentum, termed vaporization momentum, resulting from the progressive recalescence of the droplets. Through a combination of experimental visualization and theoretical analysis, we demonstrate that this momentum can cause droplet deformation and subsequent self-propelled jumping from superhydrophobic surfaces. We unravel the complex physics involving vaporization, freezing recalescence, and liquid-solid interactions, and quantify the vaporization momentum to predict droplet freezing and jumping dynamics. Second, we show that adding glycerol to a water droplet can transform these disruptive behaviors into more controllable rhythms. Instead of typical breakup or rapid self-propulsion, freezing glycerol-water droplets enter a state of gentle, cyclic levitation, repeatedly undergoing "dwelling, liftoff, flight, and impact". The tunability of glycerol enables a cyclic droplet motion driven by self-sustaining thermal oscillation. Third, we demonstrate that using a non-volatile oil-infused surface can enhance ice sublimation flux by approximately 10X compared to pure water. The ultra-fast sublimation of frozen droplets is accompanied by self-rolling, which is attributed to the disruption of cloaking oil caused by the stirring mechanism during the supercooled stage, as well as the heat conduction from the relatively high-temperature oil film. Our findings illuminate the role of supercooling and low-pressure mediated phase change in shaping fluid transport dynamics, paving the way for the design of water-surface interaction systems applicable to anti-freezing coatings, sublimation cooling, flash distillation, aerospace and deep-space exploration initiatives.

About the Speaker

Prof. Shuhuai YAO is a Professor in the Department of Mechanical and Aerospace Engineering and a joint faculty member in the Department of Chemical and Biological Engineering at the Hong Kong University of Science and Technology. She obtained her B.S. degree in Engineering Mechanics from Tsinghua University and both her M.S. and Ph.D. degrees in Mechanical Engineering from Stanford University. Following her doctoral studies, she completed postdoctoral training at Lawrence Livermore National Laboratory. Prof Yao's research focuses on the exploration of micro-/nano-scale fluid dynamics and heat transfer phenomena, with a particular interest in integrating theory and experiments to develop innovative technologies for instrumentation. Prof. Yao has published in top journals such as Naure, Nature Energy, Nature Physics, Nature Communications, Physical Review Letters, etc, and holds ten granted patents and has filed more than forty patent applications, three of which have been licensed to HKUST spin-off startups. In addition, Prof. Yao co-founded two startup companies based on her patented microfluidic technologies developed at HKUST.

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Host Prof. Qinyi Li

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