Thermal Transport Café

February 23, 2021, 8 PM (ET)

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Quench Mechanisms of Spray Cooling — from Single Droplet to Spray Level

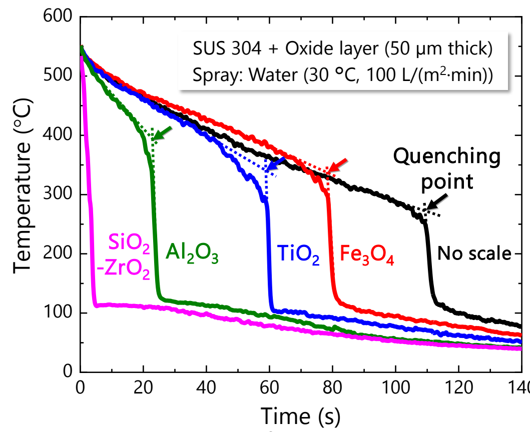


Fig. 1 Cooling curves for stainless steel with various oxide layers.

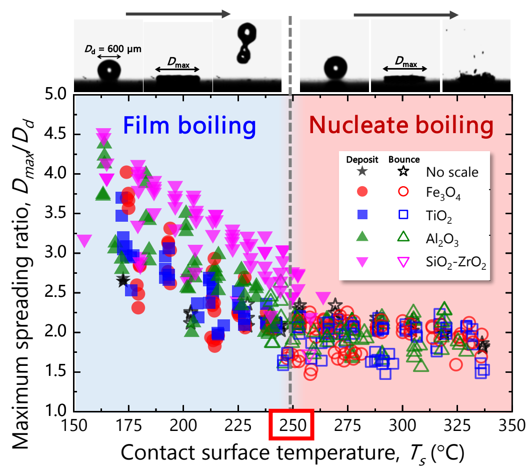
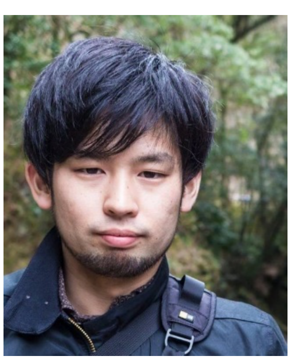


Fig. 2 Droplet impact behavior onto the surface with various oxide layers.

Due to its excellent heat transfer performance, spray cooling has been widely used in the fields including electronics, fire and nuclear safety, and metallurgy, to name a few. Despite, the complex, multiphysics, multiscale and transient nature of spray cooling remains unclear. One of the long-standing open questions is the onset of "quenching"—the rapid cooling of a hot object induced the transition from film to nucleate boiling. Accurately predicting when quenching occurs is paramount to the optimization of steel manufacturing as it determines the thermal history of the workpiece, and thus, the final properties. However, quenching temperatures ever reported range between 200 °C and > 500 °C. While spray conditions, surface roughness and wettability have been known to influence the quenching temperature, little is known about the effect of oxide layers present on the surface. Fig. 1 shows cooling curves obtained by our spray experiments for stainless steel plates with various oxide layers. Clearly, the quenching temperatures are inconsistent and even reported to be over 350 °C which exceeds the thermodynamic limit of superheat (so water should not touch the surface!). To address this controversy, we then investigate the fundamental process of droplet impact onto a surface heated at different temperature levels. High-speed imaging allows to identify the transition of droplet impact behavior, which corresponds to the onset of quenching. Instead of *conventionally-defined* quenching temperature as in the literature, we defined so-called "contact surface temperature" calculated via transient heat conduction analysis. Consequently, we found a unique contact surface temperature (ca. 250 °C) for the droplet behavior transition regardless of the composition and thickness of the oxide layer (Fig. 2). Although the meaning of this 250 °C is still under investigation (and happy to discuss here), our findings will provide one perspective of quenching mechanism and inform the optimization of spray cooling. In this talk, I would also like to discuss how such local and microscopic phenomena of single droplets can be linked to the macroscopic results of spray cooling.



Dr Yutaku Kita is an Assistant Professor of Mechanical Engineering and the International Institute for Carbon-Neutral Energy Research (I^2CNER) at Kyushu University, Japan. He joined Thermofluid Physics Laboratory, Kyushu University as a faculty member in 2019 right after completing his Dr.Eng. under the guidance of Profs Yas Takata (Kyushu University), Jungho Kim (University of Maryland, College Park) and Khellil Sefiane (University of Edinburgh). Yutaku's research is centered in fundamental problems coupling multiphase flows, interfacial phenomena, wetting, and phase change heat transfer, primarily for systems involving nano/micro/millimeter-sized droplets. He picks such problems particularly from current/future industrial applications e.g. spray cooling in steelmaking and microelectronics, condensers in power plants and data centers, and microfluidics for bioassay. Yutaku is passionate in experiments with optical techniques (thermography, interferometry, and flow visualization) to capture flows and heat transfer at various time/spatial scales.

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