ME – PhD Thesis Colloquium

DYNAMICS OF LEIDENFROST DROPLETS ON MICRO-TEXTURED SURFACES

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ABSTRACT

Water droplets, when placed on heated substrates maintained at temperatures significantly higher than the saturation temperature, levitate on their own vapor. This phenomenon is called the Leidenfrost phenomenon. This thesis delves into the Leidenfrost state of droplets and its implications for heat dissipation in cooling applications, with a specific focus on the dependence of Leidenfrost temperature (LFT) and associated flow dynamics on surface micro-textured substrates. The heat transfer in the Leidenfrost state is severely limited because of the presence of the thin insulating vapor layer over which the droplet levitates. The initial part of the thesis reports on the dependence of Leidenfrost temperature of a deionized water droplet on the substrate morphology. A pressure-based model is proposed to explain droplet and vapor dynamics, revealing that the LFT increases with the height of micropillars and spacing between them. The LFT is shown to increase by two times compared to that on a smooth substrate, reaching ~ 507 °C on specific microtextured substrates. A semi-analytical model is developed to elucidate the influence of excess vapor gap between the top of the pillars and the base of the droplet on the substrate permeability. This vapor gap is shown to be crucial in determining the range of temperatures that sustain transition boiling and the rate of evaporation of a droplet in the Leidenfrost state. The subsequent part of the thesis presents a framework for modeling the evaporation of Leidenfrost droplets on micro-textured surfaces. A theoretical model is developed to determine the total heat transferred to a Leidenfrost droplet on microtextured substrates, showing the dependence of the rate of evaporation on the shape of the liquid-vapor interface. The study considers the variations in the vapor gap over micro-pillared surfaces with different substrate permeability, droplet volume, and wall superheat. We show that the curved shape of the liquid-vapor interface predicts the rate of evaporation of a Leidenfrost droplet accurately as compared to when the interface is assumed to be flat. The final part of the thesis explores the role of substrate permeability and the excess vapor gap on the internal convection in Leidenfrost droplets. Internal flow velocity is reported to be higher on smooth substrates and on microtextured substrates with low permeability compared to that on tall and sparse micropillars where the permeability is higher. The convective flow velocity is observed to increase with an increase in substrate temperature. We develop a model to explain the impact of substrate flow permeability and wall temperature on the excess vapor gap and vapor shear stress at the liquid-vapor interface beneath the droplet that consequently determines the internal velocity within levitating droplets.

ABOUT THE SPEAKER

Datta Prasad M R is a Ph.D. student in the department of Mechanical Engineering at Indian Institute of Science Bangalore. He obtained his B.Tech degree from Amrita School of Engineering and did his Masters in the Department of Aerospace Engineering, Indian Institute of Science. His current research focuses on the dynamics of Leidenfrost droplets on micro-textured surfaces.