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Surface Phosphor Thermometry behind a Water Film in a Rectangular Cooling Channel

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Extended Abstract

This ongoing study aims to better understand the phenomena of phase change in heat exchangers through experimentation using a custom-made setup. A rectangular transmural heat exchanger with flowing water as a cooling fluid in an open circuit has been designed and built to study the impact of ebullition in the heat transfer process. The heat exchanger consists of a horizontal channel plate heated by electric resistances embedded into the material bulk, with the top surface cooled down by a stream of water injected at ambient temperature. The rectangular channel plate is either flat or fitted with an array of vertical pins to optimize the heat transfer coefficient. In the course of its passage through the channel, water heats up and boils. A maximum evaporation mass ratio of 50% at the channel outlet can be attained for the selected channel length. The upper wall of the cooling channel has been equipped with a transparent optical port view allowing the visualization and characterization of a region of interest of the exchange surface with optical techniques.

The first round of investigation was performed under various heating powers and water mass flow rates. The topology of the liquid and gas phases was monitored using a contrast agent, pulsed UV LEDs and high-speed video cameras. The exchange surface steady-state temperature and wall heat transfer coefficient were estimated using an inverse method applied to the output of an array of thermocouples inserted within the heated wall [1]. However, inverse methods cannot give any information on the influence of structures at a much smaller scale than the typical distance between two thermocouple measurement points (e.g., small bubbles and surface features). An unsteady, high-resolution two-dimensional characterization of the surface temperature is thus deemed necessary to investigate the phase-change phenomenon thoroughly. Phosphor thermometry (PT) offers such a perspective as it can provide a more direct, quasi-non-intrusive temperature measurement of the heated surface.

PT is a measurement technique based on luminescence emission by thermographic phosphors under the excitation of UV or visible light, often from a laser source. Those phosphors can be applied to a given surface as a paint by being chemically bonded with binders [2]. The surface temperature can then be estimated using the temperature dependence of the emitted luminescence signal, the most common techniques being the measurement of signal time decay and intensity ratios between two spectral bands. In the current investigation, the incident laser beam and the luminescence light pass through the water channel, which represents a significant challenge. The current study starts with moderate flow heating, averting any vapor formation to progressively lay down the groundwork for future measurements with a multiphase water flow. The thermocouple array serving as the primary sensor in the preceding investigations provides a reference for temperature estimation. Several combinations of thermographic phosphors and binders are tested and compared against each other. The phosphor thermometry response (spectral response, lifetime sensitivity, and phosphor coating durability), temperature measurement precision and accuracy are also characterized for various water flow rates and field depths.

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