Development of a High-fidelity Flow Boiling Database for Validation of High-void-fraction Flow Regime Models

PI: Xiaodong Sun – University of Michigan

Program: NEAMS-4: Fundamentals of Multiphase Boiling Flow for High-Pressure, High-Void Conditions

Collaborators: Annalisa Manera – University of Michigan; Yang Liu – Virginia Tech; Adrian Tentner – Argonne National Laboratory; and Yixing Sung – Westinghouse Electric Company

ABSTRACT:

Modern reactor designs and operating practices require accurate predictions of two-phase flows for a better understanding of the system safety margins. Three-dimensional (3-D) multiphase computational fluid dynamics (MCFD) codes are emerging as a powerful and potentially practical tool for applications where detailed local flow information is needed, such as Nek-2P, the MCFD component of the NEAMS toolkit. To further advance Nek-2P, it requires high-quality and high-resolution experimental data of high void fraction steam-water boiling flows that include bubbly, slug, churn, and annular flows under conditions relevant to high-pressure nuclear reactor systems, i.e., at prototypic BWR pressures, flow rates, and heat fluxes as well as certain PWR accident conditions. In addition, film boiling that occurs at dry-out conditions (e.g., BWR critical power, LOCAs in LWRs) is also very important for reactor design and safety analysis. These experimental data are essential to the development and validation of physics-based MCFD models.

Most of the existing two-phase flow data currently being used for MCFD code development have several deficiencies as far as code validation and uncertainty quantification are concerned. Most data do not contain complete flow information of both phases. The other major deficiency is that in the existing databases, the measurement uncertainties are not typically quantified in a systematic and rigorous manner. Any of these deficiencies could greatly reduce the value of data for code validation purposes. In addition, current MCFD models could result in very different void-fraction distributions for the same flow conditions. Model development has been hindered by the lack of adequately resolved experimental data, and consequently, MCFD codes cannot be reliably used to predict two-phase flows under LWR conditions.

The primary objective of this proposed research is to develop a comprehensive, high-resolution, MCFD-validation-grade flow boiling database from rod-bundle geometry simulating current LWR fuel designs by taking advantage of the instrumentation and facility developed by the research team. In addition, the applicability of the data through initial evaluations of selected test cases using Nek-2P boiling closure models will be studied and demonstrated for two-phase flow simulations. The following specific objectives are proposed:

1. Perform detailed and systematic uncertainty quantification for the instruments developed in the research team's labs and other two-phase instruments that will be employed in this project, including X-ray radiography, high-speed imaging, PIV-PLIF, gamma densitometer, wire-mesh sensor, conductivity probe, and hot-film velocimetry, to determine the applicable ranges (void fraction and flow regimes) and associated measurement uncertainties for each selected measurement technique;

2. Experimentally investigate the flow boiling from subcooled boiling to film boiling over a wide void fraction range in a tubular test section and a rod-bundle test section up to 6.89 MPa; and

3. Validate and improve boiling-related closure models in Nek-2P and other MCFD codes using the high-resolution flow boiling database.