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Hydrodynamics of Two-Phase Flow under the Geometric Effects of Pipe Orientation and U-bends

PI: Seungjin Kim, Purdue University **Collaborators**: N/A

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ABSTRACT:

Fundamental understanding of two-phase hydrodynamic phenomena is critical to the design and safe operation of existing and proposed nuclear power plants. Most two-phase flow experiments have been performed in simple geometries and orientations, but real nuclear systems include piping with different orientations (with angles of inclination ranging from vertical and horizontal) and flow restrictions, such as elbows or inverted U-bends, where little data exists. As a result, fundamental two-phase flow parameters and phenomena under these varied geometries are not well understood and cannot be predicted with models developed for vertical upward two-phase flow conditions. Significant gaps also exist in the available multiphase computational fluid dynamics (MCFD) models for two-phase flows in these geometries, due to the limited experimental database. The objectives of this study are therefore to (a) perform experiments and establish a comprehensive and detailed database for two-phase parameters at a range of upward-inclined orientations and through U-bends with varying ratios of radius of curvature to pipe diameter (R_c/D); (b) evaluate and develop closure models applicable to two-phase flow subject to such geometric effects, and (c) evaluate and improve MCFD predictive capabilities in these scenarios.

To accomplish these objectives, the existing inclinable test facility at the PI's laboratory will be used. The facility can be fully inclined from 0° to 90° in increments of 0.1°, and consists of an upward section, a downward section, and a connecting U-bend made of 25.4 mm diameter pipe. It can achieve flow conditions from $\mathrm{Re}_f = 1{,}300$ to $110{,}000$ and $\mathrm{Re}_g = 50$ to $40{,}000$, covering a wide range of two-phase flow configurations of interest. Four-sensor conductivity probes will be used for detailed local time-averaged void fraction, bubble velocity, Sauter-mean diameter, and interfacial area concentration measurement at over 100 points across the pipe cross section. An impedance meter and high-speed camera will be used to aid in flow regime identification, while measurements from the pressure transmitter will enable the calculation of frictional pressure loss. The gamma densitometer and LDA system will be used for benchmarking the void fraction measurements and single-phase liquid velocity profiles, respectively. Transport phenomena of two-phase flow in pipes over a wide range of inclination angles will be studied, including the angles at which characteristic differences between the vertical and horizontal two-phase flows are highlighted. U-bends with at least three different R_c/D ratios will be used to investigate the effect of the degree of curvature on two-phase flows. The extensive database established in the experiments will be used not only to evaluate existing models but to develop new closure relations applicable to two-phase flows with geometric effects. More specifically, these include two-phase frictional pressure loss (as well as the minor loss), relative velocity and interfacial drag, objective flow classification methods, and void fraction and interfacial area transport models. In parallel to experimental studies, MCFD simulations will be performed and benchmarked against the experimental data. Any discrepancies will be studied, and improvements will be made by employing proper closure relations.

The deliverables of the proposed study will include a comprehensive database of local and global two-phase flow parameters, newly developed closure models applicable to two-phase flows subject to geometric effects of interest, improved MCFD code capable of accounting for the effects of flow orientation and U-bend on two-phase flow transport, and technical reports with detailed summaries of these results. The knowledge gained at the completion of the proposed study will subsequently be used to improve the design and safety analysis of nuclear reactor systems, including advanced nuclear reactors.