Bubble Lift-off Size in Subcooled Flow Boiling for Inclined Heating Surface

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Abstract: The study of bubble characteristics for inclined heating surface is essential to successful implementation of In-Vessel Retention (IVR) technique following the critical heat flux (CHF). An experimental facility has been designed with a high-speed video camera system to investigate the bubble lift-off process for different inclination angles of heating surface from downward-facing horizontal to vertical position.

Keywords: Lift-off diameter, inclination angle, subcooled flow boiling, in-vessel retention, flow visualization.

1. Introduction

In-Vessel Retention is an effective method for protecting the reactor pressure vessel integrity in case of a major nuclear reactor accident. For the LWR, the effectiveness of this strategy relies soundly on decay heat removal capability, the critical heat flux (CHF), from the external surface of RPV lower plenum, whose orientation angle varies gradually from heading downward horizontal to the vertical position. The heat transfer from the outer surface of RPV to coolant is significantly affected by the vapor quality i.e., the void fraction. The significant void has started from the net vapor generation points (NVG), and according to Basu et al. [1], the NVG is the point where the bubble lift-off rather than the departure from the heating surface. The source term, the rate of vapor added to the bulk, and the sink term, the condensation rate in the liquid-vapor interface, of the two-fluid model used to predict the void fraction in subcooled flow boiling. Along with the interfacial area transport equation [2], the two-fluid model [3] has used in the CFD codes to analyze the thermal-hydraulic characteristics of a nuclear reactor. In the interfacial area transport equation and the void fraction prediction, bubble lift-off diameter is more significant than the departure diameter. The present research aims to evaluate the impact of channel orientation, heat flux, mass flux, and inlet subcooling on the bubble lift-off diameter in subcooled flow boiling. The data of bubble lift-off diameter are obtained with a wide range of test conditions using the current experimental facilities.

2. Experimental setup and conditions

The rectangular test section shows in Fig. 1 that consists of a stainless-steel body having three viewing windows (front, back, and one side) and three cylindrical heaters that fit on the other side with a heater case. The water flow through a square channel that has a width of 8 mm, depth of 8 mm, and a length of 25 cm. The test section is mounted on a particular type of stand so that its orientations can be adjusted to any angle from 0^0 (downward facing) to 90^0 (vertical up-flow). The present experimental matrix consists of mass flux of 430 to 1180 kg/m^{2}s, heat flux of 0.07 to 0.271 MW/m^2, inlet subcooling of 10 to 40 ^{0}C and inclination angle of heating surface from downward facing horizontal to vertical position.

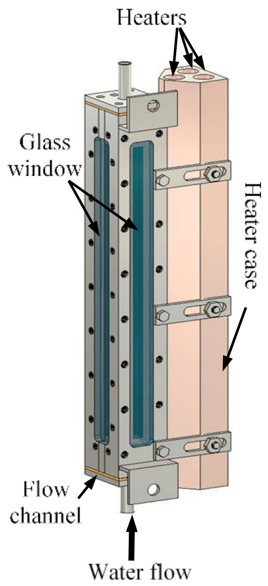

Figure 1. Test section

3. Results and discussions

Experimentally it was observed that the bubbles slid a very short distance on the heating surface, which is equal to a couple of lift-off diameter, before lift-off. An increasing trend of lift-off diameter was observed in rotating the heating surface towards the downward-facing horizontal conditions. The impact of inclination angle on bubble lift-off diameter is shown in Fig. 2. The tangential component of the buoyancy force is maximum in vertical condition that promotes the lift-off, and it reaches a minimum value. In the other hand, vapor bubbles are experienced by the buoyancy force in the perpendicular direction of quasi-steady drag force in downward-facing conditions. This buoyancy force tends to remain the vapor bubble in the heating surface, and it grows continuously until lift-off occurs. Thus the bubble has experienced the maximum lift-off size in the downward-facing horizontal flow boiling conditions. From the experiment result it also observed that the lift-off diameter increases with increasing heat flux, decreasing mass flux and inlet subcooling.

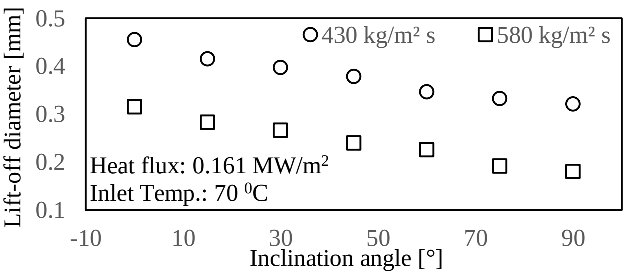

Figure 2. Impact of inclination angle on lift-off diameter

4. Conclusion

Experimental research on bubble lift-off diameter at NVG point with different inclination angle conditions for subcooled flow boiling is carried out. The bubbles were observed to slide before lift-off from the heating surface. A significant effect of orientation angle on the bubble lift-off diameter was found at low mass flux conditions, and the maximum lift-off diameter was achieved in the downward-facing horizontal heating surface, whereas the minimum one was at vertical conditions.

References:
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