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The Influence of Transverse Heat Flux Distribution on the Flow Instability for Subcooled Boiling Through a Narrow Rectangular Channel

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1. Introduction

Many engineering systems have a non-uniform power distribution, such as nuclear reactors. Different heat flux distributions lead to variation in local thermal hydraulic parameters; for single-phase and two-phase flow. Hence, areas that have high local heat flux initiate bubbles earlier compared to the low heat flux areas. Discrepancies in the Onset of Nucleate Boiling (ONB) were observed under uniform and non-uniform heat flux distribution in the transverse direction [1]. Different bubble generation may lead to different thermal hydraulic behavior through the flow channel, which especially appears after the significant bubble formation or significant void generation (SVG). Once the void fraction dramatically increases, mass and heat transfer instability occur through the channel, which is called Onset of Flow Instability (OFI). The flow channel remains stable when the slope of pump curve is lower than the one of system demand curve. On the other hand, once the slope of pump curve is higher than the one of system demand curve, the flow channels becomes unstable. In uniform heated channels, the OFI occurs at the same time with the Onset of Inlet Pressure Fluctuation (OIPF) [2]. A detailed review of flow instability under uniform heated channels is presented by Ruspini et al. [3]. Many experimental researches were conducted to investigate the OFI behavior in conventional and narrow channels [4-6].

Flow instability consideration is very important for designing a coolant systems that can operate under two-phase flow conditions. This research experimentally investigates the influence of power distribution along the transverse direction on the flow instability for narrow rectangular channel. The study provides a detailed comparison of the thermal hydraulic behaviors under uniform and non-uniform heat flux distribution during the flow instability.

2. Experimental setup

The schematic diagram of the experimental loop is shown in Fig. 1. The facility consists of a test section, water tank, heat exchanger, circulation pump, flow meter, preheater, pressure transmitters, thermocouples, high-speed camera, and data acquisition system (DAQ). More details on the experimental loop and test parameters are given by Al-Yahia and Jo [2].

Two test sections are used to perform the experiment, a uniformly distributed heat test section, and non-uniformly heated test section. The main difference between the two test sections is the air gap located between the Aluminum and Copper block of the non-uniform test section. This gap is found to cause a higher heat flux near the edges and lower heat flux at the middle of the test section, as shown in Fig. 2. In the non-uniform test section, the local heat flux is measured using seven double thermocouples. The water flows through a narrow rectangular channel under atmospheric pressure. The channel has thickness of 2.35 mm, width of 54.0 mm, and length of 560.0 mm. The channel is heated from one side with 50 mm heater width and 300 mm length. The other side of the channel is polycarbonate window to visualize the bubble formation using high speed camera.

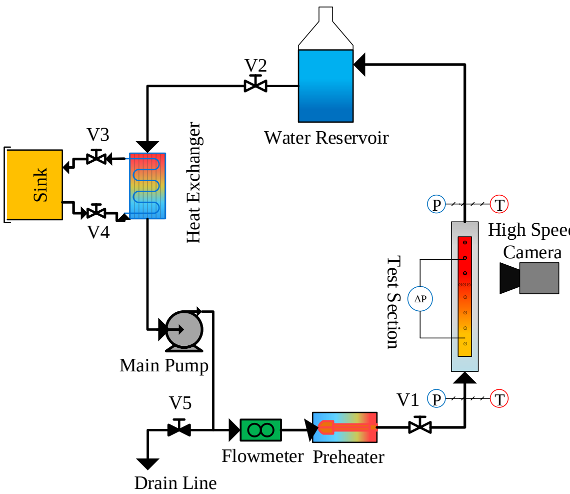

Fig. 1. Experimental loop.

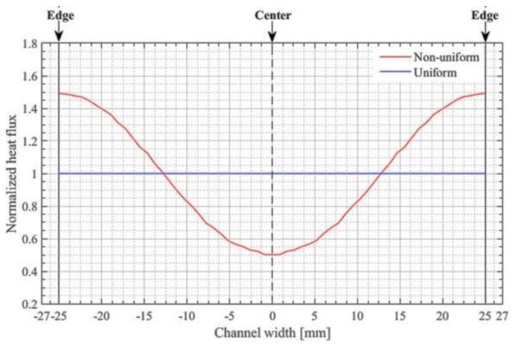

Fig. 2. Transverse heat flux distribution

3. Results and discussion

The experiments are performed by increasing power while mass flow rate remains constant. Fig. 3 shows the evolution of pressure drop and inlet pressure for uniform test section, and Fig. 4 shows the results of non-uniform test section. Initially, the flow corresponds to a single-phase, and the behavior is similar for both test section; uniform and non-uniform. While the power increases, the pressure drop slightly reduces due to the changes in water viscosity and density. Further increasing in the power, the bubbles initiate on the heated surface (ONB) as indicated in point (1) Fig.3 and Fig. 4. For uniform test section, ONB starts around the center line, as shown in Fig. 5. However for non-uniform case, ONB occurs near the edges where the local heat flux is high, as shown in image (1) Fig. 6. Bubble formation leads to a little increase in the pressure drop. Afterward, bubbles significantly generate and OIPF occurs at point (2) in Fig. 3 and Fig. 4. Owing to the high local flux for non-uniform case, OIPF occurs at power lower than the one of uniform case. After the OIPF, the pressure drop behavior between uniform and non-uniform test section differs. For uniform test section, the pressure drop rapidly increases with the power, which designates flow instability. However, the pressure drop does not rapidly increase after OIPF for the non-uniform case. For non-uniform case, the pressure drop suddenly decreases simultaneously with reduction in the amplitude of the inlet pressure fluctuation, and it reaches its minimum value at point (4). Subsequently, the pressure drop increases rapidly and the inlet pressure fluctuation increases.

The inlet pressure fluctuation is caused by the bubble generation and condensation. When the bubbles are generated, the inlet pressure increases spontaneously due to the contraction on liquid as a result of bubble expansion. Conversely, when the bubbles condense, the inlet pressure decreases due to the expansion in the liquid as a result of bubble collapsing. Different heat flux distribution leads to differences in the bubble generation rates. When the bubbles near the edges generate and the ones in the center condense or vice versa, a reduction in the inlet pressure occurs. However, when the bubbles near the edges and the center generates and condense together, the inlet pressure fluctuation rate increases. Fig. 7 can explain this phenomena, for points (3) and (5) in Fig. 6, the normalized void fraction near the edges and center exhibit similar action with the time in which the bubble generation and condensation occur simultaneously. However, shifting is observed in the peak of normalized void fraction between edge and center at point (4), because the bubble generation and condensation in the center region occur at different moment from those near the edges.

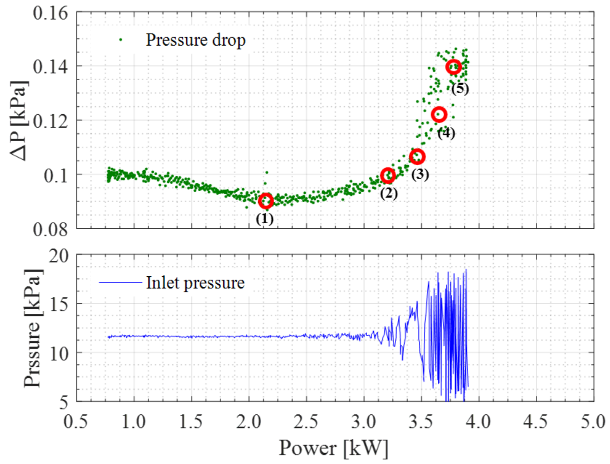

Fig. 3. Thermal hydraulic parameters for uniform test section (mass flow rate of 0.03 kg/s and inlet temperature of 35°C).

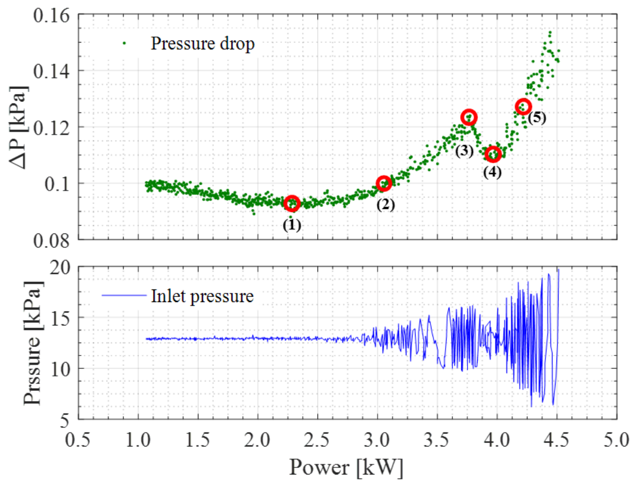

Fig. 4. Thermal hydraulic parameters for non-uniform test section (mass flow rate of 0.03 kg/s and inlet temperature of 35°C).

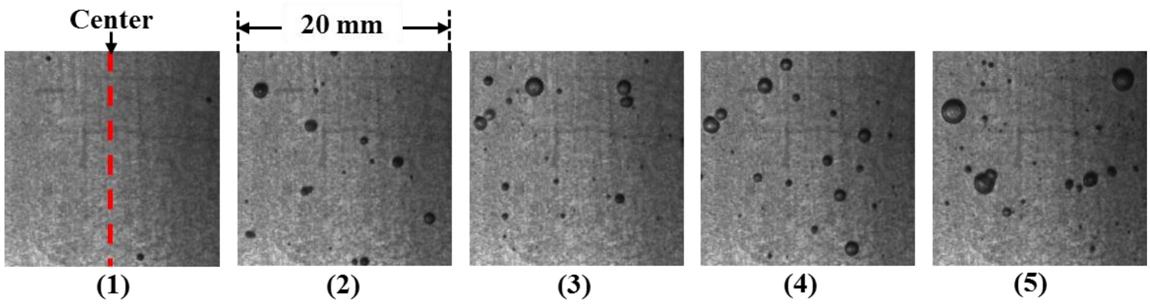

Fig. 5. Bubble images for uniform test section (mass flow rate of 0.03 kg/s and inlet temperature of 35 °C).

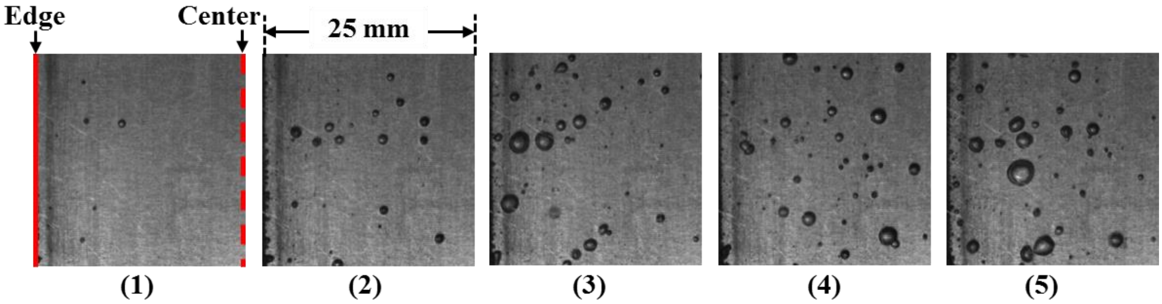

Fig. 6. Bubble images for non-uniform test section (mass flow rate of 0.03 kg/s and inlet temperature of 35 °C).

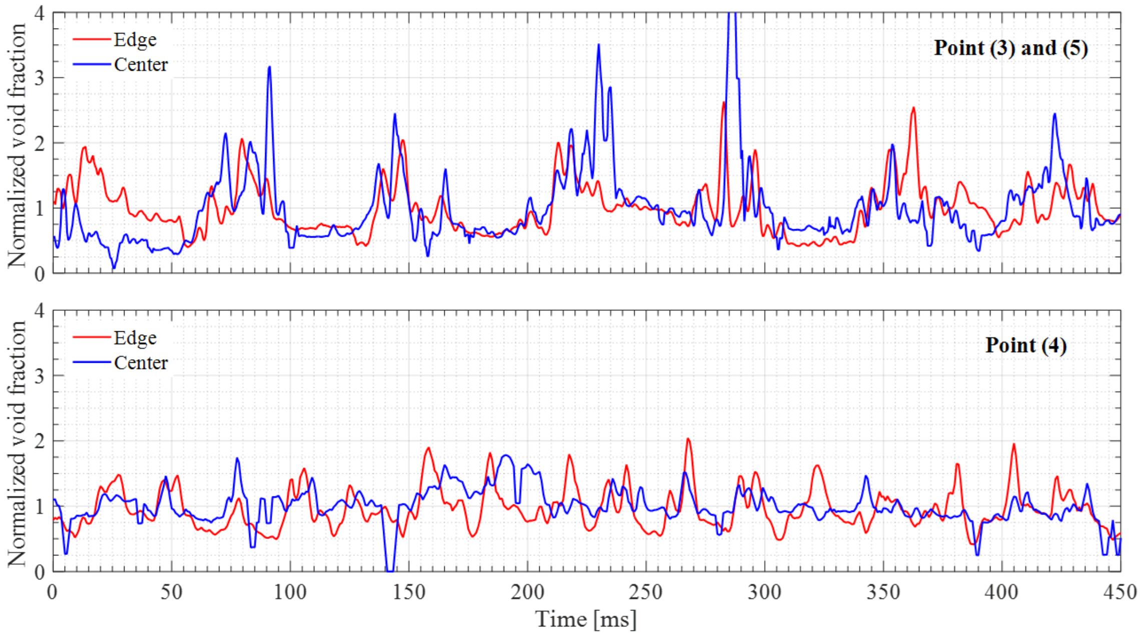

Fig. 7.Time behavior void fraction under non-uniform heat flux (mass flow rate of 0.03 kg/s and inlet temperature of 35 °C).

4. Conclusion

The influence of transverse heat flux distribution on the flow instability is experimentally investigated. Discrepancies in pressure drop and inlet pressure occur between uniformly and non-uniformly heated sections. In the uniformly heated case, the pressure drop rapidly increases after the incipience of flow instability, which occurs simultaneously with OIPF. However, in the non-uniform case, the pressure drop increases after the OIPF for a while. When the inlet pressure fluctuation reduces, the pressure drop decreases. Subsequently, pressure drop increases once again when the inlet pressure fluctuation increases.

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