Flow instability and critical heat flux for downward flow in a vertical narrow rectangular channel heated from both-sides

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1. Introduction

The static flow instability (FI) and critical heat flux (CHF) for subcooled flow boiling in a vertical narrow channels under low pressure condition are fairly crucial phenomena relative to thermal-hydraulic design and safety analysis for pool-type research reactors. It has been recommended that RRs and MTRs be designed to have sufficient margins for CHF and the onset of FI as well [1], since unstable flow could leads to premature CHF under very low wall heat flux in comparison to stable CHF. Even the fact and previous studies, however, the understanding of relationship among FI, premature CHF and stable CHF is not sufficient to date.

In this regards, subcooled flow boiling in a vertical rectangular channel was experimentally investigated to enhance the understanding of the CHF and the effect of the two-phase flow instability on it under low pressure conditions, especially for downward flow which was adopted for Jordan Research and Training Reactor (JRTR) and Kijang research reactor (KJRR) to achieve easier fuel and irradiation rig loading. In addition, visual observations of subcoold flow boiling was conducted by using high-speed video (HSV) for a clear understanding of both phenomena.

2. Methods and Results

2.1 Experimental descriptions

An experiment on the flow boiling of water under atmospheric pressure was performed using the KAIST flow boiling loop, which is consists of the test section part, a plate-fin heat exchanger, a centrifugal pump, an electromagnetic flow meter, a surge tank with an overhead water reservoir, a pre-heater and piping, as shown in Fig. 1. Three system configurations were adopted to see system dependency on flow instability and CHF; the upper plenum connected to open pool (system 1), system disconnected to open pool (system 2) and bottom plenum connected to open pool (system 3). System 1 and 3 are open systems maintaining atm. pressure at inlet and outlet, respectively. A total of 26 CHF data (premature/stable) were obtained with narrow rectangular channel with 2.35 mm in gap, 40 mm in width (30 mm in heated width) and 350 mm in heated length (see Fig.1) for with/without throttling conditions. The experiment conditions were summarized in Table 1.

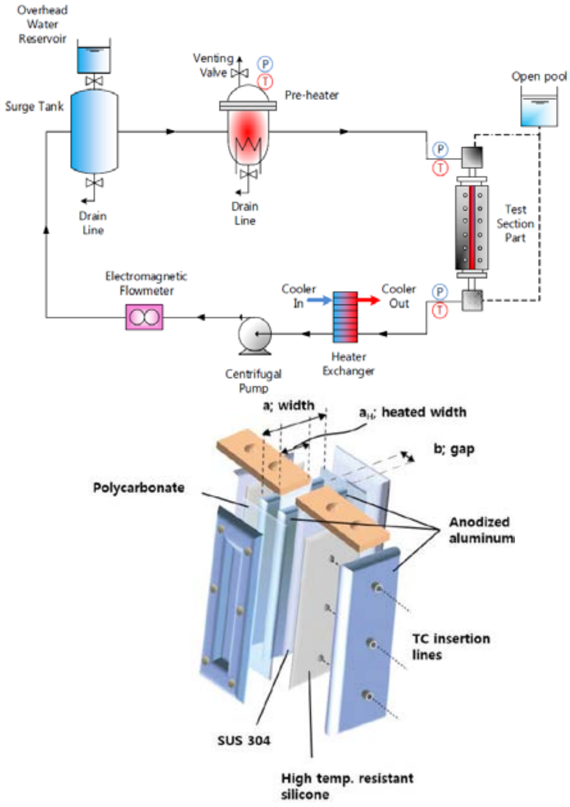

Fig. 1. Schematics of the test loop and test section.

Table I: Experimental condition

Channel dimension	Width of clearance (heated)	40 mm (30 mm)
	Gap size	2.35 mm
	Channel length	350 mm
Flow parameter	Pressure, P	~ 1 bar
	Inlet Temperature, Ti	25 - 44 °C
	Mass Flux, G	276 - 1290 kg/m^2s

2.2 Parametric trends

Regardless of the system configuration and amount of throttling, as wall heat flux was increased for given mass flux condition, the point at which channel pressure drop begin to fluctuate with distinguishable amplitude was observed as shown in Fig 1. (Onset of pressure drop fluctuation, namely OPDF). For non-throttling or low throttling conditions, premature CHF were triggered by flow excursion by the failure of the counteraction to the large pressure drop perturbation caused by vigorous boiling inside the channel, due to the insufficient throttling. (Fig. 2 (a) and Fig. 3).

For large throttling applied, however, sufficient heat flux condition could be achieved to see the fluctuating segment of pressure drop and stable CHF could be reached (Fig. 2 (b) and Fig. 3). CHF data were asymptotically approach stable value as the amount of inlet throttling increased, which were underestimated from the correlation for narrow rectangular channel for downward flow proposed by Sudo et al. [2] (Fig. 3).

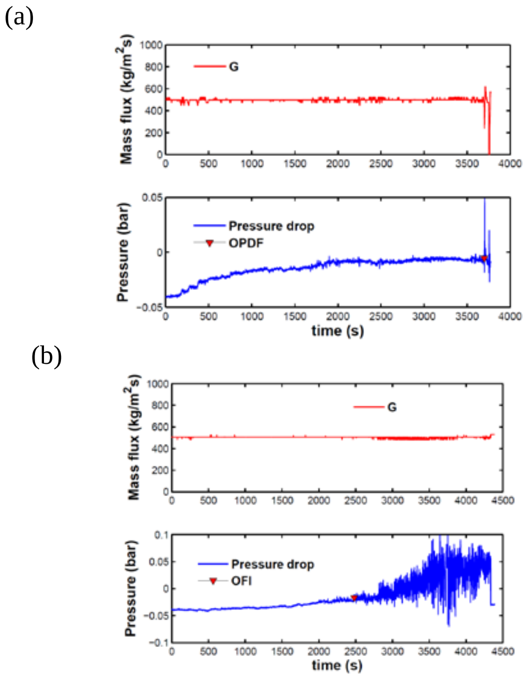

Fig. 2. For $G = 500kg/m^2s$ (a) W/O throttling ($T_i = 29\ ^oC$, $\Delta P_{thro} = 105$ mbar) (b) With large throttling ($T_i = 44\ ^oC$, $\Delta P_{thro} = 989$ mbar)

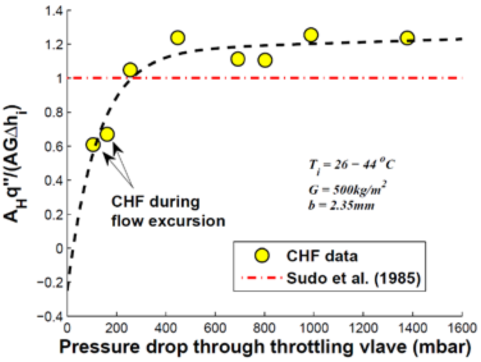

Fig. 3. Inlet throttling effect on CHF

2.3 Visualization

We visualized subcooled flow boiling for downward flow within narrow rectangular channel at the vicinity of OPDF, which directly showed that the OPDF was closely related to the coalescence of facing bubbles on opposing heated surfaces (Fig. 4). Production of large vapor due to the coalescence caused largely perturbation of channel pressure drop leads to premature CHF when a system has no resistibility to the pressure drop perturbation.

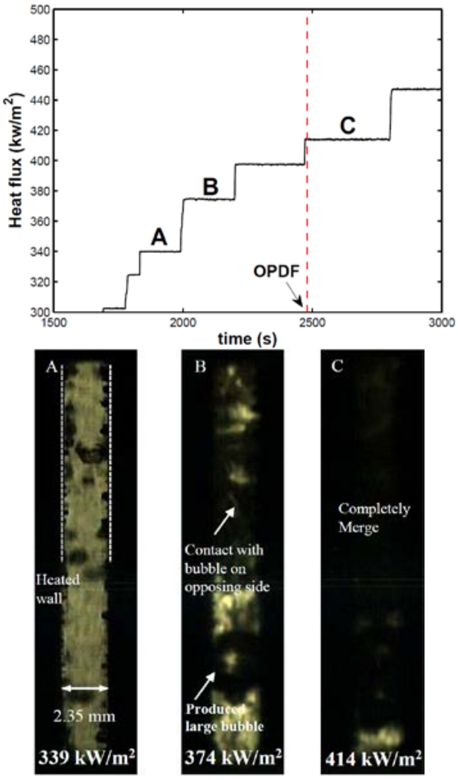

Fig. 4. Visualization of subcooled boiling (for $G = 500kg/m^2s$, $T_i = 44\ ^oC$, $\Delta P_{thro} = 989$ mbar)

3. Conclusions

We concluded that flow excursion (which is static instability) could be induced due to the OPDF (which is dynamic instability) when a system has no resistibility to the pressure drop perturbation, which is caused by the coalescence of facing bubbles on opposing heated surfaces. In more stable system with throttling applied, flow rate could be maintained and stable CHF could be reached.

REFERENCES

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