An Experimental study on Onset of Flow Instability for Downward flow within Narrow rectangular channels

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1. Introduction

For flow boiling systems, it's impossible to make stable operation under certain conditions so that these are of great concerns in the design and operation of such systems. So-called two-phase flow instability has possibility to cause heat transfer degradation and then it may lead mechanical damages to heat transfer surface, it should be avoided in normal and transient conditions. Among various two-phase instabilities, flow excursion, also known as the Ledinegg instability or Onset of Flow Instability (OFI) is major concern of thermal hydraulic design and safety analysis of research reactors which is under low flow and low pressure condition.

The preferred configuration for boiling channels is vertical upward flow since buoyancy helps the mixture flow, and the slip velocity between the two phases that is caused by their density difference actually improves the heat transfer. [1] However, boiling with downward flow is also of interest for accident conditions of upward flow system or even normal conditions of research reactors such as Jordan research and training reactor (JRTR) which adopts downward flow for easier fuel loading.

JRTR is 5MWth open pool-type research reactor which was designed to utilize plate type fuel taking account of efficient heat removal by Korea Atomic Energy Research Institute (KAERI). It is design to be cooled by downward flow through narrow rectangular channels to maximize heat removal efficiency and to minimize fuel vibrations. However, previous OFI data is very limited for narrow rectangular channel and downward flow condition. In this study, data of onset of flow excursion conditions were generated and analyzed.

2. Methods and Results

2.1 Experimental setup

A test loop is designed for this study, which is composed of test section, pre-heater, surge tank with overhead water reservoir, flow meter, pump and heat exchanger as indicated in Fig. 1. Inlet pressure is maintained at atmospheric pressure by opening to air at upper plenum. Inlet subcooling is controlled by heat exchanger and pre-heater. To obtain pressure drop in heated channel thermocouple and pressure are installed at both inlet and outlet.

Test section is designed and fabricated to construct both-side heated channels in Fig. 2. (Dimension of test sections is indicated in Table I). Heated width is designed to be shorter than total width of channel for avoiding overheating at comers

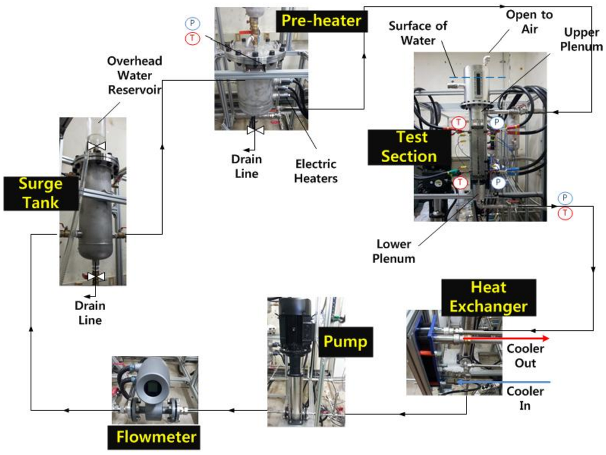

Fig. 1. Schematics of KAIST flow loop

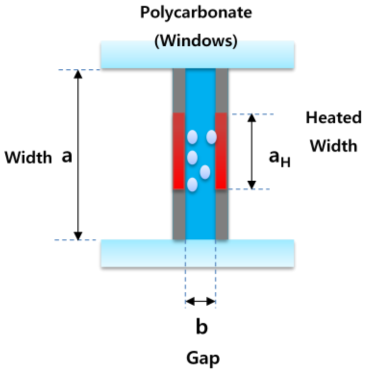

Fig. 2. Schematic of cut view of test section

Table I: Dimension of narrow rectangular channel (in mm)

No.	b	a	a_H	L_H	De	D_H	D_H / L_H
1	2.5	40	30	350	4.7	6.67	0.019
2	3.3				6.1	8.8	0.025
3	4.1				7.4	10.9	0.031

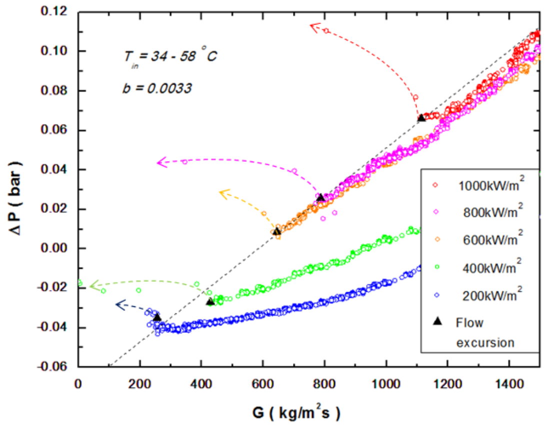

Fig. 3. Demand curves for several imposed heat flux conditions

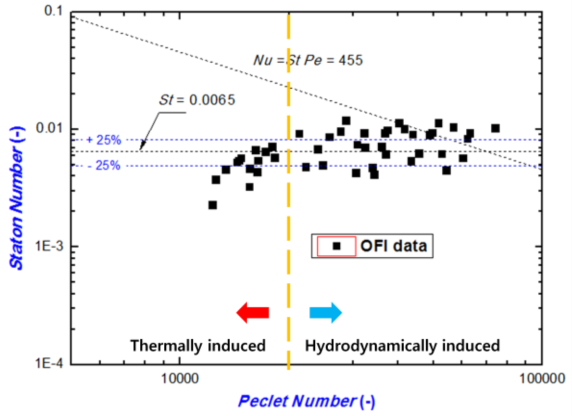

Fig. 4. Comparison experiment data to Saha and Zuber OSV correlation

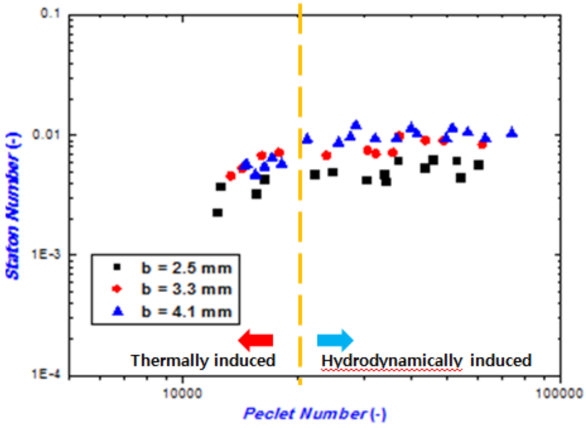

Fig. 5. Gap size effect on OFI experimental data within *St* – *Pe* domain

2.2 Experimental results

Demand curves were obtained by measuring test section pressure drop as fluid mass flux was varied starting from sufficient high mass flux for no boiling until flow excursion occur, for several imposed heat fluxes as indicated Fig. 3. For specific imposed heat flux, pressure drop decrease as mass flux decrease and then with specific mass flux condition, flow excurse and quickly reduced as pressure drop goes up. Flow excursion occurred at very near minimum point of demand curve for most imposed heat fluxes. For very low heat flux, it was possible to obtain stable pressure drop and mass flux beyond pressure drop minimum.

We identified conditions of flow excursion for OFI for all conditions which is summarized in Table Ⅱ and gathered 47 data.

Table Ⅱ: Test Matrix

T_{in}	P_{in}	Heat Flux
25~58 °C	~1bar	100~1000 kW/m^2

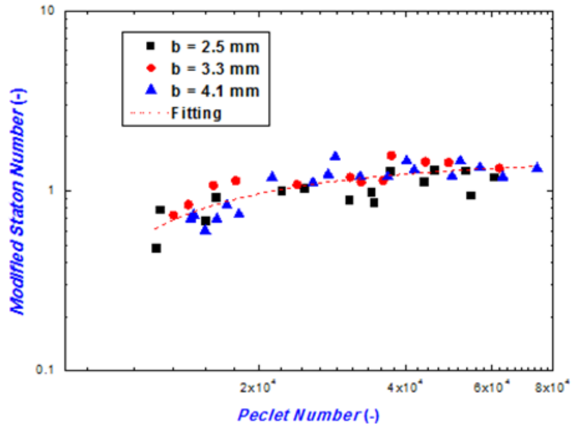

Fig. 6. OFI experimental data within modified *St* – *Pe* domain

3. Conclusions

As indicated Fig.3., all experiment data is compared to well-known Saha and Zuber Onset of Significant Void fraction(OSV) correlation within dimensionless Staton number and Peclet number domain. All OFI data is strongly related to OSV, however there are gap size effect on OFI within dimensionless St-Pe domain as indicated Fig. 5. To develop correlation predicting OFI under experiment condition, modified Stanton number should be suggested;

$$\textit{Modified St} = \frac{P_H L_H q''}{A G C_{pl} \Delta T_{OSV}} \tag{1}$$

As indicated in Fig.6. all OFI data is correlated by the proposed dimensionless parameters.

REFERENCES

[1] S. Ghiaasiaan, Two-phase flow, boiling and condensation in conventional and miniature systems, Cambridge Univ. Press, pp. 321, 2008

[2] P. Saha, N. Zuber, Point of net vapor generation and vapor void fraction in subcooled boiling, Proceedings of the 5th International Heat Transfer Conference, Tokyo, Japan, P. 175-179, 1974