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An Experimental Study on the Onset of Nucleate Boiling in Narrow Rectangular Channels for Downward Flow

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1. Introduction

Some research reactors such as Jordan Research & Training Reactor (JRTR) are designed to operate under the low pressure for downward flow. As the research reactors operates with downward flow, they have some advantages; downward flow can reduce the radioisotopes in the upper part of research reactor and simplify the locking mechanism as countervailing the buoyancy force on the nuclear fuel.

However, as the research reactor operates under the low pressure condition, the premature critical heat flux (CHF) can occur during the onset of flow instability (OFI) according to circumstances as the pressure fluctuates significantly. For that reason, it is important to know and set the margin for the onset of nucleate boiling (ONB) which is the preceding phenomena of OFI and CHF to predict and handle with OFI. In addition, research reactor is the nuclear reactor serves neutron source for many research fields such as neutron scattering, non-destructive testing, radioisotope treatment and so on, it is important to avoid ONB to get stable neutron source. IAEA also recommends for research reactors to have enough ONB margin to maintain the normal operation state in 'IAEA-TECDOC-233' (1980) [4].

Though the ONB in research reactor is emphasized for these reasons, there isn't sufficient ONB data under downward flow condition and no ONB prediction correlation for downward flow as well. In addition, in many researches; Mosyak et al.[8], Hapke et al.[2], Wu et al.[11] and Hong et al.[3], the existing ONB correlations are not suitable for narrow rectangular channel. In the present work, not only a new ONB prediction correlation would be developed, but also comparison between new correlation with several ONB correlations would be shown.

In this paper, ONB data would be analyzed to develop new ONB prediction correlation.

2. Experiment Set

The experimental loop in KAIST (Korea Advanced Institute of Science and Technology) is installed as shown in Fig.1. The experimental loop is composed of the test section, an open pool, a heat exchanger, a centrifugal pump, an electromagnetic flow meter, a surge tank, a pre-heater and piping. The experiment was performed under the atmospheric pressure as the outlet of test section is connected to open pool.

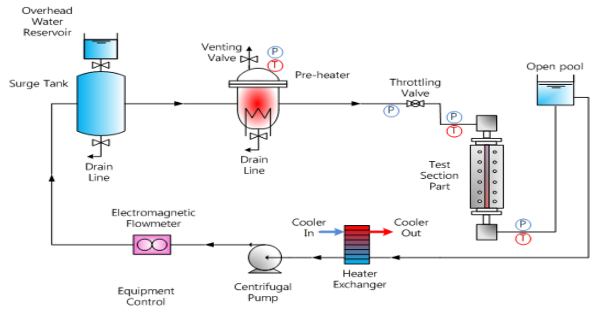

Figure 1. Schematic of experimental loop installed in KAIST [6]

The experiment was performed in a 350 mm length narrow rectangular channel (entire section is heated). In the test section, the channel width and gap are 40 mm and 2.35 mm, respectively, as shown in Fig.2. The heater width is 30 mm. Six thermocouples are installed at the back of the heaters along the axial direction. To handle the effect of conduction of the heater itself, the measured wall temperature was calibrated after the experiments.

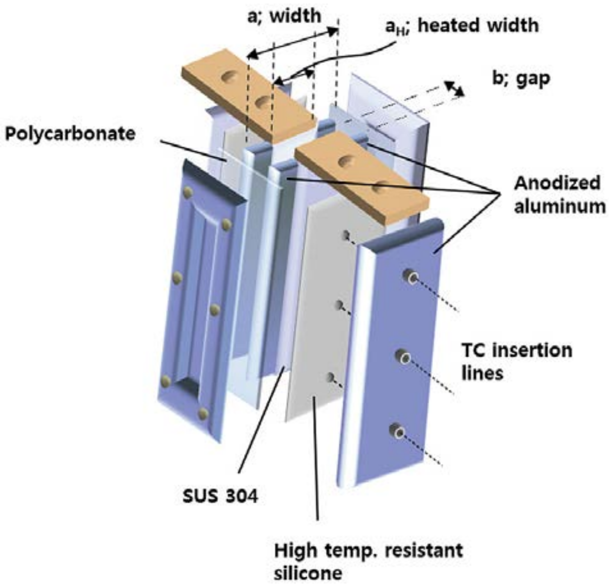

Figure 2. 3-D cut-view of test section [6]

In McAdams et al.[7], it is noted that not only the non-condensable gas and the entrapped gas, but also the dissolved gas affects the incipience of boiling considerably. For that reason, the water is degassed by pre-heated at 70°C for 2 hours before performing the experiments.

The test matrix is explained in Table 1.

Table 1. Test Matrix

Flow direction	Mass flux ($kg/m^2 s$)	Inlet subcooling (°C)	Pressure (bar)
Downward	300~1000	70	Atmospheric

3. Results

The model by Bowring (1962) [13] defines the incipience boiling point as the single-phase heat transfer and fully developed boiling heat transfer's point of intersection. In this experiment, same methodology is used for defining ONB as in Fig.3. Fig.3 shows the example of intersection point in boiling curve for the experiment.

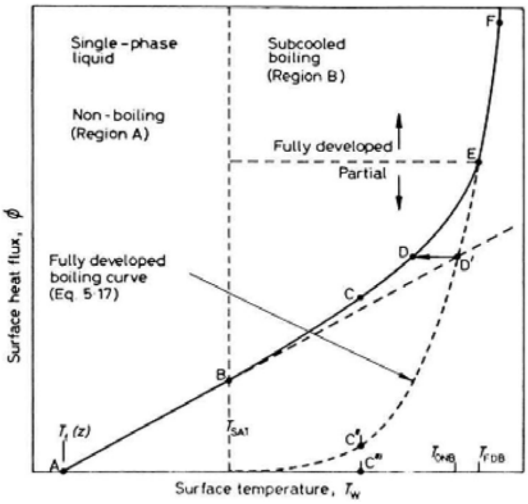

Figure 3. Wall temperature vs. Heat flux [13]

To develop the ONB prediction correlation, it is needed to compare the data with existing correlations. After analyzing experimental data through comparing with single-phase heat transfer correlations and two-phase heat transfer correlations, ONB prediction correlations could be developed.

To analyze the single-phase heat transfer data, Dittus-Boelter, Omar S. and Sudo correlations will be used for turbulent flow.

Dittus-Boelter correlation is

$$Nu = 0.023 * Re^{0.8} * Pr^{\frac{1}{3}} \quad (1)$$

for upward and downward flow.

Omar S. correlation [1] is

$$Nu = 0.01715 * (Re^{0.6704} * Pr^{0.22}) * z^{*-0.2097} * \left(\left(\frac{T_b}{T_w}\right)^{0.1757} * \left(\frac{D_h}{z}\right)^{-0.007}\right) \quad (2)$$

where $z^* = \frac{z}{D_h * Re * Pr}$ for upward and downward flow.

Sudo correlation [10] is

$$Nu = 2.25 * Gz^{0.268} \quad (3)$$

where $Gz = \frac{D_h * Re * Pr}{z}$ for a downward flow.

To analyze the two-phase heat transfer data, Lazarek & Black [5], Shah [9], and Yu [12] correlations are considered to be used.

4. Conclusion

In this study, an experiment on the single-phase heat transfer and two-phase heat transfer will be conducted. Comparison between experimental data and existing correlations will be used for developing ONB prediction correlation.

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