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An Experimental Study on the Convective Heat Transfer in Narrow Rectangular Channels for Downward Flow to Predict Onset of Nucleate Boiling

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1. Introduction

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. Due to that characteristic of research reactor, as many people work around the research reactor, research reactor should be designed to have much more conservative margin for normal operation. Boiling heat transfer is the one of the most efficient type in heat transfer modes, however, research reactor needs to avoid onset of nucleate boiling (ONB) in normal operation as IAEA recommend for research reactors to have enough ONB margin to maintain the normal operation state in 'IAEA-TECDOC-233' (1980) for the same reason explained above [1]. Jordan Research & Training Reactor (JRTR) operates under downward flow in narrow rectangular channel in fuel assembly. There isn't sufficient heat transfer data under downward flow condition and only few ONB prediction correlation as well. In the present work, not only a new ONB prediction model would be developed, but also comparison between heat transfer data with several heat transfer correlations could be shown.

In addition, as Sudo and Omar S. proposed differently about the Nussel number behaviors in upward and downward convective heat transfer, the study of convective heat transfer should be conducted continuously to determine it exactly.

In this paper, single-phase heat transfer data is analyzed by several heat transfer correlations before developing ONB prediction correlation.

2. Experiment Set

The experimental loop is located in KAIST (Korea Advanced Institute of Science and Technology) as shown in Fig.1. The experiment was performed under the atmospheric pressure. The experimental loop is made up for the test section, a heat exchanger, a centrifugal pump, a flow meter, a surge tank, a pre-heater and piping.

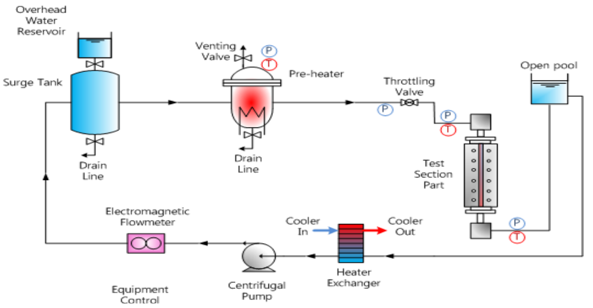


Figure 1. Schematic of experimental loop installed in KAIST [2]

The experiment was performed in a 350 mm 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 each heater along the axial direction. To exclude the effect of conduction on the heater, the measured wall temperature was calibrated after the experiments.

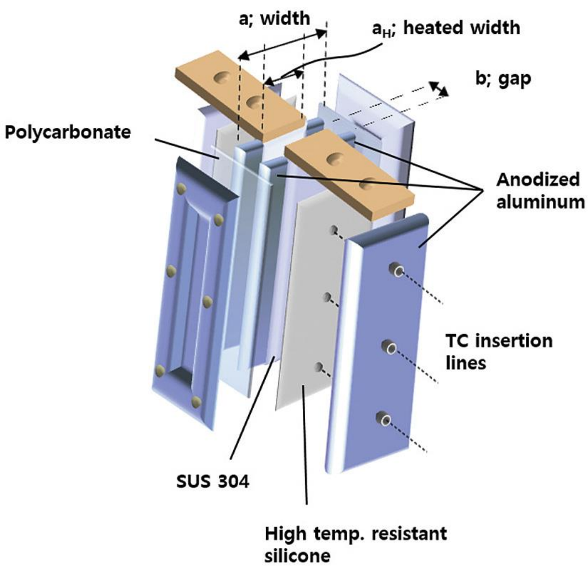


Figure 2. 3-D cut-view of test section [2]

The experiment conditions are explained in Table 1.

Table 1. Experiment conditions

Flow direction	Mass flux $(kg/m^2 s)$	Inlet Temp (°C)	Pressure (bar)
Downward	300~800	28~40	Atmospheric

3. Results

Mosyak et al. [3] defines the ONB as the deviation point of single-phase heat transfer (subcooled state) to two-phase heat transfer in boiling curve. The model by Bowring (1962), well-known model, 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 and Fig.3 shows the example of intersection point in boiling curve for the experiment.

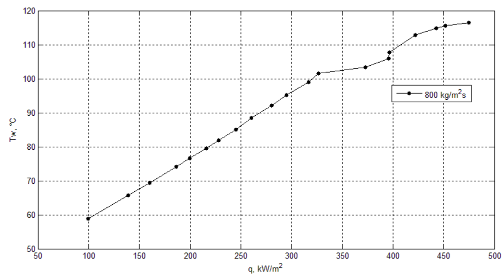


Figure 3. Wall temperature vs. Heat flux

To develop the ONB prediction correlation, it is needed to compare the data with existing correlations. After analyzing experimental data through comparing both single-phase heat transfer data with single-phase heat transfer correlations and two-phase heat transfer data with 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 are used for turbulent flow.

Dittus-Boelter correlation is

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

for upward and downward flow.

Omar S. correlation [4] is

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

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

Sudo correlation [5] is

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

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

Fig.4 shows the comparison between single-phase heat transfer data and existing correlations.

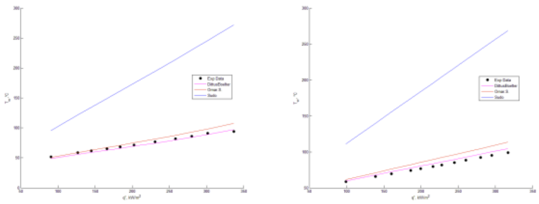
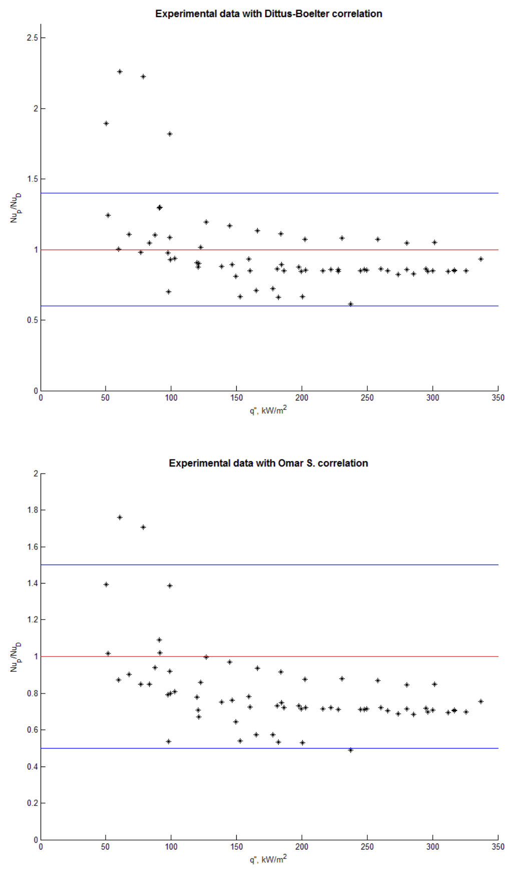


Figure 4. Single-phase data comparison with correlations

As shown in Fig.5., the experimental data agree pretty well with existing correlations except for Sudo correlation. Dittus-Boelter correlation has ±40% RMSE to meet the 94% confidence level and Omar S. correlation has ±50% RMSE to meet the 95% confidence level. Sudo correlation shows huge error as 85% RMSE to meet the 100% confidence level.

Also, the ratio of predicted Nussel number and experimental Nussel number tends to fit well as heat flux increases.



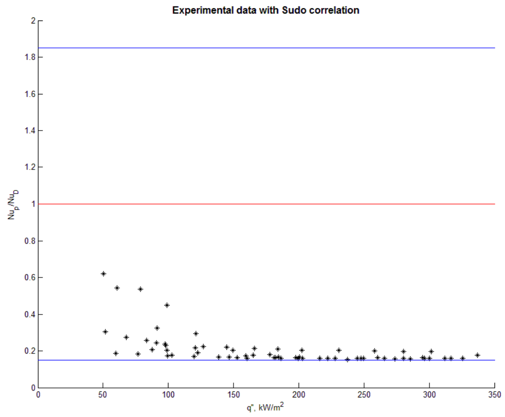


Figure 5. Comparison between experimental data and several correlations

4. Conclusion

In this study, an experiment on the single-phase heat transfer was conducted. As shown in Fig.5, comparison between experimental data and existing correlations shows quite huge difference as about 40%. Additional experiments on single-phase heat transfer at low heat flux are necessary to clarify the tendency of Nussel number among heat flux and to develop new correlation for single-phase heat transfer.

REFERENCES

[1] IAEA-TECDOC-233, “Research reactor core conversion from the use of highly enriched uranium to the use of low enriched uranium fuels guidebook”, IAEA, 1980.

[2] J. Lee, H. Chae, S.H. Chang, “Flwo instability during subcooled boiling for a downward flow at low pressure in a vertical narrow rectangular channel”, International Journal of Heat and Mass Transfer, vol. 67, pp. 1170-1180, 2013.

[3] A. Mosyak, L. Rodes, G. Hetsroni, “Boiling incipience in parallel micro-channels with low mass flux subcooled water flow”, International Journal of Multiphase Flow, vol. 47, pp. 150-159, 2012.

[4] Omar S., D. Jo, J. Park, H. Chae, “Experimental investigation of the entrance effect on the convective heat transfer in narrow-vertical rectangular channel for upward and downward flow”, Transactions of the Korean Nuclear Society Spring Meeting, 2013.

[5] Y. Sudo, K. Miyata and H. Ikawa, "Experimental study in differences in single-phase forced-convection heat transfer characteristics between upflow and downflow for narrow rectangular channel," Journal of nuclear science and technology, vol. 22, no. 3, pp. 202-212, March 1985.