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A New Correlation for Counter-Current Flow Limited CHF in Narrow Rectangular Channels

Ju Hyung Lee [*], Soon Heung Chang
Dept. of Nuclear and Quantum Eng., Korea Advanced Institute of Science and Technology,
335 Gwahak-ro, Yuseong-gu, Daejeon, 305-701, Republic of Korea
[*]*Corresponding author: leejh9841@kaist.ac.kr*

1. Introduction

Dissipating heat flux is the one of major considerations in design of systems such as thermosyphon reboilers, nuclear power plants (NPPs), and research reactors, etc. Critical heat flux (CHF) is dissipating limit at which boiling heat transfer coefficient sharply decrease and catastrophic failure of the heated surface happen. Especially for downward cooling, counter-current vapor develop at low mass flux and minimum CHF can be induced, which is related to counter-current flow limitation (CCFL) or flooding.

The counter-current flow limited CHF (CCFL CHF) have been reported in several papers. [1-3] Mishima and Nishihara conducted CHF experiment with thin rectangular channels under low mass flux/atmospheric pressure for both downward and upward flow. Their CHF experiment data for downward flow showed mass flux region in which CHFs are very low. They reported that CHF in this region is related to counter-current upward vapor flow. They developed a CHF correlation based on well-known Wallis-type CCFL correlation.

$$j_g^{*1/2} + m\, j_f^{*1/2} = C \quad (1)$$

$$j_g^* = j_g \sqrt{\frac{\rho_g}{g \Delta\rho D}} \quad (2)$$

$$j_f^* = j_f \sqrt{\frac{\rho_f}{g \Delta\rho D}} \quad (3)$$

But their CHF model related to CCFL correlation is only for zero mass flux. Sudo *et al* have been proposed an empirical CHF correlation scheme for the thermal hydraulic design and safety analysis of research reactors using plate-type fuel such as Japanese research reactor No.2,3,4 (JRR-2,3,4) and Japanese material test reactor (JMTR). [2] This correlation scheme also covers CCFL region. However, not only error is relatively high compared their own experiment data and Mishima *et al*'s but also correlation is little complicated.

For this reason, simple CCFL CHF model is suggested and new correlation based on the model is developed. These results are possible to analysis safety margin of research reactor which use plate-type fuel and be cooled by downward flow.

2. Methods and Results

2.1 Simple CCFL CHF Model

From simple mass balance equation and Wallis-type CCFL correlation, new CCFL CHF correlation can be derived as following equations:

$$(A_H/A) q_{CHF} = (h_{fg} + \Delta h_i)\rho_g j_{g,CCFL}(G) + \Delta h_i G \quad (4)$$

$$\rho_g j_{g,CCFL}(G) = \left[\frac{K - \sqrt{(1-N)(K^2+NG)}}{N}\right]^2 \quad (5)$$

where,

$$K = C(\rho_g g \Delta\rho W)^{1/4} \quad (6)$$

$$N = 1 - m(\rho_g/\rho_f)^{1/2} \quad (7)$$

2.2 Reference Data

For assessment of new CCFL CHF correlation, reference data is selected as shown in Table 1.

Table I: Reference Data

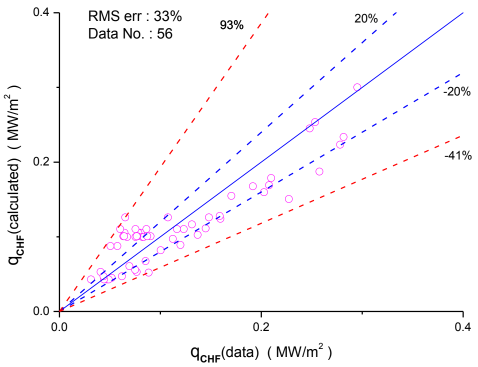
Author	Dimension (mm)	Inlet Temp. (^{0}C)	Data No.
Mishima and Nishihara [1]	40(30)*2.40*350	31 ~ 86	27
Sudo [3]	50(40)*2.80*375	38 ~ 42	29
	50(40)*2.25*750	20 ~75	

2.3 Results

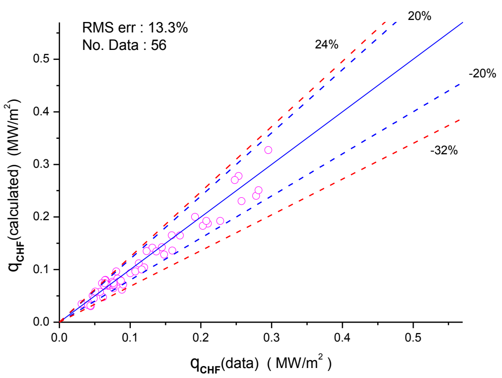
Fig. 1. (a) shows comparison between CHF predicted by JRR correlation and reference data. As mentioned in their paper, root mean square errors (RMS err) is showing up 33%.

With comparing between new CCFL CHF correlation and reference data, C and m value in Wallis CCFL correlation are recommended 0.54 and 0.69, respectively. Fig 1. (b) shows the comparison CHF predicted by new correlation and reference data. The result shows new correlation is in good agreement with data; the error is within -32% and 24% for 56 CHF data. RMS err is also extremely low, 13.3%.

Fig.2. show trends of CCFL CHF and upward mass flux of vapor as function of total mass flux. As mass flux increases, upward flow rate of vapor decrease since downward flow rate of liquid also increase. As the result, CHF increase not much near zero mass flux.



(a)



(b)

Fig. 1. (a) Comparison of CHF predicted by JRR correlation with reference data, (b) Comparison of CHF predicted by new CHF correlation with reference data

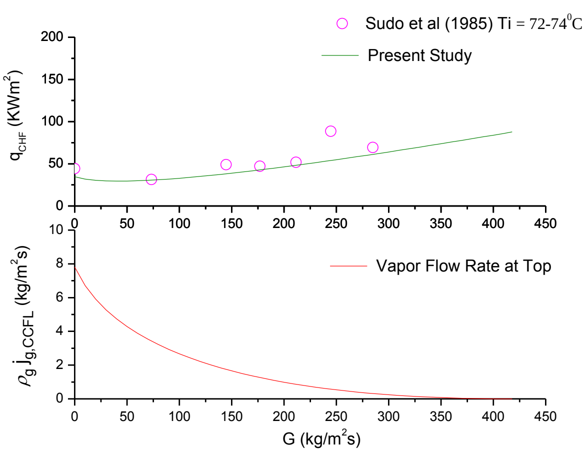


Fig. 2. CHF behavior & Upward mass flux of vapor versus mass flux

3. Conclusions

A new correlation for CCFL CHF in narrow rectangular channels is developed based on very simple CHF model with Wallis CCFL correlation. The correlation is in good agreement with 56 reference data for m = 0.54 and C = 0.69 ; Rms err. is 13.3% .

REFERENCES

[1] K. Mishima and Nishihara, The Effect of Flow Direction and Magnitude on CHF for Low Pressure water in Thin Rectangular Channels, Nuclear Engineering and Design, Vol.86, p. 165-181, 1985.

[2] M. Kaminaga, K. Yamamoto and Y. Sudo, Improvement of critical heat flux correlation for research reactors using plate-type fuel, Journal of Nuclear Science and Technology, Vol.35, No. 12, p.943-951, 1998

[3] Y. Sudo, K. Miyata, H. Ikawa, M. Kaminaga and M. Ohikawara, Experimental study of differences in DNB heat flux between upflow and downflow in vertical rectangular channel, Vol.22, No. 8, p.604-618, 1985