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An experimental study of the post-CHF phenomena on flow-boiling of R-134a in an annulus geometry

Kwi Lim Lee[a]*, Soon Heung Chang[b]
[a]*Korea Atomic Energy Research Institute, 150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, Republic of Korea*
[b]*Korea Advanced Institute of Science and Technology, 373-1, Guseong-dong, Yuseong-gu, Daejeon 305-701, Republic of Korea*
[*]*Corresponding author: kllee@kaeri.re.kr*

1. Introduction

An experimental study was performed in the post-CHF condition using R-134a in an annulus channel. The experiments were conducted under the outlet pressures of 11 ~ 20 bar, the mass fluxes of 100 ~ 400 kg/m^{2}s and the inlet temperatures of 25 ~ 51 ^{o}C.

About 300 of post-CHF data are obtained in the annular geometry and are compared with the several post-CHF correlations. The results show the large prediction uncertainty, so the empirical correlation for an annulus channel is developed with the present experimental results. The heat transfer coefficient was calculated based on the heater rod temperature and the saturated vapor property. The average errors and RMS errors of the predictions are 0.17 % and 3.4 %, respectively.

2. Experimental Methods and Results

2.1 Test section

A vertical annular channel with one heated rod and outer channel is shown in Fig. 2. The test section consists of a body of an inner rectangular flow channel (De=10.97 mm, Dh=38.90 mm) of 19x19 mm^2, a single heater rod with the outer diameter of 9.5 mm in the center of flow channel and visualization windows of two sides. The heater rod consists of sheath or cladding made of Inconel 600 of 1 mm thickness, an electrical insulation layer of MgO which fills between the sheath layer and heating element and spiral-strip heating element which is filled by Al_2O_3. The rod is heated indirectly by 22 kW AC(alternating current) power supply for 1830 mm length. Power shape of the heater rod is uniform throughout the heated section.

2.2 Experimental procedure and test condition

In the present study the experiment was performed for the refrigerant in the mass flux varying from 100 to 400 kg/m^{2}s, the pressure from 11 to 20 bar and the inlet temperature from 25 to 51 ^{o}C. Table 1 shows the test condition. The post-dryout tests were performed until the maximum wall temperature is less than about 550 ^{o}C in order to avoid the physical melting. The uncertainties of the measurement parameters were analyzed by the error propagation method. The uncertainties of the applied heat flux and mass flux were less than ±2.5% and ± 2.0 %, respectively. The heat balance tests conducted to estimate the heat loss showed the negligible heat loss. Uncertainties for the pressure and fluid temperature measurements are ±9 kPa and ± 0.5 ^{o}C.

2.3 Experimental results and discussion

The present works represent the characteristics of the flow boiling heat transfer or R-134a in an annular channel in the condition of the post-CHF. About 700 post-CHF data were obtained in an annular channel.

301 data points were extracted from the post-dryout experiments in an annulus channel for the film boiling region. These post dryout data are compared with the thermal equilibrium models and thermal non-equilibrium models. The results show the large prediction uncertainty, which are summarized in Table. 1. The CSO correlation shows the best prediction for the present experiment results with an average error of 19.8% and a RMS error of 24 %. The predictions of Saha and Hein & Kohler models under-estimate the present results with average errors of 71.1 and 64.4 %, respectively. The Groeneveld of the equilibrium model predicts the present experiment results with an average error of 11.3 and a RMS error of 30.8 %.

Because empirical correlations are restricted to the range from which they were derived, the correlation for an annulus channel is developed with the present experimental results. The heat transfer coefficient was calculated based on the saturated vapor temperature and the measured wall temperature of the heater rod.

The empirical correlation for the present experimental condition is based on the modifications of the Dittus- Boelter correlation for single-phase heat transfer. Under the present fixed conditions of heated length and tube diameter, the correlation is developed employing a “two-phase” Reynolds number Re2ø. The following correlation is obtained for the heat transfer coefficients in an annular channel:

$$h = 0.0214\left(\frac{K_v}{D}\right)\frac{x_c^{0.3837}\left[\mathrm{Re}_v\left\{x_e+\frac{\rho_v}{\rho_l}(1-x_e)\right\}\right]^{0.2724}\mathrm{Pr}_{vf}^{0.4818}}{x_e^{0.3282}}$$

$$\mathrm{Re}_{2\phi} = \mathrm{Re}_v[(x_e+\frac{\rho_v}{\rho_l}(1-x_e)]$$

where ρs are the densities, xe is the equilibrium quality and Prvf is the Prandtl number at the film temperature.

Fig. 1 shows the comparison of the measured heat transfer coefficients with the Groeneveld and CSO model. Groenevled and CSO correlations show the over-estimations of the wall superheats. The reason is explained by the cold wall effect. Because the existing correlation and models are based on the tube geometry and a few post-dryout tests were performed in an annulus, so this empirical correlation can be used for the application of the similar geometry.

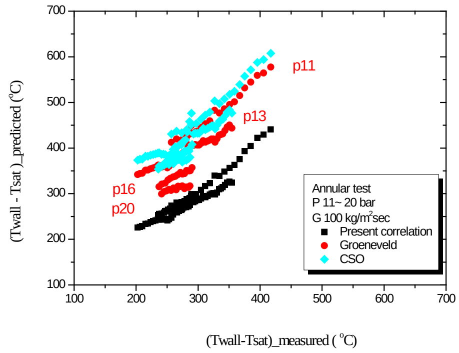

Fig. 1. Comparison of the measured heat transfer coefficients with the Groeneveld and CSO model

Table 1. Heat transfer coefficient prediction in post-CHF region by existing correlations

Crrelation		Average Error (%)	RMS Error (%)
Equilib rium	Dougall-Rohsenow	70.2	72.0
	Groeneveld	11.3	30.8
	Condie-Bengston	96.3	97.7
Non-equilibr ium	Groeneveld-Delorme	23.2	28.6
	Hein & Kohler	71.1	72.9
	Chen et al.	19.8	24.0
	Saha	64.4	66.4
	Present correlation	0.17	3.4

3. Conclusions

In this study, experiments were performed to investigate the post-dryout characteristics in a vertical annular channel in the post-dryout condition with a new refrigerant of R-134a under the outlet pressure of 11 ~ 20 bar, mass fluxes of 100 ~ 400 kg/m^{2}s, and inlet temperatures of 25 ~ 51 ^{o}C. From the data analysis, the following conclusions are obtained.

About 700 of post-CHF data were obtained with a new refrigerant of R-134a in an annulus channel at high pressure and low flow condition, which shows the overall heat transfer characteristics with rapidly decreased heat transfer coefficients and very high wall temperatures from the pre-CHF and post-CHF through the CHF.

301 data points were extracted from the post-dryout experiments for the film boiling region. These post-dryout data are compared with the thermal equilibrium model and thermal non-equilibrium model. The results show the large prediction uncertainty. The CSO correlation shows the best prediction for the present experiment results with an average error of 19.8% and a RMS error of 24 %. The predictions of Saha and Hein & Kohler models under-estimate the present results with average errors of 71.1 and 64.4 %, respectively. The Groeneveld of the equilibrium model predicts the present experiment results with an average error of 11.3 and a RMS error of 30.8 %.

The empirical correlation for an annulus channel is developed with the present experimental results. The heat transfer coefficient was calculated based on the saturated vapor temperature and the wall temperature of the heater rod. The average error and RMS error of the prediction are 0.17% and 3.4.%, respectively.

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