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Prediction of Low-Pressure Critical Heat Flux using SPACE-RR Code

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1. Introduction

SPACE-RR is a system code developed from SPACE for research reactor safety analysis[1]. In the code, wall friction and convective heat transfer correlations applicable for plate-type or finned-rod type fueled reactor core are newly added to solve temperature and pressure distribution of the research reactor system. In addition, various design limit correlations are embedded in the code to evaluate safety margin of the reactor core. Especially, two critical heat flux (CHF) correlations are newly added. First one is Kaminaga et al. (1998) correlation developed by JAEA. This correlation is developed to evaluate safety limit of the plate-type fueled core[2]. The other is HANARO (1992) correlation developed by KAERI. This correlation is applicable to finned fuel rod geometry such as ones currently powering HANARO[3]. In this study, the prediction capability of the embedded CHF correlations is checked by comparing the calculation results with those from experiments.

2. Methods and Results

In this study, the test sections and boundary conditions of two experiments selected from literatures are simulated using SPACE-RR code. In this section, the test section geometries and boundary conditions of each tests are summarized, and their results are compared with code predictions.

2.1 Experiment by Mirshak et al. (1959)

In order to assess the prediction performance of the Kaminaga et al. (1998) correlation, data of Mirshak et al. (1959) test are utilized[4]. Figure 1 shows the cross-section view of the two types of test sections used in the experiment. For each tests, the CHF is achieved by increasing the outlet coolant temperature while maintaining the heater power at constant level. Table I summarizes the test section specification. Total 65 test data are provided in the reference.

Figure 2 shows the code nodalization of the test section where PIPE component is used to simulate coolant channel. The heated length was divided to 20 sub-volumes and single sub-volume was assigned to each unheated region at the inlet and outlet. TFBC components are used at the inlet and outlet to simulate prescribed flow and pressure boundary conditions. For each simulation case, the code was run by linearly increasing the mass flow rate to the desired condition, and then the heat structure power was linearly increased until MCHFR value reached 1.0. Since the initial boundary conditions for code run are guessed utilizing single-phase conservation laws, the pressure value at the CHF point tend to become higher than reference values. Therefore, the code is run again with corrected pressure boundary conditions based on differences with reference and initial run results. For comparison purpose, the test data have been compared with 2006 version of AECL lookup table (AECL LUT hereafter) and Kaminaga et al. (1998) correlations. Figure 3 compares the measured and predicted CHF values. The figure shows the effect of pressure correction. The average and standard deviation (after 2nd run) of M/P (measured-to-predicted ratio) of tested correlations were found out to be 0.91/0.07 for Kaminaga et al. (1998) and 1.00/0.11 for AECL LUT, respectively.

2.2 Experiment by WNRE (1989)

In order to check the CHF prediction capability for finned fuel rods, part of WNRE (Whiteshell Nuclear Research Establishment) test results are utilized here[7]. Figure 4 shows the design of one of their heaters where 8 vertical fins surround the aluminum cladding. The heater was installed inside glass tube during the experiment. Table II lists the test section specification. The tests were carried out by maintaining the flow rate, inlet temperature, and outlet pressure, and the power was gradually increased until burnout occurred. In this study 19 test conditions were simulated. Additionally, the test conditions were not explicitly described in the reference which had to be guessed based upon energy and momentum conservation.

The same nodalization as shown in Fig. 2 and the same simulation procedure as used in the Mirshak et al. (1959) tests are adopted here. Figure 5 compares the measured and the predicted CHFs where average and standard deviation of M/P of tested correlation were evaluated to be 0.93 and 0.18, respectively.

Table I: Test Section Specification (Mirshak et al. (1959))

Item	Value
Geometry (Rectangular channel)	
Width/Thickness	2.5”, 1/2”(max.)
Length	22.25”
Heater plate width/thickness	2”, 0.0038” (or 0.025”)

Heated length	19.25”
Geometry (Annular channel)	
Inner/Outer diameter	0.5” (or 0.790”)/0.5625” (or 0.8425”)
Heater rod diameter	0.5” (or 0.790”)
Heated length	24”
Test condition (65 cases)	
Velocity	5.4~41.6 ft/s
Pressure	24.5~85.7 psia
Subcooling	6~74 ºC
Flow direction	Downward

Table II: Test Section Specification (WNRE (1989))

Item	Value
Geometry (Tube I.D.= 17 mm)	
Hydraulic diameter	7.3 mm
Length	600 mm
Heater diameter	10 mm (including fin)/7.95 mm (base)
Fin thickness	0.76 mm
Geometry (Tube I.D.= 24 mm)	
Hydraulic diameter	13.66 mm
Length	600 mm
Heater geometry	Same as above
Test condition (19 cases)	
Mass flux	1,000~5,900 kg/m^2/s
Pressure	110~350 kPa
Inlet temperature	15~62 ºC
Flow direction	Upward

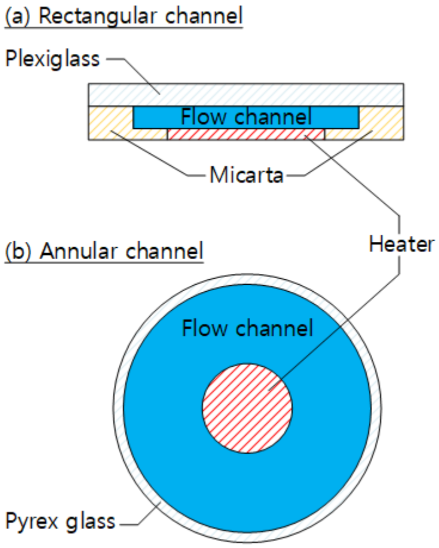

Fig. 1. Cross-section view of the test section (taken from [5]).

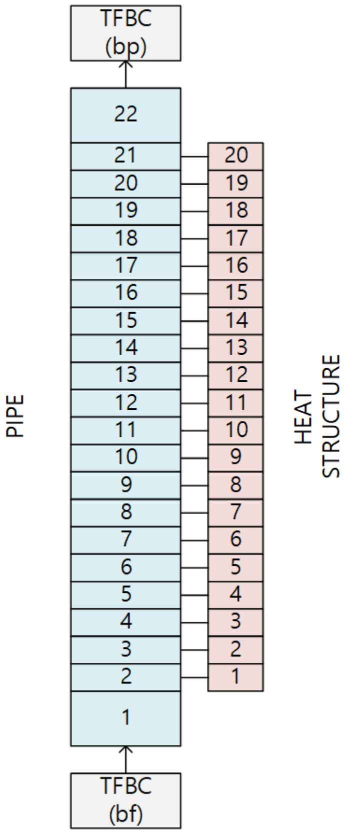

Fig. 2. Code nodalization (not to scale, taken from [6]).

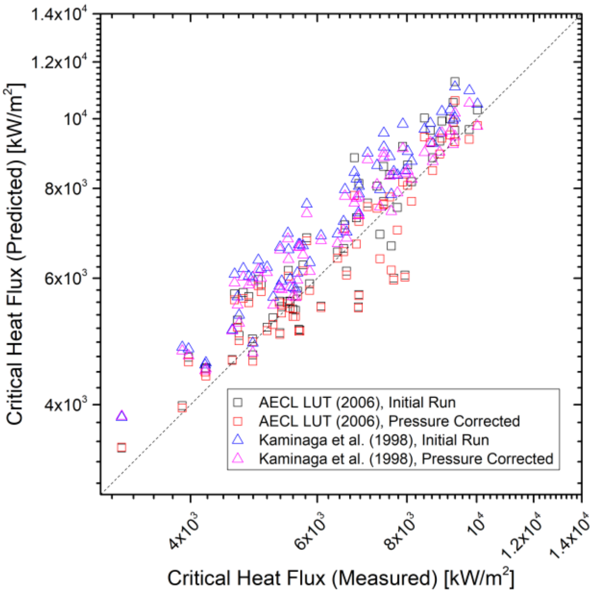

Fig. 3. Code prediction of Mirshak et al. (1959) test.

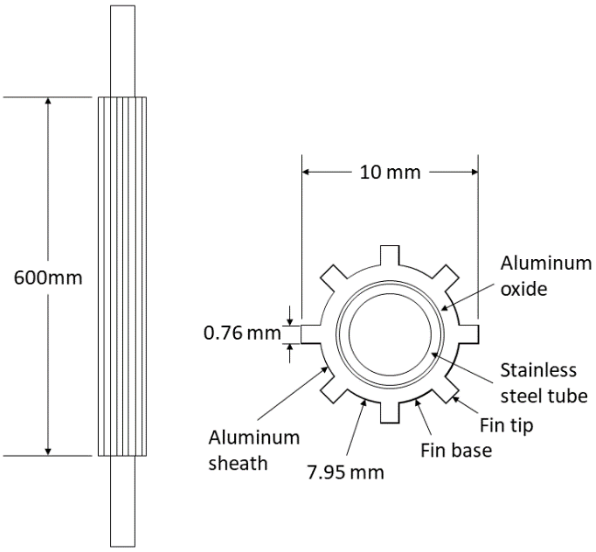

Fig. 4. Front and cross-section view of the heater (not to scale).

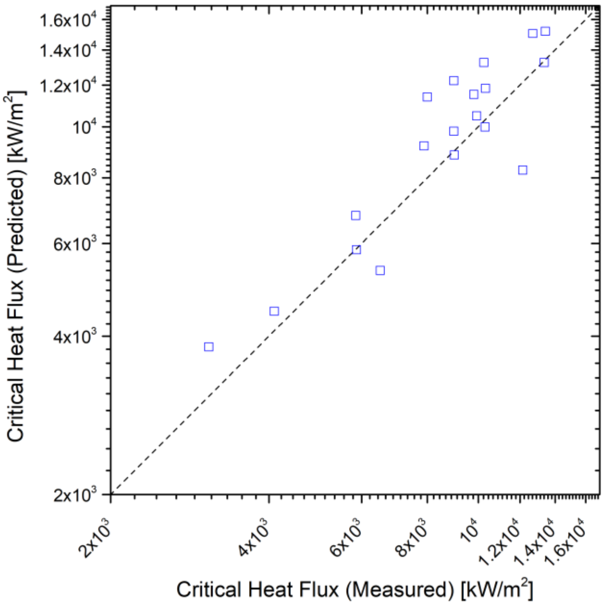

Fig. 5. Code prediction of WNRE (1989) test.

3. Conclusions

In this study, the low-pressure CHF experiments were simulated by safety analysis code SPACE-RR using newly embedded correlations developed for plate-type and finned rod fuels. The simulation results on the rectangular channel showed that the newly implemented correlations seem to follow the overall trend of CHF measurement data. In terms of M/P statistics, 2006 version of AECL LUT gave better mean predictions while Kaminaga et al. (1998) correlation have exhibited narrower scatter ranges. In addition, the CHF prediction on finned rod type geometry have shown that the implemented correlations follow the overall behavior of the tests. However, due to limited number of tests cases were utilized, the current conclusions should be supplemented through comparison with additional data.

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