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3-Pin Critical Heat Flux Test Results for CANDU Application of the Fuel Test Loop in HANARO

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1. INTRODUCTION

As an irradiation test facility for nuclear fuel performance in HANARO (High-flux Advanced Neutron Application Reactor), 3-Pin Fuel Test Loop is being developed that can irradiate the pin to the maximum number of 3 at the core irradiation hole by considering for it's utility and user's irradiation requirement. The FTL will serve for the irradiation of test fuels and materials at the high pressure and temperature conditions of PWR and CANDU reactors. Conceptual design of the 3-Pin FTL was set up in 2001 and the basic design composed of a design requirement and basic piping and instrument diagram had been completed in 2002. Safety analysis report to get a license from Korea Institute of Nuclear Safety is being prepared and mock-up test for verifying In-Pile Test Section (IPS) design is being promoted. [1,2,3]

A critical heat flux correlation is essential in order to carry out reliable safety analysis and evaluate a safety margin for the design basis accidents (DBAs). A critical heat flux test facility which has the equivalent geometry with the IPS of the FTL has been constructed in KAERI. Two sets of critical heat flux tests for PWR and CANDU reactors are scheduled to be carried out. In this paper, experimental work for CANDU reactors is explained and the obtained results are compared with several CHF correlations.

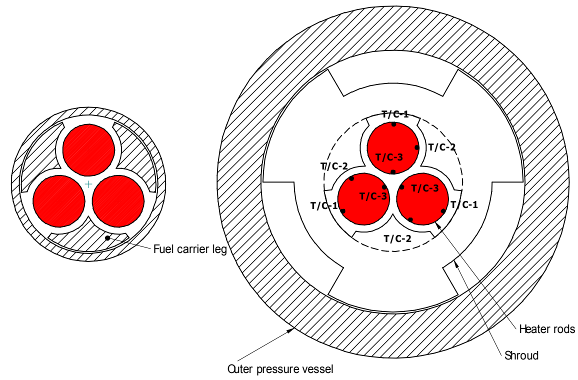
2. DESCRIPTION OF THE TEST FACILITY

The present CHF experiments have been performed in the Reactor Coolant System thermal hydraulic loop (RCS loop) at the Korea Atomic Energy Research Institute. A test section designed to simulate the FTL for CANDU reactors has been manufactured and installed on the RCS loop.[4,5]

2.1 Test section

The test section consists of a lower plenum, a main flow channel and an upper plenum. The main flow channel is composed of an outer pressure vessel and a shroud. Three heater rods were tied up in a bundle by four spacer grids and were inserted from the upper plenum to the test section. The heating length is 500 mm between the second and the third spacer grids from the bottom. The heater rods have uniform axial and radial heat flux profiles. Six K-type thermocouples having a sheath diameter of 0.5 mm are embedded on the surface of a heater rod to measure the surface temperature of the heater rod and to detect CHF occurrence.

Figure 1(a) shows the IPS geometry of the FTL. Three fuel carrier legs which play a role of constant flow gap with the fuels and the wall are attached on the inner wall. The detailed CHF test section geometry is shown in Fig. 1(b). A shroud which has an equivalent geometry to the IPS of the FTL was installed inside the main flow channel. The three heater rods are arrayed in the form of triangle and located inside the shroud. Three thermocouples per each heater rod are embedded on the outer wall side, fuel carrier leg side and the center side.



(a) IPS Geometry of the FTL **(b) CHF Test Section Geometry**

Fig. 1. Cross section of the test section

2.2 Test conditions

In the present study, a total of 108 CHF data were obtained. The experimental conditions under which the present data have been collected are summarized in Table.1.

Table 1. Test matrix for CANDU tests

No. of Data	Pressure (MPa)	Mass flux (kg/s-m^2)	Subcooling	
			(^{o}C)	(kJ/kg)
9	6.0	200~600	23~56	117~273
15	7.5	200~600	22~70	117~345
13	9.0	200~800	21~68	
19	10.5	200~1000	20~65	
14	11.5	200~800	19~63	
21	13.0	200~1000	18~60	
17	15.0	200~1000	16~56	

3. EXPERIMENTAL RESULTS

3.1 Characteristics of CHF

The CHF for axially uniform heating usually occurs at the top end of the heated section. Almost all CHFs occurred at the location 10mm below the top end of the heated section as expected. Figure 2 shows a typical variation of the heater wall temperatures when the CHF occurs. When the heater rod temperature is higher than the saturation temperature by 50 or 60 ^{o}C, it is judged that the CHF occurs.

3.2. Comparison with bundle correlation

The present geometry where three heater rods are arrayed in the form of triangle can be considered either as a rod bundle or an annulus. Therefore the AECL look-up table with a bundle correction factor and a correlation for an annulus were compared with the present data. [6]

Most system codes such as RELAP5/MOD3, CATHARE, CATHENA, ASSERT and MARS use the AECL look-up table to predict the CHF and they have seven correction factors to modify the AECL look-up table value. Among them, the effect of the bundle correction factor k_2 is investigated. The DSM (Direct Substitution Method) is used to obtain the $CHF_{D=8}$ from the AECL look-up table.

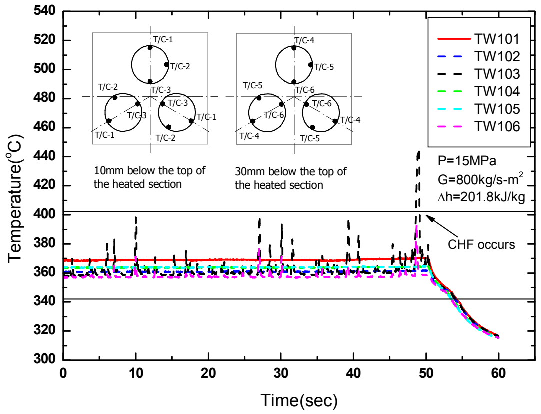


Fig. 2. Typical variation of the heater wall temperature when the CHF occurs

3.3 Comparison with annuli correlation

The present geometry can also be treated as an annulus. Therefore, a CHF correlation for annuli which was suggested by Doerffer et al. [7] was compared with the present CHF data as an alternative approach.

Figure 3 shows the comparison results for the three prediction methods. When the bundle correction factor is taken into account, the AECL look-up table shows much better results. The Doerffer's prediction is slightly lower than the measured value.

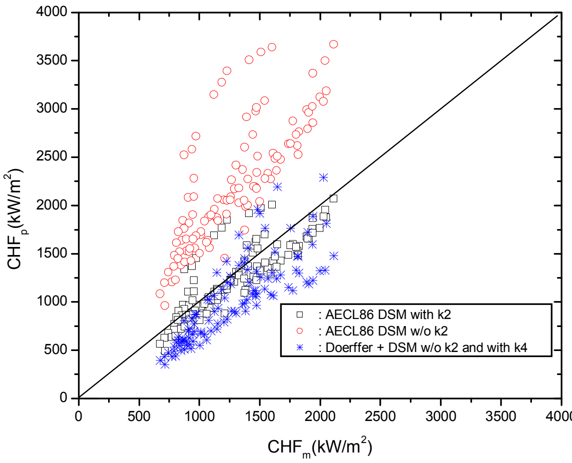


Fig. 3. Prediction of the CHF with several prediction methods

Prediction ratios for three correlations are summarized in Table 2, where average and root mean square errors are calculated. The AECL 86 DSM predicts 75.3 percent higher CHF value than the measured value on the average without the bundle correction factor. However, its prediction is much improved when the bundle correction factor is used. The average prediction ratio to measurement is 0.976 with the root mean squared (rms) error of 0.17. Meanwhile, the Doerffer's correlation results in 22.4 percent lower prediction than the measured value on the average. When we apply the Doerffer's correlation the present geometry, the definition of the gap size might be ambiguous. It is intuitionally defined as a half of the heated equivalent diameter. In this case, the gap size is 4.35 mm and the gap correction factor k_δ has a value of 1.138. If the gap size is defined as a hydraulic equivalent diameter, which is 4.5 mm, the k_δ has a value of 1.133. Therefore, the similar result is obtained regardless of the definition of the gap size. If we examine the definition of the gap correction factor, it has a maximum value of 1.14 when δ= 4.26 mm and it decreases as the gap size increases. The present gap size is very close to the maximum. It implies that the low prediction of the Doerffer's correlation cannot be much improved even though we use another definition of the gap size. Based on the prediction results, the bundle correction method results in better agreement with the CHF data than the annuli correction method.

Table 2. A summary of CHF prediction ratios

Prediction method	P/M		M/P	
	Avg.	rms	Avg.	rms
AECL86 DSM w k2	0.976	0.170	1.050	0.149
AECL86 DSM w/o k2	1.753	0.348	0.589	0.096
Doerffer + DSM w/o k2 and with k4	0.787	0.180	1.330	0.268

4. CONCLUSIONS

A critical heat flux test facility to simulate the In-Pile Test Section (IPS) of the 3-Pin Fuel Test Loop (FTL) has been constructed and used in order to obtain CHF data for CANDU application. A total of 108 experimental CHF data have been obtained in the present phase.

The obtained CHF data are compared with the existing CHF correlations. One is the 1986 AECL look-up table with or without a bundle correction factor. The other is the Doerffer's correlation for annuli geometry. It is found that the AECL 86 look-up table with a bundle correction factor results in the best prediction results among the cases considered in this paper. Therefore, the best estimate thermal hydraulic system code, MARS3.0, which uses the same look-up table for CHF prediction, can be applicable to the licensing process for CANDU reactors.

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