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Assessment of the Water CHF Look-up Table for Rod Bundles CHF Measurements

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1. Introduction

In 1986, D. C. Groeneveld et al. published a paper, “1985 AECL-UO Critical Heat Flux Lookup Table” [1]. The water critical heat flux lookup table was simply used to predict CHF in various geometries and over a wide range of conditions. More recently, geometries of nuclear fuel assemblies have become more complicated. For this reason, there have been discussions about the prediction of CHF by water CHF lookup table for complex rod bundles.

Several CHF tests for 5x5 and 6x6 matrix rod bundles array have been performed as a part of a development of CHF correlation project. Using CHF test results, the prediction of CHF by lookup table has been analyzed. Results of assessment of the water CHF lookup table for rod bundles of CHF measurements are presented in this study.

2. Methods and Results

For this study, the results of CHF test for A, B, and C sections were compared with predictions of CHF using 1985 AECL-UO CHF Lookup Table at the same flow conditions such as pressure, mass flux, and thermodynamic quality.

2.1 Test Section and Test Range

Test sections A, B, and C were made of 5x5 and 6x6 matrix arrays and the heating profile is axially uniform. The distance from the last grid spacer to the end of heated length was A>C>B. Main geometrical properties such as array, P/D, heated length, and types of grids are summarized in Table I. CHF tests were performed with upward flow in a square casing.

The test range of flow parameters were; pressure from 9480 to 16600 kPa, mass flux from 996 to 4858 kg/m^{2}s, and the thermodynamic quality at the end was from +0.045 to +0.354.

Table I: Test section information

	Test section A	Test section B	Test section C
Array	5x5	6x6	5x5
P/D*	1.3526	←	1.3263
Heated length(m)	3	←	←
MID grid	Y	Y	Y
IFM grid	N	Y	Y

*rod pitch / rod OD

2.2 CHF Correction Factors of Lookup Table

1985 AECL-UO standard CHF lookup table could be applied to an 8mm diameter tube directly or linear interpolation is required for non-table P, G and X values.

According to definitions provided in “1985 AECL-UO Critical Heat Flux Lookup Table”, the CHF correction factor is required to apply the CHF lookup table to other geometries or flow conditions.

To apply the water CHF lookup table for test sections A, B, and C, the table CHF value multiplied by correction factors K_1 to K_6 [1] defined as follow;

K_1 : subchannel or tube cross section factor

$$K_1 = \left(\frac{0.008}{D}\right)^{\frac{1}{2}} \tag{1}$$

where D = heated equivalent diameter(m),

K_2 : bundle factor

$$K_2 = \min(0.8, 0.8 \times e^{-0.5\times X^{\frac{1}{3}}}) \tag{2}$$

K_3 : grid spacer factor

$$K_3 = 1 + A \times e^{-B\times L_{sp}/D} \tag{3}$$

where $A = 1.5K^{0.5} \times \left(\frac{G}{1000}\right)^{0.2}, B = 0.10,$
K = grid pressure loss coefficient,
L_{sp} = distance from grid spacer(m),

K_4 : heated length factor

$$K_4 = e^{\left(\frac{D}{L}\times e^{2\alpha}\right)} \tag{4}$$

where $\alpha = X/[X - \rho_g/\rho_f(1-X)]$,
L = heated length from entrance to point in question(m).

K_5 : axial flux distribution factor

$$K_5 = q_{local}/q_{bla} \tag{5}$$

K_6 : flow factor, horizontal and vertical

$$K_{6,horizontal} = 1.0 \text{ if vertical flow}$$
$$K_{6,vertical} = 1.0 \tag{6}$$

for G < -400 or G > 100 kg/m^{2}s

To predict CHF using lookup table, K_1, K_2, K_3 and K_4 were calculated for each test sections and flow conditions.

Test sections A, B, and C had uniform axial power shape and upward flow. Therefore, the axial flux distribution factor K_5 and flow factor K_6 were used equal to 1.0.

2.3 Statistical Analysis

In order to assess the CHF lookup table for rod bundle CHF measurements, statistical analysis was performed for each test section. The mean and standard deviation for the ratio of measured CHF to lookup table predicted CHF are shown in Table II.

Table II: M/P Statistics for rod bundle CHF

	Test Section A	Test Section B	Test Section C
Number of Data	100	87	106
Average	2.2871	2.6101	2.3644
Standard-Deviation	0.4766	0.6754	0.4777

As can be seen from Table II, all of test sections show significantly high value of M/P average. It means that lookup table conservatively predicted CHF. It is believed that CHF lookup table didn't fully reflect the effect of mixing vane and rod bundles.

Standard deviations of all test sections were also high. It means that it is hard to predict an accurate CHF for complex rod bundles using the lookup table.

Figure 1 presents the measured CHF versus the predicted CHF by the lookup table. All points show that lookup table's predictions were lower than the measured.

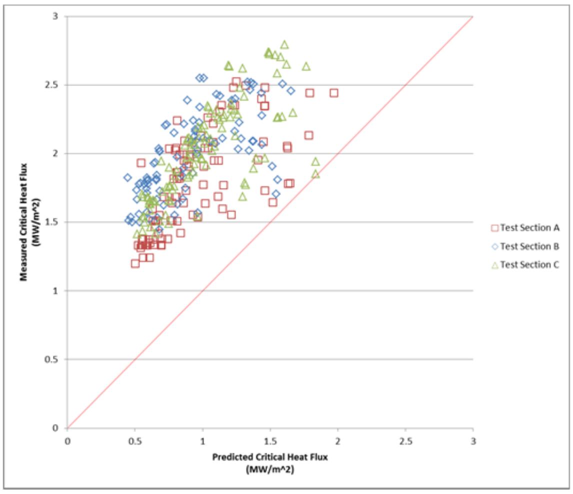

Fig. 1. Measured CHF versus predicted CHF by lookup table

2.4 Variation of Ratio of M/P CHF with parameters

In order to identify the relation between M/P and flow parameters, a scatter plot of the measured to predicted CHFs versus quality are shown in Figure 2, respectively, for all data points.

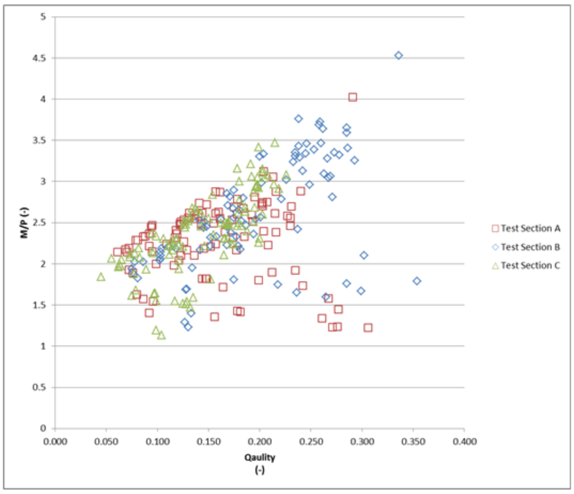

Fig. 2. M/P versus Quality

Figure 2 shows that there has been a general increase in the M/P as quality increase. However some data follow a significant difference trend that randomly scattered at relatively low M/P as quality increase. M/P statistics for these data were; number of these data 49, M/P average 1.5899, and standard deviation 0.2270.

From the data of following increase trend, prediction for rod bundles of CHF lookup table could not fully reflect increasing quality caused by complicated bundles and mixing vane. For this reason, bundle factor and heated length factor what function of quality need to adjustment or add another factor reflecting quality when apply CHF lookup table for complicated rod bundles with mixing vane.

The flow range of the randomly scattered data were; pressure from 9480 to 16570 kPa, mass flux from 1023 to 3971 kg/m^{2}s.

Figure 3 presents the flow range of randomly scattered data.

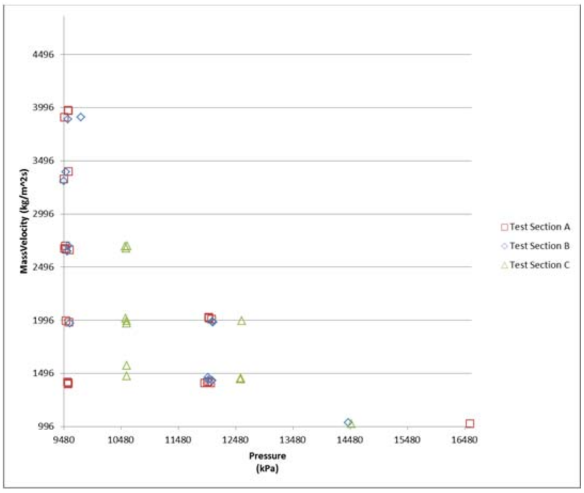

Fig. 3. Flow condition of data having difference behavior

Figure 3 shows that CHF were occurred in whole mass flux ranges at low pressure. However, range of occurred mass flux decrease as pressure increase.

The current study was unable to confirm the prediction of CHF for rod bundles by lookup table at relatively low quality whether M/P is decrease or not.

3. Conclusions

The purpose of this study is to assess the water CHF lookup table for rod bundles compared CHF measurements for rod bundle. The results of this analysis can be summarized as

i) the lookup table predicts CHF lower than measured CHF for rod bundles,
ii) it seems that lookup table did not fully reflect effect of mixing vane and it is hard to predict an accurate CHF for rod bundle with mixing vane, and
iii) factor of function of quality(K_2, K_4) need to adjustment or add another factor reflecting quality.

Further work is needed to know whether the prediction of CHF for rod bundles with mixing vane by lookup table is lower than measured or not at negative quality. Also it would be interesting to found variation of CHF and CHF prediction due to flow regime using flow regime map.

REFERENCE

[1] D. C. Groeneved, S. C. Cheng, T. Doan, 1986 AECL-UO Critical Heat Flux Lookup Table, Heat Transfer Engineering Volume 7, Issue 1-2, 1986.