Tong Axial Power Shape Factor Characteristics according to Parameters

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1. Introduction

Power capability of water-cooled nuclear reactors is limited by critical heat flux, CHF. CHF in a rod bundle of nuclear fuel depends on not only various geometric factors, such as a rod diameter, an existence of unheated guide tube, the grid spacer characteristics including mixing promoter design and so on, but also axial power distribution[1]. Nuclear power plants are operated in non-uniform axial heat flux conditions. Since it is impossible to do the CHF test with the various non-uniform axial heat flux distribution due to time and physical limitation, CHF correlation should include the non-uniform heat flux effect[2]. There are several kinds of shape factors to account for the effect[3]. Shape factor of Tong, F_c, among the various shape factors, is most commonly applied to real core design. In this paper, the F_c characteristics are analyzed according to the parameters.

2. Methods and Results

2.1 Methods

In order to know the behavior of F_c, four parameters which are system pressure, core average mass flux, core average heat flux and axial power distribution are chosen. Table I presents core conditions that are combined with 3 different non-uniform axial heat flux distributions. Of the each parameter values, the maximum and minimum values are limiting design conditions and intermediate value is nominal conditions for the real core design. Thus, the range of analysis conditions covers the real reactor core operating conditions. The F_c was calculated by THALES code[4] with the 243 combination of the parameters and the code run result of the sub-channel No. 30, expected as hot channel, was extracted to examine the F_c characteristics.

Table I: Core conditions.

System pressure (psia)	1700	2100	2500
Inlet temperature (°F)	500	550	600
Core average mass flux (Mlbm/ft^2-hr)	1	2.5	3.5
Core average heat flux (MBtu/ft^2-hr)	0.1505991	0.1882489	0.2258986

To identify the axial heat flux shape effect on F_c factor, 3 typical axial power distributions, usually classified axial shape index (ASI), were selected as shown in Fig 1. The ASI was defined as following;

$$ASI = \frac{\int_{-L/2}^{0} F_z(z)dz - \int_{0}^{L/2} F_z(z)dz}{\int_{-L/2}^{L/2} F_z(z)dz} \qquad (1)$$

where, F_z=local axial heat flux
L= total heated length

As shown in equation (1), ASI doesn't mean the shape itself but indicate the direction and amount of the skew.

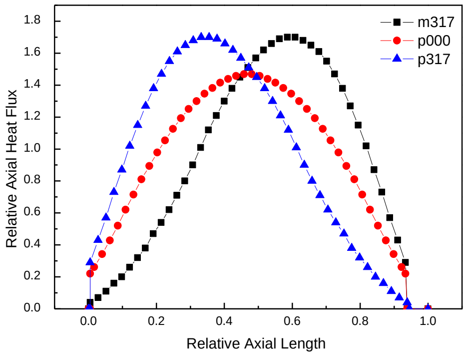

Fig. 1. Relative axial heat flux distribution.

2.2 Equation of F_c

The axial heat flux distribution upstream of the boiling crisis point affects the value of the CHF. This influence is accounted by using the F_c shape factor. The local non-uniform CHF,$q''_{crit,NU}$, is then calculated as follows[5,6];

$$q''_{crit,NU} = \frac{q''_{crit,EU}}{F_C} \qquad (2)$$

where, the subscript EU and NU refer to equivalent to uniform flux and non-uniform flux.

$$F_C = \frac{C}{q''_{crit,NU} \times (1-e^{-Cl_{crit}})} \int_0^{l_{crit}} q''(z)\, e^{-C(l_{crit}-Z)} dz \qquad (3)$$

C is empirically determined as function of the local quality at the point of CHF, x and the mass flux, G[5].

$$C = 0.15 \frac{(1-x_{crit})^{4.31}}{(G/10^6)^{0.478}} \ [in^{-1}] \qquad (4)$$

2.3 Results

Table Ⅱ indicates the core conditions of F_c represented in Fig. 2, Fig. 3, and Fig. 4. The p317 has higher power in bottom half as shown in Fig. 1, and the behavior of F_c at downstream shows trend depending on the analysis conditions in Fig. 2. Thus the F_c behavior, at expected CHF location, can be predicted in case of bottom peak shape. The p000 is symmetric cosine shape and the results are similar to p317 in Fig. 3. The m317 is top peak shape and the behavior of F_c at downstream has the difficult trend as shown in Fig. 4. The F_c of p317 are much higher than F_c of other ASIs at downstream, because F_c is the summation of local heat flux by definition of F_c, and its values are mainly affected by heat flux concentration.

In case of bottom peak shape, most of the summations are made in bottom region and the effect of axial shape is getting weaker as going to downstream.

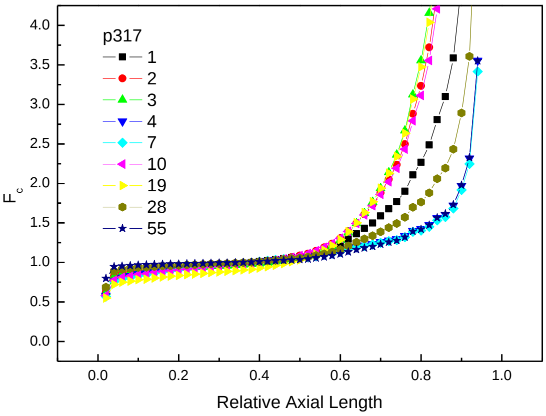

Fig. 2. F_C of the p317 along the relative axial length.

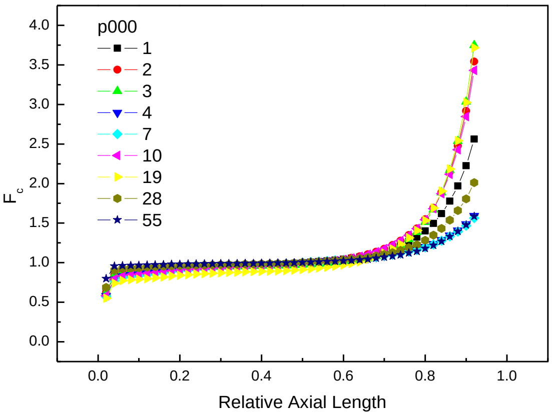

Fig. 3. F_C of the p000 along the relative axial length.

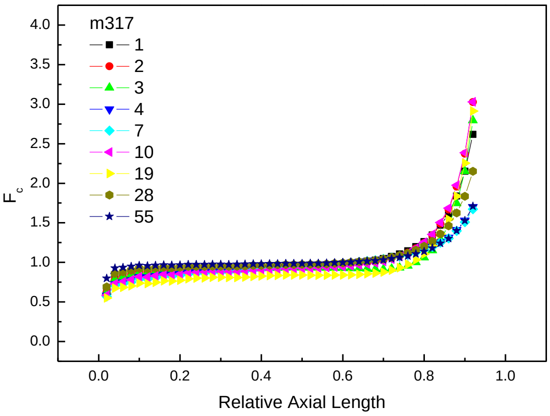

Fig. 4. F_C of the m317 along the relative axial length.

Table Ⅱ: Core conditions of label in Fig. 2, Fig. 3, and Fig. 4.

Label number	System pressure (psia)	Inlet temperature (°F)	Core average mass flux (Mlbm/ft^2-hr)	Core average heat flux (MBtu/ft^2-hr)
1	1700	500	1	0.1505991
2	1700	500	1	0.1882489
3	1700	500	1	0.2258986
4	1700	500	2.5	0.1505991
7	1700	500	3.5	0.1505991
10	1700	550	1	0.1505991
19	1700	600	1	0.1505991
28	2100	500	1	0.1505991
55	2500	500	1	0.1505991

Therefore, flow condition shows more dominant effect than axial shape at downstream. On the contrary, most summation of local heat flux concentrate on top half for top peak and axial shape effect for top peak is getting stronger as going to downstream. Consequently, as for the top peak shape F_c at downstream shows different the results according to change of flow condition.

Because each parameters affects each other, to check the independent effect of one parameter is difficult. In case of heat flux increase, the quality is also increased but mass flux is decreased at the same time. The F_c is changed due to the combined effect of the parameters. Therefore, the exact F_c can be determined by sub-channel code calculation and the regular trend according to the local flow condition can be found from the equation of F_c. Generally, the quality has more strong effect on F_c than mass flux and an increase in quality normally increases the F_c.

3. Conclusions

The F_c is mainly affected by flow condition and axial power distribution. In case of bottom peak power shape, sensitivity of F_c at downstream is influenced by flow condition. Thus, behavior of F_c at downstream can be predictable. F_c at downstream of top peak power shape is mostly affected by local heat flux shape. Therefore, it is difficult to predict change of F_c according to the flow condition, at downstream.

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