Power Profile for Plate-type Fueled Research Reactor Core Thermal Margin Analysis

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1. Introduction

For thermal-hydraulic design and safety analysis of research reactor, selection of representative power profile is carried out first. The profile is combined with engineering hot channel factors to obtain conservative outcomes in terms of thermal margins such as minimum critical heat flux ratio and maximum fuel temperature. In this study, power profile selection method utilized in plate-type fueled research reactor design is discussed and its conservativeness in thermal margin is evaluated by comparing with whole-cycle profile analysis data. In addition, the effect of applying different type of critical heat flux correlation is analyzed.

2. Methods and Results

In this section, a profile selection method and thermal margin analysis results are presented.

2.1 Axial Power Profile Selection Method

Figure 1 shows a flow logic diagram of conservative axial power profile selection method currently utilized for the research reactor design. The method is developed to select the profile having the most conservative thermal margins. The sum-to-peak (STP) quantity as described in Eq. (1) is utilized to ensure more conservative profiles in terms of fuel temperature is obtained[1]. For typical thermal-hydraulic designs, the number of axial power distributions to be considered on the whole cycle basis readily exceeds 10,000. This makes the selection process quite rigorous. To lighten this burden, KAERI has been developing and using computer code APPSPP (Axial Power Profile Selector Program for Plate Fuel) to automate the task. With the developed code, the all the user have to do is to provide the power profile data in designated data format to get the results. Then, the thermal margin analysis code is utilized to choose the representative profile.

$$STP = \sum_{i=1}^{peak\ location} \Delta Q / \max(\Delta Q) \tag{1}$$

where, ΔQ is axially discretized sub-volume plate power [W].

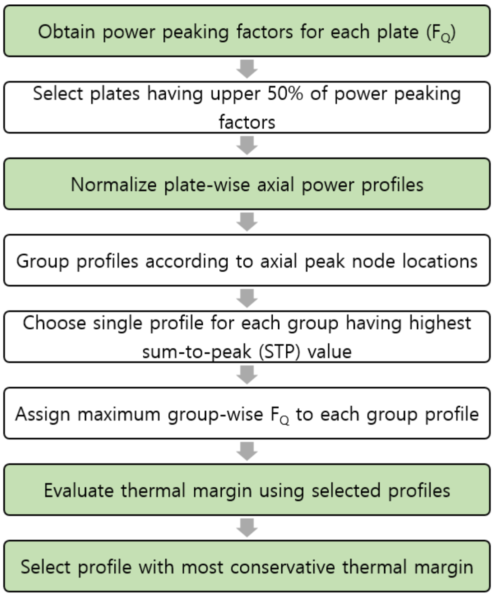

Fig. 1. Conservative Axial Power Profile Selection Method.

2.2 Characteristics of Power Profile

In this study, the results from the conservative axial power profile selection method are compared with ones from whole-cycle profile evaluation. The power profile data from 5 MW open-pool type reactor is utilized[2]. Figure 2 shows distribution of power peaking factors of each plate for entire fuel cycle (~14,000 profiles). The shape resembles that of normal distribution and the right tail appears to be elongated more than the left. Figure 3 depicts histogram of the axial power peak location from cooling channel inlet (top). This shows that the most of peaks (~80%) are located in the middle of fuel height.

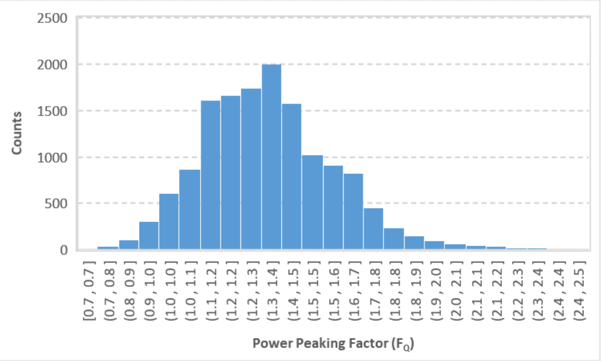

Fig. 2. Histogram of Power Peaking Factors.

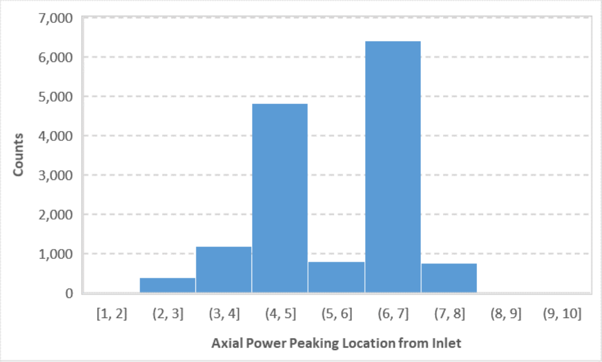

Fig. 3. Histogram of Axial Power Peak Location.

2.3 Analysis Results

Here, the analysis results from two different power profiles each came from the aforementioned methods (conservatively selected/whole-cycle) are compared. For the whole cycle analysis, the profile from each plate is analyzed with corresponding power peaking factors. On the other hand, in the conservative selection method, the highest power peaking factor is merged with the most conservative power shape in that group. In this study, the various uncertainties in manufacturing, thermal-hydraulic phenomena, core calculations are considered in terms of engineering hot channel factors (EHCFs). The uncertainty data from literature has been utilized here[3]. In addition, the same analysis code (CORAL) and geometry as in the previous study[2] is used in the calculation. One of the topics discussed in this paper is to see the effect of applying different critical heat flux correlation types (inlet/outlet). Therefore, the critical heat flux (CHF) correlation developed by Hall and Mudawar is utilized where both inlet and outlet (local) condition type correlations are developed and presented from same set of database[4]. Equations (2) and (3) show the correlations, respectively. Its applicability on narrow rectangular channel flow has been discussed by several researchers[5,6]. Table I summarizes their applicable ranges of geometric and thermal-hydraulic conditions which covers specification of the model reactor analyzed here.

Table II compares core thermal margins evaluated by two different power profile selection methods discussed in the above. The relative differences are calculated based on the conservative profile results. The whole cycle profiles simulation shows improved margins in terms of coolant and fuel temperatures. This is readily expected by the fact that the maximum power peaking is no longer forcefully merged with the conservative profile (usually more flattened profile). For many cases, the more flattened power profiles appears in the later stages of fuel cycle and the maximum power peaking exists in the earlier stages. For CHF margins, application of different correlation types exhibited diverging outcomes. When the inlet type correlation is used, the predicted CHF values were almost same which resulted in similar thermal margins. For the outlet type correlation, the CHF are more sensitive to changes in local thermal-hydraulic variables, which are affected by the power profile differences. This resulted in widened margin gaps. Since the predicted CHF from the outlet type correlation using reactor normal operating condition is far from true value (due to lack of energy balance), critical power ratio (CPR) is additionally evaluated. Since CORAL code only solves single-phase conservation equations, pressure drop correction is required to predict thermal-hydraulic variables at CHF condition. Utilizing the pressure drop multiplier previously obtained from PNU CHF test data[7] and combining with CORAL results, CP is predicted at the power where raised power profile touches CHF. The analysis showed that the evaluated CPs were similar to predictions from inlet type correlation. The relative improvement for whole-profile case were also observed which in turn showed relative conservatism in the presented profile selection method.

<u>Inlet type:</u>

$$Bo = \frac{0.0722 \cdot We_D^{-0.312} \cdot \left(\frac{\rho_f}{\rho_g}\right)^{-0.644} \cdot \left[1 - 0.900 \cdot \left(\frac{\rho_f}{\rho_g}\right)^{0.724} x_{i,*}\right]}{1 + 4 \cdot 0.0722 \cdot 0.900 \cdot We_D^{-0.312} \cdot \left(\frac{\rho_f}{\rho_g}\right)^{-0.644+0.724} \cdot \left(\frac{L}{D}\right)} \quad (2)$$

<u>Outlet (local) type:</u>

$$Bo = 0.0722 \cdot We_D^{-0.312} \cdot \left(\rho_f/\rho_g\right)^{-0.644} \cdot \left[1 - 0.900 \cdot \left(\rho_f/\rho_g\right)^{0.724} \cdot x_o\right] \quad (3)$$

where, Bo, We, ρ_f, ρ_g, $x_{i,*}$, L, and D mean boiling number [-], Weber number [-], saturated liquid density [kg/m^3], saturated vapor density [kg/m^3], pseudo-inlet quality (saturated properties from outlet pressure) [-], channel length [m], and equivalent diameter [m], respectively.

Table I: Applicable Range of Hall-Mudawar (2000) Correlation

Type	D [mm]	L/D	G [kg/m^{2}s]	P [bar]	x_i	x_o
Inlet	0.25 ~15	2 ~200	300 ~3,000	1 ~200	-2 ~0	-1 ~0
Outlet		-			-	-1 ~0.05
Model reactor	~4.5	~140	~2,500	1.7~1.8	-0.15	-0.11

Table II: Summary of Thermal Margins

	Conservative profile + Max. group F_Q	Whole cycle profiles + corresp. F_Q	Rel. Diff. [%]
$T_{cool,max}$ [°C]	58.6	54.9	-6.4
$T_{fuel,max}$ [°C]	142.2	138.0	-2.9
MCHFR (inlet type)	2.07	2.08	0.6
MCHFR (outlet type)	17.6	18.8	6.9

MCPR (outlet type)	2.2	2.5	16.0

3. Conclusions

In this study, axial power profile selection method utilized in design and analysis of plate-type fueled research reactor core has been introduced. Its conservatism in terms of thermal margins is discussed with respect to results obtained from whole-cycle profile evaluation. In terms of cirtical heat flux and fuel temperature, presented profile selection method gave relatively conservative values. In addition, effect of applying different types of critical heat flux correlation is analyzed where critical power concept is utilized for outlet type correlation. It was shown that greater conservatism could be secured when outlet type correlation is applied.

ACKNOWLEDGEMENT

This work was conducted as a part of the Development of Research Reactor Technology project sponsored by the Ministry of Science and ICT of the Korean government (522110-23).

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