Hydraulic Profiling of a Parallel Channel Type Reactor Core

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1. Introduction

An advanced reactor core which consisted of closed multiple parallel channels was optimized to maximize the thermal margin of the core. The closed multiple parallel channel configurations have different characteristics to the open channels of conventional PWRs. The channels, usually assemblies, are isolated hydraulically from each other and there is no cross flow between channels. The distribution of inlet flow rate between channels is a very important design parameter in the core because distribution of inlet flow is directly proportional to a margin for a certain hydraulic parameter. The thermal hydraulic parameter may be the boiling margin, maximum fuel temperature, and critical heat flux. The inlet flow distribution of the core was optimized for the boiling margins by grouping the inlet orifices by several hydraulic regions. The procedure is called a hydraulic profiling[1].

2. Hydraulic Profiling

The inlet flow distribution is controlled by inlet orifices installed at the inlet of channels. The inlet orifices were grouped by several hydraulic regions. The inlet orifices that belong to the same hydraulic region have the same loss coefficient. The channels were assigned to several hydraulic regions according to the global power envelope. The global power envelope was developed from the maximum values for the radial peaking factors in time and location. The global power envelope with respect to the radius of the core is shown in Fig.1.

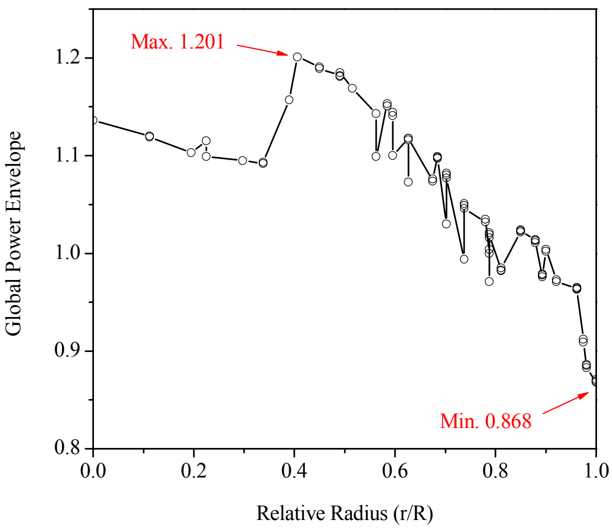

Fig.1. Global power envelope.

2.1. Optimization of Inlet Flow

The channel outlet temperature was selected as an optimizing parameter to maximize the boiling margin in this study. The inlet orifices were determined to have an inlet flow distribution that can result in the same maximum outlet temperature for all hydraulic regions. The flowchart of the optimization is shown in Fig.2.

The pressure drop through a channel, i, will be the same as the core pressure drop;

$$\Delta P_i = \frac{1}{2} K'_i G_i^2 = \frac{1}{2} K'_C G_C^2 = \Delta P_C \qquad (1)$$

where $K' = K/\rho$ is the effective loss coefficient, K is the loss coefficient, ρ is the density, G is the mass flux, the subscript i means a channel, and the subscript C means the core.

The relative inlet flow for the core flow can be calculated from eq.(1);

$$G_i / G_C = \sqrt{K'_C / K'_i} \ . \qquad (2)$$

The continuity equation results in

$$\sum_i G_i A_i = G_C \sum_i A_i \ . \qquad (3)$$

The effective loss coefficient of the core is derived from eqs.(2) and (3)

$$K'_C = \left\{ \sum_i A_i \Big/ \sum_i \frac{A_i}{\sqrt{K'_i}} \right\}^2 \ . \qquad (4)$$

The outlet temperature of a channel, i, is derived from

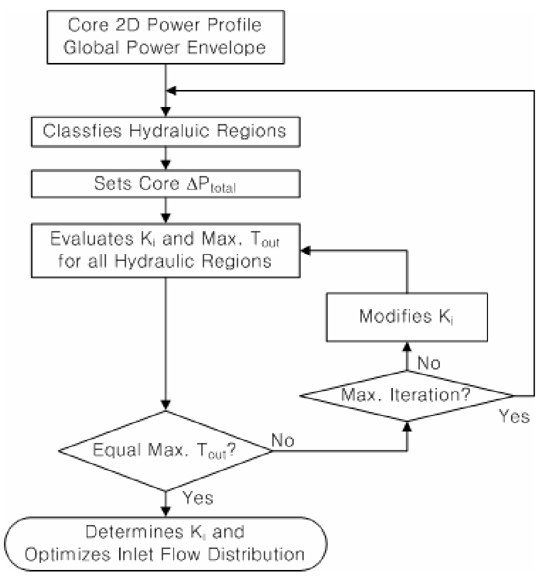

Fig.2. Flowchart of the hydraulic profiling.

the energy balance and eq.(2)

$$T_{out,i} = T_{in} + \Delta T_C F_{xy,i} \frac{D_{h,C}}{D_{h,i}} \sqrt{\frac{K'_i}{K'_C}} \tag{5}$$

where ΔT_C is the temperature rise in the core, $F_{xy,i}$ is the radial peaking factor of the channel i, and D_h is the equivalent diameter of the channel.

Let a channel N has the maximum outlet temperature, then the difference of the outlet temperature between channel i and N is

$$\delta T_i = T_{out,N} - T_{out,i} = \Delta T_C \left\{ F_{xy,i} \frac{D_{h,C}}{D_{h,N}} \sqrt{\frac{K'_N}{K'_C}} - F_{xy,i} \frac{D_{h,C}}{D_{h,i}} \sqrt{\frac{K'_i}{K'_C}} \right\}. \tag{6}$$

The effective loss coefficient of channel i should be updated as follows to have the same outlet temperature as channel N

$$(K'_i)^{new} = K'_C \left\{ \sqrt{\frac{K'_i}{K'_C}} + \frac{D_{h,i}}{D_{h,C}} \frac{\delta T_i}{\Delta T_C F_{xy,i}} \right\}^2. \tag{7}$$

The loss coefficient of the inlet orifice of a channel is determined according to the updated effective loss coefficient.

2.2. Number of Hydraulic Regions

It is apparent that an orificing results in greater thermal margins. A greater number of hydraulic regions requires a higher cost. The loss coefficients of the inlet orifices of a hydraulic region should be distinguishable from each other. There should be an optimum number of hydraulic regions.

One, three, and four for the number of hydraulic regions were investigated in this study. The outlet temperatures were evaluated as 316.5, 314.2, and 313.3 °C for the one, three, and four regions, respectively. The core pressure is 147 bar and the saturated temperature is 340.5 °C. Three and four hydraulic regions have a 10% and 13% more boiling margins than the one-region core, respectively. There was no advantage in using five hydraulic regions in a comparison with the four hydraulic regions[1]. Four was determined as an appropriate number of hydraulic regions in this study.

The result of a hydraulic profiling is shown in Fig.3. The hydraulic regions were divided into four at 1.12, 1.025, and 0.95 of the global power envelope. The loss coefficients of the inlet orifices of the four hydraulic regions were determined as 6.29, 7.39, 12.04, and 19.24, respectively. The solid line without a symbol in Fig.3 represents the relative mass flux profile and it shows that the inlet flow distribution was optimized well to follow the power profile.

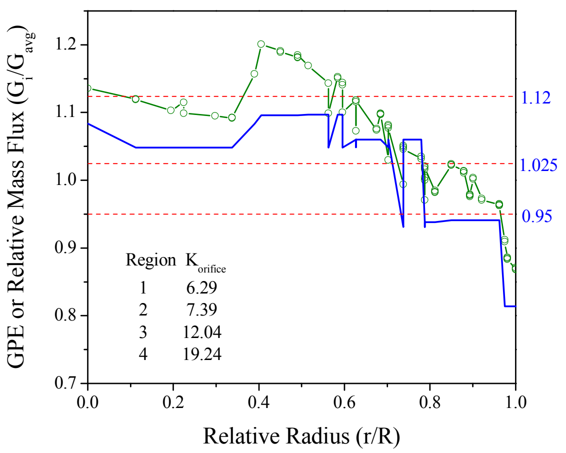

Fig.3. Results of Hydraulic Profiling

3. Conclusion

A Parallel channel type reactor core was profiled thermal-hydraulically. The channels were grouped by four hydraulic regions that had the same inlet orifice according to the global power envelope. The loss coefficients of each inlet orifice were determined to equalize the maximum outlet temperatures of all the hydraulic regions and to maximize the boiling margin. The boiling margin was increased when the channels were grouped into four by more than 13 % of the core with no hydraulic profiling.

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