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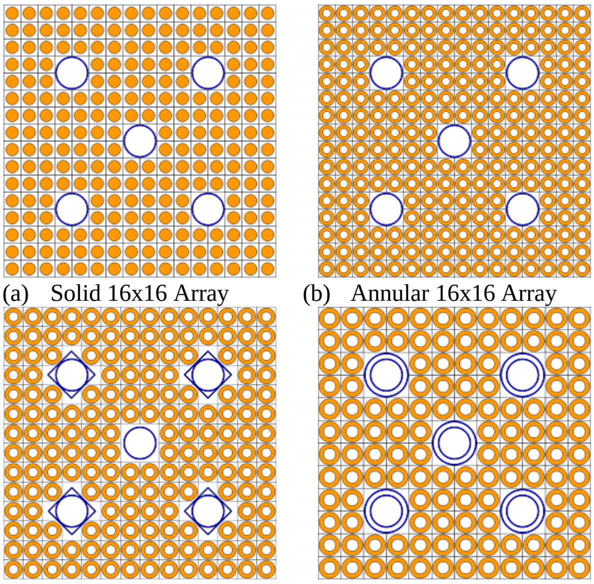
The Design of Annular Fuel Arrays for a High-Power-Density PWR

C. H. Shin*, W. K. In, D. S. Oh, T. H. Chun
Korea Atomic Energy Research Institute, P.O.Box 105, Yuseong, Daejeon, Korea, 305-353
**Corresponding author: shinch@kaeri.re.kr*

1. Introduction

The internally and externally cooled annular fuel concept for high-power-density PWR was proposed by MIT[1]. The annular fuel has several benefits; the first is that the peak temperature in a fuel pellet can be decreased by the decreasing of fuel thickness. Due to the increase of the heated area, the heat flux on the heated surface is decreased, therefore the critical heat flux can be increased. The increase of heated surface, however, leads to higher pressure drop of a fuel assembly. The heat split ratio between the inner and outer surface is significantly affected by the inner and outer gap conductance between fuel pellet and cladding. KAERI is pursuing the development of its reloading to operating PWR reactors of OPR-1000. In the fuel array of OPR-1000, the big size guide tubes and an instrumentation tube are located in the 16x16 rod bundle. It is not easy to design an aligned array with these guide tubes. The fuel assembly concepts of a 12x12, 14x14, and 16x16 array are proposed and the thermal-hydraulic characteristics are compared and estimated.



(a) Solid 16x16 Array (b) Annular 16x16 Array
(c) Annular 14x14 Array (d) Annular 12x12 Array

Fig. 1 A Fuel assembly array for a high-power-density PWR

2. Geometry of the Annular Fuel Arrays

The proposed designs, which are acceptable regarding the location and geometry for the guide tubes and an instrumentation tube of the OPR-1000 reactors are shown in Fig. 1. The general solid fuel assembly of the OPR-1000 reactor is shown in Fig. 1(a). As shown in figure, a 16x16 solid fuel assembly has 236 fuel rods, 4 guide tubes for control rods, and 1 instrumentation tube. The simplest concept for annular fuel is a 16x16 annular array, which consists of outer and inner channels. The pitch of rod-to-rod is the same but the outer diameter is increased and installed inner channels as shown in Fig. 1(b). A 14x14 array as illustrated in Fig. 1(c) has the cruciform flow channels around the guide tubes. It has been advocated that the diamond type guide tube has to be as similar with the flow area of a general subchannel as possible. An outer diameter of a 12x12 array is larger as shown in Fig. 1(d), and the inner channel area is larger, relatively. The dual guide tubes are adopted for the arrangement of the flow area around the guide tubes.

The geometrical characteristics are summarized in Table 1. To decide the dimensions of a fuel rod, the inner channel flow area should be procured to be as large as possible, because the inner channel is isolated with neighbor subchannels. The fuel loading amount ratio may be mainly determined by calculating by inner cladding diameter and cladding thickness. In these calculations, the fuel loading amount ratios were considered to maintain more than 80%.

Table 1 Fuel rod geometrical data

	Solid	12x12	14x14	16x16
Number of fuel rods	236	124	172	236
Rod pitch (mm)	12.85	17.13	14.68	12.85
GT OD (mm)	24.9	33.5	24.9	24.9
Outer clad OD (mm)	9.50	15.90	13.45	11.65
Inner clad ID (mm)		8.5	7.1	6.0
Fuel loading ratio	100%	80%	80%	86%
Flow area ratio	100%	88%	94%	93%
Rod power increase	1 .00	1.90	1.37	1.00
Heat Flux (kW/m^2)	578.4	428.6	366.9	311.3

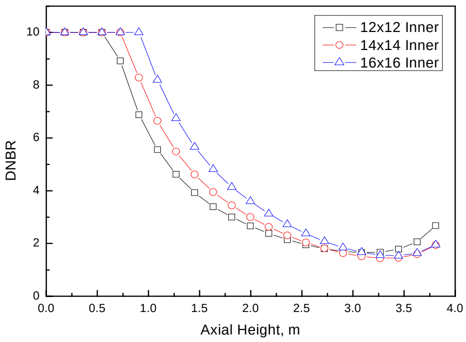
3. Results and Discussion

The subchannel analysis for an annular fuel array is carried out using MATRA-AF[2]. When the annular fuel has a 20% power uprate, the coolant inlet temperature is assumed to be reduced to maintain the same outlet temperature. The analyses were performed with a 18% overpower to allow for a transient, and the inlet temperature was increased by 2^{o}C to account for any possible non-uniformities of the core inlet temperature due to an imperfect coolant mixing in the lower plenum.

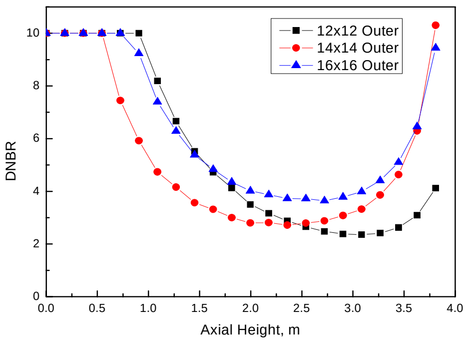
The pressure drop in the fuel assembly arrays is decided by the use of rod friction, spacer grids, etc.

Although the blockage area by the spacer grids is increased as fuel array size, increases the loss coefficients for the spacer grids were fixed at 0.6 for all cases. The pressure drops for the 12x12 and the 14x14 array was increased by 24% and 21% higher than the solid fuel, and those for the 16x16 array were increased by 38%.

The gap conductances in the inner and outer gap clearances have a strong influence on the heat split in the annular fuel. The effect of the gap conductance change on MDNBR was examined 5,000 ~ 18,000 W/m^2K for outer gap conductance and 2,000 ~ 5,000 W/ m^2K for inner gap conductance. The DNBR behaviors at the gap conductance of 3500 W/m^2K for an inner gap and 7000 W/m^2K for an outer gap are illustrated in the Fig.2. The MDNBR in the inner channel of 12x12 array is higher due to a larger flow area and a larger mass flux. The MDNBR in the outer channel, however, is the lowest. The DNBRs in the inner channel of the 14x14 and 16x16 array are similar,



(a) DNBR of inner channels



(b) DNBR of outer channels

but MDNBR in the outer channel of 16x16 array is higher.

Fig. 2 DNBR of annular fuel array

The DNBR sensitivity for the power uprate is compared in the fig. 3. For the 16x16 solid fuel, the MDNBR is decreased below safety criteria, 1.3 at the 120% power uprate, but the annular fuels have above criteria for the given gap conductance conditions. The sensitivities of MDNBR for the outer channel show similar gradient features, but for the inner channel, the gradient is rapidly decreasing at the 16x16 array. The hydraulic diameter ratio, inner to outer channel is 1.12, 1.02, and 0.94 for 12x12, 14x14, and 16x16, respectively. For the 16x16 array, the hydraulic diameter ratio is the lowest for the 16x16 array, and then the parameters related to DNBR correlation are sensitive to the heat flow into the channel for the decreasing diameter. These sensitivity features are also affected by gap conductance variations. The trend of sensitivity for the 12x12 array is similar to the solid fuel. The 12x12 array with larger inner channel diameter has a benefit in relation to sensitivity. The flow area ratio between inner and outer channel for the DNBR balance should be considered as an important parameter.

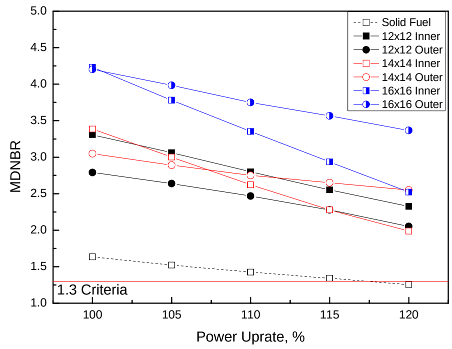


Fig. 3 DNBR sensitivity for the power uprate

4. Conclusions

In this paper, the thermal-hydraulic characteristics about annular fuel arrays are estimated for the high-power-density PWR. The 12x12, 14x14, and 16x16 annular fuel arrays are suggested for reloading to operating PWR reactors of OPR-1000.

The pressure drop in the annular fuels is increased due to the increasing friction area. The pressure drop for the 16x16 annular array is increased by 38%, even though the loss coefficient of the spacer was not strictly adopted.

The sensitivities of the outer channel are similar to solid fuel, but the inner channel is sensitive to the power density. Because the 12x12 array have a larger flow area in the inner channels, the sensitivity of MDNBR at the inner channels is lower than other arrays. In terms of the sensitivity, the 12x12 array is better.

Acknowledgment

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