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A Parametric Study on the Thermal Hydraulic Design for an Annular Fuel Assembly

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1. Introduction

Recently, MIT proposed an internally and externally cooled annular fuel for an advanced PWR which can endure a substantial power uprating.[1] To apply this annular fuel in the conventional reactors such as OPR-1000, it is desirable to investigate its a structural compatibility for its reloading to operating PWR reactors of OPR-1000 as well as other compatibilities like the fuel to moderator ratio, amount of fissile material and coolant flow area. Conventional fuel assembly has a 16x16 solid rod array with four big guide tubes and one instrumentation tube. A 12x12 annular fuel assembly design which can meet the above compatibilities was proposed, which is structurally compatible with the existing internals of OPR-1000.

Actually the advantage of an annular fuel comes from the fuel performance and thermal hydraulics. In the thermal hydraulic analysis, the mixing effect between the neighboring channels has to be carried out in a subchannel analysis. A subchannel analysis code, MATRA[2] has been developed by KAERI. However, MATRA dose not have the capability to model both an internally and externally cooled annular fuel. A subchannel code, MATRA-AF which can be coupled to MATRA and can calculate the coolant flow distribution and heat transfer fraction in the internal and external subchannels has been developed. In this paper, the characteristics and the verification of the MATRA-AF are described. The effects of the thermal hydraulic parameters are estimated through a single fuel assembly.

2. Development and Verification of MATRA-AF

MATRA-AF consists of two programs of MATRA and ANNULAR. The calculations of the mass and energy equations for each subchannel are performed in MATRA. In the ANNULAR, it will adjust the flow split to equalize the pressure loss between the internal and external channel, and the heat split from these results will be recalculated, and then the MATRA recalculates it with the MATRA input regenerated from ANNULAR. This iteration loop is repeated until the mass flow distribution and heat transfer fraction are within the error tolerance.

To verify MATRA-AF, the energy conservation and pressure loss for the single-pin are checked in a single-phase heat transfer. The data communication between both programs can be checked by energy conservation and flow split calculation comparisons to an analytical calculation. The verification of the heat split calculation can be checked by a comparison to SHARP Code[3] which considers the spacer grids. The differences of the results about the flow split and the heat split are under the 2.5%.

3. Results and Discussions

To perform the parametric study of an annular fuel assembly, the following assumptions were adopted: The fuel amount ratio is about 92% for the solid fuel of OPR-1000. The ratio of the cladding thickness to outer diameter is 0.06 for the outer cladding and 0.07 for the inner cladding. The width and conductance of the inner and outer gap calculated by DUO-Therm[4] are used for this estimation. The geometric parameters are summarized in Table 1.

Table 1 Geometric parameters for an annular fuel

		Case12C	Case12D	Case12E
	16*16	12*12	12*12	12*12
Rod Pitch	12.85	17.13	17.13	17.13
Clad OD	9.5	15.9	15.8	15.7
Rod gap	3.35	1.23	1.33	1.43
Gap thickness	0.085	0.07	0.07	0.07
Inner Clad ID	0	7.7	7.6	7.5
GT Dia	24.9	33.5	33.5	33.5
Fuel amount ratio (%)	100	92	92	92
Heat trans. area ratio (%)	100	131	129	128
Flow area ratio (%)	100	83	84	84

3.1. Cladding diameter effects

The outer cladding diameter of an annular fuel is larger than that of a solid fuel. Therefore, the thickness of the outer cladding may be thicker for saving the mechanical characteristics. To maintain the cladding thickness ratio and the fuel amount ratio, an inner cladding diameter is determined by an outer cladding diameter. A minor change of the outer diameter has relatively little impact on the MDNBR as shown in Table 2. However, the DNBR at the inner channel of a hot pin dropped by about 12% with a decreasing diameter. Therefore, the reduction of the outer diameter is limited by the DNBR margin of an inner channel.

3.2 Turbulent mixing parameters Effects

In the subchannel analysis, the investigated turbulent mixing parameters have the most marked effect on the DNBR predictions. It is difficult to apply the turbulent mixing constants of a solid fuel due to the narrow rod-to-rod gap of an annular fuel. As shown in Table 2, the DNBR margin is increasing by around 11% with the consideration of 0.5% compared to the neglected case for the turbulent mixing

3.3 Guide Tube Diameter Effects

The MDBNR in a fuel assembly arises in an outer channel adjacent to the guide tubes. The achievement of a larger flow area around a guide tube leads to an increase of the MNBDR. The guide tube diameter is changed from 33.5 mm to 24.9 mm. The MDNBR in a fuel assembly has increased from 2.26 to 2.68 however the MDNBR at the inner and outer channel of a hot pin is decreased due to a decrease of the coolant flow.

3.4 Gap Conductance Effects

In the annular, the heat, which is generated in a fuel rod, splits in to the inner and the outer channel. The gap conductance and width between the pellet and cladding have a big effect on the heat split. The effect of an inner gap is estimated with the fixed outer gap parameters as shown in Fig. 1. The MDNBR margin at the outer channel is lower than the inner channel, and the increased gap conductance at inner channel leads to an increase of the outer channel but a decrease of the inner channel as shown in Fig. 1. The decreasing of inner gap width results in an increase of the heat flux to the inner channel. The increased heat flux greatly decreases the MDNBR of inner channel.

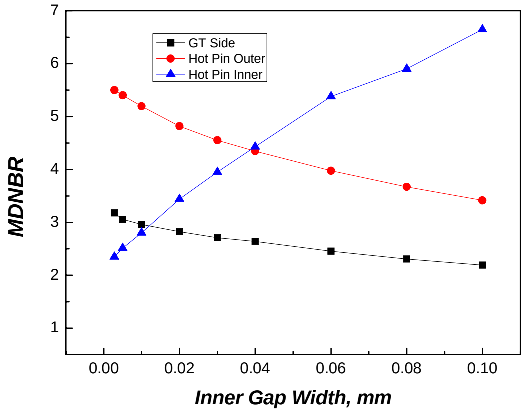

Fig. 1 The effect of a inner gap conductance

4. Conclusion

To estimate the effects of the thermal hydraulic parameters in an annular fuel assembly, a subchannel analysis was performed. A minor change of the outer cladding diameter has relatively little impact on the MDNBR. Reasonable values for the turbulent mixing parameter should be evaluated through an experiment for an annular fuel assembly with a spacer grid. The flow area around the guide tubes should be considered with the MDNBR at the inner and outer channel of a hot pin. The heat split due to the gap conductance is very important for the MDNBR of the annular fuel assembly. The criteria of a heat split ratio from this analysis could be suggested for a fuel performance design, mechanical elements and so on.

Acknowledgment

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Table 2 Parametric results for the thermal hydraulic design

		Gap Thickness		Gap Conductance		MDNBR			Heat Split	Flow Split
		mm		W/m^{2}K					q''_i/q''_o	G_i/G_o
		Inner	Outer	Inner	Outer	GT Side	Hot Pin Outer	Hot Pin Inner	at Hot Pin	at Hot Pin
OPR-1000 Solid Fuel	16x16		0.085			2.427	2.42			
Outer Diameter	Case12C	0.095	0.0300	2763.5	6641.9	2.56	4.17	5.05	1.05	1.494
	Case12D	0.095	0.0301	2773.6	6624.9	2.56	4.21	4.72	1.051	1.451
	Case12E	0.095	0.0303	2783.8	6608.2	2.54	4.22	4.47	1.053	1.427
Turbulent Mixing Effects	TDC 0.03	0.100	0.0028	2600	17000	2.61	4.08	6.06	0.852	1.454
	TDC 0.005	0.100	0.0028	2600	17000	2.50	3.70	6.08	0.853	1.480
	TDC 0.0	0.100	0.0028	2600	17000	2.26	3.61	6.11	0.854	1.496
GT Effects	GT 33.5	0.100	0.0028	2600	17000	2.26	3.61	6.11	0.854	1.496
	GT 30.0	0.100	0.0028	2600	17000	2.62	3.36	5.74	0.848	1.383
	GT 24.9	0.100	0.0028	2600	17000	2.68	3.14	5.55	0.844	1.326