DNBR Analysis of a Dual-Cooled Annular Fuel for the OPR1000 Application

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1. Introduction

A dual-cooled annular fuel (Fig. 1) for a pressurized water reactor (PWR) has been introduced for a significant amount of reactor power uprate. The Korea Atomic Energy Research Institute (KAERI) has been performing a research to develop a dual-cooled annular fuel for the power uprate of 20% in an optimized PWR in Korea, OPR1000 [1-3].

Several thermal-hydraulic tasks exist for the application of the dual-cooled annular fuel to OPR1000. The primary task is the balance of the minimum DNBR (MDNBR) between the inner and outer channels since the coolant flows through the circular inner channel of annular fuel as well as the outer subchannels formed between the fuel rods. The MDNBR balance has been known to largely depend on the thermal conductance in the inner and outer gaps. Another task is to evaluate the operating condition that the inner coolant channel is partially blocked.

This study calculated the MDNBR in the inner and outer channels depending on the thermal gap conductance, i.e., inner and outer gap width. The acceptable range of gap width is determined for the MDNBR not to exceed the DNBR limit during anticipated operational occurrences (AOOs) as well as normal operation. The limit for the flow blockage in the inner channel is also estimated based on the DNBR analysis.

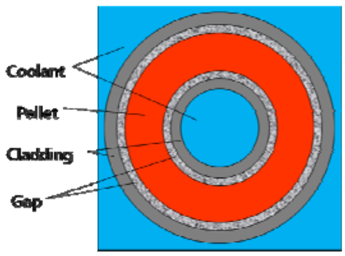

Fig. 1. Schematic of dual-cooled annular fuel.

2. Methods and Results

A subchannel analysis method is used to perform the thermal-hydraulic calculations for the OPR1000 core. A computational code, MATRA-AF, is developed to predict the thermal-hydraulic parameters for the annular fuel core. The MATRA-AF code consists of MATRA module and annular fuel module. The MATRA module [4] is a subchannel analysis code which was developed to analyze the thermal-hydraulic characteristics in fuel bundle for a PWR. The annular module is developed to calculate the flow and heat splits in the inner and outer channels of annular fuel. The MATRA-AF code is therefore able to calculate the DNBR in the inner and outer channels as well as the flow and heat splits.

2.1 MDNBR Balance in the Dual-Cooled Fuel

Based on the lumped quadrant core model and the subchannel analysis parameters, the DNBR calculation for the 12x12 annular fuel was conducted by using the MATRA-AF code over the operable range of the gap conductance in order to determine its allowable range for the MDNBR not to exceed the DNBR limit. The DNBR limit is 1.30 which is typical value of specified acceptable fuel design limit for PWR. The gap conductance changed from 3000 $W/m^2\,^oC$ to 8500 $W/m^2\,^oC$ for the inner gap and 6000 $W/m^2\,^oC$ to 20000 $W/m^2\,^oC$ for the outer gap.

The calculated MDNBR values in the inner channel are listed in Table I for various combination of inner and outer gap conductance. It can be seen that the MDNBR increases in the inner channel and decreases in the outer channel as the outer gap conductance (hgo) increases. The MDNBR in the inner channel is lower than the DNBR limit for the case of the outer gap conductance being smaller than twice the inner gap conductance (hgi), i.e., hgo < 2hgi. However, the MDNBR in the outer channel was always higher than the DNBR limit for any gap conductance examined.

TABLE I: MDNBR values in the inner channel at 120% power with 118% overpower depending on the inner and outer gap conductance (hgi, hgo)

	hgo = 6000	7000	10000	14000	20000
hgi = 3000	1.993	2.345	3.030	3.494	3.783
3500	1.489	1.816	2.493	3.000	3.350
4500	-	1.108	1.722	2.213	2.605
6500	-	-	0.881	1.288	1.650
8500	-	-	-	0.814	1.133

Fig. 2 illustrates the allowable range of the inner and outer gap conductance in which the MDNBR is higher than the DNBR limit. It shows a significant increase of the operable region as the outer gap conductance increases. The outer gap conductance should be greater than 4000 W/m^2-^oC while the inner gap conductance be smaller than approximately 7000 W/m^2-^oC. It is also noted in Fig. 2 that the MDNBR in the inner and outer channels is well balanced if the ratio of outer and inner gap conductance (hgo/hgi) is in between 2 and 3.

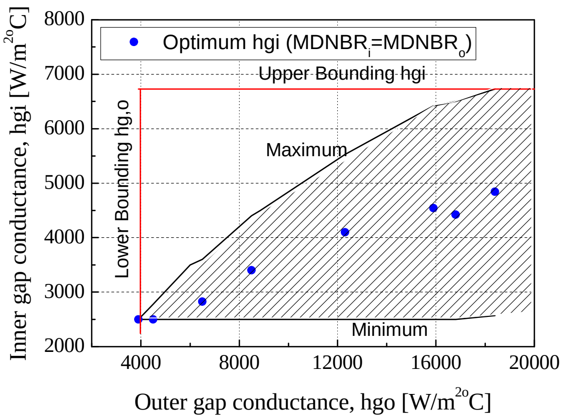

Fig. 2. Acceptable range of the gap conductance.

2.2 Flow Blockage of the Inner Channel

The isolated inner channel of the dual-cooled fuel is facing a question for a hypothetical flow blockage. The MDNBR is calculated for various partial blockages by adjusting the form loss coefficient at the entrance of the inner channel. The entrance form loss coefficient was gradually increased from 0.4 (no blockage) until the MDNBR dropped below the DNBR limit (1.30).

Fig. 3 shows the effect of entrance blockage on MDNBR and coolant mass flux in the inner channel. As the blockage increased, the mass flux decreased significantly due to the whole core flow redistribution to accommodate equal pressure drops across each channel. The MDNBR also decreased due to the decreased mass flux. The calculated MDNBR is 1.709 and 1.207 for 55% and 60% blockages, respectively. The maximum blockage of flow area in the inner channel should be therefore smaller than 55% for the MDNBR not to drop below 1.30.

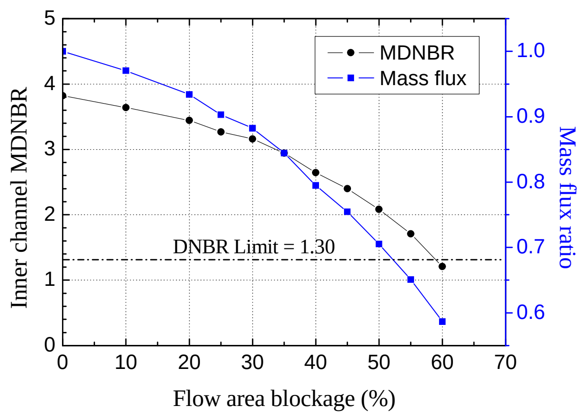

Fig. 3. Flow blockage dependent MDNBR in the inner channel.

3. Conclusions

A thermal-hydraulic analysis using the subchannel method was performed to calculate the MDNBR depending on the gap conductance and the entrance blockage in an inner channel. It was found that the MDNBR in the inner and outer channels is well balanced if the ratio of outer and inner gap conductance is in between 2 and 3. The acceptable range of the gap conductance is significantly enlarged as the outer gap conductance increases. The maximum blockage of flow area in the inner channel was calculated to be approximately 55% for the MDNBR to be greater than the DNBR limit.

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