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Thermal Hydraulics Analysis of a Dual-Cooled Annular Fuel with 18-month Cycle

ChangHwan Shin*, ChiYoung Lee, DongSeok Oh, TaeHyun Chun, and Wang Kee In
Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, Korea, 305-353
**Corresponding author: shinch@kaeri.re.kr*

1. Introduction

A dual-cooled annular fuel 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].

For the core of current OPR1000, a 12x12 annular fuel array configuration was proposed through the evaluation of several candidates. And then fuel rod dimensions were optimized as 15.9 mm for outer diameter and 8.5 mm for inner diameter. A feasibility assessment of 120% core power along with the annular fuels was conducted including nuclear physics, core thermal-hydraulics and safety analyses for the typical accidents [4]. For these work a set of design code package for annular fuel analyses were also established.

According to the results, the annular fuel showed a potential of 20% power uprate with similar to or better than the conventional solid fuel in safety margin. In addition, some technical issues like heat split imbalance and inner channel blockage were investigated and resolved by means of annular pellet design and anti-inner channel blockage lower end plug, respectively [5].

However, due to the decrease in the fuel amount for the OPR1000 core with the dual-cooled annular fuel, the cycle length was limited to 12-month reduced from 18-month. The core design and safety analysis with 18-month cycle are performing by increasing the U-235 enrichment above 5 wt%.

In this study, the thermal hydraulics characteristics are assessed under the conditions of 120% power uprate and 18-month cycle.

2. Methods and Results

To evaluate the thermal-hydraulic characteristics of the annular fuel core, the whole core subchannel analysis of MATRA-AF were developed with the conventional subchannel code MATRA [6]. It can predict the heat and flow splits between inner and outer channels in annular fuels.

2.1 Core Design

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. The radial pin power distribution in a quarter of the hot assembly and the radial assembly power of the core at cycle 6 and EFPD = 300 are illustrated in Fig. 1. The hottest rod is located around the center guide tube and two poison rods are located in the corner around the outer guide tube. The radial peak power in the hot assembly is 1.629. The axial power distribution at cycle 6 is shown in Fig 2. The axial power distribution at the EFPD=300 shows almost uniform shape with slightly bottom skewed power.

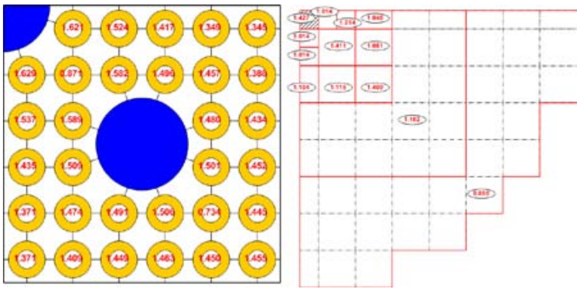

Fig. 1 Pin and assembly power distribution

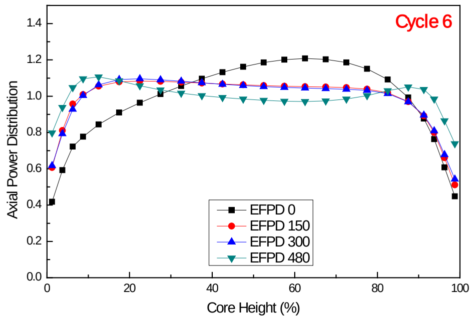

Fig. 2 Axial power distribution of cycle 6

2.2 Averaged Quality

For the power uprate of a dual-cooled annular fuel, the inlet temperature is decreased to maintain the exit temperature of OPR1000. The core averaged equilibrium quality is shown in Fig. 3. As shown in the figure, the exit quality of the annular fuel is equal to solid fuel as -0.12 and the inlet quality reflects the

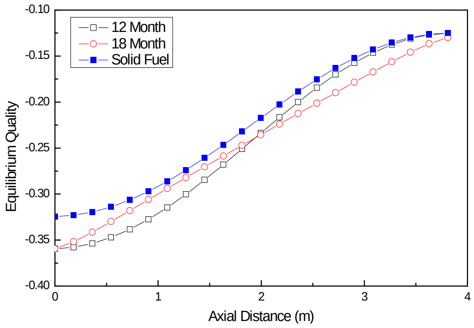

Fig. 3 Bundle averaged equilibrium quality

difference between inlet temperatures. Due to the axial power shape, the quality of the solid fuel and the 12-month cycle annular fuel with consine shape are gradually increased at the inlet and exit region and rapidly increased in the middle region, but the quality of the 18-month cycle with uniform axial shape is linearly increased. From this result, it can be confirmed that the input for the mass flux and power is correctly applied.

2.3 Pressure Loss

The pressure loss is mainly caused by the friction on the rods and the spacer grids. The friction factor is decreased with decrease in the pitch over diameter ratio (P/D). From the experiment, the friction factor for the annular fuel (P/D=1.08) was decreased to 70% of the solid fuel (P/D = 1.35) [7]. In the previous research for the 12-month cycle, the friction factor was used the same condition for the solid fuel. Therefore the pressure loss was overestimated as 162 kPa as shown in Fig. 4. However, when the friction factor for outer channel is used 75% of McAdams correlation, the pressure loss is decreased to 144 kPa, which is 9% higher than the solid fuel.

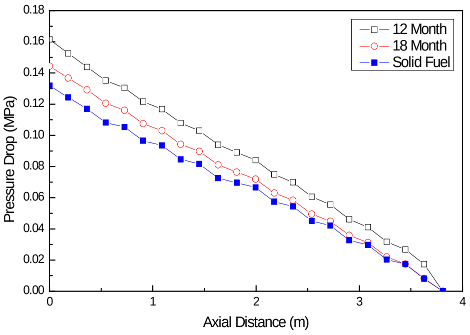

Fig. 4 Core averaged pressure

2.4 DNBR

The axial DNBR distribution is illustrated in Fig. 5. The MDNBR for the solid is located around 2/3 axial direction due to the cosine shaped axial power distribution. For the annular fuel with 18-month cycle, however, the DNBR is linearly decreased because of the uniform axial power shape as shown in Fig. 3, so the MDNBR occurs in the exit region. While the MDNBR of the solid is 2.34, the MDNBR in the inner and outer channel of the annular fuel are 3.89 and 3.54, respectively. The outer channel MDNBR of the annular fuel is 1.5 times higher than the solid fuel. However Since the gap conductance at the inner and outer gap between a fuel pellet and claddings varies along the fuel burn-up, the gap conductance effect should be considered for heat flux and DNB.

3. Conclusions

The thermal hydraulic characteristics of a dual-cooled annular fuel with 18-month cycle are assessed under the conditions of 120% power uprate. The friction loss based on experimental results is applied as 75% of a correlation for the solid fuel. Pressure loss is 9% higher than that of the solid fuel. The MDNBR for the annular fuel is 3.54 at the outer channel, which is 1.5 times higher than the solid fuel.

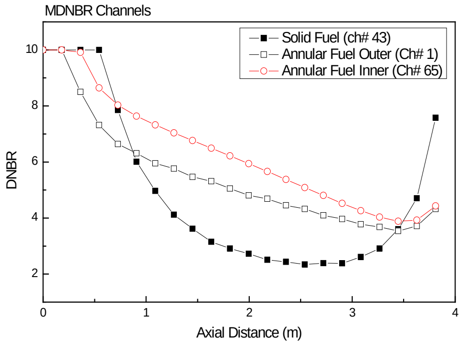

Fig. 5 DNBR trends at the MDNBR subchannel

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