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Estimation of Thermal Hydraulics Parameters 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].

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%. The thermal hydraulics characteristics was assessed under the conditions of 120% power uprate and 18-month cycle [4].

In this study, the major parameters of the thermal hydraulics on the fuel design were estimated for the MDNBR. A dual-cooled annular fuel was designed as tight lattice bundle compared with solid fuel assembly. The estimation of the pressure loss on the tight lattice rod bundle is necessary. The several designs of a spacer grid for the dual-cooled annular is suggesting. From this study about the loss coefficient of spacer grid, the design criteria will be suggested. And the effect of the thermal mixing by mixing vane of spacer grid is estimated.

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 [5]. It can predict the heat and flow splits between inner and outer channels in annular fuels.

2.1 Friction Factor of Outer Channels

For the dual-cooled annular fuel, the ratio of rod diameter and rod-to-pitch (P/D) was reduced. It is presented that the friction factor for the tight lattice rod bundle is decreased with decreasing P/D ratio. 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]. The inner channel friction factor was applied McAdams correlation, which is generally used for the solid fuel rod bundle. For the analysis, the loss coefficient of spacer grid is assumed as 0.7 and the thermal mixing factor is assumed 0.03.

The effect of the friction factor on the pressure loss in the fuel assembly is illustrated in Fig. 3. When original friction factor was applied, the pressure loss of fuel assembly is 152 kPa. However, when the friction factor for outer channel was used 70% of McAdams correlation, the pressure loss was decreased to 143 kPa. It is similar to the result (144 kPa) of a solid fuel which was estimated with spacer grid loss coefficient, 0.85.

The heat split(q''_i/q''_o) was not varied as about 1.1 for the whole test case. The variation of the flow split (G_i/G_o) was within 0.2. The variation of MDNBR by the flow split and heat split is shown in Fig. 4. The MDNBR of the outer channel is increased from 3.42 to 3.55, however that of the inner channel is sensitively decreased from 4.21 to 3.80.

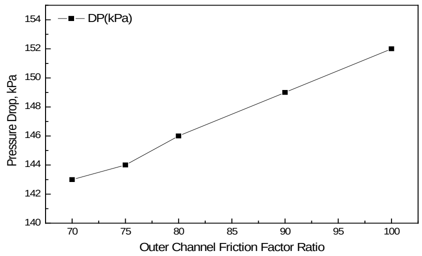

Fig. 1 Pressure loss of core by the friction factor

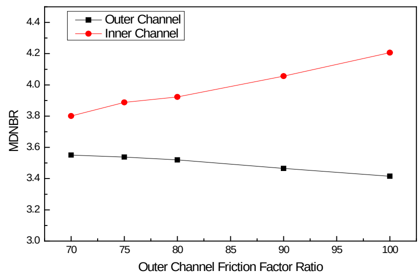

Fig. 2 MDNBR by the friction factor

2.2 Loss Coefficient of Spacer Grids

The pressure loss is mainly caused by the friction on the rods and the spacer grids. The loss coefficient of spacer grids is varied from 0.55 to 0.9. The friction factor was used 75% of McAdams correlation. The pressure loss of the core is increased from 137 kPa to 153 kPa with increasing the loss coefficient of spacer grid. The MDNBR trend by the variation of loss coefficient of the spacer grid is illustrated in Fig. 3. The increased pressure loss by spacer grid derives increase of the inner channels' flow rate. The variation of MDNBR in the inner channel is more sensitive. The value is varied from 3.54 to 4.24. The flow rate in the inner channel depends on outer channel friction factor and loss coefficient of spacer grids. The decreased flow rate due to reduced friction factor can be compensated larger loss coefficient of spacer grid within design criteria.

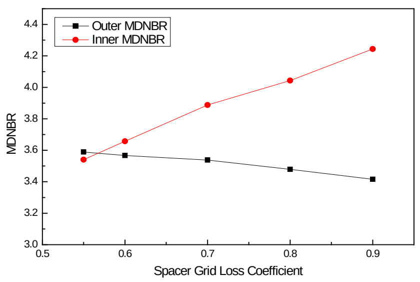

Fig. 3 MDNBR by loss coefficient of spacer grids

2.3 Thermal Mixing Factor

The thermal mixing factor in the subchannel analysis decides exchange of enthalpy between subchannels. In the recent fuel assembly, the spacer grid with mixing vane and intermediate flow mixing grid are applied to improve thermal margin from the mixing between subchannels. The appropriate design of the mixing vane for the annular fuel complements the reduced MDNBR in the outer channel. The thermal mixing factor is considered from zero to 0.05. The trend of MDNBR by the thermal mixing factor is shown in Fig. 4. Since the variation of the thermal mixing factor is affected at the outer channel, the MDNBR in the inner channel is similar for the analysis range. The maximum MDNBR in the outer channel is reached at the thermal mixing factor of 0.02. At the thermal mixing factor above 0.03, the MDNBR is slightly decreased with increasing the thermal mixing factor.

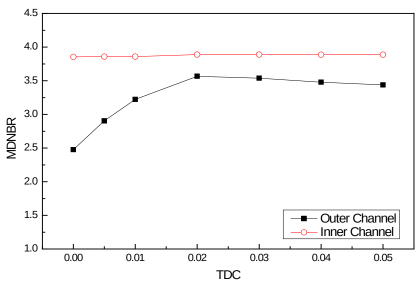

Fig. 4 MDNBR by thermal mixing factor

3. Conclusions

The thermal hydraulic parameters of a dual-cooled annular fuel with 18-month cycle are assessed for the fuel design under the conditions of 120% power uprate.

The heat split by the variation of friction factor in the outer channel was not varied as about 1.1 for the whole test case. The variation of the flow split (G_i/G_o) was within 0.2. The MDNBR of the outer channel is increased from 3.42 to 3.55, however that of the inner channel is sensitively decreased from 4.21 to 3.80.

The flow rate in the inner channel depends on outer channel friction factor and loss coefficient of spacer grids. The decreased flow rate due to reduced friction factor can be compensated larger loss coefficient of spacer grid within design criteria.

The maximum MDNBR in the outer channel is reached at the thermal mixing factor of 0.02. The optimized design of mixing vanes for the thermal margin and appropriate flow split is necessary.

Acknowledgements

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