Effects of Annular Fuel Rod Design Parameters on Heat Split

Yong Sik Yang, Tae Hyun Chun, Chang Hwan Shin, Je Geon Bang, Kun Woo Song
P. O Box 150, Yuseong, Daejeon, Korea, 305-600
Korea Atomic Energy Research Institute
yys@kaeri.re.kr

1. Introduction

A heat flux control within acceptable range is a key issue from a fuel safety and economy point of view. In the case of conventional solid type fuel, a fuel rod surface heat flux can be predicted by a simple calculation because all the generated heat flows into the coolant through only one surface.

However, in the case of double cooled annular fuel, a generated heat in a pellet can flow in the inner or outer coolant channel and the amount of heat which flows in both channels is determined by both side's heat resistance[1]. Therefore, a prediction of inner and outer surface heat flux requires an understanding of heat resistance change which is caused by an irradiation or temperature induced effect.

A new computer program, DUO_THERM, was developed[2]. This program can calculate heat resistance variation as a function of burnup and temperature or a power. By using the DUO_THERM program, we can predict the heat flux of both sides surface and the radial temperature distribution of an annular fuel rod.

In an annular fuel design, a heat flux unbalance(called heat split) problem between the inner and outer coolant channel is an important issue[3,4]. If an excessive heat split occurs, more heat flows into one side and the DNBR margin will be reduced.

As mentioned above, the heat split is affected by the heat resistance. Factors which can cause a heat resistance change during a life time are various. Irradiation is one of the most important factors because it changes fuel dimension as well as material properties such as thermal conductivity, heat capacity and porosity. Temperature or power can change heat split too. In addition to in-reactor behavior, the initial design of a fuel rod can affect the heat resistance and heat split also. In this paper, as a preliminary study for a design optimization, the important annular fuel design parameters were reviewed and their effects on a heat split were evaluated.

2. Sensitivity study of design parameter on heat split

Various rod design parameters such as the rod OD, ID, length, inner and outer clad & gap thickness, clad thickness, thermal conductivity of pellet, and pellet and clad surface roughness were selected as an important parameters. Sensitivity study was performed to investigate the effect of design parameters on the inner/outer surface heat flux changes.

Calculation of the inner and outer heat fluxes was performed by the DUO_THERM program and the sample input is summarized in Reference [2].

2.1 Effect of rod diameter on heat split

An increase of annular fuel outer diameter is very restrictive due to fuel assembly structural problems. Therefore, change of inner diameter of annular fuel is only available for changing heat split. Change of rod diameter can affect total heat resistance due to the increase of pellet thickness. The reference inner diameter is 9mm. Figure 1 and 2 show inner and outer heat flux variations due to the inner diameter reduction. As can be seen, inner surface heat flux was increased due to the reduction of inner surface area. But outer surface heat flux change was very small. These results imply that only large reduction of inner diameter can affect heat split behavior.

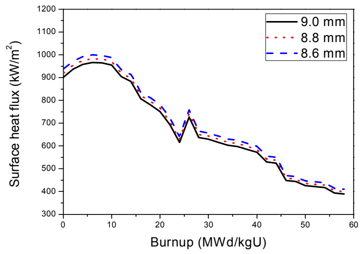

Fig. 1. Effect of the ID. change on inner surface heat flux

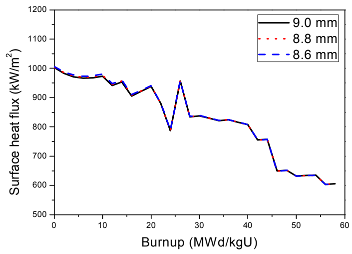

Fig. 2. Effect of the ID. change on outer surface heat flux

2.2 Effect of the initial gap width on a heat split

As mentioned in chapter 1, the inner and outer gap conductance has a majority of the total heat resistance.

Therefore, it was expected that change of the initial gap width would change the heat split. Figure 3 shows a reference inner and outer gap width and its heat flux change during an irradiation. After the change of the initial gap width (inner:70 →50μm, outer:70→90μm), a heat flux change is remarkable(Figure 4). Although, the gap width change was only 20μm, its effect on the heat split was considerable.

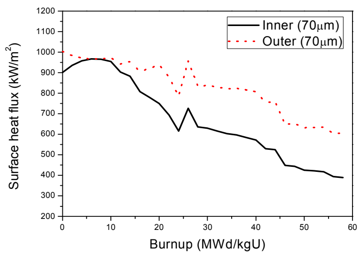

Fig. 3. Reference design heat split

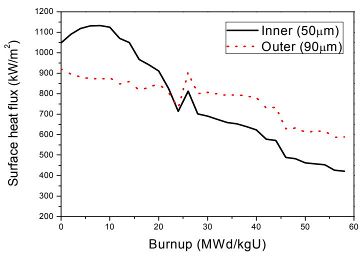

Fig. 4. Effect of the gap width change on a heat split

2.3 Effect of the fuel thermal conductivity

With a gap conductance, fuel heat resistance has major portion to the total heat resistance. Pellet thickness and thermal conductivity are important factors of a fuel heat resistance. Effect of pellet thickness change was reviewed in chapter 2.1 and showed little effect on heat split.

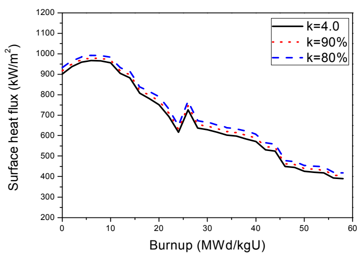

Fig. 5. Effect of fuel thermal conductivity change on inner surface heat flux

In this analysis, a reference fuel thermal conductivity was assumed as 4 W/m-K and the heat split change was calculated as a function of the fuel thermal conductivity.

As can be seen in Figure 5 and 6, a decrease of fuel thermal conductivity shows an increase of the inner surface heat flux and reduction of outer surface heat flux.

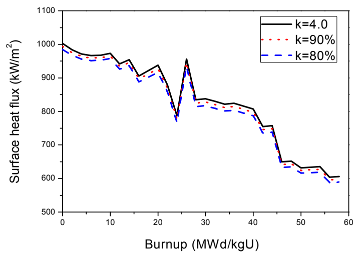

Fig. 6. Effect of the fuel thermal conductivity change on the outer surface heat flux

Figure 7 shows a variation of heat split between the reference and 80% decreased fuel thermal conductivity. It was concluded that a 20% reduction of fuel thermal conductivity can relief about a 10% heat split.

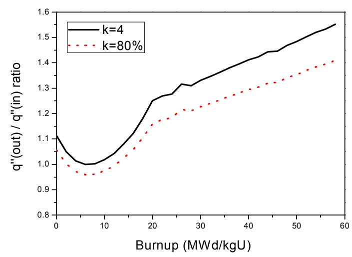

Fig. 6. Effect of fuel thermal conductivity on heat split

3. Conclusion

Using the DUO_THERM program, parametric studies were performed to evaluate the effect of various rod design parameters on an annular fuel heat split. Based on sensitivity study results, it is concluded that the initial gap width and the fuel thermal conductivity change have remarkable effects on a heat split. The results of these sensitivity studies will be reflected in an annular fuel rod design optimization.

4. References

[1] Yong sik Yang et al., "Development of UDO-THERM Ver 1.0", KAERI/TR-3604/2008

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[4] Y. S. Yang et al., "Conceptual Design of OPR-1000 Compatible Annular Fuel Assembly", ICAPP2007, France