Assessment of Inner Channel Blockage on the Annular Fuel Rod

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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].

An inner channel blockage is principal one of technical issues of the annular fuel rod. The inner channel in an annular fuel is isolated from the neighbor channels unlike the outer channels. The inner channel will be faced with a DNB accident by the partial blockage. In this paper, the largest fractional channel blockage was assessed by subchannel analysis code MATRA-AF and an end plug design to complement inlet blockage of inner channel was estimated by CFD code, CFD-ACE.[4]

2. Results and Discussions

For the case of inner channel blockage, it was assumed that, a hypothetical large particle would partially block the inner channel of the hot rod. The subchannel analysis code for annular fuel, MATRA-AF was used to simulate this event. For the conceptual design of the end plug, CFD analysis was carried out to estimate performance of complement for the inlet blockage.

2.1 MDNBR and Inlet Partial Blockage

The isolated inner channel of the dual-cooled fuel is facing a question for a hypothetical flow blockage. For the MATRA-AF analysis, it was conservatively assumed that, the inner blockage occurs at the inlet of the hottest rod in a reactor core. The entrance form loss coefficient (K_{inlet}) was gradually increased from 0.4 without blockage until 15 with 65% blockage due to valuation of orifice loss coefficient in a circular tube.

Fig. 1 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. Therefore, it is necessary for new design of the end plug to make up for the weak points of entrance blockage.

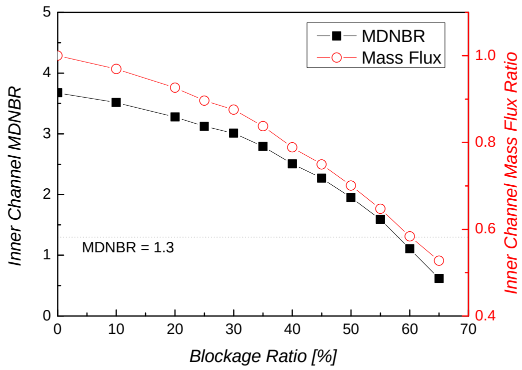
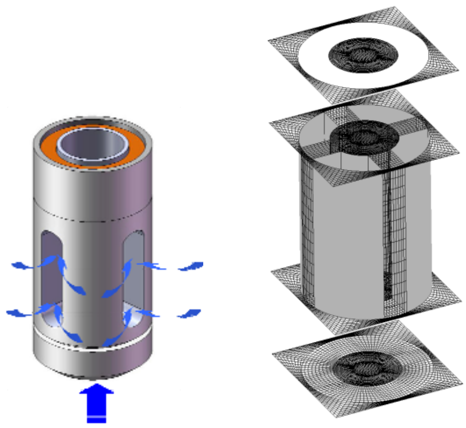


Fig. 1. Flow blockage dependent MDNBR in the inner channel.

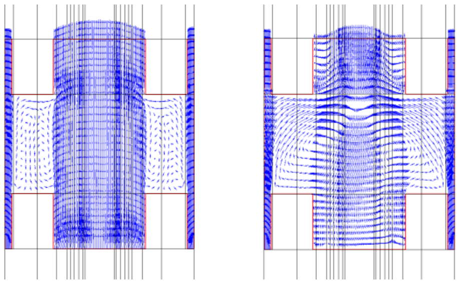
2.2 Lower End Plug with Side Holes

The conceptual design to complement the entrance blockage of inner channel was suggested by KAERI[5]. The through holes in this design are formed on a cylindrical wall of lower end plug. When the inner channel is blocked by debris, the coolant for inner channel will be supplying through the side holes as shown in fig. 2(a). To estimate performance of the side holes, CFD analysis is carried out for a single rod model. The mesh generation around an end plug for the numerical analysis shows in fig. 2(b). The out-side boundary condition is setting as symmetry condition.



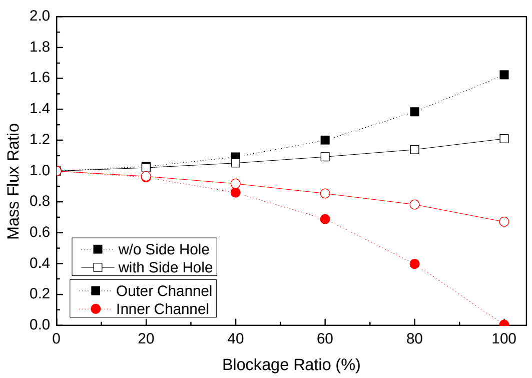
(a) End plug with side holes (b) Mesh generation
Fig. 2 Schematic diagram of lower end plug with side holes and CFD mesh generation.

The velocity profiles for the no-blockage and whole-blockage of the CFD calculation are shown in fig. 3. In the no-blockage case, the average velocity through the a side hole is estimated as 0.49 m/s, 5% of bulk velocity at exit of the inner channel . This velocity is rapidly increasing with inner channel blockage.



(a) No-blockage (b) Whole-blockage
Fig. 3 Velocity profile around side holes of end plug

The mass flux transition from no blockage to whole blockage of inner channel inlet shows in fig. 3. Along the blockage ratio of inner channel inlet, the inner channel mass flux without side holes is rapidly decreasing but case with side holes is gradually decreasing, comparatively. When the inlet of inner channel is wholly blocked, the mass flux of inner channel is maintained at least 67% and outer channel mass flux is increased up to 21% compared with no blockage case. In the fig. 1, the MDNBR at the 67% mass flux ratio is around 1.7 beyond the DNBR limit 1.3. Therefore, it is confirmed that the lower end plug with side holes has sufficient capability to complement an entrance blockage of an inner channel.



3. Conclusions

The inner channel in an dual-cooled annular fuel is isolated from the neighbor channels unlike the outer channels. In this paper, the largest fractional channel blockage was assessed by subchannel analysis code MATRA-AF and an end plug design to complement inlet blockage of inner channel was estimated by CFD code.

In the subchannel analysis, 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 and decreasing ratio of mass flux is below 60%.

In the CFD analysis for the lower end plug with side holes, the inner channel mass flux is maintained at least 67% for the whole-blockage case. The MDNBR in this mass flux condition is around 1.7. The performance of side holes on the lower end plug is confirmed to complement an entrance blockage of an inner channel.

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