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Preliminary thermal hydraulic analyses of the conceptual core models with tubular type fuel assemblies

Heetaek Chae†, Jong Hark Park and Cheol Park
Korea Atomic Energy Research Institute, Deokjin, Yuseong, Daejeon, Korea
htchae@kaeri.re.kr†

1. Introduction

A new research reactor (AHR, Advanced HANARO Reactor) based on the HANARO has been conceptually developed due to the future needs for research reactors. Through various investigations in the aspects of nuclear-physics /thermal-hydraulics /mechanical-structure, a tubular type fuel was considered as one of the fuel options of the AHR. The AHR will be a light-water-cooled and heavy-water-reflected pool type research reactor of a 20MW thermal power. The reactor will use a 19.75% enriched U_3Si_2 fuel. Tubular type fuel assembly has a few curved fuel plates arranged with a constant small gap to build up cooling channels, which is very similar to an annulus pipe with many layers.

This paper presents the preliminary thermal hydraulic characteristics and safety margins for two core configurations along with various core flow velocities. Four design criteria were set up for the AHR thermal hydraulic analyses. They are, the fuel temperature, ONB (Onset of Nucleate Boiling) margin, minimum DNBR (Departure from Nucleate Boiling Ratio) and OFIR (Onset of Flow Instability Ratio) in the normal operating conditions

2. Analysis Models

2.1 Tubular fuel assemblies and core models

Tubular fuel assembly[1] consists of curved fuel plates as shown in Fig. 1. The number of plates for each trisection is 7 for the standard fuel assembly in Fig. 1(a) and 5 for the reduced one in Fig. 1(b). Each fuel plate will be made of dispersed U_3Si_2-Al for the fuel meat and Al1060 for the cladding material. The longitudinal length of the fuel meat is 700 mm. Three stiffeners were designed to divide the cross-section into three equal regions. The reduced fuel assembly is similar to the standard fuel assembly except for the inclusion of a space for moving the control absorber rod and the flow tube as shown in Fig. 1(b).

Figure 2 shows two core models named D1 and D3. The D1 core is composed of 16 standard fuel assemblies and 6 reduced ones. The D3 core has 4 more standard ones than the D1 core. Each fuel assembly is inserted into a circular slot of an aluminum block structure.

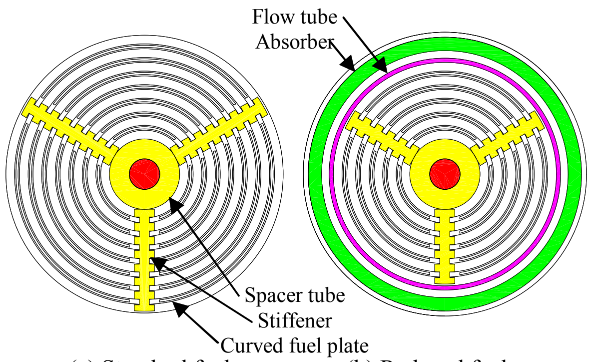
2.2 Analysis code

The thermal hydraulic analyses were performed by using the computer code COOLOD-N2[2]. The code provides a local coolant bulk temperature, fuel surface temperature, ONB temperature, DNB and OFI heat fluxes for a plate type fuel assembly.

2.3 Analysis models

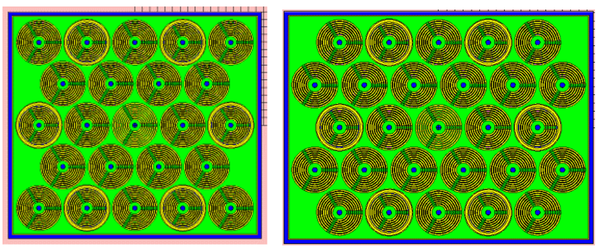
Total peaking factor (F_Q) of the core was conservatively assumed as 3.0. The axial power distribution of the HANARO core was applied by considering the control rod driving mechanism to be the same as the HANARO.

Fuel centerline temperature, ONB margin, minimum DNBR and OFIR were selected as the thermal hydraulic design parameters. The hydraulic and heat transfer correlations of the COOLOD-N2 code were used without a modification due to the similar shape to the plate type fuel and the similar operating conditions. Design criteria for the thermal hydraulic design parameters were tentatively applied as 350 ℃ for the fuel temperature, 20 ℃ for the ONB margin and 2.5 for the MDNBR and MOFIR.



(a) Standard fuel (b) Reduced fuel

Fig. 1 Cross sections of the fuel assemblies



(a) D1 core model (b) D3 core model

Fig. 2 Calculated core models

3. Results and Discussion

Calculation results for the D1 and D3 core models are summarized in Table 1 along with the core coolant velocity in the fuel region. Since the D3 model has 4 more standard fuel assemblies than the D1 model under the same core power, the average heat flux of the D1 model is 33% higher than that of the D3 model and thus the D3 core has greater safety margins.

Figures 3 to 5 show the representative variations of the thermal hydraulic parameters as the coolant velocities in the D1 core model. The maximum fuel centerline temperature at 4 m/sec is 146 ℃ and far from the design criteria of 350 ℃ because the thickness of the plate fuel is very thin. The ONB margin was satisfied at a higher velocity than 7 m/sec and the MDNBR and MOFIR criteria were fulfilled with a flow velocity over 8 m/sec. On the other hand, the flow velocity of the D3 core to satisfy the design criteria should be higher than 7.0 m/sec from Table 1. Therefore, the preliminary design velocities for the conceptual D1 and D3 core models were determined as 8.0 and 7.0 m/sec. These velocities will be temporarily used as the design values for the other designs and analyses.

Table 1 Calculation results for D1 and D3 core models

Velocity (m/sec)	Fuel temp. (℃)		ONB margin (℃)		MDNBR		MOFIR	
Model	D1	D3	D1	D3	D1	D3	D1	D3
4.0	146.1	128.4	-3.4	12.2	1.70	2.22	1.15	1.32
5.0	137.0	116.0	7.2	25.8	1.96	2.56	1.50	1.71
6.0	126.4	107.1	19.0	35.8	2.20	2.86	1.87	2.13
7.0	117.8	100.4	28.8	43.8	2.44	3.15	2.27	2.57
8.0	111.1	95.1	36.6	50.4	2.67	3.42	2.70	3.05
9.0	105.7	91.0	43.3	55.9	2.88	3.68	3.16	3.56

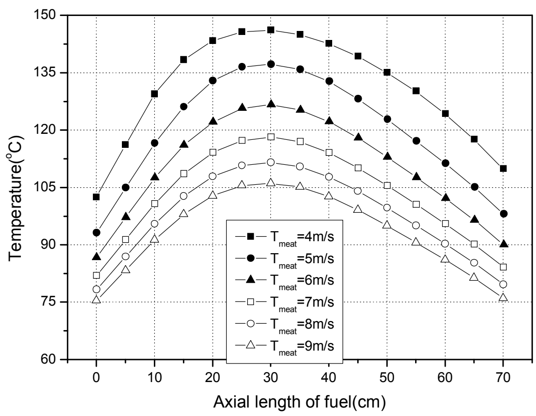


Fig. 3 Axial fuel temperature distributions of D1 core model

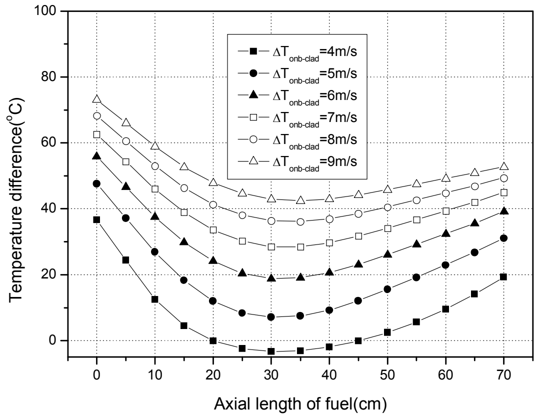


Fig. 4 Axial ONB margin distributions of D1 core model

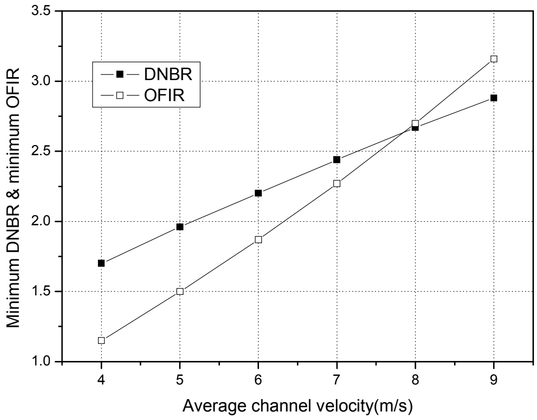


Fig. 5 MDNBR and MOFIR variations along with the coolant velocity of D1 core model

3. Conclusion

The preliminary thermal hydraulic analyses for the core models with tubular type fuels were carried out as one of the conceptual designs of the AHR. Design velocities for the conceptual D1 and D3 core models were determined as 8.0 and 7.0 m/sec to satisfy the maximum fuel temperature, the ONB margin, the minimum DNBR and OFIR as the thermal hydraulic design parameters. These velocities will be temporarily used as the design values for the other designs and analyses.

REFERENCES

[1] Ryu, J.-S., Cho, Y.-G., Yoon, D.-B., Dan, H.-J., Chae, H.-T. and Park, C., "The conceptual design of the standard and the reduced fuel assemblies for an advanced research reactor," 2005 Spring proceeding of Korean Nuclear Society, 2005

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[2] Masnori Kaminaga, "COOLOD-N2 : A Computer Code, for the analyses of steady-state thermal-hydraulics in research reactors," Technical Report, JAERI-M 94-052, Japan Atomic Energy Research Institute, 1994.3.