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Thermal Analysis on Various Power Conditions in Micro Modular Reactor Core

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Small size Nuclear Power Plants (NPPs) have been getting interest in worldwide due to safety issues. As the size of NPPs becomes small, it has less possibility for severe accident. Moreover, a new demand in a sustainable and low-cost energy is continuously increasing to remote or isolated area. The remote area where has limitation to connect power grid pays high cost to use electricity and maintenance. Micro Modular Reactor (MMR) might be alternative to supply energy at those area. Korea Atomic Energy Research Institute (KAERI) has been developing Micro Modular High Temperature Reactor (MiHTR)[1][2]. The MiHTR developed by KARIE uses the advantages of High Temperature Gas-cooled Reactor (HTGR) which might remove residual heat without electric supply. KAERI has been calculating various core options to find an optimized design [1][2]. A Core Reliable Optimization & thermo-fluid Network Analysis (CORONA) code [3] which is used to analyze HTGR core was selected to analyze the hot spot temperatures in the reactor core during normal operations. On the previous calculation, a simple verification was conducted to assure the CORONA algorithms with single fuel block [2]. In the studies reported here, a one-sixth core is selected to compare the calculated results.

2. Methods and Results

The MiHTR core layout selected by KAERI is shown in Fig. 1. A fuel compact is cooled with surrounding six coolant channels. Six fuel blocks are stacked vertically in the active core between the top and bottom reflectors. A core power is 10MWth. The inlet temperature and pressure are set at 300 °C and 3 MPa, respectively.

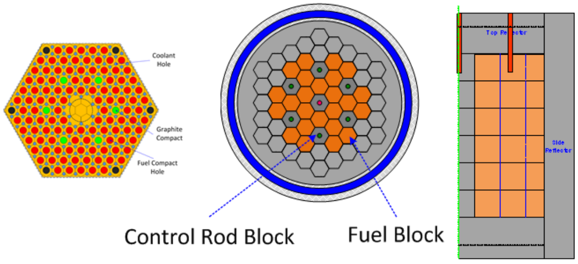


Fig. 1. Schematic of MiHTR core [1]

Numerous studies with the neutronics code have been conducted to find smaller, optimized temperature distributions and long-time operation condition[1].

2.1 Modeling

The CORONA code was applied to analyze the thermo-fluid phenomena in the MiHTR core[4]. The CORONA code solves the fluid as one-dimension and the solids as three dimensions to predict reactor core efficiently. On the previous studies, the coolant flow in the coolant channels of MiHTR showed the transitional flow of 2,300~6,000. The McEligot model 15,000<Re<600,000) [5] and the Dittus-Boelter model (10,000<Re<100,000) [6] are not suitable to predict the coolant fluid precisely. Therefore, the Gnielinski model which is valid from 2,300 to 5,000,000 [6] is applied in the thermo-fluid calculation of the MiHTR core.

The computational domain of MiHTR is shown in Fig. 2.

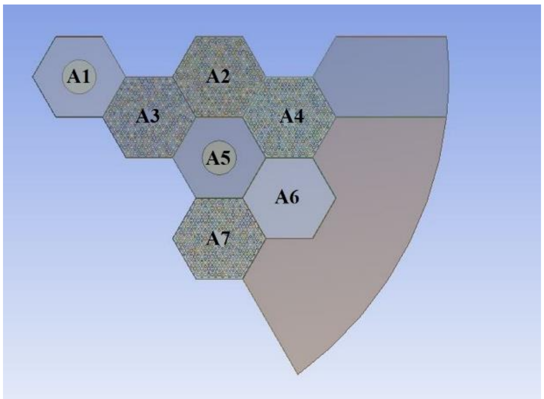
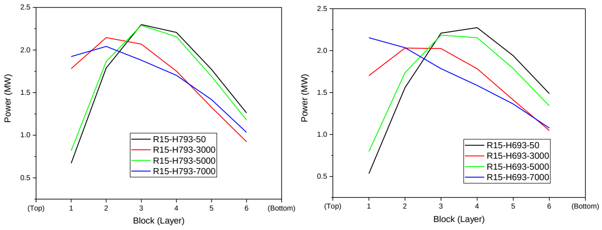


Fig. 2. One-sixth core layout of MiHTR[5]

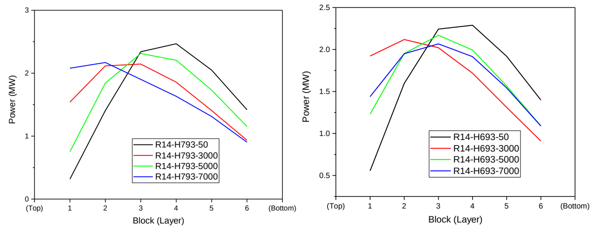
Table I shows the design conditions to predict the temperature distributions in the core. The R and H in the table I represent core radius [cm] and fuel block height [mm]. Several options are considered to have a required operation time and an optimized design with the neutronics code. A R in dimension means outer radius of core barrel and a H represents block height. The axial power profiles calculated by the neutronics code depending on the burn-up are plotted in Fig. 3 for each cases. In the Case 5, the operation time is extended up to 9000EFPD due to relatively high enrichment.

Table I: Design conditions

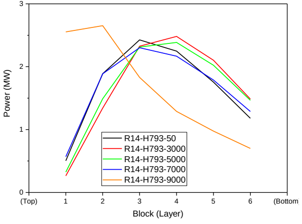
	Enrichment[w/o]	Dimension [cm/mm]
CASE 1	14.0	R150H793
CASE 2	15.0	R150H693
CASE 3	16.0	R140H793
CASE 4	17.0	R140H693
CASE 5	19.5	R140H793



(a) CASE 1 (b) CASE 2



(c) CASE 3 (d) CASE 4



(e) CASE 5

Fig. 3. Block-wise core axial power profile with burn up

2.2 Results

Fig. 4 shows the maximum temperature profiles with regard to the burn up. The maximum temperatures in the all cases does not exceed the design limit of 1250°C. As the height of fuel block decreases from 793 cm to 693 cm to reduce reactor size, the maximum temperature slightly increased due to higher power density. The maximum temperature profiles in the CASE 3 and 4 showed the larger gradient comparing to the results of CASE 1, 2 and 5.

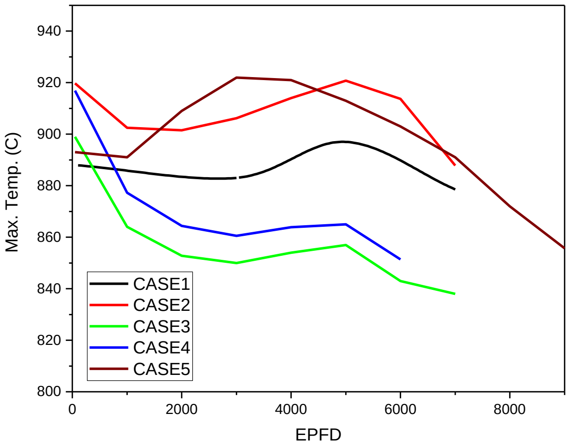
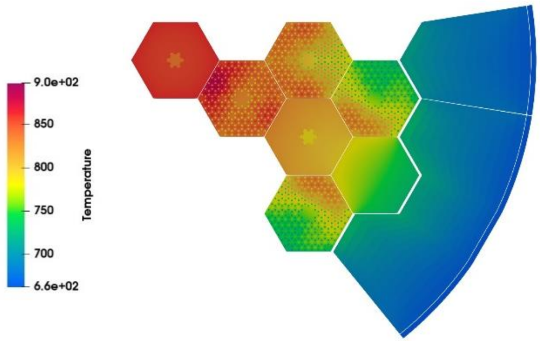


Fig. 4. Maximum temperature profiles wrt burn-up

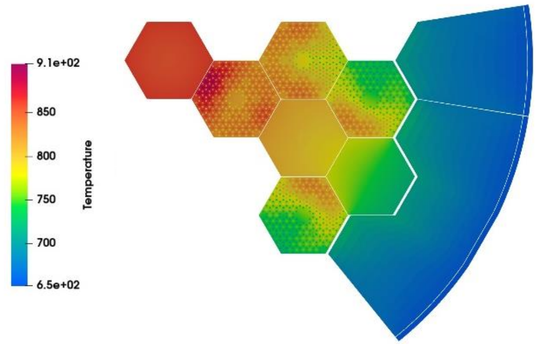
Table II represents the maximum / minimum graphite temperatures and block number shown in Fig. 2 where the maximum fuel temperature was occurred during operation period in Fig. 5. The temperature gradient inside the block of CASE 4 showed the largest value. As the uranium enrichment increases, the difference between maximum and minimum temperatures in a block tends to increase. However, the difference in the CASE 5 is lower than that in CASE 3 and 4 though the higher enrichment. It is thought that the power profiles by the neutronic analysis were well distributed inside the core for the CASE 5 with a long operation time.

Table II: Temperature differences in the single block

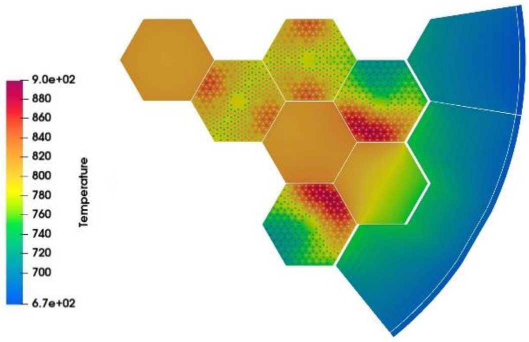
	Block #	Max.[°C]	Min.[°C]	dT[°C]
CASE 1	A7	824	745	79
CASE 2	A7	826	740	86
CASE 3	A4	865	717	148
CASE 4	A4	877	713	164
CASE 5	A4	851	716	135



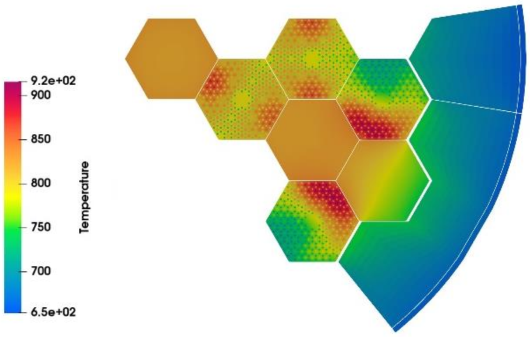
(a) CASE1-EFPD5000



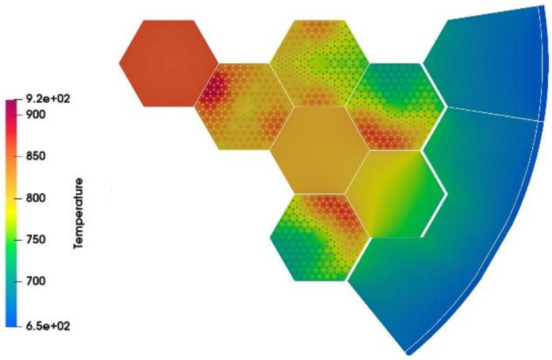
(b) CASE2-EFPD5000



(c) CASE3-EFPD50



(d) CASE4-EFPD50



(e) CASE5-EFPD3000

Fig. 5. Temperature distributions at hot spot plane.

3. Conclusions

The power profiles by the neutronic analysis were applied to predict the temperature distributions in the reactor core by the CORONA code. For the all cases, the temperature margin was sufficiently below design limit. Though the all cases satisfied the design limit, in depth studies for the temperature gradient in the block would be necessary to guarantee the integrity on the thermal stress.

Acknowledgements

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REFERENCES

[1] C. K. Jo, Core Nuclear Design of a Micro Modular High Temperature Gas-Cooled Reactor, *Transactions of the Korean Nuclear Society Autumn Meeting*, Yeosu, Korea, Oct. 25-26, 2018.

[2] S. N. Lee, S. H. Choi, N. Tak, and C. K. Jo, Thermal Analysis on the Conceptual Micro High Temperature Reactor Core, *Transactions of the Korean Nuclear Society Autumn Meeting*, Yeosu, Korea, Oct. 25-26, 2018.

[3] N. I. Tak, M. H. Kim, H. S. Lim, and J. M. Noh, A Practical Method for Whole Core Thermal Analysis of Prismatic Gas-Cooled Reactor, *Nucl. Technol.*, Vol. 177, p. 352, 2012.

[4] S. N. Lee, N. Tak, and C. K. Jo, Turbulence Model Assessment for Micro Modular Reactor, *Transactions of the Korean Nuclear Society Spring Meeting*, Jeju, Korea, May. 23-24, 2019.

[5] G. Melese and R. Katz, Thermal and Flow Design of Helim-Cooled Reactors, ANS(1984)

[6] A. Bejan, Convection Heat Transfer, 3rd Edition, WILEY, 2003.