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Calculation of Steady-State Core Thermal-Fluid Parameters Based on CORONA

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1. Introduction

Analysis of neutronic and thermal-fluid is important to design of prismatic fuel block reactor. CFD analysis has been successfully implemented to obtain the parameter of thermal-fluid in prismatic fuel block reactor. However it requires considerable computational power to analyze whole prismatic block core. Therefore steady-state thermal-fluid analysis code, named CORONA, has been under development in KAERI [1].

This study aims for obtaining the thermal-fluid parameters of prismatic fuel block reactor using CORONA code and analyzing the data based on the reactor operating condition(BOC, EOC) using the core pin power obtained from DeCART code [2].

2. CORONA

CORONA code is targeted for steady state thermal fluid analysis of prismatic core. Major applications of this code are a steady-state temperature analysis, steady state analysis for thermal-fluid parameter and a coupled analysis with the other code such as a neutronics code.

Analysis of whole prismatic fuel block requires elaborate computational efforts due to complex geometry. CORONA code adopted the several methods for reasonable accuracy and reducing processing time.

In order to simulate the heat conduction and fluid flow within complex geometry of the prismatic fuel block, the CORONA code uses the three-dimensional heat conduction equation and one-dimensional network model.

Many CFD codes require tremendous efforts to generate computational grids for the CFD analysis. The CORONA code focuses on the repetitive arrangement of unit cells in fuel block. The concept of basic unit cells enables the code to efficient generation of meshes without a mesh generator.

Whole prismatic core simulation requires a significant amount of computing power and time. A block based parallel computation method was developed for the CORONA code. Each fuel and reflector block of prismatic core is completely enclosed by the fluid boundaries. The separated blocks can be solved independently using a parallel computation.

Fig.1 shows the work flow of neutronic and thermo-fluid analysis. Neutronic core design and calculation are implemented using DeCART and CAPP. The DeCART code calculates the core pin power profile and gives it to CORONA. CORONA calculates the steady-state thermal fluid parameters (e.g. max. temperature). These data are used to evaluate neutronic core design. Also, these data are used to analysis the core transient condition and safety analysis by GAMMA+ system code. The CORONA code calculates fast and accurate result for steady state condition. It is advantageous to save the time between nuclear design and transient accident analysis.

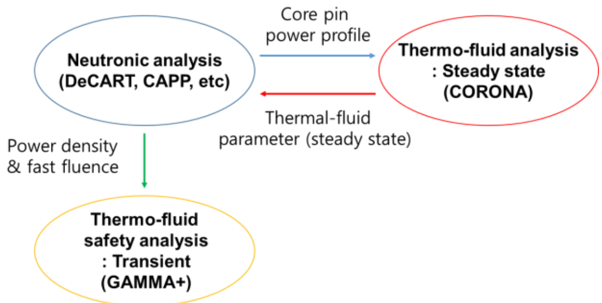

Fig. 1 Schematic of data flow of neutronic and thermo-fluid analysis

3. Result and Discussion

The ten test cases (Case(EOC,BOC) - 1, 2, 3, 4, 5) were simulated in this study to investigate an effect of the core inlet temperature as shown in Table 1. The test cases were classified according to core inlet temperature (T_{in}: 290 – 490 ℃) and total mass flow rate (m′ = 20.07 – 31.22 kg/s). Each test case was separated by core operating condition (BOC, EOC).

Fig. 2 shows the radial core pin peaking power profile and core temperature distribution with applied pin peaking obtained for case 3. (EOC, 7 column). The core peaking power profile from DeCART shows higher peaking power at block left side. Also the core temperature distribution displays a similar trend with peaking power profile. This result represents that the core temperature distribution is significantly affected by the pin power peaking.

Table 1 lists the thermal-fluid boundary conditions (power, pressure, flow rate, temperature) in each case. The calculation condition for each case was obtained at applied thermal power of 58.33 MW_{th} (=350/6) and several inlet temperatures (290-490 ℃) and flow rates (20.07-31.22 kg/s) under 7 MPa pressure. The core outlet temperature is 850℃. It should be noted here that only 1/6 section of the core was simulated due to symmetry. Fig. 3 is configuration of reactor core used to calculation. 1/6 core consist of fuel blocks, reserved shutdown control (RSC) fuel blocks, control rod block, and inner/outer reflectors.

Fig. 4 shows the comparison of maximum fuel temperature, pressure drop and bypass flow rate in core between the BOC and EOC condition. Pressure drop and bypass flow values increased in case 1 to 5 caused by changed mass flow rate.

In case of BOC, maximum fuel temperature was higher than EOC due to the higher pin peaking factor. And slope of change of maximum fuel temperature was different. It causes that the maximum fuel temperature reacts more sensitively to changing of inlet temperature and flow rate.

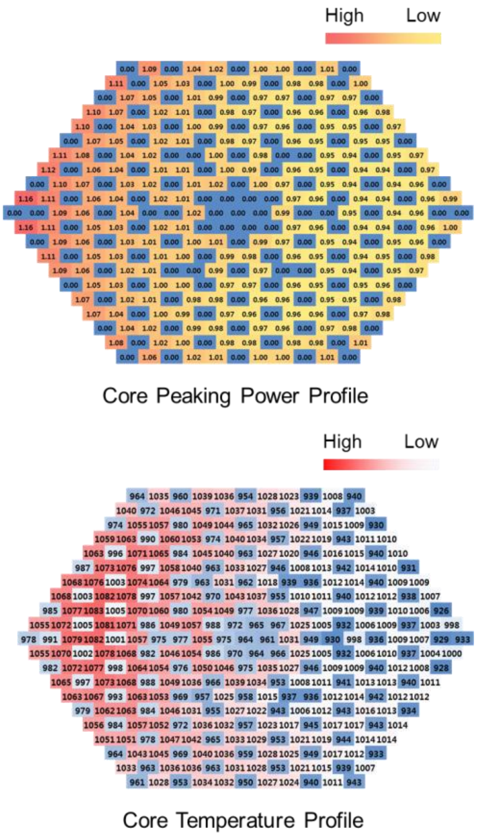

Fig. 2. Peaking power and temperature profile within fuel block (EOC, case-3, 7 column)

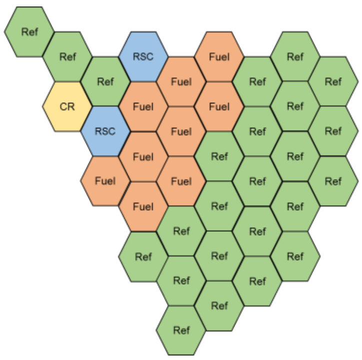

Fig. 3. 1/6 core assembly configuration

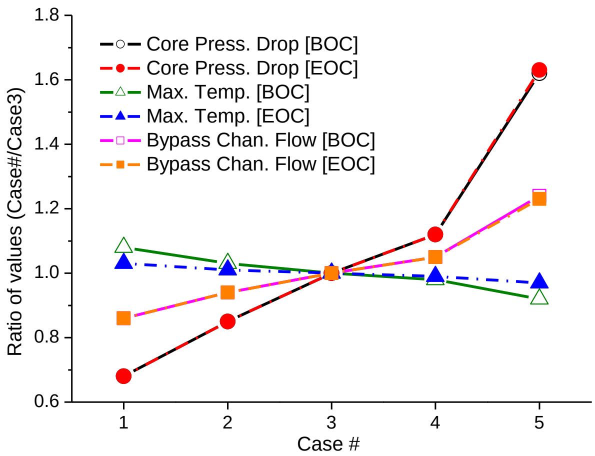

Fig. 4. Result of analysis for thermal hydraulic parameters

4. Conclusion

In this paper, thermal-fluid parameters were analyzed in reactor operating condition (BOC, EOC) with CORONA code. The three representative thermal-fluid data of fuel maximum temperature, pressure drop and bypass flow rate, were calculated depending on core inlet temperature and mass flow rate. The pressure drop and bypass flow rate were increased due to rising of inlet temperature and mass flow rate. However, the maximum fuel temperature was decreased between case-1 to 5 and only the maximum fuel temperature was reacted sensitively to changing of reactor operating condition (BOC, EOC). The significant difference of the BOC and EOC condition came from the pin power peaking. Therefore, in order to reduce the maximum fuel temperature, it needs to flatten the pin power peaking in the core.

ACKNOWLEDGEMENTS

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Table 1. Summary of reactor core at BOC and EOC

Parameter	Case-1	Case-2	Case-3	Case-4	Case-5
Thermal power [MW]	58.33	58.33	58.33	58.33	58.33
Core inlet Temp. [℃]	290	350	390	415	490
Lower plenum pressure [MPa]	7	7	7	7	7
Total mass flow rate [kg/s]	20.07	22.48	24.43	25.84	31.22