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Calculation of Thermal-Fluid Parameters for the Pre-designed VHTR Core Based on CORONA

Jun Kyu Song, Bong Hyun Cho, Nam-il Tak, Chang Keun Jo
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, 34057, Korea
**Corresponding author: jksong@kaeri.re.kr*

1. Introduction

Analysis of neutronic and thermal-fluid is important to design of prismatic fuel block reactor. KAERI has been developing CORONA code, which can be applied for steady-state analysis of thermal-fluid parameters [1] for the design of VHTR core and a coupled analysis with the neutronics code. The major thermal-fluid parameters which have to be considered in the core design include pressure drop, bypass flow rate and fuel hot spot temperature.

The purpose of this study is to produce a base and an idea to optimize VHTR core design. Through a sensitivity study of thermal-fluid parameters at the core, several pre-designed options are tested for various boundary conditions (core inlet/outlet temperatures, coolant flow rate etc.). The block pin power which is used as inputs for CORONA calculation is supplied by DeCART [2] and CAPP code [3].

2. Calculation model and boundary condition

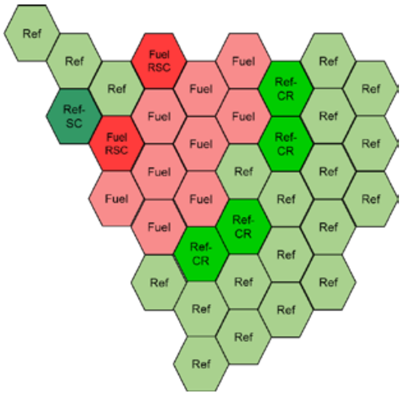
Fig. 1 shows the configuration of reactor core models used in this calculation. The VHTR core consists of fuel blocks, reserved shutdown control (RSC) fuel blocks, control rod blocks, and reflectors. In order to reduce radial pin peaking factor, several options are suggested. Option 1 core has some fuel compacts mixed with burnable poison material, located at the boundary pin close to the inner reflector side of the fuel block. Option 2 and 3 cores have replaced the fuel blocks with the RSC reflector blocks to reduce pin peaking factor. Consequently the distributions of pin peaking factor of Option 2 and 3 are flatter than that of Option 1.

Neutronic core design and calculation are implemented using DeCART and CAPP. The CAPP code calculates the core block power profile and axial power distribution. DeCART code produces the radial core pin power profile and supplies it to CORONA.

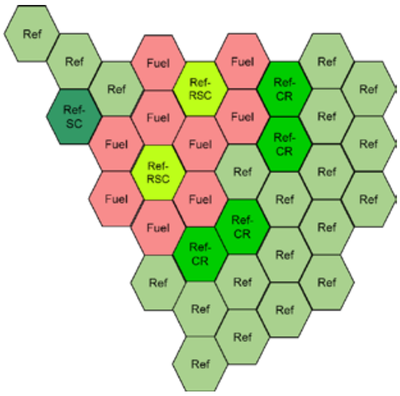
Core flow rate is calculated by the equation below, where Q is core power, $\dot{m}$ is core coolant flow rate, C_p is heat capacity and T is temperature.

$$Q = \dot{m} C_p (T_{out} - T_{in})$$

A set of boundary conditions for various core inlet and outlet temperatures (inlet Temp.: 290-450 $^{\circ}$C, outlet Temp.: 750-950 $^{\circ}$C) were obtained by fixing core power as 58.33 (=350/6) MW. It should be noted here that only 1/6 section of core was simulated due to symmetry. Table I lists the reactor core boundary conditions for the test cases.



(a) Option 1



(b) Option 2 & 3

Fig. 1. 1/6 core assembly configurations

Table I. Summary of reactor core boundary conditions

Parameter	Value
Core power [MW]	58.33 (=350/6)
Core inlet temperature [°C]	290-490
Core outlet temperature [°C]	750-950
Lower plenum pressure [MPa]	7
Core flow rate [kg/s]	17.03-43.23

3. Result and Discussion

Table II shows the summary of thermal-fluid parameters of several core designs. The identification of case name, for example, O1B290_750 includes option number (O1), reactor operating condition (B) and core inlet/outlet temperatures (290/750).

As the core inlet temperature increases, the pressure drop and bypass flow rate increase also. However, the maximum hot spot temperature decreases due to the increase of the core coolant flow rate. But when the core outlet temperature increases, all appear contrarily.

When the core outlet temperature is 750 °C, all options show that the hot spot temperature in the core is controlled within the design limit, < 1250 °C. When the core outlet temperature is 850 °C, the hot spot temperature in the core of most options excluding for the case with relatively low inlet temperature, satisfy with the design limit. However when the core outlet temperature is 950 °C, the hot spot temperature in the core of any options does not satisfy with the design limit.

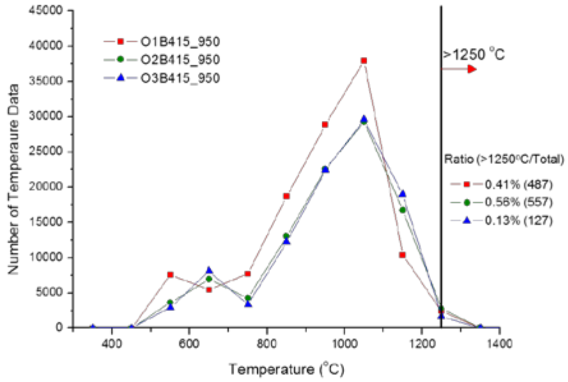
Figure 2 shows the quantity of fuel unit cell vs. cell temperature for the case of the core outlet temperature, 950 °C. The total number of fuel unit cells is about 100,000 for 1/6 section of the whole reactor core.

The majority of fuel cell belongs to the temperature range between 1,000 and 1,100 °C, share about 30 % of the total fuel unit cells. As the cell temperature range increases, number of cell rapidly decreases after the majority of fuel cell point. Finally, the portion of fuel unit cell which exceeds the design limit temperature is relatively low, that is less than 0.6 % compared to the total numbers of the fuel units in the core. It means that hot spot temperature fraction is very small and negligible compared to the whole reactor core.

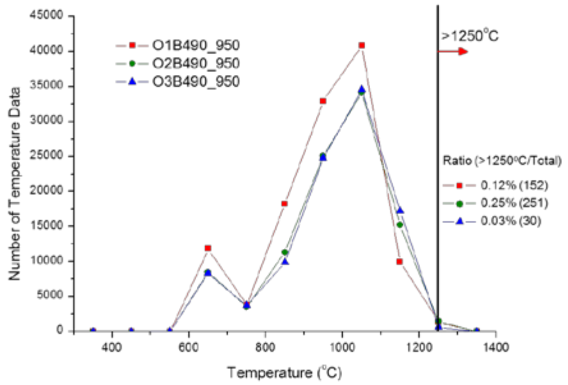
4. Conclusion

In this paper, thermal-fluid parameters were analyzed for several pre-designed core and boundary conditions with CORONA code. As the core inlet temperature increases, the pressure drop and bypass flow rate increase also. However, the maximum hot spot temperature decreases due to the increase of the core coolant flow rate.

When the core outlet temperature is 750 and 850 °C, most of all options show that the hot spot temperature in the core are controlled within the design limit. However when the core outlet temperature is 950 °C, the hot spot temperature exceeds the design limit. But even in this case, the hot spot temperature fraction is very small and negligible compared to the whole reactor core. We expect that further optimization work of VHTR core design may be possible even when the core outlet temperature is 950 °C.



(a) inlet temperature: 415 °C



(b) inlet temperature: 490 °C

Fig. 2. Quantity of fuel unit cell vs. cell temperature (core outlet temp. = 950 °C)

ACKNOWLEDGEMENTS

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[1] N. I. Tak et al., Development of a Core Thermo-fluid Analysis Code for Prismatic Gas Cooled Reactors, *Nucl. Eng. Technol.*, Vol. 46, No. 5, pp. 641-654, 2014
[2] J. Y. Cho et al., DeCART2D v1.0 User's Manual, KAERI/TR-5116/2013, KAERI, 2013.
[3] H. C. Lee et al., CAPP v2.1 User's Manual, KAERI/TR-5334/2013, 2013.

Table II. Summary of thermal-fluid parameters of considered core designs in this work

Temperature	**Option 1**			**Option 2**			**Option 3**		
Inlet/Outlet	**750** [°C]	**850** [°C]	**950** [°C]	**750** [°C]	**850** [°C]	**950** [°C]	**750** [°C]	**850** [°C]	**950** [°C]
290 [°C]	O1B290_750	O1B290_850		O2B290_750	O2B290_850		O3B290_750	O3B290_850	
Max. Fuel Temp [℃]	1126.2	1244.7		1151.7	1276.3		11 10	1226.7	
Bypass Flow [kg/s]	2.428	2.054		2.863	2.409		2.898	2.439	
Pressure Drop [kPa]	19.17	14.76		25.63	19.54		25.61	19.53	
350 [°C]	O1B350_750	O1B350_850		O2B350_750	O2B350_850		O3B350_750	O3B350_850	
Max. Fuel Temp [℃]	1098.9	1223.2	-	1127.1	1249.9	-	1090.9	1205.8	-
Bypass Flow [kg/s]	2.724	2.235		3.223	2.62		3.258	2.648	
Pressure Drop [kPa]	25.39	18.46		33.95	24.5		33.93	24.48	
390 [°C]	O1B390_750	O1B390_850		O2B390_750	O2B390_850		O3B390_750	O3B390_850	
Max. Fuel Temp [℃]	1083.8	1208.1		1111.3	1231.7		1078.5	1191.8	
Bypass Flow [kg/s]	2.99	2.383		3.537	2.803		3.571	2.832	
Pressure Drop [kPa]	31.3	21.71		41.82	28.98		41.78	28.96	
415 [°C]	O1B415_750	O1B415_850	O1B415_950	O2B415_750	O2B415_850	O2B415_950	O3B415_750	O3B415_850	O3B415_950
Max. Fuel Temp [℃]	1074.4	1197.3	1314.7	1101.5	1222	1344.5	1070.9	1184.6	1299.9
Bypass Flow [kg/s]	3.191	2.496	2.088	3.774	2.94	2.445	3.807	2.97	2.47
Pressure Drop [kPa]	36.05	24.24	18.19	48.14	32.41	24.06	48.1	32.39	24.05
490 [°C]	O1B490_750	O1B490_850	O1B490_950	O2B490_750	O2B490_850	O2B490_950	O3B490_750	O3B490_850	O3B490_950
Max. Fuel Temp [℃]	1046.5	1168.4	1291	1073.1	1195	1315.1	1049.4	1163.5	1276
Bypass Flow [kg/s]	4.039	2.944	2.352	4.763	3.481	2.76	4.801	3.51	2.783
Pressure Drop [kPa]	58.76	35.21	24.35	78.28	47.03	32.37	78.23	46.99	32.35