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FLOW MIXING BEHAVIORS IN A REACTOR

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1. Introduction

A flow distribution of coolant in a reactor is one of the most important factors in the assessment of safety and design performances. According to the core flow distribution test results of the ACOP (1/5 scale down model of the APR+ reactor), the coolant flow distribution at lower core zone is not uniform despite of the flow straightener [1]. In this paper, the boron flow distribution in a reactor vessel was assessed using a commercial CFD Code. The objective of this simulation is to assess the accuracy of CFD models for a multi-dimensional flow mixing of the emergency core cooling (ECC) water from cold legs or Direct Vessel Injection (DVI) nozzles into the downcomer and core. Mixing of single phase reactor coolant at a downcomer, core inlet, and two hot legs of the ACOP were simulated using a 1/5 scale single phase cold water reactor model [2]. The aspect ratio (L/D) is preserved to be 1. The core is simulated by a simplified core simulator. Thermal mixing phenomena due to the temperature difference between reactor coolant and emergency core cooling water were not simulated but flow mixing phenomena by the operation of reactor coolant pumps (RCPs) were simulated in the test.

2. Reactor Flow Model

To analyze the core flow distribution in the ACOP, as shown in Fig. 1, a numerical model was established. The model consisted of 4 cold legs, a reactor downcomer, and a lower core structure, and the core and hot legs were modeled. The operating conditions of the ACOP model test were 290 ℃ and 15 bars.

The total number of the elements in the calculation was 105 million. Fig. 2 show the mesh and inlet flow directions. The velocity distribution at 4 cold legs was assumed to be uniform and constant. No-slip condition was applied to the wall boundary and heat transfer between the wall and fluid was not considered. In this paper, the characteristics of velocity distribution in the ACOP were assessed by solving the fluid region only. For the analysis of turbulence, k-e turbulence model was applied.

As shown in Fig.3, 3-group power distribution was considered to simulate heat flux effects for a forced flow condition.

Power zone heat flux :

- Zone A : 5.6 MW/m^2
- Zone B : 3.5 MW/m^2
- Zone C : 2.46 MW/m^2

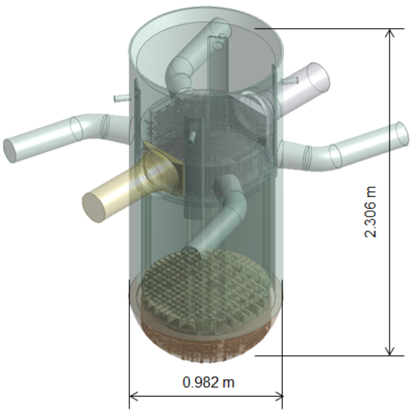

Fig. 1 1/5-Scale geometry

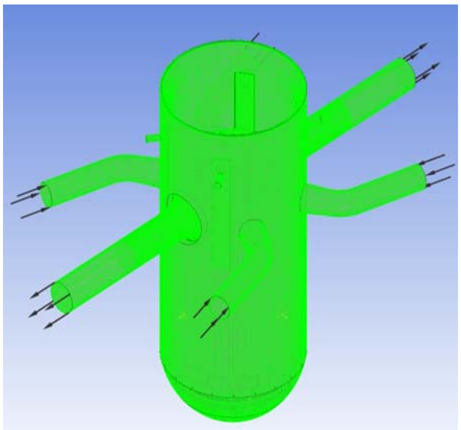

Fig. 2 Mesh and inlet condition

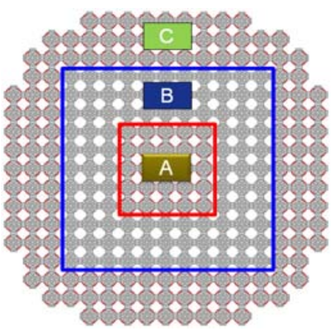

Fig. 3 Core power zone

The hot-leg velocity is measured under the 4-pump balanced flow condition.

The scaling parameters were summarized at Table 1.

Table 1. Scaling ratio of model

Parameter	Scaling Ratio	Model
Length ratio	l_R	1/5
Height ratio	l_R	1/5
Diameter	l_R	1/5
Area ratio	l_R^2	1/25
Volume ratio	l_R^3	1/125
Aspect ratio	1	1.0

3. Test Results

Fig. 4 shows the flow stream line and velocity contours at the downcomer and lower structure region for the same mass flow rate condition through 4 cold legs.

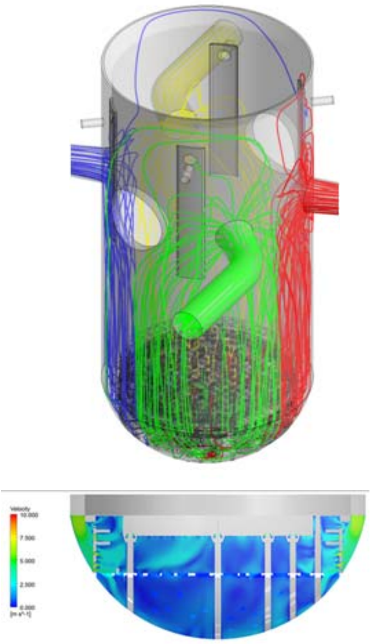

Fig. 4 Stream lines at the downcomer and flow distribution at the lower hemisphere of reactor

Fig. 5 shows the velocity contour at the core inlet for the 50 % blocked lower core structure geometry. The red color indicates higher velocity flow path and they are located at the periphery of the core. Fig. 6 shows the boron distribution at core inlet for 4-pump running condition.

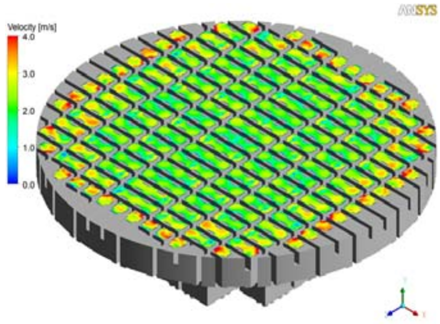

Fig. 5 Velocity contour at core inlet

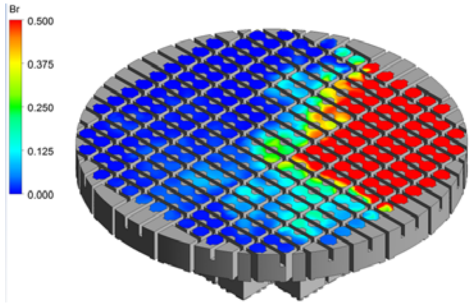

Fig. 6 Boron distribution at core inlet

As shown in Figs. 7 ~ 9, for 4-pump running condition, the boron and core flow are distributed into four quadrants. The borated water injected through cold leg is not mixed evenly over the core section. As each pump delivers water to the 1/4 of the core, uniform flow distribution at each quadrant is observed. As shown in Fig. 9, the quadrant boron distribution at the core is continued to the top of core and hot legs.

As shown in Figs. 10 ~ 11, the velocity and temperature distributions have a similar flow pattern as shown in boron distribution of four quadrants.

The boron concentration factors at two hot leg were;

- For CLI Mode
  Hot Leg 1 : 0.87 (87%)
  Hot Leg 2 : 0.13 (13%)

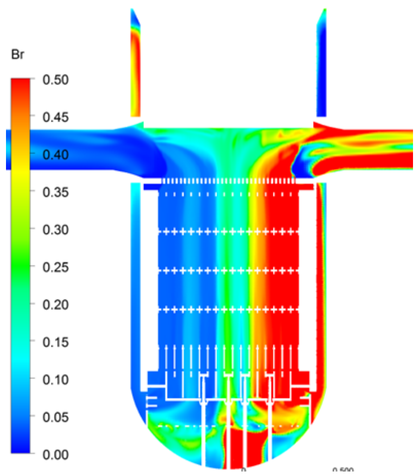

Fig. 7 Boron distribution at core

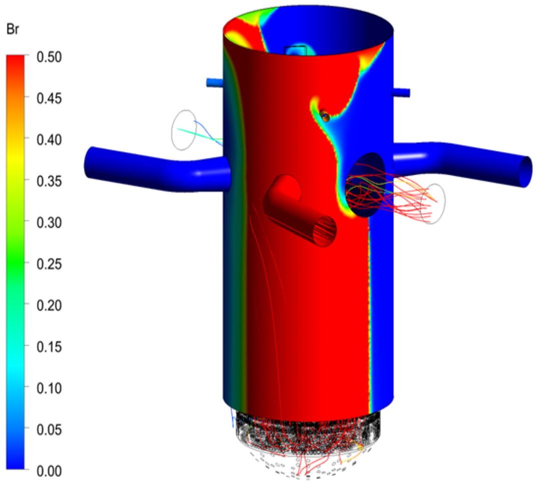

Fig. 8 Boron distribution at D/C

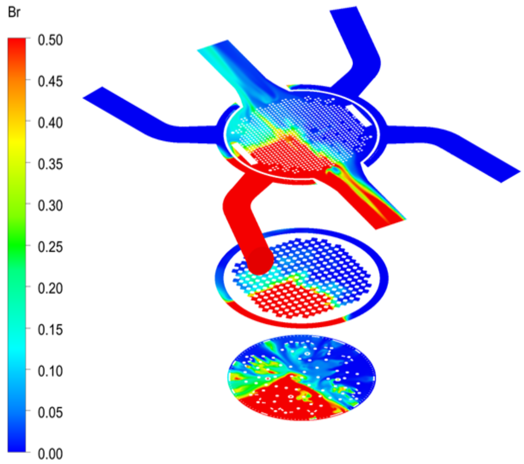

Fig. 9 Boron distribution at core

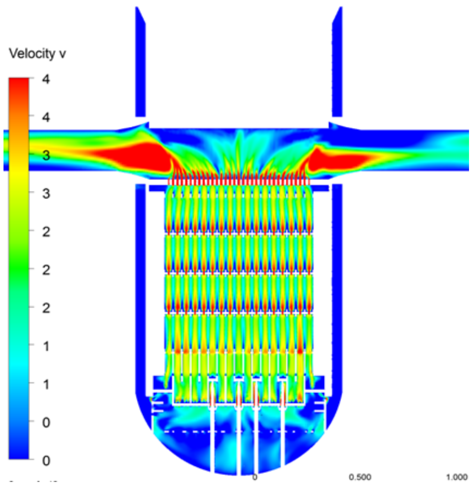

Fig. 10 Velocity distribution at reactor

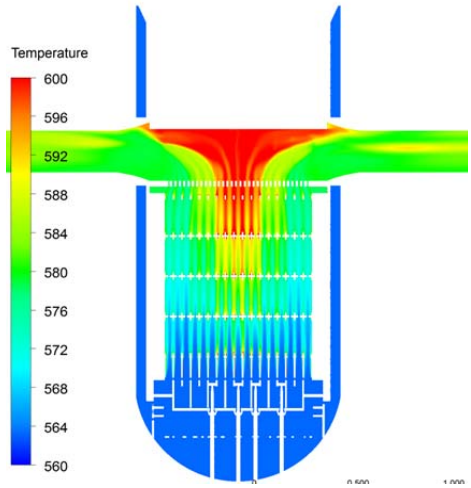

Fig. 11 Temperature distribution at reactor

4. Conclusion

The borated water distribution at the downcomer and core for the 50 % blocked core inlet geometry of APR+ was analyzed using a CFD code.

For 4-pump running condition, the flow distribution in a reactor core is divided into four quadrants. The borated water injected through DVI nozzle or cold leg is not mixed evenly over the core section. As each pump delivers water to the 1/4 of the core, uniform flow distribution in each quadrant is observed. The mixing factors of two hot legs for CLI mode are 0.87 (87%) vs. 0.13 (13%)

Acknowledgments

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REFERENCES

[1] Kim, K., Euh, D.J., Chu, I.C., Youn, Y.J., Choi, H.S., Kwon, T.S., Experimental study of the APR+ reactor core flow and pressure distributions under 4-pump running conditions, Nuclear Engineering and Design, Vol. 265, pp. 957-966, 2013.

[2] Tae-Soon Kwon et al., CFD Benchmark Calculation for the 1/5-Scale ACOP Core Flow Test, KNS, October 2012.