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A Study on the Flow Characterization in the Reactor Cavity

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1. Introduction

The Reactor Cavity is the annular space by the concrete structure, the Reactor Cavity Pool Seal Assembly (RCPSA), which consists of the welded steel and is designed to be installed between the RV and the refueling pool floor [1], and the Reactor Vessel (RV). For such reason, the RCPSA should be designed to provide the cooling air passage for ventilation to circulate high temperature air passing by the RV during the reactor operation. It means that the RCPSA is influenced by the convection of cooling air and the thermal expansion of the RV. Therefore, the flow characterization at the reactor cavity is one of the factors of the RCPSA design during the reactor operation.

In this study, the flow characterization of the cooling air in reactor cavity nearby RCPSA has been analyzed by using a 3 dimensional model and the ANSYS CFX software in order to predict the Convective Heat Transfer Coefficient (CHTC) of the RCPSA

2. Methods and Results

2.1 Configuration of Geometric Model

The reactor cavity in APR1400 is composed of three regions (outer region – top, outer region – side & RV side and inner region) for the RCPSA regarding to the heat transfer, which consists of the seal plate with the access hole, inner/outer flexure, inner/outer support, etc., the concrete and the RV (Fig. 1).

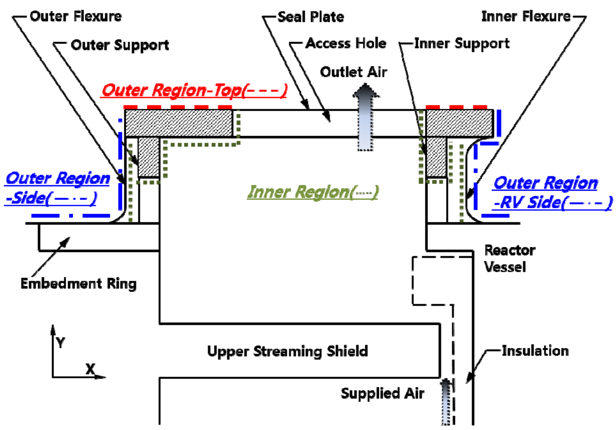

Fig. 1 Configuration at the Reactor Cavity

During reactor operation, the heat transfers from the RV seal ledge to the inner flexure. At that time, the cooling air in the reactor cavity is formed from the lower section of the RV to upper section of the RV via the upper steaming shield and the access hole of the RCPSA for the cooling of the RV and its surrounding structures.

2.2 Analysis Method

The Computational Fluid Dynamic (CFD) analysis for cooling air flow in the reactor cavity is performed in a steady state. The total element number for this analysis is about 2,400,000 and the elements are concentrated in the region of internal RCPSA to describe the swirl and eddy phenomenon. The boundary conditions are set as the 'inlet' which applies the normal speed and static temperature in the lower section of the RV, the 'outlet' defined by open condition in the containment building, the 'wall' such as the RV, insulation and concrete with temperature value and the RCPSA.

2.3 Turbulence Model

The air flow is expected that the intricate turbulence fluid flow will occur due to the swirl and eddy phenomenon that result from the complicated internal shape of the RCPSA. The κ-ω based Share Stress Transport (SST) model [2] under the condition of the steady state is chosen for the turbulence option to find valid calculation results. The APR1400 Reactor Vessel Internals (RVIs) consist of two major structures, the core support structures and internal structures.

2.4 Temperature Distribution

The temperature distribution (Fig. 2) from the CFD analysis using the turbulence model in the reactor cavity is shown. The temperature at outer flexure and seal plate of the RCPSA is influenced by that of the cooling air from the concrete wall and the RV side, which are surrounded by the insulation. The temperature at the inner flexure of the RCPSA is primarily affected by the highest temperature of the RV, which is the highest in all analysis regions. The temperature distribution in the reactor cavity also represents that the temperature of cooling air is mainly influenced by that of the insulation and RV.

2.5 Flow and CHTC Distribution

From the results, the flow (Fig. 3) is shown in a clockwise direction along the concrete wall in the inner region and the flow is divided up into two sub-flows at the low section of the access hole. The sub-flows represent that one passes through the access hole while the other goes down the refueling cavity again. The velocity of cooling air is the fastest in the access hole. Also, the velocity of cooling air in the inner region of the outer flexure is faster than that in the inner region of the inner flexure.

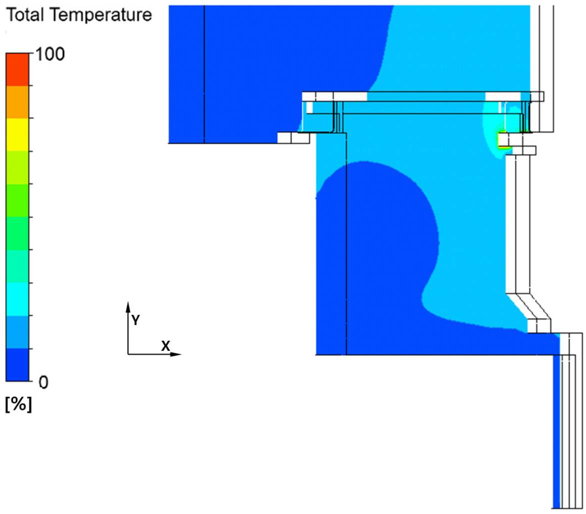

Fig. 2 Temperature Distribution at the Reactor Cavity (Cross-section via access hole)

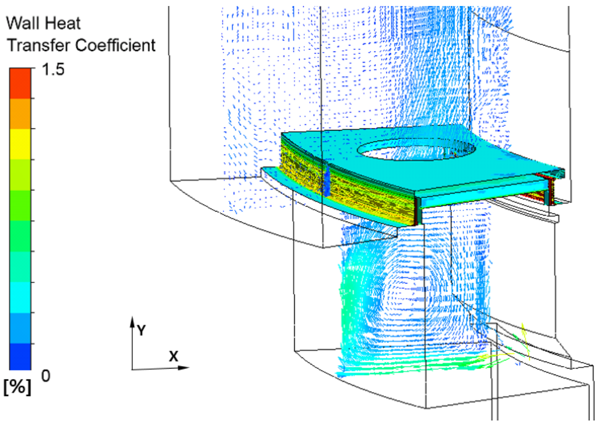

Fig. 3 Flow (relate to velocity) & CHTC

Table I: CHTC result

-	Inner Region (unitless)	Outer Region (unitless)	
		Top	Side / RV Side
Min.	1.00	0.77	0.95 / 1.24
Max.	306.73	1.48	4.12 / 4.80

The CHTC could be calculated by the velocity and the temperature of the inlet and ambient cooling air. As a result, the deviation of the CHTC at the inner region of RCPSA presents the range of up to 306.73 times of the base value (min. value in the inner region) and the deviation of the CHTC at the outer region of RCPSA relatively presents the range of 0.77 to 4.8 times of the base value. The difference between CHTCs in the inner region seems to be due to the velocity of cooling air and geometry as well as the difference between CHTCs of the side and RV side in the outer region seems to be caused by the temperature from the RV.

The CHTC at the arbitrary cross-section (a section includes the access hole) represents a value of the CHTC (Fig. 4). The CHTC in the local region, where are in the top and bottom of inner region in the inner/outer flexure, is higher than any others. The CHTC in the inner region of the inner/outer flexure is higher than it in outer region – side of the inner/outer flexure.

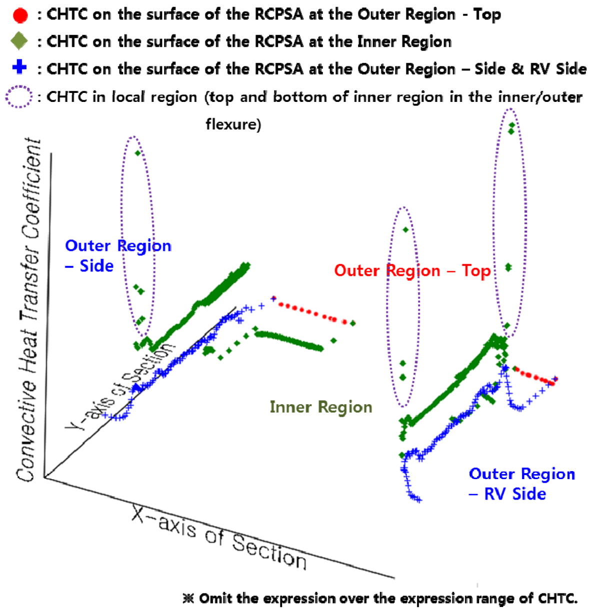

Fig. 4 CHTC (at arbitrary cross-section)

3. Conclusions

The flow distribution of the cooling air in reactor cavity nearby RCPSA has been analyzed using ANSYS CFX software to obtain the CHTC at surface of the RCPSA.

1) The temperature from the RV and the insulation is one of the critical factors for the thermal gradient of the cooling air and the CHTC in the reactor cavity.

2) The rapid change of the CHTC in inner region nearby inner and outer flexure is related to the geometry shape of the RCPSA and velocity of cooling air.

In the future, the structural integrity evaluation of the RCPSA using the fluid structure interaction (FSI) is necessary to be performed in order to identify the effect of CHTC in the local region.

REFERENCES

[1] M. G. Kim, C. S. Maeng, B. S. Kim, J. K. Hwang, I. Y. Kim, "Development of Improved Reactor Cavity Permanent Pool Seal Assembly", proceeding of the KNS, pp. 352-353, 2001.

[2] K. Yugulis, "The Use of FSI Modeling to Predict Failure of a Liner in a Pipeline Expansion-joint", STAR Global Conference 2016, 2016