Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Preliminary Calculation on the Passive Autocatalytic Recombiner Analysis Model of Severe Accident Containment Analysis Package Code

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1. Introduction

It is critical to be sure of maintaining the integrity of the containment building in a nuclear power plant (NPP) during a severe accident. Especially, after the hydrogen explosion at Fukushima accident, the means of keeping up the concentration of hydrogen in a containment low have become more important. Passive Autocatalytic Recombiner (PAR) is one of the ways to remove hydrogen by converting it into water vapor by using the catalytic reaction with oxygen. The characteristic of PAR, passive reaction, makes this mechanism possible without an electricity particularly, in the case of station black out of the NPP like Fukushima accident. After the accident, Korea has completed the installation of PAR at all NPPs in Korea as a hydrogen mitigation system.

With being equipped PARs, it is necessary to analyze and evaluate the performance of PAR. In Korea, severe accident analysis code has being developed since 2011. Severe Accident Containment Analysis Package (SACAP) is a part of this code to analyze an ex-vessel phenomena during a severe accident. SACAP also has PAR analysis model in it.

In this paper preliminary calculation on a PAR performance was conducted using PAR analysis code of SACAP and compared with the test results as well.

2. Methods and Results

The PAR performance test was conducted with Ceracomb type of PAR which is widely equipped at NPPs in Korea. The test results were compared with PAR analysis results.

2.1 Test Facility and Conditions

PAR Performance Test Facility (PPTF) is composed of a pressure vessel and a small sized PAR. The internal volume of the vessel is about 12.5 m^3 (a cylindrical shape with 3.3 m in height and 2.2 m in diameter) [3]. The small sized PAR which has four ceramic honeycomb catalysts is located in the center of the vessel. Measuring instruments for temperature, pressure, and concentration of hydrogen are located at both inlet and outlet sides of PAR. Fig.1 shows a schematic design of PPTF with measurement types and locations.

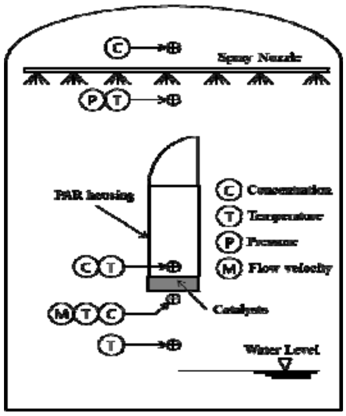

Fig. 1. PPTF with Measurement Types and Locations

The vessel is initially filled with the mixture of the air and 6.8 vol. % of hydrogen. The tests were performed with initial conditions with temperature of 60 ℃ and under the pressure 1.5 and 1.0 bar. Table I shows initial conditions of the tests.

Table I: Test Conditions (Natural Circulation Test)

Test ID	Initial Condition	
	NCT-01	NCT-02
H_2 Concentration (vol. %)	6.8	6.8
Pressure (bar)	1.5	1.0
Temperature (℃)	60	60

2.2 PAR Analysis Model

PAR analysis model included in SACAP code was developed based on the hydrogen removal rate correlations provided by manufacturers. Six models for different types of PAR (NIS, AECL, SIEMENS93, SIEMENSE98, CERACOMB, and KNT) were applied into the analysis model. The CERACOMB correlation for hydrogen removal rate is a function of S, N, k, C, P, T as below [2]:

$$R_{H_2} = f(S, N, \cdot k, C, P, T) \quad (1)$$

Where R_{H2} is hydrogen removal rate (g / sec) and S, N, k, C, P, T are safety constant, factor for the number of catalysts, test constant (g H_2 / vol. % $H_2 \cdot bar_{abs} \cdot sec$), the molar fraction of hydrogen (vol.%H_2), pressure (bar_{abs}), temperature (K), respectively.

2.3 Modeling of the PPTF

Fig. 2 shows the node diagram of PPTF. The modeling of PPTF was done with 36 volumes (35 for vessel and 1 for atmosphere), 86 junctions (30 junctions in axial direction and 56 junctions in radial directions), 38 heat conductors, and 1 PAR. The vessel is divided by one small circle with 0.8 m in diameter and four others area surrounding the circle in the plane. The height of lvol is 0.5 m except the center line volumes, which is 0.3 m. PAR is located at Lvol 40 in the middle of the center line volumes. PAR structure for thermal capacity is ignored. The vessel wall was insulated.

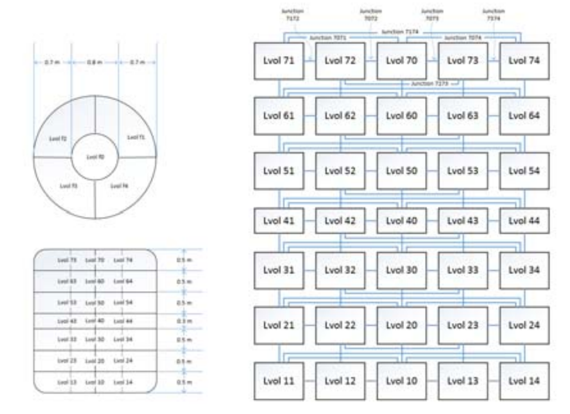

Fig. 2. Node Diagram of PPTF

2.4 Analysis Results

Fig. 3 shows that hydrogen removal rate calculated by the code under the pressure of 1.5 bar and 1.0 bar. The hydrogen removal rates are proportional to the value of the pressure as the PAR correlation mentioned above (al the conditions except pressure are same).

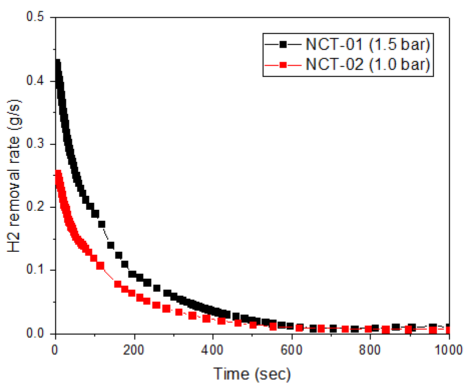

Fig. 3. Hydrogen removal rate of the SACAP analysis results

Fig. 4 and 5 show hydrogen concentration of outlet side of PAR at the PAR performance test and of the lvol containing PAR at SACAP code analysis. The hydrogen concentration of the test decreases slowly right after the beginning of the test for about 600 seconds, then reduces dramatically until removing the hydrogen in the vessel completely.

PAR generateds heat during the catalytic reaction with hydrogen and oxygen, which accelerates the natural circulation through the PAR. This process makes a virtuous cycle of hydrogen recombination. Thus, the concentration of hydrogen decreases smoothly at first stage of the test and then, starts to reduce exponentially after a trigger point, at about 600 second in this case. After passing the point PAR is able to operate its full capacity to remove hydrogen when the hydrogen and oxygen are enough to be combined.

However, the analysis results show that the hydrogen concentration decreases directly right after starting the simulation. That is why the model is developed by the hydrogen removal correlation. In addition, the test result indicates the value of specific point in a vessel, in contrast to the average value of a lumped volume in a code simulation.

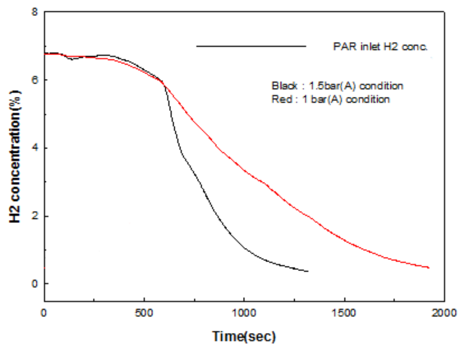

Fig. 4. Hydrogen concentration of the PAR performance test

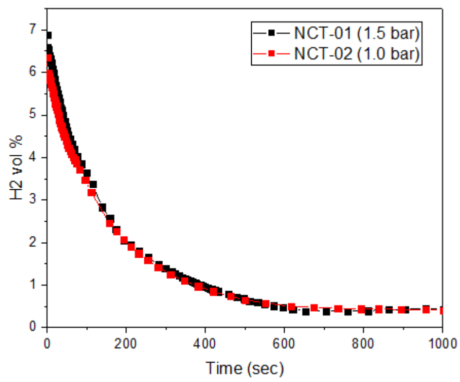

Fig. 5. Hydrogen concentration of the SACAP analysis results

Under different pressure conditions, PAR test results show different hydrogen depletion ratios. It takes about doubled time to remove the hydrogen under the pressure 1.0 bar comparing that under the pressure 1.5 bar. This happens due to relatively low mass of hydrogen could not fully accelerate the natural circulation.

However, the analysis results do not appear this kind of difference. Both of the analysis results under the pressure 1.5 bar and 1.0 bar show that the slopes of decreasing hydrogen in the vessel are similar with the test result under the pressure of 1.5 bar.

To improve the accurate of the calculation, it is needed to reflect the time delay until activating fully the hydrogen removal function of PAR.

3. Conclusions

The preliminary calculation on the PAR performance test was conducted using CERACOMB PAR analysis model of SACAP and compared with the test results. The hydrogen removal rate shows similar trends comparing with the correlation. However, the time to activate and accelerate the performance of PAR in a code is needed to adjust to fit the results of the test.

Acknowledgement

This work was supported by the Nuclear Research & Development of the Institute of Energy Technology and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy. (No.20141510101670)

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