Thermal Response of Hydrogen Recombination: Test Series PAR-01 and PAR-02

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1. Introduction

Dozens of Passive Autocatalytic Recombiners (PARs) have been installed inside containment buildings at domestic nuclear power plants to remove hydrogen in a severe accident. The combination of hydrogen and oxygen in the catalyst at the inlet of the PAR generates heat, and the buoyant flow can inhale ambient gas. The recombination characteristics of the PAR can affect the thermal response inside the PAR depending on the ambient hydrogen concentration. A current research project funded by the Korean government will develop a methodology to assess the hydrogen concentration inside the containment building by monitoring the temperature distribution inside the PAR [1]. We have been conducting a series of hydrogen recombination tests at the experimental facility, SPARC (SPray-Aerosol-Recombiner-Combustion), which was built to simulate the atmospheric environment in a severe accident. First, a preliminary test (PAR-01) was performed to evaluate the amount of hydrogen recombination reaction on our new catalyst. This study introduces the test results of PAR-02, which was conducted by modifying the catalyst and experimental conditions based on PAR-01.

2. Methods and Results

2.1 PAR fabrication and experimental facility

The lattice catalyst size (W x D x H), cell size indicated as cells per square inch (cpsi), and platinum concentration (g/ft^3) supplied by HEESUNG CATALYSTS can be customized as shown in Table 1. The PAR housing, which mounts the catalyst and acts as a chimney for the buoyant flow generated by the recombination reaction, was designed with dimensions of 216 x 110 x 1300 mm.

We installed PAR inside a SPARC vessel with an internal diameter of 3400 mm and a height of 9532 mm as shown in Fig. 1. The instrumentation includes temperature sensors, relative humidity sensors, hydrogen concentration analyzers at 14 points inside the vessel, pressure transducer, and flow meter at the PAR inlet. The hydrogen injection nozzle and steam supply nozzle are located at 550 mm and 1225 mm above the bottom of the SPARC vessel, respectively.

Table I: Catalyst and housing specifications and hydrogen injection rates

Test	Catalyst	Housing	H_2 feeding
PAR -01	186 x 92 x 100 mm 36 cpsi, 90 g/ft^3	216 x 110 x 1300 mm	0.3~0.03 g/s
PAR -02	186 x 92 x 25 mm 36 cpsi, 60 g/ft^3	216 x 110 x 1300 mm	0.1~0.03 g/s

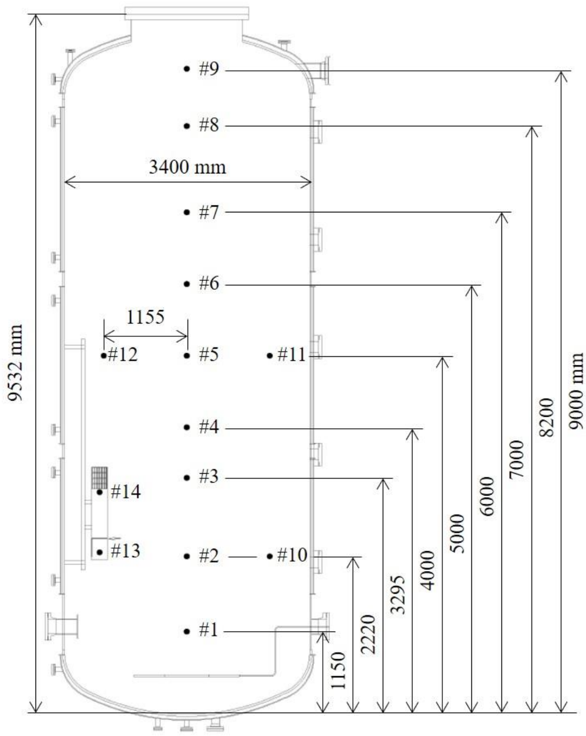

Fig. 1. Location of PAR and sensors installed in SPARC.

2.2 Experimental conditions

We sealed the SPARC vessel, heated the vessel walls, and injected steam to control the vessel's atmospheric pressure, temperature, and humidity as shown in Fig. 2. Hydrogen injection began at 10,370 seconds when the pressure, temperature, and relative humidity inside the vessel reached approximately 1.3 bar, 62 ℃, and 100%, respectively. Our recent study evaluated an accident scenario of a 2-inch cold leg rupture in the OPR1000 using the MELCOR code [1]. The initial conditions for hydrogen injection are the same as those in the upper atmosphere of the containment building when hydrogen is generated by rapid oxidation of the cladding material.

Hydrogen injection started at 0.1 g/s at 10,370 seconds and stopped at 20,300 seconds. The hydrogen injection flow rate decreased to 0.05 g/s and 0.03 g/s at 15,000 and 17,300 seconds, respectively. Steam was supplied at about 5 g/s during hydrogen injection and stopped at 24,690 seconds. The atmospheric pressure and temperature decreased after the steam injection stopped as shown in Fig. 2.

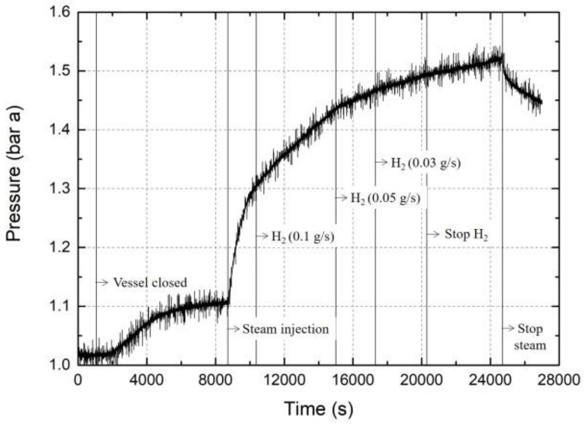

Fig. 2. SPARC vessel pressure changes in PAR-02 test.

2.3 Thermal response by hydrogen recombination

Compared to PAR-01, the catalyst height decreased from 100 mm to 25 mm in PAR-02, and the initial hydrogen injection flow rate reduced from 0.3 g/s to 0.1 g/s as shown in Table 1.

Figure 3 shows the catalyst and atmosphere temperatures inside the housing in the PAR-02 test. PAR-B2 and PAR-T2 represent the bottom and top temperatures of the catalyst, respectively. PAR-H1, PAR-H2, and SPT14 are the gas temperatures inside the housing measured at 350 mm, 500 mm, and 650 mm from the bottom of the catalyst. Here, SPT 14 is the gas temperature before the high-temperature steam produced by the recombination reaction is released from the PAR housing outlet. The catalyst surface temperature began to rise rapidly at approximately 13,320 seconds. At this time, the catalyst inlet hydrogen concentration at #13 increased to about 3.3 vol.%.

While the hydrogen concentration at #13 continuously increased from 0 vol.% to 3.3 vol.%, the catalyst temperature did not increase. Hydrogen does not immediately recombine on our catalyst surface at relatively low hydrogen concentrations, and the recombination reaction begins above a specific hydrogen concentration.

The temperatures at the bottom and top of the catalyst surface increased to 538 and 411 ℃, respectively. The gas temperature decreased by about 12 ℃ as the high-temperature steam discharged from the catalyst outlet rose from PAR-H1 to PAR-H2. The gas temperature just before the PAR outlet (SPT14) fluctuated relatively significantly.

The amount of hydrogen injected affects the catalyst and gas temperature inside the PAR housing. When the hydrogen injection rate decreased to 0.05 g/s, the temperature increase slope also reduced, and when it was changed to 0.03 g/s, the gas temperature began to drop. The temperature response under these hydrogen injection rates was similar to the hydrogen concentration behavior around the catalyst inlet. The flow velocity into the catalyst inlet remained at about 0.5 m/s and fluctuated within about ±0.1 m/s after the surface temperature rapidly increased.

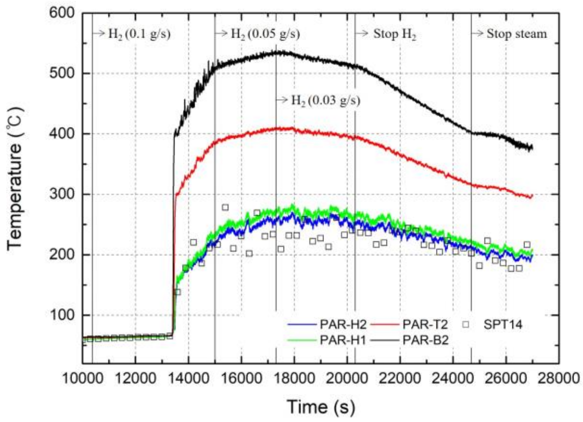

Fig. 3. Catalyst and gas temperature response in PAR-02 test.

3. Conclusions

We have been conducting a series of hydrogen recombination experiments at the SPARC test facility, which simulate the atmospheric environment during a severe accident. This study showed that the PAR inner temperature changes are similar to the PAR surrounding hydrogen concentration for a given catalyst specification and hydrogen injection rate. The experimental data can contribute to developing a methodology to not only evaluate the hydrogen recombination rate of PARs but also to predict the hydrogen concentration around PARs by monitoring the internal thermal response of PARs.

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