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Experimental Study on Hydrogen Stratification Induced by Passive Autocatalytic Recombiners

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1. Introduction

A passive auto-catalytic recombiner (PAR) is a kind of device to remove hydrogen in a gas mixture by catalytic chemical reaction of hydrogen and oxygen. Currently PARs are actively used in nuclear reactor containments in order to remove a hazard of hydrogen explosion in the containment during a severe accident because of their passive hydrogen removal characteristic. It is believed that PARs can be more popularly installed in a containment as a hydrogen mitigation system (HMS) when hydrogen behaviors interacting with PARs installed in a containment are well understood.

A hydrogen stratification phenomenon may occur in a containment by the installed PARs. Representatively hydrogen moves upward and is accumulated in a containment dome region when it is released into the containment. But, when PARs in a containment actively remove hydrogen, hydrogen released later can be accumulated in a lower region because a lighter exhaust gas of PARs occupying an upper region hinders an upward flow of the hydrogen. This PAR-induced hydrogen stratification was mentioned at PARIS-I in the frame of SARNET WP12-2 [1].

Currently it is underway to set up the SPARC test facility for an experimental simulation of the hydrogen stratification phenomenon affected by PAR or PARs activation. The purpose of the SPARC-PAR test is to experimentally reproduce the PAR-induced hydrogen stratification and supply the experimental data for validation of analytical models for a containment thermal hydraulics. This paper introduces the SPARC-PAR test facility and experimental conditions.

2. Methods and Results

2.1 SPARC Test Facility

KAERI constructed the SPARC that stands for Spray, Aerosol, Recombiner, and Combustion for simulating hydrogen behavior in a severe accident. The SPARC test facility consists of a test vessel, control and measurement system. The SPARC vessel is 3,400 mm in diameter and 9,532 mm in height, and its design pressure is 15 bar at 180 °C. We can measure temperature, pressure, and humidity at various points. The wall temperature of the test vessel can be increased when the heat transfer fluid with the desired temperature circulates within the jackets designed on the outer wall of the SPARC vessel. A gas supply system is established, and we can inject gases such as air, nitrogen, steam, hydrogen, and helium into the SPARC vessel.

2.2 PARs and Instruments installed in SPARC Vessel

To observe hydrogen stratification behavior induced by PARs, we installed the honeycomb-type PARs, as shown in Fig. 1. Two PARs are positioned at an elevation of 6,000 mm from the bottom of the SPARC vessel, and they are facing each other. We can adjust the PARs arrangement by changing an elevation of each PAR. The size of the PAR housing is 335 mm in width, 340 mm in long, and 1,400 mm in height. In the entrance of the PAR housing, up to four standard honeycomb catalyst of 150 mm width and long, and 50 mm height can be set up [2].

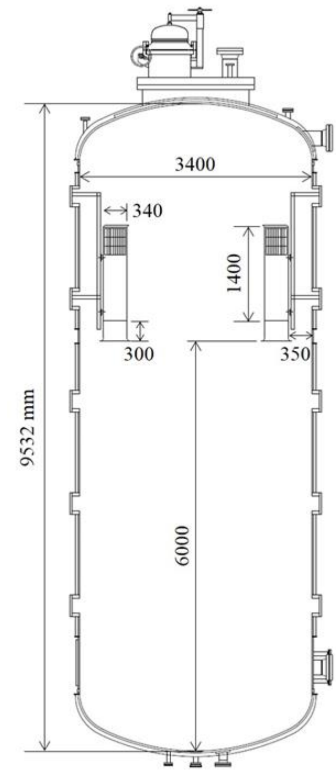

Fig. 1. Location of PARs installed in the SPARC vessel.

In general, the hydrogen recombination rate of PAR increases at high pressure and hydrogen concentration, while it declines with decreasing temperature. The hydrogen depletion rate of the PAR in this study is about 0.2 g/s at a hydrogen concentration of 4 Vol.% and at atmospheric pressure and 18 °C. To evaluate the recombination rate of PARs, we should measure the concentration of hydrogen and oxygen, and temperature at the entrance and exit of PARs. The instruments were fixed on the center of the skirt, as shown in Fig. 2, attached below the entrance of the PAR housing. The probe-type turbine flow meter (ZS30GE, Hoentzsch, Germany) with 30 mm in diameter measures the volume flow rate on the center of the skirt. To quantify the concentration of hydrogen and oxygen, sampling tubes connected with the hydrogen analyzer (FTC300, messkonzept, Germany) and the oxygen analyzer (PMA1000, M&C, Germany) located outside the vessel. Probe-type hygrometer (EE33-MFTD, E+E electronik, Austria) with 12 mm in diameter computes the relative humidity of gas mixture entering PARs. We set up the probe-type thermocouples (AFBC0FQ120U4100, WATLOW, US) with 0.508 mm in diameter on the catalyst plate to assess temperature changes induced by catalytic chemical reaction.

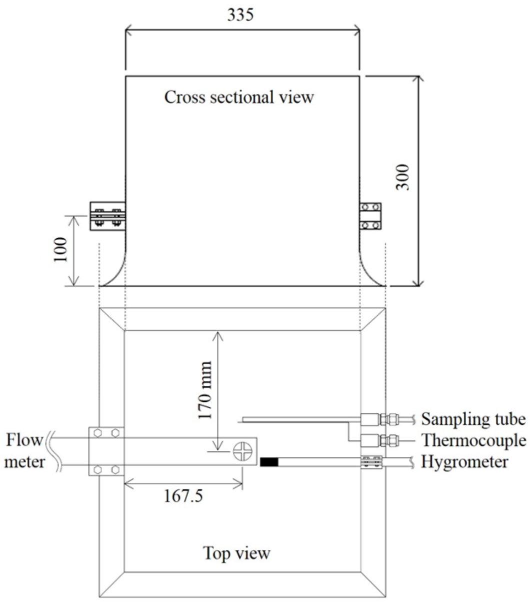

Fig. 2. Skirt attached below the entrance of the PAR housing.

Changes in the hydrogen distribution induced by PARs will be observed by 12 points in the SPARC vessel. To check the accuracy of the hydrogen analyzers, we carried out two-points calibration tests using a pure nitrogen, as an offset gas, and hydrogen of 10.4 Vol.% balanced with nitrogen, as a gain gas. The volume concentrations measured by the 14 hydrogen sensors agreed well with those of the reference gases including hydrogen within ±0.1 Vol.%, as shown in Fig. 3.

2.3 SPARC-PAR Test Conditions

Hydrogen will be injected into PARs at 0.2 g/s during 1,000 seconds from the bottom of the SPARC vessel, and we will then observe the hydrogen concentration distribution change with time and space, induced by the operation of PARs. The initial temperature will be 80 °C at atmosphere pressure. The recombination rate of PAR is defined by hydrogen mass flow rates, which will be calculated by volume flow rate, density, and hydrogen concentration. Here, we have to consider the steam content to convert the measured hydrogen concentration in the hydrogen sensor into the real hydrogen concentration in the SPARC vessel.

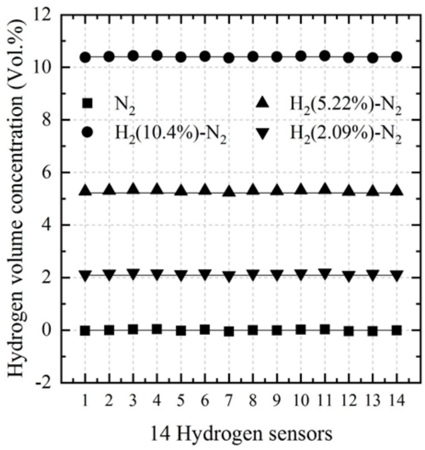

Fig. 3. Calibration test results of 14 hydrogen analyzers.

3. Conclusions

This paper introduced the setup of the SPARC-PAR test for observing the hydrogen stratification behavior induced by the operation of PARs. In the SPARC vessel, we installed PARs and the instruments for measuring the thermal-hydraulic condition and the hydrogen concentration. The change in the hydrogen distribution will be monitored during the operation of PARs. In addition, we will estimate the hydrogen recombination performance affected by the interaction between PARs with different arrangements.

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