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Helium-air stratification experiment in SPARC test facility

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1. Introduction

During a severe accident, hydrogen gas can be generated through core degradation and Molten Corium-Concrete Interaction (MCCI). Hydrogen released into a containment dome can mix with the surrounding atmosphere such as air and steam. A gas mixture of hydrogen and air is flammable, and hydrogen combustion causes a thermal and dynamic load that can threaten the integrity of a containment building as the last defense barrier. Studies on hydrogen behavior such as mixing, stratification, and combustion have been carried out since the accident at the Three Mile Island (TMI) [1]. To plan on mitigating the hydrogen risk during a severe accident, we should consider the hydrogen behavior affected by thermal-hydraulic conditions in a containment building. A large-scale experimental facility is necessary for simulating complex phenomena including convection, diffusion, and condensation. The Korea Atomic Energy Research Institute (KAERI) constructed a large-sized test facility, called SPARC (SPray-Aerosol-Recombiner-Combustion) [2]. First, we conducted a simple test case to observe the erosion of the stratification layer of a helium-air mixture using an air-vertical jet.

2. Methods and Results

2.1 Experiment method

A cylindrical vessel of the SPARC test facility has a 3.4 m diameter and 9.5 m height, with a total volume of 80 m^3. Fifty-four nozzles were designed at various locations of the vessel wall, and we can therefore install control and measurement systems in a particular place according to the test conditions. This study instituted a gas supply system for injecting a light gas and a vertical jet, and the gas analysis system was set up for measuring the concentration of light gases, such as hydrogen and helium. We have fourteen gas analyzers (FTC300, Messkonzept GmbH, Germany) to measure the concentration distribution of hydrogen or helium. As the measurement principle, the thermal conductivity depends strongly on the volume concentration of hydrogen or helium in a gas mixture. The thermal conductivity of hydrogen and helium at 300 K is 0.183 W/mK and 0.152 W/mK, respectively, which are higher than that of air, at 0.0263 W/mK. The gas analyzer sucks a gas mixture from the desired locations in a test vessel, and then estimates the heat transfer rate determined through the thermal conductivity of the sampled gas. Here, a gas mixture sampled from a SPARC vessel flows into a gas analyzer at 60 l/m through a stainless steel tube of 4.57 mm in diameter. We installed fourteen sampling tubes in a SPARC vessel to observe the gas concentration distribution during the process of a light-gas stratification and mixing, as shown in Fig. 1. At the top side of the test vessel, five sampling points were located at the center. A helium-air stratification layer is generated above at an elevation of 8,150 mm. Eight sampling tubes were installed at 400 mm far from the inner wall of the SPARC vessel. In this test case, an air-vertical jet releases into the stratification layer from an elevation of 5,150 mm at the center of the vessel. There is one sampling point at the bottom of the vessel. All sampling tubes were fixed using steel supports, and passed through the nozzles on the vessel wall. Fourteen tubes were connected with each of the gas analyzers installed outside of the SPARC vessel. It took about 25 seconds to flow from the sampling point in the test vessel to the gas analyzer.

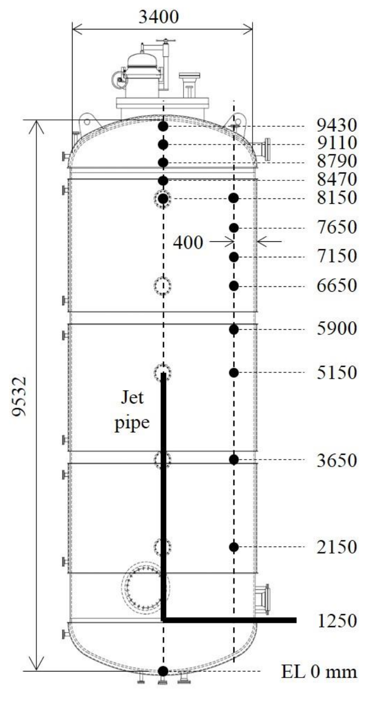

Fig. 1. Elevation of gas sampling tubes and air-vertical jet pipe installed in SPARC vessel.

A vertical-jet pipe having a 100 mm diameter was constructed from an elevation of 1,250 mm to 5,150 mm, as shown in Fig. 1. An air jet was supplied by a compressor (AS151, Kyungwon, Korea). The pressure and flow rate of the air jet can be controlled at 1 to 5 bar and 10 to 150 kg/h, respectively. We can inject an air-vertical jet into the stratification layer of a light gas.

2.2 Experiment results

The volume concentration of helium at above an elevation of 8,150 mm increased uniformly up to 30% when pure helium was injected at an elevation of 8,150 mm from 6,695 s to 10,880 s. In the concentration gradient region from an elevation of 8,150 to 6,650 mm, the volume concentration of helium decreased from 30.0% to 6.0%. From the bottom of the SPARC vessel to an elevation of 5,900 mm, the initial concentration of helium was maintained during the helium injection. A helium-air stratification layer including a volume concentration of helium of 30% was generated from an elevation of 8,150 mm.

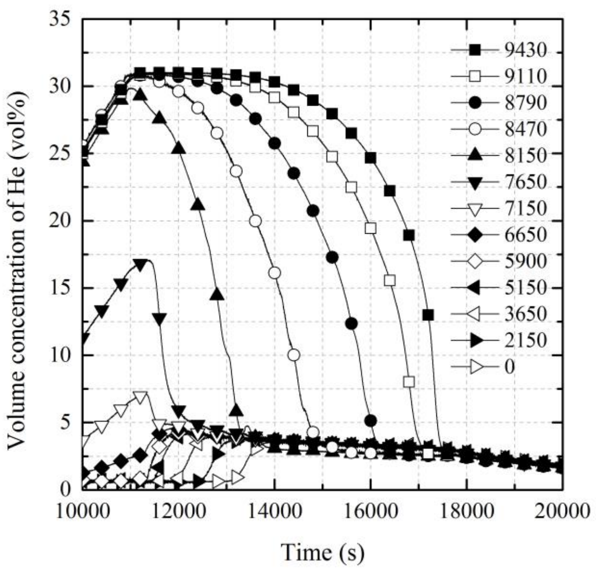

Fig. 2. Helium concentration in elevation from 0 mm to 9430 mm during the air-vertical jet injection.

Helium-air stratification was eroded by an air-vertical jet, as shown in Fig. 2. We stopped to supply helium at 10,880 s, and a vertical jet was injected at 11,233 s. The volume concentration of helium at the top side of the test vessel decreased in order of elevation during the jet injection. The initial region of the stratification layer above an elevation of 8,150 mm became continuously narrow. The arrival height of the air-vertical jet increased as the volume concentration of helium decreased. A vertical jet can go through a stratification layer if the momentum of the jet becomes bigger than the buoyancy force of the stratification layer that occurs based on the density of a light gas. The helium concentration at an elevation of 8,790 mm decreased by about 3.0% at 16,244 s, and the concentration at all sampling points was reduced by less than 3.0% at 17,488 s. After injecting an air-vertical jet, a stratification layer, initially including a volume concentration of helium of 30%, was fully mixed with air during about 6,255 s. The constant flow rate of the air jet was about 100.8 kg/h.

3. Conclusions

Helium-air stratification and mixing were observed in a SPARC vessel with a 3.4 m diameter and 9.5 m height. The volume concentration of helium was about 30% in the initial stratification layer from an elevation of 8,150 mm to 9,430 mm. The thickness of the concentration gradient region below the stratification layer was about 1.5 m, and the volume concentration of helium decreased by less than 2%. The stratification layer was eroded by an air-vertical jet injected at an elevation of 5,150 mm with a Reynold number of 20,000. The volume concentration of helium at an elevation of 8,150 mm decreased by 11% after 1700 s from the injection of an air-vertical jet. The stratification layer was eroded continuously, and the volume concentration of helium reduced in order of height. Finally, the volume concentration of helium measured from the bottom to the top of the SPARC vessel became less than 3% after 6,255 s from injecting a vertical jet, i.e., the stratification layer was fully mixed.

In the future, it will be necessary to compare this test with previous studies on the stratification and mixing of a light gas in different-scaled test facilities. We are going to visualize the erosion process using Particle Image Velocimetry (PIV) to observe the flow field near a stratification layer. These results can be useful to validate a computer code for estimating the hydrogen risk during a severe accident. In addition, we have plans to observe the hydrogen behavior, such as stratification, mixing, combustion, and mitigation by operating of Passive Autocatalytic Recombiner (PAR) in the SPARC test facility to understand the complex phenomena in a containment, as well as a code validation.

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REFERENCES

[1] A. Bentaib, N. Meynet, and A. Bleyer, Overview on hydrogen risk research and development activities: Methodology and open issues, Nuclear Engineering and Technology, Vol. 47, p. 26, 2015.
[2] Y. S. Na, S. H. Hong, and S. W. Hong, Experimental effort to observe hydrogen's behavior, Proceedings of the 11th International Topical Meeting on Nuclear Reactor Thermal Hydraulics, Operation and Safety(NUTHOS-11), Oct. 9-13, 2016, Gyeongju, Korea.