Comparison of Experimental Database of SPARC and PANDA on Stratification Erosion for Hydrogen Risk Assessment

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1. Introduction

Hydrogen combustion can threaten the integrity of the containment building in a severe accident. Dynamic and thermal loads produced by hydrogen explosion can highly influence the containment structure. An amount of hydrogen can be generated by the core degradation, and it can then be released into the containment atmosphere. In the containment dome, hydrogen gas can be stratified by its low density. Hydrogen distribution will be changed by the complex physical phenomena such as diffusion, turbulent flow, and heat transfer during accident process. It is necessary to understand the erosion mechanism of stratification of a light gas for the assessment of hydrogen risk in a severe accident. This study compares the stratification behavior of the SPARC test cases with that of the PANDA test cases in a different scale.

2. Methods and Results

In a general test on stratification erosion, stratification layer of helium, as an alternate of hydrogen, is formed on the top side of a test vessel, and jet or plume then injects into the stratification layer, as shown in Fig. 1. We can observe the change in the helium concentration distribution over time and space while a vertical jet supplies.

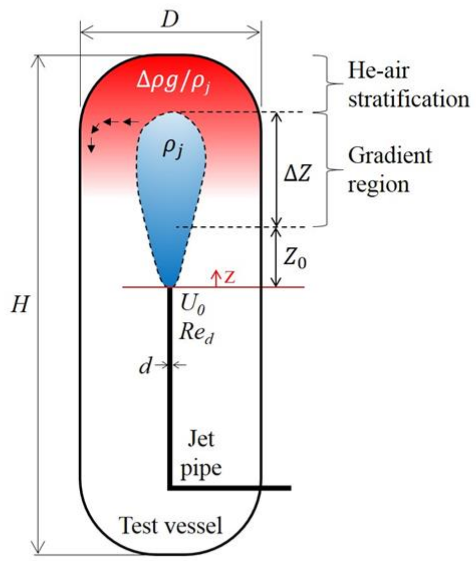

Fig. 1. General test on stratification erosion.

Here, $\triangle Z$ is a distance from the starting elevation of the gradient region to the elevation of a jet front penetrated through the stratification layer. Z_0 is a distance from the outlet of a jet pipe to the starting elevation of the gradient region. In Fig. 1, D and d indicate the diameters of a test vessel and a jet pipe, respectively, and H presents the height of a vessel. Buoyancy of a stratification layer can be defined by $\triangle\rho g/\rho_j$, and $\triangle\rho$ is the density difference between a jet and a stratification layer. Stratification can be eroded by the force balance between buoyancy and jet inertia.

This study compares the stratification behavior of the SPARC test with that of the PANDA test in a different scale. Both of the tests observed the stratification breakup induced by an air jet with different velocities (U_0), as shown in Table I.

Table I: Comparison of experimental conditions of SPARC and PANDA.

	SPARC	PANDA
D (mm)	3400	4000
H (mm)	9500	8000
d (mm)	100	75
Re_d (test cases)	20000 (SM 13)	14000 (E 20)
	30000 (SM 17)	26000 (E 23)
He (Vol.%)	30	40
Z_0 (mm)	1000	1000

These experiments were carried out at atmosphere pressure. The test facilities of SPARC and PANDA, as shown in Fig. 2, and the experimental conditions are described in details below:

2.1 SPARC Test Cases of SM 13 and SM 17

The SPARC test facility was constructed at KAERI (Korea Atomic Energy Research Institute) site for the assessment of hydrogen behavior such as stratification, combustion, and recombination. It consists of a test vessel and the measurement and control systems. The SPARC vessel is 3,400 mm in diameter and 9,500 mm in height. The SPARC tests formed a stratification layer including the helium concentration of 30 Vol.%, and air jets with Reynolds numbers of 20,000 and 30,000, which indicates the test cases of SM 13 and SM 17, respectively, then was vertically injected [1]. Here, the initial elevation of a stratification layer was 3000 mm from the outlet of a jet pipe, and the thickness of the gradient region was 2,000 mm. In the SPARC vessel, the helium distribution were measured by sampling gases into the thermal conductivity analyzers.

2.2 PANDA Test Cases of E 20 and E 23

The PANDA test facility was constructed at PSI (Paul Scherrer Institute) site in Switzerland for the assessment of the system behavior in a design of a nuclear power plant. It consists of six test vessels. The PANDA vessel for the stratification erosion test is 4,000 mm diameter and 8,000 mm height. The PANDA tests formed a stratification layer including the helium concentration of 40 Vol.%, and air jets with Reynolds numbers of 14,000 and 26,000, which indicates the test cases of E 20 and E 23, respectively, then was vertically injected [2]. Here, the initial elevation of a stratification layer was 2,500 mm from the outlet of a jet pipe, and the thickness of gradient region was 1,500 mm. In the PANDA vessel, the helium distributions were measured by sampling gas into the mass spectrometer.

Fig. 2. Test vessels: SPARC (left), and PANDA (right).

2.3 Experimental Database on Stratification Erosion

Figure 3 presents the experimental results of stratification erosion in the test conditions, as shown in Table I. SM 13 and SM 17 indicate SPARC test cases, and E 20 and E 23 present PANDA test cases. The titles of x and y-axes are the dimensionless numbers, which consists of the key variables for a stratification erosion test, as shown in Fig. 1. We derived dimensionless numbers from dimensional analysis as;

$$\tau = \frac{U_0 t}{Z_0} \quad (1)$$

$$Fr_{Z_0} = \frac{U_0}{\sqrt{\frac{\triangle \rho g}{\rho_i} Z_0}} \quad (2)$$

The functional relationship between the dimensionless numbers was found from the experimental database. In both of SPARC and PANDA tests, the degree of erosion, indicated as $\triangle Z$, increases with increasing dimensionless time, presented as τ in Fig. 3. It means that a jet front penetrates continuously into a stratification layer over time. Even though the experimental results carried out in different scaled-test facilities showed the similar erosion process, the erosion rates of SPARC tests are faster than those of PANDA.

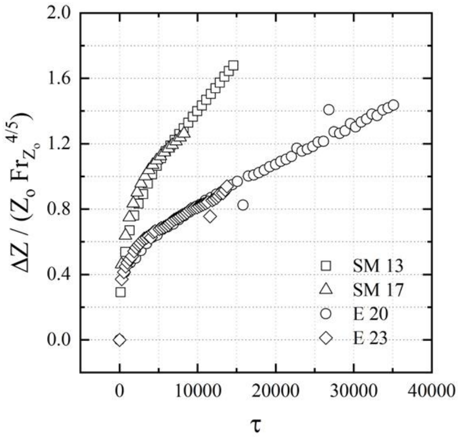

Fig. 3. Comparison of experimental database of SPARC and PANDA on stratification erosion.

3. Conclusions

This study compared the stratification behavior of the SPARC test with that of the PANDA test in a different scale. Both of experimental results showed that helium concentration of a stratification layer was diluted by the erosion mechanism. Here, the erosion rates of the SPARC test cases are faster than those of the PANDA test cases. In the future, we will consider the scale effect to make a general correlation for stratification behavior, and include the other test cases of THAI and MISTRA in our experimental database.

ACKNOWLEGMENTS

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REFERENCES

[1] Young Su Na, Woo Young Lee, and Jongtae Kim, Test on dissolution of a stratified light gas layer for hydrogen risk assessment, Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 17-18, 2018.
[2] R. Kapulla, G. Mignot, and D. Paladino, Dynamics of helium stratifications eroded by vertical air jets with different momenta, NURETH-15, Pisa, Italy, May 12-17, 2013.