Erosion correlation of stratified hydrogen by impinging jet

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1. Introduction

In a severe accident, the hydrogen distribution, as an initial condition of hydrogen combustion, is one of the issues to threaten the integrity of a containment. Complex physical phenomena of hydrogen stratification and mixing have been simulated in large-sized test vessels having a free volume of 60 m^3 to 100 m^3. The experimental results have contributed to the validation of a computer code that assesses the hydrogen behavior in a real-sized containment under a severe accident.

The previous experimental database shows the main variables that influence the behavior of hydrogen distribution [1]. The variables with dimensions such as length, mass, and time are grouped by dimensional analysis that can make dimensionless numbers regarding the hydrodynamic behavior of the hydrogen distribution [2]. A functional correlation between the dimensionless numbers can be derived from the experimental database.

The previous version of this study showed the dimensionless numbers regarding the erosion of stratified light gas by impinging jet [2]. They put the the experimental results from the different scaled test facilities into the dimensionless numbers, and they then drew the different correlations for the same phenomena of the erosion. This study added a dimensionless number regarding the size of a test vessel to derive the general erosion correlation of stratification by an impinging jet.

2. Methods and Results

2.1. Experimental database

To simulate experimentally the behavior of hydrogen distribution, helium, as an alternative gas of hydrogen, is generally stratified on the upper part of a test vessel, and a jet or plume then injects into the stratification to observe the spatial and temporal variations of the helium concentration. We constructed the experimental database carried out in the different scaled test vessels with the free volume of 60 m^3 to 100 m^3 [1].

Helium was stratified in the upper region of a general cylindrical test vessel, as shown in Fig. 1 [1]. There is a gradient region of helium below the stratification with the uniform volume concentration of helium. In Fig. 1, ΔZ is the distance between the front of a jet penetrating through helium region and Z_0 that is the distance from the exit of a jet pipe to the bottom of the initial gradient region. H indicates the height of a test vessel, and D and d present the diameters of a test vessel and a jet pipe, respectively. U_0 is the average velocity of a jet at the exit of a jet pipe. The buoyancy of the stratification is expressed by $\Delta\rho g/\rho_j$, where $\Delta\rho$ is the density difference between jet (ρ_j) and a stratified gas (ρ), and g is the acceleration of gravity. ΔZ is the dependent variable in time and the other are the independent variable.

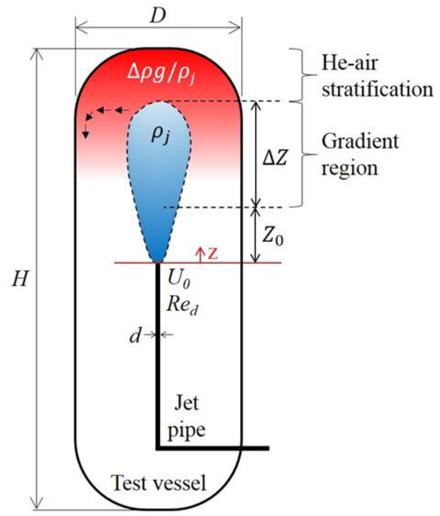

Fig. 1. Major variables influencing the erosion of a stratified light gas by impinging jet.

This study chose the four test cases in the experimental database, as shown in table 1[1]. In dimensional analysis, we considered the dimensionless number regarding a test scale that is the diameter ratio of a jet pipe to a test vessel, d/D. The diameter ratios of SPARC and PANDA are 0.029 and 0.019, respectively. The experimental database showed that ΔZ rose in time while a jet collided with the stratification.

Table I: 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

2.2. Dimensional analysis

From the experimental database, it was observed that mixing of a stratified light gas and an impinging jet is determined by the buoyancy of the stratification and the inertial force of a jet. This study chose the eight main variables such as ΔZ, Z_0, d, D, U_0, ρ_j, $\Delta\rho g$, t that influence the erosion of the stratification, as shown in Fig. 1. ΔZ indicates the degree of erosion of stratification. The initial distribution of the gradient region is from 3% to 97% of the uniform concentration of the stratification. In Buckingham's PI theorem, we derived the four dimensionless numbers, as shown in Table II, from the eight main variables.

Table II: Dimensionless numbers of erosion of stratification

#	Dimensionless number
1	$\frac{\Delta Z}{Z_0}$
2	$Fr_0 = \frac{U_0}{\sqrt{\frac{\Delta\rho g}{\rho_j} Z_0}}$
3	$\delta = \frac{d}{D}$
4	$\tau = \frac{tU_0}{Z_0}$

Equation 1 presents the functional correlation between dimensionless numbers. $\Delta Z/Z_0$ is the degree of erosion of stratification. It depends on the Froude number (Fr_0), dimensionless scale (δ) and time (τ) in Table II.

$$\frac{\Delta Z}{Z_0} = f(Fr_0, \delta, \tau) \quad (1)$$

2.3. Erosion correlation of stratification

The functional correlation of dimensionless numbers introduced above can be found by the experimental database, i.e., the variation of ΔZ in time [1]. This study assumed that the form of a correlation is a power equation. First, we found that the power, a, was 0.8 in Eq. 2 that is a correlation of $\Delta Z/Z_0$ and Fr_0.

$$\frac{\Delta Z}{Z_0} = A(Fr_0)^a \quad (2)$$

Secondly, the power, b, in Eq. 3 that is a correlation of $\Delta Z/(Z_0 \cdot Fr_0^{0.8})$ and δ was 1.2. The experimental data carried out in the different scaled test vessels was overlapped in a curved-dashed line, as shown in Fig. 2.

$$\frac{\Delta Z}{Z_0 Fr_0^{0.8}} = B(\delta)^b \quad (3)$$

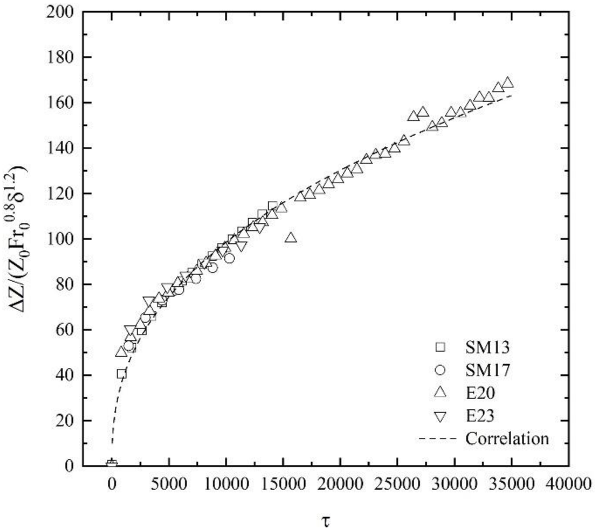

Fig. 2. Correlation between dimensionless numbers.

Finally, we derived the erosion correlation of a stratified light gas by an impinging jet as:

$$\frac{\Delta Z}{Z_0 Fr_0^{0.8} \delta^{1.2}} = 2.4\tau^{0.4} \quad (4)$$

3. Conclusion

This study derived the erosion correlation of a stratified light gas by an impinging jet. Dimensional analysis induced the dimensionless numbers regarding the breakup degree of the stratification, the ratio of the buoyancy to the inertial force, test scale, and time. The experimental database on the spatial distribution of a light gas resulted in the correlation between the dimensionless numbers. The erosion correlation could expect the behavior of a stratified hydrogen in a containment when the dimensionless numbers between a model and a prototype are similar.

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