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Test on dissolution of a stratified light gas layer for hydrogen risk assessment

Young Su Na [a*], Woo Young Lee[b], Jongtae Kim [a]
[a]*Korea Atomic Energy Research Institute, 989-111 Daedeok-daero, Yuseong-gu, Daejeon, 34057, Korea*
[b]*Hanyang University, 222 Wangsimni-ro, Seongdong-gu, Seoul, 04763, Korea*
[*]*Corresponding author: ysna@kaeri.re.kr*

1. Introduction

Hydrogen explosion can threaten the integrity of a closed containment in a severe accident. An amount of hydrogen can be generated during core degradation and MCCI (Molten Corium-Concrete Interaction), and it then could be released into the containment atmosphere. Hydrogen has low ignition energy of 0.017 mJ, and high combustion heat of 142 kJ/g, and a wide combustion region of 4~75%. Hydrogen combustion that depends on a composition ratio of a combustible gas consisting of hydrogen and air can be occurred by a little ignition potential. Flame propagation induced by a hydrogen deflagration could be developed into a detonation that makes the dynamic and thermal load.

Light density gas, such as hydrogen released into a containment dome, could be stratified by buoyancy. During a severe accident, hydrogen stratification would be dissolved by the various physical phenomena such as turbulence, diffusion, heat transfer, and condensation in a containment. It is necessary to understand the behavior of hydrogen stratification for assessing a hydrogen risk in a severe accident. Previous studies on simulating the stratification dissolution have been conducted in a large-scaled test facility such as THAI, PANDA, and MISTRA. While the previous experimental database contributed the code validation as well as understanding the physical phenomena, there is a lack of study on a force correlation regarding the behavior of stratification.

This study introduces a non-dimensional number to explain the force balance between buoyancy of stratified layer and a force to break stratification. We observed the dissolution of a stratified helium, as a substitute for hydrogen, in the top side of a cylindrical vessel by injecting vertically an air jet into stratification. This paper is based on the previous study presented at the Korean Nuclear Society Autumn Meeting [1], we added the results on visualization of the jet flow.

2. Methods and Results

2.1 Interaction Froude number

When an air jet reach a stratified layer, we can define an interaction layer that is formed between a stratification region and a jet front. Here, the buoyancy of light density gas is balanced with the momentum of jet. A vertical jet front couldn't penetrate into an interaction layer, and it could then change in a horizontal direction through an interaction layer. The volume concentration of helium on an interaction layer is reduced due to mixing with air jet. Because the buoyancy of stratification becomes weak during a jet injection, an interaction layer rises upwards. Finally, the helium stratification will completely break-up.

A force correlation between buoyancy of a stratified light gas and momentum of a jet front could be defined by an interaction Froude number, Fr_i, which is given as

$$Fr_i = \frac{U_i}{\sqrt{\frac{\rho_j - \rho_m}{\rho_j} \cdot g \cdot L_i}} \qquad \text{Eq. 1.}$$

Because a front velocity of jet impinging an interaction layer is 0, we can use velocity, U_i, and width, L_i, of jet injecting vertically without stratification. In Eq. 1, ρ_j and ρ_m are the density of jet and an interaction layer, respectively, and g is the acceleration of gravity, 9.8 m/s^2. It is expected that an interaction Froude number is unity, because buoyancy is balanced with momentum on an interaction layer. In our test, PIV (Particle Image Velocimetry) visualizes the formation of an interaction layer, as well as measures the flow field on an interaction layer to evaluate jet momentum. Gas analysis system measures the volume concentration of helium to estimate buoyancy on an interaction layer.

2.2 Flow visualization

PIV system consists of a camera (FlowSenseEO 4M, Dantec), with a pixel resolution of 2048 x 2048, and a laser (Dual Power 425-10, Dantec) with output power of 400 mJ/pulse. In a test vessel having 9.5 m height and 3.4 m in diameter, FOV (Field Of View) is 905 x 905 mm^2, and the PIV system was installed at the elevation of 8150 mm from the bottom of a vessel. A vertical-jet pipe having a 100 mm diameter was constructed from an elevation of 1,250 mm to 5,150 mm [1]. Air jet rises vertically up from the center of a vessel to the stratified region. The volume concentration of helium at above an elevation of 8,150 mm was kept uniformly up to 30%. 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% [1]. In an interaction layer, a vertical jet front didn't penetrate into the stratified helium, and it then changed in a horizontal direction, as shown in Fig. 2. We injected tracer particles into jet to visualize clearly an interaction layer. In Fig. 2, the white region indicates that tracer particles are in existence, i.e., a jet front reaches the end of the white region, on the other hand, the black region presents that there are no particles, because a jet front couldn't penetrate an interaction layer. Where, *r*, *z*, and D in Fig. 2 and 3 are a radial direction from the center of a vessel, a height from the exit of a jet pipe, and a pipe diameter, respectively.

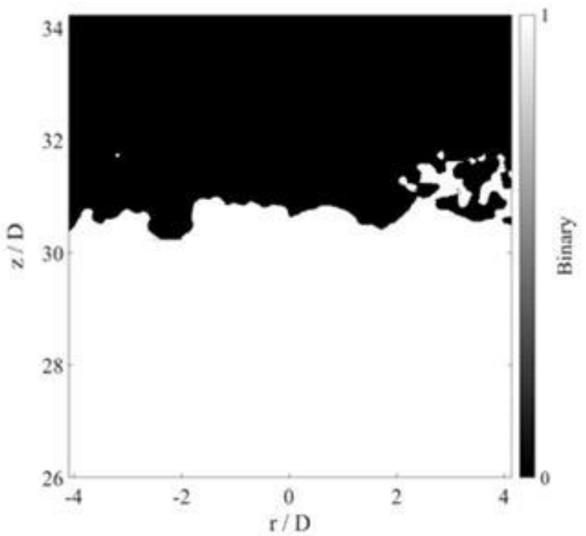

Fig. 2. Tracer particle density field at a helium-stratified layer and 1815 s after injecting a vertical jet.

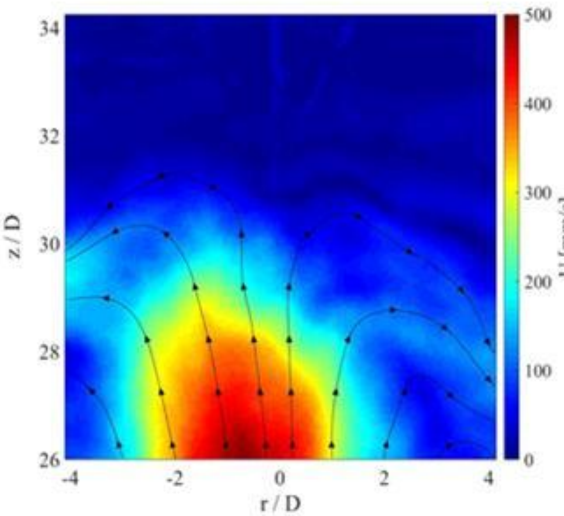

Fig. 3. Velocity field at helium-stratified layer and 1815 s after injecting a vertical jet.

2.3 Helium concentration distribution

The gas analyzer (FTC300, Messkonzept) 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 [1]. Here, the thermal conductivity of helium at 300 K is 0.152 W/mK, which is higher than that of air, as 0.0263 W/mK. We installed fourteen sampling tubes in a test vessel to observe the gas concentration distribution [1].

Jet front reached the elevation of 8150 mm at 1815 s after the start of jet injection at 0 s. Figure 4 shows the distribution of normalized density, which was defined in Eq. 1. As we expected, the interaction Froude number was calculated as about unity.

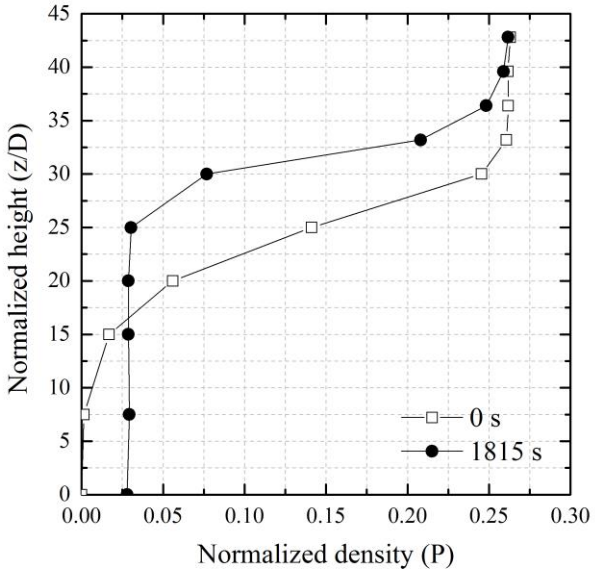

Fig. 4. Variation of density distribution of stratified helium during jet injection.

3. Conclusions

This study carried out a helium-air stratification break-up test. Helium gas was stratified up to about 30 vol% from the elevation of 8150 mm in a test vessel having 3.4 m in diameter. In the concentration gradient region from 6650 mm to 8150 mm, helium concentration decreased from 28.5 vol% to 2.0 vol%. Air jet was injected vertically from the elevation of 5150 mm to stratification on top of a test vessel. We observed an interaction layer developed when a jet front reach a stratified layer. Interaction Froude number defined as a ratio of jet momentum to buoyancy on an interaction layer was calculated as unity, i.e., buoyancy of stratified helium was balanced with momentum of a jet front, by measuring the flow field of jet and the concentration distribution of helium.

ACKNOWLEGMENTS

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