

Hydrogen Concentration Distribution in Simulated Spaces for a Hydrogen System Installed in a Large Bus in Case of Hydrogen Leakage

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ABSTRACT

For fuel cell vehicles, which have attracted attention in recent years, the prevention of hydrogen leakage is an essential safety issue.

Large fuel cell buses will require a large space to store the hydrogen system. The behavior of hydrogen that has leaked into such a large space is unknown.

In this report, we studied hydrogen concentration distribution by leaking hydrogen into simulated spaces in two cases: (1) when hydrogen gas tanks are installed on the roof of the bus, and (2) when an electricity-generating system, such as fuel cell stacks, etc., is installed at the rear of the bus.

The results of the experiments show that hydrogen concentration distribution is kept at a constant level throughout each location in the simulated space, depending on the opening area and hydrogen leakage rate. It was also found that the diffusivity of hydrogen in air is extremely high. Hydrogen diffuses through openings, preventing a high concentration from accumulating inside the space, thus keeping the concentration below the lower flammable limit (LFL) of 4% (by volume), in many cases.

INTRODUCTION

In recent years, the problem of global warming has made it necessary to take positive environmental measures against carbon dioxide emissions from automobiles. One promising development is fuel cell vehicles.

A fuel cell vehicle uses hydrogen as fuel. Generally, the hydrogen is stored in the vehicle as high-pressure gas, which is one of the available installation methods. In this case, the prevention of hydrogen leakage is an essential safety issue.

Fuel cell technology is expected to be used in large buses as well. Large fuel cell buses will require several gas tanks to be installed on the roof in order to preserve

passenger compartment space and give sufficient cruising distance. The space for the hydrogen system would therefore be larger in buses than in passenger cars. In such large spaces, if the hydrogen leaks because of loose piping joints, etc., a stationary vehicle with no airflow would let leaked hydrogen accumulate in the space. The hydrogen concentration distribution in such a large space has not yet been studied. In addition, it is generally known that hydrogen will burn at a concentration of 4% or above and explode at 18% or above. It is therefore important to know the hydrogen concentration distribution in spaces where hydrogen has leaked.

In this experiment, we studied hydrogen concentration distribution by leaking hydrogen in simulated spaces in two cases: (1) when hydrogen gas tanks are installed on the roof of a bus; and (2) when an electricity-generating system, such as fuel cell stacks, etc., is installed at the rear of the bus. In the experiment, the opening areas of the simulated spaces, the leak rates and the direction of the leaks were used as parameters.

MAIN SECTION

1. DESCRIPTION OF THE EXPERIMENT

1.1 Objective

The objective of this experiment was to study the concentration of hydrogen accumulation after leaking in minute amounts through loose joints in hydrogen piping, etc.

We examined whether or not the hydrogen concentration in the space exceeded 4% due to accumulation.

On the other hand, we excluded from this discussion significant hydrogen leaks caused by broken or disconnected piping, etc. In addition, we did not consider a scenario in which there is airflow in the space, e.g., when the bus is in motion, because hydrogen would not accumulate under these conditions.



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1.2 Conditions of the experiment

1.2.1 Simulated spaces

When installing fuel cells in a large bus, two possible spaces for storing the hydrogen system (tanks, piping, fuel cells, etc.) are the following:

- (a) On the roof of the bus for storing large gas tanks.
- (b) At the rear of the bus for storing a fuel cell system.

With regard to (a), installation of the hydrogen tanks on the roof was considered because, compared to fuel cell passenger cars, large fuel cell buses require more hydrogen fuel. This space has a large volume and extends horizontally.

Large fuel cell buses need a large generating system, because they require far more electric power than fuel cell passenger cars. Therefore, as to (b), installation of the fuel cell system at the rear of the vehicle was considered. Furthermore, since the rear of the bus is likely to have level differences (i.e., steps), we confirmed hydrogen concentration distribution and hydrogen accumulation around these steps. This space has a large volume and extends vertically.

We created spaces that simulate the scenarios in (a) and (b) above. Upon determining the dimensions of these simulated spaces, we studied the data of dimensions of non-step buses and CNG buses, etc., simplified these configurations, and came up with simple yet realistic dimensions.

1.2.2 Experimental parameters

The following parameters were used in the experiment:

- Openings in the simulated spaces
- Inflow rates (hydrogen leak rates)
- Inflow directions (hydrogen leak directions)

In the spaces mentioned in (a) and (b), in order to prevent leaking hydrogen from accumulating, openings were provided. We studied the effect of these openings.

We used a pipe with a cross-sectional area of 44.9 mm² (diameter: 7.56 mm) to carry hydrogen gas. We set the hydrogen inflow rates at 5 L/min (1.86 m/s), 30 L/min (11.1 m/s), 65 L/min (24.1 m/s) and 131 L/min (48.6 m/s). The maximum inflow rate of 131 L/min is the value specified in Japanese regulations [1] as the permissible leak rate in the event of a collision. To ensure safety during the experiment, the total accumulated hydrogen amount was determined so that the hydrogen concentration became 5% when it was uniformly distributed inside each simulated space. Accordingly, the inflow amount was set at 600 L for the space simulating the roof and at 300 L for the space simulating the rear of the bus. The hydrogen inflow time was determined for each inflow rate.

The openings and the inflow directions will be explained later, because they depend on each simulated space.

The following items were measured in the experiment:

- 1) Hydrogen concentration distribution in the simulated spaces;
- 2) Time-changes in hydrogen concentration (maintenance of hydrogen concentration);
- 3) The hydrogen concentration compared to the lower flammable limit (LFL) of 4%.

Based on these measurements, the diffusivity of hydrogen can be confirmed.

The hydrogen sensor (KE-3A : New Cosmos Electric Co., Ltd.) used in the experiment had a gas heat conduction system. Because this system detects concentration from the difference in heat conductivity between air and hydrogen, it enables hydrogen concentration to be measured without compromising the atmosphere of the measurement target areas. Regarding the instrument's performance, the full scale was 20% hydrogen concentration and the indication accuracy was $\pm 0.5\%$ of hydrogen concentration. The response time of the hydrogen sensor was about 30 seconds for a 90% response. In each experiment, we continued measuring until the sensor indicated a concentration of 1% or below.

2. SIMULATED SPACE FOR THE ROOF OF THE BUS

2.1 Experimental method (overall and around the hydrogen inflow nozzle)

Figure 1 shows a schematic view of the simulated space for the roof of the bus that was used in the experiment. Because hydrogen gas tanks will likely be installed on the roof, our experiment simulated a roof-type gas tank installation.

With regard to the opening area conditions of the experiment, openings with 0% (sealed), 5%, 10%, and 20% of the upper/side surface areas of the simulated space were provided as follows:

- (1) Sealed condition (0%);
- (2) 10% on the upper surface of the simulated space;
- (3) 5% on the side surface of the simulated space;
- (4) 10% on the side surface of the simulated space;
- (5) A total of 20% by combining (2) and (4).

In the case of (1), small openings were provided at the bottom of the simulated space to keep the pressure in the space constant. In addition, hydrogen sensors were installed at the entrances to these openings for monitoring the emission of hydrogen out of the simulated space.

To clarify the differences in concentration distribution in the space, the hydrogen inflow nozzle was set at the center in the X direction and at 1/4 in the Y direction on the floor of the space shown in Figure 1. The hydrogen inflow directions were set in a positive Y-direction and in a negative Y-direction. The sensors were installed at (1) through (12) in Figure 1.

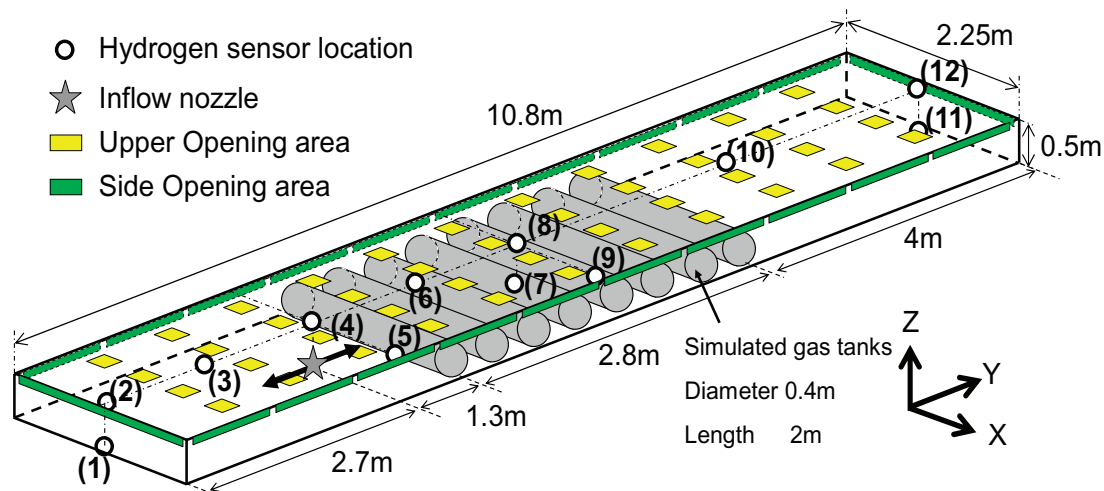


Fig. 1 Simulated Space for the Roof of a Bus

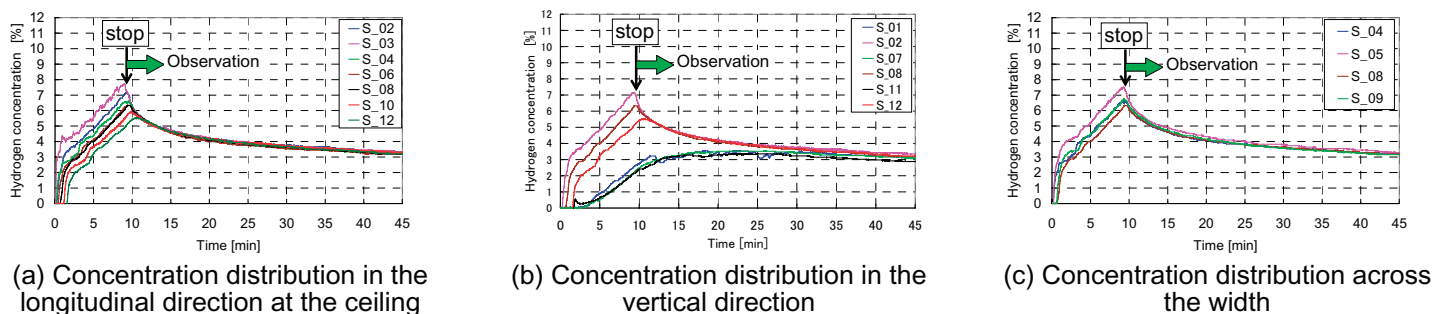


Fig. 2 Hydrogen Concentration Distribution in a Sealed Space (no gas tanks, 65 L/min, inflow in the negative Y-direction)

The locations among these sensors were as follows: (2)-(3)-(4)-(6)-(8)-(10)-(12) on the upper surface in the Y direction; (1)-(2), (7)-(8), and (11)-(12) in the Z direction; and (4)-(5) and (8)-(9) in the X direction.

2.2 Results of the experiments

2.2.1 Sealed condition (1)

Figure 2 shows the results of the experiment under sealed conditions, without simulated gas tanks, and with an inflow rate of 65 L/min in the negative Y-direction. In this experiment, the behavior of hydrogen was observed after its inflow, which lasted 10 minutes, was discontinued. The effect of hydrogen leakage from the lower openings was not considered in this experiment because the hydrogen sensors there indicated a concentration of 0.5% or below in all cases.

Graphs (a) and (c) in Figure 2 demonstrate that concentrations of almost the same level were detected by sensors installed on the upper surface of the simulated space immediately after the hydrogen inflow was stopped. This means that there is no difference in concentration across the upper part of the simulated space. In other words, hydrogen gas diffuses extremely well in the horizontal direction.

Graph (b) in Figure 2 shows that concentration distribution in the vertical direction approaches the same level as time

elapses. This is thought to be because hydrogen in the upper part of the space diffuses to the lower part. In the present case, it took about 30 minutes for the hydrogen in the upper and lower parts to reach almost the same concentrations.

Similar results were obtained in the cases in which hydrogen flowed in the positive Y-direction and gas tanks were installed as well.

The above results demonstrate that the hydrogen gas diffuses extremely well in the horizontal direction in a sealed space and that the horizontal concentration distribution in the upper part of the simulated space was almost uniform. It was also confirmed that, after hydrogen inflow had stopped, the vertical concentration distribution in the simulated space became almost uniform after a certain period had elapsed.

2.2.2 Opening conditions

As an example of opening conditions, Figure 3 shows the results of the experiment with a 10% opening in the side surface, with gas tanks and with hydrogen inflow at a rate of 30 L/min in the negative Y-direction.

These results indicate that the hydrogen concentration in each location reaches the same level about 5 minutes or later after the inflow starts. This is thought to be brought about by the hydrogen inflow into the space and the