

An Experimental Study on the Fire Response of Vehicles with Compressed Hydrogen Cylinders

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ABSTRACT

To investigate the events that could arise when fighting fires in vehicles with carbon fiber reinforced plastic (CFRP) hydrogen storage cylinders, we conducted experiments to examine whether a hydrogen jet diffusion flame caused by activation of the pressure relief device (PRD) can be extinguished and how spraying water influences the cylinder and PRD. The experiments clarified that the hydrogen jet flame cannot be extinguished easily with water or dry powder extinguishers and that spraying water during activation of the PRD may result in closure of the PRD, but is useful for maintaining the strength of CFRP composite cylinders for vehicles.

INTRODUCTION

The pressure cylinders will be equipped with a PRD to prevent rupture of the cylinder due to a fire. The PRD reduces the internal pressure of the cylinder by releasing the gas inside the cylinder when its ambient temperature rises due to a fire. The released gas is ignited by the surrounding flame and forms a jet diffusion flame.

For gas fires in common buildings, the pressure cylinders are cooled by spraying water to prevent rupture of the vessel due to the heat of fire.¹⁾ However, the vessels used in facilities are made of steel, and there have been no reports on whether the measures used for steel cylinders can also be applied to CFRP storage cylinders that are now being used on vehicles.

On the other hand, according to the California Fuel Cell Partnership emergency response guide²⁾, water should not be sprayed on the vent section of the jet flame because of the

risk of explosion when the hydrogen jet diffusion flame is extinguished.

This paper reports experiments that evaluate what risks may be present if firefighters spray water on burning composite cylinders and extinguish the jet flame. This information can be used to re-evaluate common guidance (e.g., the California Fuel Cell Partnership) that firefighters not extinguish fire involving onboard gaseous storage.

EXTINGUISHMENT TEST OF HYDROGEN JET FLAME

We investigated whether the hydrogen jet flame can be extinguished with water spray or powder quenching.

TEST METHOD

Figure 1 schematically depicts the test apparatus.

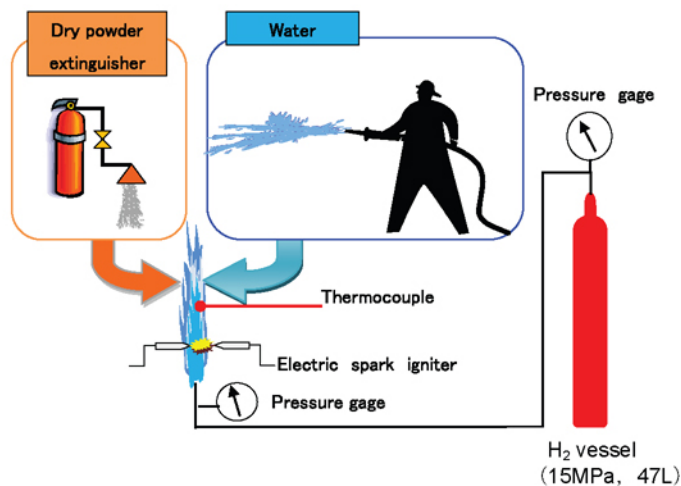


Figure 1. Schematic of test system

Hydrogen gas supplied from the vessel (15 MPa, 47 Liters) blows out into the atmosphere through the vent port (blowout aperture: 4.2 mm), simulating a gas emission hole in the event of PRD activation, and is ignited by an electric spark. The spraying water or a dry powder extinguishing agent (ABC fire extinguishing agent for automobiles) was aimed directly at the vent port. A water-spray nozzle with a maximum water discharge volume of 500 L/min · m² and a 2 inch nominal diameter was used for extinction with water spray. A vehicle fire simulator (Figure 2) was tested on asphalt pavement by connecting vent tubes to it.



Figure 2. Vehicle simulator and asphalt pavement

Two directions of vent port were used: upward and inclined downward by 45°. The vent port directed upward was installed at the center of the rear portion of the roof of the vehicle simulator, and that inclined downward was installed under the floor near the rear-wheel shaft of the vehicle.

The fire fighting was executed from forward or the rear side of the vehicle within the range from 1 to 5 meters.

Whether the flame was extinguished or not was determined by a thermocouple and infrared thermography.

TEST RESULTS

Figure 3 depicts an example of testing, and Table 1 presents the test results.

In the case of upward hydrogen discharge under the conditions shown in Table 1, it was not possible to extinguish the hydrogen jet flame by water spray or powder quenching at the vent port. Similarly the hydrogen jet flame was not easily extinguished in the case of 45° downward hydrogen discharge; however, extinction was observed in Test #4 when the blowout pressure from the vent port declined to 0.9 MPa. At a blowout pressure level of 0.9 MPa, the flame length was less than 50 cm while for a hydrogen storage cylinder of up to 50L capacity the blowout pressure would further drop to zero within a minute. In Tests #7 and #8, the hydrogen jet flame was extinguished at a blowout pressure of 0.3 and 0.2 MPa respectively; then, reignition occurred seconds after extinction due to the heated asphalt. In the vehicle fire simulator experiment, however, reignition even when it occurred did not cause any harmful events such as an explosion because the experiment was conducted on an open-air site with no enclosed spaces for hydrogen to gather.

These results suggest that the hydrogen jet flame generated by activation of the PRD of an actual vehicle cannot be easily extinguished by water spray or powder quenching; however, after once being extinguished, reignition at a low exhaust pressure is not harmful.



(a). Test 1, Upward vent, Water



(b). Test 7, 45 deg. diagonal backward vent, Dry powder extinguisher

Figure 3. Firefighting scene

Table 1. Results of hydrogen jet flame extinguishing test

#	Venting direction	Extinguisher (Orientation)	Results
#1	Upward	Water (Forward side of the vehicle)	Non-extinguished
#2		↓	
#3	↓	Dry powder extinguisher (Rear side of the vehicle)	↓
#4	45 degree diagonal backward	Water (Forward side of the vehicle)	Extinguished at the vent pressure 0.9MPa.
#5		↓	Non-extinguished
#6		Water (Rear side of the vehicle)	↓
#7		Dry powder extinguisher (Rear side of the vehicle)	Extinguished at vent pressure 0.3MPa. Reignition by the hot asphalt. No-explosion.
#8	↓	↓	Extinguished at vent pressure 0.2MPa. Reignition by the hot asphalt. No-explosion.

On the other hand, when hydrogen jet flame extinguished, the flame lift-off was able to be observed by the IR camera. In the confirmation whether the hydrogen flame was extinguished, IR camera was effective.

INFLUENCES OF WATER SPRAY IN FIGHTING FIRE AROUND THE CYLINDER AND PRD

We investigated the events that occur in the cylinder and PRD when they are heated by fire and then cooled by water spray, as well as the influences of water spray on the strength of the cylinder.

TEST METHOD (SAMPLE PREPARATION)

Figure 4 schematically depicts the test process for observing the cylinders and PRD after being heated by fire and then sprayed with water and evaluation of the influences on the strength of cylinders.