

Validation of the Localized Fire Test Method for On-Board Hydrogen Storage Systems

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ABSTRACT

The localized fire test provided in the Global Technical Regulation for Hydrogen Fuel Cell Vehicles gives two separate test methods: the 'generic installation test - Method 1' and the 'specific vehicle installation test - Method 2'. Vehicle manufacturers are required to apply either of the two methods. Focused on Method 2, the present study was conducted to determine the characteristics and validity of Method 2. Test results under identical burner flame temperature conditions and the effects of cylinder protection covers made of different materials were compared between Method 1 and Method 2.

The following results were obtained: (1) Methods 1 and 2 produced nearly identical results when the minimum temperature profile in the GTR test procedure was followed in both cases. (2) A steel protection cover on the cylinder significantly lowered cylinder surface temperatures during the fire test until activation of the thermal pressure relief device (TPRD). (3) A thermoplastic cover on the cylinder melted during the fire test and produced an engulfing pool fire during the localized fire portion of the test that accelerated activation of the TPRD. Since the advantage of early TPRD is highly dependent on where and how the pool fire is generated by the melting thermoplastic material.

CITATION: Tamura, Y., Takeuchi, M., Maeda, K., Ohtsuka, N. et al., "Validation of the Localized Fire Test Method for On-Board Hydrogen Storage Systems," *SAE Int. J. Passeng. Cars - Mech. Syst.* 7(3):2014, doi:10.4271/2014-01-0421.

INTRODUCTION

For preventing on-board compressed gas cylinders from rupturing, a thermal pressure relief device (TPRD) is installed to release the gas from the cylinder to the atmosphere upon detection of abnormal heat in case of a vehicle fire. For the cylinders of compressed natural gas vehicles (NGV), the engulfing fire test [1] has been established to evaluate the safety of those cylinders in fire accidents.

In-service failure of the NGV cylinders during the past decade [2] showed that the majority of fire incidents occurred on storage systems that did not utilize properly designed TPRD, and the remainder resulted when TPRD did not respond to protect the cylinder due to the lack of adequate heat exposure on the TPRD even though the localized fire was able to degrade the cylinder wall and eventually cause the cylinder to burst. However, localized fire exposure has not been addressed in existing standards[3]. Consequently, an localized fire test was introduced to improve safety in the UN Global Technical Regulation for Hydrogen Fuel Cell Vehicles (HFCV gtr)[3]. The test conditions are based on information derived

from actual vehicle fire tests which were conducted by the Japan Automobile Research Institute and US automobile manufacturers [2].

This test in HFCV gtr provides two different test methods - the 'generic installation test - Method 1', which is conducted in cylinder-alone conditions, and the 'specific vehicle installation test - Method 2', which involves a cylinder combined with a protective device and with the various vehicle components and hydrogen storage system that are influential in flame propagation[3]. Vehicle manufacturers are required to apply either of these two test methods.

Regarding Method 1, research has been conducted to determine the effects of intumescent paint coating and epoxy coating on the protection of the cylinder from a localized fire[4] and the effects of pressure mediums and filling pressure on TPRD activation time[5], and to compare test results between the localized and engulfing fire tests[6]. However, there has not been any research published to validate the Test Method 2, while it is vitally important to verify equivalent performance of Method 1 and Method 2.



One existing test method that has resemblance to Method 2 is the fire resistance test of fuel tanks made of a plastic material described in UN/ECE Regulation No.34, Annex 5, Section 5.0[6] (see Figure 1). This test method, like Method 2, involves a fuel tank combined with a protective device and with the various vehicle components and hydrogen storage system that are influential on flame propagation. There are, however, many differences between this test and Method 2, such as in the type of fuel used as fire source, time of exposure to flame, and the distance from the fire source to the tank.



Figure 1. The standard fire exposure test of plastic fuel tanks described in ECE R34, Annex 5 Section 5.0

To determine the characteristics of Method 2 and to evaluate its validity, the present study compared the test results of Method 2 with those of Method 1 thermocouple temperatures of burner flames and investigated the effects of cylinder protection covers made of different materials.

TEST METHOD

Figure 2 shows the diagram of the test method of the localized fire test described in the September 2013 edition of HFCV gtr [3].

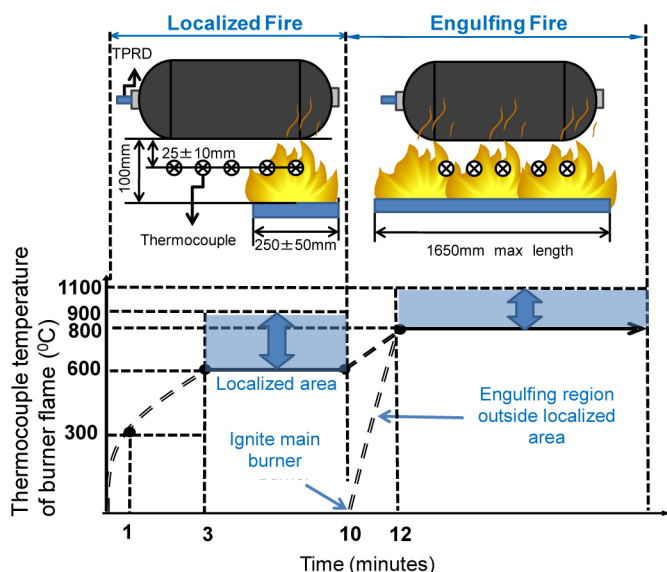


Figure 2. Localized fire test method [3]

A localized fire was applied for the first 10 minutes on the cylinder's far side from TPRD. The horizontal spread of the localized fire measured 250 ± 50 mm. The thermocouple temperatures in the localized fire area rose above 600°C (but below 900°C) during the first 3 minutes, and were maintained in the 600 – 900°C range thereafter. At 10 minutes after the test start, the localized fire was replaced by an engulfing fire stretching along the entire length of the cylinder. The temperatures in the localized-engulfing fire region rose above 800°C (below $1,100^\circ\text{C}$) in the 10–12 minutes period. The testing time in the present study is 700 second (13 minute 10 second). Thermocouple temperatures of burner flame in the present study are defined as the temperature readings of thermocouples installed 25 ± 10 mm below the bottom of the fuel cylinder and the fuel storage system.

Figure 3 shows the dimensions of the propane gas burner used in the present study. The primary characteristic of this burner is the use of burner ports made of silica fiber cloth (continuous heat resistance temperature: $1,000^\circ\text{C}$; thickness: 0.81 mm; weight: 807 g/m²) which ejects propane gas from the plethora of gaps that exist among the silica fibers, enabling the uniform heating that is required by the localized fire test [6]. The propane gas flow rate was measured by a mass flow meter.

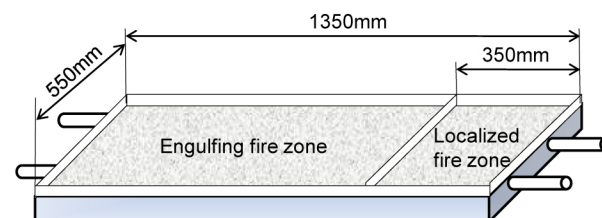


Figure 3. Propane burner for localized fire test [6].

Table 1. Test conditions

Test No.	Test method	Heating condition
1	Cylinder alone (Generic installation test – Method 1)	Propane gas flow rate is regulated to maintain the minimum temperature profile as defined in the GTR.
2-1	On-board cylinder without cover (Specific vehicle installation test – Method 2)	Propane gas flow rate is regulated to maintain the minimum temperature profile as defined in the GTR.
2-2	On-board cylinder without cover (Modified Method 2)	The same propane gas flow rate as the Test 1 flow rate pattern shown in Figure 12.
3-1	On-board cylinder with steel cover (Method 2)	Propane gas flow rate is regulated to maintain the minimum temperature profile as defined in the GTR.
3-2	On-board cylinder with steel cover (Modified Method 2)	The same propane gas flow rate as the Test 1 flow rate pattern shown in Figure 12.
4-1	On-board cylinder with polypropylene undercover (Method 2)	Propane gas flow rate is regulated to maintain the minimum temperature profile as defined in the GTR.
4-2	On-board cylinder with polypropylene undercover (Modified Method 2)	The same propane gas flow rate as the Test 1 flow rate pattern shown in Figure 12.

The test cylinder was made of carbon fiber reinforced polymer, had an aluminum liner, and measured 796 mm in length, 273 mm in diameter, and 28 liters in volume. The test cylinder was not filled with gas to avoid rupture risks and to more accurately examine the effects of test conditions such as propane gas flow rate, the thermocouple temperature of burner flame, and cylinder surface temperature.

Table 1 shows the test conditions applied in the present study.

Figure 4 shows the photographic view of the Test 1 setup before the burner ignition.

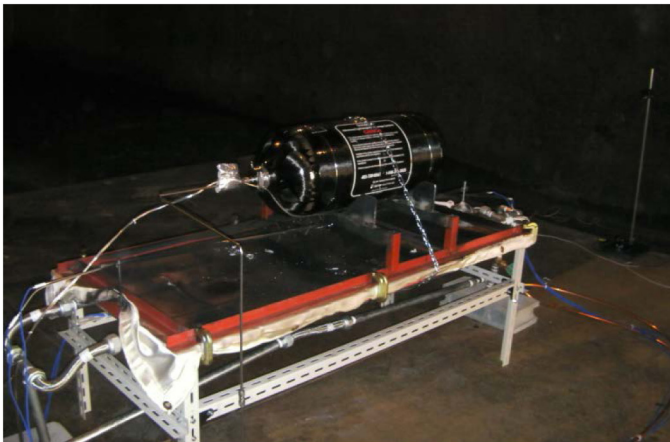


Figure 4. Test 1 setup before burner ignition

Tests 2~4 had a cylinder installed on a vehicle body in accordance with the specific vehicle installation test - Method 2, with a localized fire produced by a propane burner.

In Test 2, although the cylinder was installed on a vehicle body, there was no cylinder protection cover (Figure 6). In Test 3, however, the cylinder was enclosed completely by a steel cover (Figure 7) of a 0.5 mm sheet thickness. In Test 4, the cylinder had a sheet-shaped propylene cover of a 4.5 mm thickness (Figure 8).

Side view

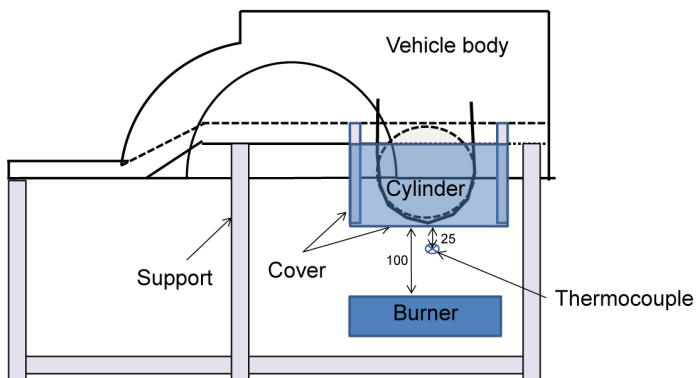


Figure 5

Rear view

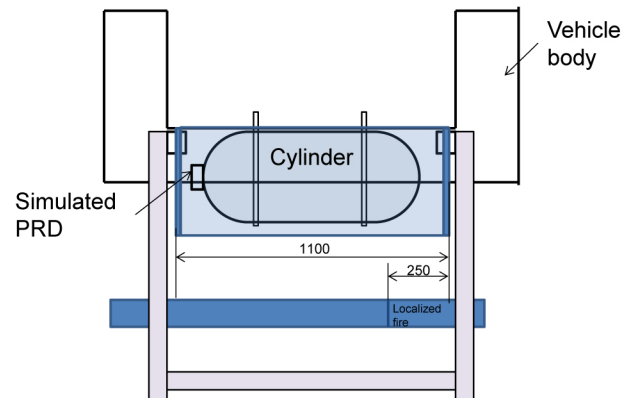


Figure 5. (cont.) Diagram of the Method-2 test setup

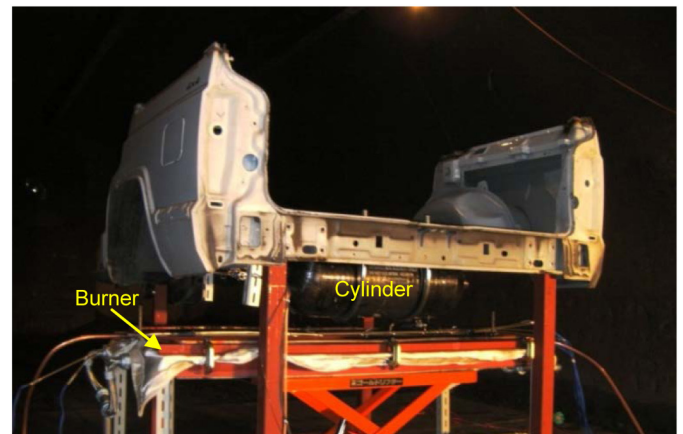


Figure 6. Test 2 setup before burner ignition



Figure 7. Test 3 setup before burner ignition

Tests 2-1, 3-1, and 4-1 are verifications of the test procedure, the propane gas flow rate is regulated to maintain the minimum temperature profile (Figure 2) as defined in the GTR.