

Investigation of the Allowable Flow Rate of Hydrogen Leakage on Receptacle

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ABSTRACT

In this study, hydrogen was leaked using a nozzle that simulated an actual leak port (with varied materials and diameters), and the possibility of ignition was verified to collect data useful for establishing standards for the allowable flow rate of hydrogen leakage on receptacle. With the flow rate of a hydrogen leak set at 250 mL/h(NTP) (hereinafter mL/h is NTP condition) or less, ignition of leaked hydrogen with an electric spark and a small methane-fueled flame was attempted. The results confirmed that ignition of 200 mL/h of hydrogen was not achieved under tested conditions. In some cases, hydrogen at a flow rate of 250 mL/h was ignited. Tissue paper placed in contact with the flame at a flow rate of 250 mL/h combusted, resulting the flame went out almost immediately. Therefore, it was determined that a hydrogen leak at approximately 200 mL/h that occurred in this test is a very low possibility of ignition or spreading.

INTRODUCTION

The allowable flow rate of leakage from the receptacle of vehicles that use compressed natural gas as fuel is specified as 200 mL/h in North America by ANSI/AGA NGV1-1994, CGA NGV1-M94, and as 200 mL/h in Japan by JASO E203, in accordance with the NGV1 standard. However, the allowable flow rate of leakage for vehicles that use compressed hydrogen gas as fuel is specified as 20 mL/h by SAE J2600 in the United States. In the event that hydrogen leaks from the receptacle, the matter of the highest concern is that leaked hydrogen could be ignited by some ignition source to form a flame and then develop into a fire. The volume of leaked hydrogen that is not ignited through contact with an ignition source has a low level of risk and is an allowable flow rate of leakage. Therefore, we conducted ignition tests while varying the flow rate of hydrogen, diameter of the leak port, and material of the leak port for the purpose of collecting data concerning the standard for the receptacle.

EXPERIMENTAL PROCEDURE

Hydrogen was ejected from a nozzle simulating a leak port at flow rates of 200 mL/h and 250 mL/h. Ignition was attempted with the use of an electric spark and a small methane-fueled flame to check the possibility of ignition.

NOZZLE FORM

The nozzles used for the test are depicted in Table 1. Nozzles simulating the leak port were prepared by opening a hole in 3/8-inch caps sold on the market (Fig. 1). The hatched portion is the channel through which hydrogen gas passes. Nozzle diameter d was set to several sizes within the range of 1.0 mm to 0.03 mm to investigate the influence of flow velocity; furthermore, nozzles made of three types of material (stainless-steel, brass, and nylon) were used to investigate the influence of the material.

Table 1. Nozzle type

Material	Nozzle Diameter, d [mm]
Stainless-Steel	0.03 , 0.16 , 0.5 , 0.7 , 1.0
Brass	0.17 , 0.5 , 0.7 , 1.0
Nylon	0.16 or 0.17 , 0.5 , 0.7 , 1.0

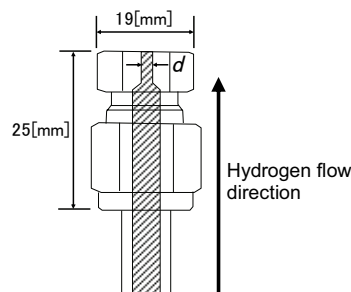


Figure 1. Nozzle form

IGNITION METHOD

Ignition of hydrogen with an electric spark and a pilot flame was attempted. The method for ignition with an electric spark is presented in Fig. 2. The electric spark was generated by placing electrodes at an interval of 1 mm, applying an ignition voltage of 12 kV, and setting the discharge energy to 30 mJ; ignition was performed at 2 mm above the nozzle port. Thermocouples were installed near the nozzle port and at 10 mm above the nozzle port to measure temperatures. A pilot flame was generated by forming a flame of methane gas at a flow rate of 0.4 L/min; then the flame was placed completely in contact with the nozzle port for ignition. Incidentally ignition of a pilot flame did not measure temperature at 10 mm above the nozzle port.

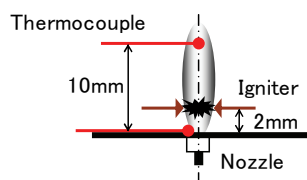


Figure 2. Ignition method of electric spark

SCHEMATIC OF TESTING DIAGRAM

A schematic diagram of the testing apparatus is presented in Fig. 3. The hydrogen flow rate was controlled using a mass-flow controller; the ignition of hydrogen, which is invisible to the naked eye, was detected after visualizing the flame with a Schlieren device and an infrared thermography device.

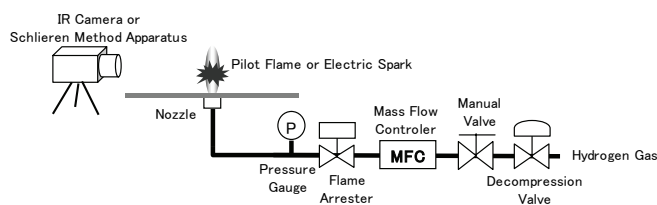


Figure 3. Schematic of testing diagram

RESULT AND DISCUSSION

STAINLESS-STEEL NOZZLE

Results of checking the possibility of ignition with a stainless-steel nozzle are presented in Table 2. Ignition was detected using the Schlieren device. Hydrogen at a flow rate of 200 mL/h was not ignited under any condition. However, hydrogen at a flow rate of 250 mL/h was ignited by electric spark at nozzle diameters of 0.16 mm and 0.5 mm. It was ignited by a pilot flame at any nozzle diameter other than 0.03 mm; therefore, ignition by pilot flame occurred under a larger number of conditions. The duration of the flame when hydrogen was ignited was short (e.g., 4 to 45 s).

Table 2. Ignitionability of stainless steel nozzle

Nozzle diameter [mm]	Electric spark (Distance of 2mm)		Pilot flame (Distance of 0mm)	
	200 [mL/h]	250 [mL/h]	200 [mL/h]	250 [mL/h]
0.03	×	×	×	×
0.16	×	○	×	○
0.5	×	○	×	○
0.7	×	×	×	○
1.0	×	×	×	○

○: Ignition ×: No ignition

Among the six conditions where hydrogen was ignited, the images of ignition by electric spark and pilot flame at a nozzle diameter of 0.5 mm are presented in Figs. 4 and 5. The temperature and hydrogen feed-tubing pressure (hereinafter called "hydrogen pressure") after ignition are indicated in Figs. 6 and 7. The graph is plotted by setting the time of detecting ignition to 0 s. In the case of ignition by electric spark, it could be assumed that the temperature outside the flame was measured because the temperature at a distance of 10 mm from the nozzle port resulted in a very low level of 32 °C (Fig. 6). Therefore, the height of the flame could be estimated as less than 10 mm. Also, in ignitions under other conditions, the temperature at a distance of 10 mm from the nozzle port was 35 °C or less, so it could also be assumed that the height of the flame was less than 10 mm. In this case, the reason for the higher temperature of the nozzle (Fig. 7) was that the nozzle was heated due to the influence of the pilot flame that contacted the nozzle port during ignition.

The hydrogen pressure was 0.04 kPa(Gauge) at a flow rate of 250 mL/h and a nozzle diameter of 0.16 mm, and it was below the lower limit of detection at a nozzle diameter of 0.5 mm or larger. Furthermore, it was observed that the hydrogen pressure rose after the flame went out because water vapor generated by the combustion of hydrogen condensed into drops near the nozzle port and the nozzle port was blocked by the drops of water.

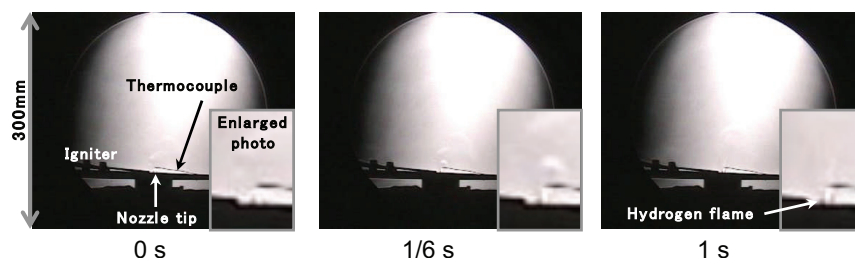


Figure 4. Schlieren image of ignition by electric spark with stainless steel nozzle
(Nozzle diameter: 0.5 mm, Hydrogen flow rate: 250 mL/h)

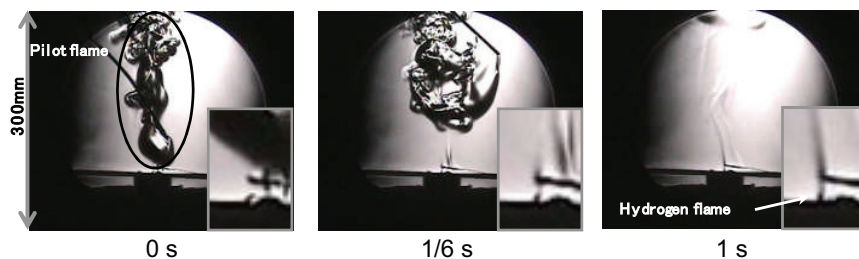


Figure 5. Schlieren image of ignition by pilot flame with stainless steel nozzle
(Nozzle diameter: 0.5 mm, Hydrogen flow rate: 250 mL/h)

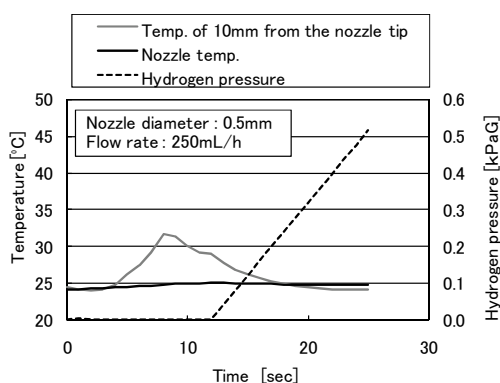


Figure 6. Temperature and pressure curve during the ignition test by electric spark with stainless-steel nozzle
(Flame holding time: 9 s)

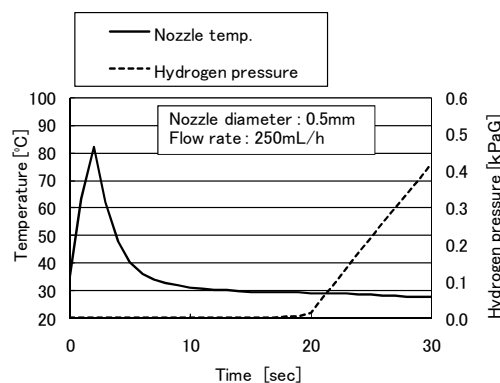


Figure 7. Temperature and pressure curve during the ignition test by pilot flame with stainless-steel nozzle
(Flame holding time: 18 s)

BRASS NOZZLE

Results of checking the possibility of ignition with a brass nozzle are presented in Table 3. Ignition was detected using an infrared thermography device. As was the case with a stainless-steel nozzle, hydrogen at a flow rate of 250 mL/h was ignited by electric spark at nozzle diameters of 0.17 mm and 0.5 mm although hydrogen at a flow rate of 200 mL/h was not ignited under any condition. In contrast, hydrogen was ignited by pilot flame at nozzle diameters of 0.17 mm to 1.0 mm. The flame's duration was 1 to 25 s, which was generally shorter than that with the stainless-steel nozzle.

Table 3. Ignitionability of brass nozzle

Nozzle diameter [mm]	Electric spark (Distance of 2mm)		Pilot flame (Distance of 0mm)	
	200 [mL/h]	250 [mL/h]	200 [mL/h]	250 [mL/h]
0.17	×	○	×	○
0.5	×	○	×	○
0.7	×	×	×	○
1.0	×	×	×	○

○: Ignition ×: No ignition

Hydrogen ignited under six conditions. Infrared temperature images of ignitions by an electric spark and a pilot flame at a nozzle diameter of 0.17 mm are presented in Figs. 8 and 9; the temperatures and