SGS 6 - 19

Examination of the safety of rooftop gas cylinders against heating by direct sunlight

National Traffic Safety and Environment Lab.

1. Background and purpose

In a container that stores gas under high pressure, the control of the temperature is generally important. This is because, as the container warms up and the internal pressure rises, the risk of the gas container bursting increases. Therefore, the Law Concerning the Safety of High-Pressure Gases requires that gas containers be provided with a sunshade during their storage and transportation.

Similarly, regulations concerning motor vehicles loaded with high-pressure gas containers require a sunshade. On the other hand, concerning the risk of heating gas containers, the relationship between the increase in internal pressure and the strength and durability of the gas container is important. JARI has conducted researches on this relationship between the internal pressure and the strength and durability of the gas container [1]-[4]. Further, 85°C is generally considered as one of the maximum admissible gas temperatures for tests for validating the design of a container [5]. "The Technical Regulation on Compressed Hydrogen Fuel Containers for Motor Vehicles JARI S001 (2004)" seems to have been established with the above points in mind.

The purpose of the present study was to check the effectiveness of the currently prescribed sunshade. Therefore, assuming a case where the bus was parked in hot season during the daytime in the open air, where it was likely to be heated to a high temperature, we surveyed thermal conditions in actual circumstances, and checked whether the surface temperature of the gas cylinders would not exceed 85°C, the limit defined for the container design validation test. If the temperature of the surface of the cylinders heated by sunlight would not exceed this limit of 85°C, the current regulations would be valid in terms of heating by sunlight while the bus was parked.

It should be noted that this study contemplated only the question of heating by sunlight, and not such other questions as the influence of heating during the filling of hydrogen.

2. Method of examination

The test consisted in placing a simulated experimental sunshade in a place exposed to direct sunlight in the premises of the Institute (Chofu, Tokyo) in the hot season of 2006, i.e., from mid-August to late September, everyday from 10:00 to 17:00, and conducting measurements. Among the results of measurement, we looked at cases where the outside air temperature exceeded 35°C and examined their maximum temperature.

2.1 Subjects examined

The examination was done on the subjects (I) to (III) below:

(I) Examination of the maximum temperature of the surface of the gas cylinders when they were protected from sunlight and the maximum outside air temperature; Examined to what extent the temperature increased in actual situation.

(II) Examination of increase in temperature with and without the sunshade ; Examined whether the sunshade was actually effective.

(III) Examination of the influence of sunlight reflectivity on increase in temperature depending on painting color; It is possible that the reflectivity of sunlight of the sunshade change depending on its painting color and that this influence the increase in temperature in the sunshade. For this reason, we prepared two sunshades, one in white with a high reflectivity (77%) and the other in black with a low reflectivity (1%) and checked for the influence of painting color on the increase in temperature.

2.2 Experimental setup

Fig.1 show the experimental setup. In Fig.1(a), we made the sunshade of FRP (fiber reinforced plastics), material usually used in bus rooftops, and painted it in white, the color most unaffected by sunlight. Further, we provided the sunshade with two vents as shown in Fig.1(a), because we expected that the bus rooftop is provided with vents to prevent the accumulation of hydrogen upon leakage (and the same vents on the opposite side).

We installed three gas cylinders inside the sunshade and one outside the sunshade. They are installed at a height of 50 cm horizontally in a two-level structure of wood pallets to avoid the influence of radiation heat from the ground.

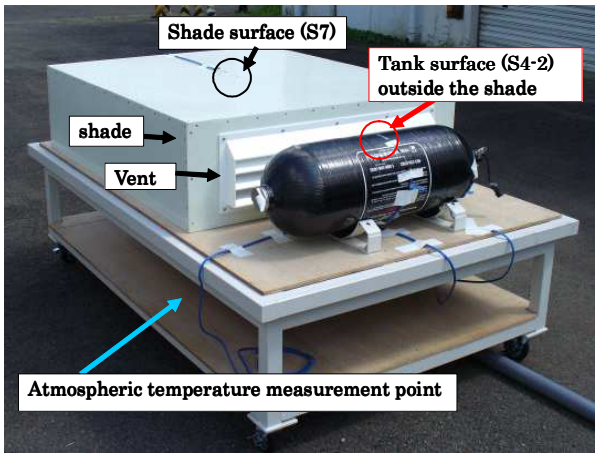
We used a thermocouple to measure the temperature. The points of measurement were, as shown in Fig.2, the bottom, the center, and around the main check valve (S1-1 to S4-3) of each gas cylinder; the center of the outer surface (S7) and the center of the inner surface (S6) of the sunshade; the outside air temperature; and the atmosphere temperature in the sunshade (the temperature around the gas cylinder: S5). The outside air was defined as the space present under the platform on which the gas cylinders were installed, as shown in Fig.1(a).

Further, we prepared two boxes made of FRP as shown in Fig.3 to examine the effects of the painting colors of the sunshade and installed them in a place exposed to direct sunlight so that we could confirm difference of temperatures depending on the surface color in the same environment. The reflectivity measured of the two boxes were 77% for the white one and 1% for the black one.

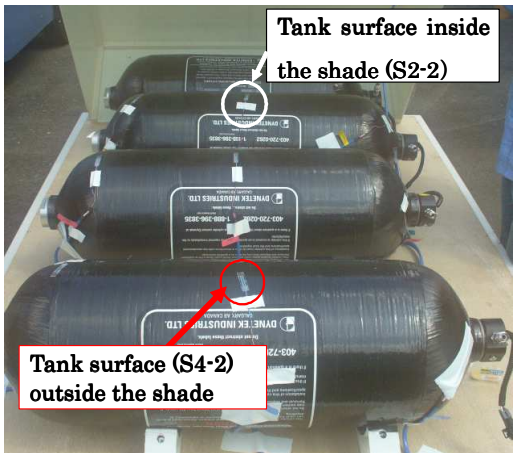
3. Results of examination

3.1 Validation of measurement data

Considering the weather conditions, the increase in temperature, the sunshine conditions of the test site during the hot season of 2006, the number of data we could actually use in the examination was eight (eight days). The following discussion is based on the data from such eight days. Table 1 shows the weather conditions and the maximum temperatures of the eight days.



(a) Outline



(b) inside shade

Fig.1 Dummy shade test device

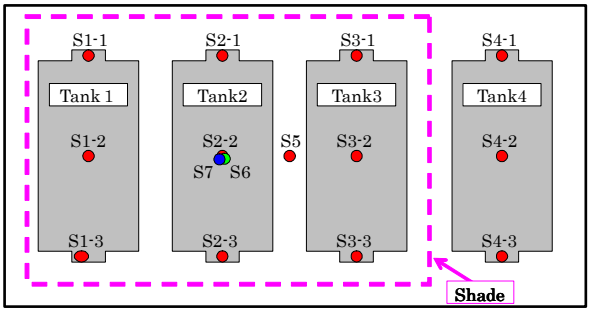


Fig.2 Temperature measurement point

Fig.3 Boxes for comparing a temperature rise by the reflectance difference

Table 2 shows the maximum temperatures of the June-September period in recorded history in two cities of the country, Chofu, Tokyo and Naha, Okinawa[6]. Tables 1and 2 suggest that the maximum temperature recorded during the present experiment in the hot season of 2006 was not significantly lower than the maximum temperatures in recorded history.

With the temperature sensors installed on cylinders in the sunshade (1-1) to (3-3), we examined the difference in temperature from that of the central sensor (2-2) and found that the difference was within ±2°C. Therefore, we assumed that the difference in temperature among the cylinders in the sunshade depending on their location was within ±2°C and from then on regarded the temperature of the sensor (2-2) as representative of the surface temperatures of the cylinders in the sunshade.

Fig.4 shows an example of the measurements of the temperatures of the outside air, the outer surface of the sunshade, the atmosphere in the sunshade, the center of the surface of the cylinder trunk (without sunshade), and the center of the surface of the cylinder trunk (with sunshade).

3.2 Examination of the maximum temperature on the surface of the cylinder with sunshade and the maximum atmosphere temperature

Fig.4 shows that the atmosphere temperatures and the temperatures on the surface of the gas cylinder in the sunshade were almost the same. When the maximum outside air temperature was about 38°C, the maximum temperature of the surface of the gas cylinder and the atmosphere in the sunshade was about 42°C.

Fig.5 shows the temperatures on the surface of the gas cylinder with sunshade deducted from Fig.4. It shows that the maximum temperature on the surface of the gas cylinder was about 47°C, falling much below 85°C, the temperature of the design validation test.

This shows that, in the range of temperatures measured in this experiment, the increase in temperature during parking does not pose any problem.

Table 1 Maximum temperature of dates of measurement

Day (2006)	weather	Tokyo (Fuchu) [℃] *1	Measurement place [℃]
8/18	Fine	32.8	38.9
8/21	Fine or sometimes cloudy	33.0	39.1
8/29	Fine or sometimes cloudy	32.9	42.5
8/31	Fine	31.9	37.2
9/2	Fine or sometimes cloudy	29.7	35.3
9/3	Fine or sometimes cloudy	31.5	36.8
9/4	Fine or sometimes cloudy	30.9	36.8
9/5	Fine	34.6	40.1

Table 2 Maximum temperatures in record history

Month	Tokyo (Fuchu) [℃]*1	Okinawa (Naha) [℃]
June	36.7 (2005/6/28)	34.1 (2001/6/28)
July	38.6 (1997/7/6)	35.0 (2006/7/6)
August	38.9 (1996/8/15)	35.6 (2001/8/9)
September	38.5 (1984/9/3)	33.3 (2001/9/5)

*1 : announced by the Meteorological Agency

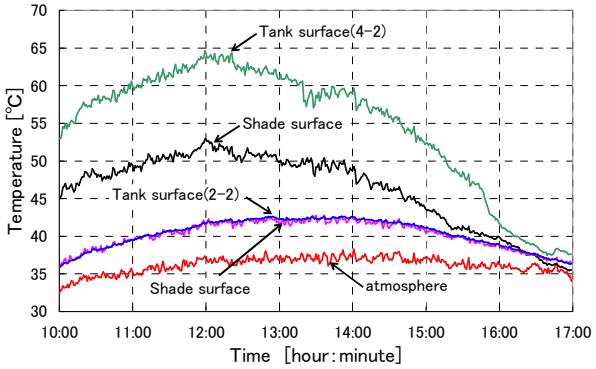


Fig.4 Temperatures on Aug. 18, 2006

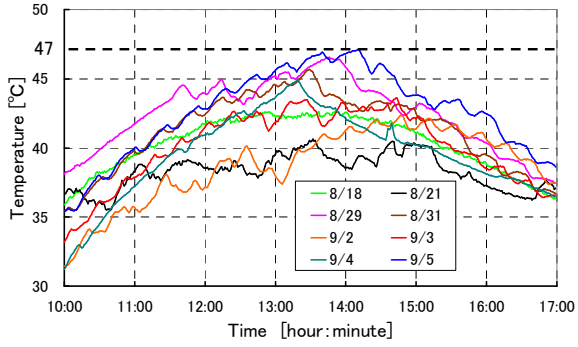


Fig.5 Temperatures on the Tank surface with sunshade

3.3 Examination of increase in temperature with and without sunshade

Fig.4 shows that, without sunshade, the maximum temperature increased to about 64℃.

Fig.6 shows the difference in temperature between the cases with and without sunshade. The maximum difference was about 23℃, which we think indicates that the sunshade was actually effective.

3.4 Influence of the painting color on the increase in temperature

Fig.7 shows the difference in temperature according to the painting colors (white and black) obtained from the measurement of Fig.3. It shows that, with the maximum difference of about 10℃, the painting color of the sunshade actually influenced the temperatures inside. Since the boxes used in the present experiment were almost completely closed without any ventilation, we think that the above results showed the maximum possible difference.

With the above results applied to those of 8-4-2, the temperature on the surface of the gas cylinder would have reached 57℃ at maximum when the sunshade had been painted in black, which, however, would still have been below 85℃, the temperature of the design validation test.

4. Summary

In the hot season of 2006, from mid-August to late September, we examined various questions relating to the heating of gas cylinders. The results of experiments conducted during the period showed the following:

- The difference in temperature between the cases with and without sunshade was 23℃ at maximum, indicating that the sunshade was actually effective.
- The measurement of the maximum temperatures on the surface of the gas cylinder and of the atmosphere showed that the maximum temperature on the surface of the gas cylinder was about 47℃, falling much below 85℃, the temperature of the design validation test.
- Given the difference in temperature depending on the painting color (white and black), which was about 10℃, the maximum temperature on the surface of the gas cylinder might increase to 57℃ at maximum, which again, however, would fall below 85℃, the temperature of the design validation test.

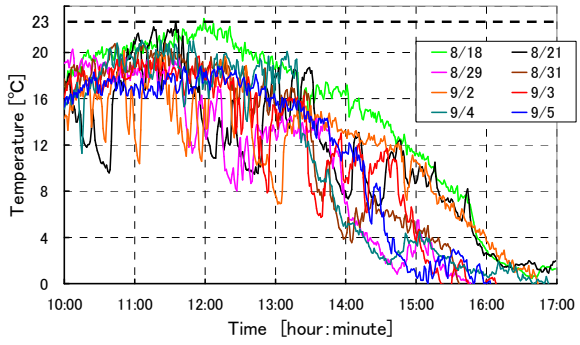


Fig.6 Difference in temperature between the cases with and without sunshade

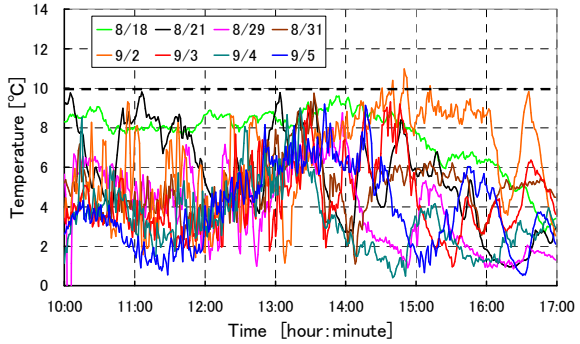


Fig.7 Difference in temperature depending on the painting colors (white and black)

<References>

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