# DEMONSTRATION STUDY OF A 70MPA HYDORGEN REFUELING STATION

Hisatoshi Ito

Mikio Nakagawa

Masakatsu Morioki

Koji Okada

Yoshito Umeda

Toho Gas Co., Ltd.

Japan

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## Abstract

Automobile manufacturers have been proceeding with conversion to 70 MPa storage pressure for fuel-cell vehicles, in order to extend their cruising range, and therefore, technology development enabling hydrogen dispensing to be made possible at 70 MPa is also desired for hydrogen refueling stations. With the objective of verifying the durability of the hydrogen refueling station as a total system and studying cost-reduction methods, in 2008 Toho Gas received a commissioned project from the New Energy and Industrial Technology Development Organization (hereafter, “NEDO”). We constructed a 70 MPa hydrogen refueling station in our Technical Research Institute in February 2010.

The three main features of the 70 MPa hydrogen refueling station are as follows:

1) Configuration using the latest domestic technology, such as a dispenser and compressor that were developed under NEDO’s “Fundamental Technology Development Project of Safe Hydrogen Utilization (2003–2007), etc.”
2) The compressor has a compression capacity of 300 Normal $m^3$/h, the highest level in Japan, enabling evaluation tests to be conducted in which commercialized hydrogen refueling stations to be widely established in and after 2015 are assumed.
3) Capability of performing direct dispensing from the compressor without passing through an accumulator, and differential-pressure refueling using accumulators.

With this hydrogen refueling station, we have been tackling the following three major problems in technology development:

1) Durability assessment of the hydrogen refueling station component equipment
2) Development of direct dispensing system
3) Establishment of hydrogen cooling technology

We started dispensing tests in March 2010 and undertook repetitive dispensing equivalent to one year in advance of the period of proliferation to demonstrate one-year maintenance-free for the compressor, accumulators, pre-cooler, dispenser, and valves. Moreover, we conducted dispensing tests to fuel-cell vehicles and high-flow rate tests for determining the equipment capacity to realize an instantaneous maximum flow rate of approximately 3,000 g/min, and also verified that the hydrogen temperature can be held to –20°C or lower. For the development of the direct dispensing method, we verified that direct dispensing can be safely performed as specified by the control procedure.

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## 1. Background: Development of our hydrogen refueling station

### 1.1 35 MPa hydrogen refueling station operated by ourselves

Toho Gas originally constructed a 35 MPa hydrogen refueling station in our Technical Research Institute (Tokai City, Aichi Prefecture) in 2002, the first as a private energy supplier. Prior to this time, we had verified the superiority of city gas over other fuels (in terms of hydrogen production efficiency, for example), developed dispensing technology, verified its safety, and established related engineering technologies. Furthermore, the hydrogen refueling station supplied fuel hydrogen to the fuel-cell vehicles, etc. that Toho Gas, Aichi Prefecture, Nagoya City, etc. have introduced, enabling us to identify the problems encountered in actual operations and proceed with development towards resolving such problems.

### 1.2 35 MPa hydrogen refueling station under the JHFC project

We participated in the Japan Hydrogen & Fuel Cell Development Project (JHFC) fostered by the Ministry of Economy, Trade and Industry of Japan, and constructed the "JHFC Expo2005 Hydrogen Refueling Station/Setominami" (dispensing pressure: 35 MPa, 2005) and the "JHFC Chubu Centrair Hydrogen Refueling Station" (dispensing pressure: 35 MPa, 2006, Photo. 1).

With the "JHFC Expo2005 Hydrogen Refueling Station/Setominami," the 35 MPa hydrogen refueling station supplied fuel hydrogen to eight fuel-cell buses introduced to transport visitors and support the local bus service, thereby enabling us to acquire demonstration data in dispensing large volumes of hydrogen.

With the "JHFC Chubu Centrair Hydrogen Refueling Station," we conducted a demonstration test of the 35 MPa hydrogen refueling station from July 2006 to March 2011. The four main features of the hydrogen refueling station are as follows:

1) Capable of supplying fuel hydrogen to fuel-cell buses used as ramp buses (passenger transportation buses) in the airport.
2) The largest hydrogen refueling capacity in Japan (100 Normal $m^3$/h).
3) Capable of combining steelmaking byproduct hydrogen in an auxiliary manner in addition to hydrogen produced using city gas as raw material.
4) Hydrogen refueling station of the highest operating rate in Japan (achieving an accumulated hydrogen dispensing volume of 10,000 kg in December 2008, the first in Japan, and achieved an accumulated volume of 14,134 kg at the end of March 2011; Fig. 1).

Photo. 1 Chubu Centrair Hydrogen Refueling Station and a fuel-cell bus

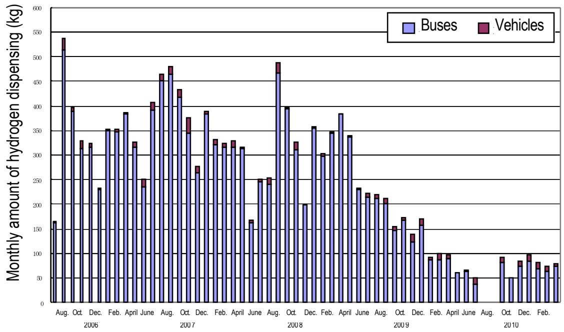


Fig. 1 Monthly dispensing amount at Chubu Centrair Hydrogen Refueling Station

**1.3 70 MPa hydrogen refueling station under the NEDO project**

Automobile manufacturers have been proceeding with conversion to 70 MPa refueling to extend the cruising range of fuel-cell vehicles, and for hydrogen refueling stations, the development of technology capable of dispensing hydrogen at 70 MPa has also been anticipated. Among the problems facing hydrogen refueling stations are that the durability of the component equipment for hydrogen refueling stations has not yet been verified, and that the construction costs for a hydrogen refueling station can be as expensive as $6\times10^8$ yen(1) (not including the cost of the hydrogen reformer). Therefore, for the purpose of verifying the durability of the hydrogen refueling station as a total system and studying cost reduction methods, in 2008 we received a commissioned project from the New Energy and Industrial Technology Development Organization (NEDO). We constructed the 70 MPa hydrogen refueling station in our Technical Research Laboratory in February 2010 (Photo. 2, Fig. 2). This hydrogen refueling station represented the first attempt to assemble individual items of equipment developed by NEDO as a working station, and to evaluate their durability by operating them in conjunction with each other.

In this paper, we describe the features of the 70 MPa hydrogen refueling station that we constructed, introduce the technical problems encountered, and report the results of tests conducted up to this time.


Photo. 2 Appearance of the 70 MPa hydrogen refueling station in Toho Gas Technical Research Institute

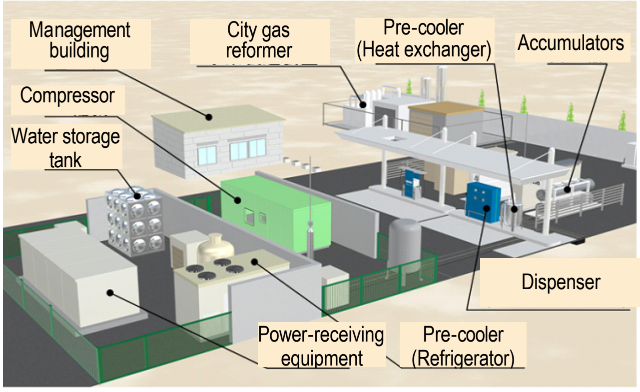


Fig. 2 General schematic diagram of the 70 MPa hydrogen refueling station

## 2. Aims

With the 70 MPa hydrogen refueling station at our Technical Research Institute, following three major technological developments were conducted.

### 2.1 Durability assessment of hydrogen refueling station component equipment

Repetitive dispensing tests were conducted using the test dispensing vessels to verify the durability of the hydrogen refueling station component equipment, including the compressor, accumulators, and valves that have been separately developed up to this time, when they are operated in conjunction with each other as a system in an actual working environment. (The target is no maintenance for one year.)

### 2.2 Development of direct dispensing method

The accumulators have a significant cost impact among the hydrogen refueling station's component elements. Conversion of the accumulators to those with a smaller capacity, or a reduction in their number results in significant cost reduction for the overall hydrogen refueling station; however, this also reduces the station's dispensing capacity (number of vehicles to which hydrogen can be dispensed). As measures for compensating this, we studied direct dispensing from the compressor to tackle the development of such a dispensing control method enabling dispensing to be performed without passing through an accumulator.

We conducted a comparison verification of multiple flow control methods, evaluation of the effect of pulsation from the compressor on dispensing, etc. to verify the feasibility of the direct dispensing method, which can eliminate use of expensive accumulators.

### 2.3 Establishment of hydrogen cooling technology

When hydrogen is dispensed at a pressure of 70 MPa, technology for pre-cooling the hydrogen to be dispensed is required to prevent the temperature of the tank installed in the fuel-cell vehicle from rising excessively. Therefore, we conducted dispensing tests making use of a test vehicle equipped with the function of measuring the temperature inside the vehicle-mounted tank, etc. under conditions where the hydrogen dispensing flow rate, etc. are changed, to evaluate the basic performance of the pre-cooler and aiming at the establishment of effective hydrogen cooling technology.

## 3. Methods

### 3.1 Overview of the 70 MPa hydrogen refueling station

#### 3.1.1 Features of the equipment

1) Configuration using the latest domestic technology, such as the dispenser and compressor developed under NEDO's "Fundamental Technology Development Project of Safe Hydrogen Utilization (2003–2007), etc."
2) The compressor has a compression capacity of 300 Normal $m^3$/h, the highest capacity in Japan, enabling evaluation tests to be conducted in which commercialized hydrogen refueling stations widely established in and after 2015(2) are assumed.
3) Capability of performing direct dispensing from the compressor without passing through an accumulator, and differential-pressure dispensing using accumulators.

#### 3.1.2 Main specifications of the hydrogen refueling station

1) Hydrogen refueling station overall

As shown in Fig. 3, the system of the 70 MPa hydrogen refueling station consists of the compressor, accumulators, dispenser, pre-cooler, and test dispensing vessels for conducting repetitive dispensing tests efficiently, as well as the reformer, which produces the hydrogen (purity: 99.99% or more) from natural gas by steam reforming. Moreover, to conduct the repetitive dispensing test efficiently, the system incorporates test dispensing vessels and a hydrogen recovery line that depressurizes the hydrogen after dispensing for re-use. Table 1 shows the main specifications.

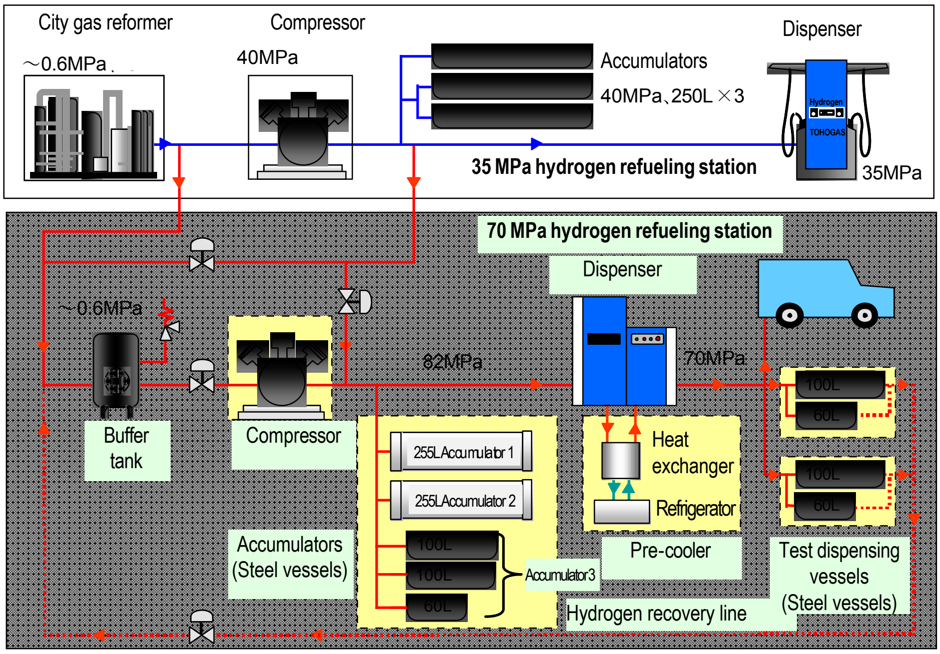


Fig. 3 System configuration of hydrogen refueling stations

Table 1 Main specification of hydrogen refueling station

| Equipment | Specifications |
|---|---|
| Reformer (also used by the existing 35 MPa hydrogen refueling station) | Raw material: Natural gas (city gas). Production method: Steam reforming, PSA purification. Purity: Volume fraction of 99.99% or higher. Production capacity: 40 Normal $m^3$/h (3.6 kg/h). |
| Compressor | Working pressure: 82 MPa. Discharge rate: 300 Normal $m^3$/h (27 kg/h). |
| Accumulators | Working pressure: 82 MPa. Volume: 255L × 2 vessels, 100L × 2 vessels, 60L × 1 vessel. |
| Dispenser | Working pressure (dispensing side): 70 MPa. |
| Pre-cooler | Hydrogen temperature (at dispensing nozzle outlet): –20°C. |
| Test dispensing vessels | Working pressure: 70 MPa. Volume: 100L × 2 vessels, 60L × 2 vessels. |

2) Compressor

The equipment developed by Hitachi Plant Technologies, Ltd., a product of the NEDO project "Fundamental Technology Development of Safe Hydrogen Utilization, etc.," was utilized. It compresses hydrogen of approx. 0.6 MPa supplied from the reformer or through the hydrogen recovery line from the test dispensing vessels (steel vessels) to 82 MPa. Its discharge gas flow rate is 300 Normal $m^3/h$ (27 kg/h), giving the compressor the highest compression capacity in Japan, based on the assumed specifications of commercialized hydrogen refueling stations to be widely established in and after 2015.

3) Accumulators

Vessels incorporating SNCM439 reduced-strength material, a product of the NEDO project "Common Ground Projection Project of Hydrogen Society Construction" were utilized. The accumulators consist of two 255L flanged accumulators, two 100L cylinder-type accumulators, and one 60L cylinder-type accumulator. They are divided into three banks: two banks each comprising one 255L accumulator, and one bank comprising two 100L accumulators and one 60L accumulator.

4) Dispenser

The dispenser capable of dispensing at 70 MPa and developed by Tokico Technology Ltd, a product of the NEDO project "Fundamental Technology Development of Safe Hydrogen Utilization, etc.," was adopted. The working pressure during dispensing is 70 MPa.

5) Pre-cooler

The pre-cooler was installed as a cooling control system that prevents the temperature rising during dispensing of hydrogen gas. We selected the pre-cooler of Taiyo Nippon Sanso Corporation, which was improved, based on the knowledge of the past demonstration test in use in Japan. It functions to ensure that the hydrogen temperature is –20°C or lower at the dispensing nozzle outlet.

## 3.2 Development system

The development system of the NEDO project "Research and Development Concerning Technical Development of Hydrogen Production, Transportation, and Storage Systems, etc., System Technology Development, and the System Technology of Hydrogen Refueling Station Equipment Compatible with 70 MPa-level Hydrogen Gas Dispensing" (2008–2011) is shown in Fig. 4. Toho Gas is responsible for the design, construction, and durability assessment of the hydrogen refueling station.

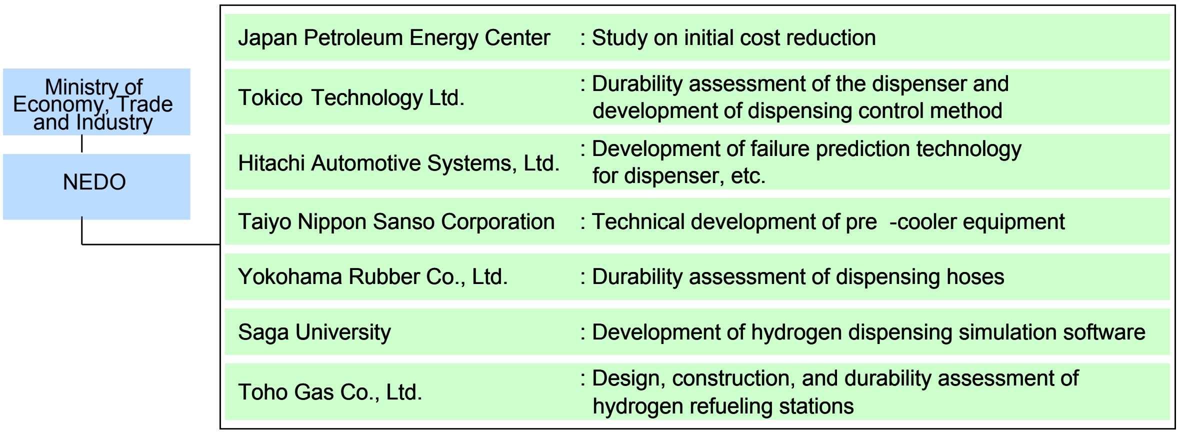


Fig. 4 Development system in the NEDO project and main fields for which respective companies are responsible

# 4. Results

## 4.1 Dispensing control method for differential-pressure dispensing

Table 2 shows the main measurement values when differential-pressure dispensing to the test dispensing vessel is performed using the accumulators. Also, Fig. 5 shows an example of the results of differential-pressure dispensing.

Table 2 Main measurement values in the dispensing test

| Measurement value | Measurement point |
|---|---|
| Test dispensing vessel pressure [MPa] | Inlet of test dispensing vessel |
| Hydrogen temperature [°C] | Dispenser outlet |
| Dispensing flow rate [g/min] | Dispenser inside |
| Degree of opening of valve [%] | Dispenser inside |

After starting dispensing, hydrogen was discharged by switching the accumulators (which are divided into three groups) in turn and dispensing was controlled by a regulating valve in the dispenser so that the pressure rising rate of the test dispensing vessel was kept constant. As a result, the dispensing pressure reached 70 MPa, at which the vessel is fully filled with hydrogen, in approximately 350 seconds (dispensing speed: approx. 1,000 g/min). Moreover, the hydrogen cooling temperature reached –20°C (on average) or lower at the dispensing nozzle outlet.

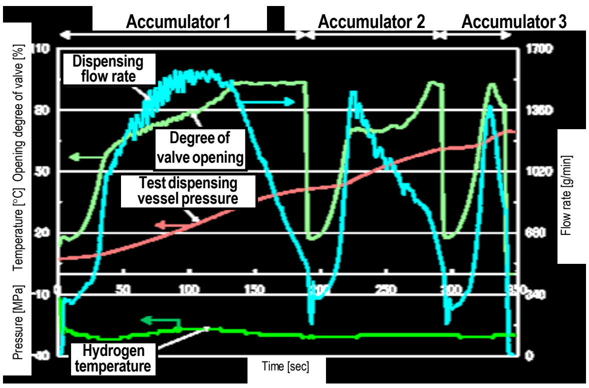


Fig. 5 Dispensing test results

Repetitive dispensing tests were conducted using this dispensing control method to make a durability assessment of the hydrogen refueling station, as described in 2.5.2.

### 4.2 Durability assessment results

Repetitive dispensing tests were conducted using the test dispensing vessel to verify the durability (target: no maintenance for one year) of the hydrogen refueling station component equipment, including the compressor, accumulators, and valves that have been separately developed up to this time, by operating them in conjunction with each other as a system in an actual working environment. (The evaluation items for each device are shown in Table 3.)

Table 3 Evaluation items for the component equipment

| Equipment | Evaluation item |
|---|---|
| Compressor | Durability, efficiency, power consumption at unload, starting characteristics, hydrogen brittleness |
| Accumulators | Durability (endurance section, packing) |
| Pre-cooler | Durability, cooling performance (temperature) |
| Dispenser | Durability (endurance section, sealing members), flow control |
| Emergency detachable coupling | Durability (endurance section, sealing members) |
| Dispensing hose | Durability (endurance section, sealing members) |
| Valves | Durability (endurance section, sealing members) |
| System | Efficiency, durability |

For the number of repetitive dispensing times, dispensing equivalent to a period of one year in advance of the period of proliferation of the hydrogen refueling stations (estimation based on the operating results of JHFC: 0.9 time/day $\times$ 300 days/year = 270 times/year). The compressor, accumulators, pre-cooler, dispenser, and valves were checked by periodic inspection to ensure that there was no performance degradation, damage, etc. to them, demonstrating that one-year no-maintenance is possible. For example, the results of Penetrant Testing (PT) of the accumulators are shown in Fig. 6. There was no damage on the inner surface of accumulators after dispensing 270 times equivalent to the dispensing number during a period of one year advance of the beginning of proliferation of the hydrogen refueling stations.

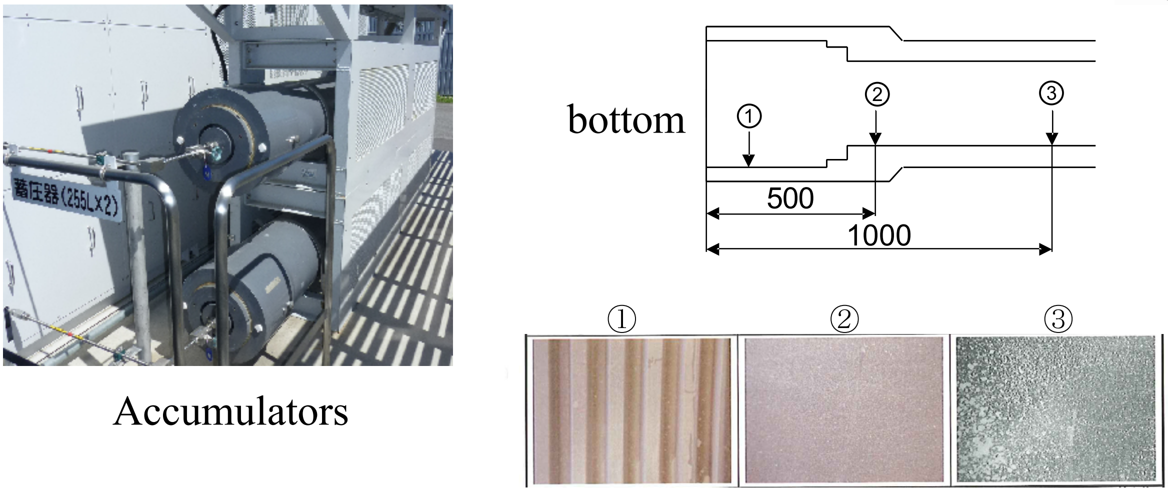


Fig.6 Results of PT of the accumulators

However, there occurred some hydrogen leakage from the emergency detachable coupling and dispensing hose. Moreover, in the pre-cooler, as the number of dispensing times increased, moisture condensed in the heat exchanger, resulting in an increasing loss of pressure. Currently, countermeasures against this phenomenon are under review by the relevant company.

At present, we are accumulating repetitive dispensing test data assuming operating conditions in the initial period of proliferation of hydrogen refueling stations in and after 2015, and are proceeding with an evaluation of durability assuming operating conditions at that time.

### 4.3 High-flow rate dispensing test

Dispensing was performed with respect to the test dispensing vessels (pressure before dispensing: 7 MPa, outside air temperature: 12.8°C). After starting dispensing, hydrogen was dispensed with the degree of opening of the regulating valve in the dispenser up to 100% by switching the three groups of accumulators in turn to measure the hydrogen flow rate, pressure, temperature, etc. The results of the high-flow rate dispensing test are shown in Fig. 7.

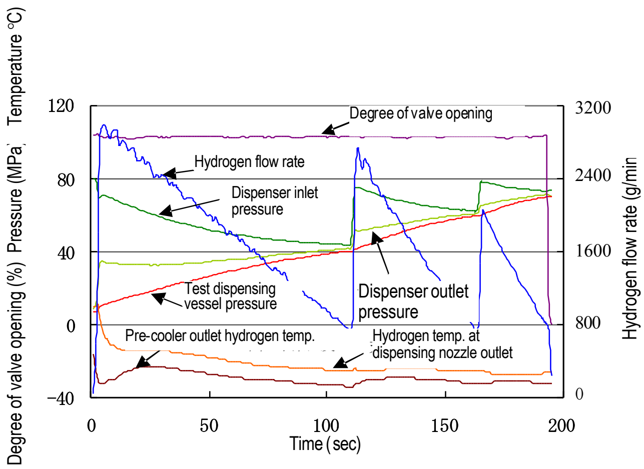


Fig. 7 Results of high-flow rate dispensing test

For dispensing from 7 MPa to 70 MPa, the dispensing time was 195 seconds the amount of dispensing was 5,500 g, the average dispensing flow rate was 1,700 g/min, and the instantaneous maximum flow rate reached approx. 3,000 g/min. The hydrogen cooling temperature was –20°C or lower (on average) at the dispensing nozzle outlet during the high-flow rate dispensing test, confirming that the specification for the hydrogen temperature was met. Moreover, an average dispensing flow rate of 1,700 g/min represents the highest level of dispensing flow rate in Japan, confirming that short-time dispensing close to a target short dispensing time of 3 minutes—the requirement of automobile manufacturers—is possible.

### 4.4 Results of consecutive twice dispensing test

To check the effect of frost forming on the dispensing coupler by hydrogen cooling on dispensing procedures, we conducted a consecutive twice dispensing test in which the dispensing time is twice as long as the dispensing time of single differential pressure dispensing, resulting in conditions where frost is likely to occur. In this consecutive twice dispensing test, we employed a method in which three banks of accumulators in the newly installed 70 MPa hydrogen refueling station and two banks of accumulators in the existing 35 MPa hydrogen refueling station, five banks in total, were used to dispense hydrogen continuously to two test dispensing vessels at the 70 MPa hydrogen refueling station.

The state of frost formation during the consecutive twice dispensing test is shown in Photo. 3. In this test, frost formed on the dispensing coupler each time, but it was verified that this did not interfere with the dispensing procedure.

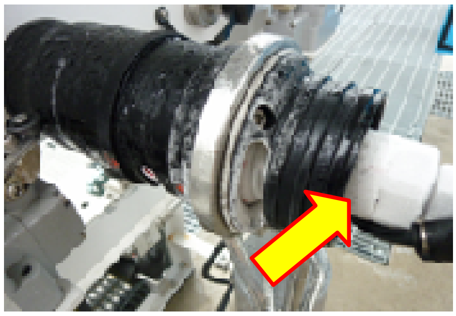

Photo. 3 Conditions of frost formation in the consecutive twice dispensing test (Frost formed on the area indicated by the arrow)

### 4.5 Results of direct dispensing test

The test results of direct dispensing to a test dispensing vessel are shown in Figure 8. Hydrogen was dispensed at an almost constant flow rate (approx. 390 g/min) from the compressor to the test dispensing vessel with the degree of opening of the regulating valve in the dispenser at 100%. The dispensing pressure reached 70 MPa, at which the vessel is fully filled with hydrogen, in approximately 820 seconds. The pressure rising rate of the test dispensing vessel was at an almost constant level of approx. 0.075 MPa/min. Moreover, the hydrogen cooling temperature reached −20°C or lower at the dispensing nozzle

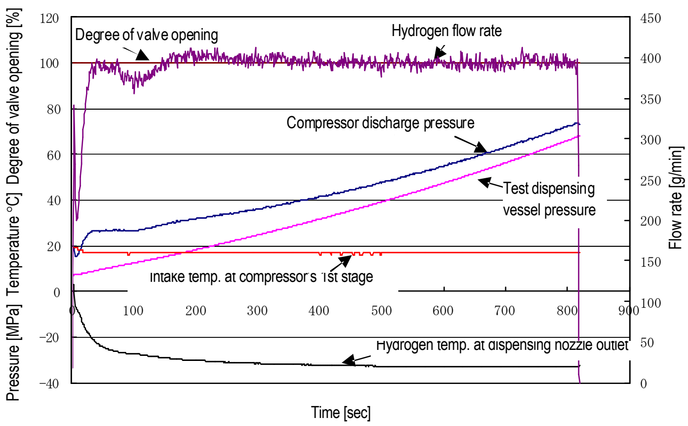


Fig.8 Results of direct dispensing test

outlet. There was no pressure pulsation during the direct dispensing test. Regarding the compressor, the discharge pressure was less than 80 MPa maximum and the intake temperature at each stage of the compressor was also within the specified temperature range, ensuring safe dispenser operations. From these results, it was verified that the 70 MPa hydrogen refueling station can perform direct dispensing safely as specified by the control procedure.

### 4.6 Results of hydrogen cooling test

Dispensing was performed using the test dispensing vessels. Pressure of the vessel before dispensing and after dispensing were 7 MPa and 70 MPa respectively. Outside air temperature of summer season, middle summer, winter season were 28.5°C～30.9°C, 19.5°C～22.3°C, 7.8°C ～ 11.4°C respectively. Average dispensing flow rate was validated from approx. 400g/min to approx. 1700g/min. The results of hydrogen cooling test are shown in Fig.9. The temperature of cooled hydrogen was -20°C or lower (on average) at the dispensing nozzle outlet under the condition of average dispensing flow rate in a range of approx. 400g/min through approx. 1700g/min and outside air temperature in a range of 7.8°C through 30.9°C, confirming that the pre-cooler system of our hydrogen refueling station meets the specification of the required hydrogen temperature.

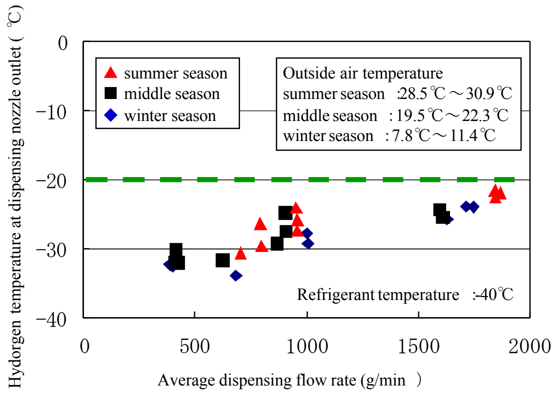


Fig.9 Results of hydrogen cooling test

### 5. Summary and future schedule

For this hydrogen refueling station, we started dispensing tests in March 2010 and undertook repetitive dispensing equivalent to one year in advance of the period of proliferation to demonstrate a one-year maintenance-free period for the compressor, accumulators, pre-cooler, dispenser, and valves. Moreover, we also conducted dispensing tests on the fuel-cell vehicles and high-flow rate tests to determine the equipment capability and verify that an instantaneous maximum flow rate of approx. 3,000 g/min is realized and the hydrogen temperature can also be held at –20°C or lower.

Furthermore, the number of dispensing times per day was increased to conduct dispensing equivalent to one-year dispensing assuming conditions for the initial period of proliferation of the hydrogen refueling stations in and after 2015 (assumption: 2.7 times/day × 350 days/year = 945 times/year) to achieve dispensing of 980 times. We are now working towards the assessment of durability through periodic inspections and the advancement of hydrogen cooling technology through continuing dispensing tests.

For the further development of the direct dispensing method, we verified that the hydrogen refueling station can perform direct dispensing safely as specified by the control procedure. In the future, we shall proceed with comparisons of several different flow-rate control methods, etc. to verify the feasibility of the direct dispensing method.

## 6. Reference

(1) 2009 results reporting symposium of NEDO fuel cell and hydrogen technology development

(2) Joint statement concerning the introduction of fuel cell vehicles onto the domestic market and the development of hydrogen supply infrastructure (January 13, 2011).

## 7. List of Tables



## 8. List of Figures



## Acknowledgments

This development has been conducted under the commissioning NEDO project "Technical Development of Hydrogen Production, Transportation, and Storage Systems, etc." We would like to express our appreciation to NEDO.