

Development of All-in-one Smart Hydrogen Station

Tetsuya YOSHIDA*

Jun TAKEUCHI*

Yuji ASANO*

ABSTRACT

An all-in-one smart hydrogen station has been developed, using Honda's original high differential pressure water electrolysis technology. The key components are packaged to be the size of a ten-foot container, reducing footprint and simplifying installation work. In addition, an interface was created to be easily understandable for those having no hydrogen refueling experience. In terms of performance, the pure water production method was revised to reduce water consumption to less than one tenth of the previous method. In addition, high-pressure water discharge technology was developed to increase the durability of the hydrogen production system. Furthermore, in order to expand the installable area to include semi-cold regions, heater functionality was added, preventing function loss from freezing. With these changes, smart hydrogen stations are being introduced by municipalities and private parties around Japan as an effective approach for achieving a hydrogen society and for promoting popularization of fuel cell vehicles.

1. Introduction

In order to reduce carbon dioxide (CO₂) emissions and reduce dependence on fossil fuels, Honda has been developing fuel cell vehicles (FCVs), which use hydrogen as their energy source and discharge only water while driving.

If the compressed hydrogen can be conveniently and efficiently made from renewable energy, it would both stimulate the popularization of FCVs and help to resolve environmental issues. Given these points, Honda is researching methods of hydrogen production concurrently with vehicle development.

To date, Honda installed a small hydrogen station assembled with commercially-available equipment at the Honda R&D Los Angeles Center in Los Angeles, CA, USA in 2001. In 2003, Honda then developed and introduced a normal pressure water electrolysis stack, which was subjected to verification testing for more than 4 years⁽¹⁾. In 2010, Honda developed a high differential pressure water electrolysis stack, which integrated Honda's original water electrolysis and hydrogen pressurization functions, updating the electrolytic method from normal pressure water electrolysis to high differential pressure water electrolysis^{(2), (3)}. These changes made the station more compact and space saving compared to other stations using standard mechanical compressors.

In March 2012, a high differential pressure water electrolysis station conforming to Japanese regulations was

installed on Saitama Prefectural Office grounds and used for 3 years as the filling station for an official vehicle, an FCX CLARITY^{(4), (5)}. Given that this was the first high differential pressure water electrolysis facility in Japan, and, even globally, without precedent as a facility on public grounds, regulatory compliance and safety verifications with risk assessment by third party officials were implemented.

However, with support from the Japanese national government, development of large-sized commercial hydrogen stations is underway. The current locations of commercial hydrogen station installations are shown in Fig. 1⁽⁶⁾. While the development started centers around the four biggest Japanese metropolitan areas, hydrogen filling systems will need to be installed in regions where the infrastructure is undeveloped in order for FCV use to spread further.

Thus, striving for simpler installations requiring less footprint than the commercial hydrogen stations, we developed the smart hydrogen station (SHS), in which key structural components are stored in a single enclosure. Furthermore, in order to increase the installable area of SHS, we added a winter support function to help prevent water from freezing and expand the installable area to include semi-cold regions.

This paper will give an overview of the SHS with further system development from the verification test station at the Saitama Prefectural Office that have accumulated experience.

* R&D Center X

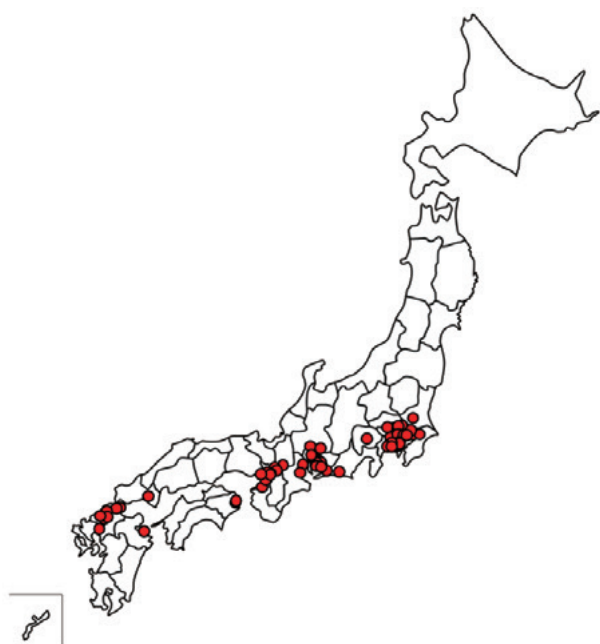


Fig. 1 Locations of commercial hydrogen stations, as of Jan. 2017

2. System Overview

An overview of the SHS is given in Fig. 2. The SHS is a compact hydrogen station, combining a high differential pressure water electrolysis system (Power Creator), developed by Honda, and storage tanks and a dispenser from Iwatani Corporation, all stored in a single

enclosure. Power Creator is capable of pressurizing hydrogen at the same time as water electrolysis, producing compressed hydrogen which meets the standards for FCV fuel⁽⁷⁾. This electrochemical method of pressurizing hydrogen generates no friction loss or motor loss, making efficiency higher than that of pressurization methods using mechanical compressors. If also combined with a renewable energy-derived power source, CO₂ emissions can also be reduced during the steps of hydrogen production and FCV fueling.

The major specifications for the SHS are given in Table 1. Hydrogen production capacity is 1.5 kg per day, allowing for a maximum annual hydrogen supply of approximately 550 kg. As FCVs can generally drive for approximately 100 km on 1 kg of hydrogen, assuming a per vehicle annual driving distance of 10,000 km, the hydrogen supplied by the SHS alone can fill approximately five vehicles. Additionally, the SHS was designed with a hydrogen storage capacity of approximately 19 kg, to allow the station to supply sufficient hydrogen for driving, even when filling multiple vehicles in succession.

In order to accelerate our progress toward a hydrogen society, in which hydrogen is widely used as a common energy source, and to proliferate FCVs across a wider range, the following items were developed from the verification test station:

- (1) A packaged unit for simplified installation
- (2) Easy user operation, which is understandable for those with no hydrogen refueling experience
- (3) Reduced water consumption and enhanced durability for the high-pressure water removal system
- (4) Installation area expanded to semi-cold regions

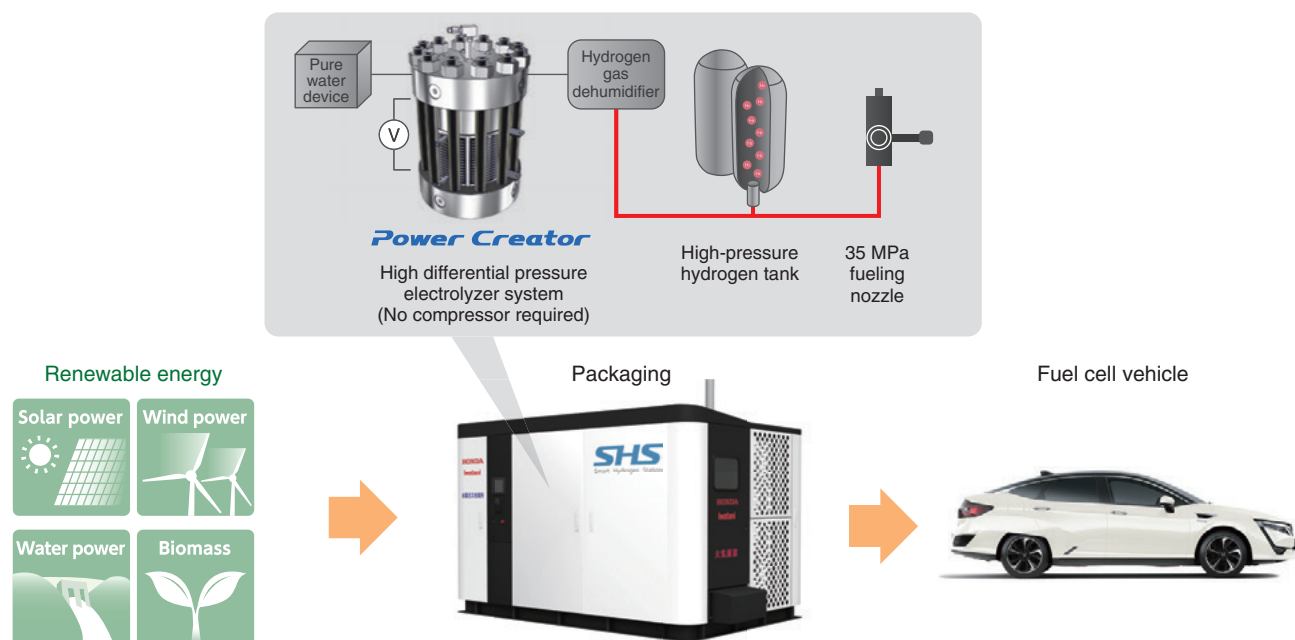


Fig. 2 Concept of SHS

Table 1 Specifications of SHS

Hydrogen production	Max capacity	1.5 kg/day (0.7 Nm ³ /h)
	Production pressure (dispensing pressure)	40 MPa (35 MPa)
	Storage capacity	Approx. 19 kg at 15°C
	Purity	>99.99%
Components	System size	W3280×D2140× H2100 (mm) Footprint: Approx. 7 m ² (10-ft container size)
	Electrolysis unit	High differential pressure electrolysis system
	Dispensing method	Double-bank cascading
	Utilities	200 V AC/tap water

3. Evolution from Verification Test Station

3.1. A Packaged Unit for Simplified Installation

To date, the verification test station used the same approach to installation as other standard commercial hydrogen stations, with the hydrogen production part, storage tanks, and a dispenser each installed as separate units. However, this dispersed approach to installation meant that the station would take up a large area (Fig. 3). Furthermore, this approach also took long time to install as pit work was required to run the piping and wiring to connect the dispersed units. Thus, seeking to help promote popularization by resolving these issues, an all-in-one SHS design was targeted. In studying the package shape, transport containers were referenced to account for easy transport by truck after factory shipment. For size, a target was set to fit the package within a ten-foot container, the smallest transport class container size.

The inner configuration of the SHS is given in Fig. 4. The user-operated dispenser is positioned on the front surface, and controls including a touch panel display for operation were positioned in the adjoining compartment to minimize the footprint. The Power Creator, which houses the high-pressure hydrogen piping, and the valve unit for cascade refueling operation are stored in the same compartment. The valve unit is positioned on the right

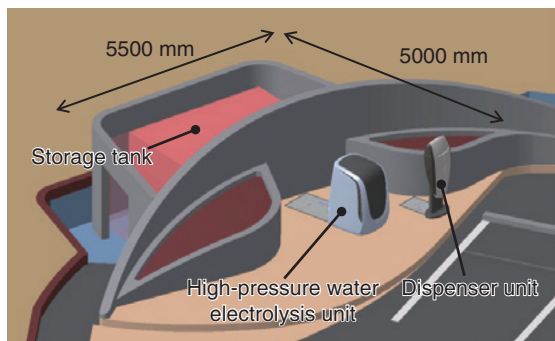


Fig. 3 External view of previous model

of the unit face, oriented in step with the storage tank connection port to minimize high-pressure hydrogen piping for the system overall.

This configuration has reduced footprint of the SHS by roughly 25% compared to the verification test station⁽⁴⁾, which had almost the same hydrogen production capacity and storage capacity.

Next, the status of SHS installation work is given in Fig. 5. As packages ship from the factory fully completed,

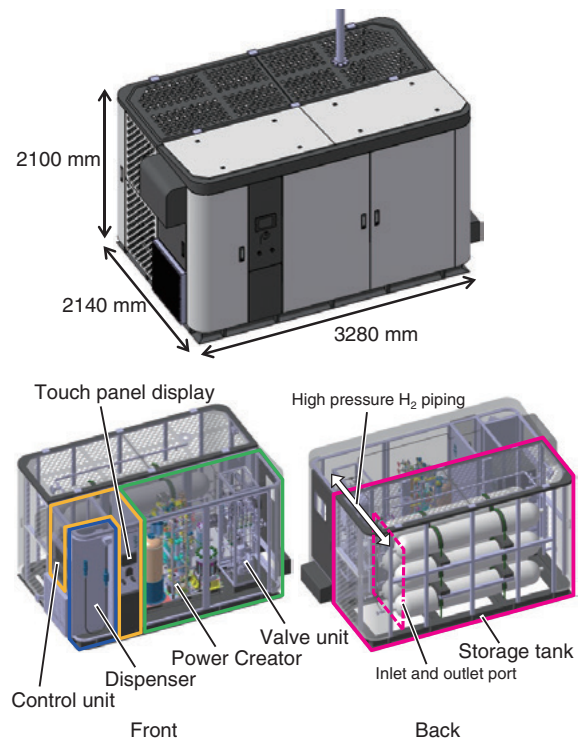


Fig. 4 Inner configuration of SHS



Fig. 5 Installation of SHS

installation is completed by simply connecting the water and electricity at the installation site. Thus, excluding any days needed for foundation work and application to the prefecture of jurisdiction for high-pressure gas equipment at the installation site, the SHS can produce hydrogen the next day after installation.

3.2. Simplified User Operation

In refueling the vehicle with hydrogen, the user operates two parts: the touch panel display and the fueling nozzle (Fig. 6).

The touch panel display is positioned directly next to the fueling nozzle holder to make filling operation easier for the user. It is positioned at a height allowing operation by smaller users.

The flow of touch panel operation is given in Fig. 7. As hydrogen refueling of vehicles is still not a widely understood process, the display visually represents each specific operational step with illustrations to make it easy for the user to understand operation. To set the user at ease, the display also shows as a guide of the time remaining until filling is complete as calculated from the fueling nozzle hydrogen pressure, storage tank pressure, pressurization rate, temperature, and other factors.

To refuel the vehicle, the user follows the instructions on the display, first opening the dispenser door, then taking out the fueling nozzle and connecting it to the vehicle. The fueling hose is 3 m long — the same length as hoses at the standard gas station. This is long enough that the user can fill up without thinking about where the vehicle is stopped, yet short enough that the hose can be folded for storage inside the dispenser door. Also, the fueling nozzle holder is positioned at the same height as the touch panel display so that the user can comfortably transition from touch panel to nozzle operation.

3.3. Reduced Water Consumption and Enhanced Durability

The SHS is designed to operate for 8 years, which

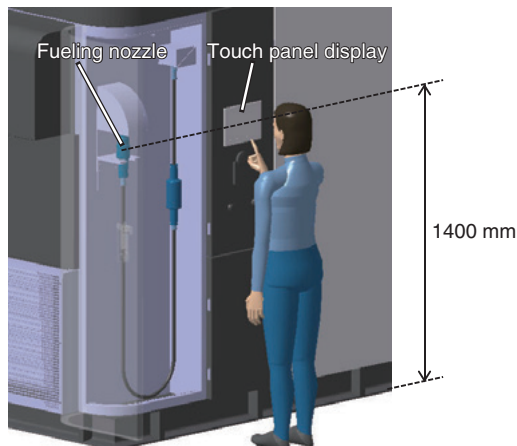


Fig. 6 User interface

is longer than the existing verification's test period. Accordingly, efforts were made to reduce water consumption and enhance durability in order to reduce running costs.

An overview of the system for supplying the water for electrolysis to the high-pressure water electrolysis stack is given in Fig. 8. Due to its chlorine and mineral content,



Fig. 7 Operation screen

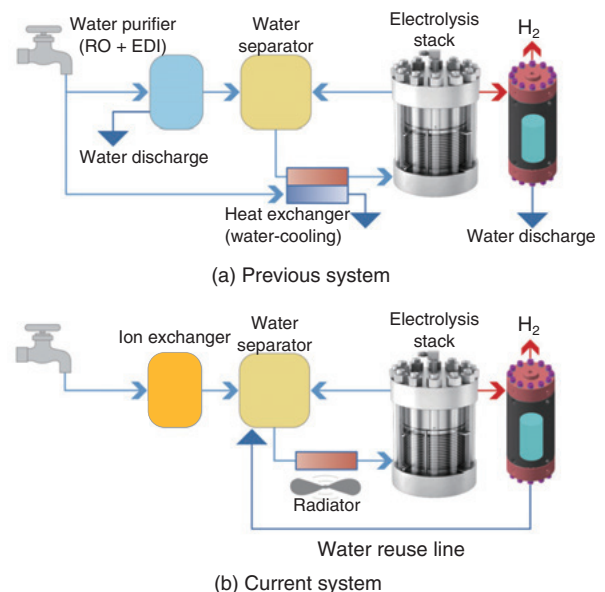


Fig. 8 Comparison of water supply systems

supplying tap water directly to the high-pressure water electrolysis stack has been found to degrade electrolysis efficiency. Therefore, a pure water production system is required to convert tap water into pure water to supply water for electrolysis. In the previous verification test station, a reverse osmosis membrane (RO) and electrodeionization system (EDI) were adopted as the pure water production system, eliminating ion concentrated water during pure water production [Fig. 8(a)]. As high-pressure water was also eliminated when moving to the high-pressure hydrogen side in the electrolysis, this system eliminated roughly two thirds of the tap water used as water for electrolysis.

Therefore, as a result of revising and checking the water quality levels required to maintain electrolysis efficiency, the approach was changed to an ion exchange resin system, allowing for pure water production without eliminating the ion concentrated water [Fig. 8(b)]. Also, the system can now reuse high-pressure water as water for electrolysis. Furthermore, cooling for the heat generated from the electrolysis stack was switched from water cooling to air cooling, reducing water usage to less than one tenth the volume used in the verification test station.

Next up to enhance durability of the hydrogen production system, efforts were made to enhance the high-pressure water discharge method as it was damaging the flow paths. The structure of the high-pressure water lines for the high-pressure water electrolysis system is given in Fig. 9. High-pressure hydrogen gas and liquid water coexist in the high-pressure hydrogen delivery lines of the high-pressure water electrolysis stack. As there are regulations⁽⁷⁾ on the allowable impurity concentrations for hydrogen for fueling FCVs, moisture should be separated and removed as

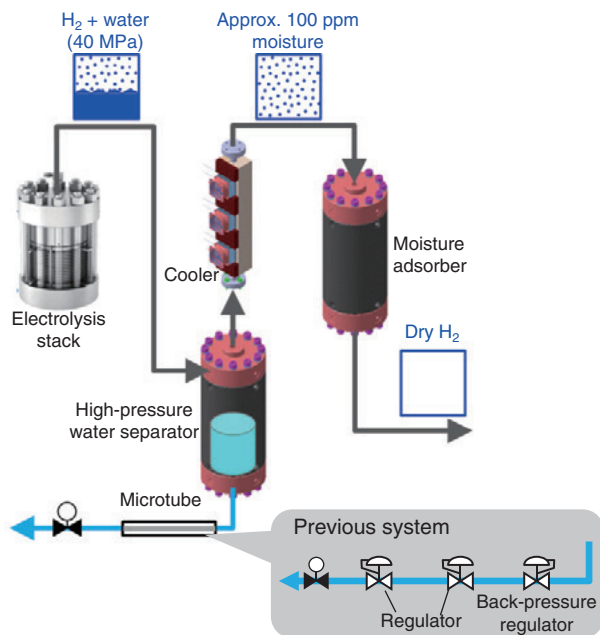


Fig. 9 Construction of water removal system in high pressure hydrogen line

well. As the first step in moisture removal, a high-pressure hydrogen separator is in place, using gravity to separate the liquid water. In the previous verification test station to date, the approach was to discharge the continuously pooled high-pressure water in the separator to an ambient pressure environment while maintaining the hydrogen pressure. This was implemented by installing multiple pressure regulators in series to step down the pressure incrementally. However, with the water passing through extremely narrow, short flow path gaps in the pressure regulators during the pressure drop process, the hydrogen dissolved in with the water would suddenly generate bubbles. This bubble generation phenomenon damaged the surface of the flow paths, resulting in loss of function (Fig. 10).

A new approach was taken as a remedy to suppress this phenomenon: pressure was stepped down gradually while discharging the water slowly through long, small bore metal microtubes instead of the narrow, short gaps in the pressure regulators. With this approach, the produced hydrogen was confirmed to maintain pressure at 40 MPa without using the pressure regulators, and high-pressure water could be discharged at a constant flow rate of approximately 40 cm³/min. Change in rate of discharge with the microtubes is shown in Fig. 11. The flow paths were confirmed to be

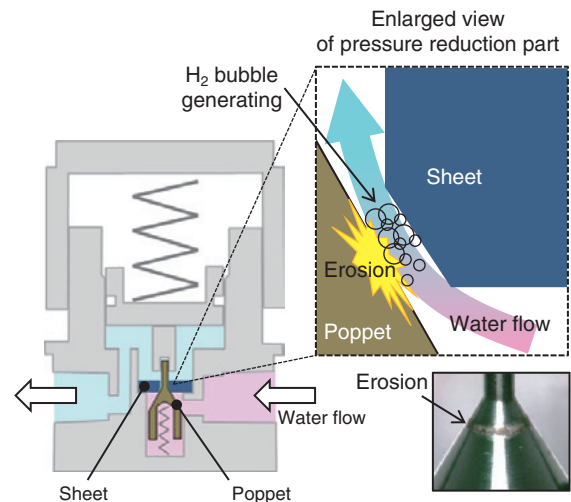


Fig. 10 Erosion mechanism of microchannel (inside of pressure regulator)

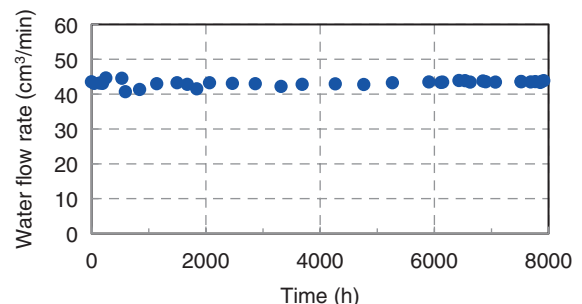


Fig. 11 Discharging water flow rate by using microtube

undamaged after 8000 hours with the microtubes, resulting in a prospective service life of 8 years.

3.4. Installation Area Expanded to Semi-cold Regions

Water runs through the water feed section, the separated water residual in the high-pressure hydrogen lines, and several other parts of the SHS system. Thus, verification test has to date been conducted in warm regions with no risk of water freezing in winter. Measures to prevent water from freezing will be needed to install the SHS over a wider region and promote hydrogen energy use. As the first step, the minimum installation environment temperature was set to -10°C with the goal of installing in semi-cold regions⁽⁸⁾.

An overview of the measures for sub-freezing temperatures is given in Fig. 12. First, as the enclosure is ventilated at all times, a heater was installed to keep water from freezing in the systems when temperatures fall below the freezing point. Next, a hose-type water heating device was added to the water feed line to help prevent freezing in the radiator, which comes in direct contact with ambient air.

Operational data in sub-freezing temperatures is given in Fig. 13. Both water temperature and enclosure internal

temperature were kept above 0°C , confirming that operation is possible in environments of -10°C . With these changes, the first hydrogen station in the Tohoku region was opened in March 2016 in Sendai, Miyagi Prefecture, bringing us one step closer to the popularization of FCVs.

4. Installation Progress

Public appeals and installation of the SHS are being promoted as a means of achieving the low-carbon hydrogen society promoted by the Ministry of the Environment subsidy program and of promoting popularization of FCVs. As of June 2017, 13 station installations have been completed (Fig. 14) and are operating as filling stations for official vehicles and other FCVs. Hopes are to further expand installations to other regions with demand and contribute to the popularization of FCVs.

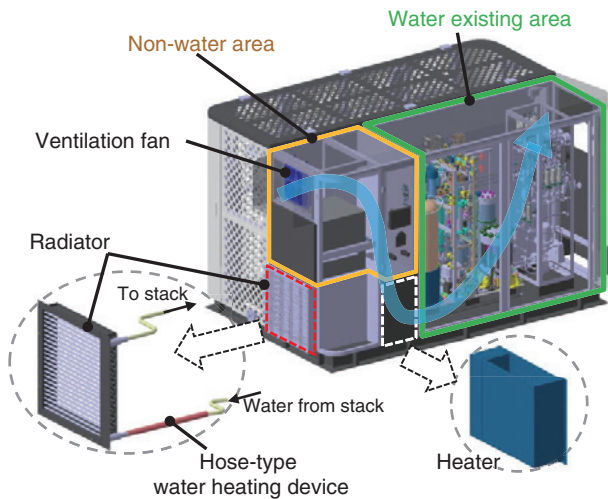


Fig. 12 Adding heating devices for semi-cold region



Fig. 14 Locations of SHS installations, as of June 2017

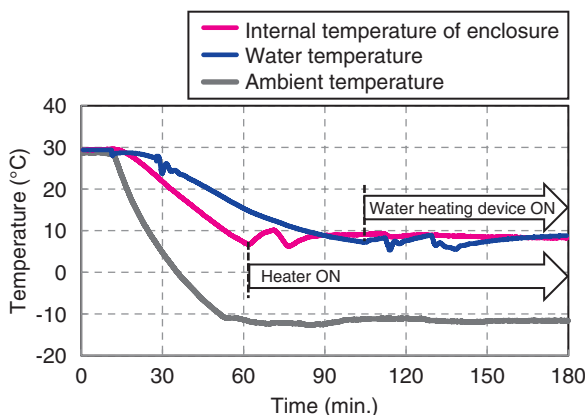


Fig. 13 Effect of heating devices

5. Conclusion

An all-in-one smart hydrogen station was developed, attaining the following results:

- (1) Footprint was reduced and installation work was simplified by containing the key components in an all-in-one package, sized to fit within a ten-foot container.
- (2) An interface allowing for simple operation was created in the interest of making operation easier for the user.
- (3) Water consumption was reduced to less than one tenth of the previous model. The high-pressure water discharge method was modified, enhancing durability.
- (4) Functionality for preventing water from freezing was added, expanding the installable area to include semi-cold regions.

References

- (1) Okabe, M., Nakazawa, K., Taruya, K., Handa, K.: Verification Test of Solar-powered Hydrogen Station (SHS) with Photovoltaic Modules, Honda R&D Technical Review, Vol. 20, No. 1, p. 72-79
- (2) Nakazawa, K., Nagaoka, H., Takeuchi, J., Moburg, F., Yamashita, I., Okabe, M.: Introduction of High Differential Pressure Water Electrolysis-type Solar Hydrogen Station (SHS2), Honda R&D Technical Review, Vol. 22, No. 2, p. 28-35
- (3) Nagaoka, H., Yoshida, N., Cun, D., Yamashita, I., Okabe, M.: Verification Test of High Differential Pressure Water Electrolysis-type Solar Hydrogen Station (SHS2), Honda R&D Technical Review, Vol. 24, No. 2, p. 74-81
- (4) Takeuchi, J., Nakazawa, K., Yoshida, N., Ito, J., Okabe, M., Yamashita, I.: Introduction of Solar Hydrogen Station Installed in Japan, Honda R&D Technical Review, Vol. 25, No. 1, p. 86-92
- (5) Yoshida, N., Miyake, A.: Verification Test Results for Solar Hydrogen Station in Japan, Honda R&D Technical Review, Vol. 26, No. 2, p. 200-206
- (6) <http://www.fccj.jp/hystation/>, 2017/1/31
- (7) ISO 14687-2: Hydrogen fuel - Product specification - Part 2: Proton exchange membrane (PEM) fuel cell applications for road vehicles, (2012)
- (8) Ministry of Land, Infrastructure, Transport and Tourism: Jutaku no Shoenerugi Kijun, (2013) (in Japanese)

■ Author ■



Tetsuya YOSHIDA



Jun TAKEUCHI



Yuji ASANO