Development of Hydro H₂eat (Hydro Heat): Utilization of Hydrogen Fuel in Hot-Air Heaters

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Abstract

The average global temperature has risen by approximately 1.1°C compared to pre-industrial levels. The Paris Agreement was adopted in 2015, and Japan subsequently declared its goal of achieving carbon neutrality by 2050. In line with this goal, various initiatives including legislation and other measures are being promoted to advance the social implementation of hydrogen, an energy source attracting attention as a next-generation solution. In the road paving industry in particular, there is strong demand for the development of burners capable of using hydrogen as fuel. In collaboration with Tokyo Gas Co., Ltd., our company began developing a hydrogen burner and, in March 2023, completed a 500 kW-class model[1]). Furthermore, building on the hydrogen combustion technology acquired through this work, we have been expanding into fields beyond asphalt plants (hereinafter referred to as "APs") through the development of a hydrogen jet heater. This paper reports on demonstration tests conducted in cold regions using a prototype hydrogen jet heater.

1. Introduction

Since the Industrial Revolution in the latter half of the 18th century, humanity has benefited from thermal and electrical energy while consuming large quantities of fossil fuels. As a result, by 2020, the global average temperature had already risen by approximately 1.1°C compared to pre-industrial levels. If the current situation persists, it is predicted that temperatures will continue to rise. The relationship between climate change and weather-related disasters is not yet clear. However, climate change is expected to heighten the risks of extreme rainfall, heatwaves, and the reduction of Antarctic Sea ice.

In response to this situation, the Paris Agreement was adopted at the 21st Conference of the Parties (COP21) to the United Nations Framework Convention on Climate Change in 2015, and since then, countries around the world have been working toward carbon neutrality[2]). Amidst these efforts, Donald Trump was inaugurated as the 47th President of the United States on January 20, 2025, and the United States—the world's second-largest emitter of greenhouse gases—announced its withdrawal from the Paris Agreement. In the future, deregulation of the fossil fuel industry and expansion of oil and natural gas production are anticipated, which may hinder efforts to address climate change. With the absence of the United States—a top emitter of greenhouse gases—in initiatives to curb global warming, it becomes even more crucial for the global community to maintain a high level of commitment to reducing greenhouse gas emissions. In this context, Japan is promoting nationwide efforts aimed at simultaneously achieving decarbonization and economic growth, with the goal of reaching net-zero emissions by 2050.

For companies, achieving net-zero requires managing greenhouse gas emissions throughout the supply chain under Scope 1, 2, and 3. Scope 1 and 2 refer to emissions generated through a company's own operations. Scope 3 covers emissions that occur from raw material procurement to those generated after product sales. In addition to addressing Scope 1 and 2, it is also essential to reduce emissions under Scope 3. In product development, companies are responsible for taking measures to address "Category 11: Use of sold products" as part of their Scope 3 efforts.

In the pursuit of achieving net-zero emissions, hydrogen has gained attention as a next-generation energy resource. Hydrogen can generate either electrical or thermal energy through its reaction with oxygen and is characterized by a process that does not produce CO_2 emissions. While it is commonly known that hydrogen can be produced from water via electrolysis, it can also be generated from various other resources and waste materials, such as fossil fuels, methanol, sewage sludge, and waste plastics. Depending on the production method, hydrogen can be a carbon-free energy.

Given this background, our company is developing a burner that is able to use hydrogen fuel, which is expected to serve as an alternative to the fossil fuels traditionally used. It is considered reasonable that the introduction of hydrogen burners to asphalt plants (AP) should proceed in balance with the development of hydrogen infrastructure. Currently, compressed hydrogen and liquefied hydrogen are available as hydrogen infrastructure options for transportation, but compressed hydrogen is considered more practical for everyday use. Among products that can be realistically operated using compressed hydrogen, hot-air heaters are expected to have demand. Specifically, in Hokkaido—where demand is likely to be high—there are facilities that produce hydrogen from livestock manure, and efforts to utilize hydrogen are actively underway. For example, a jet heater is a type of hot-air heater and is essential at construction sites during winter. The jet heater is used to prevent cold-related issues and quality degradation due to freezing during concrete curing. Believing that the use of hydrogen fuel, which does not emit CO_2 or CO, could also contribute to improved user safety, we have started to develop a hydrogen-powered jet heater[3)].

In this test, we examined whether the developed hydrogen jet heater (the trademark name is Hydro H₂eat) could be used, like conventional models, inside concrete curing tents in cold regions. The combustion of hydrogen generates water vapor, and we anticipated that this might affect the humidity within the tent. Therefore, a conventional kerosene jet heater was also installed under the same conditions to observe changes in temperature and humidity inside the tent. The test period was set during the coldest time of year, when jet heaters are most frequently operated, to simulate actual use of the hydrogen jet heater in cold climates[3)].

This paper reports on the features of the prototype hydrogen jet heater we developed, as well as the demonstration test conducted in cold regions using the prototype.

2. Hydrogen Jet Heater — Development of "Hydro H₂eat"

2.1 Development of Hydrogen Combustion Technology

The road paving industry is also actively working to reduce greenhouse gas emissions. Approximately 80% of CO_2 emissions generated at APs come from the combustion of fossil fuels, most notably in the drying and heating process of aggregates using burners. Therefore, we have initiated the development of a burner capable of using hydrogen — a next-generation energy source — as fuel, so as to achieve exclusive hydrogen combustion at APs by 2050.

While utilizing hydrogen as burner fuel offers the advantage of realizing carbon neutrality, the following concerns arise in comparison to heavy oil and city gas[3]):

1. The combustion speed of hydrogen is approximately 6.6 times faster than that of methane[5]), increasing the likelihood of backfire.
2. Locally, the combustion temperatures may become extremely high, leading to increased formation of thermal NO_x, that is, nitrogen oxides.
3. The thermal load near the burner becomes higher, posing the risk of thermal damage to combustion devices such as the burner and combustion chamber.

Taking these concerns into consideration, we conducted hydrogen combustion tests using burners. By burning hydrogen with a 500-kW heating burner for APs, we confirmed that the expected thermal output could be obtained and clarified the correlation between generated NO_x concentrations and various parameters. The development of the 500 kW-class hydrogen burner was completed jointly with Tokyo Gas Co., Ltd. in 2023[4]). We installed this hydrogen burner in a small-scale AP and conducted asphalt mixture production tests, confirming that, with respect to the potential effects of water vapor generated during hydrogen combustion on the plant and on the quality of the asphalt mixture, operation could be carried out in the same manner as with our company's conventional gas burners[1)].

2.2 Hydro H₂eat Prototype Unit

Hot-air burners used for heating are required to generate air temperatures exceeding 1000°C: however, hot-air heaters are expected to produce warm air approximately 20 to 30°C higher than the ambient temperature, like stoves.

We are currently developing a hydrogen-fueled jet heater named "Hydro H$_2$eat (Hydro Heat)" utilizing the technology developed through the 500-kW hydrogen burner. **Photo 1** shows the prototype of Hydro Heat we have developed. The method of generating warm air in Hydro Heat involves a structure in which combustion gas and cold air are mixed within a mixing chamber.

Photo 1: Hydro Heat Test Unit

Photo 2: Demonstration Test Scene (Rikubetsu-cho)

3. Combustion Test of Hydro Heat

3.1 Test Conditions

To evaluate the practicality and operability of Hydro Heat, as well as to conduct a durability test in cold climates, demonstration tests were carried out in two locations: a mountainous area in Rikubetsu-cho[6]) — known as one of the coldest places in Japan, where temperatures can drop below −30°C — and a riverside area in Makubetsu-cho. Cold-region testing of vehicles and air conditioners is also conducted in Rikubetsu-cho. **Photo 2** shows the demonstration test in Rikubetsu-cho.

Assuming usage at a concrete curing site in a cold region,

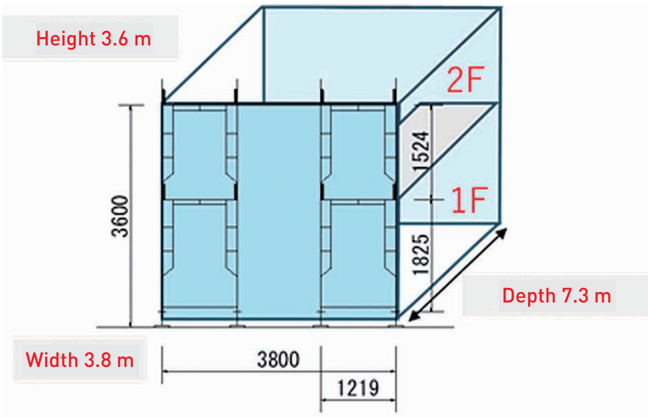

Figure 1: Exterior Diagram of Thermal Enclosure[3])

where jet heaters are commonly used, we compared the performance of Hydro Heat and a conventional kerosene-fueled jet heater by operating them continuously for 24 hours inside separate thermal enclosures. In this test, to maintain the temperature inside the enclosure at approximately 15°C, the hydrogen combustion rate of Hydro Heat was adjusted using a mass flow controller. The conventional fixed-output heater was controlled by a thermostat, which switched the device on and off to regulate the amount of kerosene burned.

3.2 Test Equipment

3.2.1 Thermal Enclosure

Figure 1 shows the external diagram of the thermal enclosure used in the test. In the 2024 Edition of the Road Design Manual issued by the Hokkaido Regional Development Bureau, it is specified that concrete construction must be carried out in accordance with cold-weather concrete procedures when the average daily temperature is expected to fall below 4°C[7]). Furthermore,

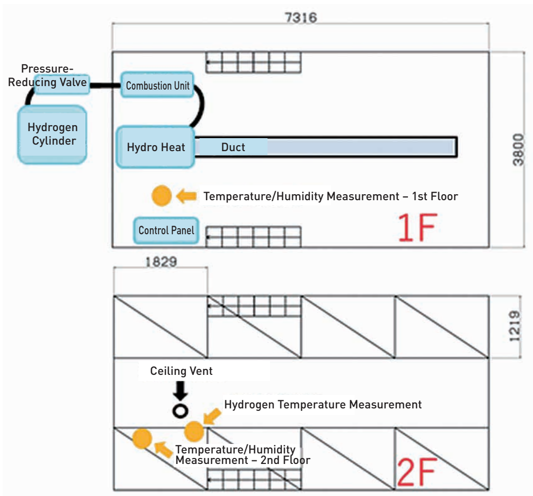

Figure 2: Installation of Hydro Heat Equipment and Measurement Points

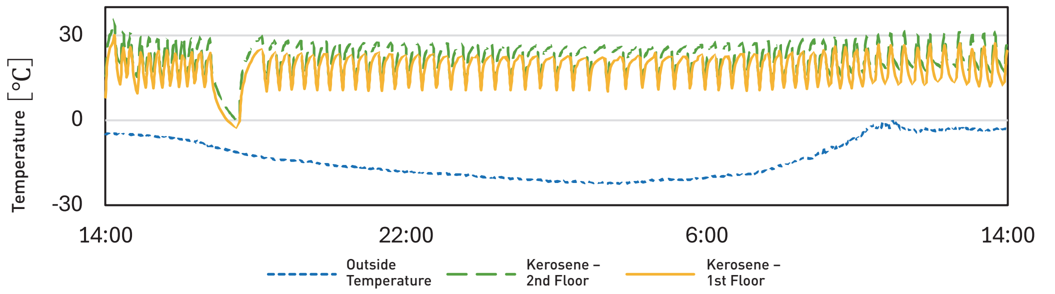

Figure 3: Inside Temperature of the Kerosene Jet Heater Enclosure (Rikubetsu-cho)

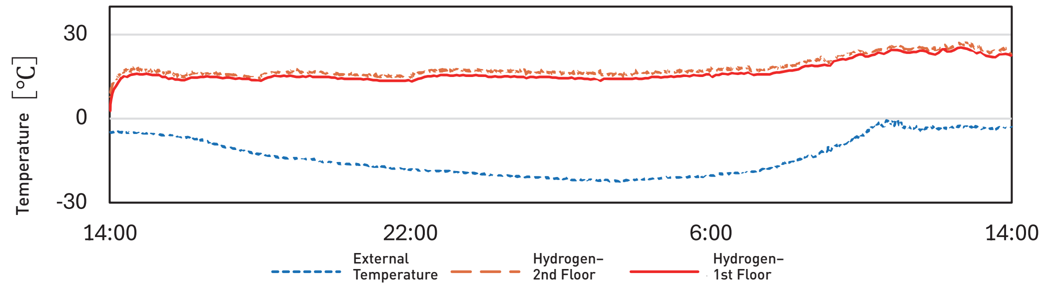

Figure 4: Inside Temperature of the Hydro Heat Enclosure (Rikubetsu-cho)

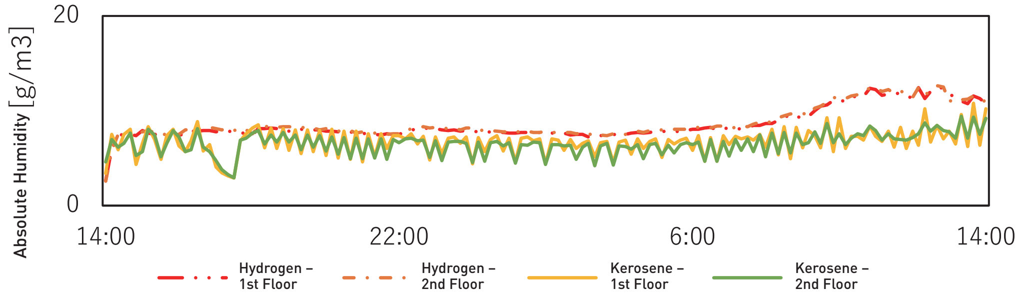

Figure 5: Humidity Inside the Enclosure (Rikubetsu-cho)

it is defined as a standard guideline that concrete exposed to severe weather conditions must be kept at a temperature of 5°C or higher until it gains sufficient strength to prevent early frost damage, and then maintained at 0°C or higher for an additional two days. Therefore, it is necessary to maintain the temperature inside the thermal enclosure at 5°C or higher for a certain

Photo 3: Interior Wall Surface of Hydro Heat Enclosure

period[7]). In actual cold-weather concrete construction carried out in cold regions, as shown in **Photo 2**, the work area is covered with a thermal enclosure, and a jet heater is used to maintain a constant temperature inside the enclosure during the curing process.

3.2.2 Hydrogen Supply Line to Hydro Heat

In this test, hydrogen was supplied using a hydrogen cylinder bundle—a frame assembly that holds multiple gas cylinders together and consolidates their outlets into a single connection. Hydrogen at 19.6 MPa was supplied from the bundle and then reduced in pressure to 0.2 MPa by a pressure-reducing valve before being fed to the combustion device. If hydrogen were supplied to Hydro Heat at high pressure, it could damage the equipment or cause flameouts due to sudden pressure fluctuations. Therefore, the hydrogen was reduced in pressure before being supplied to the combustion device[1]).

3.3 Test Measurement Items

In this test, in addition to measuring the outside air temperature and the temperature and humidity inside the enclosure, the hydrogen concentration inside the enclosure was continuously monitored on the Hydro Heat side for safety purposes.

Figure 2 shows the measurement points and the installation location of Hydro Heat within the thermal enclosure. A ventilation port was provided in the ceiling of the enclosure.

3.4 Test Results

3.4.1 Temperature Measurement Results Inside the Enclosure

In the test conducted in Rikubetsu-cho, the outside air temperature, the temperature inside the enclosure with the kerosene jet heater, and the temperature inside the enclosure with Hydro Heat were measured. The results are shown in **Figures 3** and **4**. During the test in Rikubetsu-cho in February 2024, the maximum outside temperature recorded was −0.2 °C and the minimum was −22 °C, resulting in a temperature difference of more than 20 °C between day and night[3]).

Figure 3 shows the temperature graph for the enclosure with kerosene jet heater. It shows large fluctuations in temperature over short periods. This is due to the use of a thermostat to control the kerosene jet heater by switching it on and off, to automatically maintain the temperature within a certain range. However, if the temperature control range is narrowed, the on-off cycles occur more frequently. In contrast, Hydro Heat allows for easier adjustment of warm air temperature through output control. As shown in **Figure 4**, compared to the kerosene jet heater, Hydro Heat was able to operate continuously without causing abrupt temperature fluctuations. However, the hydrogen flow rate is manually controlled using a mass flow controller, and therefore the temperature cannot be automatically controlled. As a result, the thermal enclosure was affected by changes in the outside air temperature. During the daytime, the flow rate was reduced as much as possible, but the internal temperature of the enclosure still increased. In this test, Hydro Heat was able to maintain the internal temperature of the enclosure within the same control range as the kerosene jet heater. Similar temperature trends were observed in the measurements taken in Makubetsu-cho[3]).

Table 1 Fuel Consumption

Fuel (Test Site)	Consumption	Total Thermal Energy	CO_2 Emission
Kerosene (Rikubetsu)	46.5 L	1605 MJ	115.8 kg
Hydrogen (Rikubetsu)	129 m^3	1389 MJ	0 kg

Photo 4: Improved Hydro Heat

3.4.2 Measurement Results of Humidity Inside the Enclosure

Figure 5 shows the results of absolute humidity measurements inside the enclosures of Hydro Heat and kerosene jet heaters. The results indicate no significant difference in the internal temperature between Hydro Heat and kerosene jet heater enclosures. However, the absolute humidity inside the Hydro Heat enclosure was approximately 3–4 g/m^3 higher. As shown in **Photo 3**, a visibly large amount of condensed water was clearly observed inside the Hydro Heat enclosure. This is likely because hydrogen combustion produces only water, resulting in a significantly higher moisture content in the exhaust gas compared to kerosene combustion, and consequently a larger amount of condensation on the enclosure walls.

These results indicate that Hydro Heat can maintain a high humidity inside the tent, helping to prevent rapid surface drying of the concrete surface. Therefore, Hydro Heat is considered capable of creating favorable conditions for concrete curing[3]).

3.4.3 Estimation Results of Fuel Consumption

In this demonstration test, CO_2 emissions from the kerosene jet heater were 115.8 kg in the test in Rikubetsu-cho and 91.4 kg in the test in Makubetsu-cho. Since Hydro Heat does not emit CO_2 during combustion, using carbon-neutral hydrogen allows for a reduction in CO_2 emissions.

Table 1 shows the fuel consumption during the tests. The amount of thermal energy obtained from the fuel was 1,605 MJ for the kerosene jet heater and 1,389 MJ for Hydro Heat. Possible reasons for the lower total heat output from Hydro Heat include the following factors:

1) Temperature Inside the Enclosure

The temperature graphs inside the enclosure shown in **Figures 3** and **4** indicate that the kerosene jet heater generally maintained a higher temperature. This is likely due to differences in control methods—specifically, between the ON-OFF flow control used for the kerosene jet heater and the continuous flow control—resulting in a higher combustion rate for the kerosene jet heater.

2) Combustion Efficiency

Based on the odor inside the enclosure, it is considered that the kerosene jet heater, which repeatedly ignites and extinguishes, emitted odors caused by unburned kerosene (such as an acetaldehyde-like smell), indicating incomplete combustion. In contrast, Hydro Heat consistently showed a hydrogen concentration of 0 ppm inside the enclosure, suggesting that it operated with high combustion efficiency.

3) Condensed Water on Wall Surfaces

Since more condensed water was observed on the wall surfaces of the Hydro Heat enclosure, it is possible that the latent heat of condensation contributed to maintaining the internal temperature.

Currently, the price of gray hydrogen is approximately ten times higher per unit of thermal energy than that of kerosene, and carbon-neutral hydrogen is about four times more expensive than gray hydrogen. Due to this price disparity, hydrogen fuel is not currently advantageous compared with kerosene, even if stable operation can be ensured. Therefore, it will be important to monitor how government and administrative support for hydrogen fuel utilization develops in the future[3]).

4. Features of Hydro Heat

Unlike conventional kerosene jet heaters, Hydro Heat, developed to use hydrogen fuel, has the following features[3]):

1.Maintenance of a High-Humidity Environment through Water Vapor in the Combustion Exhaust

Hydro Heat helps prevent rapid drying by maintaining a humid environment. This creates favorable conditions for applications where sudden drying poses a problem, such as in concrete curing.

2.Odorless Combustion Exhaust

Since the only byproduct of combustion is water vapor, the exhaust is odorless. This eliminates discomfort caused by unpleasant odors and enhances comfort in heated spaces.

3.Reduced Environmental Impact

Unlike liquid fuels such as kerosene, hydrogen poses no risk of environmental pollution such as contamination of rivers or soil due to fuel leakage.

4.Reduction in Greenhouse Gas Emissions

Since no CO_2 is generated during combustion, Hydro Heat contributes to achieving carbon neutrality.

5.Improved Safety of Exhaust Emissions

There is no risk of carbon monoxide poisoning during operation in enclosed spaces. Accordingly, Hydro Heat ensures a higher level of safety for workers while heating within the enclosure.

5. Improvements to Hydro Heat

The cold-region demonstration tests revealed issues related to the operability of the Hydro Heat prototype, such as its mobility, installation, and handling. To operate the Hydro Heat prototype used in the tests, not only the main unit but also a control unit, combustion system, and other components are required. Consequently, it became clear that improvements were needed to address the need for installation space and the lack of user-friendliness due to the heavy weight requiring significant labor for setup.

Photo 4 shows an improved model, which was redesigned from the prototype. In the improved equipment, the main unit, combustion system, and control unit were integrated into a single structure, achieving in a more compact and lightweight design compared to the prototype.

6. Conclusion

Based on the results of the cold-region demonstration tests, it was confirmed that the Hydro Heat prototype was capable of maintaining the internal temperature of an insulated enclosure, comparable to conventional kerosene jet heaters. Despite the concerns about condensation and freezing due to the increased amount of water vapor specific to cold climates, no issues were observed inside the concrete curing tent.

Using carbon-neutral hydrogen with Hydro Heat enables a reduction in greenhouse gas emissions. However, operational challenges also became apparent, and an improved version was developed based on the prototype, achieving a reduction in both the weight and size of the equipment. Going forward, further improvements in usability and durability are planned in preparation for commercialization.

Hydrogen fuel is currently more expensive than fossil fuels like kerosene. Nevertheless, initiatives such as government support and subsidies are beginning to take shape with an eye toward 2030 and 2050. With carbon neutrality and net-zero emissions in mind, our product development will continue, aiming for early practical implementation of Hydro Heat and promoting the expansion of hydrogen energy use to contribute to the realization of a hydrogen-based society.

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