

Combustion of Thermally Decomposed Ammonia Gas Using a Hydrogen Burner for Asphalt Plants

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Abstract

NIKKO Co., Ltd. has been developing burners that use ammonia and hydrogen as fuels, aiming to reduce greenhouse gas emissions from asphalt plants by 50% by 2030 (compared to 2013 levels) and to achieve net-zero emissions by 2050. As one method of utilizing ammonia as a fuel, instead of combusting ammonia directly, an approach involving the combustion of a mixed gas of hydrogen and nitrogen obtained through the thermal decomposition of ammonia is considered. This paper presents the results of combustion tests using a simulated thermally decomposed gas (a mixture of hydrogen and nitrogen) with a 100 kW-class ammonia burner developed through joint research with Osaka University, as well as the results of combustion tests using thermally decomposed gas generated by a commercially available decomposition device as fuel for a 500 kW-class hydrogen burner developed in collaboration with Tokyo Gas Co., Ltd.

1. Introduction

NIKKO Co., Ltd. has been developing burners for asphalt plants (hereinafter abbreviated as "AP") configured to use hydrogen-based fuels (hydrogen and ammonia) to achieve a 50% reduction in greenhouse gas emissions from NIKKO's APs by 2030 (compared to 2013 levels) and net zero emissions by 2050¹⁾. Among the burners, a hydrogen burner has already been tested using a small-scale test AP for aggregate drying and asphalt mixture production and yielded favorable results²⁾.

When applying hydrogen burners to APs, in regions where gas can be supplied through pipelines, a similar operation to that of plants currently using natural gas can be expected. However, depending on the location of the plant, gas supply through a pipeline may not be feasible. In such cases, when hydrogen gas is used, typically it is transported in liquid form using tanker trucks, and stored on-site by constructing a facility. This approach is extremely costly because hydrogen has a very low boiling point of -253°C³⁾⁴⁾.

Ammonia is a compound that functions as a hydrogen carrier and liquefies at approximately 0.8 MPa at room temperature, becoming gaseous upon heating. Thus, similar to propane, ammonia can be stored and transported in liquid form and can be taken out as a gas by heating under mild conditions. Compared to liquefied hydrogen, the storage and transportation can be achieved using less expensive equipment, making ammonia advantageous from a cost perspective⁴⁾⁵⁾.

When using ammonia as burner fuel, an approach in addition to direct combustion is possible where the ammonia is first decomposed and then the resulting hydrogen is combusted. This approach of decomposing ammonia into hydrogen for use is already known for applications such as long-distance transportation by tanker and hydrogen production from ammonia at hubs like hydrogen stations³⁾⁶⁾, as well as for generating atmosphere gases used in metallurgy⁷⁾.

From the perspective of fuel use in APs, the approach of combusting gas obtained through the thermal decomposition of ammonia may offer advantages over the

direct combustion method, particularly in meeting demands such as a wide turndown range or rapid fluctuations in output under highly disturbed conditions, due to the high combustibility of hydrogen.

In addition, since the dryer of an asphalt plant (AP) uses a direct heating method, the flame and hot air are used inside the dryer to dry the aggregates. The nitrogen contained in the thermally decomposed gas from ammonia is considered to function similarly to the nitrogen in the air supplied by the burner fan. Therefore, it is believed that the thermally decomposed gas can be used as fuel without separating nitrogen and hydrogen.

Accordingly, gas obtained by thermally decomposing ammonia on-site may be used as fuel by utilizing ammonia as a hydrogen carrier, without separating hydrogen from nitrogen, enabling a simpler system configuration.

This paper presents the results of two tests conducted to examine whether ammonia thermal decomposition gas can be used as fuel for hydrogen burners.

The first test involved combustion testing using simulated gas and hydrogen gas with a 100 kW-class test burner for ammonia developed in collaboration with Osaka University. The second test involved combustion testing using ammonia thermal decomposition gas generated by a commercially available decomposition device, with a 500 kW-class hydrogen burner jointly developed with Tokyo Gas Co., Ltd.

2. Combustion Test using Simulated Thermally Decomposed NH₃ Gas with a 100 kW-Class Burner

In a hydrogen-only combustion test with a 500 kW-class hydrogen burner, the NO_x concentration was approximately 20 ppm at 16% O₂ equivalent, confirming that when pure hydrogen gas is used as fuel, combustion with extremely low thermal NO_x emissions is possible.

The gas obtained by thermally decomposing ammonia is a mixture of approximately 75 mol% hydrogen and 25 mol% nitrogen. However, depending on the decomposition and processing conditions, it is expected to contain several hundred to several thousand ppm of unreacted ammonia³⁾.

The ammonia contained in this thermally decomposed gas can be a source of fuel NO_x. However, when focusing on the use of ammonia as a fuel, there has been little knowledge regarding the allowable concentration of

ammonia at which NO_x generation can be considered negligible.

Therefore, to investigate the differences and trends in NO_x emissions and combustibility depending on fuel composition, combustion tests were conducted using a 100 kW-class test burner with hydrogen and simulated thermally decomposed gas composed of hydrogen and nitrogen in a 3:1 ratio, into which ammonia was mixed.

2.1 Test Method

Figure 1 shows the 100 kW-class burner used in the tests. The tests were conducted at the Central Mechanical Building on the Suita Campus of Osaka University. The flow rates of hydrogen and ammonia were measured and adjusted using a mass flow controller (manufactured by Azbil Corporation). The nitrogen flow rate was measured and adjusted using an ultrasonic flowmeter (manufactured by Keyence Corporation). These gases were mixed in-line before reaching the burner nozzle and then combusted. The exhaust gas was analyzed by a portable combustion gas analyzer (from HODAKA CO., LTD), an automatic nitrogen oxide analyzer and a CO/CO₂/O₂ automatic analyzer (from Yanaco), and a MEXA exhaust gas measurement system (from Horiba Ltd.).

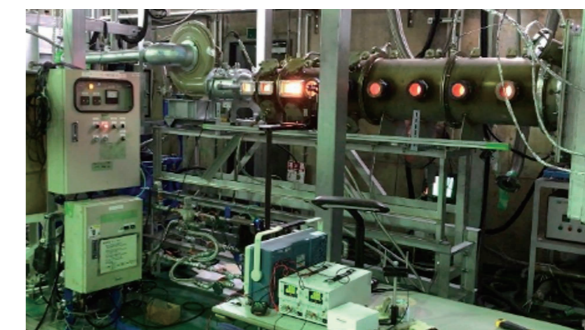


Figure 1: 100-kW Burner Used for Tests

Since the test flow and equipment used are the same as those used in the ammonia tests, please refer to the previously published report for details⁸⁾.

2.2 Test Results

Figures 2 and 3 present images of 100 kW combustion flames for the following gases: pure hydrogen gas; a gas mixture of hydrogen and nitrogen in a 3:1 ratio; the pure hydrogen gas blended with ammonia at 0.5% and 5% on a heat input basis; and the gas mixture of hydrogen

and nitrogen blended with ammonia at 0.5% and 5% on a heat input basis. It should be noted that the co-combustion ratios of 0.5% and 5% correspond to ammonia concentrations of approximately 0.28% and 2.9%, respectively. These images indicate that the combustion flame was colorless when using pure hydrogen or the hydrogen-nitrogen mixture without added ammonia. With the addition of ammonia, the flame took on a whitish color. In terms of flame shape, the hydrogen-nitrogen mixture produced a larger flame protruding further forward, compared to the flame from the pure hydrogen, which was due to the increased flow rate caused by the inclusion of nitrogen.

Furthermore, the results of exhaust gas analysis confirmed that when the ammonia blend ratio is 10% or less, the NO_x concentration meets the typical exhaust gas standard for APs, which is 230 ppm at 16% O₂ equivalence.

Therefore, even if the thermally decomposed ammonia gas contains several hundred to several thousand ppm of unreacted ammonia, it is highly likely that fuel-NO_x will pose no problems when used as fuel.

In addition, comparing the NO_x concentrations between pure hydrogen gas and the hydrogen-nitrogen mixture without ammonia, the latter showed lower NO_x levels. This is considered to be because the hydrogen was diluted by the nitrogen, resulting in slower combustion, lower local gas temperatures, and consequently reduced formation of thermal NO_x. These findings suggest that depending on the ammonia concentration in the thermally decomposed gas, even lower NO_x emissions may be achievable than with hydrogen-only combustion.

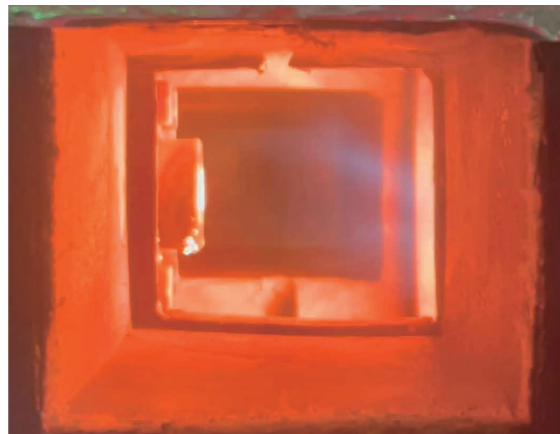
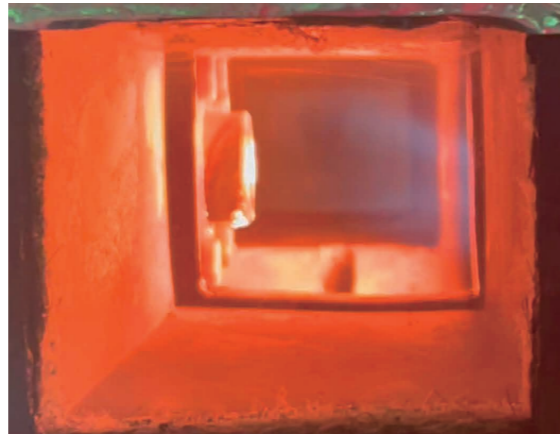


Figure 2: Flame of Hydrogen-Ammonia Mixed Gas
(Ammonia Co-Firing Ratio: Top 0%, Middle 0.5%, Bottom 5%)



Figure 3: Flame of Hydrogen-Nitrogen-Ammonia Mixed Gas
(Hydrogen : Nitrogen = 3:1, Ammonia Co-Firing Ratio: Top 0%, Middle 0.5%, Bottom 5%)

3. Combustion Test using Simulated Thermally Decomposed Ammonia Gas with a 500 kW-Class Burner

The combustion test of simulated thermally decomposed ammonia gas using a 100-kW burner revealed that the decomposed gas containing trace amounts of unreacted ammonia could likely be used as burner fuel similar to hydrogen gas, from an NO_x emissions perspective, without the need for any ammonia removal system. Based on these findings, a combustion test was conducted, where ammonia gas was thermally decomposed using a commercially available decomposition device, and the resulting gas was combusted with a 500 kW-class burner. The results were compared with those of propane gas combustion.

3.1 Test Method

The combustion test was conducted by connecting a 500-kW hydrogen burner to a test combustion furnace at Nikko Co., Ltd., and carrying out the combustion of thermally decomposed gas. The thermally decomposed ammonia gas was generated using a commercially available decomposition device. The flow rate of propane used as a reference fuel was measured using an ultrasonic flowmeter (from Keyence Corporation) and adjusted to a specified rate. For the thermally decomposed ammonia gas, the ammonia flow rate was similarly adjusted prior to supply to the decomposition device for proper control of the total flow rate. Unreacted ammonia in the thermally decomposed gas, as well as unburned ammonia and NO,

N₂O, and NO₂ in the combustion exhaust gas, were collected from a sampling port of the piping in aluminum sampling bags and analyzed using the MEXA system. The O₂, CO, and NO_x in the exhaust gas were collected through a sampling port at the furnace outlet, and their concentrations were measured using a portable combustion gas analyzer (from HODAKA Co., LTD.).

3.2 Test Results

Figure 4 presents the combustion flames of propane and thermally decomposed gas at approximately 500 kW output using a 500 kW-class hydrogen burner. The flame of the thermally decomposed gas appears orange in color. In previous tests, this coloration was not observed during hydrogen combustion, which may be attributed to trace amounts of unreacted ammonia.

Gas analysis results indicated that the ammonia concentration in the thermally decomposed gas was 200 ppm or less. The NO_x concentrations during individual combustion of propane and the thermally decomposed gas were nearly the same, both being below 20 ppm at 16% O₂ equivalence. Furthermore, neither N₂O nor ammonia was detected in the exhaust gas. These results indicate that thermally decomposed ammonia gas can be suitable for use as fuel, similar to hydrogen, natural gas, and propane.

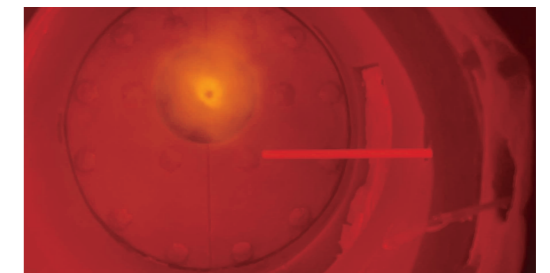
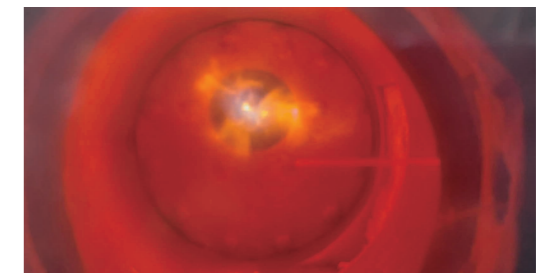


Figure 4: Flame Photographs during Propane-only Combustion and Thermally Decomposed Gas-only Combustion Using a 500 kW Hydrogen Burner
(Output: Approximately 500 kW, Air Ratio: Approximately 2, Top: Propane-only Combustion, Bottom: Thermally Decomposed Gas-only Combustion)

4. Future Challenges and Outlook for Implementation in APs

The 500-kW hydrogen burner jointly developed with Tokyo Gas Co., Ltd. has confirmed that thermally decomposed ammonia gas can be combusted in a furnace and that the presence of trace amounts of unreacted ammonia in the decomposed gas does not lead to problems related to NOx generation.

Our future challenges include verifying whether NOx and ammonia concentrations in the exhaust gas remain within regulatory limits during combustion inside a dryer, and whether the quality of the asphalt mixture is unaffected. Additionally, when introducing this system into actual plants, a reactor for ammonia thermal decomposition will be required. Such a system must be capable of accommodating the intermittent operation and rapid output fluctuations characteristic of APs, while also enabling effective thermal management and waste heat recovery. In this paper, the tests were conducted using a 500 kW-class burner. However, burners used in APs typically range from 5 to 12 MW. Therefore, in step with the development of a carbon-free ammonia supply infrastructure in Japan, we plan to advance the development of larger-scale burners and plant systems.

5. Conclusion

As an alternative to the direct combustion of ammonia, one practical approach for fuel utilization is to convert ammonia into thermally decomposed gas and then combust it. To evaluate the effectiveness of this approach for burners used in APs, combustion tests were conducted using a 100-kW burner with a simulated decomposition gas composed of hydrogen, nitrogen, and ammonia, as well as comparative tests using a 500 kW-class hydrogen burner with propane and thermally decomposed gas alone.

The results confirmed that thermally decomposed gas can be combusted with a hydrogen burner in the same manner as hydrogen gas. Moreover, when the ammonia concentration in the decomposed gas was equal to or less than 200 ppm, the resulting NOx levels were comparable to those observed when using hydrogen as fuel.

Moving forward, in line with the wider adoption of carbon-free ammonia, we will make efforts to apply this approach to higher-output burners, conduct asphalt mixture production tests to assess compatibility with

actual plants and confirm mixture performance, and continue development of plant systems.

Acknowledgments

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