Aggregate Drying Tests Using an Asphalt Plant Hydrogen Burner Fueled by Cracked Ammonia Gas

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Abstract

NIKKO Co., Ltd. has been developing various types of burners to achieve its targets of reducing greenhouse gas emissions from asphalt plants (hereinafter referred to as APs) by 50% before 2030 (relative to fiscal year 2013 levels) and achieving carbon neutrality by 2050[1]. Among these burners, our hydrogen burner for APs has demonstrated favorable performance in asphalt mixture production tests conducted using a small-scale test plant[2]. However, when hydrogen is used as the main fuel source, challenges remain regarding its storage and supply at plants located in areas where hydrogen cannot readily be delivered through gas pipelines. To address this issue, NIKKO has investigated the feasibility of using ammonia as a hydrogen carrier by thermally decomposing ammonia on-site to produce hydrogen, which is then combusted in a hydrogen burner[8]. This paper presents the results of joint experiments conducted with Maeda Road Construction Co., Ltd. using a small-scale test AP. In these experiments, cracked ammonia gas was supplied to a hydrogen burner, and tests were carried out to evaluate aggregate drying and heating as well as asphalt mixture production.

1. Introduction

Japan has set targets of reducing greenhouse gas emissions by 46% by 2030 and achieving net-zero emissions by 2050. The aggregate drying and heating process accounts for approximately 70% of CO_2 emissions from asphalt plants (APs). Accordingly, it is anticipated that meeting the stringent CO_2 emission reduction targets beyond 2030 will be difficult through reductions in fuel consumption or energy-saving technologies alone, and that fundamental measures, including fuel switching, will be required. To address these societal challenges, NIKKO Co., Ltd. has developed burners compatible with various types of fuels[2)6)]. Among these, a hydrogen burner has been tested in a small-scale test AP for aggregate drying and asphalt mixture production, with favorable results[2)].

When hydrogen is used as a fuel, hydrogen burners can be used at plants in areas where hydrogen can be supplied through pipelines. In other areas, however, expensive equipment is required to transport and store hydrogen at a high energy density[3)4)]. Therefore, we investigated an approach in which ammonia, a type of hydrogen carrier, is decomposed on-site and converted into hydrogen for use as fuel[7)8)]. Ammonia can be liquefied under pressure at room temperature and can therefore be handled in a manner similar to LPG. It is thus considered more advantageous than hydrogen in terms of transportation and storage[4)5)]. Accordingly, if hydrogen can be produced by decomposing ammonia on-site, it may be possible to benefit from both the combustion advantages of hydrogen and the transportation and storage advantages of ammonia. The gas obtained by thermal decomposition of ammonia is a mixture of hydrogen and nitrogen and contains a small amount of unreacted ammonia. From the standpoint of energy utilization, it is considered preferable to combust the gas mixture directly rather than produce pure hydrogen from the ammonia decomposition gas, as this would simplify the equipment configuration.

From the tests conducted to date, it was confirmed that the small hydrogen burner for APs was capable of maintaining a stable flame while combusting cracked ammonia gas. The NOx concentration in the exhaust gas was comparable to that obtained when propane was burned and met the regulatory limit for drying furnaces specified under the Air Pollution Control Act. In addition, neither unburned ammonia nor N_2O was detected[8)]. However, these tests were conducted using an in-house combustion furnace. In an AP, the burner is directly connected to a rotary dryer and is used in a direct heating system. Therefore, for practical use in an actual AP, it is necessary to confirm that a stable flame can be maintained under aggregate drying and heating conditions in the dryer, that the NOx concentration in the exhaust gas meets the regulatory limit, and that no unburned ammonia is present. Similarly, it is also necessary to confirm that no problems arise with the properties or other relevant characteristics of the asphalt mixture produced.

Since the in-house burner combustion tests yielded favorable results, this paper presents the results of tests conducted with the cooperation of Maeda Road Construction Co., Ltd. In these tests, cracked ammonia gas was supplied to a hydrogen burner, and aggregate drying and heating and asphalt mixture production tests were conducted using a small-scale test AP.

2. Aggregate Drying and Heating Tests

To evaluate the suitability of cracked ammonia gas for use in APs, aggregate drying and heating and asphalt mixture production tests were conducted using a small-scale test AP.

2.1 Test Method

2.1.1 Fuels and Burners Used

Tests were conducted using heavy fuel oil A and CNG (13A), which are standard fuels used in APs, as well as hydrogen, a hydrogen-nitrogen gas mixture (mixed in-line at a volume ratio of 3:1), and cracked ammonia gas for comparison. CNG, hydrogen, the hydrogen-nitrogen gas mixture, and cracked ammonia gas were burned using a 500-kW-class hydrogen burner (Photo 1). Heavy fuel oil A was burned using a small 500-kW-class heavy-oil burner.

2.1.2 Test Plant and Equipment Flow

The tests were conducted using a small-scale test AP (Photo 2) located at the test site of the Technical Research Institute of Maeda Road Construction Co., Ltd. For details of the plant, refer to our previous report. A commercially available electric-furnace-type cracking unit was used for the thermal decomposition of ammonia.

Figure 1 shows a flow diagram of the fuel gas supply lines. Ammonia was supplied from a cylinder and converted by the cracking unit into cracked ammonia gas (a nitrogen-hydrogen gas mixture containing a small amount of unreacted ammonia), which was then supplied to the burner. CNG and hydrogen were supplied from cylinder bundles through separate supply lines, which merged immediately upstream of the burner. The ammonia flow rate was measured using an ultrasonic flowmeter, the hydrogen flow rate using a mass flow controller, and the CNG flow rate using a mass flowmeter, and each was adjusted to the specified flow rate. The ammonia and hydrogen supply lines were also connected to nitrogen lines for purging. During purging, the supply lines were switched to the abatement furnace, where residual gas in the piping was combusted and discharged from the system.

2.1.3 Test Measurement Items

The items measured during the tests were as follows: aggregate temperature (aggregate at the inlet and outlet), aggregate moisture content (before and after the test), NH_3 in the cracked ammonia gas, and exhaust gas components (NOx, O_2, CO, CO_2, SOx, H_2O, soot and dust, moisture content, NH_3, NO, N_2O, and NO_2).
The measurement locations and details of the measurement methods are shown in Table 1.

2.1.4 Asphalt Mixture Evaluation Items

The production, paving, and evaluation of the asphalt mixtures were conducted by Maeda Road Construction Co., Ltd. The main evaluation criteria/parameters were mixture properties (mixing quality and Marshall test) and constructability (workability and finish).

Table 1: Exhaust Gas Measurement Methods

Measurement Item	Measurement Method
Moisture content	Absorption tube method
Gas composition analysis	Orsat method
Soot and dust	Circular filter paper method
Sulfur oxides	Ion chromatography method
Nitrogen oxides	Ion chromatography method
CO	FT-IR method
NO、N_2O、NO_2、NH_3	FT-IR method



Photo 1: 500-kW-class Hydrogen Burner



Photo 2: Test Plant

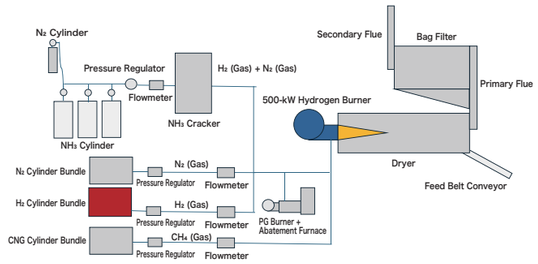
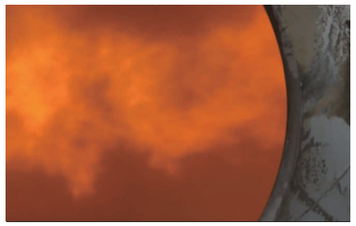


Figure 1: Flow Diagram

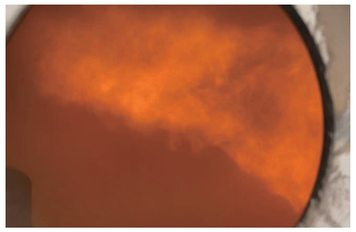
2.1.5 Test Conditions

The aggregate feed rate was set at 5 t/h. The aggregate and its composition were those used for dense-graded asphalt mixture (13). The burner output was adjusted so that the aggregate temperature reached approximately 200°C. The burner air ratio was set at 1.2.

For heavy oil A and CNG, the respective fuels were used from the start of dryer heating to dry and heat the aggregate. In contrast, for hydrogen, the hydrogen-nitrogen gas mixture, and cracked ammonia gas, CNG was used to heat the dryer. After the dryer temperature had stabilized, the fuel was switched to the targeted test gas, and gas analysis and other measurements were performed once the temperature had leveled off again.



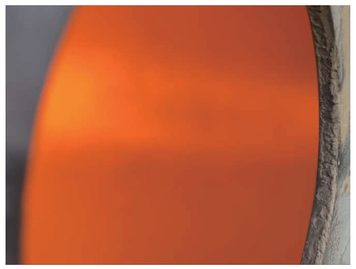
a. CNG Combustion, 420 kW, Air Ratio 1.2



b. Hydrogen Combustion, 400 kW, Air Ratio 1.2



c. Hydrogen + Nitrogen Combustion, 400 kW, Air Ratio 1.2



d. Ammonia Cracking Gas Combustion, 450 kW, Air Ratio 1.2

Photo 3: Flames in the Dryer with Various Fuels

2.2 Test Results

2.2.1 Flame Output Response and Flame Stability

Photos 3(a)–(d) show the combustion flames in the dryer for each fuel. It was confirmed that, when cracked ammonia gas was used as the fuel, combustion could be sustained and a stable flame could be maintained during aggregate drying and heating in the dryer, and the burner output could be varied as required, as with heavy fuel oil A and hydrogen.

2.2.2 Aggregate Drying and Heating

Cracked ammonia gas was capable of heating the aggregate to 205–210°C. The moisture content of the aggregate decreased from 5.4% before heating to 0.06% after heating. This drying and heating performance was nearly equivalent to that obtained with heavy fuel oil A and hydrogen, for which the moisture contents decreased from 4.5% and 5.1% before heating to 0.08% and 0.05% after heating, respectively.

2.2.3 Exhaust Gas Composition

Table 2 shows the exhaust gas composition for each fuel.

The NOx concentrations, corrected to 16% O_2, were 16.7 ppm and 7.1 ppm for heavy fuel oil A and CNG, compared with 22.9 ppm, 11.3 ppm, and 20.9 ppm for hydrogen, the hydrogen-nitrogen gas mixture, and cracked ammonia gas, respectively. The NOx concentration for cracked ammonia gas was nearly equivalent to that for hydrogen combustion alone, while the hydrogen-nitrogen gas mixture showed an even lower NOx concentration. This is considered to be because the dilution of hydrogen with nitrogen suppressed the formation of thermal NOx. In the case of cracked ammonia gas, the small amount of unreacted NH_3 contained in the gas is considered to have served as a source of NOx, resulting in a NOx concentration comparable to that for hydrogen.

The lower NOx concentrations for heavy fuel oil A and CNG are considered to be due to the presence of approximately 1,000 ppm of CO during combustion, which is considered to have reduced NOx formation.

Although several hundred ppm of unreacted ammonia was present in the cracked ammonia gas before combustion, no ammonia was detected in the gas sampled from the exhaust duct. In addition, no ammonia odor was detected from the dried aggregate or in the dryer or exhaust duct during inspection after the tests. These results suggest that the small amount of unreacted ammonia contained in the cracked ammonia gas was combusted by the burner flame.

Approximately 3% CO_2 was detected for heavy fuel oil A and CNG, whereas 0.2–0.6% CO_2 was detected for hydrogen, the hydrogen-nitrogen gas mixture, and cracked ammonia gas. The CO_2 detected for the latter fuels is considered to have originated not from hydrogen or ammonia but from CNG used during the heating-up process.

The moisture contents in the exhaust duct were 12.2% and 13.7% for heavy fuel oil A and CNG, compared with 17.4%, 19.7%, and 19.3% for hydrogen, the hydrogen-nitrogen gas mixture, and cracked ammonia gas, respectively. This is considered to be because hydrogen produces a greater amount of water per unit of calorific value than hydrocarbon fuels. No water condensation or significant dust deposition was observed in the exhaust duct during inspection after the tests; however, the long-term effects will need to be investigated in the future.

Table 2: Exhaust Gas Measurement Results

Aggregate feed rate (target)	5t/h	5t/h	5t/h	5t/h	5t/h
Fuel	Heavy fuel oil A	CNG	H_2	N_2+H_2(N_2:H_2=1:3)	Ammonia cracking gas
Fuel output at stable aggregate temperature	400 kW	Approx. 430 kW	410 kW	Approx. 400 kW	Approx. 450 kW
Burner air ratio	2.5	Approx. 1.25	Approx. 1.2	Approx. 1.2	Approx. 1.2
O_2 (%)	17.7	16.8	17.5	17	16.7
CO_2 (%)	3.2	3	0.6	0.2	0.4
CO (ppm)	805	1216	5	4	6
NO_x (ppm)	11	6	16	9	18
NOx (ppm, corrected to 16% O_2)	16.7	7.1	22.9	11.3	20.9
Dust concentration (g/m³)	0.006	0.006	-	0.002	0.004
Odor index (-)	27	17	16	26	26
Wet gas flow rate (m³/h)	3000	2710	2320	2230	2020
Dry gas flow rate (m³/h)	2600	2340	1820	1790	1630
Exhaust gas temperature (°C)	53	59	65	73	66
Moisture content (%)	12.2	13.7	17.4	19.7	19.3

2.2.4 Asphalt Mixture Production and Paving Tests

The asphalt mixture production and paving tests were conducted by Maeda Road Construction Co., Ltd. The asphalt mixture produced using cracked ammonia gas as the fuel exhibited properties equivalent to those of the mixture produced using heavy fuel oil A and had met the specified criteria. The paving tests also confirmed that the constructability of the asphalt mixture was comparable to that of the mixture produced using heavy fuel oil A and that the mixture could be successfully paved[9]).

3. Future Challenges and Prospects for Implementation in APs

The results of the aggregate drying and heating and asphalt mixture production tests conducted using the small-scale test AP showed that, even when ammonia was decomposed on-site and the unpurified cracked ammonia gas was used as the fuel, the exhaust gas met the NOx regulatory limit and no unburned ammonia was detected. The properties of the asphalt mixture were also equivalent to those of mixtures produced using conventional fuels such as heavy fuel oil A and natural gas, and no problems were observed with handling during paving.

Future challenges include confirming that 5–12 MW-class burners used in actual APs, like the 500-kW-class hydrogen burner used in the present tests, can achieve low NOx emissions without unburned ammonia and exhibit satisfactory output response characteristics, as well as developing a larger-scale ammonia cracking unit suitable for energy use in APs.

4. Conclusions

Aggregate drying and asphalt mixture production tests were conducted using cracked ammonia gas as fuel for a hydrogen burner for APs in a small-scale test AP, and the results were compared with those obtained using heavy fuel oil A, natural gas, hydrogen, and a hydrogen-nitrogen gas mixture as fuels.

When cracked ammonia gas was used as the fuel, a stable flame could be maintained in the dryer, and the NOx concentration in the exhaust gas was confirmed to be nearly equivalent to that obtained with hydrogen combustion alone. In addition, no unburned ammonia was detected. The properties of the asphalt mixture met the specified criteria, and its constructability was confirmed to be comparable to that of the mixture produced using heavy fuel oil A. When the hydrogen-nitrogen gas mixture was used as the fuel, the NOx concentration was lower than that obtained with hydrogen combustion alone and cracked ammonia gas. This suggests that removing ammonia after the cracking process could reduce the NOx concentration to a level lower than that obtained when pure hydrogen is used as the fuel.

In the future, as carbon-free ammonia becomes more widely adopted in Japan, we plan to verify the applicability of cracked ammonia gas to larger-scale burners and develop an ammonia cracking unit suitable for APs.

Acknowledgments

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