



Development of Ammonia-oxyfuel combustion technology for industrial furnaces

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1. Introduction

Domestic CO₂ emissions total approximately 1.04 billion tons, of which emissions from industrial furnaces account for about 130 million tons, or 12% of the total¹⁾. To achieve a carbon-neutral society, our company has contributed to reducing CO₂ emissions from industrial furnaces through energy saving based on oxy-fuel combustion. However, achieving carbon neutrality requires the use of carbon-free fuels.

To address this challenge, our company has been promoting the project "Development of Ammonia Combustion Technology for Industrial Furnaces", supported by the New Energy and Industrial Technology Development Organization (NEDO), since fiscal year 2021. In this project, to apply ammonia, a carbon-free fuel, to industrial furnaces, we will develop ammonia-oxyfuel combustion technology that combines oxy-fuel combustion techniques, and will conduct demonstration tests in a glass melting furnace, where heat transfer is primarily driven by radiative heat radiation. Since glass melting furnaces are operated at higher temperatures than other industrial furnaces and have strict quality requirements, the knowledge gained from this technology development will lead to applications in other industrial furnaces, such as steel heating furnaces and aluminum melting furnaces.

This report introduces an ammonia-oxyfuel burner that achieves enhanced heat transfer and NO_x suppression, developed through the evaluation of combustion characteristics of 200 kW-scale ammonia-oxyfuel combustion and demonstration tests in a glass melting furnace.



Fig. 1 Burner combustion state in a glass melting furnace (Heavy oil-air combustion, regenerative combustion)

2. Technology Introduction

2.1 Ammonia Combustion Technology

Hydrogen and ammonia are attracting attention as carbon-free fuels. Table 1 shows an example of the physical characteristics of methane, which is a fossil fuel, hydrogen, and ammonia²⁾. Since ammonia can be liquefied more easily than hydrogen, it is superior in terms of transportation and storage. In addition to its use as a hydrogen carrier, its use for heat through direct combustion is also expected. However, the application of ammonia combustion to industrial furnaces faces several challenges: ammonia has a slow burning velocity and low combustivity poor flame stability; it has low radiant intensity and poor heat transfer performance; and it tends to generate large amounts of NO_x during combustion.

To solve these challenges, flame enhancement through oxy-fuel combustion and NO_x reduction through staged combustion are effective. Oxy-fuel combustion is a combustion method that increases the oxygen concentration in the oxidizer, and it can increase the flame temperature and burning velocity and enables stabilization of combustion even in ammonia flames, which have slow burning velocities²⁾. Staged combustion is a combustion method in which oxygen is supplied in stages to form a fuel-rich flame in the primary combustion zone near the burner, followed by a fuel-lean flame in the secondary combustion zone with staging oxygen to achieve complete combustion. This makes it

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possible to reduce NOx emissions (Fig. 2)³.

The technology development was conducted by applying oxy-fuel combustion and staged combustion to ammonia combustion, with the goal of achieving a heat transfer efficiency of 55% or higher and a NOx concentration of 360 ppm or lower (converted to 15% O₂).

Table 1 Thermophysical properties and combustion characteristics of ammonia

Fuel type		NH ₃	CH ₄	H ₂
Boiling point	[°C]	-33	-162	-253
Lower heating value (LHV)	[MJ/Nm ³]	14.1	35.8	10.8
Adiabatic flame temperature	[°C]	1750	1970	2120
Burning velocity	[m/s]	0.07	0.37	2.91

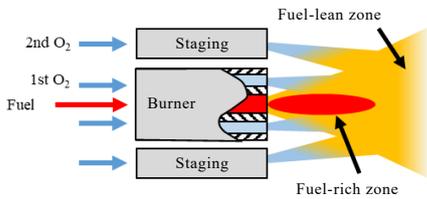


Fig. 2 Burner overview

2.2 Performance Evaluation Using a Test Furnace

2.2.1 Test Overview

Using the burner described above, the combustion characteristics of ammonia were evaluated (Fig. 4) in the 200 kW-scale test furnace owned by our company shown in Fig. 3. The test furnace simulates a reverberatory furnace. The furnace temperature was measured using multiple thermocouples installed on the ceiling and bottom of the furnace, and the exhaust gas composition was evaluated by sampling a portion of the exhaust gas from the flue. Additionally, water-cooled copper pipes simulating the material to be heated were provided at the bottom of the furnace, and heat transfer to the material was evaluated based on the amount of heat removed (Fig. 5).

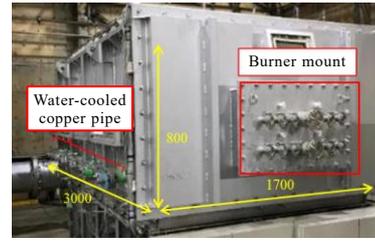


Fig. 3 Test furnace



Fig. 4 Ammonia flame in the test furnace

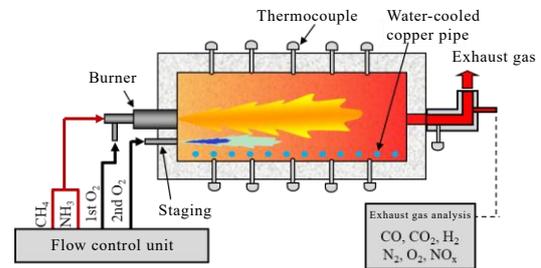


Fig. 5 Test equipment

2.2.2 Furnace Temperature

Fig. 6 shows the results of the furnace ceiling temperature distribution for methane combustion and ammonia combustion. These results were obtained by supplying oxygen only to the burner body without staged combustion. To reproduce the furnace environment of a glass melting furnace, the combustion rate heat input was adjusted to 120 kW for methane combustion and 160 kW for ammonia combustion so that the furnace temperature would reach 1500°C. Additionally, the oxygen ratio, which represents the ratio of the supplied oxygen amount to the theoretical oxygen amount for complete combustion, was set to 1.05. Compared with methane combustion, the maximum temperature in ammonia combustion is lower and its position is shifted further from the burner. This can be considered that combustion was completed at a position further from the burner due to the low burning velocity of ammonia.

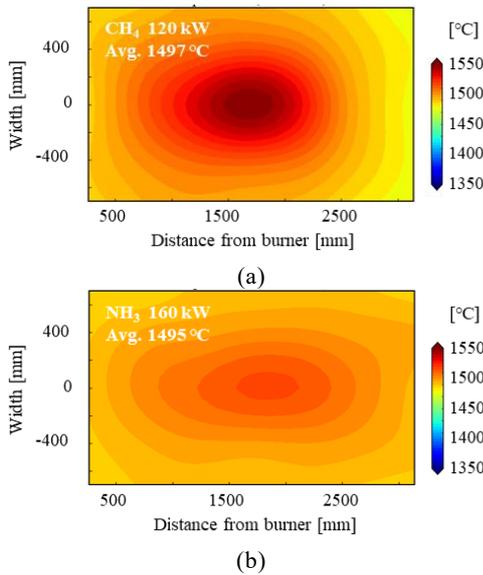


Fig. 6 Furnace ceiling temperature distribution:
(a) Methane, (b) Ammonia

2.2.3 NOx Emissions

Fig. 7 shows the results of NOx emissions for methane combustion and ammonia combustion at a furnace temperature of 1500°C. The effects of staged combustion were compared for ammonia combustion only. The NOx emissions were converted to an oxygen concentration of 15%, which is the emission standard for glass melting furnaces in flat glass manufacturing, using the NOx conversion formula (1) based on the oxygen concentration in exhaust gas as defined by the Air Pollution Control Law.

Compared with methane combustion, NOx concentrations in ammonia combustion increased by approximately ten times. It was confirmed that the NOx emissions could be significantly suppressed by combining staged combustion and further performing optimization, achieving the target of 360 ppm or lower.

$$C = (21 - O_n) / (21 - O_s) \times C_s \quad (1)$$

C: Concentration of nitrogen oxides to be compared with the emission standard [ppm]

O_n: Standard oxygen concentration defined for each type of facility [%]

O_s: Oxygen concentration in the exhaust gas [%]

C_s: Concentration of nitrogen oxides in the exhaust gas [ppm]

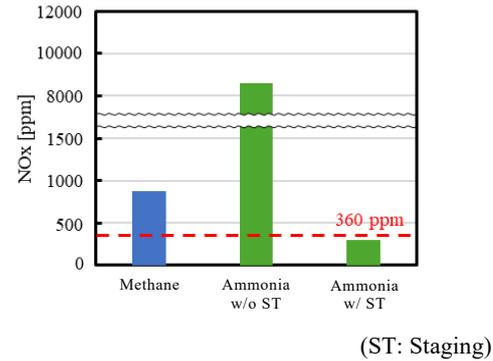
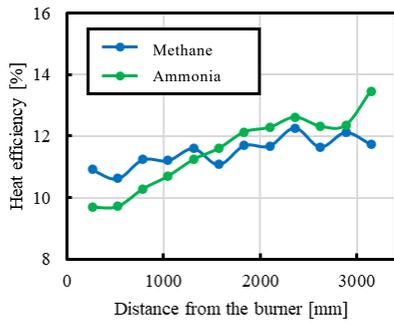


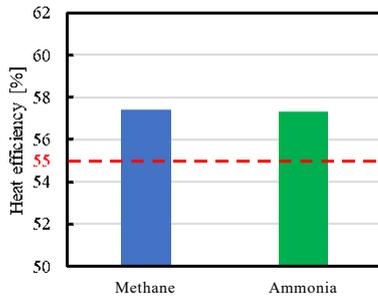
Fig. 7 NOx emissions

2.2.4 Heat Transfer Efficiency

Fig. 8 shows the results of comparing the heat transfer distribution to the furnace bottom and the heat transfer efficiency between methane combustion and ammonia combustion. Heat transfer efficiency represents the ratio of the total heat transfer amount to the heat input. The combustion conditions for both methane and ammonia were a combustion rate the heat input of 240 kW and an oxygen ratio of 1.05, with a furnace temperature of approximately 1200°C. Comparing the heat transfer distribution, it can be seen that for ammonia combustion, the heat transfer is smaller near the burner and larger on the downstream side of the furnace (Fig. 8(a)). As shown in Fig. 6, it can be considered that the ammonia flame has a lower temperature and smaller radiation, which led to a decrease in heat transfer near the burner. On the other hand, to obtain the same heat value heat input, ammonia requires a flow rate approximately 2.5 times that of methane. Therefore, it can be considered that the amount of combustion exhaust gas increased, resulting in an increase in heat transfer due to developed convective heat transfer on the downstream side of the furnace. Comparing the heat transfer efficiency across the entire furnace bottom area, the values for methane combustion and ammonia combustion were equivalent, and both achieved the target of 55% or higher (Fig. 8(b)).



(a)



(b)

Fig. 8 Heat transfer efficiency on the furnace bottom: (a) Heat transfer distribution, (b) Heat transfer efficiency (entire area)

2.3 Demonstration Test

Based on the results from the test using our company's 200 kW test furnace, a demonstration test was conducted in a glass melting furnace. Fig. 9 shows an overview of the glass melting furnace. In this test, two 200 kW-class ammonia-oxyfuel burners were installed downstream of ten existing heavy oil-oxyfuel burners, and a continuous test was performed for a maximum of 48 hours. Fig. 10 shows the NOx behavior emission trends in the flue gas during the test period. For comparison, the results of city gas combustion using the same burner are also shown; however, no increase in NOx emissions was observed under any of the combustion conditions. This demonstration test is the world's first initiative in a glass melting furnace, and leads to the expectation of the application of ammonia-oxyfuel combustion to industrial furnaces.

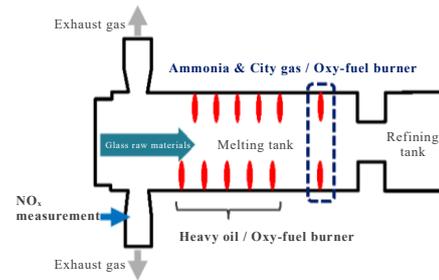


Fig. 9 Overview of the glass melting furnace
Source: R. Akagi, 4th Symposium on Ammonia Energy (2025)

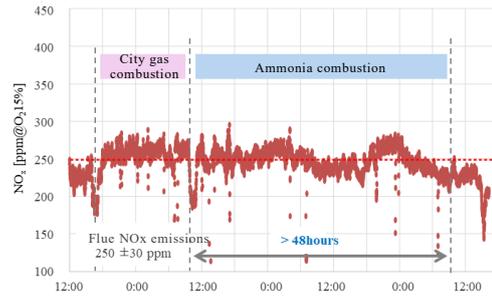


Fig. 10 NOx emission trends in the flue

Source: H. Imai, New Glass Forum / GlassTrend Joint Seminar (2024)

3. Conclusion

This report introduced ammonia-oxyfuel combustion technology for applying ammonia, a carbon-free fuel, to industrial furnaces with the aim of achieving a carbon-neutral society. While there were concerns that ammonia has poor radiative heat transfer and produces large amounts of NOx when burned, its applicability to industrial furnaces by combining it with our company's oxy-fuel combustion techniques was suggested. In the future, we aim to establish scale-up technologies and complete ammonia-oxyfuel combustion technology that is applicable to various industrial furnaces, thereby contributing to the realization of a carbon-neutral society.

4. Acknowledgements

The promotion of the "Development of Ammonia Combustion Technology for Industrial Furnaces" is supported by the New Energy and Industrial Technology Development Organization NEDO. In the promotion of this project, we received significant cooperation from the Institute of Fluid Science, Tohoku University (Professor Kobayashi and members of the Hayakawa Laboratory) and the National Institute of Advanced Industrial Science

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References

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