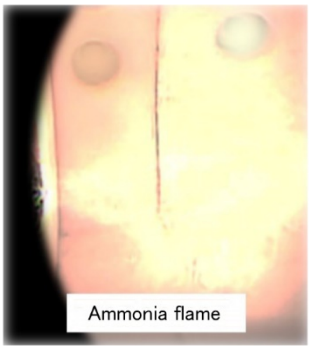
Development of Ammonia Co-firing Technology for Coal-fired Boilers toward Decarbonized Society



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Thermal power generation utilizing hydrogen and ammonia as fuels is considered one of the leading options for decarbonization to achieve carbon neutrality by 2050. In particular, the decarbonization of coal-fired boilers by ammonia co-firing is presented in the national roadmap for the establishment of a fuel ammonia supply chain. Mitsubishi Heavy Industries, Ltd. (MHI) is developing technologies to enable higher ammonia co-firing rate for both circular firing and opposed firing systems of coal-fired boilers in order to meet various customer requirements. This report presents findings on the combustion characteristics of ammonia obtained to date and a schedule for future development toward realizing the practical use of this technology.

1. Introduction

The Japanese government set a new target of reducing greenhouse gas emissions by 46% by fiscal 2030 and submitted a Long-term Strategy as a Growth Strategy under the Paris Agreement (1) to the United Nations in October 2021. Toward this reduction target, the Green Growth Strategy Through Achieving Carbon Neutrality in 2050 (2) associated with carbon neutrality by 2050 shows that the development for increasing the ammonia co-firing rate used for coal-fired power plants will be promoted, along with a growth strategy process chart for fuel ammonia. The Sixth Strategic Energy Plan (3) includes measures with regard to thermal power generation, which is a major source of CO_2 emissions, to reduce its power generation amount itself in order for decarbonization, but it is also stated that an appropriate portfolio of thermal power generation, including coal, will be maintained.

Thermal power generation is an important power supplier that supports a stable supply of electricity and electric power resilience, and it also has an important function as a power regulator that compensates for the variability of power generated by wind and solar power generation. Therefore, there is a need to reduce CO_2 emissions from thermal power generation while maintaining these functions, and one approach is to use ammonia, which emits no CO_2 when burned, for thermal power generation.

We have declared "MISSION NET ZERO", which includes contribution to the reduction of CO_2 emissions from customers' existing facilities. This report introduces the technological development that we have been working on to achieve higher ammonia co-firing rate in existing coal-fired boilers.

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2. Ammonia co-firing in coal-fired boilers

The development of ammonia co-firing technology for coal-fired boilers is being considered for practical use, as the needs of electric power companies are increasing to achieve both a stable supply of electricity and decarbonization.

2.1 Use of ammonia as boiler fuel

Figure 1 shows the technological issues in modifying a coal-fired boiler to an ammonia co-fired boiler in consideration of the characteristics of ammonia. In order to put ammonia co-fired boilers into practical use, it is necessary to plan modifications based on the results of technological studies and verifications to solve these issues.

(1) Technological issues in development of ammonia-fired burner

Ammonia burns at a low speed (about 1/5 that of methane) and includes nitrogen. Therefore, firing ammonia is accompanied by the issue of reducing unburned ammonia downstream of the boiler and NOx emissions. To solve this issue, it is essential to realize stable ignition of the ammonia burner and to control the combustion area with appropriate air distribution. To achieve stable ignition, it is necessary to optimize the fuel-air mixing, air velocity, and flame stabilization structure. To suppress NOx increase and unburned ammonia, it is important to create a high-temperature reducing atmosphere near the burner to promote NOx reduction, and to prevent unburned ammonia from flowing out by employing a two-stage combustion air injection method at the upper part of the furnace and by optimizing the flow rate.

(2) Technological issues of boiler plant itself

In terms of boiler performance, it is necessary to study the effects of changes in radiation heat transfer characteristics caused by changes in flame temperature and combustion gas properties on the heat absorption of the furnace and bank sections. It is also necessary to study the effects of changes in exhaust gas properties and gas volume on downstream equipment of the boiler and draft systems such as fans, to consider start-up methods and handling upon emergency shutdown, as well as to examine the specifications required for plant operation from the standpoints of performance and safety. In addition, it is important to consider measures to prevent ammonia leakage, such as the additional installation of ammonia detoxification equipment and fuel purge systems, and the formulation of an operation policy in the event of fuel shutdown.

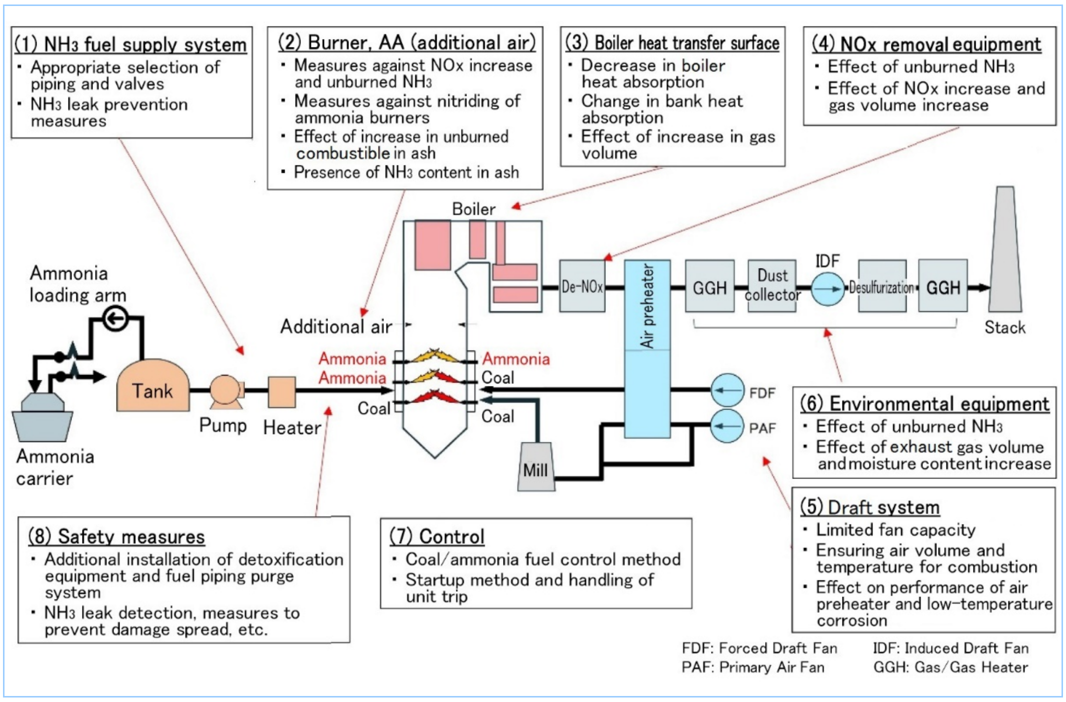


Figure 1 Technological issues in modifying coal-fired boiler to ammonia co-fired boiler

2.2 Approach to higher ammonia co-firing rate

When coal and ammonia are co-fired, it is necessary to consider the mutual effects of combustion reactions. When coal and ammonia are co-fired in each burner, it becomes difficult to control NOx and unburned fuel emissions when the combustion conditions required for both coal and ammonia cannot be maintained simultaneously due to a higher ammonia co-firing rate. On the other hand, if the coal burner and ammonia burner are independent (single-fuel) burners, it is easy to control the air ratio of each, and NOx emissions can be controlled even at higher ammonia co-firing rate. In addition, the co-firing rate can be altered to any level by adjusting the number of operating burners and the burner load.

MHI offers two types of boiler systems: opposed firing and circular firing systems. **Figure 2** shows the concept of increasing the ammonia co-firing rate using single-fuel burners for each system. The opposed firing system fires fuel with burners arranged facing each other at the front and rear of the boiler. The figure shows a boiler with a total of six stages, three at the front and three at the rear in the height direction, and four burners in each stage. The circular firing system fires fuel with burners installed at the four corners of the boiler and swirls the flame. The figure shows a boiler with six stages of burners arranged in the vertical direction. Each stage has one coal mill. Conversion to ammonia co-firing is done by replacing the coal burner with an ammonia single-fuel burner for each burner stage according to the ammonia co-firing rate. The co-firing rate can be adjusted to any level by the selection of the stage in which the burners are to be replaced and the operating burner load. For example, the conversion to an ammonia co-firing rate of 20 cal.% can be achieved by replacing one stage of burners, which correspond to one mill, with ammonia single-fuel burners.

The selection of the stage at which the ammonia single-fuel burners are installed and the operating burner load region will be studied for each operational need, such as the specifications of individual units and the co-firing rate, after the base design concept has been established, reflecting the results of future development as appropriate.

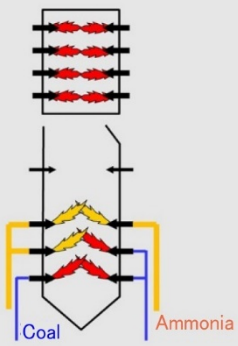
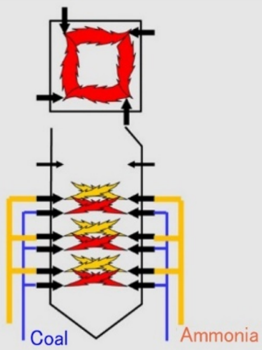
Ammonia co-firing rate	50cal.%	
Burner type	Single-fuel burner	
Combustion system	Opposed firing	Circular firing
Schematic diagram of burner stage in which ammonia is used		

Figure 2 Concept of higher ammonia co-firing rate for boilers with opposed firing and circular firing systems
These are examples of arrangements for a co-firing rate of 50 cal.%, indicating that the coal burners in three of the six stages are replaced by ammonia single-fuel burners.

3. Combustion characteristics of ammonia

In evaluating the boiler performance with modified burners, a combustion performance (NOx, unburned combustible in ash, unburned ammonia, etc.) prediction model for coal-ammonia co-firing is needed to be incorporated into the boiler combustion simulation. To build this model, we have accumulated data on the oxidation and thermal decomposition of ammonia and reactions during coal-ammonia co-firing using a basic combustion test furnace. In addition, we conduct combustion tests to select burner types for the burner development of both opposed firing and circular firing systems. Based on the results of these tests, we will validate the combustion performance of the selected burners through large-scale combustion tests on a full-scale burner equivalent to actual equipment, and also verify the accuracy of the combustion performance prediction model.

This chapter presents the combustion test results obtained from the basic combustion test furnace and small-scale combustion test furnace.

3.1 Combustion test results obtained from basic combustion test furnace

The basic combustion test furnace is a two-stage electric furnace (DTF) (4) that simulates the high-temperature environment inside a boiler, and as shown in **Figure 3**, the amount of combustion air and temperature in the upper and lower stages can be adjusted independently. As shown in the figure, combustion conditions can be set for the upper stage of the two-stage electric furnace to simulate the burner combustion area of a boiler and for the lower stage to simulate the complete combustion area.

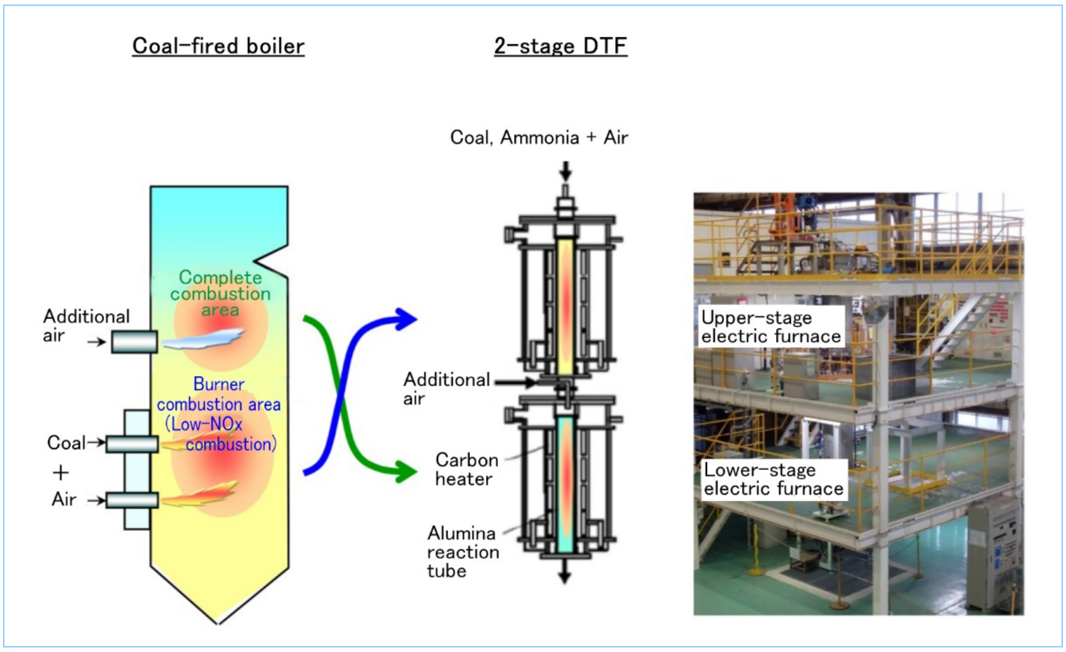


Figure 3 Basic combustion test furnace (two-stage electric furnace (DTF))

Figure 4 shows the trend of NOx generation at the combustion furnace outlet when coal and ammonia are mixed in the basic combustion test furnace and the co-firing rate and the upper-stage air ratio are varied at a given temperature.

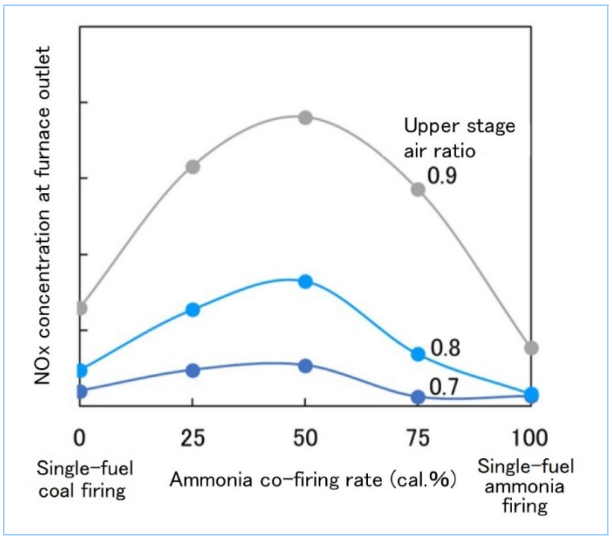


Figure 4 Relationship between ammonia co-firing rate and NOx generation

The amount of NOx generation was suppressed by lowering the air ratio in the upper stage. The amount of NOx increased with an increase in the ammonia co-firing rate, with a tendency to reach a maximum value at about 50 cal.%. It was found that, in the case where coal and ammonia were mixed and then fired, the air ratio setting around the burner was important because the sensitivity to the air ratio was high. Therefore, to increase the ammonia co-firing rate, the method of burning coal and ammonia using single-fuel dedicated burners for each and then co-firing them in the boiler is considered to provide better control of the combustion performance than the method of mixing coal and ammonia and then burning the mixture using a single burner. As reported in the previous section, the advantage from increasing the ammonia co-firing rate was produced by using burners that burn coal and ammonia separately.

3.2 NOx emission characteristics obtained from small-scale combustion test furnace

Using a small-scale combustion test furnace, a combustion test was conducted with the coal burner and ammonia burner installed separately as single-fuel burners. Coal-ammonia co-firing and single-fuel ammonia-firing tests were conducted for several burner types assuming both circular and opposed firing systems.

Figure 5 shows the relationship between the ammonia co-firing rate and the amount of NOx generation in co-firing with coal single-fuel and ammonia single-fuel burners. Even when the ammonia co-firing rate was increased, NOx generation could be suppressed to the same level or less as in the case of single-fuel coal-firing. In addition, stable combustion was confirmed for each burner type, and unburned ammonia was not detected at the furnace outlet. By setting the optimal combustion conditions for each fuel type in the coal single-fuel burner and ammonia single-fuel burner, it was confirmed that NOx generation could be suppressed even when the ammonia co-firing rate was increased, and that a trend similar to the test results obtained from the basic combustion furnace was shown.

Based on these test results, we plan to proceed with the trial design of a burner to be applied to the actual boiler, select a burner type through burner combustion tests, and validate it through combustion test with full-scale burner equivalent to actual equipment.

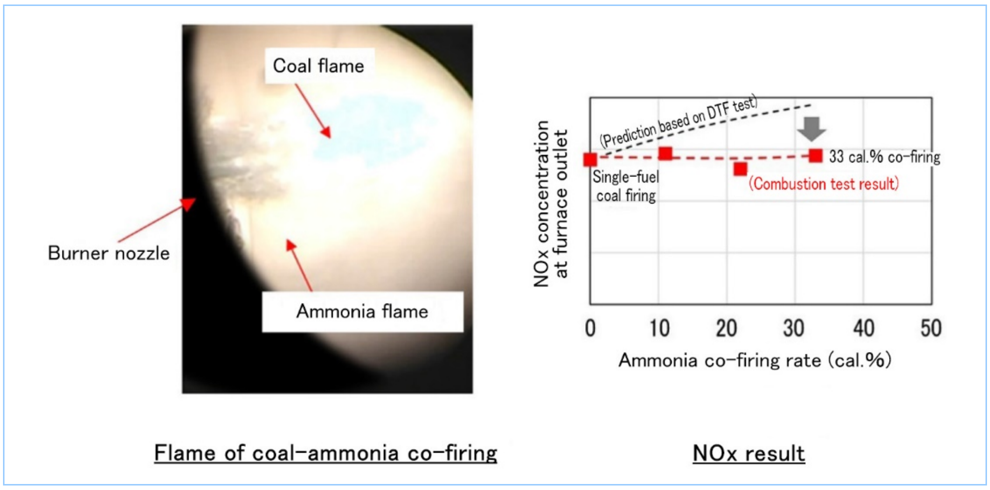


Figure 5 NOx emission characteristics obtained from small-scale combustion test furnace

4. Schedule for practical application

We are currently working on the development and demonstration of high-ratio ammonia co-firing technology in coal-fired boilers under the Green Innovation Fund Project / Fuel Ammonia Supply Chain Establishment of the New Energy and Industrial Technology Development Organization (NEDO), with the aim of high-ratio ammonia co-firing[5]. As shown in **Figure 6**, we aim to develop an ammonia single-fuel burner by FY2024 through combustion tests with full-scale burner equivalent to actual equipment. In addition, we are also working on a basic equipment plan and feasibility study for the demonstration of an ammonia co-firing boiler in an actual plant in cooperation with JERA Co., Inc., aiming to validate more than 50% ammonia co-firing in two units, a circular firing system and an opposed firing system, in the demonstration operation in the actual plant.

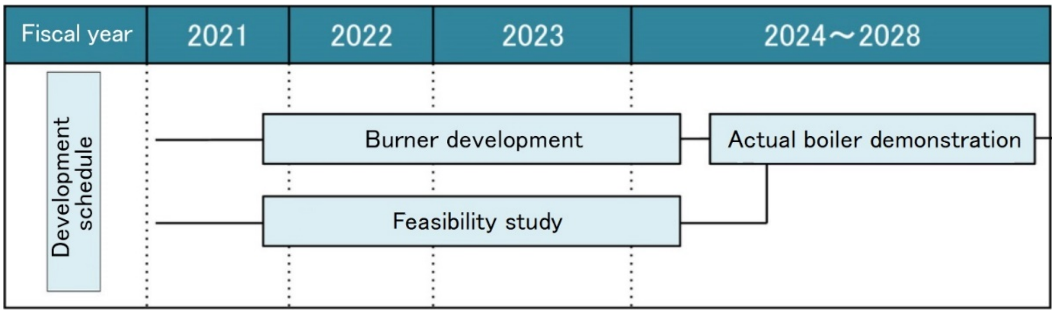


Figure 6 Schedule for practical application

5. Conclusion

In order to realize the decarbonization of coal-fired boilers, the development of ammonia co-firing technology is important to promote both decarbonization and stable power supply. Against this background, this report presented technological issues in the use of ammonia as a boiler fuel and efforts toward its practical application in the future. We have been developing an ammonia single-fuel burner that can be applied to high-ratio ammonia co-firing in the future, and presented our approach to high-ratio ammonia co-firing and the combustion characteristics of ammonia-coal co-firing that we have obtained so far. We will work hard on such development to contribute to the decarbonization of boiler users in Japan and abroad as well as to the construction of ammonia supply chains. Through this development, we will achieve our "MISSION NET ZERO" and contribute to the realization of a carbon neutral society.

In addition, the developments shown in chapter 4 are the New Energy and Industrial Technology Development Organization (NEDO) JPNP21020 Green Innovation Fund Project / Fuel Ammonia Supply Chain Establishment / High-ratio co-firing and single-fuel firing needed for ammonia power generation / Development and demonstration of high-ratio ammonia co-firing technology (including single-fuel firing technology) in coal-fired boilers / Demonstration project of high-ratio ammonia co-firing in the commercial coal-fired power plants utilizing ammonia single-fuel burners".

References

(1) Long-term Strategy as a Growth Strategy under the Paris Agreement, Oct. 22, 2021, https://www.mofa.go.jp/mofaj/files/100285601.pdf
(2) Green Growth Strategy Through Achieving Carbon Neutrality in 2050, June 6, 2021, https://www.meti.go.jp/press/2021/09/20210914003/20210914003-b.pdf
(3) Strategic Energy Plan, Agency for Natural Resources and Energy, Oct. 6, 2021, https://www.enecho.meti.go.jp/category/others/basic_plan/pdf/20211022_01.pdf
(4) Taniguchi, M. et al., Staged Combustion Properties for Pulverized Coals at High Temperature, Combustion and Flame, Vol. 158, Issue 11 (2011) p.2261-2271
(5) JERA and MHI Start a Demonstration Project to Develop Technology to Increase the Ammonia Co-firing Rate at Coal-fired Boilers, Mitsubishi Heavy Industries, Ltd. Press release (2022), https:// www.mhi.com/jp/news/22010702.html