Reduction of CO_2 Emissions in Conventional Boilers

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Contemporary society relies heavily on fossil fuels and thus faces environmental problems that include global warming and the depletion of resources. It is essential to develop a new high-efficiency coal-based power generation system to ensure a stable energy supply. Mitsubishi Heavy Industries, Ltd. (MHI) has vast experience with new power generation technologies based on coal-fired conventional boilers. This paper describes three related developing technical trends: advanced biomass energy technology, A-USC (advanced ultra-super critical) boilers, and oxy-fuel combustion.

1. Introductionn

Contemporary society relies heavily on fossil fuels including coal, crude oil, and natural gas as primary energy sources. This has caused environmental problems including global warming and the depletion of resources.

The development of a new high-efficiency power generation system is essential to reducing environmental burdens and ensuring sustainable economic development. A stable energy supply has become a key issue, given the recent fluctuations in crude oil prices. Therefore, the development of a high-efficiency power generation system with a stable and secure supply of coal is very important.

MHI has developed various high-efficiency power generation systems including the Integrated Gasification Combined Cycle (IGCC) and Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) systems. This paper describes MHI's developments of three other technologies: advanced biomass energy technology, which is a CO_2 emission reduction technology based on conventional coal-fired boilers; advanced ultra-super critical boilers (A-USC); and oxy-fuel combustion.

2. Development of CO_2 emission reduction technology

2.1 Advanced biomass energy technology

Biomass is part of the carbon cycle in which carbon dioxide in the atmosphere is fixed in biological matter by solar energy. The amount of CO_2 in the atmosphere does not increase as long as the balance between consumption and production is maintained, even if biomass is consumed. The use of biomass is thus considered to be an effective measure for reducing CO_2 emissions. The perspective of forest management and cultivation or effective use of biomass-derived wastes, development and implementation of advanced energy utilization technology for biomass resources is now essential.

Table 1 compares the main biomass utilization technologies. This paper discusses trends in fuel mixing combustion in large-capacity conventional coal-fired boilers.

Table 1 Comparison of biomass energy utilization technologies

Item	Direct firing	Multi-fuel combustion in coal-fired boiler	Production of gasified liquid fuel	Pyrolysis system	Ethanol fermentation	Methane fermentation
Raw material	All plants	Wood chip	All plants	All plants, Sludge	Sugar, amyloid	Compost, sewage sludge
Product	Steam, electric power	Electric power	Methanol, Dimethyl ether	Pyrolysis gas	Ethanol	Methane
Energy conversion efficiency	Low (electric power) High (steam)	High (electric power)	High (liquid fuel)	High (solid or fuel gas)	Low-medium (liquid fuel)	Low-medium (liquid fuel)
Features	Close to the biomass production site.. Small scale.	Applicable to high-efficiency plant.	Valuable byproduct (methanol and dimethyl ether.)	Applicable to high-efficiency plant	Valuable byproduct (methanol). Limitation on biomass material.	Applicable to high water content biomass. Limitation on biomass material.

(1) Efforts to develop biomass–coal mixing combustion system

High-efficiency power generation through the use of biomass will be achievable by burning woody biomass with coal directly in the existing coal-fired boilers of high-efficiency power plants. These fuels can be mixed in two ways. The first is to pulverize both the woody biomass and the coal in a coal pulverizer and then inject the mixture into the furnace via a coal burner. The second is to pulverize the woody biomass in a dedicated pulverizer for woody biomass and then inject the pulverized biomass into the furnace through a dedicated burner.

The first method requires only a simple modification of existing facilities because it uses the existing coal pulverizer. However, the coal pulverizer's capacity is limited when pulverizing woody biomass, whose primary component is elastic material. This puts an upper limit on the mixing ratio of biomass with a heat input ratio of 1–5%.

Using the dedicated pulverizer, on the other hand, enables to achieve a further increased biomass mixing ratio.

(2) Pretreatment equipment for raw materials

Pretreatment equipment such as crushers may not be required for woody biomass in chip or pellet form, depending on the size or type, although dryers or magnetic separators are installed as required.

(3) Supply and combustion equipment

・ Mixing pulverization method using a coal pulverizer

Three methods are available for mixing the biomass with coal: mixing in a coal yard, mixing on a coal conveyor, and mixing in a coal feeder. It is desirable to supply a constant amount of biomass at the coal feeder to control the fluctuations in the mixing ratio that result from poor mixture in a coal bunker caused by differences in the specific gravity of the fuels. When the mixing ratio is 1–5%, the normal practice is to mix the coal and biomass on the conveyor.

・ Pulverization method using a dedicated pulverizer

This method requires a dedicated pulverizer for woody biomass. The pulverized woody biomass is normally carried to the dedicated burner by conveying air. The biomass is more flammable than is coal because of its high-volatile matter content, although its grindability is less than that of coal due to its elasticity. This causes excessive power consumption in the pulverizer. Selecting the optimal grinding particle diameter is therefore a key issue.

(4) Environmental characteristics

The nitrogen content of biomass is lower than that of coal, and NOx emission are generally less in proportion to the mixing ratio, or at least at the same level. Characteristics are a function of the manner of mixing and the grinding particle diameter. Because the ash content of biomass is less than that of coal, the production of soot and dust show a downward trend in proportion to the biomass mixing ratio.

(5) Development efforts

MHI has plenty of experience with circular firing boilers using wood waste or bagasse as fuel in its subsidiaries in Brazil, where the use of biomass has been widespread. We have developed based on the production, shipment, related know-how and knowledge about the mixed combustion for various types of woody biomass in both our domestic and overseas.

In cooperation with the Shikoku Electric Power Co., MHI conducted mixing combustion tests using woody biomass in the 156-MW Saijo No. 1 boiler. This was the first such experiment with Japanese domestic electric power companies and now full-scale operation with a mixing ratio of 2% is underway.

MHI also conducted biomass mixing combustion testing of the 900-MW Maizuru No. 1 boiler in collaboration with the Kansai Electric Power Co. where full-scale operation started using biomass combustion with an average mixing ratio of 3% in 2008. Furthermore, along with the Hokuriku Electric Power Co., MHI has operated the 700-MW Tsuruga No. 2 boiler with a mixing ratio of 3%, and confirmed its excellent operational performance. Each of these units used the mixing pulverization method utilizing existing coal pulverizers.

2.2 Development of the next-generation advanced ultra super critical (A-USC) boiler

Increasing efficiency by raising the temperature and steam pressure of thermal electric power plants is an effective means of reducing CO_2 emissions. Governments in Europe, the United States, and Japan have all promoted basic research into next-generation 700°C A-USC plants with the goal of attaining a net thermal efficiency of 46% on the basis of higher calorific value.

Commercializing the A-USC, however, has presented some challenges, such as the development and practical application of new materials suitable for high-temperature and high-pressure use, the development of related manufacturing technologies, and the establishment of a design method that is reliable and economically feasible.

Figure 1 shows the planned development schedule. This covers the nine-year period from the basic development such as material development to verification tests such as field tests. Five years have been allotted for demonstration tests. Securing Japan's energy future using coal-fired thermal power generation is an urgent priority. At the same time, continued research and development are imperative to establish the new materials and manufacturing technologies required to put the high-steam conditions of the A-USC into practical use.

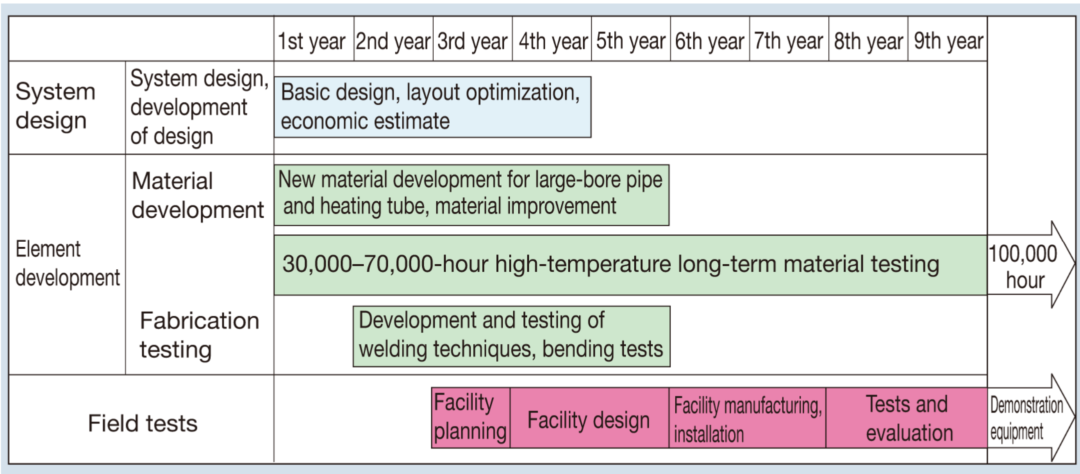

Figure 1 Government project schedule for A-USC technological development

(1) Material development

The development of materials that can withstand the 700°C steam conditions is essential; these are unlike conventional materials and must maintain their strength at high temperatures. The use of Ni or Fe-Ni-base alloys with sufficiently high tensile strength in the high-temperature zone is essential. In addition to Ni-base alloys such as Alloy617, CCA617, Haynes230, Alloy740, and Nionic263, an Fe-Ni-base alloy referred to as HR6W is currently under development in Japan as a candidate for boiler materials.

Because expensive Ni-base alloys are used, it is important to control the scope and establish a design method that ensures economic efficiency.

(2) Development of manufacturing technology

Overall verification is required for Ni-base or Fe-Ni-base alloys that are used in high-temperature and high-pressure steam conditions. This includes the development of bending technology; the development of welding materials and methods for joining these materials together and with dissimilar metals; the optimization of welding conditions; the acquisition of knowledge of the microstructure and of joint strength and toughness; and the development of heat treatment processes and inspection methods for welded areas.

(3) Structural considerations

The thermal expansion in main and reheating steam pipes must be considered, and the structural reliability of valves installed in high-temperature zones must be examined.

2.3 Oxy-fuel combustion

Capture and storage is the most direct and effective method of reducing CO_2 emissions into the atmosphere. CO_2 can be captured in two ways. The first is to absorb and separate the CO_2 from exhaust gases using an absorbent. The second method is a new oxy-fuel combustion method that captures CO_2 emissions, where the nitrogen is separated from the air used in the combustion and CO_2-based exhaust gases recirculated from the boiler outlet are mixed and burned (**Figure 2**).

We discuss the development trends of this oxy-fuel combustion method below.

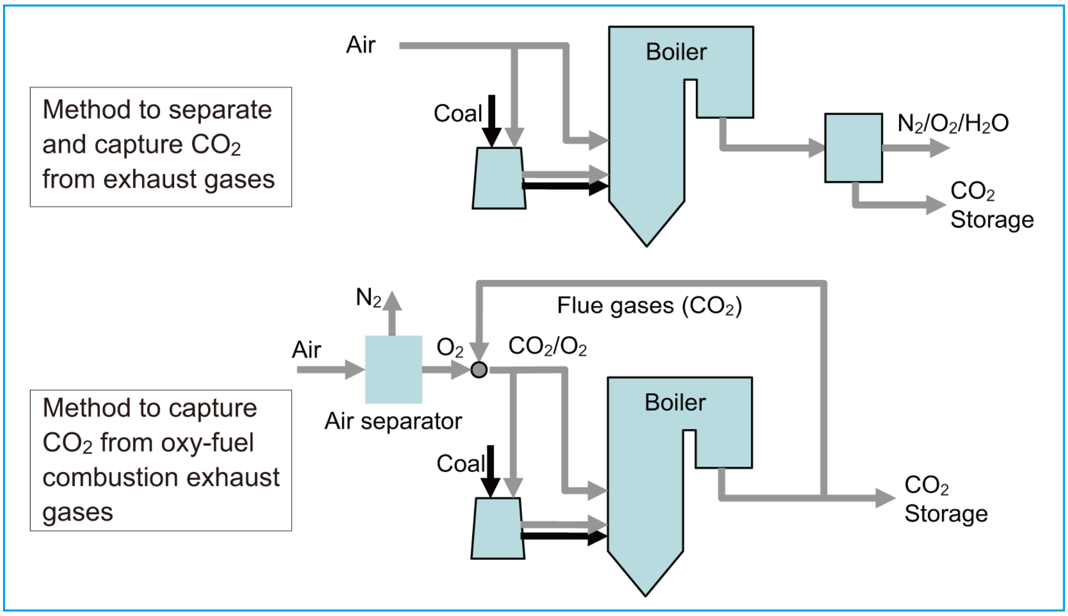

Figure 2 CO_2 capture methods in conventional boilers

(1) Oxy-fuel combustion method

Burning coal using the O_2 separated from the air can increase the CO_2 concentration in the exhaust gas to more than 90%. This makes the separation of CO_2 from exhaust gas unnecessary, and at the same time, it enables to capture the CO_2 using compression and cooling processes.

In a power generation system using this concept, the oxy-fuel combustion recirculates CO_2-based exhaust gases and mixes them with the O_2 used for combustion, settling the concentration of the O_2 to the appropriate value. Thus, the increase in flame temperatures can be controlled. If a low-cost and low-motorization air separator can be developed, the oxy-fuel combustion will be a promising method that is more economical than other CO_2 capturing systems and presents lower technological hurdles.

(2) Oxy-fuel combustion tests

To determine the optimum oxy-fuel combustion properties, MHI constructed an exhaust-gas recirculating system that included a test furnace with a 1/100 scale burner and evaluated the oxy-fuel combustion properties. **Figure 3** compares sample test results of oxy-fuel combustion with ordinary air combustion. We confirmed that the flame brightness in oxy-fuel combustion was higher than that of air combustion, and that the combustion itself was smooth and stable.


(a) Oxy-fuel combustion

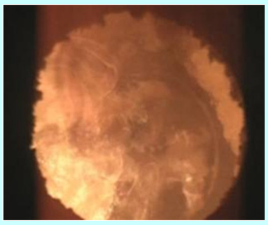
(b) Air combustion

Figure 3 Comparison of combustion conditions

We found that the NO_X emission in the oxy-fuel combustion were 1/2 to 1/3 that of air combustion due to the effect of returning the circulation gas into the reduction zone in the furnace. We will continue to test larger scale burners.

3. Conclusion

Amid growing demand for a fewer CO_2-burden power generation toward low-carbon society, the price of coal rarely fluctuates, unlike that of crude oil or natural gas, and a stable supply of coal is available. Reducing CO_2 emissions from coal-fired thermal power generation is a top priority in maintaining a stable future power supply. By combining next-generation developments such as IGCC and IGFC with CO_2 emission reduction technologies using conventional boilers as described in this paper, MHI hopes to promote a wide range of technological improvements for coal-fired power generation and offer clean-coal utilization technology harmonizing with global environmental priorities.

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