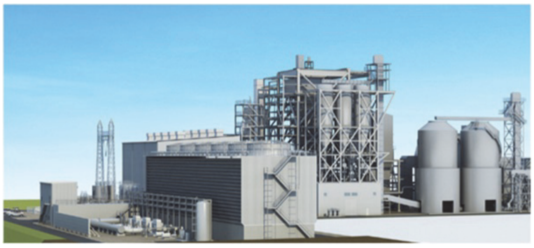
Efforts Toward Steam Power Plant Utilized Pulverized Biomass Exclusive Firing Technology



AKIHIRO IKEDA*1 HISASHI SHIMO*2
HIROSHI TSUJIKAWA*3 TAKATOSHI YAMASHITA*4
MAKOTO SUDO*5 HIROTAKA NAKAJIMA*5

With the growing interest in global warming, renewable energy sources, which contribute to low carbonization and decarbonization, have been expanding across the globe in recent years. Among renewable energy sources, biomass power generation system can serve as a stable and adjustable power source with a large capacity and can help to reduce CO_2 emissions in thermal power plants from the aspect of a carbon neutrality concept. After developing a pulverized coal-fired power generation system with a high biomass co-firing ratio and testing it using an actual unit, Mitsubishi Hitachi Power Systems, Ltd. (MHPS) developed a highly-efficient power generation system with the exclusive firing of pulverized biomass while taking into consideration the biomass grindability/combustibility/ash deposition in the boiler. This system is a technology that can be applied to not only newly-constructed thermal power plants, but also existing coal-fired thermal power plants without accompanying substantial equipment modification.

1. Introduction

The Paris Agreement adopted at the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (COP21) in 2015 sets the goal of realizing virtually-zero greenhouse gas emissions in the second half of this century (the absorption of the equivalent amount of man-made emissions, i.e., net-zero emissions). Under these circumstances, there is an increasing worldwide trend toward the widespread utilization of renewable energy, which can contribute to low carbonization and decarbonization. Power generation systems using woody biomass as fuel in particular can function as a robust power source with large capacity without being affected by weather conditions, compared with other renewable energy sources, and are regarded as an important power source. In this biomass power generation, MHPS has developed a biomass power generation system in which pulverized biomass is directly fired, enabling higher efficiency (higher temperature and higher pressure steam conditions), lower power consumption by auxiliary equipment and a higher operational rate than circulating fluidized bed (CFB) boilers, which are the typical type of biomass-fired boilers with a conventional medium output capacity (75-112 MW). This report presents our power generation system with the pulverized biomass fired boiler in terms of its development, characteristics and application record.

2. Biomass exclusive firing technology for pulverized-fuel direct combustion boilers

Generally, in order to utilize biomass fuel for power plants, CFB boilers have been selected as the typical biomass-fired boiler, and pulverized fuel fired boilers have not been applied due to technical problems for pulverizing fiber-rich biomass fuel. In the case of CFB boilers, however, it

*1 Manager, Power Systems Project Engineering Department, Project Management Division, Mitsubishi Hitachi Power Systems, Ltd.
*2 Chief Staff Manager, Power Systems Project Engineering Department, Project Management Division, Mitsubishi Hitachi Power Systems, Ltd.
*3 Power Systems Project Engineering Department, Project Management Division, Mitsubishi Hitachi Power Systems, Ltd.
*4 Manager, Boiler Business Strategy Planning Department, Boiler Technology Integration Division, Mitsubishi Hitachi Power Systems, Ltd.
*5 Boiler Business Strategy Planning Department, Boiler Technology Integration Division, Mitsubishi Hitachi Power Systems, Ltd.

is necessary to manage the circulating sand conditions and to take measures for the erosion of the furnace tubes, consequently increasing the maintenance cost and period. In addition, the furnace draft loss in CFB boilers is characteristically high, leading to the large power consumption of auxiliary equipment in the air/flue gas fan system. On the other hand, pulverized biomass firing technology involves relatively low operation and maintenance cost due to its high efficiency and reliability. MHPS has developed the pulverized biomass fired boiler to achieve key technologies such as the biomass firing system and ash deposition prevention for wood pellets (dried, grinded and densified material).

(1) Establishment of pulverized biomass firing system

MHPS has developed the pulverized biomass firing system depending on the concept of ensuring high reliability and combustion efficiency by adjusting the operating parameters without any substantial modification of the conventional pulverized coal firing system.

Figure 1 illustrates the outline of our pulverized biomass firing system.

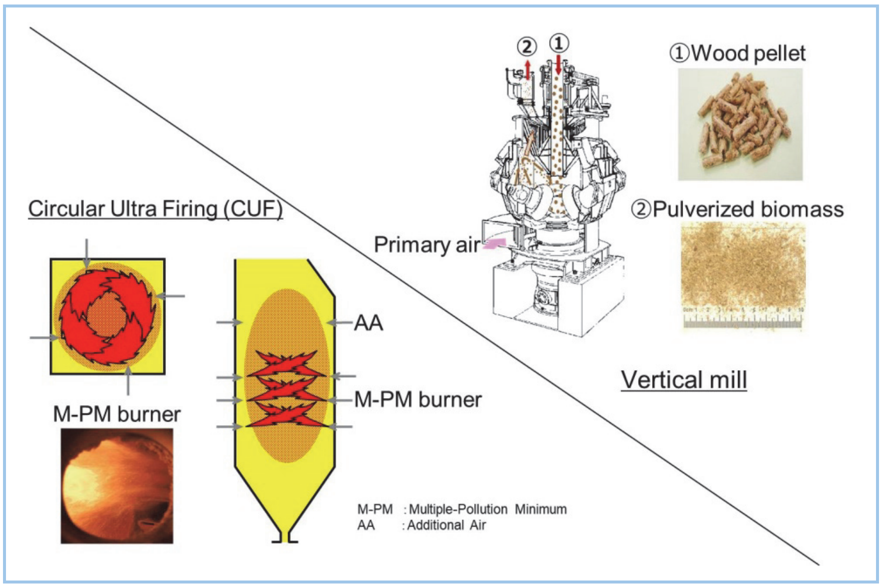


Figure 1 Pulverized biomass firing technology

The grindability of biomass fuel is lower than that of coal since biomass fuel contains fibers. Therefore, if wood pellets are pulverized to a particle size as small as that of pulverized coal (≈75 μm), the differential pressure and the power consumption of mills are substantially increased. In terms of economical operation, the appropriate particle size of pulverized wood pellets is approximately 1 mm or lower. However, this particle size is larger than conventional pulverized coal, and we faced difficulties in discharging biomass particles from the mill and in ensuring biomass ignition stability and high combustion efficiency.

In order to improve biomass particle discharge from the mill, the velocity of conveying air flow (i.e., primary air flow) in the mill is increased by increasing the primary air flow rate compared to conventional coal mills. We actually successfully demonstrated that wood pellets pulverized (disintegrated) to the appropriate particle size were continuously discharged from our test mill. The continuous and stable operation of biomass mills that are almost the same design as coal mills has also been confirmed in the existing power plants.

With regard to ensuring the stable ignition and high combustion efficiency of coarsely pulverized biomass particles, the circular ultra-firing (CUF) system is adopted. In this system, pulverized fuel and combustion air are injected from the burners to form an imaginary circle in a furnace, and a good mixture of the fuel and the air results in the efficient combustion of biomass fuel.

Our low-NOx burner (M-PM burner), which has a significant amount of experience in coal firing, is used as the biomass burner. The burner performance was demonstrated with our test burner, and its application to exiting power plants has also confirmed stable and appropriate combustion according to the measurement results (e.g., heat flux distribution, unburned carbon content in ash and NOx level).

(2) Ash deposition prevention technology

Generally, biomass fuel contains higher alkali metal components (e.g., Na and K) than coal, and this property is also applicable to wood pellets. The alkali metals in biomass are volatized in the furnace, turning into NaCl or KCl gases. The amount of these gases is increased with the higher flue gas temperature in the furnace. By these gaseous alkali species reaching the downstream heat exchanger sections, cooling and condensing, ash deposition may occur on the tube surface. In the case of pulverized fuel fired boilers, the furnace temperature is higher than other types of boilers. Therefore ash deposition prevention becomes necessary.

Figure 2 shows the effect of coal fly ash injection to solve this ash deposition problem. The injected coal ash reacts with NaCl or KCl gases in the furnace, thereby reducing the amount of gaseous alkali species.

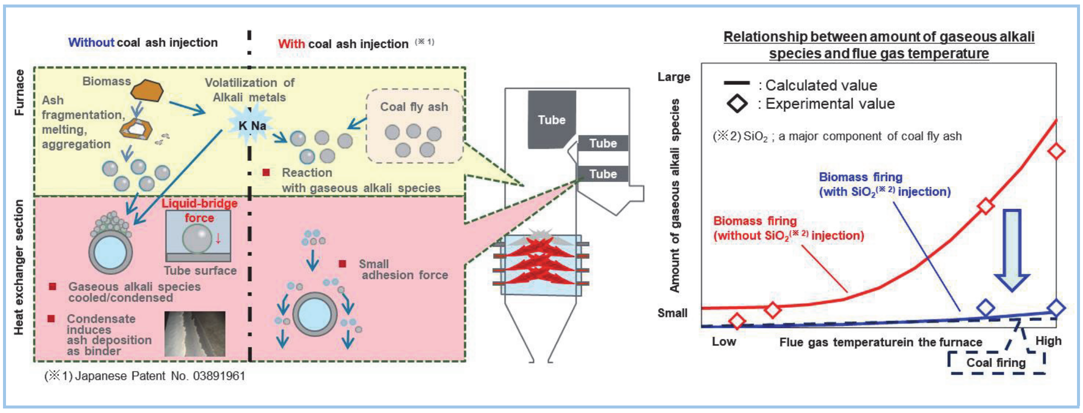


Figure 2 Ash deposition mechanism and effect of ash deposition prevention by coal ash introduction

The effect of this technology has been demonstrated with overseas biomass-fired boilers, which have been retrofitted by our group company as described later. By injecting the optimal amount of coal fly ash based on biomass and coal ash properties, this pulverized biomass fired boiler can be applied with the arrangement of a heating surface equivalent to conventional pulverized coal-fired boilers.

3. Characteristics of power plants with pulverized biomass fired boiler

Figure 3 shows the characteristics of a power plant with a pulverized biomass fired boiler and its conceptual diagram. This system is mostly characterized by the injection of coal-derived fly ash into the furnace, which prevents ash deposition on the surface of the boiler furnace wall or tubes. With consideration given to biomass exclusive firing, special measures and design efforts have also been implemented in the other components of the plant including boiler auxiliary equipment and flue gas treatment equipment. Described below are the characteristics of each component and the design considerations.

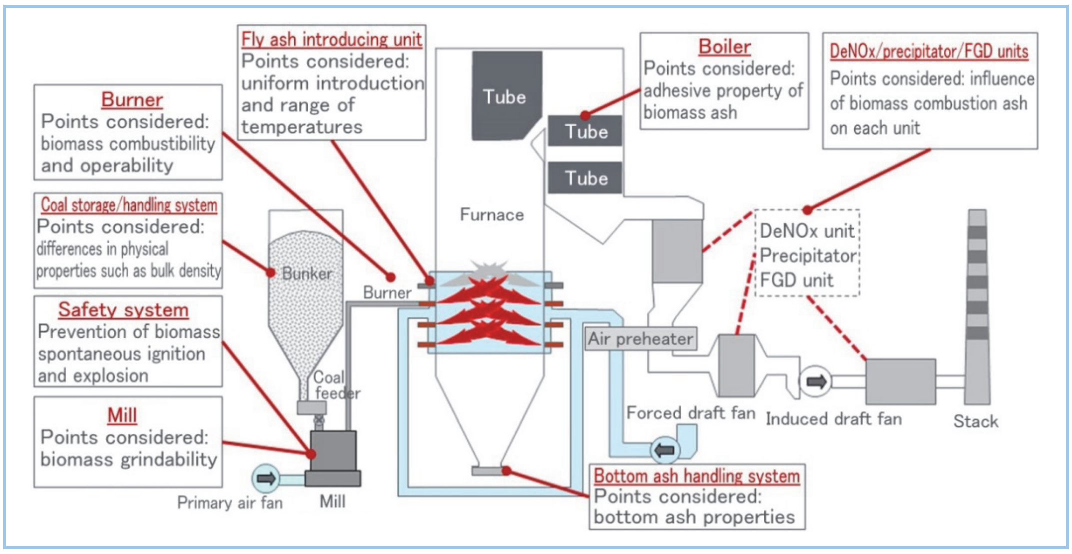


Figure 3 Conceptual diagram of power generation facility with boiler exclusively fired with pulverized biomass

3.1 Biomass safety system

Wood pellets are higher in volatile matter content than coal, and under an atmosphere exceeding 100°C, oxidation and heat accumulation tend to be accelerated through the release of volatile matter. In the case of biomass firing, it is therefore necessary to prevent ignition in the mill by appropriately controlling and maintaining the mill inlet/outlet air temperatures to be lower than those of coal-fired boilers. With biomass in use, fine powder can be produced easily. Compared with coal, the minimum ignition energy of biomass is approximately 1/10 and the lower explosion concentration limit is about 40%. Therefore, the preventive measures for dust explosions to be taken need to be stronger than conventional pulverized coal-fired boilers. Dust explosions occur in an atmosphere where three elements (dust concentration, source of ignition, and oxygen) are present under the right conditions. The mill and the pulverized fuel chute, which are exposed to the aforementioned atmosphere more frequently with biomass than coal, are equipped with an explosion suppression system (consisting of a container filled with fire extinguishing media, pressure sensors, etc.) in the case of unexpected dust explosions. Upstream management including removal of foreign matter and metals in the fuel handling system, is also important.

3.2 Air quality control system

(1) DeNOx unit

Regarding the elevated speed of NOx removal catalyst degradation owing to ash deposition and reduced catalyst activity caused by catalyst poisoning components in biomass, the impact is mitigated by injecting coal ash into the boiler furnace while determining the amount of catalysts in accordance with the environmental regulation values and considering the installation of a backup layer as needed.

(2) Precipitator

Compared with coal-fired boiler fly ash, the fly ash discharged in a biomass fired boiler tends to contain a relatively-higher amount of unburned combustibles, because the ash content in the biomass is lower than coal. As a result, the electrical resistance of dust at the boiler outlet is lowered and the particle size becomes relatively smaller, which may cause a risk of reducing the dust removal rate of the electric precipitator. Therefore, in our system, the carrying over of fly ash, which includes unburned combustibles, could be prevented by adopting a bag filter which is less susceptible to the characteristics of fly ash,

(3) Flue gas desulfurization (FGD) unit

The quality standard for wood pellets: ISO-17225-2:2014 (Solid biofuels - Fuel specifications and classes – Part 2: Graded wood pellets) specifies the sulfur content in fuel (<0.05 wt%). As long as it is below this limit, a desulfurization absorption tower does not need to be installed in principle. In addition, it is also possible to install a simple FGD unit in which calcium hydroxide is sprayed at the bag filter inlet flue gas duct. As such, the FGD system can be designed in accordance with the environmental regulation values.

3.3 Bottom ash handling system

Compared with coal-fired boilers, biomass-fired boilers tend to discharge bottom ash containing a relatively-higher amount of unburned combustibles because of their differential ash content in terms of the fuel characteristics and particle size. Therefore, our system is designed to reduce the amount of unburned combustibles in ash discharged from the system via the bottom of the boiler, by incorporating a subsystem for recycling through which the bottom ash is collected temporarily in the bottom ash tank by the submerged drag chain conveyor (DCC) before being transported to the mill inlet through the conveyor and the screw feeder.

3.4 Thermal efficiency of the plant

For a power plant with a pulverized biomass fired boiler, the reheat cycle system is applied. In addition, the main and reheat steam temperatures are set at 566°C/566°C at the inlet of the steam turbine. The cycle has been designed to target at least a plant generator thermal efficiency (lower heat value or LHV basis) of 40% in both 75 MW and 112 MW class biomass-fired power plants.

3.5 Operational rate and auxiliary power ratio

As described above, CFB boilers generally allow the bed material to be circulated at a specified speed in the furnace to enhance the combustion efficiency. Because this circulating bed material leads to erosion and corrosion wastage, it is necessary to plan furnace refractory material repair and measures for the corrosion wastage of the boiler tube. Moreover, high pressure is required in the air and gas duct systems, and the amount of auxiliary power required for plant operation (auxiliary power ratio) is also relatively high. On the other hand, the pulverized-fuel direct combustion system incurs relatively-low maintenance costs for such repairs and measures for corrosion wastage, and the boiler shutdown period per scheduled inspection can be somewhat shortened. As the necessary pressures in the boiler furnace and the air and gas duct systems can also be kept low, it becomes possible to realize a high operational rate and a low auxiliary power ratio (the power required for a plant is about 70-80% of the typical 75-112 MW class CFB boiler power plant). Therefore, the application of a power generation system with pulverized biomass fired boiler can be considered to be a fast-acting solution for independent power producers (IPPs) that require a high net plant thermal efficiency, off-grid power generation facilities for which a high operational rate and stable operation are needed, and existing coal-fired thermal power plants planning a fuel shift to biomass to reduce CO_2 emissions and other cases.

4. MHPS and group company experiences with power plants in which pulverized biomass is co-fired or exclusively fired

(1) High biomass co-firing ratio performance

We have supplied multiple plants in Japan, including new 112 MW class coal and biomass co-firing power plants with a high biomass co-firing ratio. It has been confirmed that all the plants achieved 30% biomass co-firing (calorie basis) at the rated load.

(2) Modification of coal-fired power plants to enable biomass firing

Table 1 lists the overseas modification projects for biomass firing in which our group company Mitsubishi Hitachi Power Systems Europe GmbH (MHPS-EDE) took part. In all the projects, the goal was to change the fuel from coal to biomass. These plants have been operating stably without major problems.

Table 1 Boiler retrofitting projects for biomass exclusive firing

Item	Studstrap #3	Drax #1-#3	Avedore #1	Atikokan
Plant location	Denmark	UK	Denmark	Canada
Output (MWe)	350	660	250	200
Biomass exclusive firing starting year	2016	2016	2017	2016
Major modification coverage for biomass exclusive firing	• Mill remodeling • Burner modification	• Burner modification	• Mill modification • Burner modification	• Mill modification • Burner modification
Plant operation pattern	Winter: biomass Summer: coal	Biomass in all year round	Winter: biomass Summer: coal	About 1/3 of a year (peaking power source)

Studstrup #3

Avedore #1

Photograph source: Presentation handout of the "8th IEA-CCC Biomass Co-firing Workshop" in Copenhagen, Denmark on Sep. 11, 2018

5. Conclusion

We have established a power generation system that utilizes pulverized biomass fired boilers, after going through the design concept described in this report, demonstration with a combustion test unit, operation of domestic power plant with a high co-firing ratio of pulverized biomass, and overseas boiler retrofitting projects from coal firing to biomass firing. Our system is a technology that provides quick outcomes, with the ability to simultaneously fulfil the roles of reducing CO_2 emissions in terms of carbon neutrality and serving as a stable and highly-efficient power source. By applying this technology to not only newly-constructed power plants, but also existing coal-fired thermal power plants, we intend to further contribute to the realization of a low-carbon society by setting out to widely introduce highly-efficient and stably-operable renewable energy power sources.

References

(1) T. Yokoshiki, et.al., Operating Results of Coal and Biomass Fuel Fired Boiler, Mitsubishi Juko Giho Vol.55 No.4 (2018)
(2) T. Yokoshiki, et.al., Biomass Fuel Fired Boiler Technology, Mitsubishi Juko Giho Vol.54 No.3 (2017)